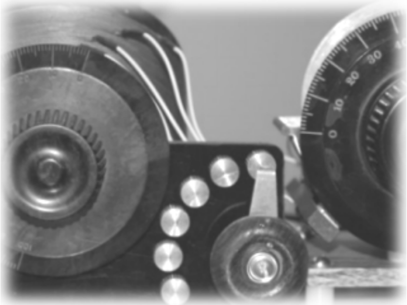
NOTES:

KEVIN'S WEBSURFER HANDBOOK X
FOR CRYSTAL RADIO

MY WEB PAGE VISITED



Kevin Smith
2012

NOTES:

Printing / Binding Instructions

1. Choose “fit to page” in print menu
2. Print document double sided on letter size paper
3. Cut the entire printed document in half
4. Fold over making sure the page numbering is continuous
5. For the cover: Print just the first page on card stock paper
   Cut the cover in half as well
6. Assemble the covers on the document
7. Punch the left side for a binding, spiral or comb as desired

www.lessmiths.com/~kjsmith/crystal/cr0intro.shtml

KJ Smith

NOTES:

INTRODUCTION

In March of 2009 while shopping for some sensors on ebay, quite on a lark I typed "Crystal Radio" as a search term not really knowing what to expect. My search was not totally random, I have always been interested in radio communications and in radio propagation as a geophysical probe of the ionosphere, (more about that here). Additionally as a child I had once a small "Spy Pen" crystal radio what always facinated me, and as an adult I had given a crystal radio toy kit to my second son who showed much interest in computers and electrical things. He has since gone on to his Master's degree in EE and now workd designing computer chips at Intel in Silicone Valley. So, maybe it was the radio?

Vaguely I thought to find a crystal radio or radio kit of some sort to play with, something more serious than a cheap plastic toy. What I found was suprising, so much there. I explored the listings, odds and ends mostly of course, its ebay after all, and a few completed radios new and vintage, and one in partictular which caught my eye. There were several kits by someone calling himself Xtalman including one he calls Dunwoody which seemed to exactly fit my idea, a kit, easy enough for a beginner but serious enough to satisfy a more educated mind. I decided to pull the trigger, the radio was offered "buy it now", so I did! So began my journey into a black hole of interest, somebody really ought to post warnings on all crystal radios.. "WARNING, may cause serious refocusing of lifestyle".

In the time since, I have plunged deeply into the web literature, joined the Xtal Set Society, and built homebrews of my own in addition to purchasing a few sets, (described separately). In the following pages I present each radio with the ideas and motavations that move me to own, admire, and use them. It has become a facinating journey for me which I wish to share so that others may understand and catch the bug for themselves, so that other radio builders may view and comment, with suggestions perhaps for improvement, and so us newbies may heed the WARNING, and STILL take the plunge!

The Xtal Set Society Dedicated to once again building and experimenting with radio electronics Great source for plans and books, kits and parts. I joined the society as soon as I finished my Mystery Set.

Dave Schmarder Dave's Homemade Radios, literally 10's of different sets all with interesting features and each a pleasure to look at. Much technical background and good design ideas can be found as well. I like this page.

Scott's Crystal Radios Mount Your Own Crystals Here I learned, and successfully applied, a good technique to mount my own crystals.

Part 2, Inspiration:, Sites with radio plans and projects, so many ideas.

Mike Peebles Crystal Radios - Peebles Originals!

Tom's Handmade Radios Nice selection of radios, superb craftmanship, for sale!.

Birmingham Alabama Crystal Radio Group Nice contest page, many lovely contest radios

Jim's Crystal Radio Page Crystal radios with ferrite cores, and a Mystery Set.

Larry J Solomon Solomon Radios, several variations on the Mystery Set and others..

Rainer Steinfuehr Gollum´s Crystal Receiver World.

So Many more, if I missed your site my sincere apologies.

The Stay Tuned Website is probably the site I visit most often of all. This excellent effort contains an enormous amount of information, vintage plans and projects, Contest Radios, Museums, and more. Download Professor Coyle's coil calculators, you will use them constantly. This is the only source for MB Sleeper's 101 radio receiving circuits I have found.

The Smith-Kettlewell Technical File ENERGY-FREE RADIO: THE CRYSTAL RADIO SET REVISITED This is also a great introductory page with a great deal of design tips and background. There is no author and its embedded in an eye research center website, oh well.. I highly recommend this page.

Owen Pool WB4LFH Crystal Radio Resources Owen Pool's great site with much fundamental background, projects, teaching, contest results and so much more.

Steve Mcdonald VE7SL Radio Notebook Crystal Radio DXing Great site for discussions of DXing with crystal radios and double-tuned design fundamentals.

Mike Tuggle DESIGNING A DX CRYSTAL SET Mike's discussion of his Lyonodyne-17 and the concepts behind its design.

Dick Kleijer crystal-radio.eu
Dick Kleijer's site contains great discussions of theory and the results of numerous experiments with his crystal radios.

CONTENTS:

Acknowledgements:
http://www.lessmiths.com/~kjsmith/crystal/ack.shtml

Radio hobby in general and certainly crystal radio is a mentored hobby with most practitioners able and willing to help one get started and do well in this hobby. In my researches for information I have been greatly aided by the many helpful web resources built by this community. I wish to offer here my sincere thanks for your efforts. I certainly would not have come as far as I have without this help! The following list is only partial to the number of sites I visited and if your page is not listed I offer my apologies. This list represents those sites I found most significant and helpful in terms of 1) Crystal Radio Fundamentals and 2) Set Design Inspiration.

Part 1, Fundamentals:, Sites where I spend most of my time.

Lance Borden BORDEN RADIO COMPANY The start of my adventure, serious crystal radio kits, a seriously fine gentleman.

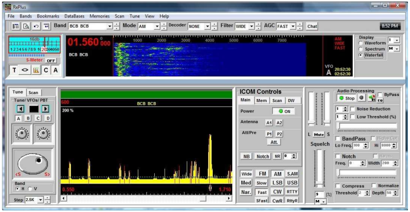
Kenneth A. Kuhn Crystal Radio Engineering Kenneth Kuhn's excellent pages on the fundamentals and design of crystal radios and all their associated parts, excellently written, accessable to the non-specialist yet precise and clear. I spent hours studying these documents.

Alan R. Klase CRYSTAL SET DESIGN 102 Alan Klase's site is chock-a-block full of great work and ideas for interesting sets. His Design 102 gave me good insights in the various incarnations a crystal radio may take.

Darryl Boyd Stay Tuned Website: see #58 Crystal Radio Circuits 101


local
distant
fringe
60 miles
50,000 Watts
Palestine
Waco
Fort Polk South
Jasper
Bryan
Huntsville
Austin
Kingwood
Beaumont
San Marcos
Houston
Port Arthur
Pasadena
Galveston
Lake Jackson
Victoria
Beeville
Corpus Christi
Kingsville
Daytime Coverage Pattern for KGOW-AM
© 2010 radio-locator.com
local
distant
40 miles
Crockett
Lufkin
15,000 Watts (ya, right!)
Cameron
Huntsville
Livingston
Bryan
Brenham
Spring
Kingwood
Beaumont
Houston
Pasadena
Missouri City
Gonzales
Texas City
Galveston
El Campo
Cuero
Lake Jackson
Bay City
Victoria
X = My receiving location
Nighttime Coverage Pattern for KGOW-AM
© 2010 radio-locator.com

More disturbingly, it takes the joy out of the hobby. Mercifully, my handy dandy wave trap goes a long way to solve much of the trouble, but not far enough. I need to direct my efforts in trapping this station now.

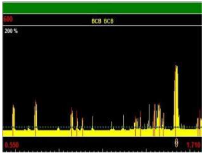


Question: Is this spectrum normal? Is it common for one station to so dominate the scene? I sometimes wonder if they arent cheating on their power output there. I know, probably not. My next project may be finding a way to use this energy to charge my batteries or light my house, or heck, to power my radios! The following plot shows that while by day I am merely in trouble, at night things are near hopeless. The band scan is a night spectrum. Sad thing is, I don't partictularily care to listen to sports on radio, (or television for that matter).

CHAPTER I

Resources for Theory and Design

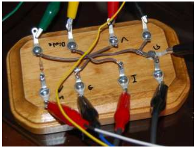
Some thoughts on KGOW 1560 "The Game".
http://www.lessmiths.com/~kjsmith/crystal/kgow.shtml



Over the months of playing with my hobby, my radios, learning, reading, i have come across a small fly in the ointment of an otherwise very enjoyable hobby. From time to time while listening to my radios I would find the airwaves filled with a single station, KGOW blasting across my entire tuning range. It was curious and interesting at first, radios would receive strong clear signals with or without a crystal or rectifier which seemed to me thoroughly at odds with what I supposed I was learning about how radios work. Discussions on Rap-n-Tap provided some, but not deep insights into my problem. Mostly I was advised to check twice and thrice all my connections. The most frustratingly bothersome aspect was that, it affected all my radios. Maybe my antenna and/or ground was responsible. Even when hooking up my "Sleeper #1" (shunting a diode across the phones) gave me the problem, in fact gave me the problem in spades. Turns out I am able to receive KGOW clearly merely by attaching the antenna and ground across the phones, no diode, no nada.

Looking somewhat deeper into the mystery, I chose to look closer, not at my antenna and ground, but at the BC band itself. Using my Icon R75 and RxPlus software, I made a band scan of the BC activity. What I found was most troubling for my location. The plot below shows a screen capture of the scan. Clearly KGOW stands out 2 to 3 times stronger than any other local station. It dominates the scene and saturates my post.

My radio "laboratory"
http://www.lessmiths.com/~kjsmith/crystal/lab.shtml



Having now acquired several crystal radios by purchase (two) or building my own (four), I begin to wonder how they stack up against each other and against other radios I read about and dream of on the net. It can be fairly common to hear radio performance described in qualitative terms, "high Q", "sharp tuning", "highly sensitive", etc. Without measured numbers to back them up, it is extremely difficult to judge the subjective notes of different radio users. It is inevitable I believe that in this hobby that one ends up getting together as much test equipment as possible, (read "affordable") in order to know more objectively about the radios one builds and/or uses. This page is the tale of my own effort to equip a small "laboratory" of sorts for just such purpose.

My first needs were related to my building projects and included meters for measuring capacitance and inductance. I have excellent-quality bench meters for other hobby projects including a Keithley 192 and 181 voltmeter with IEEE 488 computer interfaces. These are voltmeters only though, nothing else. My first purchase then was a capacitance/inductance meter. It worked great for capacitance, but the lowest range for inductance, 20mH unfortunately is useless. So, this meter was quickly followed by a stand-alone inductance meter ranging down to 200uH. I use these frequently when making or measuring coils, and measuring capacitors purchased on ebay, better to design a radio around a specific componant.

My next needs follow logically, what about the radios I build?, how do they do? For the non-electrical engineer, testing radios is a bit of a daunting task and this page is by no means intended to be a tutorial. I do give my experiences so that perhaps someone with the same idea may benefit and possibly avoid the mistakes I have certainly made. I describe my equipment and the protocols used in my testing, but I STRONGLY refer the reader to the following two pages for technical guidance and explanations, most of what I do came directly from here:
Dick Kleijer crystal-radio.eu http://www.crystal-radio.eu/enqmeting.htm
Gollum´s Crystal Receiver World
http://home.snafu.de/wumpus/gollum/testing.htm article by C.A. Lauter
I heartily express my appreciation to our European friends for making available on the web these excellent technical tutorials for crystal radio testing.

*****

Testing and understanding your set from the Antenna at the front, the tank in the middle and on to the Diode at the back and then the Radio complete, the whole shebang!

ANTENNA TUNING UNIT.. Design notes and Models, Effect of earth resistivity..

COIL Q.. Summary of web research on expected values of Q for various coil designs.

with a surface area of 1,600 square feet. The native lead occurred along a part of the margin of the ore body in a zone about 9 inches thick separated from the wall rock by clay gouge. The ore generally was argentiferous steel galena partly or completely altered to cerussite and anglesite with minor minerals including wulfenite, litharge (?), quartz and limonite. The native lead occurred as threads, sheets to one-half inch thick and pods up to 4xIX2.S inches.

sheared, massive, and 'steel' (a dense, extremely fine-grained, almost cryptocrystalline type). Sheared and steel galena textures were caused by post-ore shearing of coarse-grained galena and it was not uncommon to find the three varieties side-by-side. These textural variations had important implications for exploration because the more massive and free-grained types, which are less friable, were not affected as much by oxidation. As galena was released by erosion from the oxidized vein subcrops, it tended to develop a protective white rind of the Pb sulfate anglesite, and to collect downhill from the vein as a dispersion (float) train.

THE GEOLOGY AND MINERAL DEPOSITS OF THE TOBY-HORSETHIEF CREEK MAP AREA, NORTHERN PURCELL MOUNTAINS, SOUTHEAST BRITISH COLUMBIA., OPEN FILE 1990-26. By Alasdaire Pope
mine consist of massive panidiomorphic galena, sphalerite, pyrite, sucrosic cerussite and banded dolomite, galena, sphalerite and pyrite. In hand specimens bleischweif texture (steel galena), indicating deformation by simple shear (McClay, 1980) is frequently seen.

PROCEEDINGS OF THE THIRTY-THIRD ANNUAL MEETING OF THE N4INERALOGICAL SOCIETY OF AMERICA AT BOSTON, MASSACHUSETTS.
NATIVE LEAD, PRESIDIO COUNTY, TEXAS JORRN T. I_ONSDALAEN D KATHRYNO . DICKSON University of Texas, Austin, Texas
Approximately 3,000 pounds of ore containing native lead was recovered from three small tabular ore bodies in the western part of the shafter District, presidio county, Texas. Two of the ore bodies were vein-like in limestone with clay gouge walls. The metallic lead was localized at the centers of the veins. The third ore body was flat lying disk-shaped about 4 feet thick

DIODE TEST.. Describes protocols and results of testing many different diodes, diode classes, crystals, and even two different vacuum tube diodes.

DIODE PROTOCOL.. Describes a useful protocol for determination of Diode Is, n, and Ro.

DIODE CALIBRATION.. A simple set of modelled characteristics with variations in Is and n.

RADIO TEST.. Describes protocols and results of radio performance testing on my sets.

Conclusion
So, for an investment in a few key pieces of good equipment, yes at some non-trivial cost, you can appreciate the hobby so much more. I have an oscilloscope as well, but so far have not explored its value. I prefer the recording and spreadsheet methods as they give a better record of the results and allow graphing and easy comparison. Knowing how your sets perform, being able to test your diodes, knowing your coil inductance are all important aspects of knowing your radios. I certainly recommend this!
Ciao!

Steel galena owes its fine-grained texture either to mechanical deformation of larger crystals or to a beginning transformation to anglesite. It is supposed to be rich in silver but this is by no means always true. $PbS+4O=PbSO_4$ (Anglesite)

Geology of Colorado and Western are Deposits By Arthur Lakes, 1893.
A coarse galena is generally poor in silver, while fine grained "steel galena" is generally rich in silver, but the reverse may also be the case.

Waldschmidt, 1921. Hecla East Vein, Coeur d'Alene
The coarsest galena examined showed cleavage faces from 2 to 4 mm, square, but generally it is much finer grained than this. The fine-grained galena is commonly known as steel galena because freshly fractured surfaces have a steel-like luster. In all the specimens examed, this steel galena appeared to be in an intimate mixture of galena, tetrahedrite, sphalerite, pyrite, gnague, and other minerals present in the ore.
It appears that the original ore body consisted chiefly of galena, sphalerite, pyrite, pyrrhotite, tetrahedrite, freibergite, quartz and siderite. When movement took place along the O'Neil Fault and possibly along with minor slips, the ore body was grreatly crushed, during which time the galena acted as a putty-like mass for the suspension of broken fragments of the harder minerals. This breaking resulted in the formation of the typical steel galena.

Great mining camps of Canada 1. The history and geology of the Keno Hill Silver Camp, Yukon Territory.
Keno Hill mineralization "silver-lead-zinc veins in lastic metasedimentary terranes". Galena is present mainly as the common coarse-grained, well-crystallized and friable type, but also displays several other textures, such as fine-grained,

Steel Galena from the Tintic Mining District, a classic silver locality in Utah. (The excessively sparkally surface in the photo is from the flash.) Note also the presence of Anglesite alteration, (the clearish anglesite crystals separated from the galena by a dark finer grained almost greenish alteration zone). This is good radio material, but you may need hunt a bit more for hot spots than the finer-grained stuff above.

Steel Galena Notes off the web:

USGS Bull 625, 1917
Galena of the Coeur d'Alene District contains appreciable silver, is generally not so well crystallized, and has a much less perfect cleavage.

Mineral Deposits, Waldemar Lindgren, 1919

ANTENNA TUNING
Notes on simulations for a Tuggle Front End
http://www.lessmiths.com/~kjsmith/crystal/atu.shtml
By Kevin Smith

Introduction:

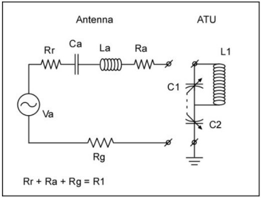
When designing my radios I always make extensive use of Mike Peebles and Dan Petersen's "Professor Coil" spreadsheet. This tool along with the many tutorials and explanations online have vastly eased the design work around homebrew coil winding. We can now model a coil with good accuracy prior to the actual job and thus better match the coil to the other components we plan to include. One quickly becomes aware that most coils for the broadcast band vary around a nominal 220 or so uH. More than this and most variable capacitors will have too much bottom-end capacitance to tune the top of the band. Less than this and you need caps with fairly high values when fully meshed, 500+pF or more.

All the above is pretty straight forward. On the other hand, when I have been reviewing double-tuned set designs, I often note that the coil used for the ATU (antenna tuning unit) will have an inductance quite a bit lower than the main tank coil. Professor Coil doesn’t address this aspect of coil design and I have found little discussion online concerning ATU design. Mostly this seems to be dealt with in passing or as a digression when dealing with other subjects. The most useful web sites for addressing this aspect of crystal set design include Dick Kleijer's excellent work and Ramon Vargas's detailed analysis of the "Tuggle Front End", that’s about it. Neither site discusses the ramifications of varying different parameters such as the Earth Resistance, Coil Inductance, etc although Kleijier's site includes a great calculator page to allow one to ask these questions. In my explorations of ATU design (primarily Tuggle) I have made extensive use of Kleijier'e page and for this I am deeply in his debt. My hat's off to Dick, thanks so much.

The following discussion presents the results of many models cranked through the design calculator. I wished to understand what factors play main roles and which have minor parts.

For a conventional detector-circuit coil one can pretty much control all the main factors, really only the inductance and capacitance of the circuit. The main and only surprise comes in the form of "stray capacitance" resulting from the spacing of the coil wires. This can readily be 1) guessed at and 2) minimized by good coil winding technique. For the antenna circuit by contrast many of the needed parameters, earth resistance, antenna capacitance and inductance, and antenna resistance in the forms of actual wire resistance and radiation resistance are, for most of us, unknown and only guessed at. The following figure illustrates the antenna and ATU with a list of the main "components" that need to be understood and/or modeled.

The Antenna Equivalent Circuit consists of an AC voltage source Va (the signal of interest), in series with some radiation resistance Rr, antenna capacitance Ca, antenna inductance La, antenna resistance Rr, and finally a ground



From Leadville Colorado, the specimens below are the best examples of "steel galena" I have yet come across. The samples have a dull weathered surface skin deep hiding a massive, fine-grained lead-silver mining ore of a classic Rocky Mountain type. On a fresh surface the sample has a fine texture and flat grey color. This is not museum material, and its difficult (to impossible) to locate on ebay, but its the real mccoy when it comes to crystal radio. Don't even bother with the pretty pretty Missoury galena, it rightly belongs behind a glass display, not in a radio. Chips from this sample, potted in woods metal, rectifies strongly almost regardless of where the cat's whisker touches, instant sound.

Steel galena is difficult to find for sale due primarily to its lack of excellent crystal cleavage. Galena, as is well known, has beautiful LARGE crystal structure. Who would buy that ugly-looking grey junk?

Kevin

resistance Rg for the return path to complete the circuit. In addition the ATU consists of a coupling capacitance C2, and a tank with inductance L1 and capacitance C1. The capacitance and inductance of the ATU is needed to tune out the reactance of the various components of the antenna for which we do not have data. What to do?

Without an antenna analyzer (expensive) one can only estimate the many component values based on published antenna models. Ken Khun's engineering page has a number of nice models and a good discussion of the antenna parameters we will be trying to understand and use. For my personal setup my antenna consists of about 75' of 14awg wire averaging about 10-12' high and with another 25' of lead-in. For such an antenna Khun models a 30m antenna 3m high which approximates my situation closely enough. Wire resistance is negligible as is the radiation resistance which he shows to vary between some 0.1 to 1.5 ohms. Such an antenna is capacitive by nature and will have about 220 - 375pF along with some small 20uH inductance, not too far off a standard "dummy" antenna. This pretty much leaves earth resistance Rg as the main unknown parameter.

For Rg one has the option of punting and taking the "Standard" value of 25 ohms. In my modeling I have found this parameter to be critical and highly sensitive. I do not recommend guessing here, it is recommended one go to the internet page of their state, county, or local government and search for reports on ground or soil resistivity (or conductivity). As this is an important agricultural and engineering parameter, it has been surveyed for most places and should be available with some effort. Effort well rewarded. Earth resistivity for the Texas Gulf Coast is a mercifully low 10 - 15 ohm meters, but for many regions this will not be the case.

Earth resistivity depends on a number of variables including the material, moisture, mineral salt, and temperature. A table of typical ranges in ohm meters for some different soils follows:

Loam	5	-	50	ohm meter
Clay	4	-	100	
Sand/Gravel	50	-	1,000	
Limestone	5	-	10,000	
Sandstone	20	-	2,000	
Granite	1,000	-	2,000	
Slates	600	-	5,000	

Moisture up to about 17% dramatically lowers resistivity, mineral salts are needed and pure water is an insulator, and as the temperature approaches freezing the resistivity also rises dramatically. All this factors into your estimation of Rg. The actual resistivity seen by the circuit depends on the earth resistivity and the type of grounding system you have installed. The more metal in the ground, and deeper, the lower the resistance. Know thy earth! A map of USA soil resistivity follows:

"Substitution of other atoms for lead in galena is not very extensive. Among the elements which do accur in small amounts are: Sb, As, Bi, Ag, Ti, Zn, Cd, Fe, Mn and Cu. In many cases these may be present in impurity minerals (acanthite Ag2S, sphalerite, chalcopyrite, etc.) rather than in the galena structure."

Why is this interesting for the radio engineer? The following is my own theory, (speculation mostly). Most of you who have worked with galena detectors have noted that hot spots generally occur on or adjacent to fractures, lines or discontinuities on the crystal face, seldomly on the smooth lustrous face itself. Rectification occurs at the junction of two minerals, or of a mineral with a cat's whisker metal. Many explanations have been offered, most having to do with the position and nature of the crystal lattice at the point of contact, and the perceived presence of "impurities" (atoms other than lead) in the galena crystal matrix. As noted above, "Steel Galena" is a often an ore of silver containing not only galena, but abundant admixtures of associated minerals generally too small to see and thus seldomly described except in detailed mining reports as above. In addition, the very small grain size of common steel galena allows numerous physical and mineral discontinuities on the small detector surface area, and thus numerous hot spots. I speculate that many/most of these hot spots may in fact be at the junctions of galena and other minerals along with the light contact of the ever-so-sharp cat's whisker itself. Other galena (lead) deposits such as the Missouri / Tri-State region are not associated with silver mineralization (Tri-State ores typically have only about 30ppm Ag). These show large museum quality crystal faces but have poor detector properties.

"The coarsest galena examined showed cleavage faces from 2 to 4 mm, square, but generally it is much finer grained than this. The fine-grained galena is commonly known as steel galena because freshly fractured surfaces have a steel-like luster. In all the specimens examed, this steel galena appeared to be in an intimate mixture of galena, tetrahedrite, sphalerite, pyrite, gnague, and other minerals present in the ore."....
"It appears that the original ore body consisted chiefly of galena, sphalerite, pyrite, pyrrhotite, tetrahedrite, freibergite, quartz and siderite. When movement took place along the O'Neil Fault and possibly along with minor slips, the ore body was greatly crushed, during which time the galena acted as a putty-like mass for the suspension of broken fragments of the harder minerals. This breaking resulted in the formation of the typical steel galena."....

In this ore, galena is NOT the silver-bearing mineral. Rather, the silver is in the freibergite and to a lesser extent in the tetrahedrite. Very interesting. Quoting from classic mineralogy texts on galena I find the following:

Dana's Manual of Minerology: (Hurlbut)
"Pb 86.6, S 13.4 per cent. Silver is usually present, probably as admixtures of silver minerals such as argentite or tetrahedrite."

Elements of Mineralogy: (Mason and Berry)
"Commonly, galena is very nearly pure PbS. The silver, arsenic, and antimony reported in chemical analyses are largely due to the inclusions of argentite of tetrahedrite, small amounts of which are difficult to detect in a black opaque mineral."

An Introduction to the Rock Forming Minerals: (Deer, Howie and Zussman)

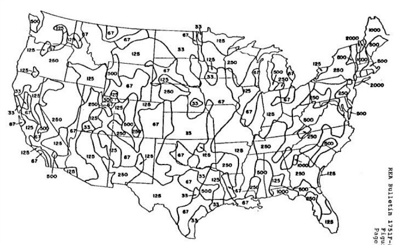


FIGURE 2
Estimated Average Earth Resistivity in U.S. (ohm-meters)

Modeling:

All the above discussion is great but... What is important really? The following section presents the results of applying different parameters to get a feel for the sensitivity of it all. To begin with I need explain my base assumptions. All the models are based on Kleijer's calculation spreadsheet which requires inputs for the following parameters:

Frequency
Coil inductance
LC circuit Q unloaded
* Complex impedance of antenna or
Series Resistance (Rg+Ra+Rr)
Series Capacitance Ca
Series Inductance La

* If the series values are given, the complex impedance is calculated.

1) Frequency is chosen per your interest, I have taken models at F = 550-1100-1700 kHz.

2) Coil inductance one has control over when winding. I have chosen base values that resonate with about 400pF tank capacitance, with some sensitivities.

3) Unloaded Q I do not have. For modeling I have taken Vargas's measures for a 4.5" coil wound with 660/46 Litz wire. I assume this will be about as good a coil as one can wind. I also made a sensitivity for lower Q. Q is a function of frequency and I have used the appropriate value of Q to match the modeled frequency.

4) Series Resistance is basically what the earth and ground system will deliver plus a small 1-2 ohm contribution from Ra and Rr. I have modeled four cases 10, 15, 25 and 50 ohms. The first two cases reflect my needs on the Gulf Coast with low resistivity soil. The 25 ohm case is a "typical" or "standard" grround. Finally, many will have much higher resistivity soils and you need to know just how difficult things can get!

5) Series capacitance I based for my specific antenna on the model of Ken Kuhn (Mathematical Model of Wire Antenna). The capacitance of a 30m antenna 3m high he calculated to range from 220pF and low frequencies to 375pF and high frequencies. I input the correct capacitance to match the frequency modeled.

6) Series inductance I just input 20 uH every time.

Some thoughts on "Steel Galena" and its use as a crystal detector/rectifier for radio waves.
http://www.lessmiths.com/~kjsmith/crystal/sgalena.shtml

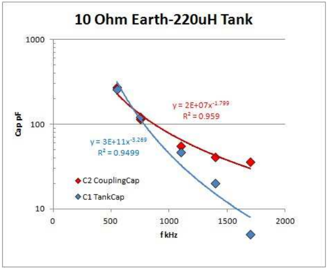
I have recently become interested in crystal radios and am especially interested in the "cystal" in the radio. This is due to my background as a geologist / mineralogist / petrologist / oil exploration geologist. I have read in several radio websites concerning steel galena describing it as argentiferous as well as fine grained and useful as an excellent detector with numerous hot spots. While commonly associated with silver ores, I have never read of galena itself as being much silver bearing as a mineral. This puzzle sent me to the web to see what I could find on this "steel" variety.

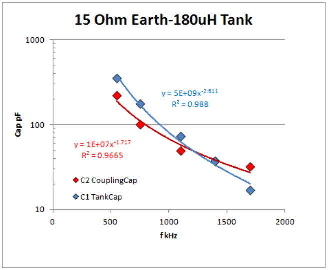
Steel Galena does indeed associate most closely with silver ore deposits, especially in the classic Rocky Mountain silver districts like Leadville in Colorado, Coeur d'Alene in Idaho, and Tintic / Park City of Utah. In all cases the ore bodies themselves are in sheared and altered sedimentary rocks. Mineralization is due to hydrothermal movements of water with movement aided by the sheared, and crushed zones having fine to extremely fine grain size, hence its name "steel".

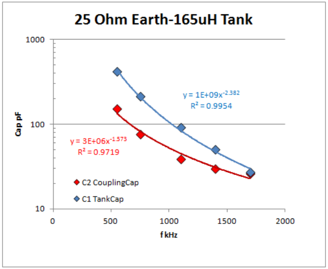
To give a sense of the deposits themselves I wish to quote a couple accurate petrological descriptions:

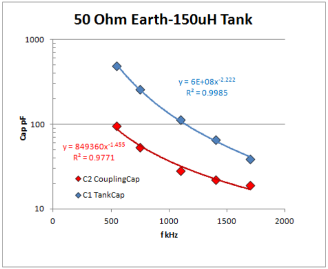
Waldschmidt, 1921: Hecla East Vein, Coeur d'Alene

The data and plots for four different scenarios follow:

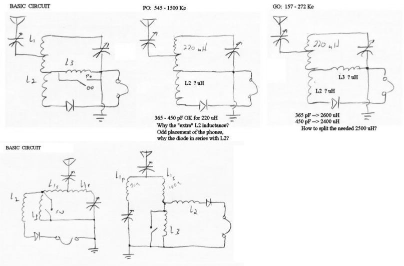




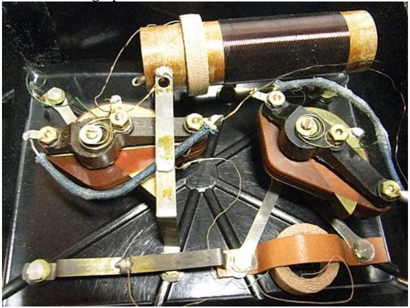




The above plots show the calculated capacitance versus frequency for four different models of Earth Resistivity / Tank Inductance. In each case I maintain the same log capacitance



Innards Photograph from an actual set..

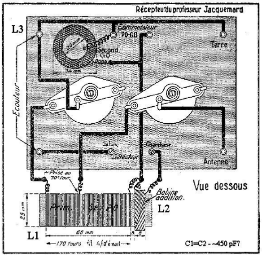


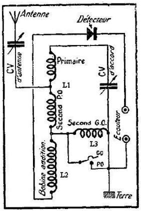
calculations from above:
LW tuning with assumed 450pF cap is 2300 - 2400 uH

The following photos show the set and the references mentionned above.

(some useful translations for my anglophone friends:
PO = Petits Ondes = Short waves [so named prior to the utility of the HF bands was known]
GO = Grandes Ondes = Long Waves
Bobine Addition = Additional Coil)

Jacquemard Schematic and layout..





L1 - 25mm x 68mm, 170t, 4/10 (~28awg)
tap at turn 70 220uH
L2 - 25mm x 8mm x 35mm
L3 - 20mm id, 34mm od, 5-7mm thick?

Circuit Analysis/Redraws of above..

vs frequency scale for easy comparison. The cases modeled represent increasing earth resistance presented to the ATU from a very low 10 ohms to a fairly high 50 ohms. Actual earths can go up to two orders of magnitude higher. I chose L1 inductances such that the maximum needed capacitance would approach 500pFs, easily found on many variable caps. With respect to the coupling cap (C2, red curve), as the earth resistivity increases the needed capacitance declines. The tank cap value needs to resonate with the inductor and increases with smaller-value inductance. In searching for a 500pF max cap value, the choice of inductance needs to decrease with increasing earth resistance. Parameters other than Rg, L1 and C1-C2 have minor impact on the models.

Conclusions:

From the plots one can readily see that above 10 ohm earth the two variable capacitors on the ATU do not track well. As the earth resistivity increases, the worse the tracking. Most locations are not blessed with a low resistivity earth and this needs to be factored into the ATU design. There is little to be done, changing the design coil inductance will change the needed capacitance on BOTH C1 and C2, (larger L1 leads to smaller C1 and C2 for resonance and vice versa). A possible solution well worth trying is to use a dual-gang capacitor where one section has a different value than the other, the above plots give an easy way to decide the max values needed. Use the smaller gang on the coupling circuit and the larget on the tank. Experience tells us that ganging the capacitors on a "Tuggle" front end works well, but from the models I have to imagine one might squeeze a bit more performance by giving up the convenience of one-dial tuning on the ATU, especially where your earth has a fairly high resistance.

The best design concept will be to know first and critically your earth resistance. If this is just a guessed-at parameter then I strongly urge you to put down the Litz, set aside the silver-plated caps, store the holy-grail diodes and go do some research on your local ground. All the time, expense, and effort on the greatest "state-of-the-art" crystal receiver will be wasted if the ground is not attended to. If the resistivity of your earth is high in ohm-meters, get more metal in the ground or consider a counter-poise. The following table from LEM Instruments shows the relation between earth resistivity in ohm meters and actual earth resistance in ohms as a function of the earthing method used.

Models and Data:

10 ohm / 220 uH Lowest resistivity Earth Case sensitivities

Ohm	pF	uH	uH	Qu	kHz	cpl	tank
Rg	Ca	La	L1		f	C2	C1
10	220	20	220	475	550	442	228
10	300	20	220	400	1100	68	36
10	375	20	220	200	1700	44	-3
10	220	20	220	700	550	273	255
10	260	20	220	640	750	114	122
10	300	20	220	585	1100	55	47
10	340	20	220	440	1400	41	20
10	375	20	220	300	1700	36	5
10	220	20	200	700	550	304	287
10	300	20	200	585	1100	58	54
10	375	20	200	300	1700	38	7

Professeur Jacquemard Poste a Galene
http://www.lessmiths.com/~kjsmith/crystal/jmrd.shtml

A bit of a mystery this one, I am hankering to build a breadboard repro of the set if only to play with this bizarre (to me) circuit.

data and information on the set is not small, but not enough:

from the schematic:
L1: form 25mm dia, 68mm long selenoid, 170 turns 4/10 wire
calculation- 0.4mm-26awg wire, 220uH coil
L2: ID 25mm, W 8mm. OD, #turns, guage not given
L3: ID 20mm, OD 34mm. W, #turns, guage not given

estimation from photo:
L2: OD about 32-35mm, wire guage is small in the 32+ range
L3: W maybe 6-8mm, wire guage is small in the 32+ range

from book:
MW = 545 - 1500 Kc
LW = 157 - 272 Kc

from calculations:
MW tuning with 220uH typically 365 - 450 pF

from clues in the two publications
1. most Vcaps are 450pF
2. most GO coils 120turns x two coils

15 ohm / 180 uH Low resistivity Earth Case sensitivities

Ohm	pF	uH	uH	Qu	kHz	cpl	tank
Rg	Ca	La	L1		f	C2	C1
15	220	20	180	475	550	337	328
15	300	20	180	400	1100	61	63
15	375	20	180	200	1700	40	10
15	220	20	180	700	550	220	352
15	260	20	180	640	750	100	176
15	300	20	180	585	1100	49	73
15	340	20	180	440	1400	37	37
15	375	20	180	300	1700	32	17
15	220	20	130	700	550	313	511
15	300	20	130	585	1100	59	110
15	375	20	130	300	1700	38	30
15	220	20	205	700	550	195	302
15	300	20	205	585	1100	45	61
15	375	20	205	300	1700	30	13

25 ohm / 165 uH "Standard" resistivity Earth Case sensitivities

Ohm	pF	uH	uH	Qu	kHz	cpl	tank
Rg	Ca	La	L1		f	C2	C1
25	220	20	165	475	550	213	396
25	300	20	165	400	1100	48	84
25	375	20	165	200	1700	32	22
25	220	20	150	700	550	164	462
25	300	20	150	585	1100	41	102
25	375	20	150	300	1700	27	31

25	220	20	165	700	550	151	416
25	260	20	165	640	750	76	213
25	300	20	165	585	1100	39	91
25	340	20	165	440	1400	30	50
25	375	20	165	300	1700	26	27
25	220	20	200	700	550	130	335
25	300	20	200	585	1100	35	72
25	375	20	200	300	1700	24	20

50 ohm / 150 uH High resistivity Earth Case sensitivities

Ohm	pF	uH	uH	Qu	kHz	cpl	tank
Rg	Ca	La	L1		f	C2	C1
50	220	20	150	475	550	128	476
50	300	20	150	400	1100	34	108
50	375	20	150	200	1700	24	35
50	220	20	150	700	550	96	490
50	260	20	150	640	750	53	256
50	300	20	150	585	1100	28	113
50	340	20	150	440	1400	22	65
50	375	20	150	300	1700	19	39
50	220	20	125	700	550	110	595
50	300	20	125	585	1100	31	139
50	375	20	125	300	1700	21	49

Kevin Smith
09/2011

CHAPTER V

Other Thoughts and Speculations

Coil Q:
http://www.lessmiths.com/~kjsmith/crystal/coilq.shtml
Kevin Smith

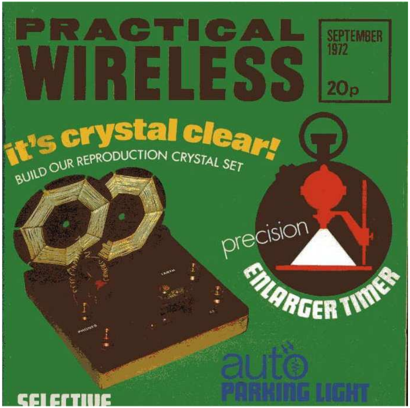
Introduction:

I have been building and studying crystal radios for some time now and slowly begin to learn a few things about these marvelous sets. In this section I begin my exploration of coil, coil quality and that mysterious dimensionless factor, Q... This page thus is a bit preliminary as I have not yet begun any measurements to determine the Q of my coils. Please bear with me.

My purpose here is to present some facts and data that has resulted from my explorations of the web. I have often wondered at what the quality factor of my coils should be and as often realized that I really do not have any expectations as to what is possible. Now, having dome some research, I can with some confidance say that this is solved. Coils as used in crystal radio broadcast band reception typically employ coils with Q factors ranging from 100+ (pretty lousy) through the several 100's (decent) and on up to 1000 or more for those remarkable Big-Litz wonders ($$$). Knowing the expected (or actual) Q of your coil is important in so far as it impacts the choice of diode to be used in the set. On my page of Diode Calibration I present a summary graphic which indicates how the diode Rd value relates to the tank parallel resistance Rp. This Rp in turn is a function of the coil Q. Schezzam! So here we are.

In your set construction, with a good effort and good engineering practice one can easily expect to wind a solenoid coil in the Q = 200 range without much trouble, even with a cardboard form, sealed, of course. With various "open" coils, spiderweb, basket weave, diamond weave, etc. you may expect to double that.. possibly. The advantage in open coils derives from first the separation between adjacent wire turns which reduces self-capacitance in the coil, and secondly from the obvious lack of a form. All materials used in the coil will have some amount of dielectric losses associated with them and the less material used the better. Air core coils are best in this respect. I am not here to speak about ferrite coils as I have no experience with them. Frankly, they seem (to me) a bit like cheating.

The following graph presents data that I have scoured off the web. My primary sources include Hund and Groot, 1925*, Wes Hayward, Dave Schmarder, Ken Khun, Mike Tuggle, Steve Ratzlaff, and Dick Kleijer. 10,000 thanks for those who post their data on the web! The following plot gives the Q value as a function of coil Rs (series resistance. In striving for a high Q coil, in effect one is eliminating losses and lowering the series resistance as much as possible. There is more to it of course. The Q formula Qu = 2pifL / Rs tells us that Q is also a function of the coil inductance L and the frequency f of the measurement. All measurements chosen for plotting are made around 1 Mhz and most of the coils are in the L = 200 - 350 uH range. So, despite the formula, in this plot the coil Rp is the main driver. From the plot it should be apparent that winding a coil with Q = 200 or better should be a no-brainer. If your coil Q is less, you just aren't trying. At the high end, Q's > 1000 seem to be pretty extreme and these coils are expensive. You better be using big Litz 660/46 and use a basket design (although the two best coils on the plot were solenoids).



Practical Wireless, September 1972 cover.

ANTIQUE RADIO

By Marc Ellis

Mailbag Time Again!

It's time once again to give our readers the floor. Receiving mail from you is certainly one of the most enjoyable parts of this job! It's instructive, it's fun, and it keeps me in touch with your interests—which is a great help in planning the column.

Brackets
Earth
Adjustment
Phones
Cats whisker
Crystal
Aerial

Here's a pictorial of the reproduction 1922 British crystal set built by reader D.B. Millar from plans in Practical Wireless *magazine. The set was tuned by swinging the front pancake coil over the back one.*

My way of responding to your letters is to acknowledge them on these pages. If I tried to respond personally, particularly to the many requests for schematics, technical advice, and other information, I wouldn't have time to write *Antique Radio*.

So instead I share the letters, referring the questions and requests to the readership at large and passing along the many interesting tips and other pieces of information. For maximum impact, and in order not to interrupt the flow of ongoing projects or stories, your letters are saved up and put together, in a special column or two, three or four times a year.

Since it does take another couple of months after I write a column for the magazine to hit the streets, it can be six months or more before you see your request or comment in print! So please be patient.

CRYSTAL SET COMMENTS

The series of articles on the NBS crystal set drew a lot of attention, and I'm still receiving comments from readers on that subject. Let's start with one from *Rudolf Mangold* (Penn Valley, CA), who remembers building crystal sets with his dad in the early 1920's. Even though the NBS set was designed to be scratch-built, Rudy doesn't understand why a capacitor wasn't used across the phones. The phones act as an RF choke, attenuating the flow of current through the crystal unless bypassed. "If we would show a crystal set without a capacitor at our radio club, we would be laughed at." Rudy and his dad made their own phone capacitors by sandwiching alternate layers of metal foil and tissue paper.

D.B. Millar (Annapolis, MD) built a kind of British equivalent of the NBS set from vintage plans published in the UK magazine *Practical Wireless* (September, 1972). It was offered as a means for listening to the BBC 50th anniversary program (November, 1972) commemorating the first broadcast in 1922. That set didn't have a phone capacitor either, but (using a formula from Ghirardi's *Radio Physics Course*) Millar built one from aluminum foil and masking tape—rolling up the "sandwich" into a neat cylinder.

Many folks who don't have the patience to fool with a cat's whisker (myself included) like to substitute a modern semiconductor diode for the galena while experimenting with crystal-set circuits. *George H. Haby* (Altadena, CA), who is 88 years old, goes us one better by using *four* diodes hooked up as a standard full-wave rectifier. The input terminals are connected where the crystal normally goes; the output terminals to the headphones.

Vincent Bashore (San Ysidro, CA) received his first crystal set as a birthday present in 1928, then got into building them. He once gave up school lunches for a week to accumulate parts money for a set using a coil wound on a maple rolling pin and tuned by a brass slider.

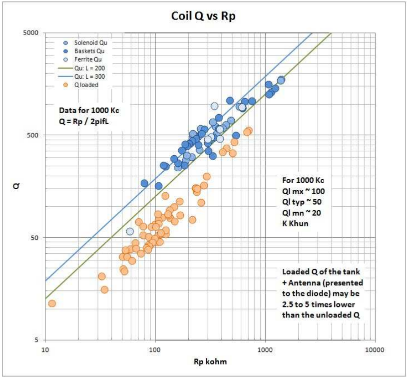
A photo received from *Robert S. Davey* (Frankfort, IN) shows a set he built from plans in *Popular Mechanics* (January, 1977). The published set used a 3½-inch-diameter, cylindrical salt container as a form, but Bob seems to have used some other kind of tube. For flexibility in experimentation, he substituted clip-lead coil connections for the permanent ones suggested in the article.

A. Ross (1926 Hafor Circle, Iowa City, IA 52246) is looking for two of the references I mentioned during the NBS set series: *How to Build Your Radio Receiver*,

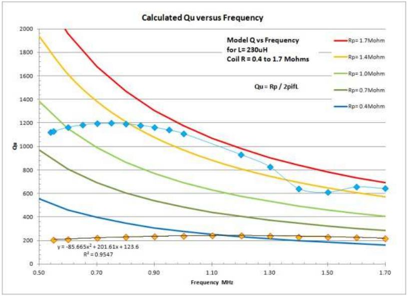
March 1995, Popular Electronics

64

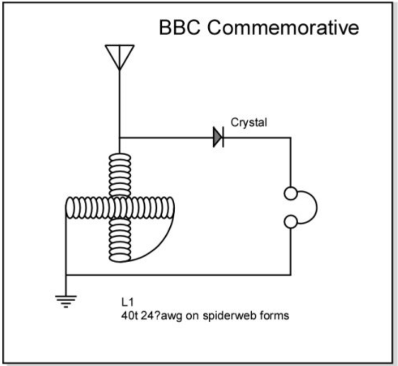
Popular Electronics, March 1995



On the plot I also post in orange circles my estimate of what the loaded Q presented to the diode (Antenna + Tank) might look like. Loaded Q will always be lower than the unloaded Q by several times. I have estimated that high-end sets (big litz, silver-plated ceramic insulated caps, best wiring practices) may lower the Q by about 2 1/2 times (B Tongue's performance set has Q = 700). At the low end (vintage components, small solid wire coils, taps) the load may lower Q by up to 5 times. Ken Khun in his excellent web book states that typical sets at 1Mhz have a loaded Q between 20 and 100, 50 typical and this is where most of the data falls. I scaled the divisor by Qu to produce the above plot but note that this is merely an estimate. Somewhere some bloke has no doubt tuned a big litz coil with cheapo capacitors. Having an idea of your set's Ql will allow a better selection of the proper diode for matching.



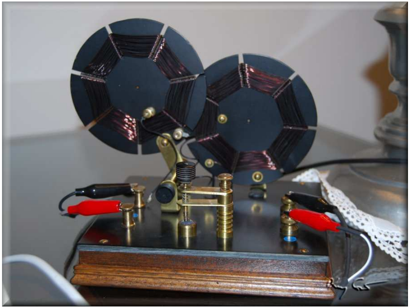
The above plot is from a series of measurements on two of my coils kindly made for me by Steve Ratzlaff, AA7U. The blue diamonds are the measurements on a 660/46 Litz basket beast and the yellow diamonds are measurements on a modest 18awg tapped solenoid wound of a cardboard form. The data from the low Q coil form a lovely continuum across the BCB band while the litz coil data above 1MHz or so seem to be declining and erratic. Steve measured the coil a great many times and found good consistant results. The measurements are excellent but I must say, I am a bit suspicious that the high-Q coil may be at the limit of the HP Q-meter calibration, or perhaps 660/46 litz Q tops out at 0.7-0.8 MHz and crashes above that. (I have not yet found time to persue this). The plot



Circuit Diagram of same.

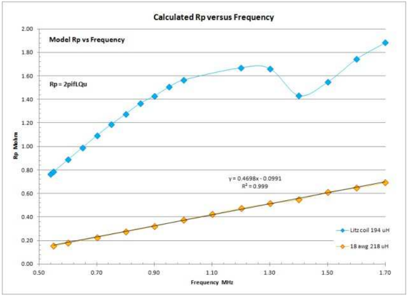
plans? Or, was this a kit? As I cannot locate an actual copy of the Sept 72 journal, I still can only speculate. I do hope it is a true homebuilt.

The following photos show the set and the references mentionned above.



Portrait of the beauty..

also includes Q vs f curves at constant Rp values. It is clear that, while tuning across the BCB spectrum, the Rp of the coil changes continuously.



Calculating the coil Rp from the data (Q:C:f), I have reproduced the above graph of the coil Rp vs frequency. It is evident that the trend follows a perfectly straight line for the low-Q coil. I would expect a similar straight-line relation for the litz coil but again things look strange. My impression here is that of a much steeper Rp vs f relation where the calibration on the Q-meter breaks down near 1MHz (Rp ~1.5 MOhm) and the data wanders until a second linear trend (with about the same slope) is re-established between 1.4 to 1.7MHz.

Now time for a few calculations, just how good can a coil Q get?

The following calculation is made to determine the AC resistance of the Litz wire used in a coil:
From different Litz wire manufacturing sites one can find tables and data allowing the calculation of the resistance of your favorite litz wire.

The formula for the D.C. resistance of any Litz construction is:

Rdc = Rs (1.0515)^Nb * (1.025)^Nc / Ns

Where:
Rdc = Resistance in Ohms/1000 ft.
Rs = Maximum D.C. resistance of the individual strands (4544 for 46awg wire)
Nb = Number of Bunching operations (assume = 2)
Nc = Number of Cabling operations (assume = 1)
Ns = Number of individual strands (assume = 660)

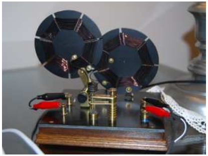
Rdc = 4544 (1.015)^2 (1.025)^1 / 660 = 7.27 ohms / 1000 ft.

The ratio of AC resistance to DC resistance of any Litz construction is:

Rac/Rdc = S + K (N Di / Do)^2 * G

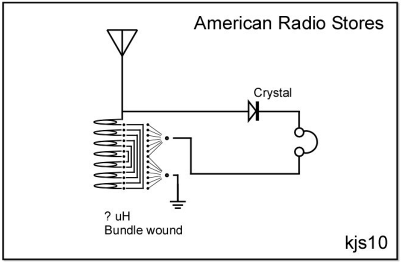
Where:
S = Resistance ratio of individual strands when isolated (1.0003 for 46awg wire)
G = Eddy Current basis factor = (Di * sqrt(f) / 10.44)^4
F = Operating Frequency in HZ (assume 1MHz)
N = Number of strands in the cable = 660
Di = Diameter of the individual strands over the copper in inches = 0.0016

BBC 1922 - 1972 Commerative
http://www.lessmiths.com/~kjsmith/crystal/bbc.shtml



A bit of a mystery this one, I found this radio on ebay and it was just SO pretty that I had to have it. The circuit is a simple variometer of pancake-coil design. Being a variometer has its drawbacks such as limited sensitivity and gawd-awful selectivity. If this piece wasn't so darned cute I would let it adorn the shelf indefinately. The set does have one mysterious element for me. Who made it? When? Some research on the web resulted in two interesting discoveries and an added mystery. On Darryl boyd's excellent web site I found in the plans section a mention of this very set, or one very near to it taken from the March 1995 issue fo Popular Electronics. The reference was to the September 1972 British journal Popular Wireless, the text I have shamelessly copied and placed below, the critical text highlighted in red. I subsequently found an image of the cover of the Prac Wireless issue with the set nicely featured. So, I have to assume this set is homemade at or soon after the publication of the plans in that issue. I assume the set was made in USA, but cannot be sure at all.

The new mystery? well, if you look closely at the radio I have, the drawing in the Pop Electronics article and the photo of the radio on the Prac Wireless cover, you will see virtually the EXACT SAME set right down to the hardware and placement. Only a few minor differences. My mystery then is this, was this an extremely faithful homebuilt version from detailed



Circuit schematic for the set.

Portrait, set and box.

Do = Diameter of the finished cable over the strands in inches = 0.056
K = Constant depending on the number of strands = 2

Rac/Rdc = 1.0003 +2(660*0.0016 / 0.056)^2 * (0.0016*1000 / 10.44)^4 = 1.393

Therefore the AC Resistance of 660/46 litz wire is approximately:

The A.C. resistance is: 1.39 * 7.27 = 10.13 ohms/1000ft.

A 5inch diameter basket weave coil made from 660/46 Litz wire having an inductance of 230 uH will typically require some 40 turns or about 53ft of wire. At 10.13 Ohm/kft, that comes to an AC wire resistance of 0.53 ohms for the coil alone. Were all the losses represented by series resistance of the wire, the coil would have, at 1 MHz an unloaded Q = 2700! Naturally, wire resistance is not the only source of loss in the tank. There is a capacitor, metallic objects intruding into the magnetic field of the coil, diaelectric losses, eddy current and other losses. Its no wonder that the best coils just top out above Q = 1000 or so.

This is where I leave things. Time to get measuring. Below I provide my input data, have at it!

Kevin Smith

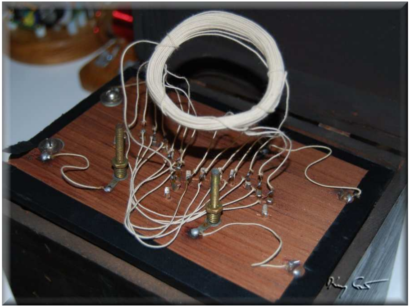
*Note that in 1925 the importance of coil Rs was understood, but the factor Q was apparently not used. I have taken (quite painfully) the L and Rs data from their plots and calculated the resulting Q. I recommend to those interested to download the pdf of their paper.

Radio-Frequency Resistance and Inductance

Qu = 2pifL / Rs

		1Mhz		
Coil Type	Wire	Rs	L	Q
		awg	ohm	uH
solenoid	660/46	0.90	200	1400
solenoid	660/46	0.91	200	1375
solenoid	175/46	2.88	265	579
solenoid	12	2.98	230	485
solenoid	14	3.28	230	440
solenoid	16	3.52	230	410
solenoid	18	4.01	230	360
solenoid	50/46	4.89	275	353
solenoid	32/38	6.20	327	331
solenoid	20	4.66	230	310
solenoid	16	7.60	319	264
solenoid	28	8.80	360	257
solenoid	22	5.78	230	250
solenoid	24	8.10	319	247
solenoid	28	10.10	360	224
solenoid	28	10.30	360	220
solenoid	50/46	10.84	378	219
solenoid	24	6.72	230	215
solenoid	28	9.60	327	214
solenoid	28	9.70	319	207
solenoid	26	8.03	230	180
solenoid	28		327	
Basket weave	660/46	1.03	186	1134
Spider	660/46	1.38	241	1000++
Basket weave	660/46	1.08	186	1082
Spider	660/46	0.90	150	1000+
spider	660/46			816

Inside I expected to find a typical tapped selenoid, the box is certainly large enough for one. What I found suprised and rather shocked me. It still does! The coil is bundle-wound, a mass of 26-30 dcc wire about 2.25 inches diameter. I was unaware that such a design would work. It is impossible to check how the tap wires are attached, they seem to just get wound into the coil with no apparent connection. It appears to be continuous wires from one switch set wound around and around and then exiting to the second switch set. That sounds like eight independent coils wound together. Another odd circuit characteristic is the fact that the tap points between the two tap switches are wired to each other (see photo and schematic). Perhaps connecting in such a manner combines them into a single longer coil, hard to speculate. How this coil works is different from anything I have experienced in crystal radio. Completing the schematic, rectification takes place via an ordinary cat's whisker and small potted galena crystal, whew! This is certainly an interesting design if not otherwise efficient or selective. It is a welcome addition to my small menagerie of vintage sets.



Spider	165/46	1.94	232	750
Basket weave	175/46	2.56	265	650
spider	660/46			641
Spider	100/45	2.41	238	620
Spider	100/45	2.44	241	620
Spider	100/45	1.73	149	540
spider	175/46	4.94	373	474
Loose Basket	32/38	5.30	317	376
Spider	40/44	4.16	248	375
Spider	40/44	4.16	225	340
Spider	40/44	2.93	154	330
Spider	32/38	7.50	331	277
Loose Basket	24.00	7.60	317	262
Basket weave	22.00	6.82	265	244
Loose Basket	28.00	8.50	317	234
Spider	24.00	9.50	327	216
Basket weave	32/38	10.40	332	201
Spider	28.00	10.60	327	194
Honeycomb	32/38	12.00	355	186
Spider	28.00	12.00	330	173
Basket weave	24.00	13.80	323	147
Basket weave	28.00	16.40	323	124
Honeycomb	24.00	18.50	347	118
Honeycomb	28.00	27.50	347	79
ferrite rod	50/46	2.58	250	610
toroid	22	3.93	240	384
toroid	18	3.20	195	383
toroid	22	8.20	449	344
toroid	175/46	4.82	244	318
toroid	50/46	5.23	248	298
ferrite rod	22		80	
ferrite rod	22	16.94	158	58.6

2Layer Bank	32/38	9.40	327	219
3Layer Bank	32/38	13.00	336	162
2Layer Bank	24	14.20	323	143
2Layer Bank	28	16.80	323	121
4Layer Bank	32/38	19.50	360	116
3Layer Bank	24	21.00	333	100
3Layer Bank	28	24.00	333	87
4Layer Bank	24	29.00	336	73
4Layer Bank	28	32.50	336	65
Double Layer	28	inf	355	0

American Radio Stores, Inc.
http://www.lessmiths.com/~kjsmith/crystal/ars.shtml

An interesting vintage crystal set recently came up for bidding on Ebay, an American Radio Stores, Inc radio in good working condition. This set interested me because, from the photos provided, it looked to have a fairly classic 1920's circuit with tuning accomplished via two switches to taps on the coil. I presumed that they are units and 10's taps as outlined on the classic Bureau of standards Circuar #121 set. A modest bid brought the radio to my doorstep a couple weeks later.

Looking at the radio when it arrived showed me that this was, even for the time, a fairly inexpensive set lightly built with cheap but workable parts. As expected, the radio has fair sensitivity and abysmal selectivity. (Recall, I bought it for the classic design not its DX potential). Somewhat to my consternation, the front panel was attached to the box by four small brads that could not be removed. No chance to view the inductor in the interior without compromising the vintage nature of the radio. I agonized over the question of whether to tear into the box or preserve the radio. After deliberating some 30 - 40 nanoseconds I was scheming for the most efficient and least destructive procedure to access the interior. My handy Dremmel neatly sliced the small brads one by one leaving no marks on the box or panel.

An Analytical Approach to the measurement of coil Q
http://www.lessmiths.com/~kjsmith/crystal/coilqm.shtml
Kevin Smith

Background:

Measuring the values of your radio components is an interesting and fun part of the Crystal Radio Hobby. Not only does it help you design better radios, but helps to understand the physics behind the wires and plates. The radio coil, one of the principal components is generally that part wound by hand. All other components, diode, variable capacitor are usually bought ready-made. The coil sits at the heart of the set and yet it remains devilishly difficult to measure and characterize. Even cheapo inductance meters, (I mean, my cheapo meter) do not properly measure the coil inductance at radio frequency. Coil quality, well that is a whole other matter. Quality, or the Q-factor as it is often called is a bench-intensive and measurement-intensive proposition that even the most dedicated radio fan may shy away from.

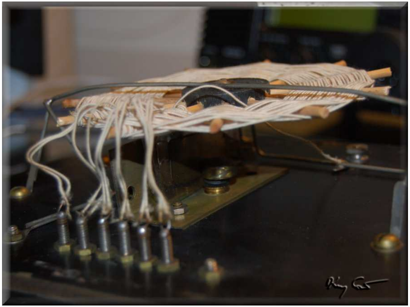
If you wish to know your coil Q-factor you have the choice of tracking down and paying a lot of money for an old HP or Boonton Q-Meter, or setting up a test bench and making the required measurements yourself. A number of techniques for measuring the Q of a coil have been published and excellent summaries can be found in "Q Factor Measurements on L-C Circuits" by Jacques Audet, and "Experiments with Coils and Q-Measurement" a web page by Wes Hayward.

All the techniques discussed involve variously setting up a parallel or series tank containing the coil to be tested and an accompanying capacitor to tune it to the needed measurement frequency. The tank is generally energized with a signal generator and measured with an oscilloscope or sensitive digital voltmeter. Other components often may include attenuators, SWR analyzers, Spectrum analyzers etc. Sources of error enter with coupling, loading, uncertainty as to the actual internal resistance of the source generator, and the need for several independent measurements which are then multiplied or divided together, adding additional error. All this works very well for the engineer with good bench practice, good equipment ($$), and the patience to perform the measurements several times to check repeatability. All these things plus the required anality coefficient the current author lacks.

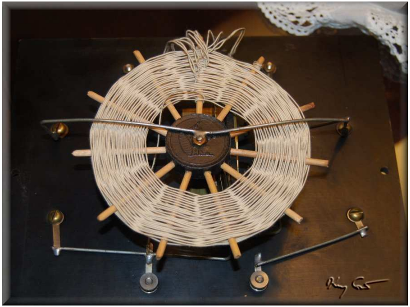
In this paper I propose an alternative approach that takes an analytical look at the oscillating tank waveform and determines the coil Q from that. This technique dispenses with a majority of the equipment involved with traditional methods but does require a digital oscilloscope. In recent years the affordability of these scopes has greatly increased. If you have a digital scope, or access to one, or were looking for an excuse to purchase one, then read on, this technique may be for you.

Some Theory:

The inspiration for this technique is certainly not new. I first found the following simple circuit, (Figure 1) on page 22 of Bucher’s 1919 "Wireless Experimenter’s Manual". Having a good deal of experience capturing and evaluating damped radio oscillations for a Spark Gap transmitter, I immediately saw the utility of the circuit for a simple Q determination based on the damping decrement of the tank.



A peek, such as it is, at the set condensers and cam tuning assembly.



The spiderweb coil with vintage cloth-covered wires, taps and wireing.

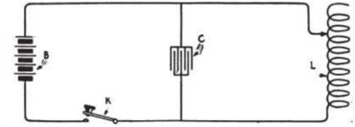


FIG. 8. Simple oscillation circuit illustrating the production of radio frequency currents.

Figure 1. Simple oscillation circuit, Bucher 1919.

As a professional Geologist, I must admit that most math involving more than ten fingers and ten toes (for advanced computations) is not my specialty. As such I will keep this aspect to an absolute minimum. Still, a bit of algebra may be useful to explain damping and logarithmic decrement. RF oscillations in a tank circuit are damped due to losses (primarily resistive) associated with that circuit. The amount of damping thus is related to the quality, or Q of the tank. In old texts the damping is generally determined by measuring the "Logarithmic Decrement" or the amplitude of successive oscillation peaks and taking the log of the ratio.

$$d = \ln(A1/A2) \qquad (1)$$

A more generalized version of this formula taking into account measurements over many periods can be expressed as:

$$d = 1/n \ln(Ao/An) \qquad (2)$$

Where n is the number of periods analyzed, Ao is the amplitude of the first peak and An is the amplitude of the peak n periods away. This equation allows a very simple determination of the log decrement with high accuracy. Because damping is due to resistive losses in the circuit, it can be related to the circuit components as follows, (Bucher, 1919):

d = pi (R / 2pifL) (3)

The angular frequency is often expressed as w= 2pif so this can be substituted into equation (3) above to simplify as

d = pi R / w L (4)

We turn now to looking at Q and its relation to the circuit components. The general expression for Q is:

Q = 2pifL / R (5)

Simplifying to

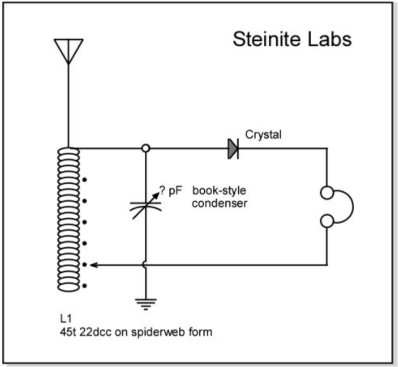
Q = w L / R (6)

With the term w L in both expressions, we can solve for w L in each and set them equal to each other:

QR = piR / d so:

Q = pi / d (7)

Dreadful, wasn't it? The inspiration here is that with a simple determination of the logarithmic decrement, deriving the circuit Q is a trivial exercise even a geologist can manage. No signal generators, no attenuators, no multiple measurements. All this should serve to reduce sources of error and give a faster and easier way to determine the quality of that most central component of your crystal radio, the coil.



Circuit as best I can make out

Portrait of the Steinite set

Setup:

The following schematic shows the setup, (Figure 2). In this configuration, I have used a simple 9V battery to stimulate the coil and have the scope connected to the tank via a coupling coil. An earlier configuration with a power supply resulted in too much noise and ripple to obtain a good reading. The tank is coupled lightly to the scope with a coupling coil. This coupling coil is simply two turns of hookup wire about 4 inches in diameter placed an inch or two from the coil to be tested and I have found no reason to space it further. Between the coupling coil and oscilloscope I utilize the 1:100 probe although testing with my 1:10 probe showed little impact. In this way, the coil under test is clean and well isolated from the measurement circuit.

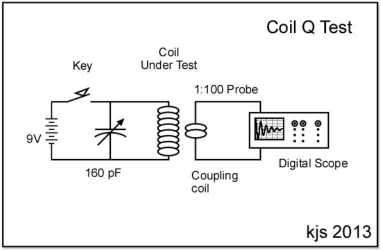


Figure 2. Schematic of test circuit.

For the tank I have used a small CT1C150 military spec cap ("APC"-type) with a capacitance range from about 20 to 160 pF. These are silver or nickel plated (depending on the source of information) and ceramic (steatite) insulated and should have a high Q with little impact on the test. At least this is the general assumption used in most Q-measurement articles I have run across. In actual fact the capacitor Q is not infinite and not even that high so resistive losses associated with the capacitor can be expected to lower the measured Q. One needs to keep this in mind and know that this measurement is on the resonator, not on the coil itself. More on this topic in a later section. The APC capacitance range is limited but sufficient for my intended test frequencies of 1.0 to 1.1 MHz, this is a test, not a radio.

Keying, or pulsing the circuit is somewhat tricky. In order to obtain a clean wave trace the pulse contact needs to be fast and sharp. Contact "bounce" and arcing, especially at radio frequency are difficult to avoid and pulsing the circuit several times may be needed prior to finding a clean trace. I initially used a transmitter key but found the contactor at RF to be messy with visible arcing. The best method I have found for pulsing the circuit is to connect a pointed probe to one side of the circuit and tap it sharply but lightly against the hot side of the battery. After a few tries one gets a "feel" for the contact. Pulse the circuit and get a wave, things are this simple.

Procedure:

Hang the coil under test on a stand where it is clear of other components or metal objects. Connect the coil as per the schematic. Connect the probe and scope to the coupling coil leads and set the scope for a good scale, (Figure 3). I generally use 5uS / division horizontal scale which gives me 40 to 50 oscillations at about 1 MHz. For higher Q coils I may go to

A Vintage Steinite
http://www.lessmiths.com/~kjsmith/crystal/steinite.shtml

Steinite standard from the mid-1920's. This set has lost its decal but not its classic look. It has a good condition enclosed crystal detector which works very well, binding and phone posts and labels in the typical Steinite lettering. Six taps on the interior spider-web coil and a mica and brass plate "book-style" condenser complete the tuning of this unit. Inside all the components are original with original soldering. It is unfortunate that the condenser is not working as expected. Peering in between the coil tap wires I can see what appears to be 3 or 5 brass plates separated by mica dielectrics. The tuning dial on top turns a shaft with a small cam that alternately compresses the plates together and lets them spring apart. I can see only the outside plate returning to its open position when the cam is open, the others remain compressed so the variation in capacitance is minimal. Well, I can enjoy one station. In fact the tuning is very broad so when "running" the radio has two or more stations competing for my attention. Well, its lovely just the same.

The following photos show the set and its interior.

10uS / division for a longer recording. Set the scope trigger appropriately to capture the data.

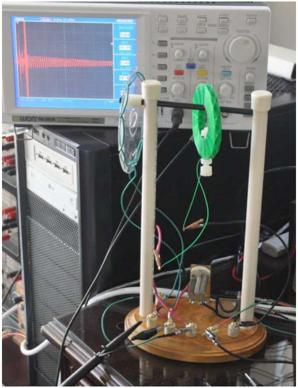


Figure 3. Photo of the test setup.

Tap, or "key" the battery to pulse the tank and review the waveform on the screen. Setting the scope on its measurement mode allows reading the wave frequency with each pulse. Adjust the capacitance after each pulse to bring the tank to the desired frequency, near 1 MHz in my case. Once at the desired frequency you are collecting data. When you get a good clean oscillation free of contact hash and noise, send the data to the computer for analysis. For my scope set at 5uS/div it returns

5000 data points to the computer. At 1 MHz that is about 100 data points per cycle, more than enough sampling to avoid any question of aliasing.

The decrement measurement is based on measuring two peaks. The data is in digital format so one should eliminate "estimation error" by actually reading the value off the spreadsheet, noting both time (in uS) and amplitude. Before taking readings, care must be taken to center the oscillations around zero. Amplitude measurements assume that the waveform is symmetrical around zero yet the scope may or, more likely, may not be set perfectly for this. In the spreadsheet the solution is simply to take the average of all the readings and subtract that from each.

Type the values for “to” (initial peak time), “tn” (final peak time), Ao (initial peak amplitude) and An (final peak amplifude), and the number of periods analyzed “n”.

$$T = tn - to \text{ in uS} \qquad (8)$$
$$f = 1/T \text{ in MHz} \qquad (9)$$

$$d = 1/n \ln(Ao/An) \qquad (10)$$
$$Q = pi / d \qquad (7)$$

Next, disconnect the battery and coil and measure carefully the capacitance, C, that was used in the test. With this you can calculate the actual coil inductance from the frequency and capacitance. Why buy an expensive L meter?

$$L \text{ (uH)} = 1E6 * ((1/ 2pif)^2) / C \text{ (pF)} \qquad (12)$$

Example One:

CHAPTER IV

Radios I have acquired (read: paid waay too much for, with no regrets)

An example to show off a bit. This test was made with a close-wound tapped solenoid on a 3" cardboard form. The graphic in Figure 4 shows some initial contact hash followed by a lovely damped oscillation. Measurements on this coil showed a test frequency of 1.055 MHz, L of 215 uH and C = 106 pF. Q was calculated at 167. A decent coil but not great.

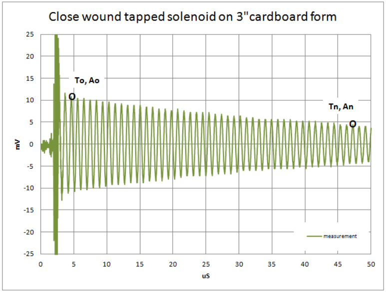


Figure 4. Oscillogram of a coil under test.

$n = 45$
$T = (t_n - t_o) / n = (47.24 - 4.59)/45 = 0.948$ uS
$f = 1/T = 1/0.948 = 1.055$ MHz

$A_o =$ $= 11.2$ mV
$A_n =$ $= 4.80$

$d = 1/n \ln(A_o/A_n) = 1/45 \exp(11.2/4.80) = 0.01883$
$Q = \pi / d = 3.142 / 0.01883$ $= 167$

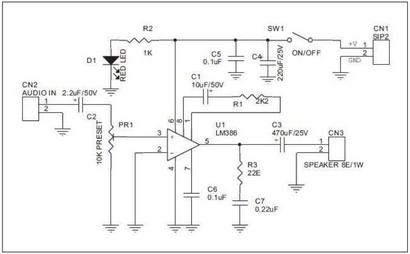
To test the validity of this technique we need a bit more theory, just to be certain this is working. With the data in spreadsheet form, it becomes possible to model the coil from a theoretical standpoint. The model can then be plotted with and compared to the acquired data to test for correlation. Various web pages, especially university-sponsored lab exercises provide a good source for practical techniques and their theoretical underpinnings. Some good sources I utilized include:
"Damped oscillations in RLC circuits" by Barbara Dziurdzia at AGH University of Science and Technology in Cracow, "RLC Circuits" a lab note from Rice University, and "Oscillations and Resonances in LRC Circuits" from Durham University in the UK. And very many others.

From the above we find the general equation for damped electrical oscillations as:

qc = qo * e^(-a*t) * cos(2pif * t + phi) (13)

Where
qc is the charge in volts
qo is the initial charge
a is the damping factor (=Rs/2L (series) and = 1/2RpC (parallel)
R is the coil resistance in ohms
L is the coil inductance in uH
t is the time in uS
f is the frequency in MHz
and phi is the phase angle

The phase angle and qo charge are initial conditions and adjustments should be minor to fit the calculated oscillation to actual. L, the inductance comes from the calculation we made with equation (12), and frequency comes from equation (9).



It even looks nice from behind, vintage binding posts, naturally..

Schematic of the kit, (AnyKits.com) A005. The kit is configured with a maximum gain between 45 and 50, too high for headphones but too low really for listening with the speaker easily. You will note the location of R1 (in series with a 10uF capacitor) between pins 1 and 8 on the LM386. If you short the resistor leaving only the capacitor, then the gain will increase to the maximum of 200. If you do such a project, I recommend you download the LM386 datasheet from National Instruments.

This leaves the resistance of the coil (R) as the primary variable. Model the above equation in the spreadsheet by adjusting R until the model results match the measured oscillation from the coil. From the above example we see Figure 5 with the modeled damped wave overlaid on the test oscillation.

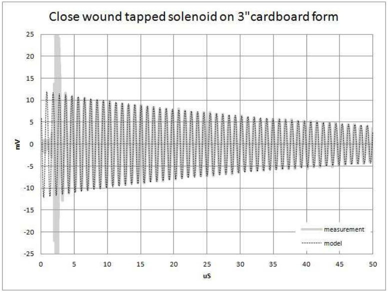


Figure 5. Oscillogram with modeled damped wave response.

Here the background data from the test is in grey and overlaying it is the dashed model in black. The fit is nearly perfect using a resistance of 0.22 Mohms. Relating resistivity to Q we have the following equation (5):

Q = Rp / 2pifL

Substituting f = 1.055 MHz, C = 106 pF, and R = 0.237 Mohms the result is Q = 167, exactly the same as with the decrement method. An exact match will not always be the case, but they ought to be fairly close. The match between theory and the decrement method gives confidence that this analytical technique is as robust as it is simple.

qc = qo * e^(-t/2RpC) * cos(2pif * t + phi)
qc = 12.2 exp(-t/2*Rp*106)*cos(6.283*1.055*t + 1)

Where t = 0 to 50 uS
R = 0.237 Mohm in this case for best match.

Q = Rp / 2pifL = 237000 / 6.283 * 1.055 * 215 = 167

Example Two:

To be sure the technique works I have also assessed the quality of a 5inch diameter basket weave coil wound from 660/46 litz wire. Such coils are rightly considered "performance coils" for their low skin-effect and low resistivity.

I was initially worried that the audio input impedance may cause me trouble. I read so much about this, impedance matching, transformers, etc etc, almost a fetish really. I have subsequently learned that the LM386 input impedance is about 800 Megohms, the 10k pot being the limiting factor. So, with considerable relief, I concluded this ought not present any problems with the crystal radio circuits. I find the amplifier works very nicely with my radios. The sound is as good as the Radio Shack unit.

The amplifier certainly adds to the vintage "look" of my setup. Well, you be the judge, I hope I come close, please check out the photos...

From the front, wooden base, full display of components, big adequate volume control..

crystal radios one builds with passion, creating something more than a mere radio, but a work of art, a piece of furniture. Still, the technology itself is primitive dating back to the dawn of radio. When I look at the mini amplifier, it looks like a toy yet inside there is the most wonderful technology, solid state integrated circuitry. We take this advanced technology and slap it inside a cheap plastic box, an appliance. Naturally, I don't complain about the price, but for my project I wish for something above.

The solution struck me as obvious, give the same care and respect for the amplifier as I do the radio. I also sought to maintain a "vintage" visual aspect for the unit, breadboard layout, antique binding posts and a large adequate volume control knob, (the pitiful volume control wheel on my RS mini has already come apart once and threatens to break at any time). I wanted a nice lacquered base and sturdy speaker enclosure. The enclosure was the main challenge. I finally ended up with a heavy plactic goblet from a local thrift shop cut down to a tapered cylinder into which the speaker can be placed tightly. The rest of the set is modular with plug-in connections for the audio in, power, speaker, and volume control potentiometer. A question, do I add a brass knife switch for the on-off? I worry I am out of room on the base. Still pondering this.

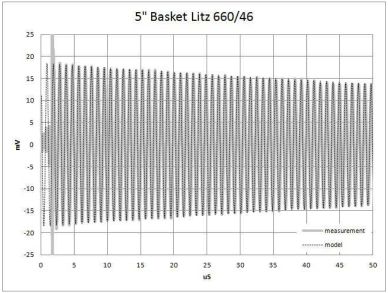


Figure 6. Second oscillogram with modeled damped wave response.

The coil tested values as follows:

$n = 45$
$T = (tn - to) / n = (47.82 - 4.70)/45 = 0.958$ uS
$f = 1/T = 1/0.958 = 1.044$ MHz

$Ao =$ $= 18.05$ mV
$An =$ $= 13.65$

$d = 1/n \ln(Ao/An) = 1/45 \exp(18.05/13.65) = 0.00621$
$Q = pi / d = 3.142 / 0.00621 = 506$

And:

$qc = qo * e^{(-t/2RpC)} * \cos(2pif * t + phi)$
$C = 123$ pF

qc = 18.55 exp(-t / 2*Rp*123)*cos(6.283*1.044*t + 1)

Where t = 0 to 50 uS
R = 0.627 Mohm in this case for best match.

Q = Rp / 2pifL = 627000 / 6.283 * 1.044 * 189 = 506

The results above for a big litz coil clearly demonstrate its superiority to a more common tapped solenoid. Published data though has let me to expect a big litz coil Q to be in the 1000+ range. I have run this test backwards and forwards, checking all possible causes for this unexpected low Q with no difference in the final value. In fact I am quite impressed with the repeatability of the technique and the correspondence between the results from the decrement and those from modeling the wave form.

To be certain I even tested the coil using the old -3dB method. As stated previously, I am uncomfortable using a signal generator in addition to the scope, and I have already found trouble connecting the 1:100 scope probe directly to the tank, as is necessary in this method. With that said, the results yield a bandwidth of 2.3kHz about a nominal frequency of 1018.8kHz for a tank Q = 450. I suspect the method (with the problems noted) lowballs somewhat the final result. In any case, this confirms the test to have a moderate Q and nothing like the expected values one reads online.

Notes on Capacitor Q and its impact on the measurement value.

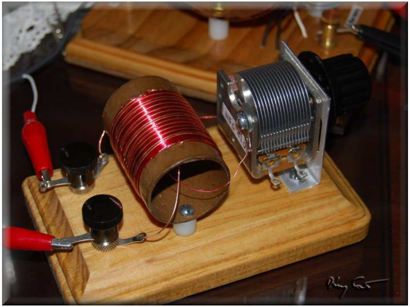
This is where we begin to think more seriously about the capacitor used to resonate the tank. The assumption of very high Q needs to be questioned. I stated in the setup discussion

A breadboard Audio Amplifier
http://www.lessmiths.com/~kjsmith/crystal/amp.shtml

A little project stemming from my persistant difficulty in hearing. (Losing one's hearing is never fun to admit, but combined with crystal radio, well, its trouble!) I hope I do not offend any "purists" with this project. Still, I understand that many crystal radio owners keep a small amplifier too, for "those times" when, well, you know.. So, this amplifier project, its for, well, those times.. (I suspect Radio Shack would have discontinued their nifty Mini Amplifier years ago had it not been for the crystal radio community.)

My idea was to build my own unit rather than use a store-bought amplifier. Additionally, I wished to put my own stamp on it, make it unique. I started with a kit for the basic layout and electronics. I wanted to base things on the NI LM386 chip which is a good part and hard to break. I found several distributers of what appears to me as the exact same kit and so chose the cheapest $6 dollar kit. NI sells the LM386 for 34 cents a pop and would even provide a few "samples" but then I would be stuck laying things out and wireing.. Been there, done that. A printed circuit board is just SO much easier to use.

One of my inspirations for this project also stems from the nature of modern electronics in general, and the Radio Shack mini amplifier in partictular. Using my RS mini, I am always struck by the contrast between electronics new and old. With



Wave Trap

my opinion that the capacitor Q ought to be high enough as to not influence the coil Q measurement in any significant manner. I said that for three reasons: 1) Just about every published article starts with such an assumption and 2) I had not done much research on the subject of capacitor Q and so had no particular expectations other than assumption 1 and finally 3) I had no measurements or specific knowledge of the Q for the capacitor used in my setup.

Reason 1 is a punt and should be rejected, reason 2 has been remedied and I give some analysis on the interesting subject of capacitor ESR (Equivelant Series Resistance) on a separate page so that readers may set their own expectations. For the third reason I have received the kind assistance of Steve Ratzlaff, AA7U who offered to make actual Q measurements on the coils and APC capacitors with his HP4342A Q-meter, results follow:

Litz basket coil,
550kc 1127Q;
1000kc 1140Q,
1700kc 674Q (194.2 uH on aade.com LC meter)

Solenoid coil,
550kc 205Q,
1000kc 240Q,
1700kc 222Q (218.2 uH on aade.com LC meter)

Using Steve's Litz wound ferrite rod coil (1000kc 1047Q) as the reference for external caps:

100 pF silver mica (99.2 pF meter):859Q at 1068kc (Q meter alone and coil 1025Q)

APC cap with red/black leads (149 pF meter): 937Q at 904kc (Q meter alone and coil 1060Q)
APC cap with my Litz leads (149 pF meter): 995Q at 904kc (Q meter alone and coil 1060Q)

Steve's measurements above provide important datapoints with which to calibrate my technique. Note first of all that the Litz coil is not a modest 506Q but a robust 1140Q at 1MHz. The reason for my low measurement was my assumption of a high-Q capacitor. Steve's measurements of two of my APC's are 995 and 937, hardly very high. There is an obvious need for a correction. Wes Hayward in his excellent notes on Q measurements provides the key in the form of the following formula:

$$Ql = (Qc * Qres) / (Qc - Qres) \qquad (14)$$

where Ql is the desired coil Q, Qres is the measured Q of the tank/resonator, and Qc is the tank capacitor Q.

Substituting the values Qres = 532 and Qc = 995 the equation simplifies thus:
Ql = (937 * 506) / (937 - 506)
Ql = 1100.

The result is distressingly close to Steve's measured value of 1140Q. This shows the possible level of accuracy in the analytical technique used, both reassuringly high and very "Litz-like".

Taking the first solenoid and substituting the values Qres = 167 and Qc = 937 the equation simplifies thus:
Ql = (937 * 167) / (937 - 167)
Ql = 203.

Wavetrap, a useful gadget
http://www.lessmiths.com/~kjsmith/crystal/wt.shtml

This little gadget is most handy for crunching those local behemoths that always seem to be directing their strongest signals right in your direction. My wave trap is a bit of a combination of 1) Osterhoudt's QRM coil, 2) a design I found online on Owen Pool's excellent web site, and 3) a bit of my own seeing as how I had some, but not all of the ingredients needed from both traps. That is, I used what I found in the junk box.

The trap is formed on a stiff cardboard paper core with 1 1/4 inch outside diameter. On this I drilled holes for winding the tank coil, 110 turns of #30 awg enameled wire. Both Poole and Osterhoudt recommend #32, but 30 is what I had. Over this I would a coupling coil, 15 turns space wound of #22 awg enameled wire. Tuning of the tank is completed with a 410 pF var cap.

Tuning is sharp and deep, it takes a bit of getting used to, but then, schezzam!!!.. problem station gone! I luv it.

This is slightly low to Steve's measured 240Q. I am of the opinion that the original tank measurement may have been a bit on the low side. Still, again the results are within the ballpark and the technique works if you have a good measure on the Q of the capacitor used in your tank. Alternatively, starting with a known coil Q, the technique will work equally well to determine the Q of an unknown capacitor.

Conclusion:

If you have access to, or own a digital oscilloscope, or have been hankering to purchase one, then the time may be now. The analytical method presented above is simple in practice and robust in theory. I would also say that, by working with your wave forms, you learn to recognize your data and soon get a good "feel" for what is good and what is not. The technique also produces, should you wish, an auditable report of the wave and analysis. It is hard to argue against the results with the waveform sitting there staring right at you!

Measuring your coil Q should not be difficult.

A copy of the evaluation spreadsheet in xls format can be found here CoilQbyDecrement_kjs.xls

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Bibliography:

Jacques Audet, VE2AZX., Q Factor Measurements on L-C Circuits., QEX - January/February 2012, pp 7 - 11.
http://www.arrl.org/files/file/QEX_Next_Issue/Jan-Feb_2012/QEX_1_12_Audet.pdf

EE. Bucher, 1919, "Wireless Experimenter's Manual", Wireless Press, New York.

Wes Hayward, W7ZOI, Experiments with Coils and Q-Measurement, October, 2007 (Updates 01Dec07, 08Dec08. http://web.archive.org/web/20101226143919/http://w7zoi.net/coilq.pdf

Steve Ratzlaff, AA7U kindly made detail measurements on the Q of the capacitors and coils used in this report.

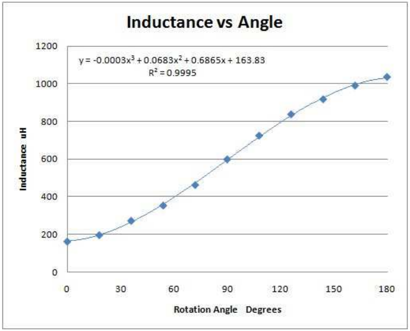
Dick Kleijer , 2013, Measuring the Q of LC Circuits, http://www.crystal-radio.eu/enqmeting.htm

Barbara Dziurdzia, 2013, Damped oscillations in RLC circuits, AGH University of Science and Technology in Cracow, http://home.agh.edu.pl/~lyson/downloads/Manual_8.pdf

Rice University EE., RLC Circuits, http://www.owlnet.rice.edu/~phys102/Lab/RLC_circuits.pdf

Durham University EE., Oscillations and Resonances in LRC Circuits,
http://level1.physics.dur.ac.uk/projects/script/lcr.pdf

of the inductance versus rotation angle and a photo of the Variometer mounted in its stand, ready for use.



Perhaps the less-than-optimal condition was a factor, but I was in luck to win the coil with an only bid. I had no illusions that this was a long-shot deal, the chances of the variometer being functional were poor. My expectations were not deceived when it arrived sometime later. Nope, it didnt work. The question was, could it be restored, and just how did the thing work, how were the connections made anyway? Inspection quickly led to three obvious broken connections and an understanding as to how the connections were intended. A few dabs of solder later and under the meter I had a fully-functionning variometer! All that was left was to give the vintage coil a lovely stand to show it off.

Measurements of the Inductance show a large variation, from 163 uH to 1036 uH. This should give good duty to electrically "lengthen" my woefully short antenna. Shown below is a plot

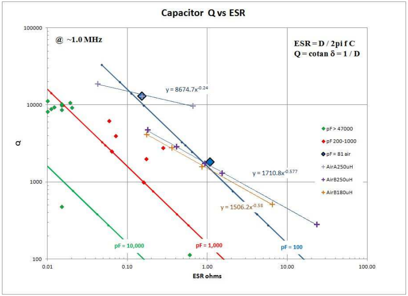
Crystal Radio Capacitors and ESR
Kevin Smith

In my ongoing effort to understand crystal radios and the theory that makes them work I have recently turned to setting my expectations concerning capacitance. The tuning capacitor is, next the coil itself, the principal component of the set. Few builders fabricate their own tuning caps so I suppose it is possible to take them a bit for granted. I have been reading on the radio forums some threads concerning radio Q and the subject of the variable cap Q seems to be getting more attention. So, what is the deal?

I set about my study by gathering what I could find on the web and at the close of this note I include a short reference list of useful pages from which I extracted data the ideas. I wish to extend special thanks to Ben Tongue who, as usual, has provided the essential measurements and background. The plot below of capacitor Q versus Equivalent Series Resistance (ESR) summarizes my findings. It is a bit busy as there are a number of interesting and important ideas represented in the relationships presented.

Any discussion of component quality needs first to acknowledge that the fight to increase the component Q is in reality a fight to eliminate (not possible) or reduce as much as feasible the resistive losses associated with that component. It helps then to look not just at Q, but at how Q relates to the component ESR. There are two fundamental equations that describe this relation: 1) Q = cotan theta = 1/D. D is the dissipation factor and is an attribute of the dielectric material used in the construction of the capacitor. Equation 2) ESR = D / 2pi f C. This equation tells us that capacitor losses expected due to resistance are both angular frequency and capacitance dependant. It is important to remember that not all Q's are created equal. What we want is to keep the ESR to a minimum.

On the plot there are a number of data trends presented. Note first that both plot axes are logarithmic, it makes a difference on how one thinks of the data. Additionally, note that the plot is specific (mostly) for data at 1.0 MHz. I make the assumption that a cap that is superior at that frequency is likely to be superior across the BCB.



The first things to discuss are the three slanting lines. These are computed from a table of Dissipation Factors at 1.0MHz by Dr. Johnson. I have supplied the capacitances and calculated the resulting Q and ESR values. When one goes looking at capacitor data sheets or summary tables one is likely to find data computed at 100 KHz and 1.0 MHz (mercifully) but that

Vintage Variometer / Loading Coil
http://www.lessmiths.com/~kjsmith/crystal/lcoil.shtml

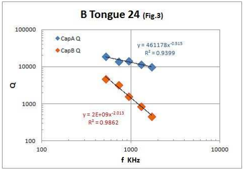
My receiving station is pretty typical I expect, decent ground, so so antenna and I have been hankering for some time to add a loading coil to my station to better match that antenna with my radios. Lack of urgency or just plain laziness perhaps have kept me from working on this project. Part of my hesitancy has been the idea of utilizing a variometer as a loading coil, and these are not easy to find.

Variometers are variable induction coils that function by being connected in series and changing the mutual inductance between them. Most variometers though have a relatively small range of inductances making them of limited suitability for, well, just about anything in crystal radio. They find a home mostly these days as a control for regeneration in such circuits. Alternatively they make a nice variable inductance load on your antenna, the purpose I was seeking. Only, I really wished to find/make something with quite a lot of wire to get a good range of inductances going. It was by some degree of luck I believe that I noticed some time back on ebay a rather beat-up looking variometer on offer. The variometer, shown below, was a basketball weave design and importantly, was wound in at least three layers suggesting a lot of inductance.

the likely capacitor data will be specific to caps in the uF range, or 10^6 higher that what we need in a crystal radio tank. Be careful not to get enamored with the high Q values occasionally quoted, check the capacitance. From the plot it should be apparent that not all Q's are created equal. Larger-value caps have lower ESR and so the Q's are often agreeably high. I have plotted a few specific cap measurements from various sources.

Two measurements should stand out; these are indicated by the larger blue diamonds. These are measurements by Bill Hebbert and presented by Ben Tongue in section B of his Article 24. I reproduce his Figure three below, with grateful apologies for the liberties I have taken,

By replotting Ben's figure I can calculate the relation between Q and frequency (table below) and so compute the estimated Q at any frequency. On my main plot I give Ben's Capacitor A and B for 1.0 MHz given the 250 uH inductor. Ben states that the plot assumes 20pF stray added. Since the capacitance needed to resonate at 1 MHz and 250 uH is 101 pF, I make the assumption his caps were set to 81 pF. This accounts for why the diamonds are set slightly off the 100 pF line of the plot. Given his Q measurements it is easy to compute the ESR for each cap. This is the world of the crystal radio builder. I include the ESR at the BCB endpoints for each cap as well to give the full picture.



pF		f	Q	
tank	cap	MHz	Cap A	Cap B
375	355	520	19000	4750
190	170	730	14000	3230
114	94	943	14400	1610
101	81	1000	*13148*	*1828*
60	40	1300	11600	870
35	15	1710	9800	460

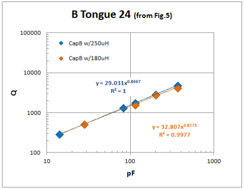
for I = 250 uH and 20pF stray in tank
(Q data in italics is computed)

The quest for high Q is indeed a quest for low ESR as long as you work in the capacitance range needed. One interesting piece of advice I have occasionally seen is that, to increase your tank Q, it is better to use lower-value coils and higher-value tuning caps. As much of the losses in the tank derive from losses in the coil this makes excellent sense. I wish to ask the question what about those higher-value caps? The plot immediately suggests that moving to higher capacitance drives down the ESR, this is a good thing. It may or may not improve the cap Q but I am not sure it matters as long as resistive losses are minimized. To better set my expectations I have again turned to Ben's Cap B data.

The small plot below takes data presented in his Figure 5. Data presented include Q at various capacitances and frequencies. I cross-plotted his data for pF and Q for the appropriate frequencies using both 250 uH and 180 uH inductances. Reading the actual Q off the tiny plot was an estimate at best, but it is interesting. This allows one to estimate his cap Q at any capacitance setting. The table below

CHAPTER III

Accessories on Breadboards



provides the estimated Q, and calculated D, and ESR for the capacitances from Fig 5 (with 20pF stray added). The values of Q do not improve by moving to higher capacitances but the ESR of the cap is slightly (at low tuning freq) and well improved (at the high tuning freq). This is the goal. It is worthy to note that the tuning frequencies do not line up with the original data from Ben's Fig 3 as seen on my main plot. While Ben specifically noted that his figure 3 included 20pF strays, in his figure 5 he speaks in absolute capacitances. I did my best to correct for this but there remains some ambiguity in the presentation. The point remains though; moving to higher capacitances in the tank will lower the tank losses due to ESR.

250 inductor (w/20pF stray)

tank pF	KHz	D	Q	ESR ohm
385	513	0.0002083	4800	0.177
220	679	0.0003448	2900	0.404
134	870	0.0005714	1750	0.917
101	1000	0.0007638	1309	1.502
34	1726	0.0034973	286	23.046

180 inductor (w/20pF stray)

tank pF	KHz	D	Q	ESR ohm
385	605	0.0002381	4200	0.172
220	800	0.0003571	2800	0.355

134	1025	0.0006250	1600	0.852
48	1712	0.0019341	517	6.425

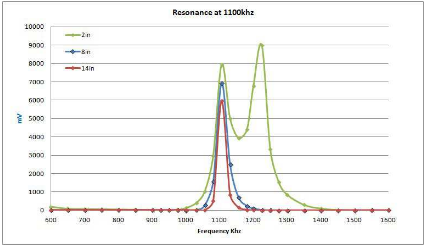
On the main plot then I have included for Ben's Cap B a second Q vs. ESR curve to illustrate the estimated benefit of using a higher tuning capacitance range. The new curve slides mostly to lower ESR (especially at the high end of the tuning range) and also to slightly lower Q. The improvements made appear modest from the modeled data and, for the case of a high-Q capacitor the possible improvements may be slight indeed. It is comforting to know that at least there should be no negative impact. Lower ESR certainly improves tank overall efficiency. This is a win-win situation where the set designer wins twice!

In seeking the "Holy Grail" tank capacitor I would add to the list of valuable features. We have ceramic stator supports, silver plating on the vanes, and good wiper contacts as features desired. I would add to this an extended tuning range if the capacitor is truly to be considered "Holy". With a standard 230 uH coil the tuning for the BCB ranges from 40 to 380 pF or so. With a 180 uH coil the capacitance needed ranges from 50 to 490 pF, (stray capacitance not accounted for).

Two questions immediately come to mind with this analysis:

1) To how low a coil inductance can you go?
2) If you find a few of these super-caps can you send me one?

kjs 6/2013 (in France)



A look at the resonance curves above (including an over-coupled 2-inch spacing case) is very interesting. I include this as a nice demonstration of resonance at various conditions of coupling. The 2-inch coupling case clearly demonstrates the problem of over-coupling in a radio. Two resonance peaks show up and tuning brings in different stations at the same time. Total power is still very high, just not useful. The 8-inch case is pretty close to critical with good power and the two-peak problem eliminated. Bandwith is still pretty high at 22khz (the curves are made with the 4 parallel HP's). Finally when separated to 14 inches the power loss is not too bad and bandwidth has narrowed to 10 giving a loaded Q of 107 as mentionned above.

It ain't Litz, but PD Close!
kjs 11/2012

tuggle tuner on this set is in the 50-80 ohm range giving an excellent match and maximum power transfer to the tank.

At the back end things get more complicated, a diode is present! For my testing I have included a step to determine, under test conditions of course, the optimum load resistance for maximum power transfer to the phones. Maximum power output means that the load resistance matches the output resistance of the tank/diode combination. The principal factors which influence this include the frequency and tank coil Q (which don't change from test to test), the diode Rd and characteristic, and the signal voltage being rectified.

Signal level and diode characteristic are inter-related and together determine the resistance of rectification. At very low signal voltages rectification takes place on the "square-law" portion of the diode with large swings in resistance with signal sine wave. Larger signal levels rectify higher on the characteristic curve (peak-detection region) with consequant lower resistances and less variation. The Rl shown on my table thus is specific for my test. My radio signal is in the 6-8 mV region placing it in the peak-detection portion of HP5082-2835 diode and possibly borderline square-law / peak detection on the FO-215. This explains why the optimum Rl is lower that of the HP but pretty close to the FO-215. It may also help explain why the FO bottomed out on the 14-inch separation, there was just no longer much signal for it to work with.

References:

AVX Basin Capacitor Formulas.
http://www.avx.com/docs/Catalogs/cbasic.pdf

Ben Tongue 1999, Sensitivity and selectivity issues in crystal radio sets including diode problems; measurements of the Q of variable and fixed capacitors, RF loss in slide switches and loss tangent of various dielectrics.
http://www.bentongue.com/xtalset/24Cmnts/24Cmnts.html

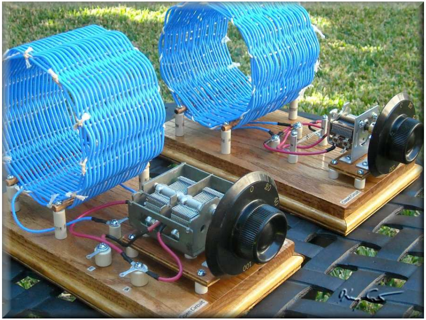
Wikipedia, Types of Capacitors, Ohmic Losses, Dissipation Factor and Q.
http://en.wikipedia.org/wiki/Types_of_capacitor#Ohmic_losses.2C_ESR.2C_dissipation_factor.2C_and_quality_factor

Dr. Gary L. Johnson, 2001. Lossy Capacitors
http://www.eece.ksu.edu/~gjohnson/tcchap3.pdf

Pin = Power into the set in microwatts
Pout = Power out the back end (into the phones) also in microwatts
Eff = Set efficiency or Sensitivity and is the ratio on Pout to Pin * 100
BW = -3dB Bandwidth of the set at 1100khz (f res)
QL = Loaded Q of the set = f res / BW
Rx = Input resistance of the set in ohms
Rl = Load resistance on the tank in kohms
Rd = Junction resistance of the diode in the set

The power numbers are fairly straight forward and represent the power calculated across the dummy antenna resistor and load resitor. Input to the set is from a signal generator with a 200mVpp signal output. Losses due to the dummy were accounted for and the input power is that presented to the set itself. Looking at the Efficiency and QL numbers one sees nicely the tradoff between sensitivity and selectivity. The larger the spacing between the sets, the higher the QL, but at a sacrifice of sensitivity. While the numbers look low, they are still good for crystal sets and the 107 QL is a superlative number. By comparison, I have looked at a High-Performance built by Dave Schmarder (see my Radio Test page) with big Litz and super capicitors and this set max's out around QL = 120-125. I would opine that any QL above 100 is "Performance Quality".

Note for a bit the Rx numbers. Impedance matching for maximum power transfer starts at the antenna and antenna tuner. The dummy antenna used for the measurements mimics a fairly typical longwire with an output impedance between 25 and 50 ohms. Of the many radios I have measured, most have set input resistances between 100 and 250 or so ohms. The



Performance summary:

Measured Qloaded 0.2Vin at 1100 KHz									
Radio	Pin	Pout	Eff	BW	Ql	Rx	Rl	Rd	
	uW	uW	%	KHz	-3Db	ohm	kohm	kohm	
Teflon 8	45	8.5	24.5	22	50	86	76	575	HP2835x4
Teflon 14	62	2.0	4.6	10	107	56	275	575	HP2835x4
Teflon 8 215	46	12.3	34.8	19	58	85	130	150	FO 215
Teflon 14 215	7	0.0001	0.0015	12	91	689	130	150	FO 215

As mentionned at the start of the article, this set was designed as a high-performance rig. Lets take a look at the numbers and assess how well I did. On the spreadsheet above I have indicated the essential measures of the set in four configurations, two spacing tests (8 inches and 14 inches) with 4 parallel HP 5082-2835 diodes and two spacing tests with the holy grail FO-215 diode. First an explanation of the units:

Diode Modeling Update

Kevin Smith
http://www.lessmiths.com/~kjsmith/crystal/dmodel.shtml

The following explains my first attempt to compare a measured diode characteristics with calculated plots based on the Shockley Equation.

I have been taking serious look into diode modeling and measurement recently in an attempt to better understand these solid-state successors to the humble crystal and cat's whisker detector. There is much good information on diodes to be found in many excellent web sites of course, but there is nothing quite like actually making the measurements and working with them to get a good feel. This page reports some of my protocols and test setups which I have found to be useful.

Most probably the single best web article for the measurement of diode Is and n parameters is given by Ben Tongue in his Article 16. In this article he describes an interesting circuit for the measurement as well as protocols for making them. For my purposes I did not wish to make this a construction project and felt I might get along with good quality meters and my already-built "Diode Test Jig". Essentially Ben Tongue's method consists of making two precision measurements of Voltage and Current through a diode at small signal levels, essentially about 3 and 6 times Is (sufficiently low that the voltage drop across the series resistance Ro can be ignored). The measurements are then substituted into the Shockley equation Is*{exp[(qe/(n*k*T))*(V-I*Rs)]-1} and solved simultaneously for the two data pairs. Mike Tuggle has provided a nice excel spreadsheet to do the math. This spreadsheet, Cal_n_Is.xls forms the basis of my technique and

I am thus indebted to both Ben Tongue and Mike Tuggle for making this project feasible.

In addition to simply calculating the main parameters Is and n, I also wished to measure enough points to plot a characteristic curve, and to compare the measured curve with one calculated directly from the Shockley equation. My first spreadsheet then combined Tongue/Tuggle calculation protocol and a graphical view of the match between measured and theoretical. I did make a few methodology modifications which I thought/hoped would allow added accuracy:

1) Using the full Shockly equation without simplifying for an assumed 25dC room temperature. While the 25dC assumption is generally good and probably within the measurement error (or perhaps not), including the actual measured temperature eliminates doubts of inaccuracies due to this parameter. With the power of PC's and spreadsheets there is no reason simplify the equation.

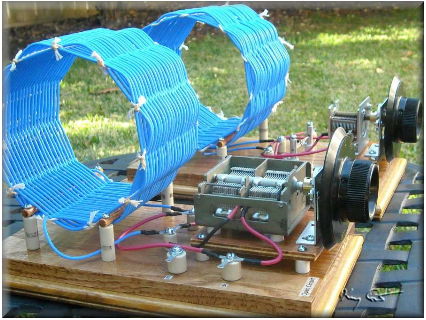
2) Used Vd = 0.04 and 0.05 V (adequately close to Ben Tongue's recommended 0.039 and 0.055 V) whenever possible. Note for some diodes with significantly different forward voltage drops, Si diodes in partictular I had to use higher values for Vd.

3) Reporting: I decided that, as there is no unique solution to n and Is, each is dependant on the valuse Vd and Id, I feel that reporting both Vd and Id is necessary for repeatability. Naturally I also include the ambient temperature in the report as well, and

4) I included a calculation for Ro (or Rg if you are using Tongue's reference) as that is the goal of the exercise.

from 4 to 7 or more khz off peak tuning when I remove my hand from the dial. The set is fairly modular and readily modified so I am keeping my eyes open for better quality caps. I am afraid I must learn to live with hand capacitance. Oh well, we see about the next set!

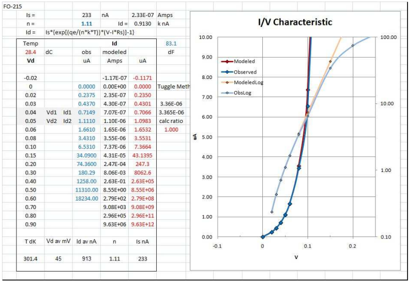
Portrait of set, ummmm..



With high-efficiency coils, very loose coupling is permitted with acceptable power levels, thus allowing very narrow bandwidths to be achieved. This can only be accomplished with separate base boards. To further minimize losses I have used short direct lengths of large 16 AWG stranded copper hookup wire and importantly, I have insulated all components and electrical connections from the board with ceramic standoffs. Finally, for the coils I have utilized a very lovely sky-blue teflon-insulated, silver plated wire of 18 AWG, strictly military spec, ($$$). I know, I KNOW.. This isn's a Litz Blitz set and yes, the performance suffers a little because of this. Still, I have good performance measures to tell me I am certainly on the right path. Note also that wire of such size and insulation is quite thick and to get the desired inductance required very large coils of some 4 3/4 inch diameter. The coils dominate the set visually and provide the name.

The tuning capacitors I would allow are most likely the weakeast link in the chain. I have chosen fairly generic though not bad-quality caps. The antenna tuner has a dual-gang cap with sections 465pF and 375pF respectively, well matched for my needs. Note, from my studies of antenna tuning (elsewhere on my pages) I have noted that a tuggle tuner does not necessarily require equal-size sections on the tuning cap. In fact, I would state that tracking is better if the ground section max's out at a lower capacitance that the tank section. The cap has aluminum blades and ceramic insulation and is a decent capacitor. For the tuning tank I chose a standard 410pF single gang unit from the Crystal Set Society. These are aluminum blade caps with phenolic insulation, OK but not superb. Both tank and atu include 3:1 reduction gears to help spread the band and allow more careful tuning. I did not allow for hand capacitance which I have noted is indeed a problem. When I tune the set to resonance with a signal generator, I find I am

A screen shot shown below:



FO-215

Is =		233	nA	2.33E-07	Amps
n =		1.11	Id =	0.9130	k nA
Id =	Is*{exp[(qe/(n*k*T))*(V-I*Rs)]-1}				
Temp			Id		83.1
28.4	dC	obs	modeled		dF
Vd		uA	Amps	uA	
-0.02			-1.17E-07	-0.1171	
0		0.0000	0.00E+00	0.0000	Tuggle Meth
0.02		0.2375	2.35E-07	0.2350	
0.03		0.4370	4.30E-07	0.4301	3.36E-06
0.04	Vd1 Id1	0.7149	7.07E-07	0.7066	3.365E-06
0.05	Vd2 Id2	1.1110	1.10E-06	1.0983	calc ratio
0.06		1.6610	1.65E-06	1.6532	1.000
0.08		3.4310	3.55E-06	3.5531	
0.10		6.5310	7.37E-06	7.3664	
0.15		34.0900	4.31E-05	43.1395	
0.20		74.3600	2.47E-04	247.3	
0.30		180.29	8.06E-03	8062.6	
0.40		1258.00	2.63E-01	2.63E+05	
0.50		11310.00	8.55E+00	8.55E+06	
0.60		18234.00	2.79E+02	2.79E+08	
0.70			9.08E+03	9.08E+09	
0.80			2.96E+05	2.96E+11	
0.90			9.63E+06	9.63E+12	
T dK	Vd av mV	Id av nA	n	Is nA	
301.4	45	913	1.11	233	

To use the sheet one need only adjust the voltage Vd to that shown in the first column and record the current Id. If only Vd1/Vd2 and Id1/Id2 are measured then the next step is to adjust the value for "n" until the match between the two equations is exact. I even provided a simple ratio calculation to easily test for a match.

While the math is good and results excellent, I quickly found a couple deficiencies in my method,

1) measurements require high precision and its nearly impossible to land EXACTLY at the voltage required. I needed only to get quite close, let the meters stabilize for 2 - 5 minutes, and then record BOTH Vd and Id.

2) the work is rather tedious and, for a large number of diodes it pays dividends to measure only the needed Vd and Id and let the plot aside. My second spreadsheet thus dispenses with the plot. It is with my second spreadsheet that all my data tables and results are posted.

3) better comparisons between diodes can be made if one targets specific Currents rather than Voltages, discussion on this below.

A view of my current data reporting spreadsheet showing ALL input parameters as well as determined values of n, Is, and Rd.
Data input fields in blue: (target Id1 close to 1.0 uA and Id2 close to 0.5 uA).
Calculated fields in red and black.
Adjustment field "n" in green: (adjust value of n until the ratio of the two calculations = exactly 1).

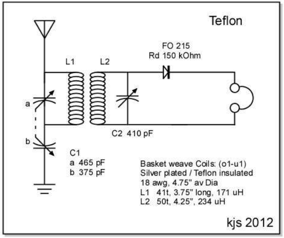
Spreadsheet for calculation of diode n and Is							Tuggle Method from "Cal_n_Is.xls"						
Diode		n	Is	Rd	Temperature		Vd2	Id2	Vd1	Id1	Calc	Calc. Using	Calc. Using
under test			nA	k Ohm	dF	dC	V	uA	V	uA	ratio	Vd1 and Id2	Vd2 and Id1
HP 5082-2835		1.0713	12	2206	80.2	26.8	0.10215	0.4961	0.12215	1.0384	1.0000	4.124E-05	4.124E-05
1N5711	blue	1.0683	6	4541	80.0	26.7	0.12115	0.4917	0.13981	0.9757	1.0000	7.931E-05	7.931E-05

(Note: the engineers in the crowd will have noticed in the above report than I am carrying a degree of precision not justified by the level of accuracy in my measurements. The final results of n, Is, and Rd should be rounded off to not more than three significant figures.)
A copy of my spreadsheet can be downloaded here..

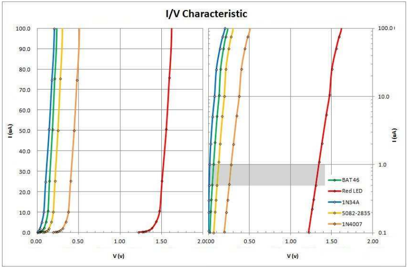
While measuring a good number of diodes, both Germanium, Schottky, Silicon, and even a few LED's, I noted that Tongue's recommended measurements at Vd = 0.039 and 0.055 V resulted in current reports spread out over more than two orders of magnitude. As the determination of Is and n is not unique but a function of Id, I felt uneasy by this method. While most Germanium diodes I have measured have a fairly narrow range of Forward Voltage drops, (Vf), that of Schottky's can range up to a tenth of a volt. This is the factor responsible for the huge range of measured Id values, see the following plot of I/V characteristics for some selected diodes:

My Teflon Warrior
http://www.lessmiths.com/~kjsmith/crystal/teflon.shtml

With this current radio I am making my entry into the "Performance Radio" constructors club. I have tried to follow all the best practices of high-end crystal set design while giving the set my own personal breadboard mark. Two central themes guided my design on this set, simplicity and simplicity. From the circuit diagram below you will note that I have chosen, not surprisingly, a simple double-tuned circuit layout with a Tuggle front end and a Tank/Detector circuit with no circuit decorations whatsoever. No taps. No selectivity enhancement. No Benny. No Decoration. No nada. This is a basic radio wherein I have striven to keep losses, including insertion losses, to an absolute minimum. Should I wish to include selectivity enhancement and/or benny at a later time, they will go on an outboard platform along with transformer and phone plug. The radio itself is simplicity realized.



As can be seen in the set photos below, this design follows standard practice of placing the open and closed circuits of the set on separate baseboards. This is important as it allows easy and wide adjustment of the coupling between the coils.



In order to get what I feel is a better comparison between diodes, I have decided to target not some pre-determined voltage, but rather target currents of Id = 0.5 and 1.0 uA. On the above plot on the right (with Log Id vs Vd scale) it will be clear that I am aiming at the same part of the characteristic curve regardless of Vf. Hopefully this will allow good comparison between diodes with rather different Vf, even as far as including Silicon and LED's in my mix. On va voir....

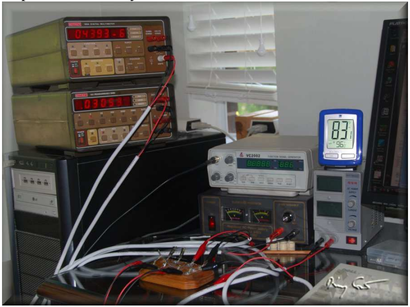
Shockley equation Id = Is*{exp[(qe/(n*k*T))*(V-I*Rs)]-1}
where:
n = ideality factor
Is = Saturation current in Amps
Id = Diode Current in Amps
Vd = Diode Voltage
k = boltzmann = 1.38E-23 J/K
T = temp K = 300
K = dC + 273.15 Kelvin
qe = electron charge = 1.609E-19 cmb

Often simplified to:
$Id = Is*(\exp(Vd/(0.0256789*n))-1)$ [at room temperature]

Diode Resistance $Rd = VT * n / Is$
Where:
$T = 300K$
$VT = k*T/qe = 0.0256789$
SO: $Rd = k * T / qe * n / Is$

I cannot express enough my indebtedness and thanks to Ben Tongue and Ken Khun for their great work and web documentation in matters Diode!

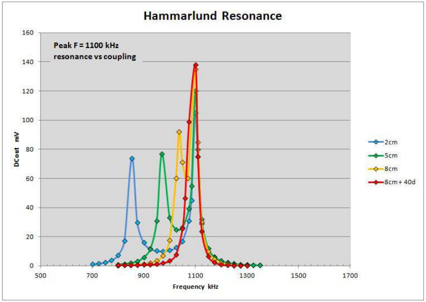
A photo of the current "bench" setup. Keithey 195A pico-ampmeter + Keithley 192 DMM bench meter.



Kevin 09/2011

effects I can easily hear when tuning the set. Oh well.. Better be forewarned next time! This does not necessarily mean that double-tuned rigs MUST be built in modular fashion with separate tuning and detection units, but it certainly suggests it.
With the lack of surface real-estate to lengthen the coil separation, I made a small modification on the set as seen in the third photo above. There you see the possibility to rotate the outer coil away from vertical thus further lowering the coupling. I can get a max 40 degree rotation which just gets the coils to critical coupling. No more ghosts on the band! Still, I think my next double-tuned rig will indeed be modular. Experience is such a good teacher!

kjs 07/2011



A few words on resonance: When making my measurements I noted a curious effect in the resonance curves. They became increasingly asymmetrical with wider spacing of the coils and actually had a double hump at the maximum spacing of 10 cm. This is the exact opposite of how I expect resonance to work. I set to measuring the Vout across a significant portion of the MW band for each of the coil separations and present a graph below:

It should be readily apparent from the above graph that my set is badly over-coupled even at its widest separation of 10cm. I suspect critical coupling for the set is with a coil separation in the 15 - 20 cm range. Yet one more design consideration to keep in mind when making a new set! The double hump causes two problems for the set, one: it tunes each station twice and two: has the possibility to bring in two stations at the same time if they have the right separation on the band. Both these

Spreadsheet for calculation of diode n and Is (@1.0uA)

Diode		n	Is nA	Rd k Ohm
Germanium Diodes				
FO-215	ITT	1.11	175	163
FO-215	ITT	1.10	196	144
1N277	black	1.50	2293	17
1N277	black	1.60	2296	18
1N270	bonafide	1.28	915	36
1N270	blue	1.26	857	38
1N270	blue	1.66	2310	19
D18	russia	1.20	194	160
D18	russia	1.27	193	170
GAZ 51	Tesla	1.14	140	211
GAZ 51	Tesla	1.52	617	64
OA 5	Tesla	1.85	3384	14
OA 5	Tesla	1.48	1996	19
D9E	russia	1.42	2161	17
D9E	russia	1.54	2414	16
1N34A	bonafide	1.82	2153	22
1N34A	bonafide	1.25	1392	23
1N34A	green	1.57	1389	29
1N34A	green	1.30	1185	28
1N34A	green	1.32	1554	22
1N34A 37	orange	1.10	1458	19
1N34A 37	orange	1.36	1370	26

1N34A	red	1.34	833	42
1N34A	red	1.32	993	34
D310	russia	1.01	1215	21
Diode		n	Is	Rd
			nA	k Ohm
GD 402A	russia	1.55	970	41
GD 402A	russia	1.71	1360	33
UK A	russia	1.56	1565	26
UK A	russia	2.00	5766	9
UK B red	russia	1.64	2049	21
UK B red	russia	1.85	3777	13
UK C ora	russia	1.92	3462	14
UK C ora	russia	1.95	3354	15
UK D blk	russia	2.00	4901	10
UK E blk	russia	2.00	5862	9
UK F blk	russia	1.82	3523	13
UK G blue	russia	1.86	3123	15
Average		1.39	1334	54
Schottky Diodes				
HP 5082-2835		1.07	12	2206
1SS98		1.08	12	2302
1SS98		1.06	13	2188
1N5711	blue	1.07	6	4541
1N5711	blue	1.07	6	4816
1N60		1.09	178	158
1N60		1.10	161	176
BAT 46		1.12	141	204

Sensitivity on the other hand, well, it sucks. 2 to 11 percent Vdc/Vpp are very low numbers, many of my single tuned sets range from S = 10 to 50 and my Minstrel Boy getting over 60 percent. What happened? The data show the SEC to be involved here. Note that with capacitance in series the sensitivity is about 10% but when shunted across the tank the selectivity improves, but the sensitivity crashes down to 2-3%. I really expected better for this set. This is my second double-tuned rig, my first was a simple set using solid magnet wire close-wound on 3" cardboard cores and having 6 twisted taps, all Q lowering. This sets' coils have no taps and no cores and ought to have significantly better Q. The primary difference between the two sets is the presence of the benny and SEC on my new set. I am worrying about insertion losses more than offsetting the improvements in the coils.

The severe loss of sensitivity when using the SEC on this set also reminds me of my experience with my Fleming set, a modified MRL#2 using SEC. There I also found loss of sensitivity when the SEC was in the circuit. At the time I concluded that the circuit was inappropriate for testing the SEC concept, now I am not so sure. This set employs a high-performance circuit (if not high-performance parts) and is fully correct for the SEC inclusion. One additional test I intend to make when time allows is to completely remove the SEC and Benny ornamentation from the set and re-test the sensitivity. I suspect that insertion losses are killing me. Dave Schmarder has the most experience with this design feature, I wonder what his thoughts are? Have you tested a set with and without the SEC? What have you found? I am suspicious of this feature now.

capacitor which places the capacitance either 1) in series with the top of the tank and detector, or 2) shunted parallel across the tank. I make a full set of measurements with the SEC cap set fully to each the series and shunt positions. The above paired measurements are made for each of three coil coupling positions. The two coils can be shifted along two rails to bring them from essentially touching to a maximum separation of about 10 cm, or about one coil diameter. This is the max separation obtainable on my breadboard as the Hammarlund caps are quite large and take up much space. To evaluate the impact of coupling, I measured with the coils separated 1cm, 5cm and the max 10cm.

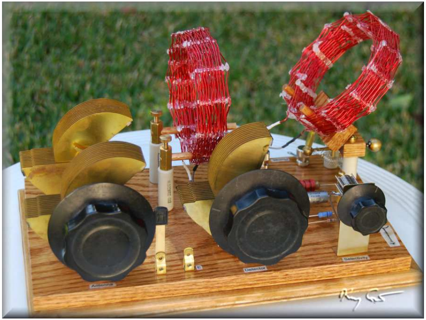
OK, enough with the preliminaries let's look at the data!

	1 cm		5 cm		10 cm		
SEC	series	shunt	series	shunt	series	shunt	
Res	214	46.2	209	51.7	217	52.6	mV
BW	16	14	17	11	18	13	kHz
Q	68	81	66	100	63	87	
S	11%	2%	10%	3%	11%	3%	Vdc/Vpp

The table at left presents the measurements (Res = resonant peak Vout mV : BW = bandwidth and -3dB : Q = under load : S = sensitivity = Vdc/Vpp) vertically and the different cases horizontally. Bandwidths for the cases all range between 16 - 18 kHz for SEC in series and 11 - 14 kHz for SEC in shunt. These are pretty good numbers for a standard (non-DX Contest) rig and correspond to Ql in the 65 - 85 range. Context for this comes from Ken Khun's excellent engineering pages where he notes for crystal sets that loaded Q normally ranges between 10 (poor) to 50 (typical) to 100 (very good). My set here then is pretty good in this respect and confirms my eardrum assessment above.

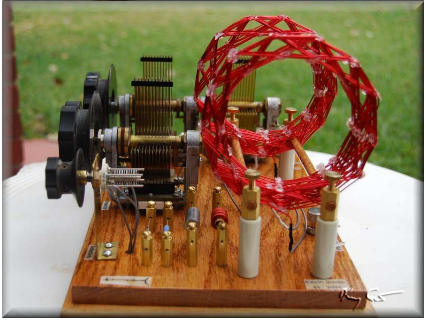
BAT 46		1.18	172	177
1N34A ?	schottky	1.11	317	90
1N34A ?	schottky	1.24	482	66
1N5819		1.19	750	41
1N5819		1.14	807	36
Diode		n	Is	Rd
			nA	k Ohm
1SS16	NEC	6.24	14288	11
1SS16		2.27	4101	14
Average		1.13	276	1137
Silicon Diodes				
1N914		1.95	5	9293
1N914		2.02	7	7618
1N4148		2.00	6	8934
1N4148		2.00	6	9323
1N4007		1.51	1	64311
1N4007		1.51	1	77954
6A10		1.57	2	19275
6A10		1.54	2	20379
1N4736A	Zener	1.15	0	1.91E+09
1N4736A	Zener	1.14	0	2.50E+09
KB 130	russian	1.14	0	5.83E+08
KB 130	russian	1.16	0	4.36E+08
UK H	russian	1.94	8	6263
UK H	russian	1.77	4	12548
UK I	russian	1.78	0	260253

KD 401A	russian	1.51	0	232930
KD 401A	russian	1.38	0	1539619
D 220	russian	1.26	0	322405
D 220	russian	1.24	0	537707
D 223A	russian	1.20	0	10262661
Diode		n	Is	Rd
			nA	k Ohm
D 223A	russian	1.20	0	8565213
UK J	russian	1.46	4	9849
UK J	russian	1.40	2	20013
Average		1.52	2	2.37E+08
Light Emitting Diodes				
Red		2.15	0	1.70E+12
Red		2.07	0	5.52E+12
Amber		1.56	0	2.09E+17
Amber		1.62	0	6.46E+16
Yellow		1.59	0	8.03E+17
Yellow		1.38	0	2.87E+20
Green		2.05	0	4.23E+13
Green		2.07	0	4.34E+13
Water Green		3.27	0	4.85E+13
Water Green		1.93	0	5.79E+19
White-Gn		1.44	0	1.05E+20
White-Gn		3.04	0	6.88E+09
Average		2.01	0	3.76E+19



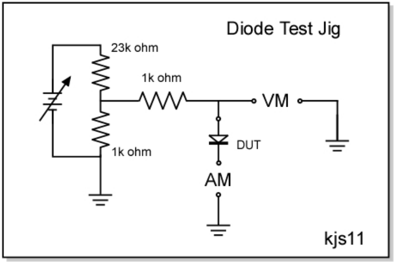
A few words of the performance of my Hammerlund set are in order. When I first started using the set I noted with satisfaction that, by my eardrum meter, the set seemed to indeed tune quite sharply. This is certainly my principal goal in making this double-tuned set. The only fly in the ointment was that the radio seemed quite insensitive, the stations coming in very weakly and needing amplification. The SEC control did have an interesting and dramatic effect when used, but it also hugely lowered an overall low sensitive set. With these thoughts in mind, I have spent some time making some preliminary measurements on the sets' resonance, sensitivity and selectivity.

To characterize the set completely, I measure under a number of different cases. I wish to test the effect of the selectivity enhancement circuit (SEC). The SEC uses a 20pF differential



Diode Test
Kevin Smith
http://www.lessmiths.com/~kjsmith/crystal/dtest.shtml

So, what is the best diode out there to use? Do crystals always show poor sensitivity compared to germanium? What about Fleming's marvelous device, the vacuum diode? I start by using a test jig, the design shamelessly modified from Dan Petersen in the Nov 2009 Crystal Set Society Newsletter, (if you aren't a member, go sign up to be.. NOW):



This is a very simple circuit allowing power input, attaching a diode for testing, and sampling both the curent and voltage across the diode under test, (DUT). I made a simple modification by adding a voltage divider, about 20:1 at the power input. The power supply can be connected either at the front across the divider, or after the divider in front of the 100k current limiting resistor for higher voltage readings. I get the input voltage from a modest 18V, 2A regulated DC power supply. This unit has both volt and amp controls with digital readouts, nice to use and dosnt take up much room on my desk. Here is a case where I recommend you look at getting a new unit. I looked long and hard on ebay, but found few bargins and few units with the same features. Still, the supply regulator was never designed to adjust the output to precise small values making it somewhat difficult/tedious to adjust. Adding a small rheostat to the test jig may aid for making fine adjustments on the voltage. Another piece of equipment you will need for this test is an amp meter. I use a nice small digital meter I found new on ebay for $15 shipping included. It reads amps to a lowest range of 200uA, more than enough precision for the task. For that price get two. The DVM is, of course, my trusty Keithley workhorse. Easy protocol as follows:

1) Set up the test with the diode and meters clipped to the jig.

2) Adjust the power supply until the reading on the DVM meter is where you plan to measure. Adjust the voltage (DVM readout) in steps from 0 to 1.0 Volt in 0.1 V increments and record the current (Amps) in a spreadsheet.

3) Repeat at each tenth volt recording while the spreadsheet makes a sweet graph.

Test Results

First, I offer a quick look at my diode modeling setup. I am currently upping the ante on resolution in order to determine diode parameters Is and n, hoping for success soon! Setup and protocol..

Over a period of a few weeks I ran I-V characterization tests on a good number and variety of diodes, crystals and my two tubes to see how very thing stacks up. The following presents the resulting curves, diode photos, and some puzzling questions/conclusions I churned up in the process. I start off with the realization that when one orders diodes, it is by no

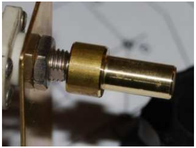
Something was needed here! At left is a photo of a very sweet brass shaft converter machined by my clever and capable EE elder brother, many beaucoup thanks for your addition to the project! Not being an engineer myself I was able to follow very poor practice and just wired the whole lot together, crossed my fingers and hooked the sucker up.. Ya Hey! There be sounds here!

The set is playing as I type these words and I am most hopeful for a successful performance goal. Although much testing and measuring yet remains to be done, the set by ear calibration tunes quite sharply. The coils have 4.2 inch OD and 3.2 inch ID and can slide upwards of 4-5 inches separation for looser coupling. The selectivity control has a dramatic effect on sensitivity and, I am sure, on selectivity as well.. to be measured soon so stay tuned.

The photos below present the set in its final functionning form.

tried this before on a version of an MRL-2 but it was a disappointment, not the right set for the test. As this set was to employ a high-performance circuit, an SEC would be appropriate. The set itself is only moderate performance though, the caps having fairly high-loss brass plates and my coils wound with solid wire. This set also ploughs new ground for me in my first basketweave coils. Basketweave coils recuce stray capacitance and increase coil Q by eliminating the need for lossy coil formers. As these were my first, I merely used solid wire I had in the house. As they are wound of 20awg solid wire, they are quite springy and I had to hot-glue the bejeezes out of them to get them to stay put. I do one day expect to build a truly hi-performance set, but this is just a stepping stone to test components and design. As such, I tossed a benny into the circuit for good measure.

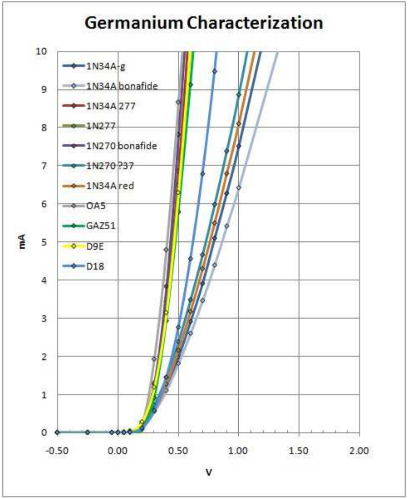
The design calls for non-tapped coils to increase coil Q. While the coil Q is not great, it is certainly considerably better than any of my earlier cardboard tube or even PVC selonoids and it ought to have a decent tank parallel resistance. Matching (hopefully) to this I used a germanium FO-215 diode from Mike Peebles. The combination in these diodes of low n (~1.1) and Is (190) gives a diode with moderately high junction resistance on the order of 150+ kOhm which should work well with the solid-wire coils in the tank.



The selectivity enhancement circuit called for a cool 20pF differential cap which I found at Surplus Sales of Nebraska. The cap itself is a cute little item but the shaft was a short 1/4in long and only 0.19in in diameter.

means certain what one will get. This seems especially true for the supposedly ubiquitous 1N34A. Unless you see the part number actually on the diode, you probably need to test it to know what it really is. So, lets take a look!

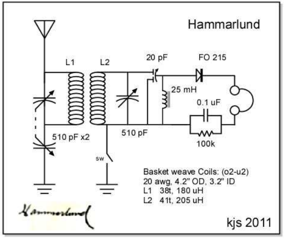
Germanium Diodes



Hammarlund, Double-Tuned

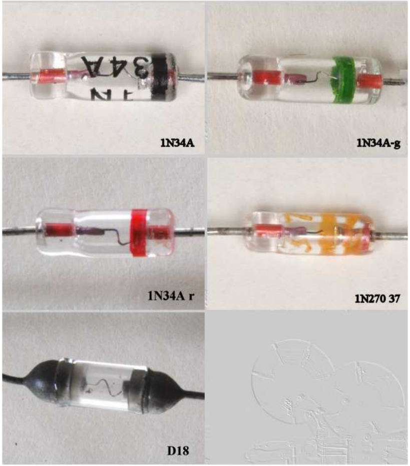
http://www.lessmiths.com/~kjsmith/crystal/ham.shtml

This fine radio features three beautiful and high-quality Hammarlund square-law 510pF variable capacitors. I have been hankering for some time to build a radio with more than just OK to mediocre performance, which translates to a double-tuned set with a properly tuned front end. The capacitors mentioned before were, at first, a poor choice for this project as I needed for the antenna tuner a two-ganged variable cap and the Hammarlund units were only single. Additionally, I only had one! With what I can only call considerable luck, two additional identical capacitors were listed over the last several months on ebay giving me three total. The caps are high quality and very heavy construction and I figured I ought to be able to dismantle them enough to give a common shaft to two thus ganging them as needed. This turned out to be the case and the project was a go.

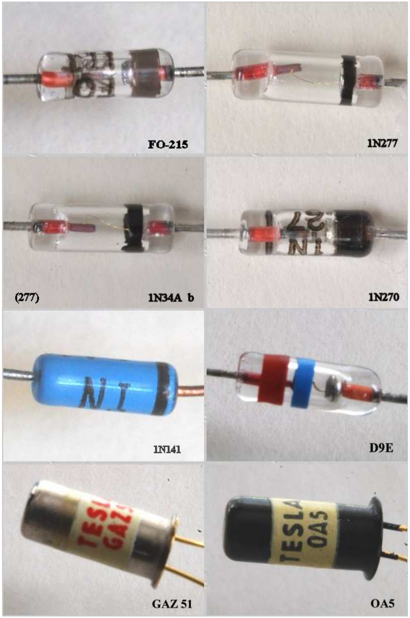


Additionally, with each radio I build, I like to test and learn new circuit concepts and ideas. This radio was to be made with a farily simple double-tuned circuit, a tuggle-tuned front end and variable coupling. I also wished to test and play with the "Hobbydyne" or selectivity enhancement ideas presented by Dave Schmarder on his excellent site. I had

1N34A series



1N270-277 series



When I did get around to hooking the set up to the signal generator I found to my relief that indeed the set has good (not great) selectivity and really excellent sensitivity. Bandwidth around a nominal 1100KHz signal to -3dB is 22KHz giving this set a loaded Q of 51. This is right in the middle range of set loaded Q to be expected for a "typical" crystal set given by Kenneth Khun in his notes on Resonant Circuits. Importantly as well, this set does a much better job at rejecting KGOW than my other sets. I attribute this to the main coils being toroids. KGOW blasts down my direction with a very powerful ground wave and I suspect that the other set coils, mostly open selenoids and / or spiderweb, are picking up the signal and flooding my set across the tuning range. Toroid coils confine the magnetic fields within the torus and thus couple poorly if at all to surrounding fields, including KGOW. Thank you Magnavox for making such lovely coils!!

View from above.

f l =	1088	kHz
f h =	1110	kHz
f res =	1100	kHz
BW =	22	kHz
Q =	51	
S =	61%	

Performance summary for the set is quite pleasing. When I first started listening to the radio I immediately got the sinking feeling that the selectivity would be no better then many of my earlier sets, a disappointing prospect especially as this set was meant to be a higher performer. Part of the problem what just the sets' general quirky and difficult three-dial tuning method. I soon got used to fiddling with the dials and found I could usually "tune out" most any nearby or interfering station from the one of interest, it just took some effort.

Here we see a set of Germanium diodes and photos of the diodes under test. Immediately you should notice two sets of curves, what I call the "1N34A" set and the "1N270-277" set. In this analysis, the second set appears clearly superior in sensitivity and deservedly so. In the photos it is clear that one bunch of diodes I purchased as 1N34A were in fact better 1N277, the black band and thin gold contact wire as well as common curve unite these. "True" 1N34A's have a more robust contact wire. I also purchased a 1N270 and received pretty orange diodes with the number "37" stamped on it, a fairly robust contact wire and a curve that most closely resembles a 1N34A, go figure. Mercifully, I DID manage to get some bona-fide 1N34A's with the part number on the diode, as well as a single bona-fide ITT 1N270 diode with the part number. These are my base for comarison.

In addition to the standard Germanium Diodes tested above, I also have latched my hands on a few "other" germanium diodes for the fun of testing. These include two vintage Russian types, a D9E (in the 270 class) and a D18 (transitional between 270 and 1N34A). Additionally, I got a few FUZZ diodes popular, I suspect, with the guitar gadget crowd. These are larger packages in metal cases so I cannot see how the internal contact is made other that they are stated to be gold bonded point contact type. Clearly these are highly sensitive diodes in my 270 class, the OA5 looking best of the lot. Interestingly, I recently purchased from good Mr. Peebles a few of his "Holy Grail" ITT FO-215 diodes. My measured characteristic for one of these is a dead laydown on the gold-bonded OA5. From the photos, these are in different packaging with the FO-215 in a traditional glass casing. What makes the FO-215 so great is the fact that its resistance Rd is an interesting 150k ohm or so which matches very well with typical moderate Q tank curcuits. Interestingly, I find that an old Russian D18 diode has very similar characteristics to the FO-215 and so much also be placed into the "Holy Grail" class of germanium diode. Take your pick!

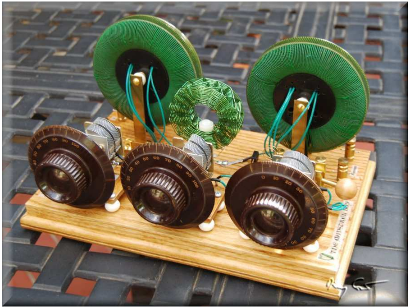
Spreadsheet for calculation of Germanium diode n and Is (modified from Mike Tuggle's spreadsheet)

Spreadsheet for calculation of diode n and Is					Tuggle Method from "Cal_n_Is.xls"					
Diode		n	Is	Rd	Temperature		Vd2	Id2	Vd1	Id1
under test			nA	k Ohm	dF	dC	V	uA	V	uA
FO-215	ITT	1.0993	196	144	80.7	27.1	0.03574	0.49730	0.05123	1.00250
FO-215	ITT	1.1050	175	163	80.9	27.2	0.03882	0.50990	0.05735	1.13850
1N270	blue	1.6610	2310	19	82.4	28.0	0.00835	0.49630	0.01635	1.07150
1N270	bonafide	1.2790	915	36	82.4	28.0	0.01432	0.49660	0.02437	0.99860
1N270	blue	1.2590	857	38	82.5	28.1	0.01505	0.50440	0.02829	1.18850
1N277	black	1.4990	2293	17	81.5	27.5	0.00765	0.50180	0.01402	1.00250
1N277	black	1.6042	2296	18	81.6	27.6	0.00821	0.50400	0.01639	1.11620
1N141	blue	1.1795	726	42	85.1	29.5	0.01642	0.51540	0.03075	1.25650
1N141	blue	1.2570	1402	23	84.5	29.2	0.01024	0.51750	0.01795	1.02980
D310	russia	1.0059	1215	21	83.6	28.7	0.00915	0.51170	0.01695	1.11490
D9E	russia	1.5350	2414	16	81.1	27.3	0.00748	0.50250	0.01522	1.13280
D9E	russia	1.4200	2161	17	80.6	27.0	0.00755	0.49570	0.01402	1.01000
GAZ 51	Tesla	1.5152	617	64	83.1	28.4	0.02356	0.50850	0.03782	1.00240
GAZ 51	Tesla	1.1379	140	211	82.9	28.3	0.04491	0.50280	0.06275	1.03850
OA 5	Tesla	1.8490	3384	14	83.4	28.6	0.00664	0.50370	0.01255	1.01480
OA 5	Tesla	1.4810	1996	19	83.3	28.5	0.00865	0.50550	0.01645	1.07020
1N34A	bonafide	1.8220	2153	22	81.6	27.6	0.00995	0.50780	0.01911	1.08050
1N34A	green	1.3210	1554	22	82.9	28.3	0.00945	0.49530	0.01695	0.99850
1N34A	bonafide	1.2500	1392	23	82.2	27.9	0.00995	0.50250	0.02014	1.20570
1N34A	green	1.3030	1185	28	83.1	28.4	0.01175	0.49420	0.02135	1.04750
1N34A	green	1.5740	1389	29	82.7	28.2	0.01237	0.49350	0.02327	1.07190
1N34A	red	1.3220	993	34	83.6	28.7	0.01401	0.50250	0.02475	1.05390
1N34A	red	1.3430	833	42	83.3	28.5	0.01675	0.51570	0.02765	1.01250
1N34A 37	orange	1.0955	1458	19	83.3	28.5	0.00861	0.51740	0.01495	1.01250
1N34A 37	orange	1.3550	1370	26	83.6	28.7	0.01091	0.49990	0.01925	1.00190
D18	russia	1.2040	194	160	82.5	28.1	0.04004	0.50910	0.05913	1.10500
D18	russia	1.2706	193	170	82.9	28.3	0.04215	0.50250	0.06415	1.16550
GD 402A	russia	1.7080	1360	33	83.6	28.7	0.01365	0.49200	0.02785	1.19350
GD 402A	russia	1.5535	970	41	83.4	28.6	0.01719	0.51780	0.03185	1.17270

Averages: n = 1.38 Is = 1315 nA Rd = 52 kOhm

The above spreadsheet is based on measurements of the diodes shown above. For the determination of Is and n, I chose at random two examples from my collection of various diodes, (all germanium in this case) and measured via a modified version of the methodology outlined by Ben Tongue and Mike

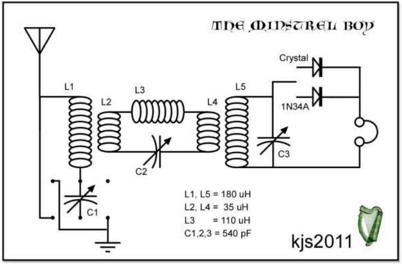
Unfortunately the primaries do not have taps. 180 uH is a bit low for MW work and would require a variable cap with a fairly high top end. I chose three identical 2-gang 270 pF caps tied in parallel to give three 20 - 540 pF tuning. The link circuit consists of two serial 35 pF secondaries for a total of 70 pF, not enough to tune with so I would need to add further inductance. Here is another new feature for me. I made for this set my first honeycomb-style coil, green, of course. I gave the link coil 110 uH for a total link inductance of 180 uH, just as in the primaries. All tune with the three variable caps. Additionally I added a series-parallel knife switch for the antenna circuit capacitance. For my setup the series position will work best, but this will add utility later on. (One green feature I tested and subsequently abandoned was a green LED diode, but even with bias I found it to be hopelessly in-sensitive).



Portrait of set, Wearin O'the Green..

sharpen the tuning overall. This method forms a triple-tuned set with its consequent quirkiness and occasionaly annoying tuning. Still, I find this part of the fun, I am not looking for tuning efficiency, just sharpness.

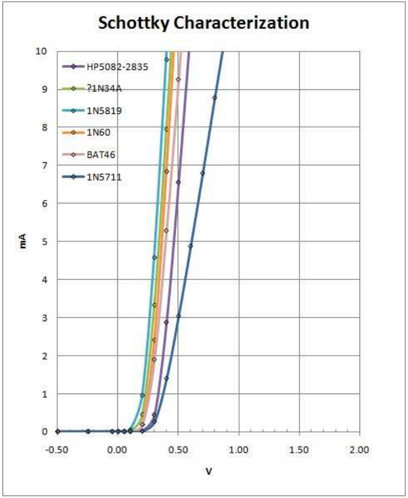
The lovely green color and large size of the coils would be a prominant design feature and this immediately suggested an Irish theme for the set. I settled on naming it "The Minstrel Boy" from a patriotic Irish song written by Thomas Moore, reproduced at the bottom of this page. Of course the name also reflects the idea that I expect to listen to music on the set, it will be a minstrel for me. This decision then set in motion the need for other green features, green hookup wire and making a link coil from green magnet wire. Finally a 1N34A diode I bought a couple years back from Dave Schmarder with the green band to cap things off.



The toroid coils have identical features including a primary with 180 uH and a secondary coupling coil with 35 uH.

Tuggle. For this work I have chosen to set Id2 about 0.5uA and Id1 about 1.0uA and then read the needed voltage. This is the inverse of the normal method but the justification is that for any diode regardless of forward voltage drop the measurement is made at the same part of the LOG I vs V characteristic. This allows comparison between all diodes. I have included the actual room temperature in the calculations in order to eliminate this variable as a source of doubt or error. All the measured parameters as well as the determined results are presented in order to facilitate repeatability.

Schottky Diodes



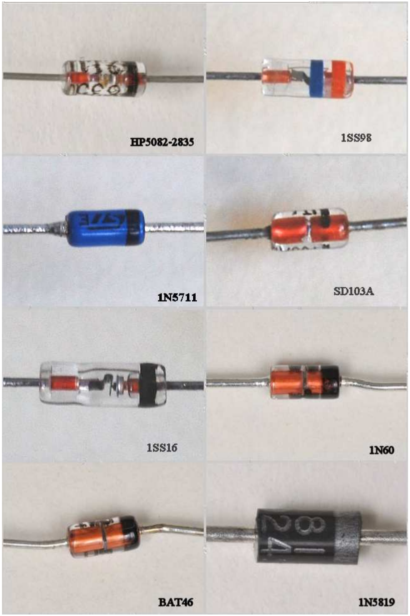
The Minstrel Boy, my triple-tuned triple-threat!

http://www.lessmiths.com/~kjsmith/crystal/minstrel.shtml

I am always on the lookout to find interesting and different circuits with which to construct my radio projects. About a year or more ago I found on ebay an interesting deal for a set of three vintage toroid Magnavox (Model D) air-core coils. They are wound from a beautiful lime-green cloth-covered wire and I just had to make an effort. I assumed, correctly as it turns out but not obvious from the description, that they would come with internal coupling coils. I also assumed they would have a tap somewhere on the main coil but in this I was to be disappointed. I was also disappointed to discover that in one of the three coils the secondary connection was broken. Oh well, my project needed only two coils and I knew these would make a fine radio. I already had a link-coupled design in mind.

Toroid coils are interesting in that they confine the magnetic field within the center axis of the toroid. Because of this, stray coupling seldomely causes a problem, but then again, coupling in general is not easy. So, I had the idea these would be my ticket to exploring designs with capacitive or link couplings between circuits. Eventually I began scouring the net and my books/references for circuits employing link coupling. This coupling method seems to come in two main varieties, tuned (such as found in the Crystal Set Societys' "My Marconi" set), and untuned (as found say in MRL's #42 set). Tuning the link is not needed, but it was something I wanted in an effort to virtually no difference between the Narrow and Broad performance. Oh well... At least I understand now why Osterhoudt removed the choke from the MRL#2 set.

Q for this single-tuned radio is comparable to other radios I have built. This is a circuit demonstration radio presenting Fleming's valve. Nor have I finished with the SEC concept. The circuit utilized here is not ideal for the SEC, ground is taken off the top of the coil, its an odd, if interesting, configuration. I will give the SEC another shot with some other radio. Overall, I am very pleased with the set and enjoy listening to the local Spanish music format station with the warm glow of the tube keeping me company. Oh that glow....



Schottky diodes are very sensitive diodes that work excellently in crystal radios. Their construction and theory are different and I confess to not fully understanding these components. Still, from the characteristic curves, they are excellent! Again, note that you dont always get what you bargain for. Here I found what was supposed to be 1N34A's to be some sort of Schottky of unknown pedigree. The 1N5819, while having the lowest forward voltage drop, has a rather very high Junction Capacitance and will not perform well. Posts on the RaidoBoard Crystal Radio Forum however highly recommend the 1N5711 for crystal sets although the characteristic curve dosnt look that fabulous. Many web pages out there on Shottky diodes, I recommend you do your homework. Of all the schottky's, I note that Ben Tongue recommends most highly the HP5083-2835. The high resistance Rd makes them useful for DX sets with very very high Q tanks. Even so the diodes need to be paralleled with up to 4 or 5 diodes to match correctly the Rd with the tank Rp. I have found these somewhat hard to find and expensive, especially when one requires using several in parallel. I recently measured a few 1SS98 diodes and I discover them to have characteristics extermely similar to the HP and I feel they deseve more attention. Sadly, on ebay they seem to be just as difficult to find and expensive. No free ride!

Spreadsheet below for calculation of Schottky diode n and Is (modified from Mike Tuggle's spreadsheet)

BROAD		Valve			Diode		
	SEC open	Res	525	mV	Res	338	mV
	Tap 4	BW =	54	kHz	BW =	40	kHz
		Q =	20		Q =	28	
		S =	26%		S =	17%	
	SEC meshed	Res	635	mV	Res	605	mV
	Tap 4	BW =	126	kHz	BW =	69	kHz
		Q =	9		Q =	16	
		S =	32%		S =	30%	
	no SEC				Res	816	mV
	Tap 4				BW =	42	kHz
					Q =	26	
Fres = 1100KHz					S =	41%	

Looking at the performance in the Broad setting we find the SEC has a definite impact. As before, the valve has higher sensitivity than the diode, but here we see a classic tradeoff between sensitivity and selectivity. Turning the SEC to its maximum selective position (lowest capacitance) helps, (Q increases from 9 to 20 with the valve) but at the price of lower sensitivity, (Decrease from 32% to 26%). More disturbingly, the overall sensitivity in the broad setting, which ought to be higher than in the narrow setting, (that is, greater than 40%) is quite the opposite, (less than 30%). Additionally, setting the SEC to its most selective position merely returns the radio to a selectivity already found in the narrow setting (narrow Q = 18, broad Q = 20) while lowering the sensitivity. So, I consider the SEC in this circuit a bit of a failure. My suspicion is that the insertion losses associated with the SEC are damaging and no real selectivity boost is given that was not already found in the narrow setting. To address this, I removed the choke and minimized the capacitance of the SEC, effectively removing it from the radio. Re-testing the radio now showed a return to good sensitivity and moderate Q. Actually, with this test I see

(Russian D9E, a 1N270 equivalent) and the tube/valve (Russian 6C19P) in place.

NARROW			Valve			Diode		
	SEC open		Res	974	mV	Res	826	mV
	Tap 5	Tap 4	BW =	58	kHz	BW =	42	kHz
			Q =	19		Q =	26	
			S =	49%		S =	41%	
	SEC meshed		Res	973	mV	Res	804	mV
	Tap 5	Tap 4	BW =	63	kHz	BW =	46	kHz
			Q =	17		Q =	24	
Fres = 1100KHz			S =	49%		S =	40%	

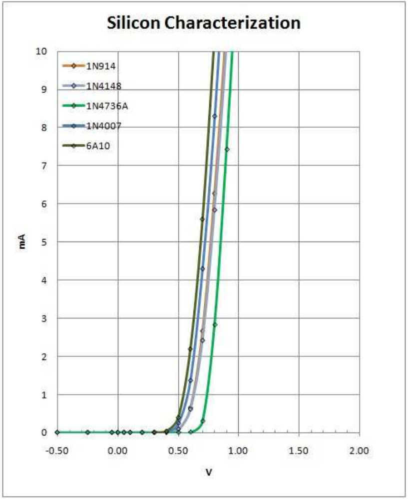
Looking first at the radio in the Narrow switch setting. The table at left indicates the peak output DC signal in mV at resonance, the measured bandwidth at -3dB above and below resonance, calculated radio Q and Sensitivity (Sensitivity here is simply 100 * DCout / ACin). The table shows that the SEC circuit itself provides no change in performance. This is expected as noted above, the SEC doesn't impact the circuit in the narrow setting. I ran the valve at 6.3 V on the heater filament and am surprised to see that the radio sensitivity is higher with the valve than with a diode. Dissappointingly, the valve had a poor effect on the radio Q, going from Q = 25 with the diode to Q = 18 with the valve. I have to imagine the valve has a rather different impedance / capacitance characteristic from the diode. Still, the good sensitivity is pleasing to see.

Spreadsheet for calculation of diode n and Is							Tuggle Method from "Cal_n_Is.xls"			
Diode		n	Is	Rd	Temperature		Vd2	Id2	Vd1	Id1
under test			nA	k Ohm	dF	dC	V	uA	V	uA
HP 5082-2835		1.0713	12	2206	80.2	26.8	0.10215	0.4961	0.12215	1.0384
1SS98		1.0626	13	2188	83.8	28.8	0.10245	0.5081	0.12085	1.0036
1SS98		1.0753	12	2302	83.8	28.8	0.10430	0.5001	0.12383	1.0208
1N5711	blue	1.0683	6	4541	80.0	26.7	0.12115	0.4917	0.13981	0.9757
1N5711	blue	1.0733	6	4816	80.2	26.8	0.12323	0.4917	0.14261	0.9979
SD103A	50pF	1.0443	112	241	83.3	28.5	0.04611	0.5053	0.06185	0.9934
SD103A	50pF	1.0435	109	247	83.4	28.6	0.04648	0.5021	0.06305	1.0201
1N60		1.0884	178	158	80.4	26.9	0.03743	0.4988	0.05311	1.0065
1N60		1.1040	161	176	80.0	26.7	0.03989	0.4955	0.05729	1.0508
BAT 46		1.1185	141	204	80.0	26.7	0.04304	0.4878	0.06032	1.0055
BAT 46		1.1839	172	177	80.7	27.1	0.04173	0.5048	0.05839	0.9972
1N34A ?	schottky	1.1104	317	90	80.4	26.9	0.02710	0.5019	0.04068	1.0003
1N34A ?	schottky	1.2359	482	66	80.4	26.9	0.02269	0.5016	0.03615	1.0197
1N5819	100pF	1.1881	750	41	80.6	27.0	0.01551	0.4957	0.02586	0.9975
1N5819	100pF	1.1425	807	36	80.7	27.1	0.01453	0.5155	0.02541	1.1074
1SS16	NEC	6.2400	14288	11	81.3	27.4	0.00564	0.5099	0.01165	1.0733
1SS16	NEC	2.2700	4101	14	81.5	27.5	0.00684	0.5083	0.01385	1.0947

Averages: n = 1.48 Is = 1275 nA Rd = 1030 kOhm

The above spreadsheet is based on measurements of the diodes shown above. For the determination of Is and n, I chose at random two examples from my collection of various diodes, (all schottky in this case) and measured via a modified version of the methodology outlined by Ben Tongue and Mike Tuggle. For this work I have chosen to set Id2 about 0.5uA and Id1 about 1.0uA and then read the needed voltage. This is the inverse of the normal method but the justification is that for any diode regardless of forward voltage drop the measurement is made at the same part of the LOG I vs V characteristic. This allows comparison between all diodes. I have included the actual room temperature in the calculations in order to eliminate this variable as a source of doubt or error. All the measured parameters as well as the determined results are presented in order to facilitate repeatability.

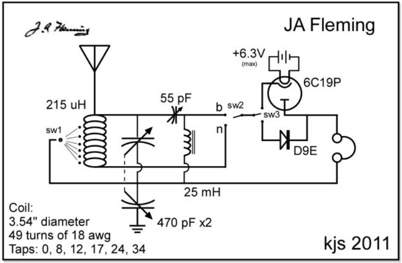
Silicon Diodes



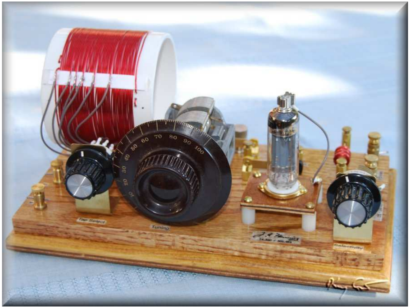
The glow.... Oh the glow!

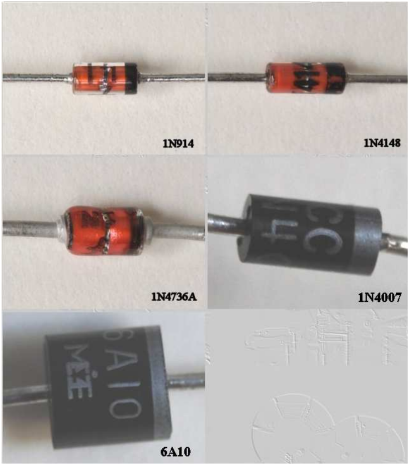
PERFORMANCE:

So, is is a keeper? Does it perform well? Is Fleming's valve a revolution? The following tests answer all these questions and them some. We start by noting from the circuit diagram above that this is essentially two radios depending on whether it is switched in the Narrow or the Broad setting. Importantly, in the narrow position the SEC option is essentially out of the circuit. This will be seen in the measurements as well. A note here, all measurements were made at a nominal 1100KHz with a signal generator and the output of the generator was a sine wave with 2.0V p-p. This is a strong signal and may impact the results, especially concerning sensitivity, but it makes for easier measurements and ready comparison between sets. For this set I made identical measurements with both the diode



The actual set with its controls, taps, tuning and SEC shown below:





Silicon diodes have good characteristics, but an unacceptably high forward voltage drop making them a very poor choice for crystal radio unless used with bias. The 1N4736A is a Zenner diode.

Spreadsheet for calculation of Silicon diode n and Is (modified from Mike Tuggle's spreadsheet)

Spreadsheet for calculation of diode n and Is							Tuggle Method from "Cal_n_Is.xls"			
Diode		n	Is	Rd	Temperature		Vd2	Id2	Vd1	Id1
under test			nA	k Ohm	dF	dC	V	uA	V	uA
1N914		1.9510	5.4	9293	82.0	27.8	0.22733	0.4895	0.26229	0.9855
1N914		2.0236	6.9	7618	82.9	28.3	0.22354	0.4857	0.26423	1.0653
1N4148		1.9950	5.8	8934	83.1	28.4	0.23194	0.5117	0.27037	1.0841
1N4148		2.0041	5.6	9323	83.3	28.5	0.23177	0.4803	0.27346	1.0801
1N4007		1.5139	0.6	64311	83.3	28.5	0.26320	0.5041	0.29137	1.0355
1N4007		1.5140	0.5	77954	83.3	28.5	0.26951	0.4885	0.29807	1.0133
6A10		1.5680	2.1	19275	83.3	28.5	0.22129	0.4902	0.25023	1.0026
6A10		1.5368	2.0	20379	83.3	28.5	0.22021	0.4942	0.24764	0.9871
1N4736A	Zener	1.1505	0.00002	1.9E+09	83.4	28.6	0.51439	0.4961	0.53702	1.0609
1N4736A	Zener	1.1365	0.00001	2.5E+09	83.4	28.6	0.51663	0.5017	0.53648	0.9853
KB 130	russian	1.1403	0.00005	5.8E+08	83.4	28.6	0.47531	0.5012	0.49587	1.0061
KB 130	russian	1.1649	0.00007	4.4E+08	83.4	28.6	0.47567	0.4929	0.49746	1.0155
UK H	russian	1.9443	8	6263	83.6	28.7	0.20333	0.4486	0.24405	1.0175
UK H	russian	1.7727	4	12548	83.1	28.4	0.22717	0.5148	0.25707	0.9916

Averages: n = 1.52 Is = 2 nA Rd = 2.4E8 kOhm

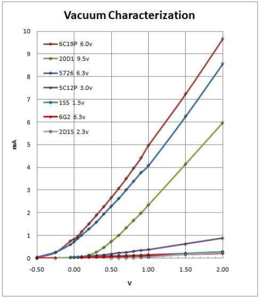
The above spreadsheet is based on measurements of the diodes shown above. For the determination of Is and n, I chose at random two examples from my collection of various diodes, (all silicon in this case) and measured with a modified methodology to that outlined by Ben Tongue and Mike Tuggle. In this case, with the radically different forward voltage drop of these diodes from Germanium or Schottky diodes, I have kept the Id values constant (about Id2=0.5uA and Id1=1.0uA) and varied Vd. I have included the actual room temperature in the calculations in order to eliminate this variable as a source of doubt or error. All the measured parameters as well as the determined results are presented in order to facilitate repeatability.

Additionally I purchased a small variety of tubes for testing. The results of this study are discussed in full under the Radio Lab : Diode Test section of my page. Of all the tubes tested, I finally chose the Russian 6C19P as the tube having the most sensitive characteristic and a handsome appearnce. The tube is a power-hungry beast though, (1.1 Amp current draw at its rated 6.3 V), and this radio requires a power supply, but its worth it! The following graph plots the characteristics of seven tubes I tested for the project.

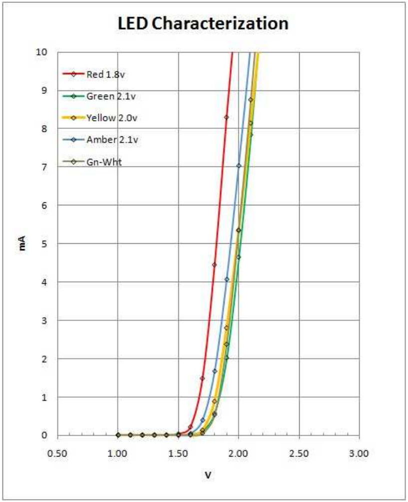
While the project radio was to feature the Fleming valve, I naturally wish to have an interesting circuit as well. As always, it would be a breadboard set and single tuned for ease of use. I also wished to utilize and test Dave Schmarder's selectivity enhancement circuit (SEC) in the set. This last item to compensate for the typical poor selectivity in single-tuned circuits. One circuit that caught my eye from an early time was Modern Radio Labs' MRL#2 set. To this set I would add the SEC modification. In such configuration I notice that it bears a remarkably close resemblance to Set #6 in W.J. Mays' Boys Book of Crystal Sets (BBCS). The MRL#8 set also shows design affinities and includes the choke missing in MRL#2, a fact noted by Mr. Osterhoudt himself. In the end my circuit design, shown below, must be considered a close, (but not exact), member of a family of radio circuits consisting of MRL#2, MRL#8, and BBCS#6.

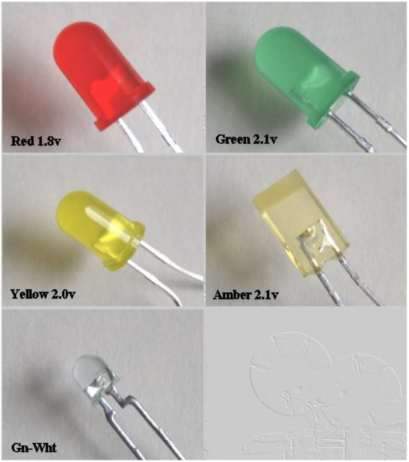
Most avenues of research proved futile until he recalled his prior work on the Edison Effect. He literally retrieved the original bulbs he had experimented on previously and set up a test to apply the effect for radio wave rectification. His experiments were certainly successful. This idea proved a novel and unanticipated use of a prior-known effect amounting to true discovery and thus was awarded British (24,850) and American (803,684) patents in 1905, these successfully defended against De Forest's subsequent infringements. Pondering this interesting history, I began wondering about the Fleming diode and thinking, in crystal radio, this is not amplification, so why not? Also, one must consider the glow, oh the glow… I just had to build this.

Finding a correct tube for the project is a bit of a story in itself. I have never worked with tubes and, while it appeared natural that diode tubes ought to exist as well as triode/pentode/etc (they do), I had no idea what tube was what nor how to know what would work for radio rectification. Many diode tubes I found are for power supply work and may not be appropriate for radio detection at all, (actually they work fine). Jumping into the search both feet, I waded through the datasheets of many/most diode tubes to get to know them well enough to choose.



Light Emitting Diodes

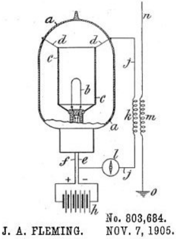




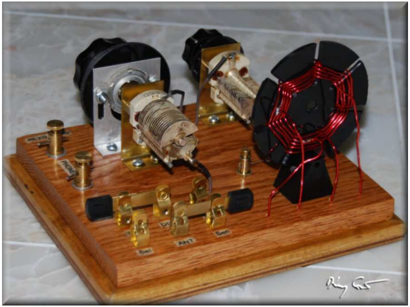
As long as I am measuring various and sundry diodes, I figure I ought to include that most ubiquitous of modern diode, the LED. Found everywhere, these diodes are rapidly becoming the low-energy light source of choice for many lighting applications. I have read occasionally of someone asking whether these ought to be useful for radio applications as well. To this question the answer is generally a resounding "No!". The turn-on voltage is waaay above any reasonable value

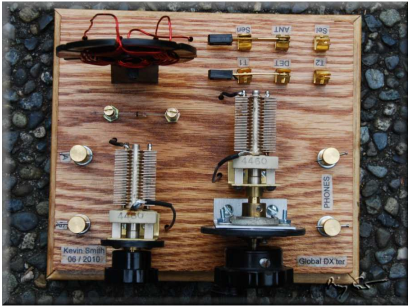
Powered by Fleming's amazing valve
http://www.lessmiths.com/~kjsmith/crystal/flm.shtml

Crystal radio circuits come in a seemingly endless variety of forms and possibilities. That and the historical context of their importance at the dawn of the radio-age makes them a fascinating hobby. I enjoy making these radios, learning and exploring new and interesting circuit ideas, incorporating vintage components into my sets, and finding historical connections between the radios and the fathers of the technology.



My latest project involves a passive receiver rectifying the signals with a vacuum diode. Professor John Ambrose Fleming had consulted for Edison Electric in Britain and had experimented extensively with Edison two-electrode bulbs in the 1880’s, presenting his results on the “Edison Effect” to the Royal Society of London in 1889, and the Royal Institution in early 1890, and finally his definitive paper to the Physical Society of London in 1896. Later after the turn of the century he began consulting for Marconi seeking better mechanisms for radiotelegraphic detection of radio signals.





expected to be delivered by an antenna to a crystal set. Still, this simple answer avoids the actual question, what in fact does the characteristic curve of a LED really look like? Where is the turn-on voltage with respect to the published junction voltage, (assuming you can find that).

To provide just such a look I visited my local electronics store and bought a small handful of LED's, most with the junction voltage listed and took them home to measure. Typical LED junction voltages seem to range from about 1.8v to 2.1v or more. The turn-on voltages look closer to 1.6v-1.7v. Anyone used to working with Carborundum crystals or silicon diodes will be used to biasing their rectifier to get good sensitivity. These LED's once on have a very sharp rise and with a proper bias should work quite well as detector diodes. As a bonus you will get a sweet glow as well. OK, not as cool as the glow of a vacuum diode, but certainly more sensitive!

Spreadsheet for calculation of Light Emitting Diode n and Is (modified from Mike Tuggle's spreadsheet)

Spreadsheet for calculation of diode n and Is						Tuggle Method from "Cal_n_Is.xls"			
Diode	n	Is	Rd	Temperature		Vd2	Id2	Vd1	Id1
under test		nA	k Ohm	dF	dC	V	uA	V	uA
Red	2.1547	0.00000	1.7E+12	80.7	27.1	1.30114	0.4995	1.33895	0.9875
Red	2.0720	0.00000	5.5E+12	80.7	27.1	1.31649	0.5038	1.35690	1.0745
Amber	1.5627	0.00000	2.1E+17	80.4	26.9	1.42768	0.5046	1.45571	1.0131
Amber	1.6163	0.00000	6.5E+16	80.2	26.8	1.42525	0.4963	1.45532	1.0229
Yellow	1.5860	0.00000	8.0E+17	80.4	26.9	1.50347	0.5065	1.53292	1.0422
Yellow	1.3763	0.00000	2.9E+20	80.7	27.1	1.51826	0.5003	1.54291	1.0031
Green	2.0490	0.00000	4.2E+13	80.7	27.1	1.41068	0.5116	1.44647	1.0082
Green	2.0650	0.00000	4.3E+13	80.4	26.9	1.42153	0.5075	1.45762	1.0009
Water Green	3.2709	0.00000	4.8E+13	80.4	26.9	2.22240	0.5085	2.27970	1.0045
Water Green	1.9273	0.00000	5.8E+19	80.9	27.2	2.03170	0.5099	2.06510	0.9993
White-Gn	1.4366	0.00000	1.1E+20	80.9	27.2	1.54780	0.5143	1.57610	1.1050
White-Gn	3.0358	0.00001	6.9E+09	80.7	27.1	1.37740	0.5111	1.43020	1.0043

Averages: n = 2.01 Is = Tr nA Rd = 3.8E19 kOhm

The above spreadsheet is based on measurements of the diodes shown above. For the determination of Is and n, I chose at random two examples from my collection of various diodes, (all led's in this case) and measured with a modified methodology to that outlined by Ben Tongue and Mike Tuggle. In this case, with the radically different forward voltage drop of these diodes from Germanium or Schottky diodes, I have kept the Id values constant (about Id2=0.5uA and Id1=1.0uA) and varied Vd. I have included the actual room temperature in the calculations in order to eliminate this variable as a source of doubt or error. All the measured parameters as well as the determined results are presented in order to facilitate repeatability.

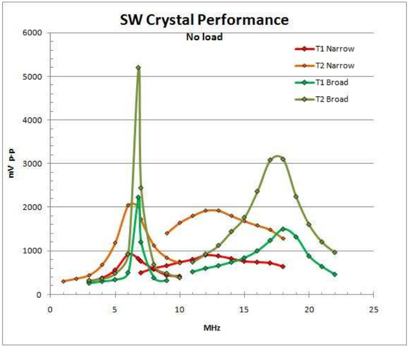
Why know the values of Is, n, and Rd of your diodes?

I have been attempting to get a handle on the main diode parameters Is, n, and Rd and how they impact the operation of a crystal radio. My method of choice is to use a graphical approach, plotting charts where variations between plotted parameters become apparent and easy to visualize. I have developed an interesting chart from the measurements above that compares many diodes with respect to Is, n, and Rd, and to understand how this fits into a matching situation with a fuzzy indication of typical tank impedance limits.

Ultimately one seeks a diode with an Rd that matches with and conjugate to the impedance it sees from the tank (+antenna). In the following discussions I will start with the cross-plot of Is to Rd and then proceed to a look at how received RF power plays a part in the selection and why low Is and n are desired.

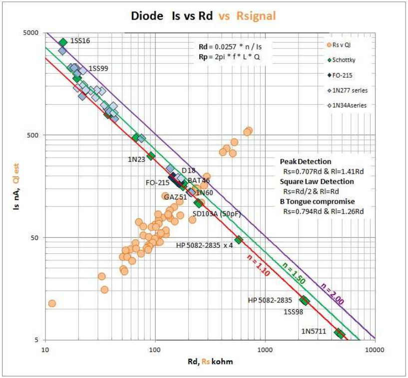
What I found then, was a farily sensitive but, to be truthful, woefully selective set tuning from 6 to about 17-18 MHz. Not bad for a single-tuned rig.

Final thoughts. Upon returning to my home base, I quickly hooked the set to my longwire to make first impressions of actual reception. In midday I was able to pick up a spanish language format broadcast and two english language religous format stations and a brief encounter with WWV. At night the bands are flooded with competing stations, success! Note that all this with my handy dandy Radio Shack mini-amplifier. When I connected a crystal earphone and used my poor hearing, there was nothing as expected. One pity is the ongoing presence, even on this set, of KGOW 1.65MHz forever audible in the background. I consider the set a success as I was not expecting selectivity in a single-tuned rig. Still, with the bands dominated by religous and spanish broadcasts, I cant say it differs much from the local Houston AM fare. Oh well...



The plot above charts the received signal strength (p-p mV) versus input frequency for the four possible switch configurations (Detector on tap 1 or 2, Antenna on selective [top of coil] or broad [on tap t1]. These four conditions were tested with the tuning cap fully meshed (low frequency) and fully open (high frequency) to give an idea of the actual tuning range as compared to the calculated range. All measurements were made with no load on the output, and the antenna trim cap in the full meshed position. Other conditions not shown were also tested.

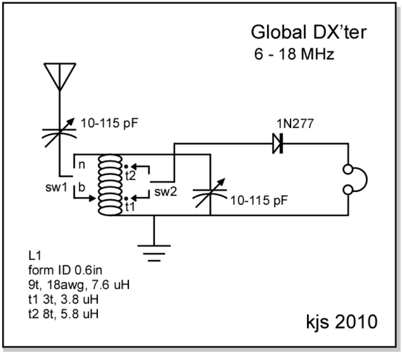
The results indicate that placing the antenna low on the coil, on the T1 position gives the best sensitivity and selectivity in tuning. The detector, a 1N277 germanium diode placed high on the coil at T2 also gives dramatic increase in sensitivity.



The plot above shows the relationship between diode Is and Rd. Rd is calculated via the equation Rd = VT * n / Is where VT is the thermal voltage = k * T / q = 0.0257V at room temperature and Is and n are from the measured diodes. k is Boltzmann's constant = 1.38E-23 J/K and q is the electron charge = 1.609E-19 coulombs. On such a plot I can show lines of constant n, and plot the values for individual diodes for which I have spent considerable effort to determine the parameters Is, n and Rd (where Is is the diode saturation current, n is the ideality factor, and Rd is the diode resistance). On the plot it should be evident how changes in n or Is impact a diodes' Rd.

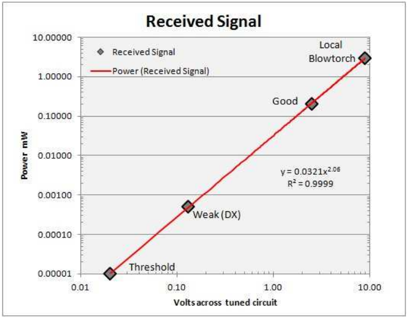
Additionally I have plotted RF signal Rs as orange circles from published coil unloaded Q (see my section on Coil Q). To convert from Qu to Ql I have made the assumption that loaded Q is about 1/5 unloaded Q for low-end sets while in performance sets it may approach 1/2.5 the unloaded Q. This is only an estimate then, but starting from actual data. To make the conversion to Rs I simply plugged the data into the standard equation R = 2pi*f*L*Q using a scaling factor to divide down Qu to Ql from high Q (1400/2.5) to low Q (100/5). This provides a nice visual display of the expected range for Rs in many crystal sets. I plot the Rs against the value of Ql used. Note that these data are for the case at about 1MHz and inductances between 200 and 300uH, as published.

Matching the diode to the tank is a matter of finding a diode with both sensitive qualities (low n) and an Rd close to the Rs presented to the diode (as per Ben Tongue's suggestions for Peak and Square Law detection). Those diodes with Is's in the 100 - 250 nA (100-280 kohm for n=1.1) or so range have the possibility to match while connected to the top of the tank coil without the use of Q-lowering taps, while untapped matching to high-end high-performance big-Litz baskets will require diodes with Is's in the 35 - 60 nA (500-800 kohm for n=1.1) range. Most "typical" germanium diodes have high Is values (>500, >60kohm) and will require a tap. Diodes such as FO-215, BAT 46, 1N60 and GAZ51 can be matched to many tanks without taps. For tanks with high quality Litz coils one will be using HP 5082-2835 or 1SS98 diodes, generally 3 to 4 in parallel to lower the Rd to the desired range. (Curiously, I have not found any diodes with Rd values in the 300 to 4500 kohm range.) Note that both resistance and impedance are frequency-specific so a match at one frequency will not remain matched across the broadcast band.

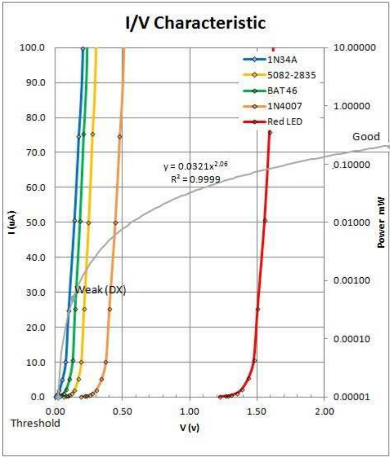


Initial testing on the set was dismal. NO RECEPTION. There followed many hours of double checking all wireing, solder joints, fidelity to the schematic, etc. Everything checked out, no good. Time to seek professional help, which happily corresponded to my annual visit home. There my radio engineer brother took the radio and gave it his close attention, puzzled over it as had I, and concluded a defective part somewhere. This he soon found in the tuning capacitor which had had a connection slip off its set point. This easily corrected, the radio seemed ready for testing. Unfortunately he did not have an antenna handy (he works in uhf+ research stuff) so all I could do was hook the set to a signal generator and test its performance, summarized below.

at 3 turns and 8 turns from the ground (center) of the coil. I ended with 9 turns on the final set with testing giving me a 7.6 mH coil. The final schematic presented below.

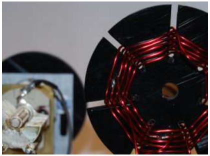


The above is an interesting plot taken from the text discussion in "Crystal Set Analysis" by Berthold Bosch. It presents received signal strength across the tuned circuit for various scenarios from threshold audibility to local blowtorch. This plot should be considered a single example specific to his location and antenna/ground system. In the text he describes his antenna an an inverted L 43m long (140') and 10m high (32'), an excellent antenna most of us do not have the real estate to erect, but offsetting this is a poor ground with Rg = 210ohms. Given the offsetting conditions I would imagine this is a good generic example of what received signal voltage and power levels presented across the LC circuit to the diode are likely to be. Bosch cited 40nV as the threshold of audible detectability (impedance matched conditions with 16kohm RF impedance / 4kohm DC phones) and for this plot I pushed it back to 20nV as it gave a superior regression fit.



This plot at left takes some actual diode I/V measurements rather than the models presented below and plots them along with the above RF voltage across the LC circuit versus RF power in mW. Here one sees that pushing for very very low Vf (via high Is / low n combinations) pushes the limit of detectable signal power from the antenna. At such minute power levels I imagine the reverse leakage current becomes significant and probably offsets the low operating point gains sought.

Global DX'ter
http://www.lessmiths.com/~kjsmith/crystal/sw2.shtml



Finally, a shortwave set comes off the design bureau and out into the world. This is a type of set I have been planning and pondering on for some time. With many crystal radio design possibilites this will certainly not be the only SW set I plan, but it is my first effort, my chance to "do it" on shortwave. For a first effort I settled on a fairly simple design, a single-tuned rig with some degree of control, but not overly much. I took as my base a design by Rainer Steinfuehr on his Crystal Reciever World site. This design features a high Q spider coil with two taps, and adjustable capacitance on both the antenna and tuning circuits. It made a rather lovely small set indeed.

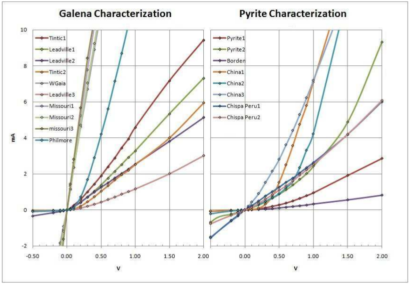
The specifics of the design were entirely my own and were based on the frequency range I wished to target and the specifications of the materials I had available for the project. In partictular, I had available small good-quality 10 - 115 pF variable caps for which my clever elder brother had lathed lovely 1/4 inch shaft extenders for use with standard tuning knobs. My target spectrum was about 5 to 18 MHZ as that is where the dominant international BC action takes place. With luck that would also allow receiving WWV at 10 and 15MHz as well. Digging into the design spreadsheets, it seemed an inductor with 7 to 9 mH would best deliver the goods. I made a spider form from a circlar cut of 1/8 inch Delrin plastic and wound 11 turns of 18awg magnet wire, carefully soldering taps

f l =	1066	kHz
f h =	1134	kHz
f res =	1101	kHz
BW =	68	kHz
Q =	16	
S =	13%	

Performance summary of my Bremer-Tully Set is so so with a set Q (loaded) of 16, -3db bandwidth of 68 kHz and a sensitivity calculation only 13%, not so great. I rather expected as much as this is a single-tuned set of very simple circuit design. Compensating slightly is the fact that it tunes with a single dial which is certainly more user-friendly. It does require a wave trap to cut out powerhouse KGOW blazing away and flooding the entire BC band on this set if left untrapped. Most of my radios have higher sensitivity so this set definitely benefits from my audio amplifier.

Bank winding in six banks: 4 wires / side, 10 windings per bank, times 6 = 60 turns. Coil form 3 inches in diameter, space wound 0.8 inches wide calculates to 376 uH, pretty close to my measured 377 uH. Measurements: Primary B-P = 20 uH. Secondary F-G = 377 uH, G-T = 210 uH, T-F = 65 uH. I know, 65 + 210 not equal 377, I measured it several times to be sure!

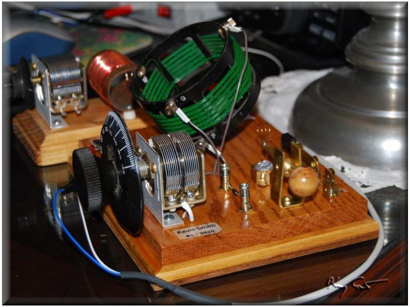
Crystal Galena and Pyrite Diodes



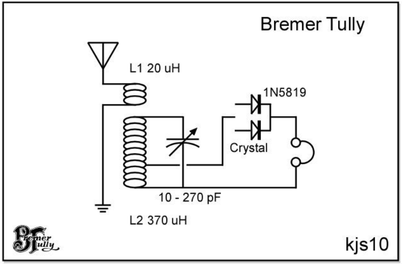
The above curves demonstrate the wide variation in properties and qualities that can be found in natural crystals of galena or pyrite, the two most common and best quality natural stones. In each crystal test I first poked around the crystal for some time to 1) determine a typical sensitivity for the crystal in question and 2) to locate the best hot spot with which to test. This turns out to be a non-trivial exercise on the diode test setup. In a crystal radio one need only listen for the loudest spot. With the test setup one needs test both the forward and reverse current in order to determine if the whisker is on a hot spot or not. Very tedious work! (In retrospect, if I were starting over making a test jig, I would definately add a DPDT switch to readily change between forward and reverse current measurements. I'd probably toss in a rheostat for fine adjustments as well).

For many crystals there are limited number of possible hot spots, but these may be hot indeed. For most of my "Steel Galena" samples (Tintic Utah, or Leadville Colorado) there are numerous hot spots under virtually every place I touch the probe, but in general the sensitivity is good to so so. These crystals are very kind to work with in terms of finding spots and avoiding frustration. Mirror galena on the other hand may have quality hot spots, but any hot spots at all are rare and frustratingly difficult to locate. Here my Philmore detector crystal shines with an almost ideal "Galena" response. To chase down this rabbit I purchased some lovely mirror galena from Sweetwater Missouri. I broke off a few appropriate-size chunks to pot in woods metal and test. At first I was very excited with the high currents I was seeing at moderate voltages. Figured I had struck gold. When these crystals failed miserably to rectify anything in my radios, I re-measured things in both forward and reverse directions. These crystals obey Ohm's law and act like typical resistors, not suitable for radio work at all.

For my pyrite crystals the work has been especially tedious and frustrating. With one of the crystals one "hot spot" alternated, entirely on its own, between hot and bad while I was making the measurements. I would start over and over, sometimes getting interesting readings then suddenly it would drop to low values and I'd start over, back and forth. I present this data as best as I have measured, and I don't intend to go back! You see at least one of the crystals, my "China 1", (from a lead/silver mine in Hunan) gave a sweet classic-looking curve. More to the point, "ideal" curves for natural minerals, are difficult to come by. Most crystals you use will be less than ideal. The good news is that, while listening to your set, poking about for a good spot is far easier than what I have



Circuit schematic for the set.



tune down to 500 kHz. The closest variable cap I have found is a cute little 2-gang 10-270pF unit. This is as low as I have found at the low end for a standard-configuration variable cap. The goal then is to try and keep the circuit capacitance as low as I can, which I translate into keeping the circuit as simple as possible.
My circuit is further constrained by the coil itself. It is essentially an "oatmeal box" type setup with an aperiodic small inductance primary and large inductance secondary. Tuning then must be single on the detector side only. My only option is whether I connect the crystal/diode to the tap post or to the top of the coil. I went with the tap, so shoot me! One complication I maintained, as I do on all my sets, is to keep a switch between using a crystal and cat's whisker or using a diode. In this case I chose a Schottky 1N5819, the most sensitive diode I have yet tested, (diode test). I have yet to test just how high on the BC band I can tune, but KGOW at 1560 kHz sure gives me trouble.

gone through to produce these curves. Your ear will take care of you!

In the photo I indicate groupings based on an easy measure of performance. I note the current in milliamps for each set where the plate voltage is set at 0.5V. The greater the current the better are your chances to get a sensitive crystal, assuming Ohm's Law is not followed! Crystals in the "dead zone" on the left will have their woods metal re-melted for new detector crystals and the bad ones tossed, its tough love for crystals. I find that easily half the potted crystals I make are tossed this way, and only a few can be considered superlative.

Vacuum Diodes

When I decided early on to construct a radio based on the vacuum diode (see my Fleming Radio section), I had to find a suitable tube for the project. That began with an extensive search through the datasheets checking vacuum diode properties and reviewing the characteristic curves for a large number of diode tubes. In the above figure I plot the characteristics as best I can on a commpn plot for comparison. I was hoping to find a good candidate with sensitive characteristics and low energy consumption. As you will find, such a beast did not exist. Following this research began a period ot purchase and testing.

I have tested seven different tube types including 6.3V rectifier diodes that take a lot of power to run and are not really suitable for battery use, a 9v dual diode tube (20D1), a pentode/diode tube (1S5) that is designed to run on a battery at 1.5V and 50mA, and a couple miscellaneous but cute tubes. In testing the 1S5, I found the filament never glowed incandescant at 1.5V and, on measuring, was barely sensitive to anything. I cannot imagine this tube would make much of a diode for crystal radio use. I tested different manufacture 1S5 tubes from two different suppliers. No dice. Finally, I tried to push the tube to operate at higher-than-specified voltages. At 4.3V the I-V curve was still very flat, but shifted slightly higher, crossing the Amp axis at about 0.4 mA, (see graph). At 5.5V one of my tubes gave up the ghost and I didnt do more. I pretty much rule the 1S5 out for my crystal radio work. Looks like i'll be needing the power supply when I get around to building/operating that Fleming Radio.

A question remains as to what in fact is different about these tubes to give such different characteristics. While the I/V

A Bremer- Tully Transformer

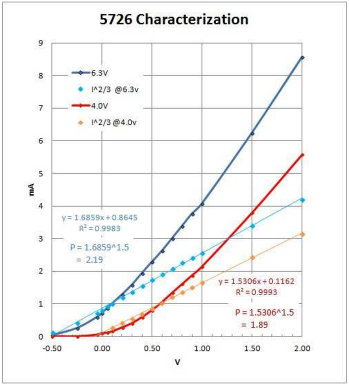
http://www.lessmiths.com/~kjsmith/crystal/brt.shtml

I recently won on eBay and lovely NOS Bremer Tully air core transformer its inspection tag still faithfully wired to the base, (and so it will remain on the final radio). It is absolutly gorgeous and I was the only bidder when it sold, for such a great price! Honestly, I was not totally sure what I was getting when I bid other than it looked like a coil and, from the ebay photo, maybe would work for shortwaves. Calling it a transformer was confusing although I understand all coupled coils are transformers. Perhaps that is why I was the only bidder, well, so much the better! When it arrived I got a good look, very interesting winding technique. The tuning coil is wound with somthing like #30 dcc or dsc wire. The winding is in 6 bank-wound groups of about 10 windings each. Inside is a small primary antenna coil. I promptly got out my handy-dandy inductance meter and measured 377 uH on the tuning and 20 uH on the primary. In addition, there is a tap on the tuning coil one "stack" in. 377 uH is a bit on the high side for BC work and I'm not sure I'll ever get the top end of the band but still, the transformer works beautifully.

My calculations for a setup using a 377uH coil suggest that a minimum total capacitance of 23 pF will allow tuning up to 1700kHz. This is a tall order, most variable capacitors I have found have a minimum value in the 20 - 25pF range. Add another 15 - 25pF of stray circuit capacitance and I am way over the line. The good news is that only 270pF is needed to

characteristic of most vacuum diodes pretty much follow the Langmuir-Child Law, the steepness of the I/V characteristic is largely due to the geometry of the tube elements and the volume of electron space-charge between them. JB Calvert's Theory of Vacuum Tubes informs one that this is the property called Perveance in a vacuum diode. Measuring this requires plotting I raised to the 2/3 power against V and taking the slope of the best-fit line through the data. This slope raised to the 3/2 power is the perveance. The following chart illustrates graphically the relation bewtween the tube characteristic and perveance. For the 5726 tube I plot the characteristic in dark blue for the tube heated with the design 6.3 volts. In light blue I have plotted the measurements and raised them to the 2/3 power. One sees immediately that the new curve is linear. The slope of the curve raised to the 3/2 power yields the perveance factor for the tube.

(Note in addition that when running the tube at a more sensitive point with 4 volts only on the heater the perveance is slightly less than spec.).



With my measurements calculating the perveance is practical and quickly done, results as follows:

Tube	Perveance	R2
6C19P	2.54	0.997
5726	2.19	0.998
6DN3	5.40	0.997
20D1	2.02	0.985
5C12P	0.32	0.999
1S5	0.063	0.999
2D1S	0.155	0.975
6G2	0.050	0.999

however, is NOT the inventor of the oscillating and regenerative feedback circuit, which forms the basis of all radio amplification and truly opened radio to a mass mode of communication. This honor goes to E.H. Armstrong, the man who dug into the tube and worked out correctly for the first time its basic theory and operation. The two men fought a bitter 19-year litigation battle over this honor that in the end was awarded to De Forest by the Supreme Court in what amounts to a technicality.

From what I have read of De Forest’s writings, patents, and exchanges with Armstrong in the Proceedings of the Society of Radio Engineers, it is pretty clear that De Forest never really understood how his tubes worked. So, he was never in a position to develop the tubes to their full potential. Armstrong for his part seems to have treated De Forest with academic contempt. Armstrong went on to invent the super-heterodyne (1918) and super-regenerative (1922) amplifier circuits and created almost single-handedly FM radio (1933) as we know it today. His life ended in tragedy, representing the closing chapter in the age of great individual inventors, finally crushed by the greed of corporate America. Virtually all advances following his were the product of team efforts in company or government research laboratories.

If therefore you have misgivings as to my honoring De Forest with a radio, please understand I do so not for his Supreme Court victory but to honor the inventor of the triode tube, a debt which even Armstrong would always acknowledge. Should you still feel uncertain, then just enjoy the sweet irony in honoring the father of the triode tube with a crystal radio.

De Forest circuit diagram (aka Sleeper #18).

f l =	996	kHz	f l =	833	kHz
f h =	1161	kHz	f h =	1228	kHz
f res =	1085	kHz	f res =	1141	kHz
BW =	165	kHz	BW =	395	kHz
Q =	7		Q =	3	
S =	37%	0d	S =	42%	30d

Performance summary of my DeForest is really just abysmal, it has a low set QL of 7 reflecting a huge bandwidth of 165 KHz but my sensitivity calculation is 37% for the condition of tight coupling. This set clearly trades Q and bandwidth for sensitivity. The set is technically double tuned with variable capacitance in the detector circuit and variable inductance via taps on the antenna circuit. The inductors are loosely coupled via rotating the inner inductor with respect to the outer. What I discover in fact is that rotating the inductor changes the tuning and so it "feels" more like a variometer rather than a variocoupler. Rotating the rotor 30 degrees to loosen the coupling does not narrow the bandwidth, in fact it increases to 395 KHz. I have much to test still on this set, it is a disappointment as I expected a much better QL. Measurements were made with the detector circuit farily optimized for a test frequency of about 1100 kHz, but I wonder if I can better optimize the tap settings for the antenna circuit. More to come.

What's in a name?

The name De Forest in the history of radio is one few engineers can hear without a fairly strong opinion. Dr. Lee De Forest is the acknowledged inventor of the triode radio tube. De Forest

The perveance numbers above range from 0.02 to over 2 mA/V^3/2 (with >2 being good for small-signal detection) and clearly shows my choice of the 6C19P to be an excellent one. I am surprised to see a huge 5.4 for the 6DN3 diode, a color television damping diode. It takes a Novar 9-pin socket and is a large tube so doing more with this tube may have to wait a bit.

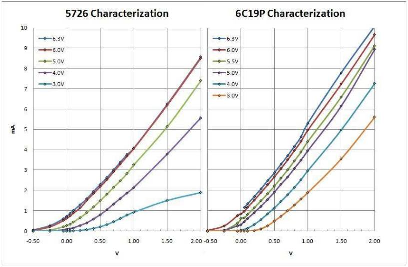
Calvert's 2001 published data

Tube	Perveance
6AL5	2.42
6H6	0.50
7Y4	0.58
2X2A	0.017
6V3-A	2.3
6AX4GT	1.42
6AV6	0.085
1A3	0.075

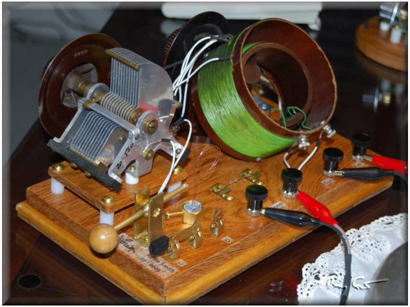
The high-perveance diode tube types I tested show an interesting property in that their characteristic curves do not pass through the origin of the graph. These curves are wholly acceptable as crystal radio detectors although they will require power to operate. What I have noticed with such tubes is that when I turn them off after using them with a radio, on cooling they go through a period of much increased sensitivity (very loud) before fading to nothing. It is as though running them at the full 6.3V lowers their full potential as crystal radio rectifiers. The reason is in the high perveance of the tubes, the anode is already proximate to the space charge before any plate voltage is applied. Effectively, while the plate (anode) "Zero" voltage is measured with respect to ground, the plate itself is still positive with respect to the cathodic space charge.

Small currents will continue to flow even with a negative bias to the plate, (Contact potential).

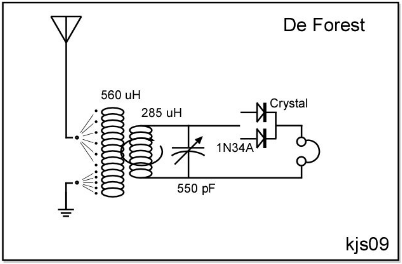
In order to explore this idea, I ran a series of tests with the tubes running at lower operating voltages (effectively diminishing the space charge thus lowering the perveance) as shown:



Here you see the impact of lower operating voltages. With the tube operating between 3 and 4 volts the characteristic curves begin to pass through the origin as in regular solid-state diodes and crystals. It is precisely in this voltage range that I found the radio sensitivity, as measured by loudness to my ear, to be most pronounced. It appears that the diode characteristic needs to pass through the origin of the I-V graph for highest sensitivity. This takes me to the 20D1 tube which operates at 9v but only 200mA. This will still take a power supply to use, but the good thing is that the characteristic curve passes



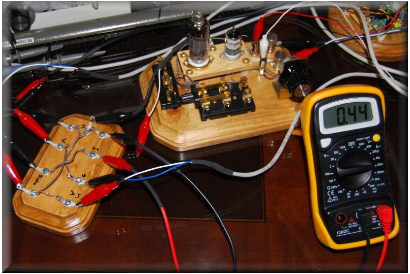
View from behind with my cat's whisker crystal detector, SPDT knife and 1N34A diode.



View from above highlighting the tap wiring, SO much work!

through the origin. Running at its design parameters the tube looks a lot like the 6C19P at 4v.

Photo of the lab with my diode test jig, amp meter, and diode vacuum tubes under test.



on each switch. The wood knobs have a nice easy action, the switch passing readily between contact buttons.

The radio works quite well, in its tightly-coupled setting it is quite sensitive with a strong signal. Its selectivity on the other hand leaves much to be desired. This can be expected from the circuit layout with only the secondary circuit capacitively tuned and the detector tied at the top. I was hoping that by varying the coupling I could achieve some increase in selectivity, but it de-tunes the station with an additional unacceptable loss of sensitivity. Take this outside the urban environment with such crowded airwaves and the set ought to perform admirably. Signals come in strong with the steel galena nearly as well as with the diode. I like this set.

Portrait of set, ummmm..

As most of the components for this set were ready made, the construction planning felt a bit much like assembling a kit. I had originally intended to use modern tap-selector switches as well. In order to make the construction challenging, and more importantly, to maintain the vintage look and feel of the set, I quickly abandoned the modern switches and chose to fabricate instead classical wiper switches in the early style. Of course, I also include my own style cat's whisker and SPDT knife switching to a more modern diode. The diode is my only nod to post war technology. In the crystal cup I have some lovely Utah steel galena potted in wood's metal, finely crystalline, hot as hell all over its surface.

As one can clearly see, my obvious preference is for the breadboard style of early radio. Much of the fascination and beauty of these sets lies in the component hardware. To enclose them behind panels or put them in boxes seems such a waste. The base is a box with about ¼ inch of space inside to hide the bolts and wires. I did need a small panel to place the wiper switches on. This is made of 1/8 inch black Delrin plastic resin, a very hard and nice to work with material. In fact though, it is a bit too shiny, too "plasticy" for my taste. Well, that is what I had.

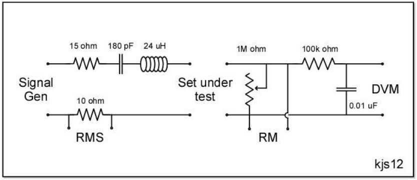
Fabricating the wiper switches, buttons, and leads to the inductor was an odyssey in its own right, amply satisfying my desire for more challenge. Attaching the leads to the primary, soldering without damaging the windings, and the added touch of shrink-wrap "mittens" was a labor of love. I do hope it is justified by the final presentation. The rest of the construction and wiring was a piece of cake by comparison. The wiper switch knobs are wood with a felt buffer against the panel. Behind the panel compression springs keep a steady pressure

RADIO TEST

Kevin Smith
http://www.lessmiths.com/~kjsmith/crystal/rtest.shtml

OK, now that you have built a radio, or several, how do they perform? Without a bit of objective testing you will never really know. I have often read descriptions of radio performance such as "tunes very sharply" or "separates two closely spaced stations" and/or etc. These are qualitative descriptions that do not really give you much information. To know your radio, it takes some measuring. I am making the assumption here that, as a homebrew radio builder, you will find tinkering and measuring your sets just as interesting as their design and construction.

For testing, I have pretty much lifted the excellent procedure outlined by Charles Lauter with a few modifications to suit my own philosophy. I will give my own protocol but first let's look at the needed equipment and test setup. Testing a crystal set requires two pieces of homemade equipment, a dummy antenna in front of the set which allows measurement points, and a measurement load at the back end. Other pieces of equipment include a signal generator, an rms voltmeter, a resistance meter, and a good digital voltmeter. Circuit schematics for the homebrew components are shown below.



For the tests I originally found an old analog signal generator on ebay which I sadly found to be wholly inadequate. The unit was by no means cheap but the dial was difficult to read with any precision and the "play" in the dial made readings hopelessly inaccurate. Finally, it gave no indication of the attenuation or voltage output levels, rms or pp, of the signal. I have since found a nice, reasonably-priced new digital unit, (max's out at 2Mhz so strictly for AM band work) that gives good readings, gives me the output voltage level in pp, and can even produce different wave forms. I recommend if you are seeking to equip your lab, go this way from the start!

To calculate the signal input power you will need a good rms voltmeter. This is a non-trivial item and, after my experience with the vintage signal generator I was leery of getting a used meter. In any case, an expensive dedicated single-use piece of equipment seemed extravagant. For this measurement I have found entirely acceptable results using an oscilloscope which, of course, is useful for so much more and belongs in your lab regardless!

It is on the back end of the measurement where I diverge from Lauter's protocol significantly. He recommends placing in all

De Forest, Vintage beauty
http://www.lessmiths.com/~kjsmith/crystal/deforest.shtml

My latest effort, I call this my “DeForest” after the principal component of the radio. Over the last few months of visiting ebay and finding essential radio parts and browsing, I have stumbled across an occasional vintage piece that I just loved and needed to bid aggressively on. My intent is not to just stash these in a drawer somewhere for the pleasure of owning, but to use them in projects. This project is built around a lovely De Forest Radio Telephone and Telegraph Company Vario-Coupler. The vario-coupler, wound in beautiful apple-green silk covered wire 24 gauge or so, has a tapped primary stator measured at 560 uH and an untapped internal rotor of 285 uH. Other vintage components in this set include a Windham square-law tuning variable capacitor, 20 to 550 pF, and an Atwater-Kent 3 ¼ inch tuning knob. The second 3 inch knob on the vario-coupler is a vintage Radion Dial made by the American Hard Rubber Co.

I built the radio according to Sleeper hook-up #18. It is a fairly straightforward hookup but with sophisticated features including a double-tuned design, a tapped primary tuned via single and multiple taps, and variable coupling. The secondary coil is tuned with a vintage variable capacitor. As the secondary coil is the rotor inside the primary, there is no provision for tapping and the detector circuit is connected to the top of the coil. This set could use some selectivity enhancement circuitry I suppose, but oh well...

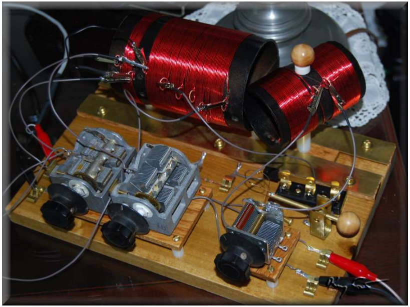
radios to be tested a 1N34A diode and then use a standard 2k ohm load resistance to make the output measurements. This may give a standard and comparable result, but it does not insure a good impedance match and does not reflect the intended usage and setup of many crystal sets, especially sets intended for high-performance. Here I am interested to learn just what is the optimal load resistance for my set under the test conditions. Note the caveat "under the test conditions". This may not reflect actual usage unless you take precautions. You will want to set the generator to an input voltage similar to what you expect the radio to receive in actual operation. You will probably want to signal level work the diode in its peak-detection region but not so high as to saturate the diode, (In making a loaded Q measurement you want to make sure that the diode impedance stays constant; otherwise, the change in diode impedance (as the tank attenuates the signal before the diode) will change the load on the tank and the bandwidth measurement won't really reflect the Q of the tank). Finally, for the output voltage you need a good voltmeter with very high input impedance that will not load down the set under test. This really means a good DVM. I use a used Keithley 192 bench meter with a 2M ohm input impedance, and as a backup a used Keithley 180 bench electrometer. Overkill perhaps, but for just in case...

Getting back to the load resistance then, my protocol is to find the optimum resistance to deliver the maximum power (not voltage!) to the load. This is a bit of a tedious process but will amply rewarded. Having tuned and peaked the set to the measurement frequency, I then take a series of resistance/voltage readings to find the maximum power output. In my circuit this is accomplished with the variable 1M pot. The resistance meter and voltmeter cannot be connected to the load at the same time making this a tiresome road to follow.

Once I find the optimum load resistance, I set the pot to that and proceed to the main testing for sensitivity and bandwidth/Q measurements.

Test Protocol as follows:

1) Connect the set to be tested between the dummy antenna and measurement load as per the above diagram.
2) Connect the signal generator to the dummy antenna and set the frequency and voltage output. I typically test in the center of the BCB at 1100khz and use a 200mVpp output sine wave.
3) Set the load resistance to somewhere around 50k ohms. The exact value is not critical as it will be adjusted later.
4) Connect the DVM and tune the set to peak the output voltage. Care here is amply rewarded, especially with double-tuned sets.
5) Once peaked it is necessary to adjust the generator frequency to re-peak the output voltage as hand-capacitance or other factors may have prevented perfect tuning. You now have your set properly tuned for maximum output. Presumably this also means the best possible impedance match between the set and dummy antenna. This is the resonant frequency (f res).
6) Record the frequency and output voltage.
7) Now find the optimum load resistance. This is done by making a series of paired measurements of load resistance and output voltage. Power in uW = mVout * Rl khoms.
8) Set the load resistor pot to the value where power output is highest, this is the optimum load for the test. Record this.
9) With the signal generator re-peak the output voltage and re-record the resonant frequency (f res) and output voltage (Vout mV).
10) Multiply mVout by 0.707 to find the -3dB level.

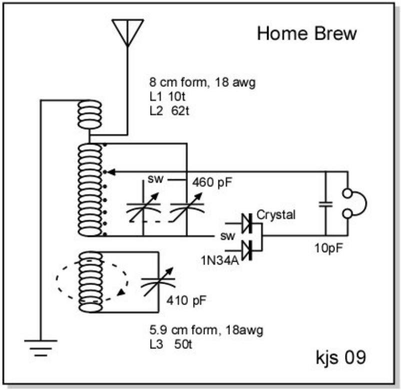


f l =	1095	kHz
f h =	1116	kHz
f res =	1105	kHz
BW =	21	kHz
Q =	53	
S =	15%	

My homebrew in its Galenatron configuration shows fair Q at 53 and poor-fair sensitivity of 15%. There is a 1cm separation between the antenna coil and detector coil which may help. In many radios of this design I see the coils separated by 2-3mm only. As I wound the coils on a single form, there is no experimenting here, just wondering. The variocoupler here is only a trap and was not used in this measurement. With the return to a single-tuned set you need expect performance downgrade, but greater ease of use for general listening. I feel this configuration is a good compromise for easy listening without the hassel fo manipulating two (or more) tuning dials. It is clearly superior to the Dunwoody and De Forest single-tuned sets.

general listener radio and far far from the performance achievable in high-quality DX designs. But it is teaching me as intended.

Inspired by Dan Petersen's Galenatron, I wished to play with a vario-coupler design. This hookup uses a single form with an antenna coupling coil of 10 turns and a tapped secondary coil with 62 turns. The first 2-gang vcap is unused. The single-gang variable cap tunes the rotor. So far the best position seems to be keeping the rotor in-line with the main coil. More learning to come.



11) Adjust the frequency above and below f res until the output level falls to the level calculated in step10 above. These frequencies are f high and f low. Record these.
12) The -3dB bandwidth = f high - f low. Loaded Q (QL) = f res / BW
13) Take the generator output peak-peak voltage recorded in step 2 above and convert it to rms voltage as follows: mVrms = mVpp / 2.829. This is Lauter's RF voltage E1 mV.
14) Measure the RF voltage across the 10 ohm resistor on the dummy antenna. This is Lauter's RF voltage E2 mV.
15) Input current to the dummy antenna = Lin = E2/10 (mA)
16) Input power to the dummy antenna = Pin = E1 * Lin (uW)
17) Power loss in the dummy antenna = Pda = Lin^2 * 25 (the dummy antenna resistance)
18) Power delivered to set = Px = Pin - Pda uW
19) Set input resistance = Rx ohms = Ex / Lin where Ex = E1 - (Lin * 25)
20) Set output power (uW) = Pout = Vout^2 / Rl in ohms
21) Set % efficiency (sensitivity) = 100 * Pout / Pin

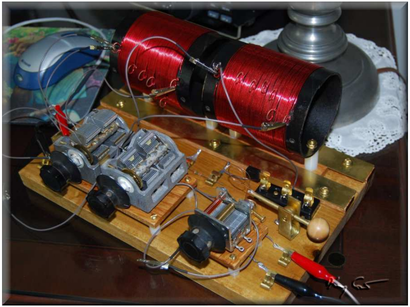
Having built a fair number of sets, and with varying quality, all the above protocol was developed to test my sets. What follows now is a discussion of how my sets stack up against each other and some notes on what one may expect in a crystal radio performance-wise. I give a summary table below of the essential data gathered on each of my sets.

Table 1

Measured Qloaded at 1100 KHz										
Radio	Vin	Pin	Pout	Eff	BW	Ql	Rx	Rl	Rd	
	V	uW	uW	%	KHz	-3Db	ohm	kohm	kohm	
Bremer Tully	0.2	30	4	15.4	22	50	143	20	200	BAT 46
Bremer Tully	0.2	26	4	19.2	25	44	166	21	18	1N277
DeForest 0d	0.2	42	10	30.4	85	13	95	24	18	1N277
Dunwoody	0.2	31	10	38.7	62	18	136	21	200	BAT 46
Fleming D	0.2	33	14	50.1	63	17	129	45	170	D18
Fleming D	0.2	27	12	49.3	83	13	158	33	2	D9E
Fleming V	0.2	34	14	49.8	70	16	122	42		6C19P
Galenatron	0.2	21	2.8	15	13	85	219	50	18	1N277
Hammerlund	0.2	26	2	8.9	30	37	166	142	150	FO 215
Homebrew 11cm	0.2	39	10.7	34.3	29	38	104	50	18	1N277
Homebrew 18cm	0.2	55	4.5	11.2	13	82	66	45	18	1N277
Homebrew 18cm	0.2	29	11.8	47.8	61	18	147	53	150	FO 215
Teflon 8	0.2	45	8.5	24.5	22	50	86	76	575	HP2835x4
Teflon 14	0.2	62	2.0	4.6	10	**107**	**56**	**275**	575	HP2835x4
Teflon 8 215	0.2	46	12.3	34.8	19	58	85	130	150	FO 215
Teflon 14 215	0.2	7	0.0001	0.0015	12	91	689	130	150	FO 215
Minstrel	0.2	39	8	23.8	51	21	104	50	160	1N60 schott
Mystery	0.2	11	0.1	1.2	163	7	446	21	28	1N34A
	Av ->	34	7	26	46	43	173	68	153	

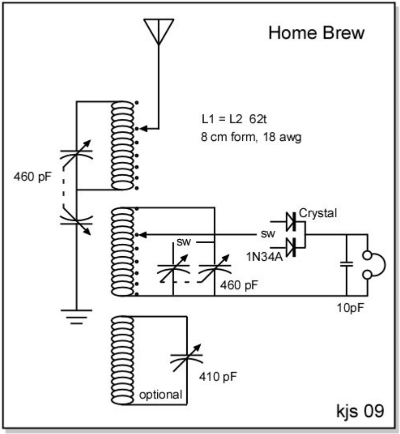
The above table of measurements were made at a nominal frequency of 1100khz and input voltage of 0.2Vpp as indicated on a digital signal generator following the protocol outlined. I give the radio name under test should you wish to refer to my pages for more on each set. The columns as follows:

Vin = 0.2V pp (0.71mV rms)
Pin = input power in uW into the set (after the dummy antenna)
Pout= output power across the load resistor in uW
% Eff = 100 * Pin/Pout
BW = bandwidth in khz at -3db
Ql = calculated loaded Q of the set
Rx = the set input resistance presented to the antenna
Rl = measured optimum load resistance for maximum power transfer
Rd = Diode junction resistance Rd used in the set



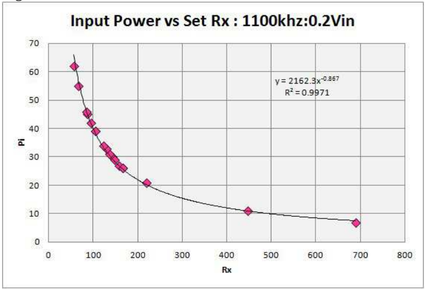
f l =	1092	kHz	f l =	1088	kHz	f l =	1094	kHz
f h =	1109	kHz	f h =	1100	kHz	f h =	1103	kHz
f res =	1099	kHz	f res =	1094	kHz	f res =	1099	kHz
BW =	16	kHz	BW =	12	kHz	BW =	9	kHz
Q =	68		Q =	93		Q =	125	
S =	22%	11cm	S =	21%	13cm	S =	15%	18cm

Here I show the performance summary for my set with three coil separations, 11cm, 13cm and 18cm. With these charts you see the value and trade-offs in loose coupling between the antenna and detector circuits. With the coils at 11cm separation they are slightly over-coupled but still with relatively good Q, 68, and fair sensitivity at 22%. Separating the coils to 13cm and then to 18cm loosens the coupling allowing narrower bandwidths and higher Q (getting to 125, woohoo!), but at the sacrifice of much sensivitity, down to 15%, still reasonable. This is an excellent performance, I must be doing something right somewhere. Of course this is still a



From the data above some interesting observations can be made.

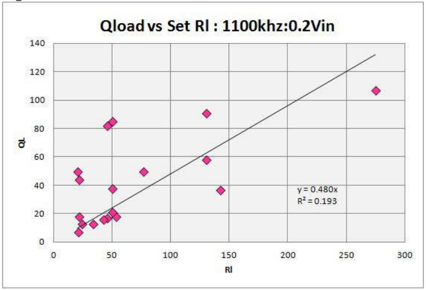
Figure 1.



In figure 1 above I show the relation of the input power versus the set resistance. The quality of the fit reflects that fact that this is largely a calculated value, but it does illustrate the importance of having a low input impedance to match that of the antenna. This is not often considered in discussions on impedance matching but is critically important. The antenna has an impedance in the 25 - 50 ohm range, not easy to get this in a set without quality parts and construction. My sets typically have an input impedance in the low 100's ohms and only two of my sets really get down to the 50-60 ohm range giving a good match to the antenna. Both of these are double-tuned sets with a tuggle front end.

If you are serious about getting DX and doing a lot of heavy lifting, you will need a good antenna tuner as part of your set design.

Figure 2.



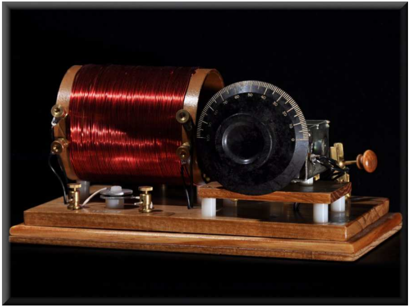
At the back end of the set things get a bit messier and are not east to show with a simple two-component plot. Here I have chosen to highlight the importance of the proper load resistance on the set loaded Q. In my set testing I have tried to pay close attention to the importance of the load on the tank and diode. Early on I considered construction of an output transformer unit that would work with different radio's as well as with different phones. Such a design can be found on Ben Tongue's excellent and highly technical web site. The plans were well beyond what I was able/willing to take on so I turned my attention to discovering just what load resistance exactly do my sets require for maximum power transfer. After all, if I found only a small range typical values, I might design

My second homemade, A double-tuned open test bed
http://www.lessmiths.com/~kjsmith/crystal/homebrew.shtml

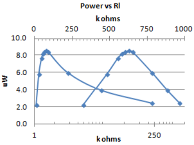
Having learned my lesson with the Mystery set, I have set myself to make a double-tuned rig with open wireing for testing multiple configurations. The concept is to seek the maximum amount of flexibility in hookup and coil design. This will mean interchangeable coils with or without taps, and wireing with allegator clips. I have chosen to hard place in the set three capacitors, 2 double gang 20 - 460 pF and one 20 - 410 single unit. The detector, as always, will switch between a diode and my own crystal stand. The modular design will allow testing coils mainly although vcaps will also easily be tested with jumpers. The number of leads and allegator clips, not all used with any one configuration will give this a bit messy look, but this is not a beauty contest but for learning. As always I include the option of using either a germanium diode or actual crystal.

The photos and circuits below show two hookups currently completed.

Double tuned circuit with tapped coils and an optional QRM trap (unused in photo). This configuration alone will keep me busy quite a while! I am learning what "sharp" tuning is. The antenna coil is tunes series-parallel but the first, (left) 2-gang vcap while I only use one gang of the second vcap. For lower inductance coils I can use the second gang in parallel.



a generic transformer that would work well with many or all minus the complicated switching.



In my testing protocol therefore, I included the important step of determining the optimum load resistance for the set under test conditions. I certainly part company with the school of thought that says to test all sets exactly the same way, including same diode (1N34A typically) and same test load. Sets are designed to work best when impedance matched and at the back end that generally means a load matched to the tank/diode combination that delivers the maxumum power. At right above I show a small plot where I varied the load resistance over a wide range and calculated the output power of the set. (I give the plot with both a linear and a more appropriate log scale). This should demonstrate the importance of optimizing the load resistance.

Optimum load resistance depends on both the tank Q and that portion of the diode detecting the signal. That in turn depends on the signal level. Very weak signals will be rectified in the square-law region of the diode characteristic and require relatively high (and variable) load resistances. Normal to strong signals will be rectified primarily along the peak-detection portion of the diode characteristic and require lower load resistance with less variation. Not shown in the above spreadsheet, I also ran measurements with a 2.0Vpp input. With this stronger signal, rectification was taking place farther out on the diode characteristic. As expected, the measured optimal load resistances for this case was similar to or lower than that for the 0.2Vpp input case.

With all that said, the plot in figure 2 is messy but the impression is that of increasing Q with increasing Rl. I view the plot as having a number of small groupings of measurements with similar conditions, each showing higher Q's associated with higher load resistance.

Figure 3.

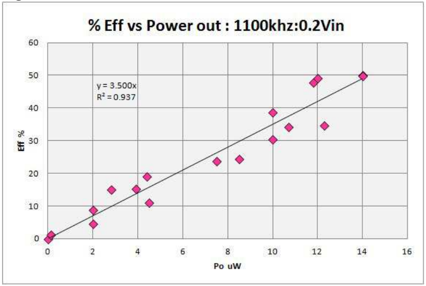
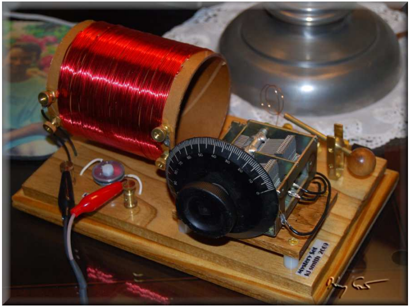
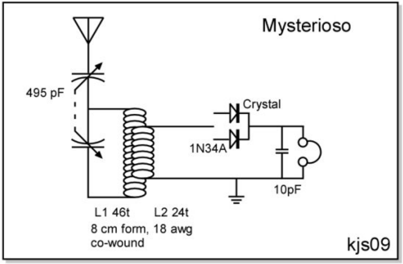


Figure 3 is most obvious with the clear benefit of good set efficiency on output power. An efficient set will better approach the maximum power transfer desired. High Q plays a part here. Still, there is always the tradeoff between selectivity (high Q) and sensitivity. An efficient set delivers more power to the load, but to go after Q you will ultimately be sacrificing sensitivity.

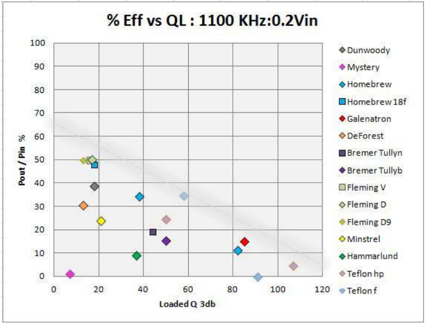




f l =	1073	kHz
f h =	1116	kHz
f res =	1097	kHz
BW =	43	kHz
Q =	26	
S =	19%	

Performance summary for the radio. My Mystery set, despite initial mis-calculations on the coil winding specs, turns out to be a fair performer. the bandwidth around a nominal 1100Khz is 43Khz giving a set Q of 26. This result is superior to both my DeForest and my kit Dunwoody, not bad for a first try! Sensitivity comes in at 19%, second after the DeForest. So, I consider this a successful entry into the world of scratch-built crystal radios.

Figure 4.



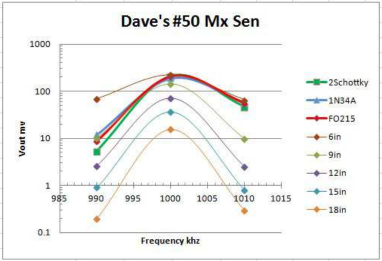
Here is the bottom line, Q verses Sensitivity, efficiency in this case. On this plot it is readily evident that I have built my fair share of loser radios, but also a good number of sets which push boundary of what can be achieved in terms of compromise between Q and sensitivity. Looking at the plot it is fairly easy to imagine a sloping line or zone running from 0 Q at 60% efficiency down to 120-130 Q at 0% efficiency. Beyond this one will probably never go with tank and antenna tuner alone. It will be time to start adding traps to your bag of tricks. Recall that the above is for the 1100khs frequency and that Q is a function of frequency.

In order to explore this final conclusion, I have taken a look at Dave Schmarder's excellent bandwidth analysis of his #50 contest set. This set is a superb work of craftsmanship and skill, experience and usage of the best ($$$) materials available. I take this to be just about the most of what can wrung out of the sky with a crystal radio. Dave’s protocol is rather different from my own and he did not make a specific -3dB bandwidth measurement so what I do from here on takes many liberties with his work, my sincere apologies in advance!

Figure 5.

Dave's Set #50 Performance Measurements (edited)

	Maximum Sensitivity Setting						BW	
	- 10 khz	1000 khz	+ 10 khz	0.707	Fl	Fh	-3db	QL
	990	1000	1010		Approximate			
	mv	mv	mv	mv	khz	khz	khz	
1N34A	11.9	188	58.9	133	996	1004	8.5	118
Schottky	5.4	208	47	147	996	1005	9.2	109
FO-215	8.8	204	55.6	144	996	1005	9.3	108
6 inches (15 cm)	69	224	66	158	995	1006	11.0	91
9 inches (23 cm)	10.4	145	10	103	996	1005	9.0	111
12 inches (30 cm)	2.6	70.7	2.5	50	996	1004	8.5	117
15 inches (38 cm)	0.9	35.8	0.8	25	996	1004	8.5	118
18 inches (46 cm)	0.2	15.5	0.3	11	996	1004	8.3	120

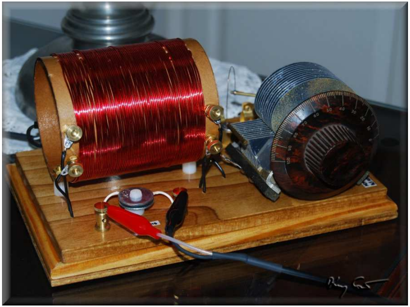


More study, more puzzling over the problem, more calculations, more frustration, more more study.. Did I say that? Short of complete disassembly, which I was loath to do, I was unsure where to go with it. Reading all I could, I came across a set with a modification with a second cap tuning the antenna, this I could test! My antenna, by the way, is a 100ft 14g stranded insulated copper wire with an additional 30ft or so of lead-in. Tuning the antenna seemed promising and when placing a cap the set suddenly found its voice! With a working radio, I had the dilemma of what to do with the case. No second cap would fit. The large vintage capacitor could easily be replaced by two small modern caps though and testing showed that in reality they tuned very effectively with a dual-gang capacitor which is what I settled for in the end. The set still dosnt tun below about 700 Khz or so. Posing the question on the Xtal Set Societie's excellent discussion forum Rap'n Tap brought elightenment from Golfguru who wisely asked the length of my winding, pointing out that the inductance of the coil should be calculated from the total length of the windings, INCLUDING the bifilar primary. Running back to Professor Coyle with a 3.27 inch length gave me 112 uH and a lower tuning range of 660 kH or so. So, "Mystery" solved...

The following is a final schematic of the set and photos of the set as it exists. I listen to it most evenings as I work.

cap, all displayed on a breadboard box with wireing hidden inside.

The risk here was inexperience and it certainly came home! My 18 AWG wire turns per inch were rather different from values assumed in the "Professor Coyle" spreadsheet, both because the sheet assumes bare wire and because my ability to close wind is not that great! My first attempt was for experience, but not for getting a useful coil. Rethinking and adjusting allowed success, almost, on the second attempt and I got 46 out of a planned 48 turns on the main coil. Assembly was difficult but in the end I had a lovely set that wouldn't bring in anything! Well, almost nothing, some weak interfering stations at the cap's full-open position. My first photo is of this incarnation.

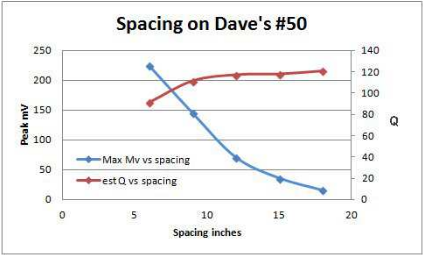


In figure 5 above I have attempted to cast Dave’s measurements into something similar to what I am doing, which is looking at the -3db BW and Q at 1100khz. I finally produced the above spreadsheet where I simply smoothed the data for the 1000khz case and estimated the bandwidth at -3dB. This makes a LOT of assumptions of course. Mostly I assume that the +-10khz measurements are well above the resonance skirt so my smooth curve is not unreasonable.

The #50 set then appears to have, at 1000khz, a -3db bandwidth of around 8-11khz depending on diode and/or spacing between the tank and antenna unit giving loaded Q's of 91-125. These numbers fall in the range of what my own data lead me to expect. Ken Kuhn's page on Resonant Circuit suggests the "typical" QL at 1Mhz ranges between 20 and 100 and Dave’s #50 set is certainly beating the best of that.

In the final figure 6 I have taken my estimated results above and looked at how Q and peak voltage (assuming constant conditions other than the spacing between the antenna and detector units so this ought to reflect power as well). It is quite apparent that the set is rapidly losing output power while Q improvements are flattening out as the spacing between tank and antenna tuner grows to 18 inches. It would appear that a -3db loaded Q of 125 is near the limit of what can be expected in a crystal set.

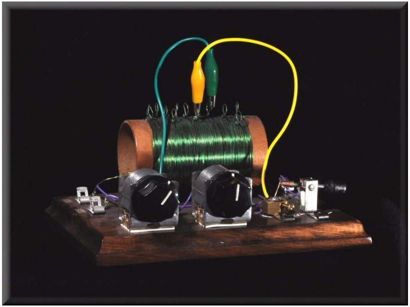
Figure 6.



My first homemade, A Mystery Set
http://www.lessmiths.com/~kjsmith/crystal/mystery.shtml

Having made the Dunwoody and experienced the thrill of listening to the local broadcasts on a radio of my own, unpowered save for what the stations themselves provide, I was thoroughly hooked on crystal radio. I hit the web for all I could find, which is considerable. My many thanks to all of you who have provided such useful and informative pages. I categorize my effort along two axes, 1) finding and reading sites with background theory and advice on crystal radio, and 2) sites of crystal radio builders to know what is possible and find inspiration. I was determined to produce a set of my own from scratch. Of all the possibilities, and there are SO MANY, I soon settled on the Mystery Set as an interesting and challenging goal. I have the impression that many, perhaps most of the experienced builders who make their presence felt on the web have built this, or modifications of this set. A worthy place to start, worthy company.

My intent, after studying so many variations of this set was to settle on the original set as published in the 1932 Brisbane Sunday Mail. If I can do well, then only can I consider modifications. My plan was to take the basic circuit, but otherwise use my own forms and wire, calculating appropriate inductor dimentions and winding specific for my needs. I sought a square coil with large dimentions, 8cm mailing tube wound with 18 AWG magnet wire, switchable detector between a diode and homebrew, and a lovely vintage 500pF



My library of Crystal Radio Hookups and theory...
http://www.lessmiths.com/~kjsmith/crystal/catalog.shtml

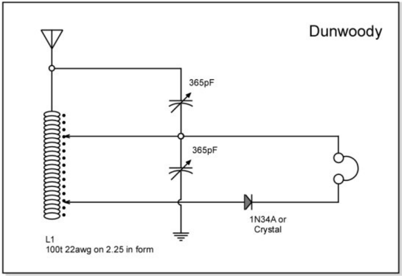
This section of my page started out as a place to put my compilation of crystal radio circuits. That compilation became a catalog featuring circuit diagrams hand-drawn by myself from various sources (as indicated on each page, see catalog reference). When I first entered the crystal radio hobby, I was amazed and more than a bit intimidated by the sheer variety of circuit possibilities. I began to make my own circuit drawings in order to get a handle on this in addition to finding interesting circuits to construct myself.

To organize the circuits from fairly easy to rather complicated, I put together a simple classification based on the number of Inductors and Tuning Capacitors in each circuit and a few of their main distinguishing features. Better classifications may exist, but this works well enough for my purpose. A legend follows so anyone may break the code. The catalog provides only minimal information about each circuit. Although an experienced builder may make the calculations to build a radio from the data provided, I mostly intend this for information only. I highly recommend if you wish build a set to consult the original reference.

Later as my experience and familiarity with crystal radio has grown, and after having built and tested a certain number of sets, more detailed and technical information has become necessary. Scouring the web has turfed up an amazing number of extremely well written and helpful web resources. While the number of excellent web sites is large, there have been a certain few that I found myself returning to time and again. From these I would print out large sections and read carefully, scribbling notes on the side, generating more questions and learning, learning, always learning.

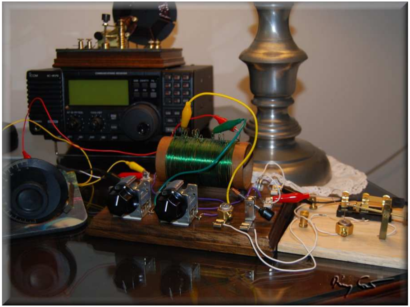
Eventually I began to assemble what were, to me, the most useful and informative pages into a handy book format. I decided to print the darned thing out to keep as a sort of Crystal Radio Handbook, something to take with me on the go, or just to read on the couch. I am NOT a "kindle" type.. The project was no trivial thing. I knew what I wanted, but casting everything into a common (more or less) format, organizing things, formatting figures, etc, it was a lot of work. For my handbooks, a glance at the table of contents shows a book organized to lead the reader along the path I followed. The authors are many and I wish to thank 10,000 times all the people who have contributed so much to this hobby on the web. My apologies if I did not choose your pages for the book, the choices of what to include and what to leave out was purely my own. The final Handbooks, there are three now, I feel represent university-level material from advanced introductory to university senior / graduate presentations on Crystal Radio. Published handbooks on crystal radio are traditionally directed primarily to the "boy scientist" adolescent, introductory in nature. I hope this these handbooks fill a gap rather than pander.

Finally, to help as reference, I eventually formatted two particularly interesting web pages as complete volumes in themselves. Ben Tongue's pages are essential reading for the serious hobbiest, even if over my head, (read.. waaaaaaay over my head). At nearly 400 pages, I have broken it into two volumes. Kenneth Khun's web book is just great, technical, but not overly, well explained as one would expect from a professor. Thanks for your efforts and for all those others whose pages I missed.



f l =	1070	kHz
f h =	1132	kHz
f res =	1100	kHz
BW =	62	kHz
Q =	18	
S =	17%	

Performance summary of my Dunwoody is so so with a set Q (loaded) of 18 but my sensitivity calculation is 17%, not so great. This may be all that can be wrung out of a single-coil radio, who knows? Most of my radio's have higher sensitivity so this set definitely benefits from my audio amplifier.



Circuit schematic for the set.

I intend these documents to be printed on double-side letter paper, folded over or cut in half and then bound. The foldbook paging system in the document only makes sense when this is done.

Crystal Radio Handbook: V1 Catalog of Crystal Radio Hook-Ups (ready for printing and binding..129pp)
pdf format, 15.7 meg size

Crystal Radio Handbook: V2 Crystal Radio Theory A Handbook of useful technical articles, (Bookfold format for printing, 262pp).
pdf format, 2.21 meg size

Crystal Radio Handbook: V3 Solid-State and Vacuum Diodes A Handbook of useful technical articles, (Bookfold format for printing, 268pp).
pdf format, 4.47 meg size

Crystal Radio Handbook: V4 Antenna / Ground and Antenna Tuning A Handbook of useful technical articles, (Bookfold format for printing, 164pp).
pdf format, 2.13 meg size

Crystal Radio Handbook: V5 Inductance, Inductors, and Measuring Q Technical look at Coils, (Bookfold format for printing, 272pp).
pdf format, 5.58 meg size

Crystal Radio Handbook: V6 Antennas and Propagation A walk down memory lane, historical and personal, (Bookfold format for printing, 234pp).
pdf format, 9.49 meg size

Crystal Radio Handbook: V7 Vacuum Diodes Dedicated entirely to vacuum diodes, (Bookfold format for printing, 210pp).
pdf format, 11.00 meg size

Crystal Radio Handbook: V8 Resonance Resonance and Coupled Circuits, (Bookfold format for printing, 252pp).
pdf format, 17.70 meg size

Kenneth Khun's Web Book on Crystal Radio Engineering (ready for printing and binding.., 113pp)
pdf format, 1.11 meg size

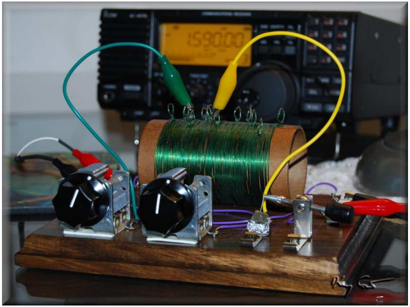
Ben Tongue's Web Book on Crystal Radio Systems Volume I (ready for printing and binding.., 185pp)
pdf format, 1.37 meg size

Ben Tongue's Web Book on Crystal Radio Systems Volume II (ready for printing and binding.., 208pp)
pdf format, 1.59 meg size

Ramon Vargas Patron's Web Book Contributions to Crystal Radio (ready for printing and binding.., 111pp)
pdf format, 1.65 meg size

This Web Page.. (because I'm so vain.., 238pp)
pdf format, 6.72 meg size

The radio now has a NOS Philmore crystal detector stand. In this photo I am testing a Pyrite crystal sitting on a crumpled aluminum foil bed, successfully detecting 1590 Khz locally here in Houston. In the background is my trusty Icon R75 giving me the straight poop on what station I am listening to. I was never really happy with the Philmore crystal holder though, it had to be improved.

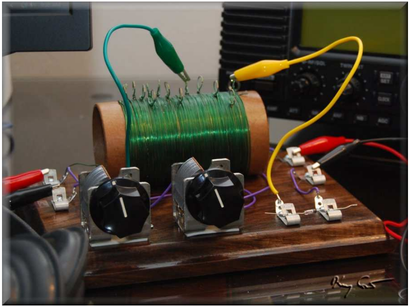


Current configuration on the Dunwoody now sporting a good brass crystal cup with set screw, also I have lifted the coil off the wood base with 1/4" standoffs. I am not sure how much of a difference that made, but seems good practice. This photo of the set taken while prototyping a homebrew detector stand of my own. I figured if I was to become a radio builder, I would need master the detector. I am a geologost so no radio is a crystal radio without a crystal, I mean, an actual crystal!

me back to my roots as a minerologist as well. In my fun I have subsequently learned to pot my own crystal detectors in woods metal, and tested a number of minerals as detectors, though in no systematic way. I did immediately notice that Galena and Pyrite, the most frequently cited minerals as detectors, are metallic sulfides so I have acquired additional samples of Stibnite, Molybdnite, Argentite, and Acanthite, only successful with the Molybinite. Seems a high degree of symmetry is needed as well.

The following photos are of the radio as originally constructed and a couple morphs as I learned to love this great hobby.

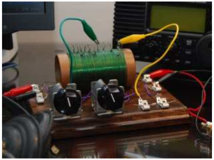
My Dunwoody in its original configuration as per the kit instructions. Clearly seen is my first-ever attempt at winding a coil, first attempt at taps in said coil, and a fine radio just the same.



CHAPTER II

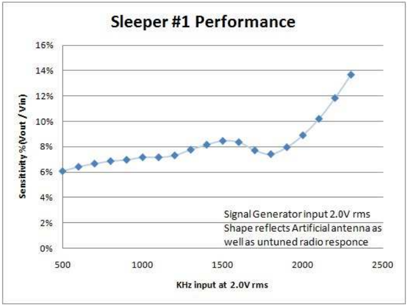
Radios I have built with my own little mitts…

Dunwoody, a kit from Borden Radio right here in Houston
http://www.lessmiths.com/~kjsmith/crystal/dunwoody.shtml



My first real intro to this fascinating world of crystal radio came with a set I purchased on Ebay from Borden Radio Company, Lance Borden. Lance is an engineer at NASA and radio amateur with a business selling crystal radio's and parts. When I first ordered my kit he was very helpful and encouraged me quite a lot. I appreciate the well-designed radio as much as his help in my introduction. The radio itself is a single-tuned set with dual 365 caps tuning on the antenna and detector sides of the single coil. The coil features numerous taps, a concept I was quite unfamiliar with and curious about when I first considered the set for purchase. I figured I had much to learn and the set seems a good and serious way to begin.

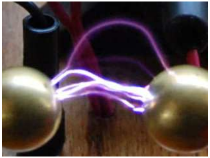
The Dunwoody comes with a 1N34A diode detector, two 365 variable capacitors, fahnestock clips, a sturdy cardboard coil form and magnet wire to make the inductor. The included instructions are clear and easy to follow. One item not included or part of the radio is a crystal detector, but the instructions give a hint by stating that the spacing for the germanium detector are the same as for a Philmore detector. That sent me to the web and introduced me to the crystal in crystal radio. I thoroughly had the bug by this time as I searched for, and eventually acquired a Philmore detector and crystal. In fact the galena crystal is remarkably hot and often performs every bit, in my opinion, as well as my germanium diode. This has led



Hooking parallel configuration to my signal generator can give an idea of the performance of the radio across the spectrum. I measured the mV output in 100 KHz increments from 500 to 2300 KHz. Across the broadcast band the set has faitly flat responce with a slight tendancy to resonance about 1500 KHz and then increasing sensitivity from 1900 KHz on up. Keep in mind that the set is hooked to a dummy antenna rather than my actual long wire. Still this gives an idea of the overall untuned nature of the circuit.

When I hook in a series configuraiton I am unable to get a measurement, only 0V DC output. I am working on why this may be the case. Drives me nuts.

A Spark-Gap Transmitter
http://www.lessmiths.com/~kjsmith/crystal/spark.shtml



Why a spark-gap transmitter? And why here on a crystal radio page? Well, the second question I'll answer first as it is easiest. The transmitter is a vintage technology device that is no longer current in the modern world and so fits thematically with the purpose of my crystal radio page. The first Question is more interesting, why build it? In late 2009 my elder brother, founder and owner of Northwest Research Engineering, LLC., in Seattle, challenged me to construct a spark-gap transmitter. He enjoyed seeing my vintage-style crystal sets and we enjoyed discussing the early history of radio together. So, it seemed a logical step to progress in this direction. Additionally, as his work is in cutting edge ionospheric research, he has little opportunity to study such retro technologies up close and personal.

DISCLAIMER:

I am not a licensed radio-amateur and in any case a spark-gap transmitter is not legal to use in the United States. As such, this project was taken on as a technology-demonstration exercise only and is not intended for actual use. Such use is not permitted. Nor is this page intended to promote the construction and use of such transmitters by others. I DO give detail on the construction and theory of the transmitter in order to better understand and appreciate the technologies used at the dawn of the modern wireless era.

The concept behind the project is to build an operating spark-gap transmitter using technology as close as possible to that used at the turn of the 20th century. Technology that would be recognizable to Marconi or Fleming. This meant no chips, no transistors, no diodes, (OK, a galena and cat's whisker is technically a diode, but you know what I mean...) no solid-state. It does not mean using vintage components as these are for the most part unobtainable and/or prohibitively expensive. With each component new or homebrew the question is: would Fleming recognize this? Sometimes I needed to stretch things somewhat, especially concerning the relays, but still I believe I have remained true to this original goal.

The transmitter was conceived as two modules, a power module and an oscillation module. Size constraints forced me to break the oscillation module further into two breadboards, one for the variable HV capacitance and the other for the oscillation transformer. The power module is the most complex piece having on it the induction coil, interrupter, capacitor, and the spark gap itself. To keep this page length manageable and allow enough space to give a good description of each component, its theory and function, I have broken the descriptions into separate links below.

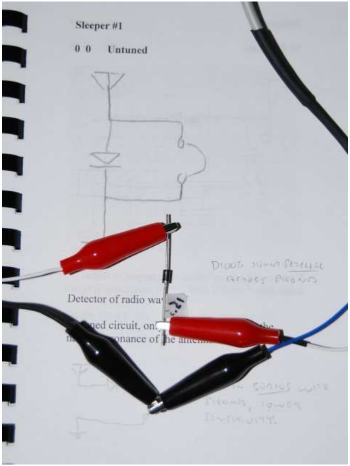
INDUCTION COIL..

COIL INTERRUPTOR..

SPARK GAP..

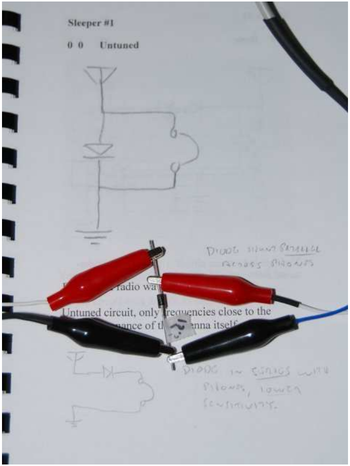
OSCILLATION CIRCUITS..

PERFORMANCE TESTING..



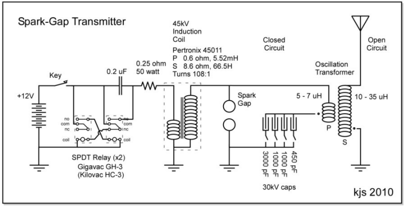
Sleeper #1

The hookup in its parallel and series configuragions. In either case I really cannot hear any signal with just a headphone or crystal earplug. With amplification I can get good signal strength with the parallel hookup giving slightly more sensitivity than the series hookup.

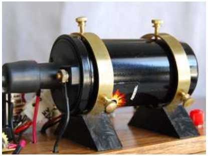


As shown, the radio passes most loudly a local powerhouse spanish format station. It is quite sensitive as one can imagine. Listening closely and you can certainly hear the other stations on the broadcast band competing for attention. My question now, do I make a breadboard extravaganza of this set? On va voir...

The following circuit diagram and photo shows the complete transmitter and how the modules integrate together:



Induction Coil



Marconi's first successful radio employed an induction coil as its main energy source. Other methods were quickly adopted that were more efficient and more powerful, but the reliable induction coil remained common throughout most of the early period of radio. Fleming describes a typical "10-inch" coil used for radio work in his day. By 10 inches, he refers to the length of spark obtainable with the coil. These coils are large and today mostly unobtainable except as specialty reproductions at outlandish prices. Fortunately the venerable induction coil remains in manufacture as the common (increasingly uncommon unfortunately) canister ignition coil found in most cars built through the 1970's. In Fleming's terms such a coil might be called a "1-inch" coil, woefully inadequate for transmitting messages to China perhaps, but ideal for this project. Standard coils generate up to about 30,000 volts and "sport" coils can put up to 45,000 volts.

When I first began researching this project I was surprised by the difficulty in finding useful technical specifications for ignition coils of various manufacture, or even of knowing what constituted a "good" versus a "bad" spec when such specs were found. What little information is generally published includes the maximum voltage naturally, often the secondary resistance, sometimes the primary resistance and the turns ratio, (ratio of primary to secondary windings). At first look there doesn't seem to be much correlation between voltage and turns ratio or

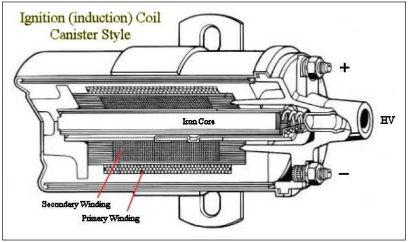
Sleeper #1
http://www.lessmiths.com/~kjsmith/crystal/sleeper.shtml

OK, this is a bit of a cheap shot for a radio, but.. it IS a radio!

It is always interesting to get down to bare essentials, to do the absolute minimum and still get a working instrument. It is not for nothing that MB Sleeper included a circuit diagram for this hookup, it is a functionning radio. This circuit is essentially a detector of radio broadcast energy. It has no tuneing functionality. Resonance is extremely broad although weakly peaking as determined by the impedence and capacitance of the antenna itself. In part my idea is to see if it is possible to determine this peak region.
I present the set photo with a 1N5819 Schottky diode but it works well with virtually any diode, only the sensitivity changes. I even tried a Zenner diode but had to attach the Radio Shack mini-amp and crank it up. Still, it worked ok. So, more to come..

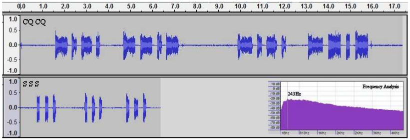
even resistances. It took a lot of research to learn the needed theory behind Kettering ignition coils and much of what is found on the web is inadequate, oversimplified, poorly founded theoretically, or downright wrong. I will try here to explain in moderate detail how the Kettering Ignition System works, the theory, and therefore how the various components (windings, primary, secondary, capacitor, resistances, etc) work together. With the right theoretical underpinnings, the specs do make a lot of sense.

Induction coils operate by storing large amounts of energy in the form of strong magnetic fields. As currents pass through the windings their electric fields generate magnetic fields, and fields in one coil induce fields in the other, primary and secondary. As long as a current is maintained in one winding its magnetic field is sustained and a corresponding field is sustained in the second winding. Conversely, moving the coil through a magnetic field or removing the field entirely will generate an electric field, (measured as voltage) in the coil. The ratio of turns between the windings determines the ratio of voltages between the coils. Although the input voltage to the primary coil is small, only 12V for a car battery, it has a large current and a great deal of magnetic energy will be stored in the primary coil. By shutting off the primary voltage source the magnetic field of the primary collapses. As this magnetic field collapses it cuts the secondary coil generating a very high voltage output. The rate of field collapse (dB/dt) determines the strength of the voltage output of the secondary. This high voltage output spikes only when the primary current is shut off causing the field collapse. Coils therefore require an interrupter to repeatedly switch the current to the primary on and off. The trick is to select materials with needed properties to achieve the results wanted. The Kettering Ignition system use in this project is described next.



The Kettering ignition system consists of a 12v battery (the source of emf), an induction coil, a capacitor, and a switch of some sort, (points, relay, vibrator etc..) in a car its points. For the coil the primary and secondary are wound in series and connected together inside the canister. The coil has inductance and impedance/resistance. As the system has LRC, (L = Inductance, R = Resistance, C = Capacitance) the circuit has a resonant frequency and this frequency determines the unit time period "dt" in the equation V = L di/dt. Even without the capacitor there remains some distributed capacitance in the coil and so opening the points will never instantaneously collapse the magnetic field, but it will be extremely fast just the same. The field is maintained by the current from the battery to ground, opening the points removes the ground and stops the current.

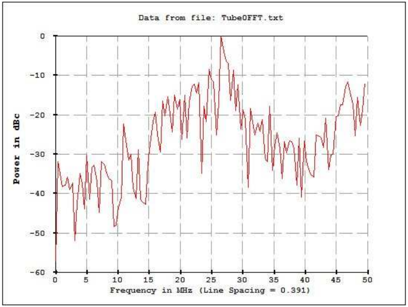
As the circuit has a more or less fixed L and R from whatever coil you have available, you can only vary C by choosing the capacitor carefully. For cars, this typically means a capacitance



Does it work? What does it sound like on an AM radio? I recorded the above plot off a small AM radio tuned to the top of the broadcast band. Plenty of signal to go around, I understand why these transmitters are no longer allowed to operate! I give you a couple CQ's and an SSS in commemoration of Marconi's first transatlantic radio reception on December 12, 1901. Fleming designed the transmitter power station at Poldhu for the transmission.

CQCQ Yes... it really IS a transmitter..
SSS

73



If I can get my arms around the frequency and learn to control this, I see this as an excellent gap for my set. But, would Professor Fleming recognize this? I must fall back to my vacuum relay justification and restate that Fleming, as the inventor of the vacuum tube, was no stranger to placing elements inside a vacuum. He would certainly recognize this.

****

Transmits:

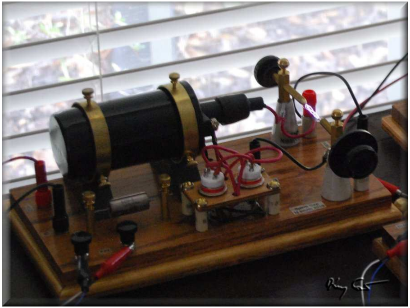
in the 0.1 to 0.2uF range. This capacitance gives a resonant frequency such that the dt will deliver a 30kv jolt to the plugs from the secondary of the coil within the period allowed by the engine timing.

A smaller dt (shorter unit time) delivers a higher secondary V (do the math) but standard coils are not designed for this and the internal insulation will probably not handle the tension. Additionally, the primary also delivers a voltage back to the switch/points/relay. A smaller dt will also result in a higher V off the primary. Of more importance, the smaller dt means that the back emf hits the points early before they have had much time to open. Either the higher V and/or the early arrival will cause arcing at the points. Arcing at the points creates a low resistivity path to ground and leaks the power away from the coil and so the secondary will also not deliver much V to the gap.

Conversely, a dt too long will slow the rate of charging and prevent the coil from being charged sufficiently in the time available (dwell time). The field collapse will be slower lowering the voltage out of the secondary, V = L di/dt. A smaller capacitance means higher frequency/smaller dt and vice versa.

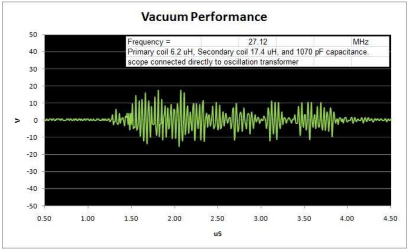
As dt is determined by the resonance of the LRC circuit, the variable you have to work with is generally the choice of capacitor value. Modern high performance coils also factor in. they have lower R (resistance) and lower L (inductance). lower L hurts because the energy stored in the coil is as follows: Energy = 1/2 LI^2. Reducing L lowers the stored energy. lower current (I) also lowers stored energy. Lower R increases the amount of current flow per unit time as well as increasing the frequency of the resonant circuit. Larger di and smaller dt means a much larger V. High performance coils are designed to deliver 45kv instead of 30kv and must have the insulation appropriate to this. The "performance" of these coils comes from two favorable factors, the high voltage assures sparking in high compression and the small dt allows sparking at high RPM's in 8 cylinder engines. That is, it’s the small dt that allows sparking at very fast cycle times. They still have roughly 100:1 turns ratio.

Photo of the induction coil / ignition coil mounted horizontally on the power breadboard. Other components seen include the interrupter relays, the capacitor used to determine the coil resonant frequency, and the active spark gap. The thing really works!



The following are a few easy specs on some popular ignition coils, only a small sampling:

oxidized. This results in an uneven and "messy" spark. More importantly, I suspect that there is a LOT of arcing taking place at the gap as well. Arcing is a continuing current that effectively shorts the closed circuit to ground. This would explain why the audio-frequency coil oscillations are present even when the sparking is present. The vacuum gap prevents oxidation and produces a clean spark with every pulse. The electrodes are also made of either zinc or tungston or some other refractory metal. The lesson to be learned, make your electrodes of something more durable than brass and get some steel wool to FREQUENTLY clean the tips!



circuits have different wavelengths and so will set in motion a variety of unwanted harmonics. Presumably, with an actual antenna close to the design specs the transmitter will perform flawlessly!

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The above analyses are presented with the transmitter and gap working in their "normal" operation mode. You will recall in my section on the spark gap that I also have tested a UHF vacuum tube spark gap. The following plots give some early interesting results needing presentation here. The RF oscillogram is quite typical of what this spark produces. You will immediately notice that instead of an RF pulse consisting of several distinct phases as before, this gap produces very clean almost pure HF tones with varying amplitude in the 27MHz range. These two differences, unphased tone and high frequency need explaining. For the difference in frequency I am really at a theoretical loss, all the formula I have tell me that the frequency results from inductance and capacitance, two parameters that did not change. I can only speculate that, as the spark resistance ought to be significantly lower in the vacuum gap, this may be the cause. More testing and more reading needed!

As for the tone itself, again I need to speculate and hypothize. If you look again at the initial audio-frequency oscillogram, you note the obvious induction coil audio oscillations as well as the initial spark. Normally these oscillations should not be seen unless the electrodes are separated far enough to prevent sparking. Initially in my testing this was the case, but with time the coil oscillations became a normal part of my responce. Additionally, with time I have had to adjust the electrodes ever closer to get consistant sparking, thus the frustration. I hypothize that the electrodes themselves are getting quite

PerTronix 45011: V max = 45000 V, P res = 0.6 ohm, S res = 8.6 ohm, P ind = 5.5 mH
Mallory 29217: V max = 58000 V, P res = 1.4 ohm, S res = 10.0 ohm, P ind = 6.6 mH
MSD 8202: V max = 45000 V, P res = 0.7 ohm, S res = 5.2 ohm, P ind = 8.0 mH
Taylor 718203: V max = 45000 V, P res = 0.7 ohm, S res = 4.7 ohm, P ind = 8.0 mH

For my project I have used the PerTronix coil above although I imagine most will do nicely. The Kettering discussion, appropriately placed here in the Induction Coil write-up, is needed understanding in the next section on the Coil Interrupter selection.

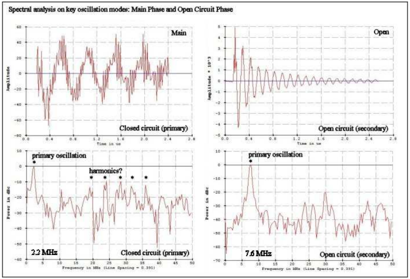
Coil Interrupter

In order to function properly an induction coil requires an interrupter circuit. The high-voltage output of the secondary winding results from the magnetic field collapse of the primary when its current source is interrupted. A single interruption will cause a single HV spike and thus a single spark. Repeated sparks require repeated charging and closings of the primary winding. For my project I was seeking a pulse-rate some 60Hz or better to give an audible tone at the receiver. Too rapid though and the induction coil will not have enough time to charge between cycles. Putting things into automotive terms, a 4-cylendar engine idling at 750 rpm must cycle the coil every 40mS, or 25Hz, no problem. For an 8-cylendar engine running at 2500 rpm you are down to 6 mS cycling (170Hz) and many coils are unable to work well at such rates. High performance coils are intended work well even at such high rates. For the transmitter I feel a cycle frequency between 60 and 100Hz would be ideal.

It would be lovely if cycle timing were the only constraint, general purpose relays typically run around 60Hz. Indeed this was my initial design, woe is me. Another concern the interrupter needs to deal with is the presence of a back emf from the induction coil primary winding. With a 100:1 turns ratio, a coil that sends a 45kV pulse out the secondary will also send back to the interrupter a 450V pulse. Small general purpose relay contactors remain rather close together even at their widest separation and so are prone to arcing with modest

Open circuit:
Secondary coil = 17.4 uH (L1)
Distributed inductance = 0 uH (Lo) (no distributed inductance)
Distributed capacitance = 25 pF (Co) (Scope probe in X10 position)
Wavelength = 59.6 sqrt((L1 + La)*Co)
Wavelength = 39m = 7.63 MHz

The two following plots give spectral analyses of the oscillations in the closed and open circuits.



This analysis gives a pretty close prediction to the values actually found on the testing and gives confidance that things are behaving as per theory. Other frequencies noted are harmonics and/or interference between the open and closed circuits. The original design was set so that both open and closed circuits resonated together at 120m. Under test the two

Right about now the observant reader must have noted that the frequencies measured, 2.11 MHz on the closed circuit, and 7.66 MHz on the open circuit, (and variations in-between) do not compare well with the design frequency desired. This certainly needs to be looked at. Recall my original design was for 2.5 MHz on both circuits with the following parameters:

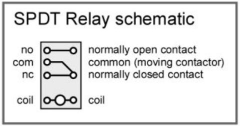
Closed circuit:
Primary coil = 2 uH
Capacitance = 2000 pF
Wavelength = 1884 * sqrt(L*C) = 119m = 2.52 MHz

Open circuit:
Secondary coil = 20 uH (L1)
Distributed inductance = 20 uH (Lo) La=Lo/3 = 6.65 uH
Distributed capacitance = 150 pF (Co)
Wavelength = 59.6 sqrt((L1 + La)*Co) = 121m = 2.48 MHz
Wavelength = 1884 * sqrt(L*C) = 121m = 2.49 MHz

Under testing conditions I have made some significant changes to the above. Specifically, the lumped inductance and capacitance are changed to P = 6.2uH (closed circuit), S = 17.4uH (open circuit), and the capacitance = 1070pF (closed circuit). Also, the design assumed a "generic" antenna with distributed values La = 6.65uH and Co = 154pF. Under test there is no antenna and the scope probe gives about 25pF capacitance and no inductance. Substituting the test values provides the following analysis:

Closed circuit:
Primary coil = 6.2 uH
Capacitance = 1070 pF
Wavelength = 1884 * sqrt(L*C) = 153m = 1.96 MHz

voltages. When I first hooked up my relay I got modest sparking from the gap and contact arcing that was quickly burning up the relay. It was my belief that the capacitor was there to slow the process and allow time for the relay contacts to separate before the back emf hit. I tried capacitors of increasingly high capacitance, they did not cure the problem. It was time to hit books and work the test bench.



What follows was a better understanding of relays in general, and SPDT relays wired in a buzzer configuration in particular. An SPDT relay has a common contactor set between two posts. The contactor has a spring which keeps it in contact with one of the posts, the "Normally Closed" (NC) position. The other post thus represents the "Normally Open" (NO) position. The relay also contains a small coil that, when energized will push the contactor towards the NO position and so breaking the NC contact. In a buzzer configuration, breaking the NC contact also de-energizes the relay coil so there will be no more push towards the NO post. The contactor will use what little momentum it has to oppose the spring and move to the NO position. In reality this momentum is not sufficient and so no contact with the NO post is ever made. This is why one always uses the NC post with the SPDT buzzer relay. A further negative consequence of this is that the contactor never separates far from the NC post. The close proximity allows breakdown of the dielectric potential of the air between the posts and arcing to occur.

Solutions to this arcing problem come in two flavors, the dielectric and the contactor separation. One solution used in high power relays is to enclose the contactors in a high-dielectric oil to suppress arcing. This is very effective but the fluid is difficult to work with, expensive, and it slows the contact frequency greatly. Recall that I am seeking at least a 60Hz contact frequency. Another way is to place the contactors in a vacuum. While not as good a dielectric as oil, it is significantly better than air and has the advantages of being easy to work with and maintains high frequency operation. Several companies manufacture vacuum relays and, while expensive, this is the route I chose. Note: there is of course a third solution to abandon relays and go solid state. This is fine if all you desire is cool sparks, but it is not in my directive.

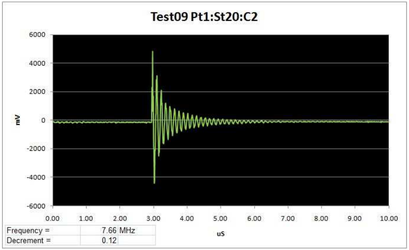
Even vacuum relays when wired as a buzzer have the contact separation problem. If the contactors remain very close then arcing can still cause trouble. The method to force the contactor to move to the fully open as well as fully closed position, allowing maximum separation, is to wire two relays in series. The resulting contact frequency (duty cycle) will be half that of a single relay. Happily the vacuum relays operate at a frequency of about 200-240Hz. That provides a 100-120Hz operation in a two-relay configuration, very sweet. Additionally, the two-relay output consists of a nice square-wave signal bringing joy to the professional radio engineer. I know this because the circuit configuration was suggested to me by my clever elder radio engineer brother. Fei chang gan xie! Of course, this solution doubles the expense of an already expensive relay. I have tried the configuration with general purpose relays and find the resulting 30Hz operation unacceptably slow.

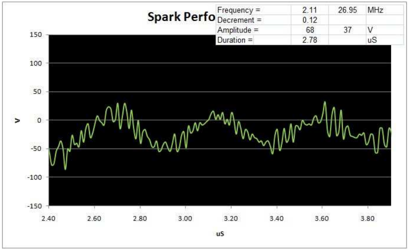
frequency. High decrements, (in the 1920's a spark-gap transmitter was required by law to keep a decrement of 0.2 or below) indicate a poorly engineered / poorly operated station. Calculations for the wave decrement as follows:

Decrement = 1/n ln (Xo/Xn) where Xo is the amplitude of one wave and Xn is the amplitude of another wave n periods following.

Damping Ratio = 1/sqrt(1+(2pi/D)^2) where pi = 3.14 and D is the decrement from above.

A particularly nice example of an isolated fully-quenched oscillation follows. I assume in this event that enough energy remained present in the closed circuit to allow an occasional isolated single spark to jump the gap. Such a spark produces a nice ring in the open circuit without the complexity associated with the main sparking from the induction coil. This plot shows the open circuit ringing nicely at 7.66 MHz frequency with an acceptable 0.12 decrement.



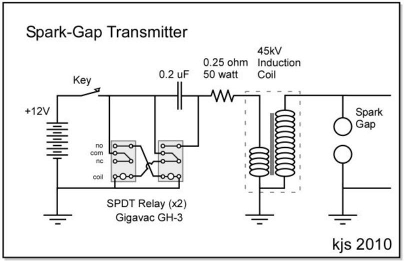


Finally, when the energy loss finally quenches the sparking at the gap, the open, secondary circuit then can freely oscillate, here with a frequency of 10.76 MHz and lasting some 3.3 uS. This last phase is the desired transmission frequency and the open circuit normally oscillates into the antenna. Decrement on this last phase is an excellent 0.04. Early spark gap transmitters struggled to reduce or eliminate the initial two phases of the event with quenched gaps.

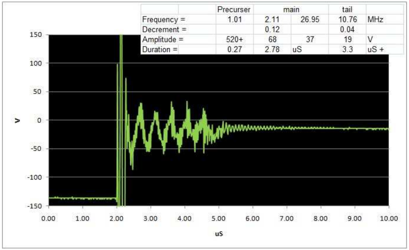
Why is decrement important? Most RF damping in a spark-gap transmitter results from interference between oscillations in the open and closed circuits of the oscillation transformer. When these waves interfere two separate wave energy peaks are radiated from the antenna causing loss of signal strength at the desired frequency and adjacent channel interference. A good spark-gap transmitter should quench the closed circuit as quickly as possible after the energy is transferred to the open antenna circuit. Once quenched the open antenna can resonate at its natural frequency. Lacking quenching as with my transmitter, the oscillation transformer needs to be carefully tuned to resonance and loosely coupled to radiate at a single

One final and somewhat late note concerning the vacuum relays. These relays, (Gigavac GH-3 or Kilovac HC-3) are load-switching devices designed to operate to 18 amps. The Pertronix coil on the other hand runs nicely at a cool 20 amps (12 V and 6 ohm, Ohm's Law here). The duty cycle is plenty slow enough to allow a longer charging time so all those amps shouldn't really be needed. I have added a 0.25 ohm ballast to the circuit to lower the current to about 14 ohms. Those cute little relays are very expensive and I have already damanged (temporarily) one of them by pushing 20 amps through. With the ballast I DO find the spark power, measured in terms of brightness, noise level, and max length is diminished somewhat, such a pity.

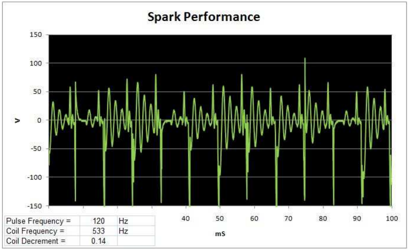
So, would Fleming recognize this? It is where I push the boundaries as I doubt that vacuum relays existed in his time. Still, relay action was well understood in Fleming's day. As for enclosing them in a vacuum? Well, I defend myself by stating that Fleming himself invented the vacuum diode. Enclosing electrical devices into vacuum bulbs was not a new idea even then. So, while the vacuum relay may not have existed, relays themselves did and Fleming would have been comfortable with the vacuum technology. I think...



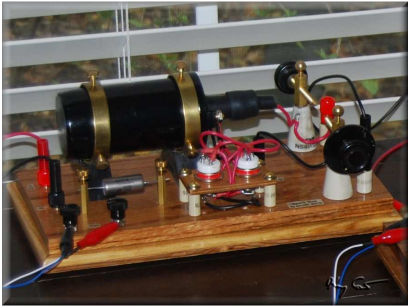
Circuit diagram of the power module indicating the wiring concept for the two-relay solution. And finally, a photo of the set with the two relays in position and ready to go.



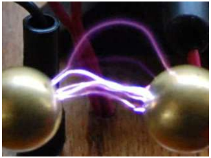
Zooming in to the radio frequency world the above plot shows the radio frequency wave in some considerable detail. This plot indicates that the oscillations given off from a spark gap are anything but pretty. The complexity results from the ringing going through several phases with the closed and open circuits, and induction coil each having their imprint. The initial (precursor) phase of the event, lasting here about 0.27 uS is the high-amplitude energy (upwards of 520+ V) of the spark as the induction coil pours its energy directly into the circuit at the gap. This is followed by the main phase, a complex 68 V amplitude ringing lasting some 2.8 uS. The ringing consists of two combined waveforms, one, a high amplitude (68 V) 2.11 MHz wave with a second lower amplitude (37 V) high frequency 27 MHz wave superimposed. This phase results while the closed (primary) circuit still retains sufficient energy to cause sparks at the gap with each main oscillation. The higher frequency wave comes from the open circuit (secondary) inductively coupling to the closed. A detail look at the main phase seen below:



This first plot above shows the response at audio frequency. In the 100 mS plotted we see 11 pulses at 120 Hz frequency. This represents the pulse frequency of the dual relay system, two relays at a nominal 240 Hz each. Each pulse starts with a high amplitude spike associated with the spark discharge and followed by two to three damped oscillations with a frequency of 533 Hz. This oscillation is associated with the natural frequency of the induction coil itself. Damping of waves is a natural oscillation feature and is refered to as the wave Decrement. Decrement is the natural log (Log to the base e) of the amplitudes of any two successive peaks in the wave train. It results from the loss of energy in the circuit during the oscillation period. Energy is lost due to resistive heating, radiation of waved into space, and interference between oscillations in the primary and secondary oscillation circuits, especially where they are closely coupled. Where resonance is high the interference losses are minimized.



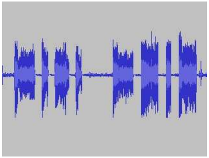
Spark Gap



The heart of the system is the probably the simplest component, the spark gap itself. After all the required background theory for the induction coil and relay setup, this component was a walk in the park. Still I need note that my gap is not intended for serious duty and so does not require extra features such a cooling fins and/or etc. Below is an early mock-up of the gap, a simple set of 1/2" brass balls tapped for a 1/4" threaded brass support rod. The entire assembly set off the base with lovely tapered ceramic standoffs.

Early use of the spark gap, especially with a weak induction coil, showed up room for improvement. When sparking the

Performance Testing the Transmitter



If you build it, will it work? And how well? This page attempts in a preliminary manner to answer these questions and provide a first look at the performance through the eyes of an oscilloscope. It will take much testing and observation/head scratching before I ferret out all the phenomena present in the set. This is one of the objectives of the project, to study and learn about spark-gap technology. The plots below are a first look, some will raise more questions than answers, but that’s the fun!

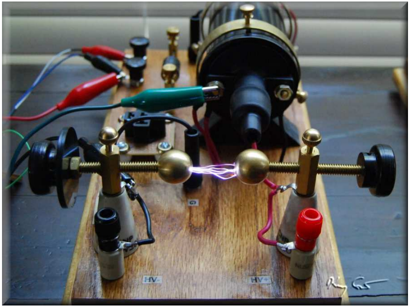
All of the scope plots presented here are made with a single hookup to the scope. The scope probe was attached to the set antenna output of the oscillation secondary coil. Many other observation points remain to be made and observed and I will update this page accordingly when needed. I present observations of the three primary oscillation frequencies expected from the set: A) the pulse frequency from the relay, B) the resonant frequency of the induction coil + power capacitor, and C) radio frequency oscillations of the transmitter itself. So little work so far, so many questions remain!

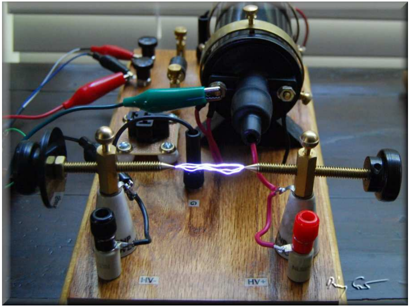
The capacitance module simply consists of high-tension modern capacitors switchable into or out of the circuit in parallel. The original intention, still in play, is to use Leyden Jars, but that is another matter. The four capacitors have values of 500, 1000, 1000, and 3000 pF giving plenty of combinations to choose from. Changing inductance is a matter of clipping to the coil at the right place. Finally, coupling the coils is a matter of sliding the secondary along rails into or out of the primary winding. The following photos give portraits of the two oscillation circuit modules.

When one walks into a room, nothing quite says "Transmitter present!" like a big oscillation transformer!

brass balls build up an oxidation layer fairly quickly. This layer increases the dielectric between them and, especially when the voltage is marginal, (my first coil was old) the sparks had trouble to jump the gap. I needed to clean the balls frequently with steel wool. The 1/2" balls spread out the field flux over a small area. One improvement was to switch from a ball-gap to a gap between sharply pointed tips. The photos below show both configurations. The points concentrate the field and creates a higher potential. This makes it easier for the sparks to form. Switching between configurations is as easy as screwing on or off the balls which cover the pointed tips.

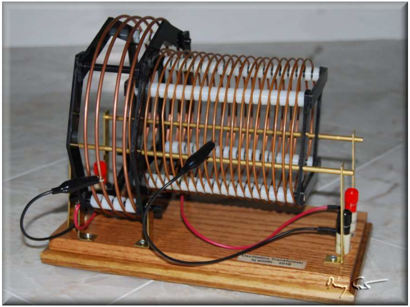
Adjustment of the gap length is easily accomplished by turning the end knobs of the threaded supports. Small top thumb-screws lock the posts at the desired position. CAUTION: Do NOT touch any metal components while the spark gap is in operation. Handle by the insulated knobs only.





In the photos above the sparks are being produced without any ballast resistance and are just over 2cm long. With the ballast I subsequently added to protect the vacuum relays, the spark power is lowered from 20 amps down to about 14 amps. The sparks obtained are smaller, about 1 to 1.5 cm. According to Fleming an induction coil capable of producing sparks up to 10 inches (25cm) in air will give a spark of 6-7 mm when connected to a load. I find with the tank circuit connected to the gap I need adjust the spark points very carefully and close, about half a mm or less to obtain consistant sparks. This can be a frustrating exercise. Air diaelectrics also have the problem of arcing when the air between the electrodes begins to ionize. A solution to this is to enclose the spark gap in a vacuum. It just so happens that occasional inexpensive vacuum spark gaps are listed on ebay. These tubes are intended for radar (UHF) applications and are rated in the few hundred volts range. As

The oscillation transformer design thus becomes a matter to choose coil lengths and diameters to give a range of values inclusive of Lsecondary = 20uH and Lprimary = 2uH. To make the transformer loosely coupled the secondary needs to slide within the primary. I chose the following parameters:
Primary: Diameter = 7", Length = 2.0", Turns = 4, uH = 3.81 max, 1/8" copper tubing
Secondary: Diameter = 5", Length = 6.0", Turns = 22, uH = 27.4 max, 1/16" copper tubing



to imagine an amateur inverted L antenna with about 20 uH distributed inductance and 150 pF distributed capacitance. As antennas are magical mystical things that nobody (meaning myself) really understands this appears entirely reasonable. In any case, the transmitter is tunable to bring it to proper resonance (hopefully) when attached to an actual antenna. These then are my fundamental design parameters:

Design frequency = 120m
Antenna Co = 150 pF
Antenna Lo = 20 uH (20000cms)
La = Lo/3 = 6.67 uH (6667cms)

L1 = Loading, or secondary coil = ?

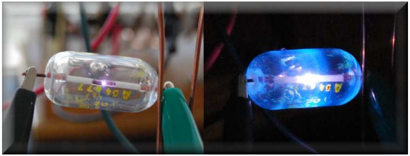
From Bucher:
Wavelength = 59.6 sqrt((L1+La)*Co)

Assuming a design frequency of 120m and solving the above equation for L1, I find:
L1 = 20 uH (20000cms)
20uH then is the value we wish for the oscillation transformer secondary winding.

For the primary winding we find in Bucher the following useful equations:
L = lambda^2 / 3550000 * C, and/or
C = lambda^2 / 3550000 * L

Therefore one starts with lambda = 120m and then either assume a capacitance or an inductance. For this project I found a good match with 2000 pF and 2 uH. To be safe both inductance and capacitance can be varied around these two design numbers.

my gap is tiny now, I felt this may be a good solution, or, alternatively I might have some fun blowing up a cool vacuum gap. The following photo shows that in fact the vacuum gap performs handsomely as a gap for my transmitter. The gap length is mercifully fixed at about a half mm and the low diaelectric allows good sparking with flat (rather than pointed) spark surfaces about 2mm in diameter. I certainly will experiment more with this kind of gap.



Thats'a some glow...!

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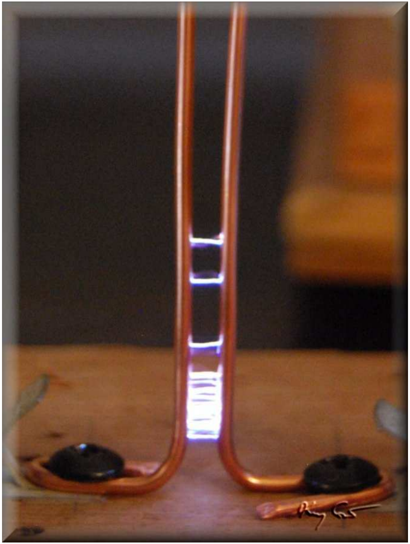
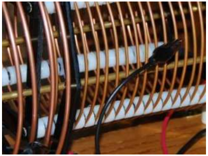
Other Sparks:

Of note, the gap itself need not remain strictly a set of pointed, flat, and/or round surfaces. Once you have a working High Voltage power supply, there are other gaps/toys waiting to be tried.
The photo below is a quick cobbled together Jacob's Ladder just to see: Will it work? The copper wire is not perfectly smooth nor can one adjust the spacing between the two verticals. Still, I can tell this will be a fun side trip with my HV power supply. Stay tuned for more.



Schazzam!!

Oscillation Circuits: HV Capacitance and Transformer



The oscillation circuit in the transmitter performs the twin functions of converting the spark's energy to trains of radio frequency oscillations and transferring them from the closed tank to the open antenna for transmission. Like any tank circuit the main components consist of capacitance and inductance, both variable in order to tune the circuit to the needed frequency. The closed circuit loosely couples to the open circuit to achieve the best resonance and lowest decrement. The design aspects of this section is where the radio theory begins and induction/relay theory ends, we are talking radio here now.

The design for the transmitter starts with a notional target transmission frequency and the design equations from two primary sources: Fleming, 1910, The Principals of Electric Wave Telegraphy and Telephony., and Bucher, 1920, The Wireless Experimenters Manual. Additionally it requires some estimate, guesstimate really, of the antenna distributed capacitance and inductance.

As the project is demonstration only, I have selected a frequency at the low end of the HF range just above the MW broadcast bands. The designs in the 1920's typically aimed at about 200m or 1.5 MHz. To keep my design close I chose 120m, or about 2.5MHz. It is a fairly quiet part of the spectrum. Keep in mind this is a notional project not intended for actual broadcast. I used charts and data presented in Bucher