Understanding and Building Crystal Radio Sets

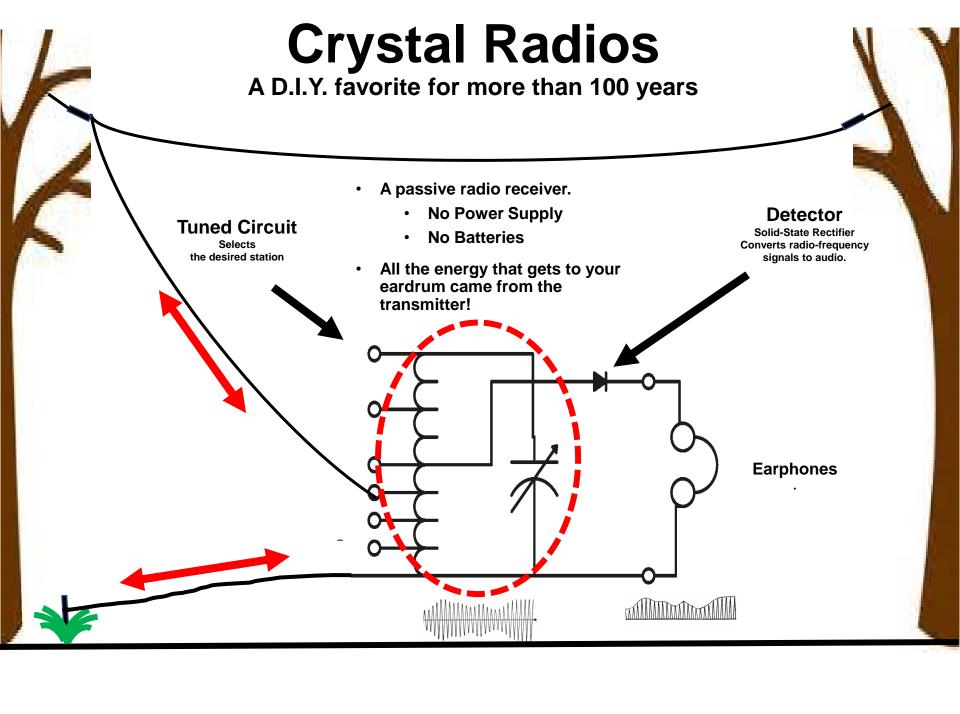
Al Klase – N3FRQ Rev. 1.3 10 Sep 2022

THIS PRESENTATION ON YouTube

SKYWAVES CRYSTAL RADIO PAGE

THE RADIO TECHNOLOGY MUSEUM

(Watch for more links within this presentation.)

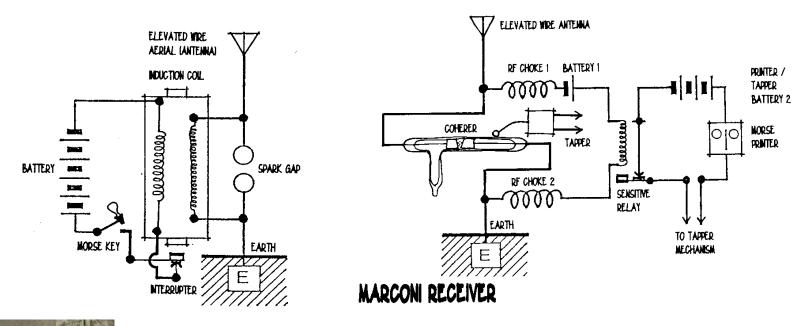


Editorial Comment

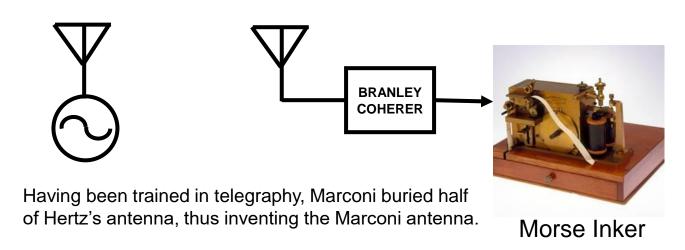
- Over the years millions of crystal radios have been built.
- The vast majority were simply dreadful performers.
- However, it's not that difficult to build a good one.



Marconi 1896



The only tuning was the natural resonance of the antennas.



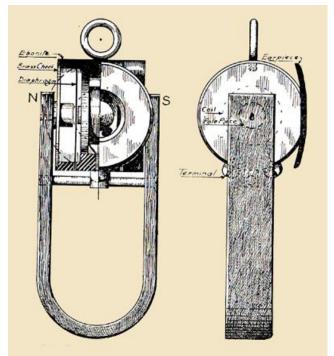
Patent 7777

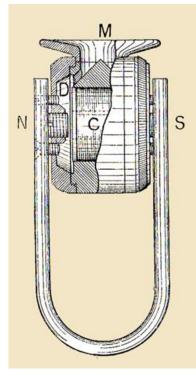
Application filed 12 April 1900

Both the TX and RX are double tuned circuits. The capacity of the Responder antenna and the loading inductance, T, form the so called "open circuit," while the spark gap in the TX and the responder (detector) in the receiver are in the "closed circuits." Telephone Sir Oliver Lodge -1898 Collier telephone receiver used in the 1901 transatlantic test

Fig. 45.—Marconi syntonic transmitter and receiver.

Collier Receiver

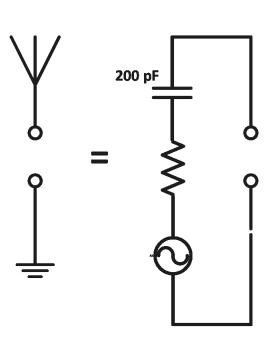




https://www.telephonecollecting.org/Bobs%20 phones/Pages/Essays/Early%20Receivers/Ea rly%20Receivers.htm

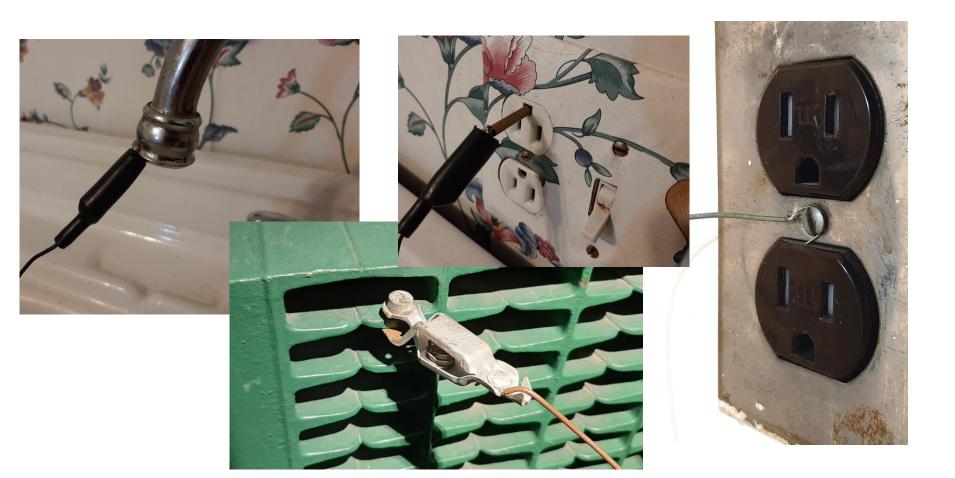
The Antennas-Ground System

- Inverted L
 - 20 Ft high x 40 Ft long = A good start
- Ham "Dipole"
 - Response falls off drastically below the half-wave frequency.
 - Short the feedline.
 - Use as a T-antenna against ground.
- Improvised
 - Wire wherever you can put it.
 - Rain gutter
 - Bed springs
 - Etc.



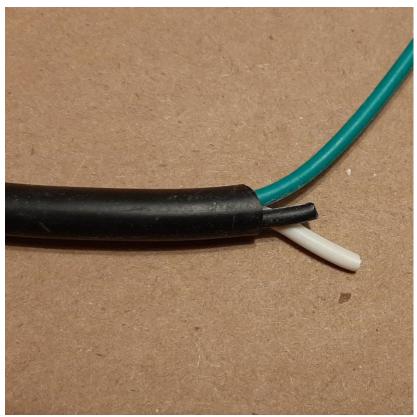
Ground is where you find it.

- A ground rod may or may not be the best ground.
- Water pipes
- Electrical safety ground



Portable Ground





The Mysterious Decibel

- Relative power measurement on a logarithmic scale.
- I can hear a 0.00001 volt signal in my best headset, but a 2.768 volt signal hurts my ears!
- That's a voltage ratio of 27,680 to 1.
- A power ratio of 109 decibels.

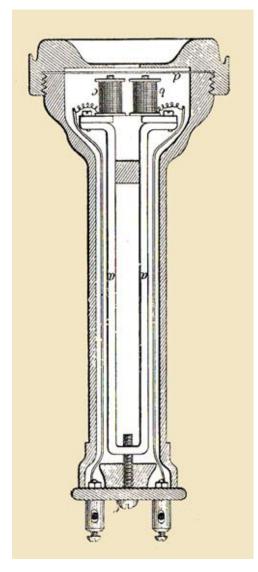
8/27/99

What Decibels Mean

- $dB = 10 \log P_2 / P_1$
- $dB = 20 \log V_2 / V_1$
- dBm = power relative to 1 milliwatt
- 1 dB smallest audible change
- 3 dB modest change twice the power
- 6 dB twice the voltage
- 10 dB 10 times power
- 20 dB 100 times power, 10 times voltage
- 30 dB 1000 times power

8/27/99

Headphones

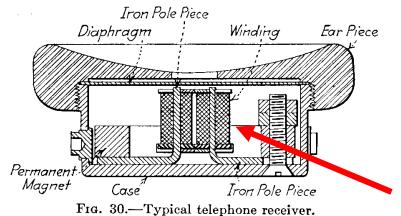


Double-Pole Telephone



"Head Telephones" Western Electric 509W

2000 Ohms DC is the traditional headset for radio work. Impedance is ≈ 10K Ohms.



"Watch Case" Receiver

About 1000 feet #40 wire/

Audio Transducers

- Traditional 2000-ohm "phones"
 - More expensive ones wound to higher resistance 4-5 K, a plus.
- Crystal Earpiece (Put a 50 -100K resistor in parallel)
- Low-impedance / High Sensitivity (+10-15 dB)
 - "Sound-Powered" phones
 - Modern Earbuds (Rare-earth magnets)
 - Requires audio matching transformer \$\$\$



Inside a traditional headset



"Crystal" earpiece About \$9 on Amazon



Navy "Deck Talker" Sound-Powered Telephone

Balanced-Armature Transducer for More Efficiency

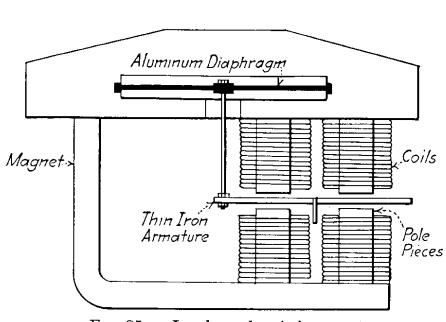


Fig. 85a.—Loud speaker (relay type).



Nathaniel Baldwin Type – C Patented 1910

Headphone Data

http://www.skywaves.ar88.net/xtalset102/headsets.htm

R	Z	SENS. dBm
25	300	-63
2K	12K	-70
3.8K	12K	-70
INFINITE	25K	-70
7-MEG	50K	-74
1300	8K	-76
150	1K	-84
30	300	-88
	25 2K 3.8K INFINITE 7-MEG 1300 150	25 300 2K 12K 3.8K 12K INFINITE 25K 7-MEG 50K 1300 8K 150 1K







Sound-Powered 'Phones



Modern "earbuds," even the cheap ones, are about as sensitive as the sound-powered 'phones.

Impedance ≈ 30-Ohms per side.

Testing the 'Phones

For high-impedance headsets:

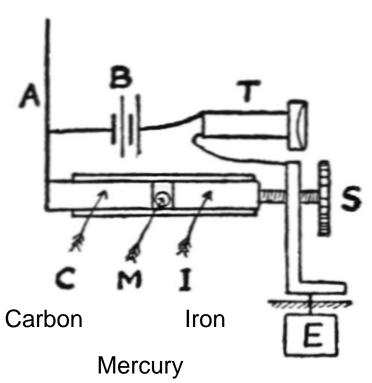
- Put the headset on.
- Hold on to one terminal.
- Touch the other terminal to ground.
- You should hear a click.

Use the same test for low-impedance Phones connected through a step-up transformer.



What About the Crystal?

It needs to be some kind of a rectifier, i.e. non-linear







Sir Jagadish Chandra Bose, professor of physical sciences, Presidency College, Calcutta, India Ca. 1899

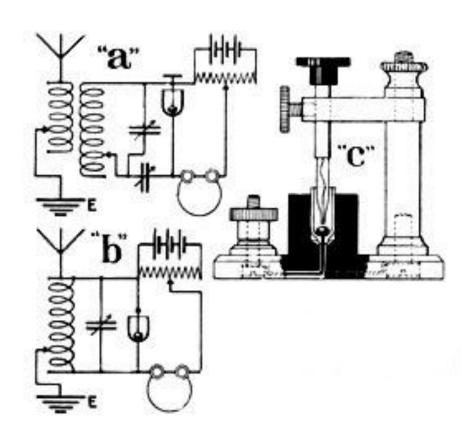
The Italian Navy Coherer

"Self-restoring Coherer"

"Imperfect Contact Detector"

Used by Marconi for early Trans-Atlantic Work 1901-1902

Fessenden Electrolytic Detector





Reginald Aubrey Fessenden

1866 –1932

First Transatlantic Two-way Radio telegraph - 1906

Greenleaf Whittier Pickard

1877-1956 (John Greenleaf Whittier's grand nephew)

Silicon Detector patent files 30 Aug 1906 Sorted through thousands of minerals. Carborundum Detector – 1909 Catswisker – 1911 Wireless Specialty Apparatus Co, - 1907

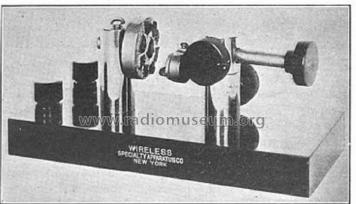
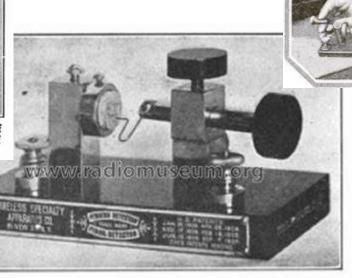


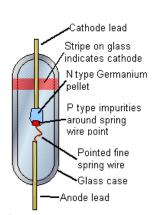
Fig. 67.—A new type of silicon detector in which a crystal of arsenic may be brought to bear against the surface of one of several silicon crystals.



69.—Pyron detector in which a fine wire is brought to b against a crystal of iron pyrites.

Choosing a Detector

- Germanium
 - Diodes
 - Transistor junctions
- Mineral
 - · Galena is most sensitive







Part numbers don't mean much!

Dump all of them out of your junk box and try them in a radio.



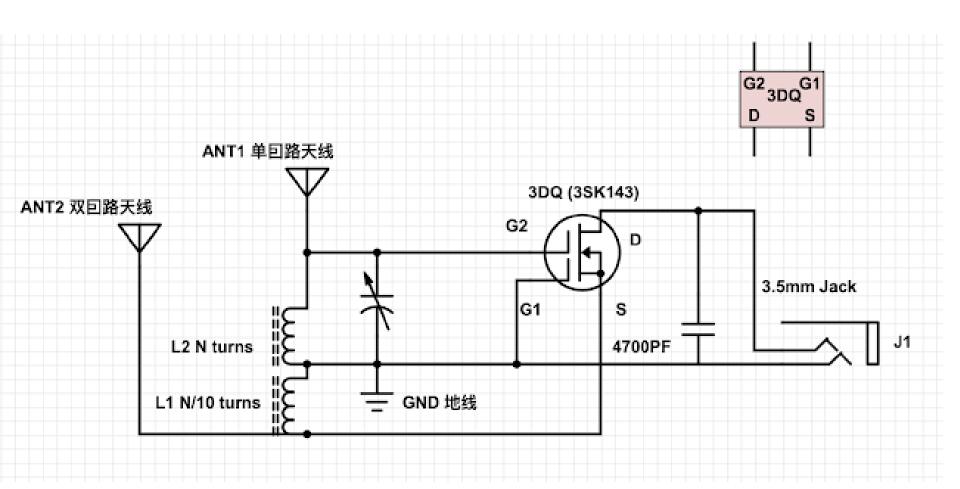


Germanium - Good



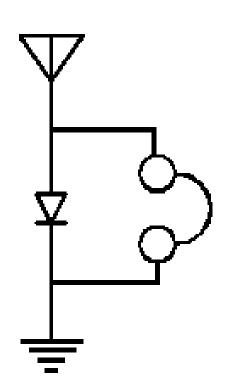
Silicon – No Good

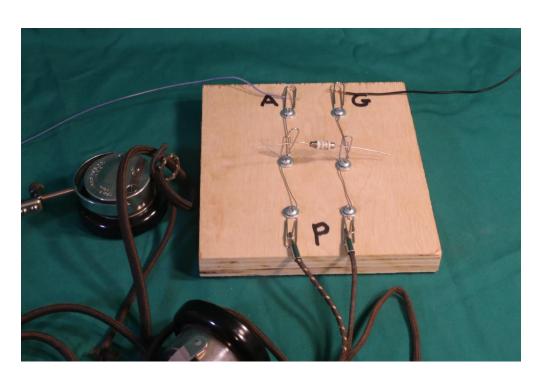
Active Rectifiers



Billy's DIY Dream Shop

Let's Build a Radio!

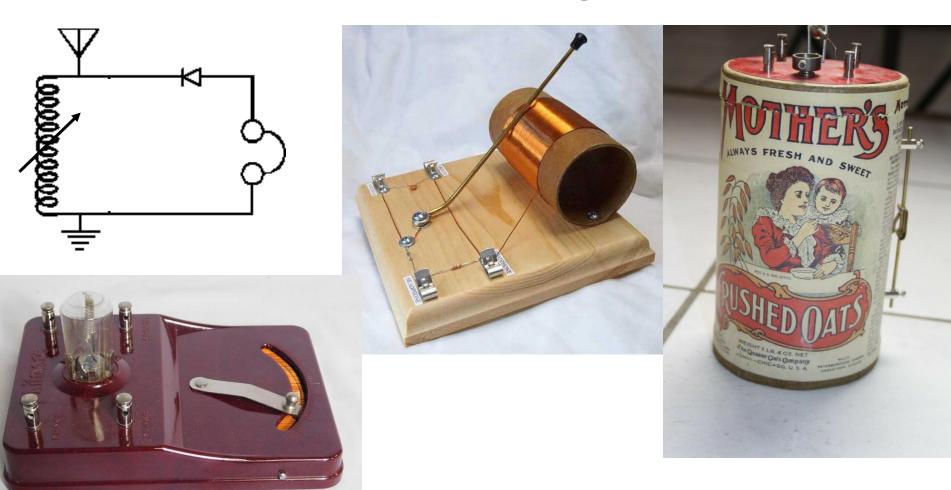




Or just use clip leads. (I got carried away.)

- The simplest radio you can build is just a diode detector and a headset.
- It will hear the strongest stations, maybe all a once.
- Now youknow you have an antenna-ground system, and a working diode and headset.
- Proceed!

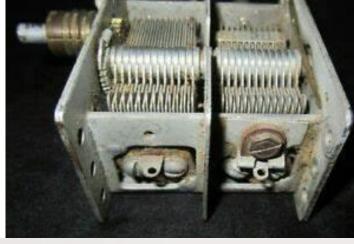
Add a Tuned Circuit



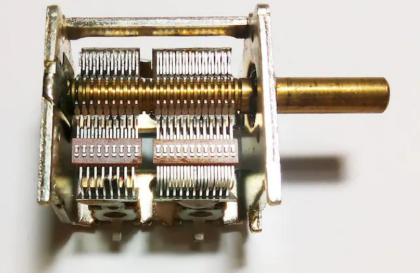
Don't waste you time on these! You can do much better!

What's Missing?





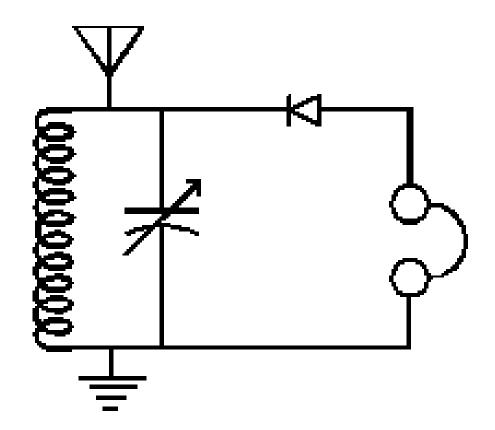




Grab the next AA5 radio wreck you see for a dollar or two.

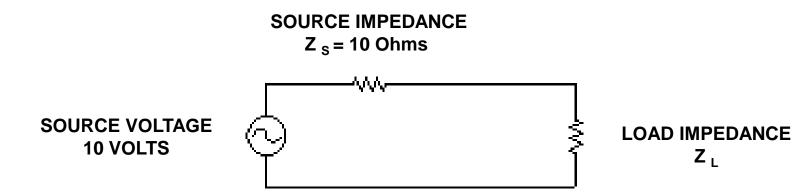
The Old Standby

Yes, this is in all the books, but it has problems.



See: CRYSTAL SET DESIGN 102

Impedance Matching



LOAD Z	WATTS OUT	PERCEN
1 OHM	0.83	40
9 OHMS	2.49	99.6
10 OHMS	2.5	100
11 OHMS	2.49	99.6
100 OHMS	0.83	40

8/27/99 26

Impedance Mismatch in dB

```
• 1:1 0 dB
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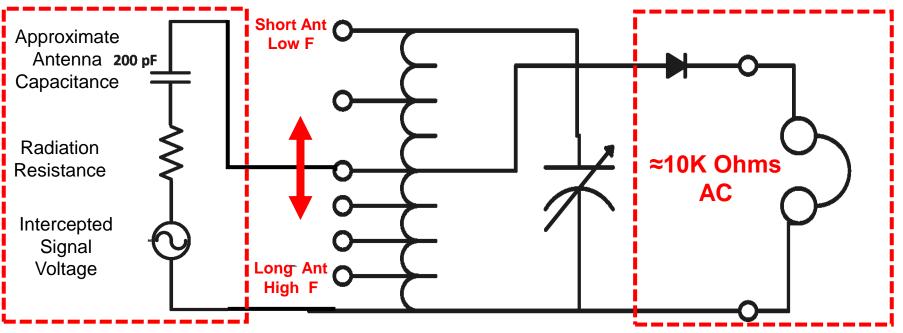
- 2:1 -0.5 dB
- 4:1 -1.9 dB
- 10:1 -4.8 dB
- 100:1 -14 dB
- 1000:1 -24 dB

8/27/99 **27**

A better solution with:

Impedance Matching

- Optimum match to the antenna is problematic.
 - Tuning a 3:1 frequency range.
 - Need to accommodate various antenna lengths.



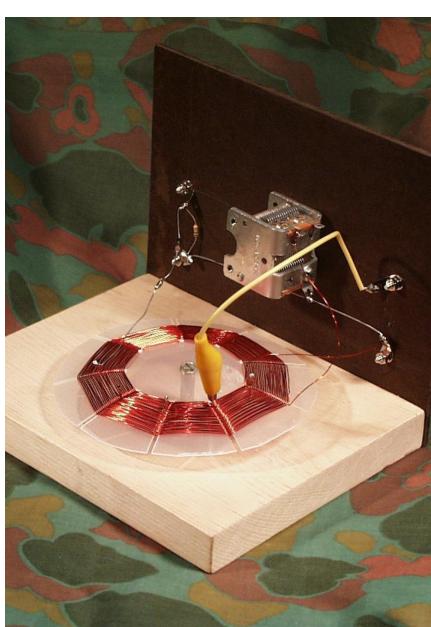
Antenna Equivalent Circuit Impedance at Resonance ≈150K Ohms

- Typical detector/headset circuit is too low an impedance to be a good match across the entire tuned circuit.
- Tapping "half-way down" makes a better match.

The Den 2 Set - ca. 1990

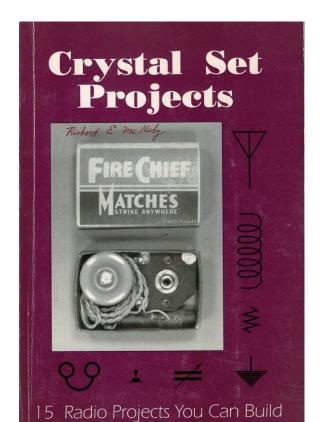


I didn't want to disappoint my Cub Scouts with the questionable antennas they'd have at home.



The Den 2 Set - ca. 1990

- Performance with a reasonable antenna:
 - Daytime: 50 KW stations out to 40-50 miles.
 - Nighttime: Hundreds of miles
 - E.g., 900, CHML, Hamilton, Ontario, ≈ 300 miles



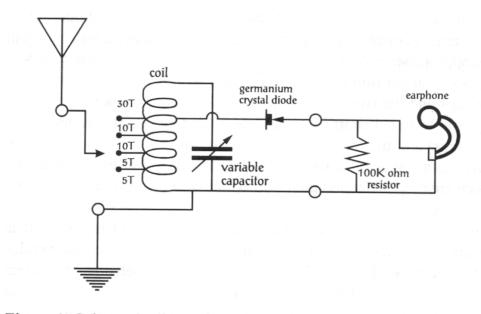


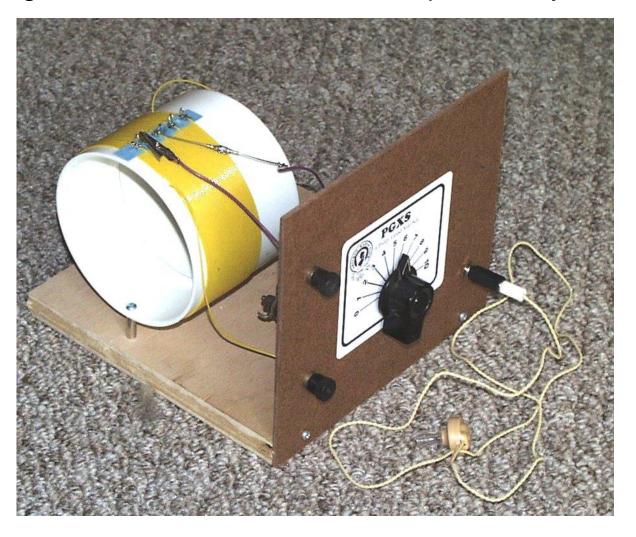
Figure 1: Schematic diagram

My design published by The Crystal Set Society, 1997.

The Pretty Good Crystal Set

ca. 2006

With apologies to Garrison Keillor and Ralph's Pretty Good Grocery



Same Circuit - Better Coil

NJARC 2006 Crystal-Set Clinic



Anchor the end of the wire and maintain tension while winding. Cardboard strip raises the turns to be tapped.

Effective Air-core Coils

- Make them big
 - Q increases by the square of the diameter.
- Make them "square"
 - Avoid very long or very narrow windings.
 - Rigorously: Winding Length ≈ 2.5 X Diameter
- Space the turns about one wire diameter
 - Close wound enameled wire suffers eddy current losses to adjacent turns..
- Insulated wire
 - Close-wound turn-spacing ≈ 1 wire diameter.
 - #26-20 hookup wire.
 - Silver-Teflon wire is great if available.
- PVC pipe is just fine
- Styrene or ABS is better



COIL WISDOM

Joe Devonshire 2021



880 WCBS, 1520 WWKB. 1130 WBBR, 1010 WINS, 1080 WTIC, 1210 WPHT

From Jefferson, ME (Half-Way Down East) about 325 miles from NYC.

A Fancy PGXS

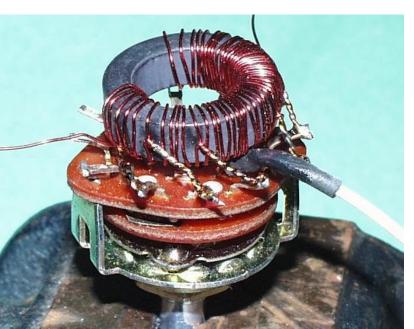


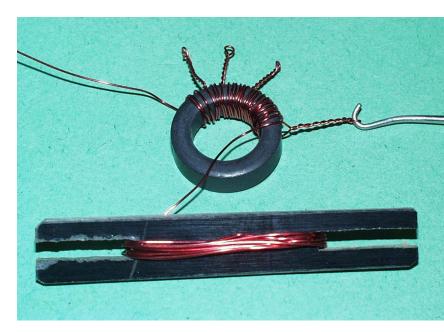
A Christmas Present

Ferrite Cores

Another approach to coils

- High inductance in a small space.
- Magnetic field is contained.
 - So, you don't have to worry about nearby conductive objects.
- Inexpensive
 - FT-82-61 toroid cores
 - 3 for\$10 on Amazon
 - Minimal wire required.



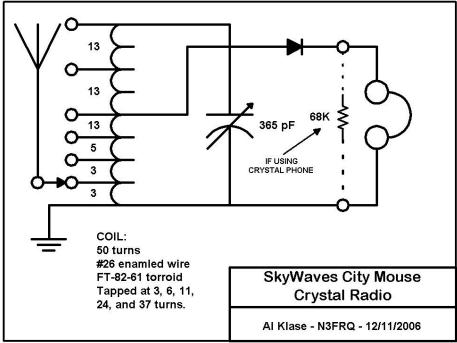


You need to know what magnetic material you have. (Mix-61 for the broadcast band)

Build Small Radios

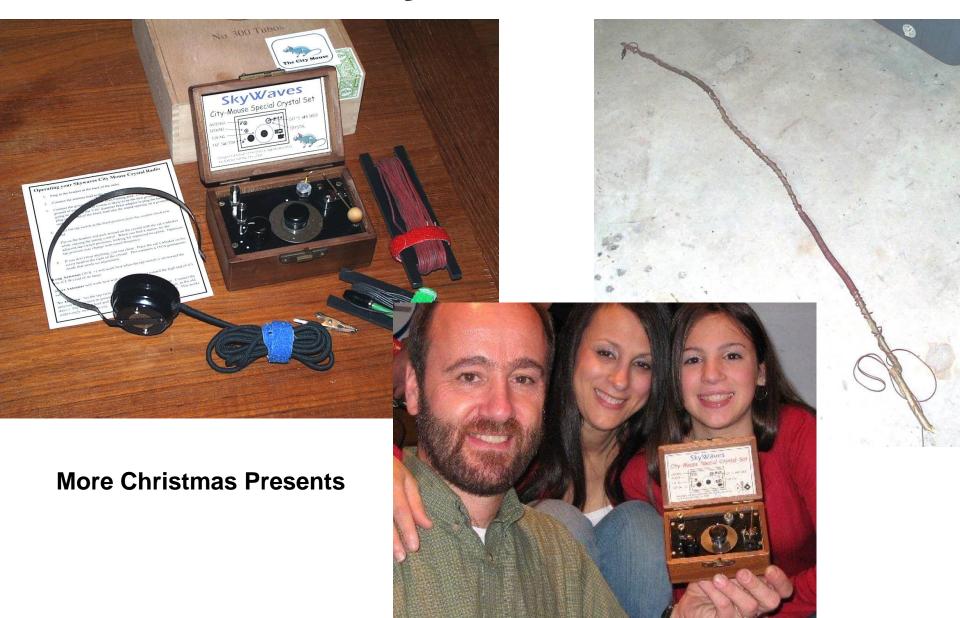


City Mouse, ca. 2006

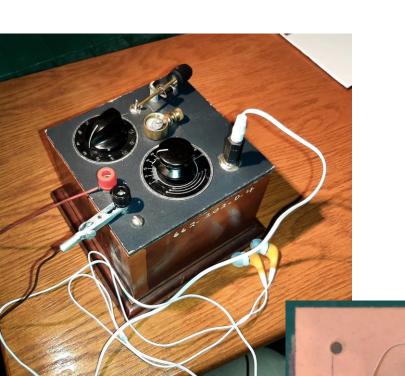


CRYSTAL SET MOBILE

City Mouse



My Livingroom Set



Triad JAF-3

13

250 pF

13

5

68K

1 uF

SkyWaves Livingroom

Crystal Radio

Al Klase - N3FRQ - Feb 2017

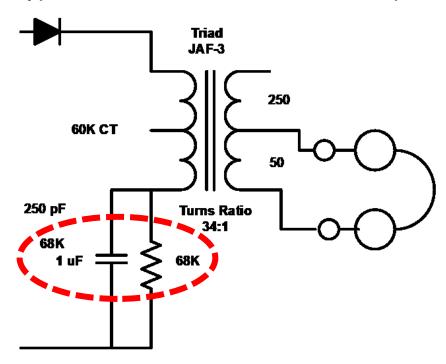
 Makes use of dollar-store earbuds.

 20-foot indoor antenna woks well here in "citymouse" territory. Cheater switch selects germanium diode.

HOMEBREW DETECTOR STAND

The "Benny" Resistor

- Pointed out by the late Ben Tongue, captain-of-industry, electrical engineer and crystal-set maven.
- The DC resistance of a matching transform primary is much smaller that the AC impedance.
- The heavy DC load on the diode detector causes distortion and loss.
- Bypassed resistor in series with the primary solves the problem.

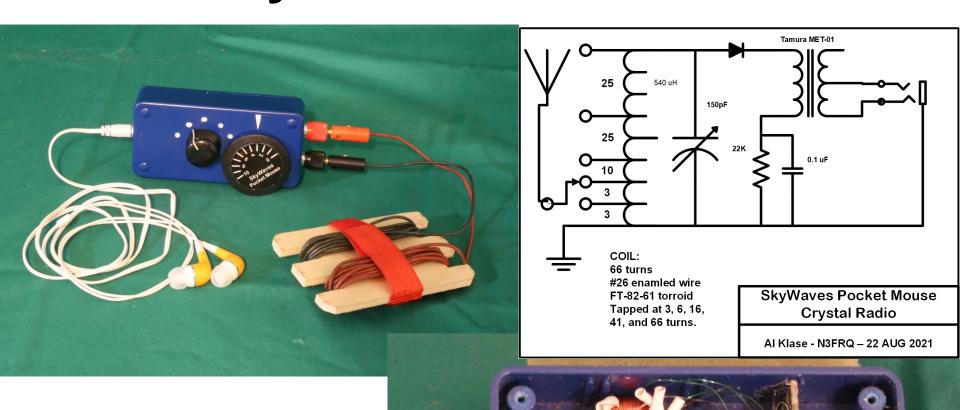


Ben Tongue on Crystal sets



Ben (left) supervising PGXS check out at our 2006 clinic.

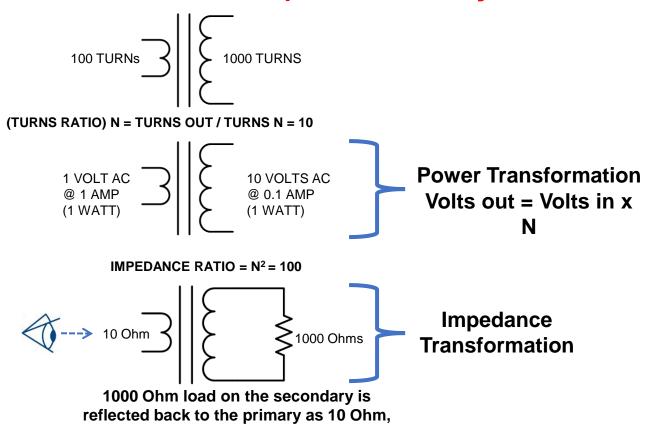
The Skywaves Pocket Mouse



TRAVELING WITH A CRYSTAL SET

Transformer Wisdom

- Transformers are used to match impedances.
- Power Out = Power In x Efficiency, but voltages and current change.
- Impedance matching is like horseshoes and hand grenades:
 Close Counts!
- Transformers don't have impedances. They have turns ratios.



Microphone Input Transformer

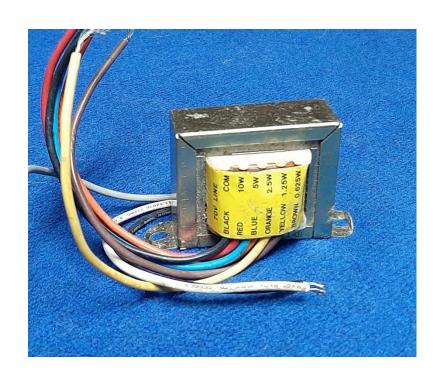


Hi-Fi Frequency Response

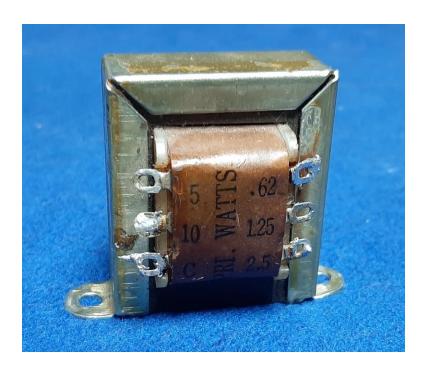
Triad A-11J \$10.70 in 1953 UTC O-1 \$14 Multiply by 9.66 to cover inflation.

Line-to-Voice-Coil Transformer

a.k.a. Line Matching Transformer



SPECO T7010
Made in Taiwan
About \$15 shipped
On Amazon

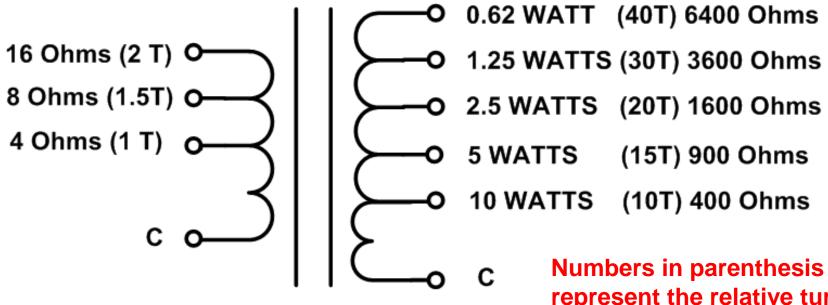


Realistic 32-1031 Made in Taiwan

Bogen T-725 \$11 on Amazon Prime

Line-to-Voice-Coil Transformer

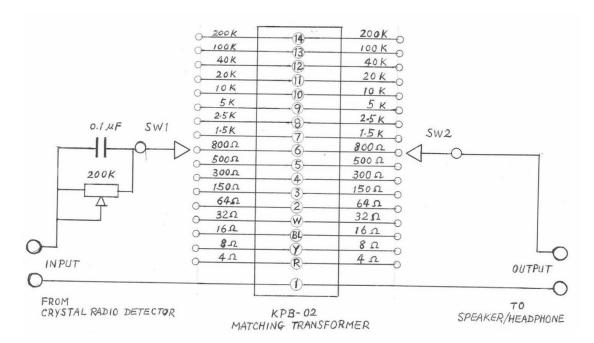
- Public-Address systems use high voltage to distribute audio to multiple speakers, avoiding excessive line loss.
- The standard is a 70-volt line.
- Transformers feed a selectable amount of power to each speaker.

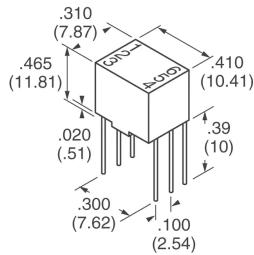


Line-to-Voice Coil Transformer Radio Shack (Realistic) 32-1031 is typical. represent the relative turns count measured by applying 1 Volt AC to the 4-ohm winding.

Currently Available Transformers

- Tamura MET-01
 - 200K CT to 1K CT
 - Mouser \$13
- Transformer KPB-02 200KΩ to 4Ω Selectable
 - Ebay \$20





High Performance Really Good Crystal Sets

Double-Tuned Circuits

- Improved Selectivity
- Improved Sensitivity
- See Classic Communications Receiver for Inspiration

More Sensitive Headsets

- "Sound-Powered 'Phones"
- Modern alternatives



The Two-Circuit Tuner **Note: detector Open Circuit Closed Circuit** connected to center tap. Marconi 4- sevens patent

"Conjugate Match"

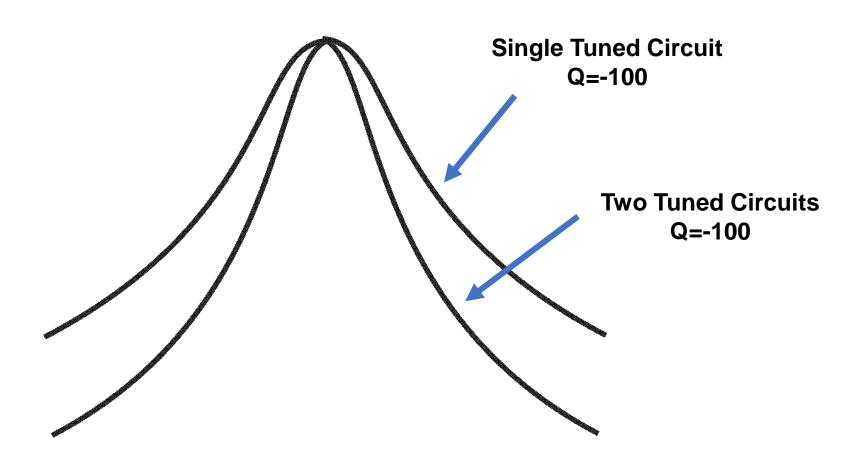
A CIRCUIT THAT WILL IMPROVE THE CRYSTAL RECEIVER
Figure T: This hook-up with a crystal detector will give high selectivity because of the coupled circuits and the method of tapping the secondary coil.

Maximum circulating current and energy transfer.

1900

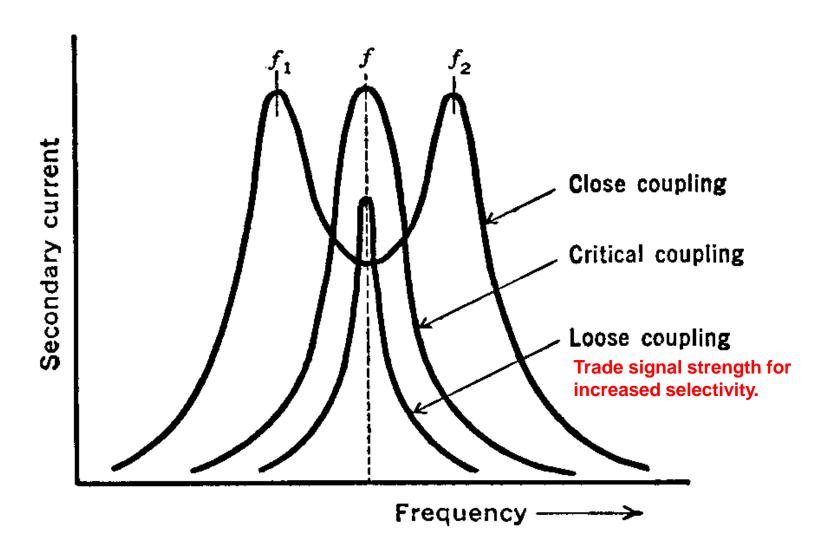
Every man's Guide to Radio - 1926

Multiple Tuned Circuits Improve Selectivity



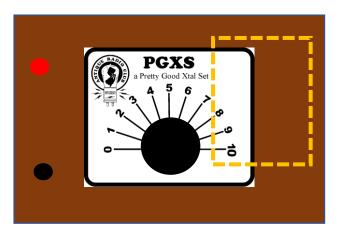
5/11/2006 49

Effects of Loose Coupling

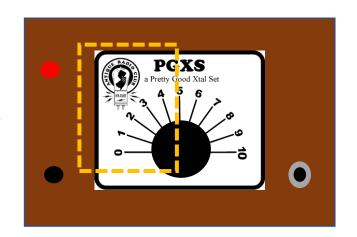


Double-Tuned The Easy Way

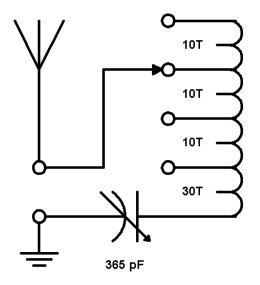
Build a second PGXS!

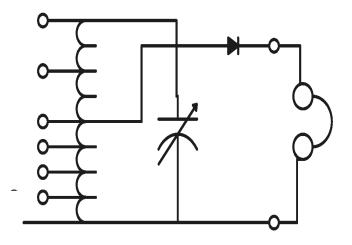


Move to vary coupling.



Coil located on the right side of the antenna tuner.





MORE INFORMATION

N3FRQ Contest Crystal Set



- 6-inch primary and secondary wound with #16 silver-Teflon wire.
- Plus wave trap coil on left.
- "Towel-bar" construction keeps coils away from conductive objects.

High Performance!



NJARC DX CONTEST LOG

NAME: Al Klase

ADDRESS: 22 Cherryville-Stanton Rd.

Flemington, NJ 08822

PHONE 908-782-4829

RECEIVER: Skywaves Contest Crystal Set ANTENNA: 65-Ft. 3-Wire Flat top at 30 Ft.

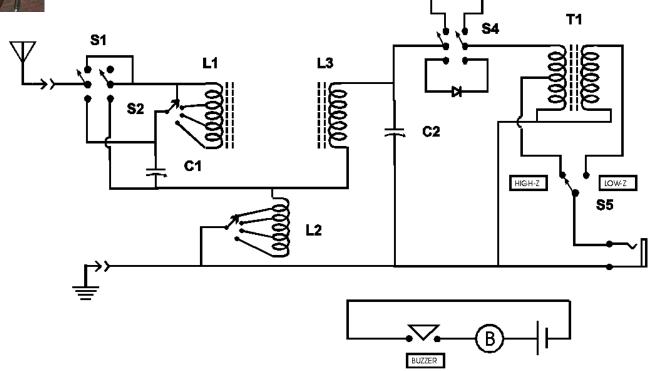
CATEGORY: 1

DATE	TIME	FREQ	LOG	CALL	LOCATION	COMMENTS
2/19/2001	01:45Z	1000	V	VMVP	CHICAGO	708 Mi.*
2/19/2001	02:03Z	670	V	VMAQ	CHICAGO	708 Mi.*
2/19/2001	02:58Z	720	V	VGN	CHICAGO	708 Mi.*
2/19/2001	03:07Z	760	V	NJR	DETROIT	482 Mi.
2/19/2001	03:10Z	750	V	VSB	ATLANTA	717 Mi.*
2/19/2001	03:17Z	650	V	VSM	NASHVILLE	736 Mi.*
2/19/2001	03:22Z	840	V	VHAS	LOUISVILLE	630 Mi.
2/19/2001	04:30Z	890	V	VLS	CHICAGO	708 Mi.*
2/19/2001	04:38Z	1110	V	VBT	CHARLOTTE	501 Mi.
2/19/2001	05:03Z	530	F	RVC	SOUTH CAICOS	1309 Mi.* RADIOVISION CRISTIANA
2/19/2001	05:25Z	570	F	R. RELOJ	CUBA	1279 Mi.* TIME SIGNAL
2/19/2001	06:00Z	870	V	WWL	NEW ORLEANS	1128 Mi.*
2/19/2001	06:07Z	890	V	VLS	CHICAGO	708 Mi.*
2/19/2001	06:30Z	1170	V	₩VA	WHEELING, WV	
			T	TOTAL MILES FOR 10 BEST STATIONS: 8709		



SkyWaves HP-002

Double-Tuned with ferrite cores
Ca. 1999



Inside



5/11/2006 55

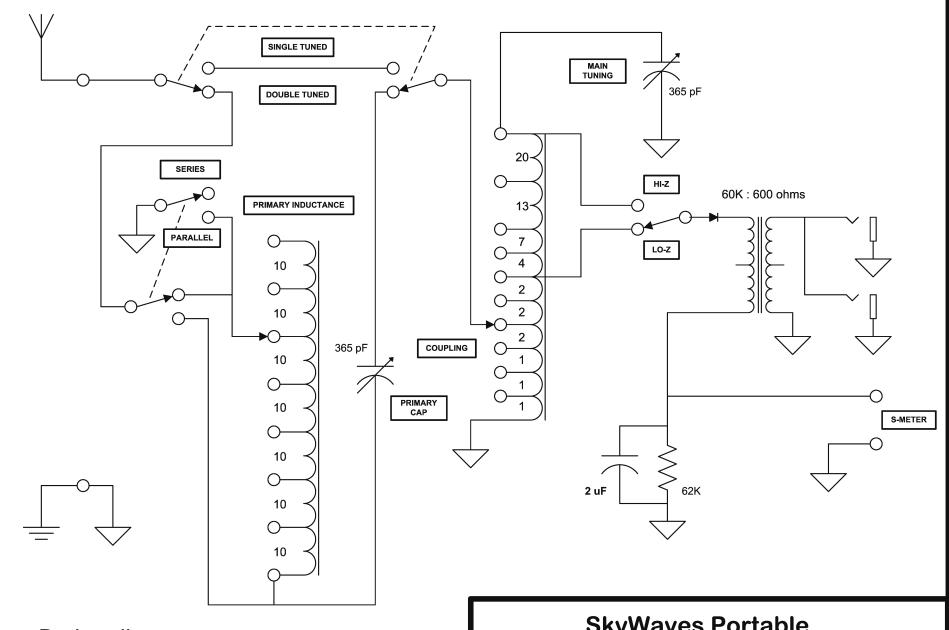
Skywaves Portable

ca. 2010



Repurposed Plastic Tackle Box

http://www.skywaves.ar88.net/xtal/Traveling/Traveling%20with %20a%20Crystal%20Set.pdf



Both coils; #26 wire on FT-82-61 cores.

SkyWaves Portable Research Crystal Radio

Al Klase - N3FRQ - 3/9/2010

Skywaves Portable - Back



Travel Kit



One more N3FRQ design

The Jersey City Special





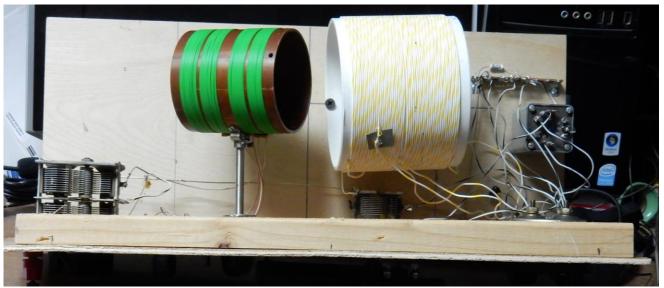
The Jersey City Project

WWI Telefunken field set served as inspiration.

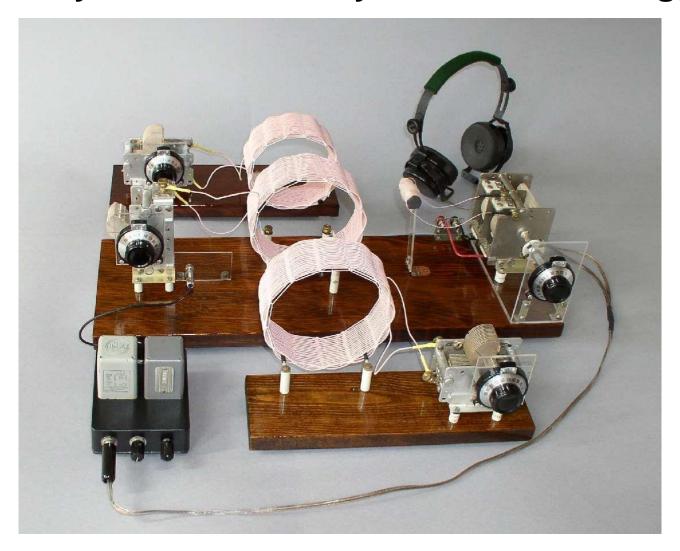
Video discussion of this set.

The Jersey City Special



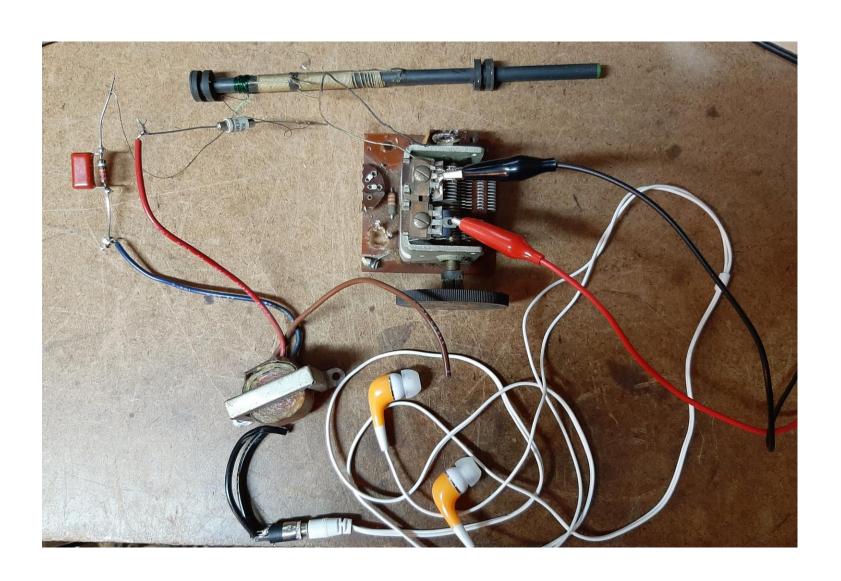


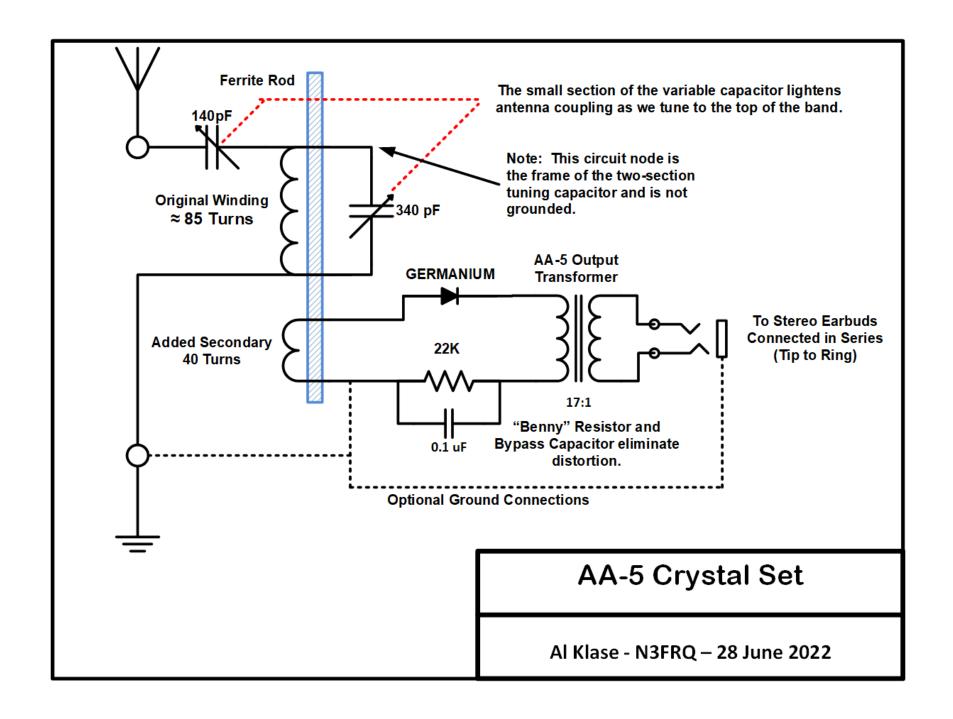
Lyonodyne Version 17 Crystal Set - Mike Tuggle

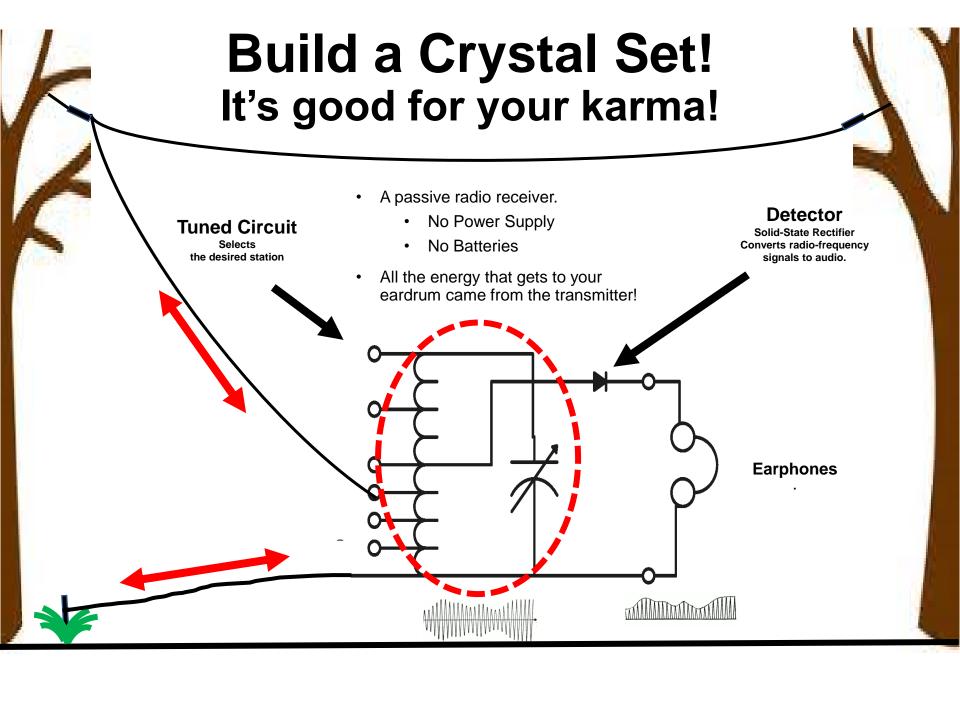


Lyonodyne 17

A Beginner's Crystal Set for the Antique Radio Guy



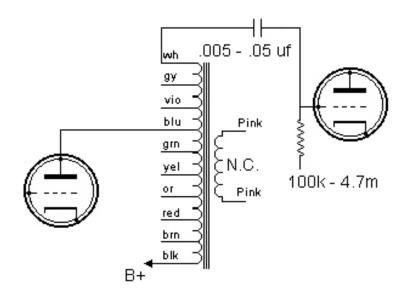




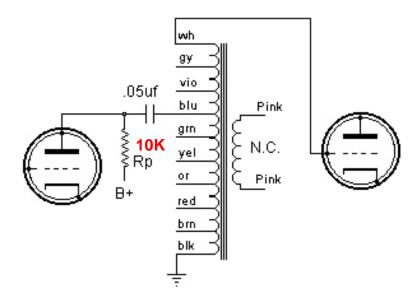
Replacing Transformers in Battery Sets

Visit Dave's Homemade Radios Dave Schmarder

http://makearadio.com/misc-stuff/t-725.php



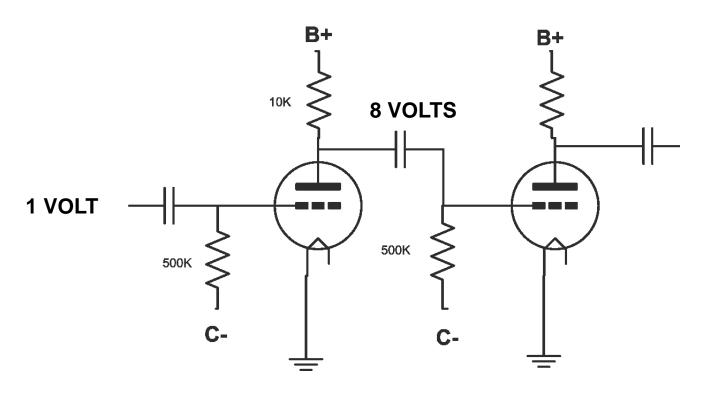
Bogen T-725 as an Interstage Auto-transformer



Bogen T-725 as an Interstage Auto Transformer Version 2

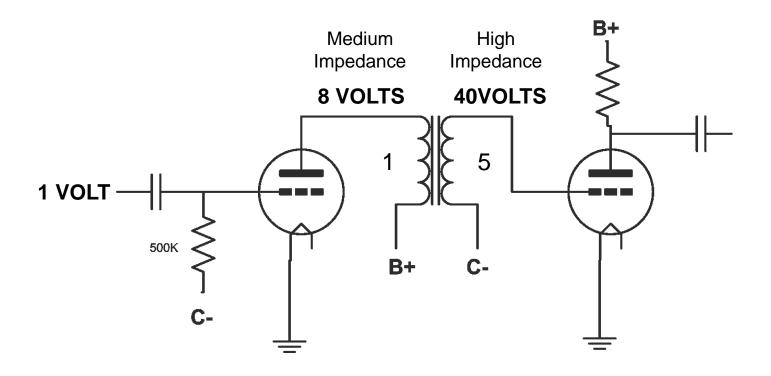
This arrangement keeps plate current out of the transformer. A good thing to do.

RC-Coupled Amplifier



- 201A Tube Amplification Factor = 8
- Stage voltage gain = 20 LOG Vout / Vin = 18 dB

Transformer-Coupled Amplifier



- 201A Amplification Factor = 8
- Transformer with 1:5 Turns Ratio
- Stage voltage gain = 20 LOG Vout / Vin = 32 dB