Understanding and Building Crystal Radio Sets

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THIS PRESENTATION ON YouTube

SKYWAVES CRYSTAL RADIO PAGE

THE RADIO TECHNOLOGY MUSEUM

(Watch for more links within this presentation.)

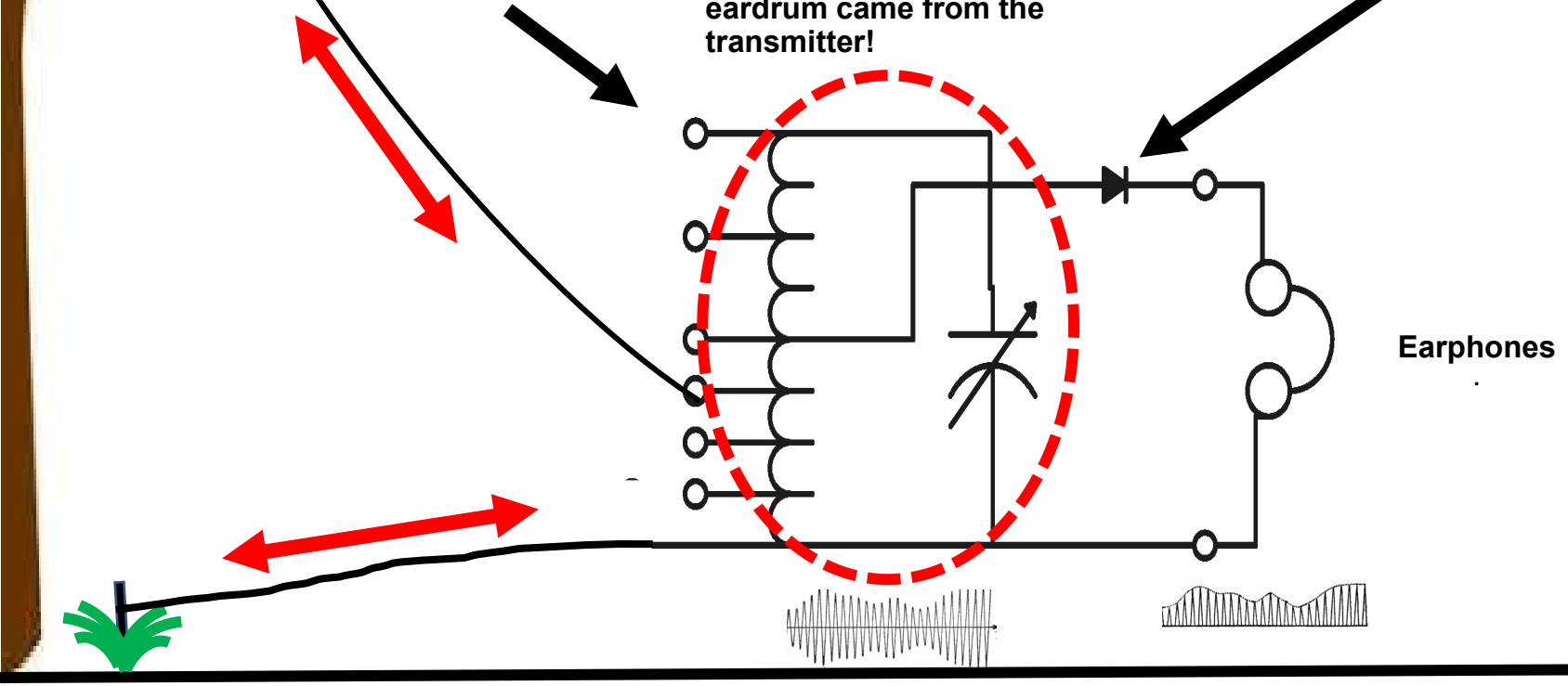
Crystal Radios

A D.I.Y. favorite for more than 100 years

- A passive radio receiver.
  - No Power Supply
  - No Batteries
- All the energy that gets to your eardrum came from the transmitter!

Tuned Circuit
Selects
the desired station

Detector
Solid-State Rectifier
Converts radio-frequency
signals to audio.

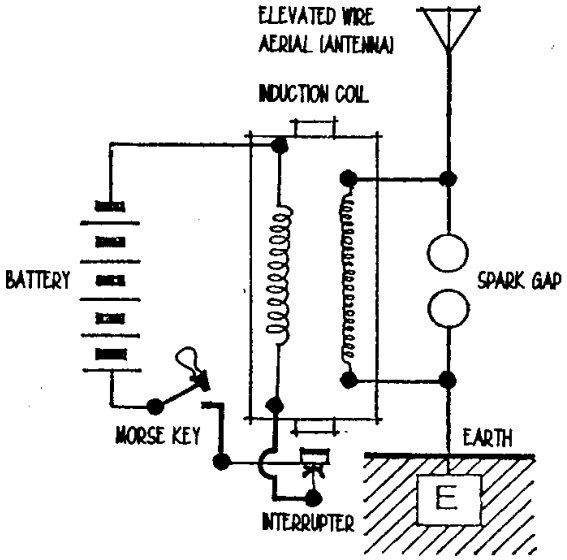


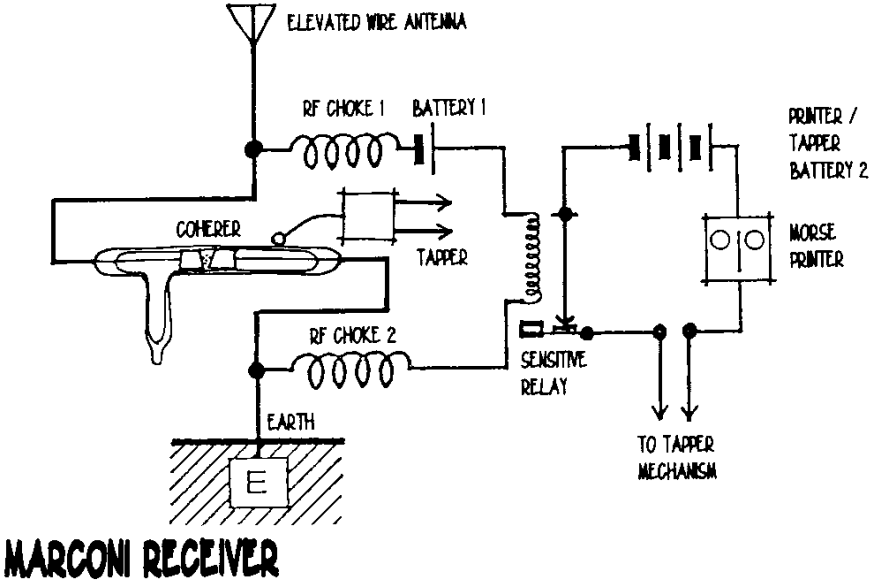
Earphones

Editorial Comment

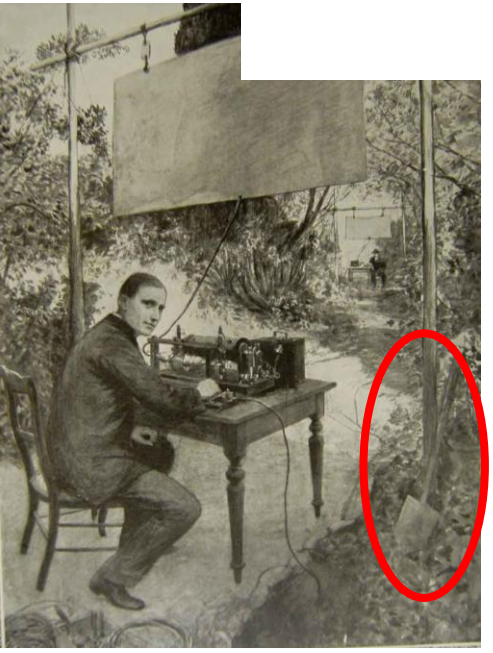
- Over the years millions of crystal radios have been built.
- The vast majority were simply dreadful performers.
- However, it's not that difficult to build a good one.

Marconi 1896

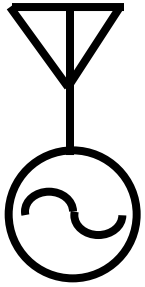


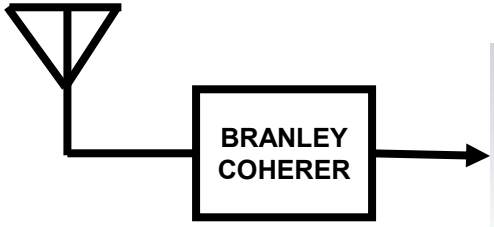


MARCONI RECEIVER



The only tuning was the natural resonance of the antennas.





Morse Inker

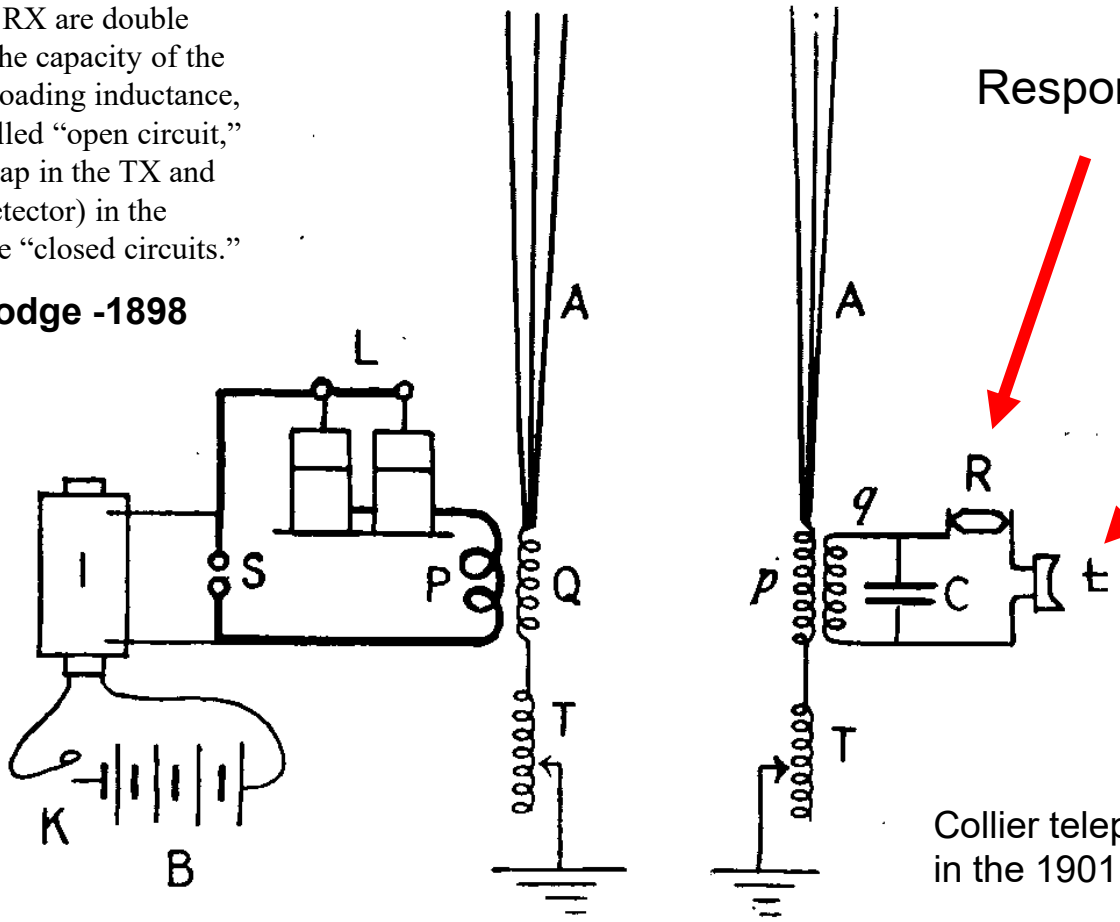
Having been trained in telegraphy, Marconi buried half of Hertz's antenna, thus inventing the Marconi antenna.

Patent 7777

Application filed 12 April 1900

Both the TX and RX are double tuned circuits. The capacity of the 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."

Sir Oliver Lodge -1898

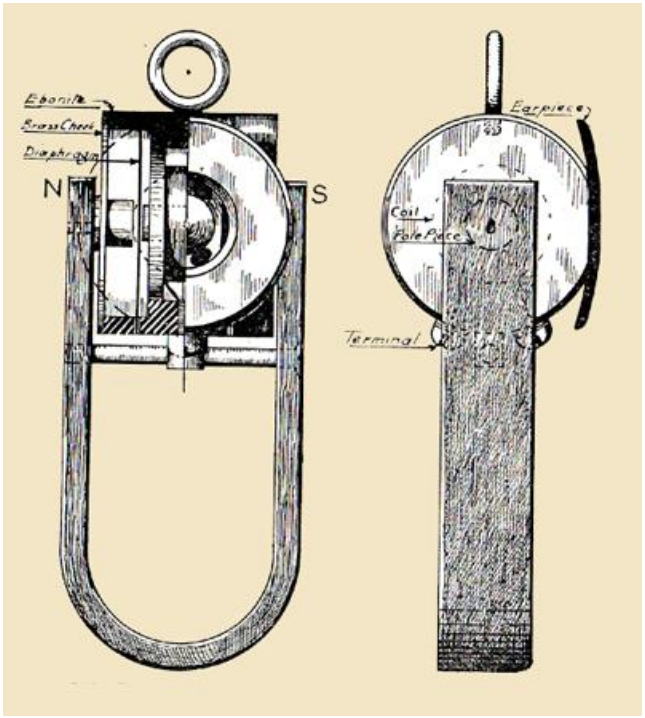


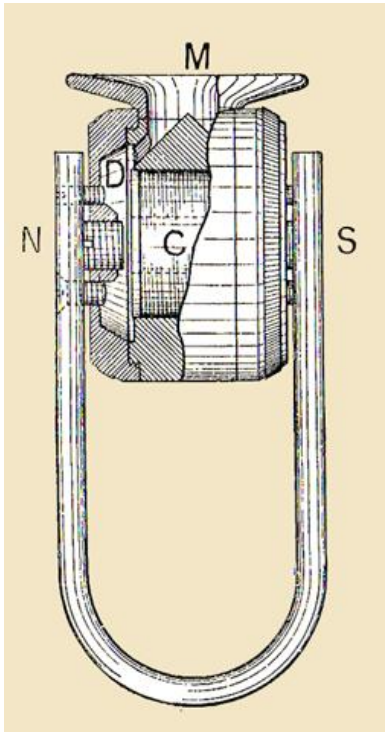
Collier telephone receiver used in the 1901 transatlantic test

FIG. 45.—Marconi syntonic transmitter and receiver.

From *The Wonders of Wireless Telegraphy*
J. A. Fleming, London, 1913

Collier Receiver

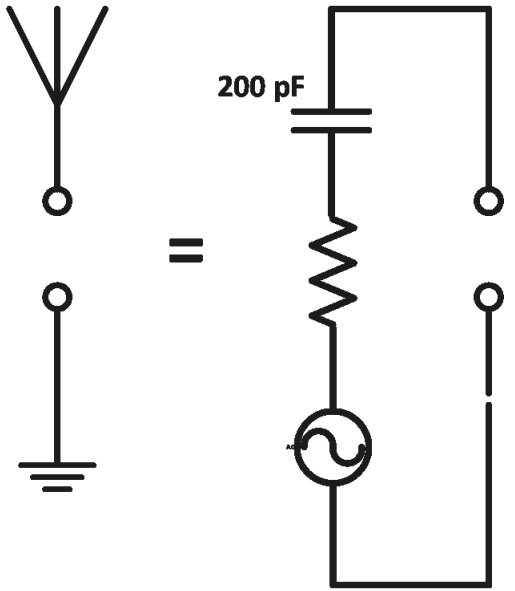




https://www.telephonecollecting.org/Bobs%20phones/Pages/Essays/Early%20Receivers/Early%20Receivers.htm

The Antennas-Ground System

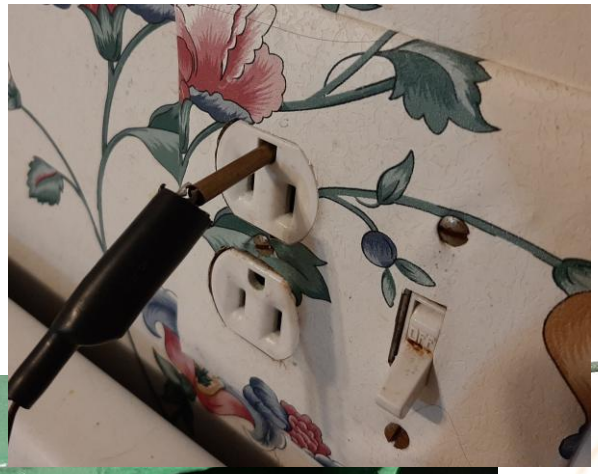
- Inverted L
  - 20 Ft high x 40 Ft long = A good start
- Ham “Dipole”
  - Response falls off drastically below the half-wave frequency.
  - Short the feedline.
  - Use as a T-antenna against ground.
- Improvised
  - Wire wherever you can put it.
  - Rain gutter
  - Bed springs
  - Etc.



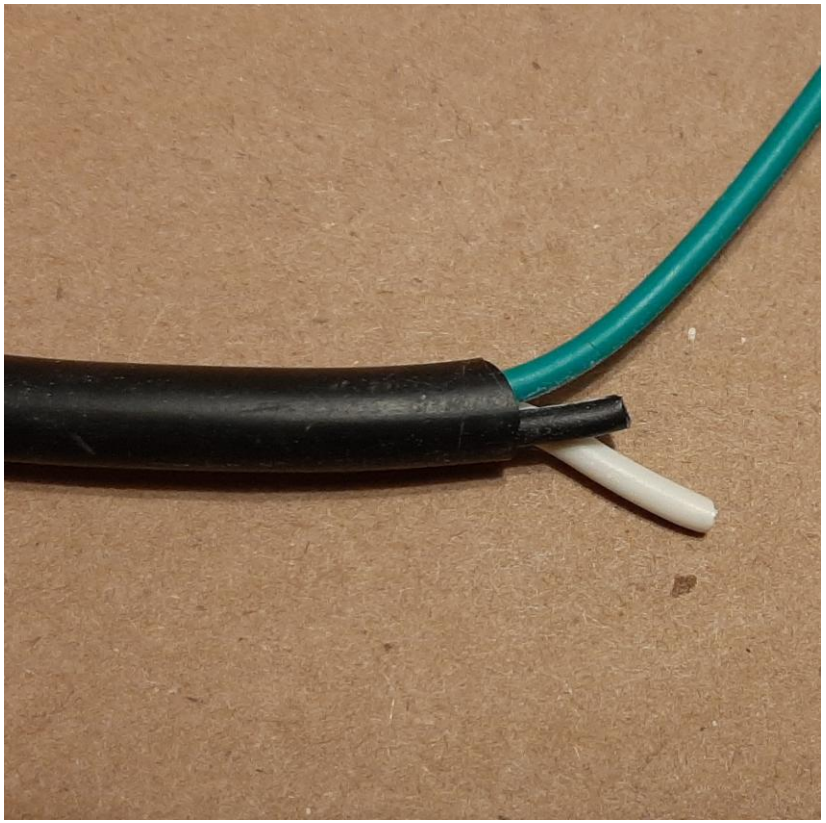
Less than ¼ Wavelength

Ground is where you find it.

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



Portable Ground



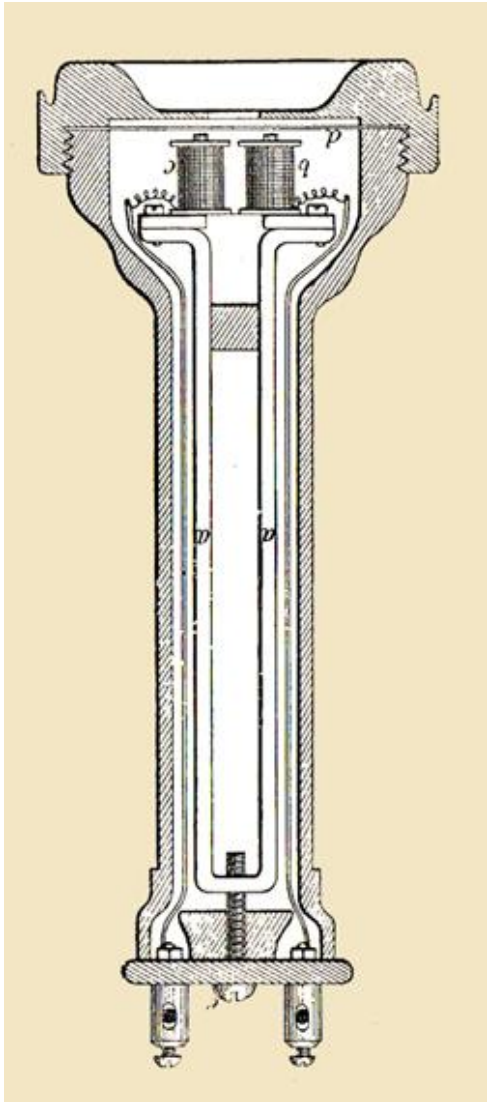
The Mysterious Decibel

- 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.

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

Headphones



Double-Pole Telephone

"Head Telephones"
Western Electric 509W

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

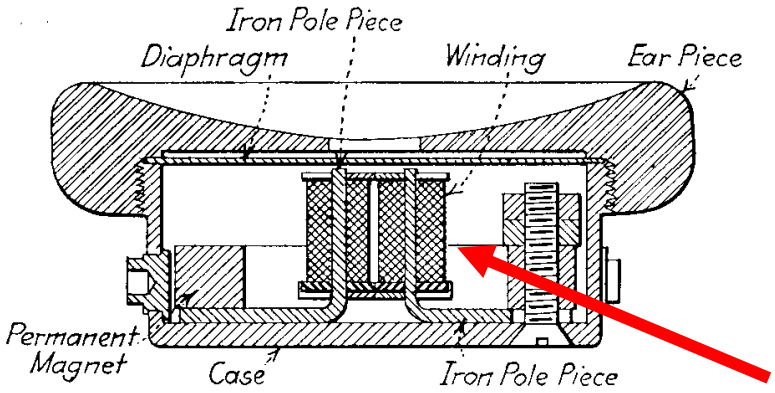


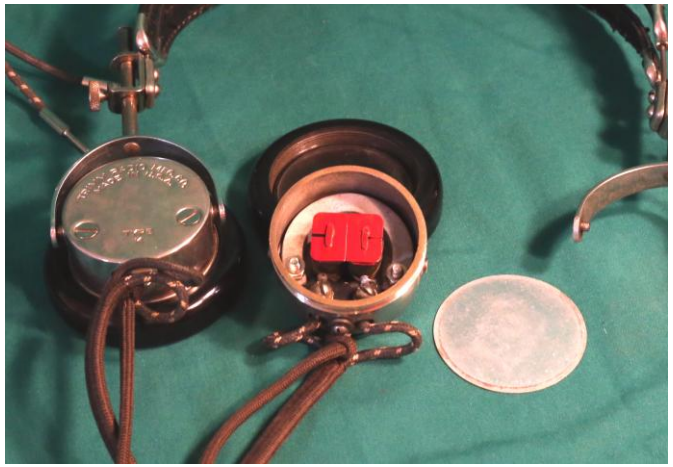
FIG. 30.—Typical telephone receiver.

"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

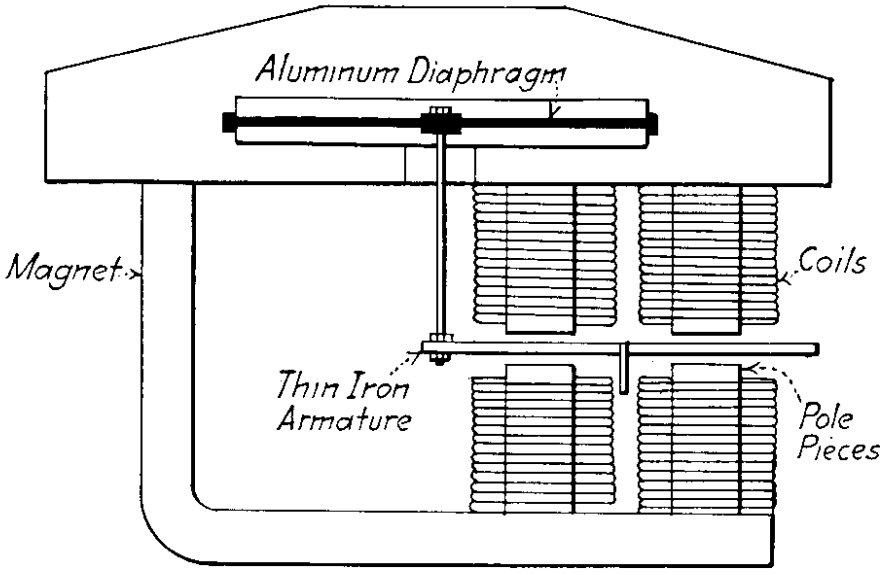


FIG. 85*a*.—Loud speaker (relay type).

Nathaniel Baldwin
Type – C
Patented 1910

Headphone Data

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

HEADSET	R	Z	SENS. dBm
NAVY LO-Z	25	300	-63
TRIMM TYPE K	2K	12K	-70
TRIMM FEATHER WT.	3.8K	12K	-70
MOUSER XTAL PLUG	INFINITE	25K	-70
BRUSH XTAL	7-MEG	50K	-74
BALDWIN TYPE C	1300	8K	-76
SOUND POWERED #1	150	1K	-84
SOUND POWERED #2	30	300	-88

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

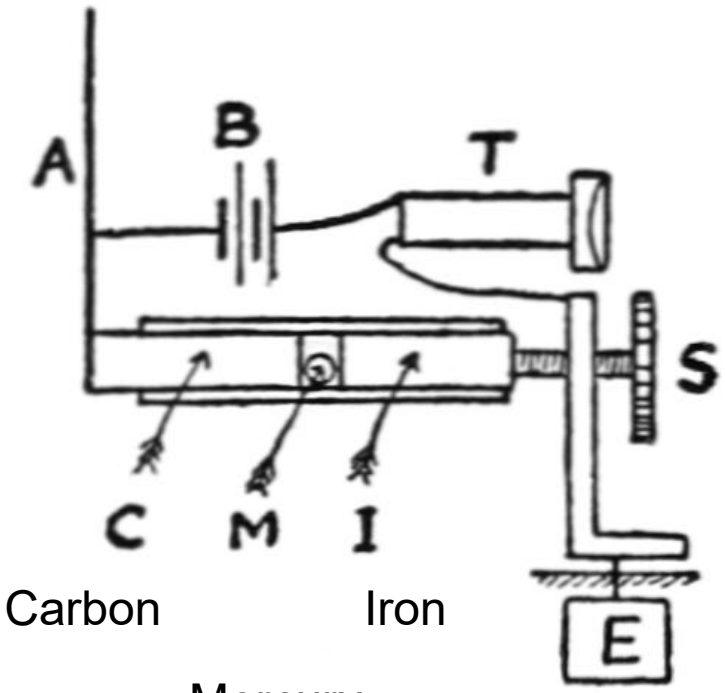
For high-impedance headsets:

- 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

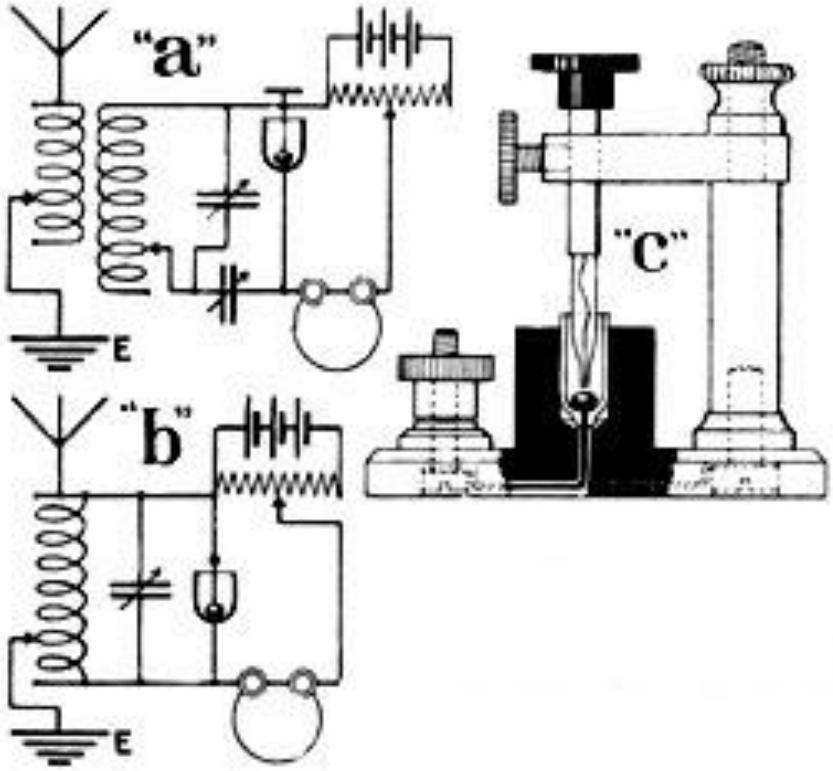
The Italian Navy Coherer

"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

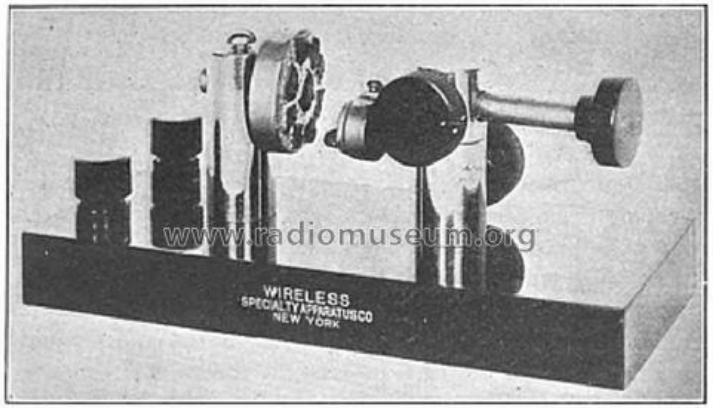
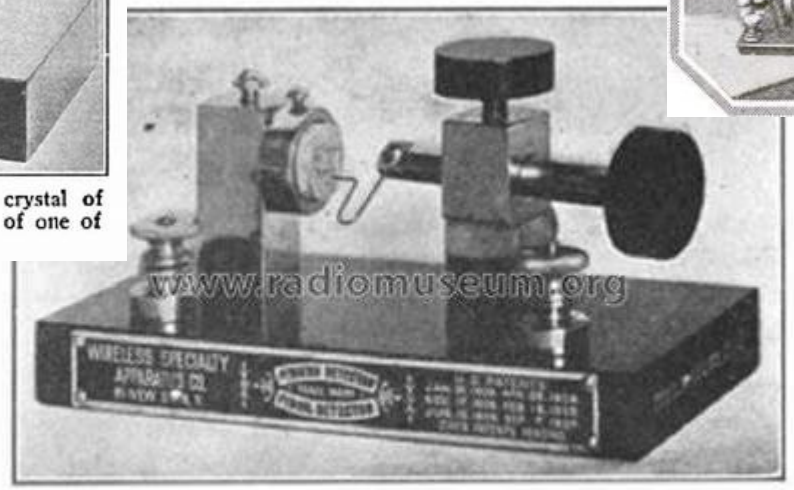


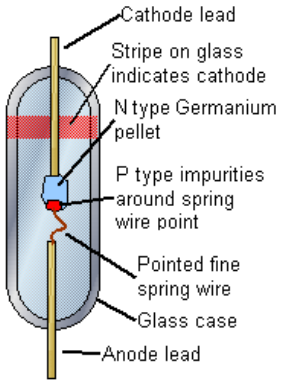
FIG. 67.—A new type of silicon detector in which a crystal of *arsenic* may be brought to bear against the surface of one of several *silicon* crystals.

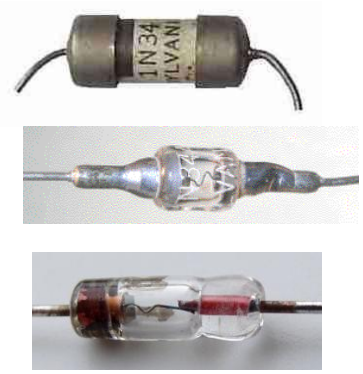


69.—Pyron detector in which a fine wire is brought to b against a crystal of iron pyrites.

Choosing a Detector

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

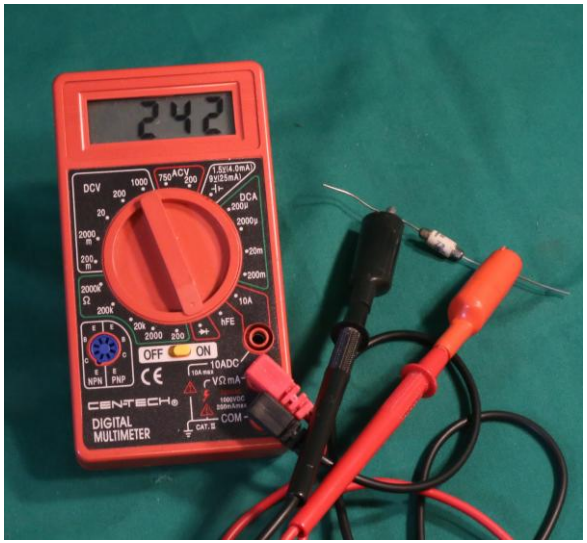




Part numbers don't mean much!

DMM indicates forward drop in millivolts.

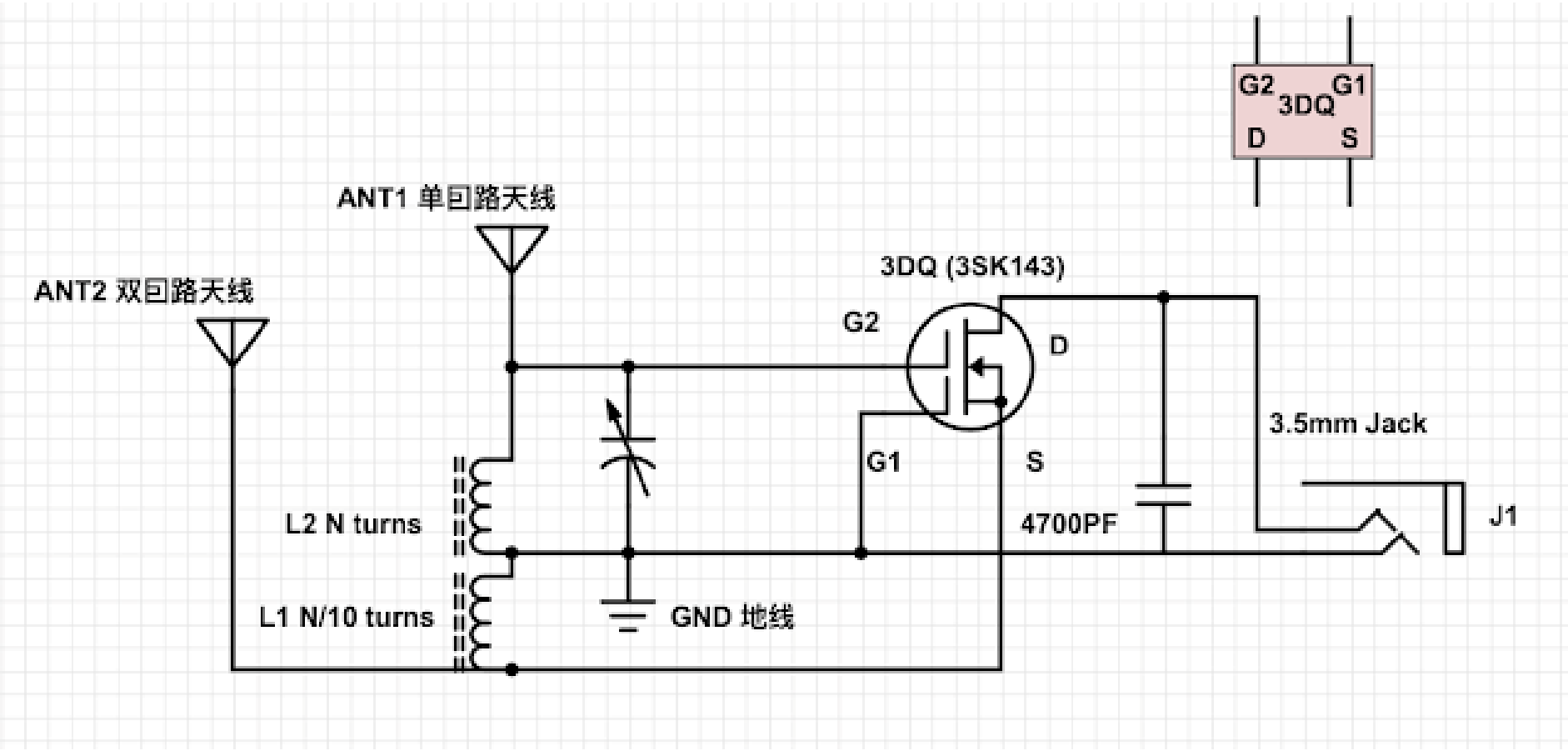
Dump all of them out of your junk box and try them in a radio.



Germanium - Good

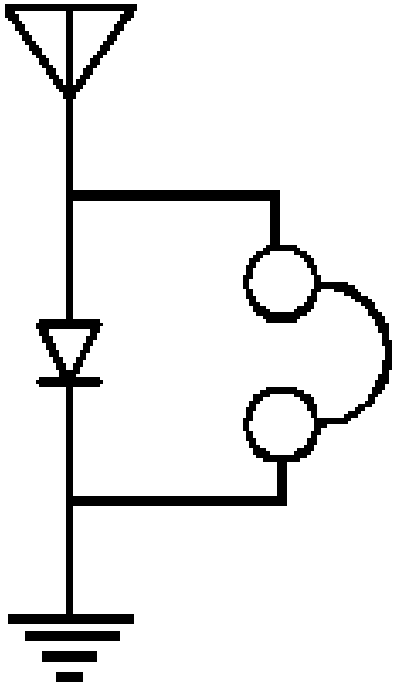
Silicon – No Good

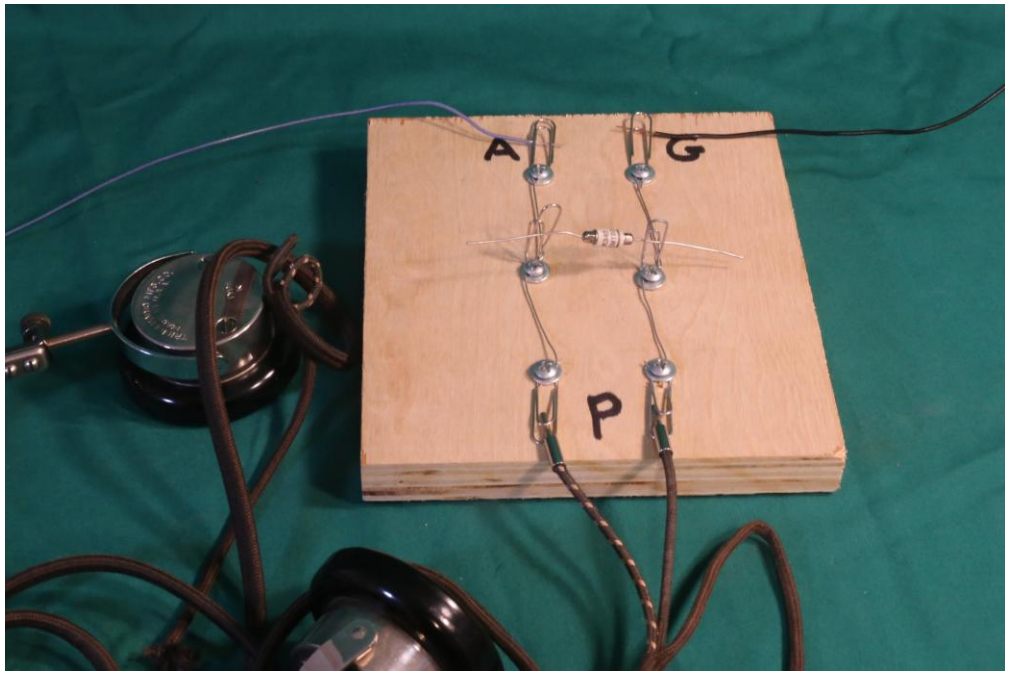
Active Rectifiers



[High Sensitivity Crystal Set]

Let's Build a Radio!

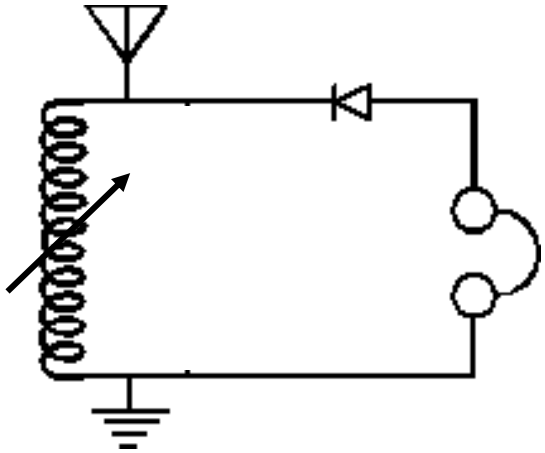


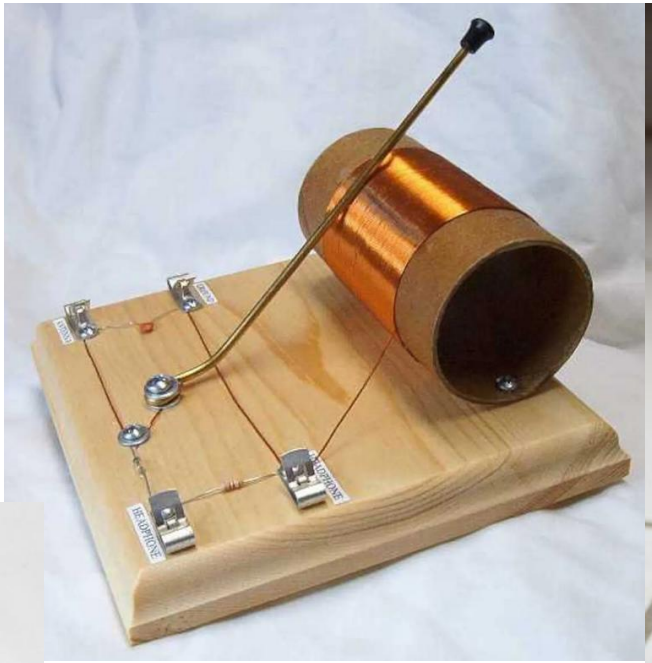


Or just use clip leads. (I got carried away.)

- 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

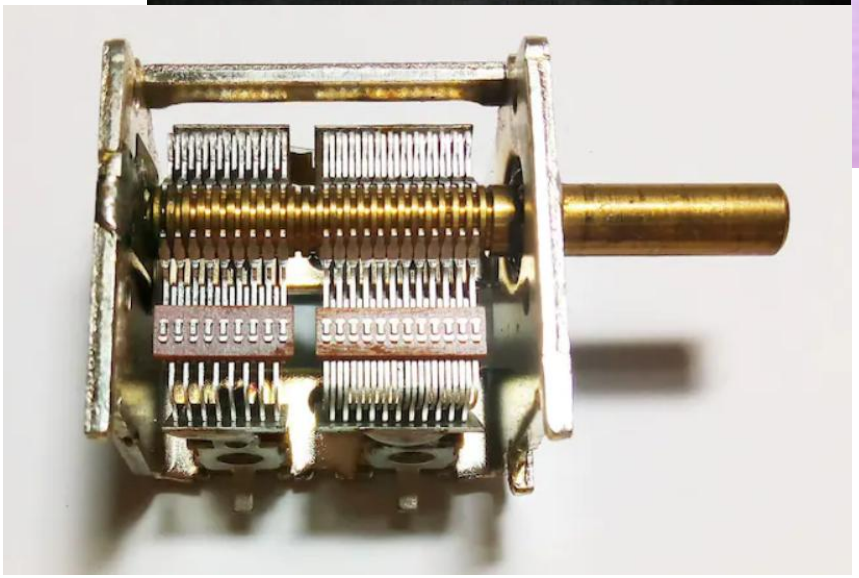




Don’t waste you time on these!
You can do much better!

What's Missing?

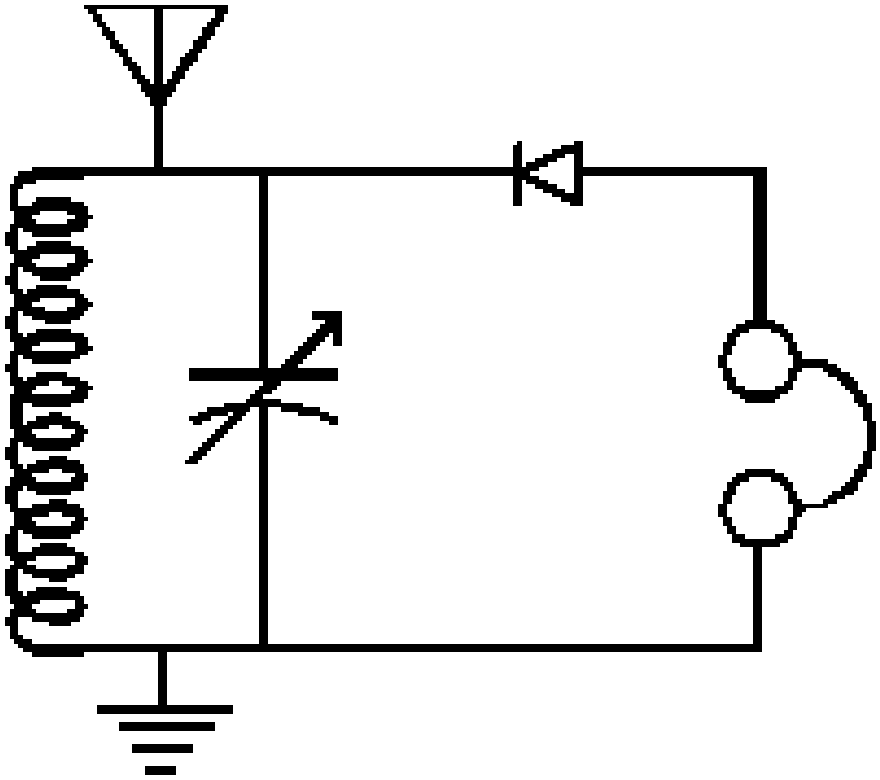
$25 on Amazon



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

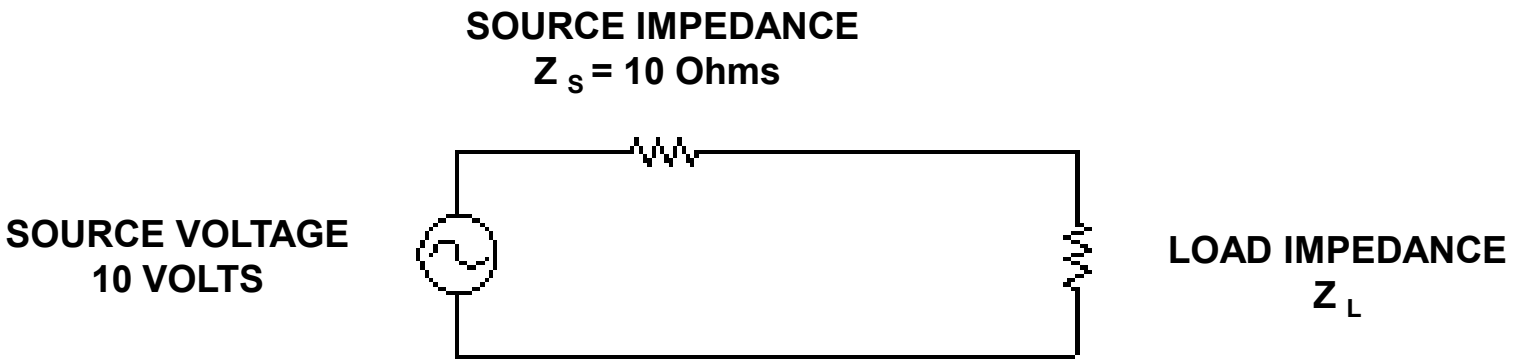
The Old Standby

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



See: [CRYSTAL SET DESIGN 102]

Impedance Matching



LOAD Z	WATTS OUT	PERCENT
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

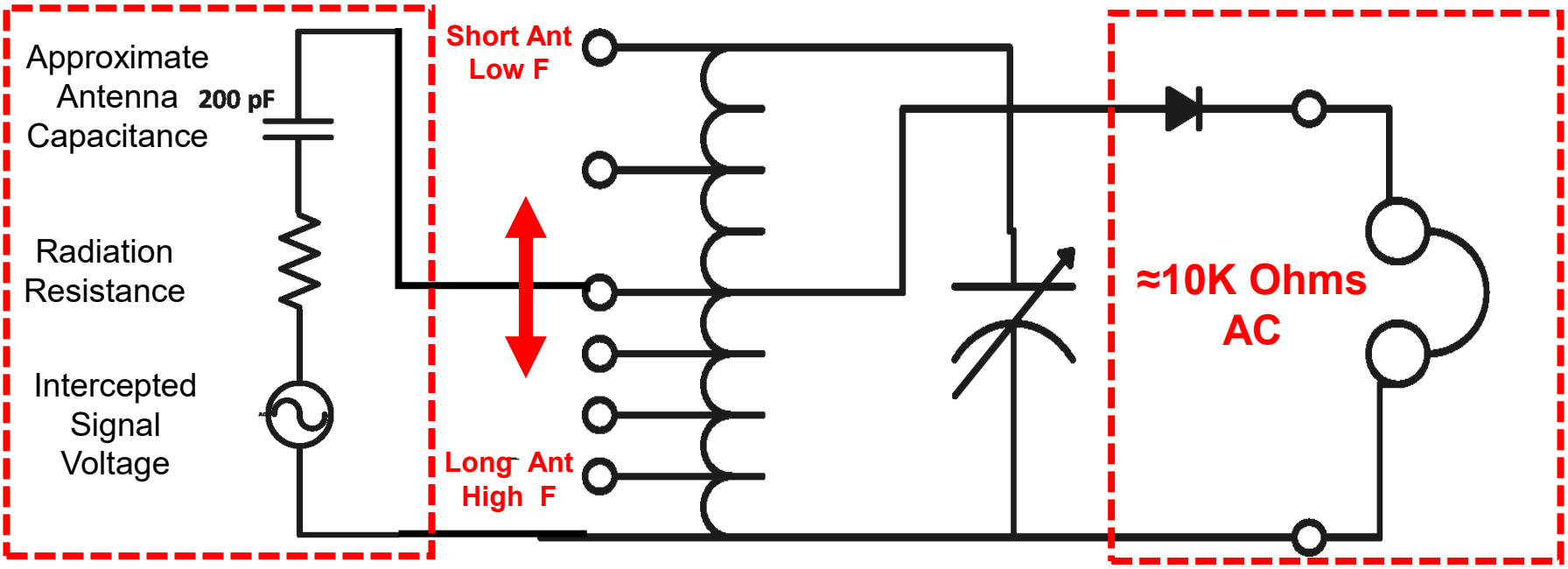
Impedance Mismatch in dB

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

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.

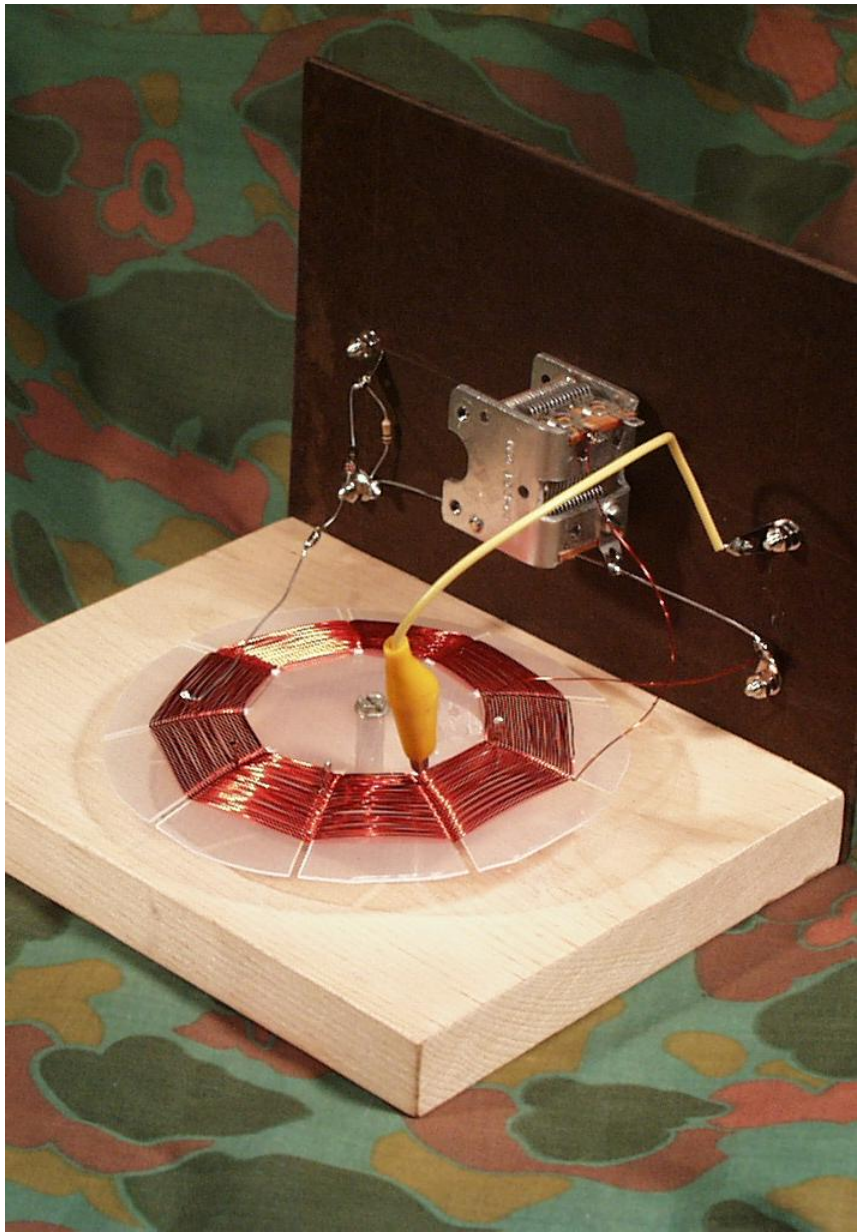


Antenna Equivalent Circuit

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.

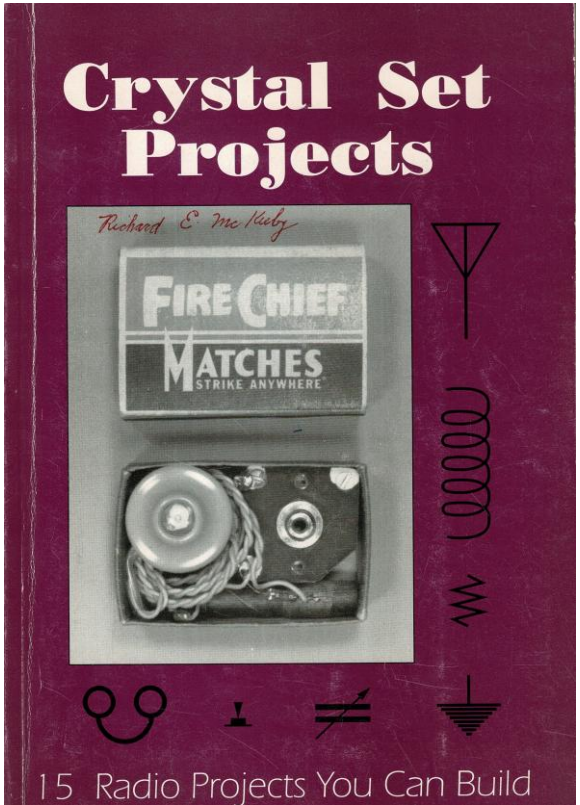
The Den 2 Set - ca. 1990



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



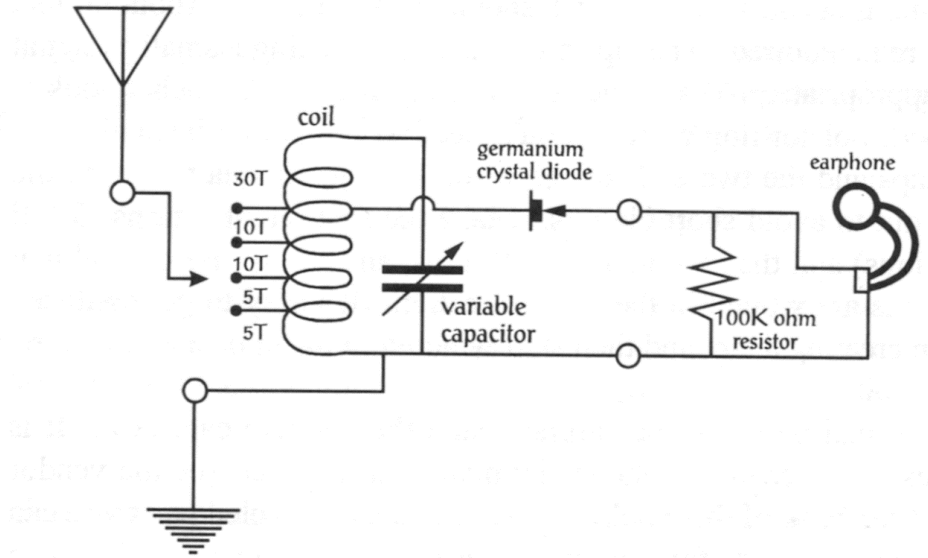


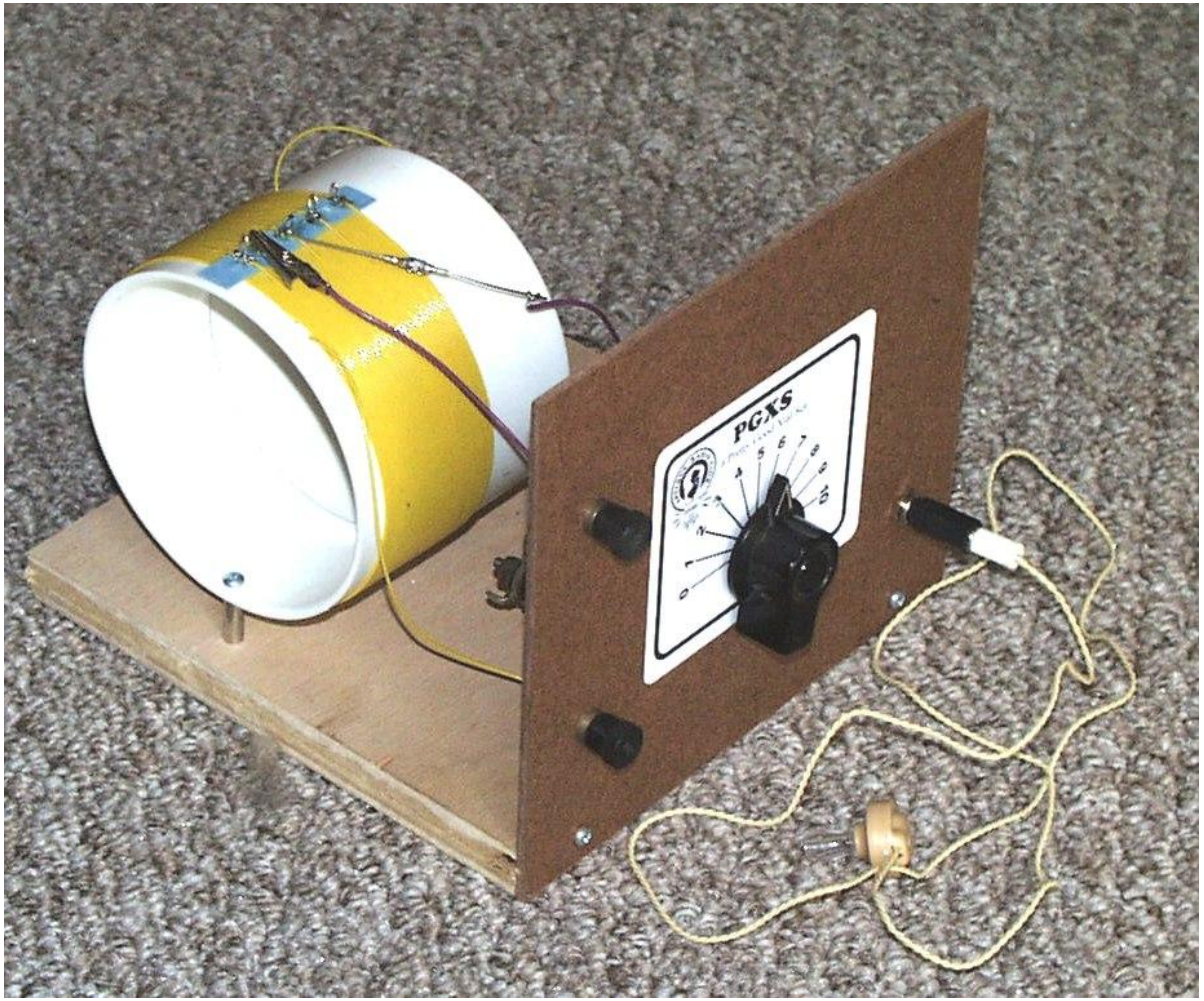
Figure 1: Schematic diagram

My design published by The Crystal Set Society, 1997.

The Pretty Good Crystal Set

ca. 2006

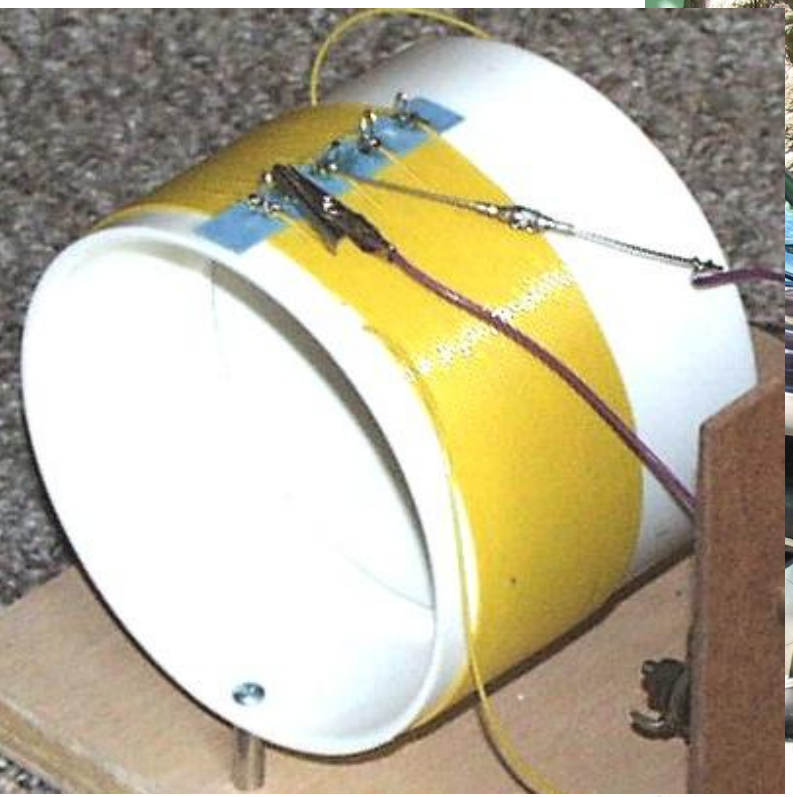
With apologies to Garrison Keillor and Ralph's Pretty Good Grocery



Same Circuit – Better Coil

PGXS II

NJARC 2006 Crystal-Set Clinic

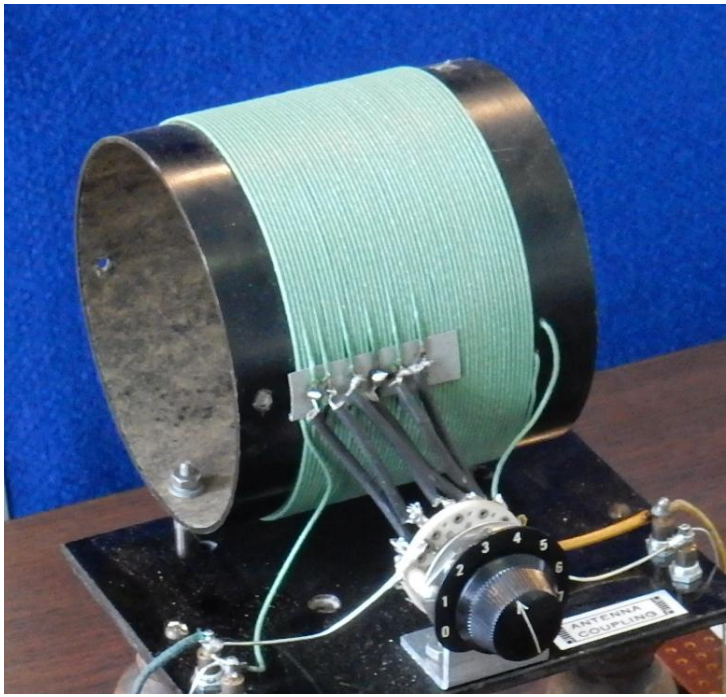


41/2” ABS pipe coupling

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

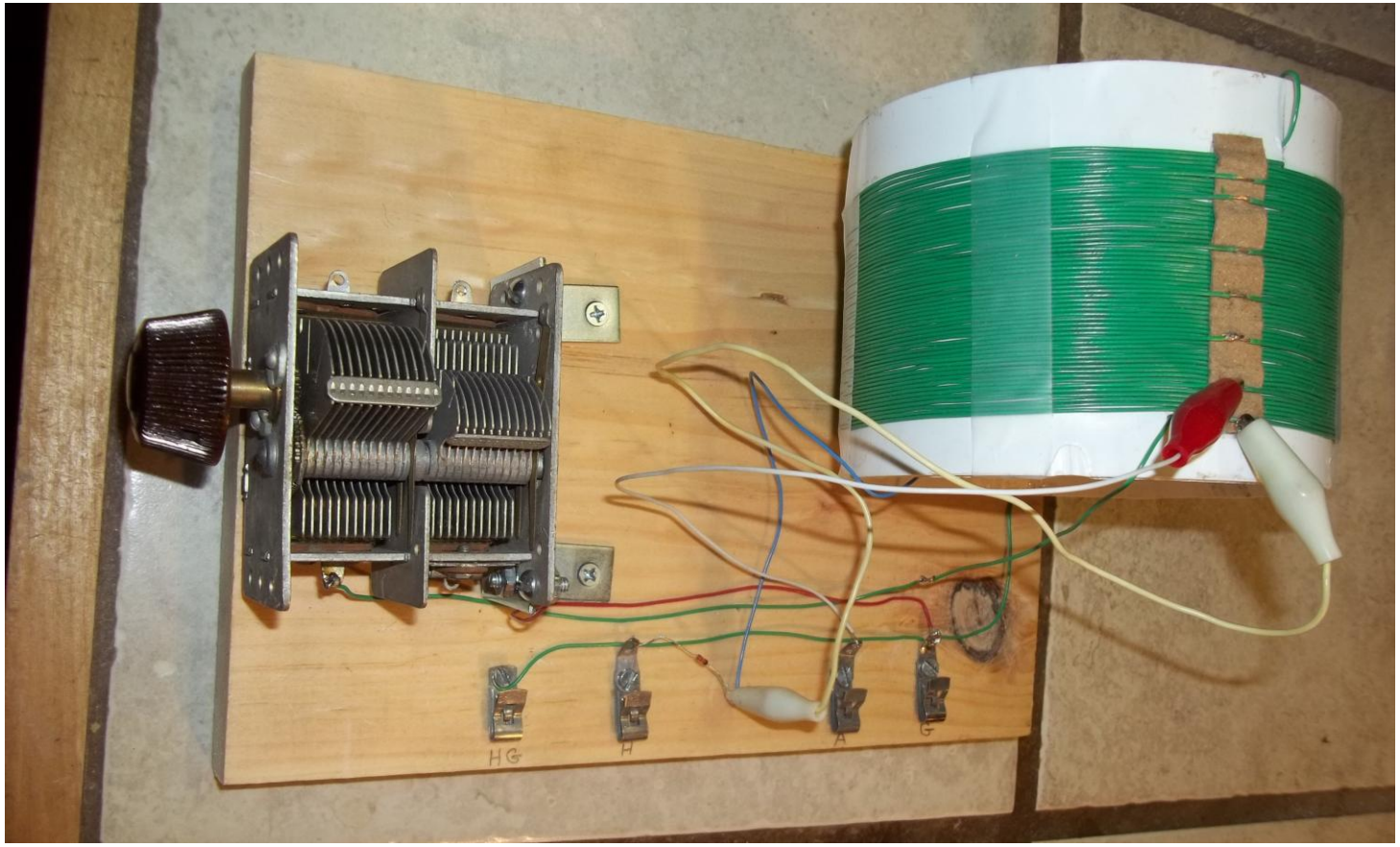
Effective Air-core Coils

- 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.

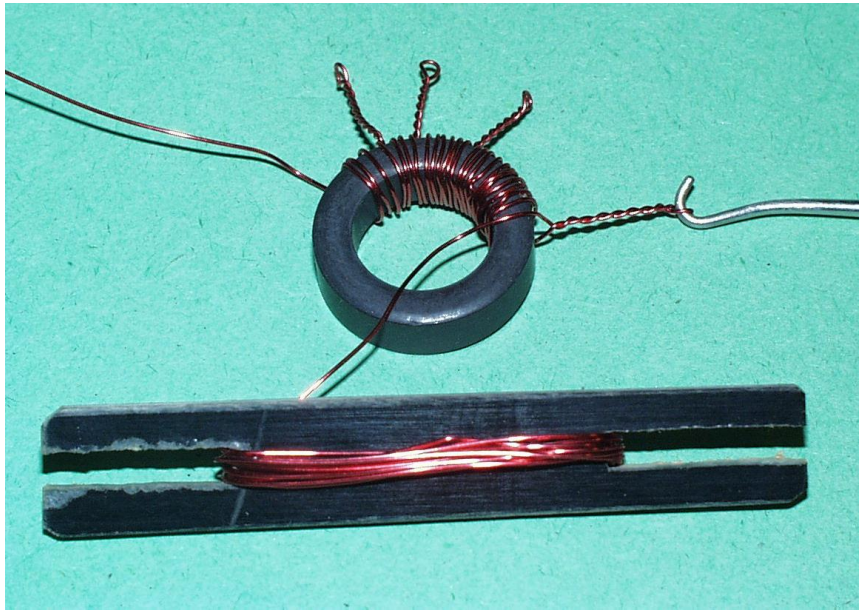
A Fancy PGXS

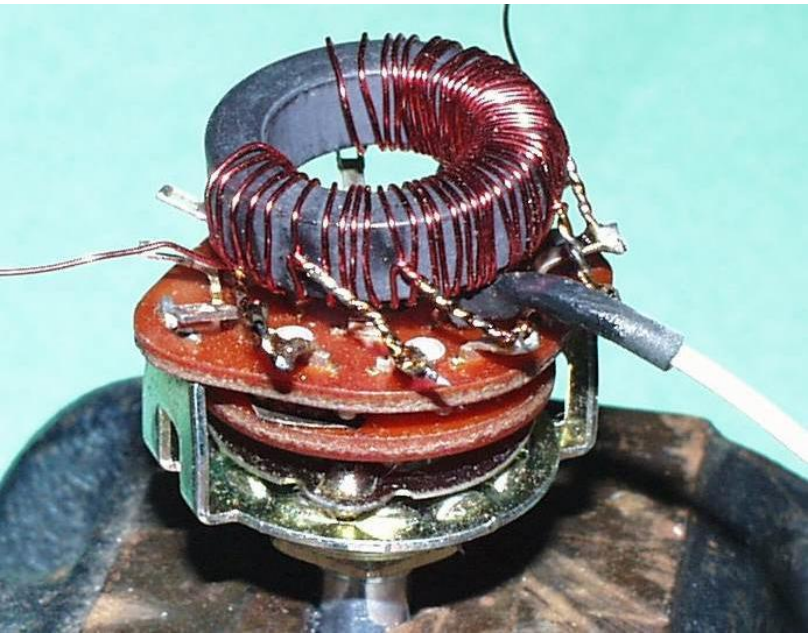
A Christmas Present

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.

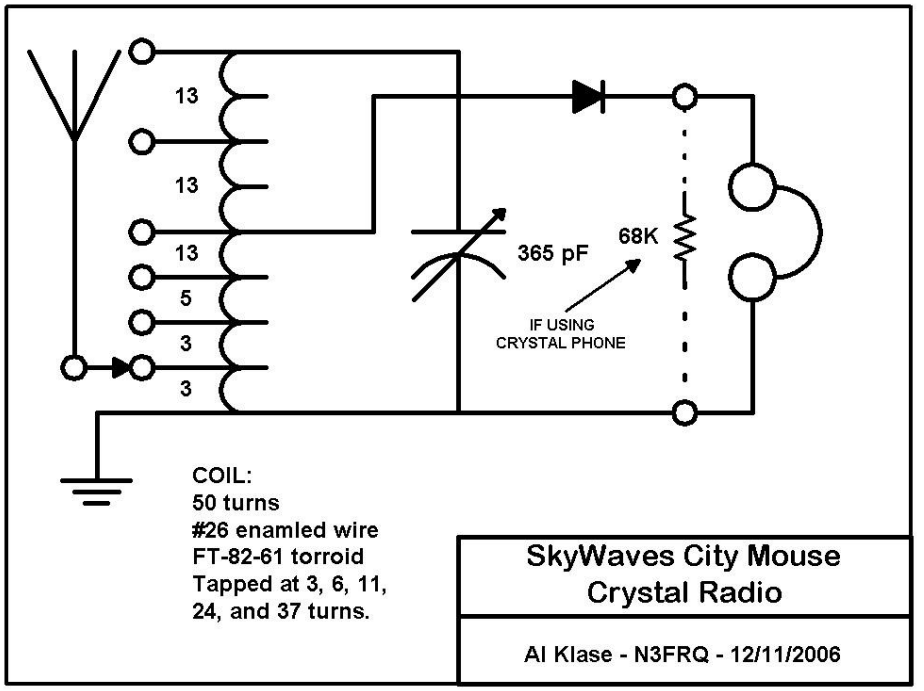




You need to know what magnetic material you have. (Mix-61 for the broadcast band)

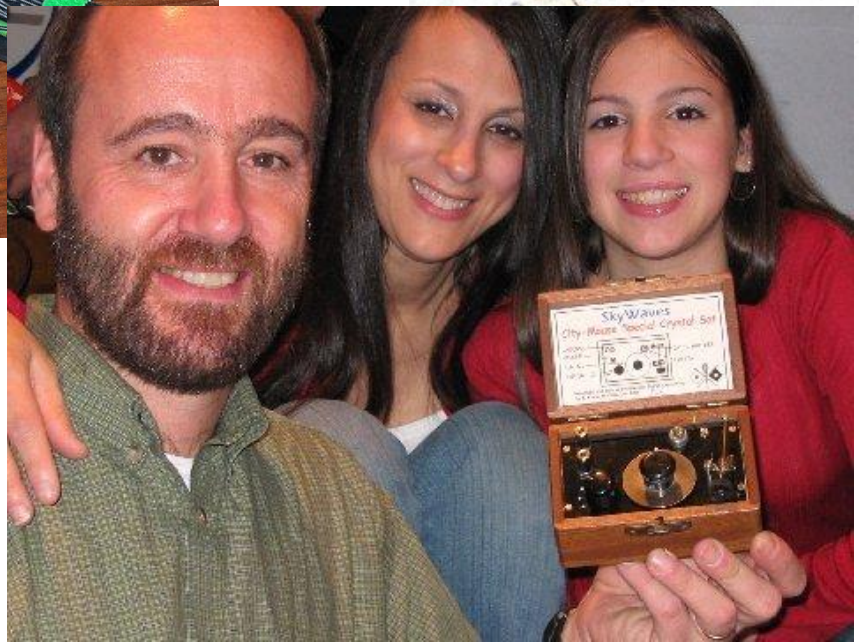
Build Small Radios

- City Mouse, ca. 2006



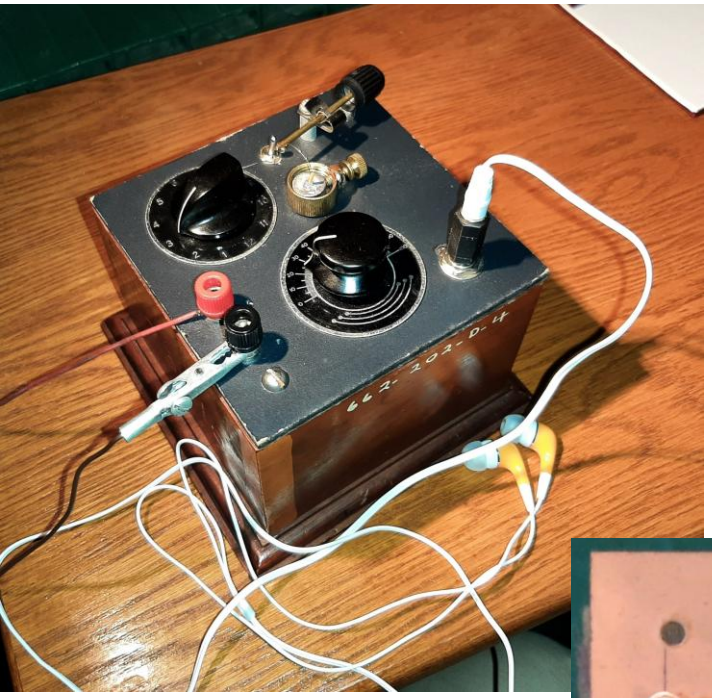
CRYSTAL SET MOBILE

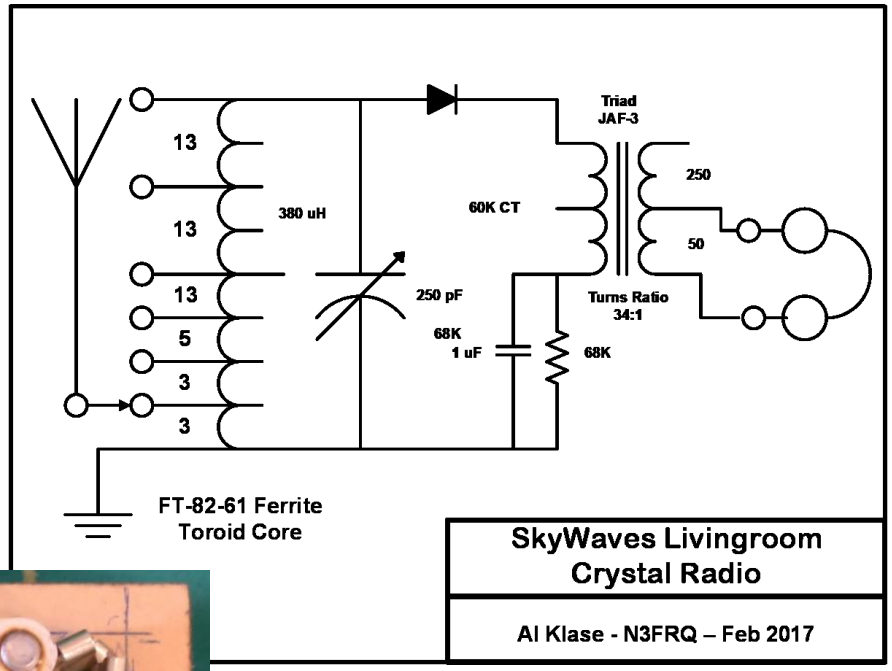
City Mouse



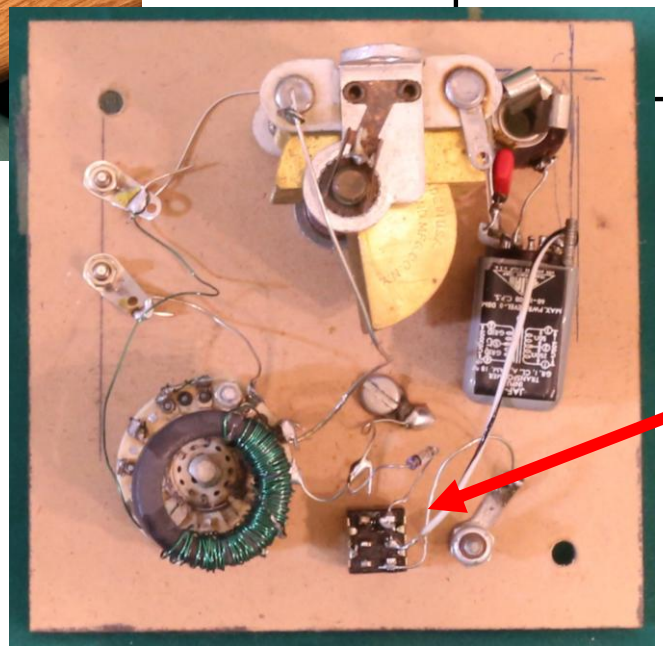
More Christmas Presents

My Livingroom Set





- Makes use of dollar-store earbuds.
- 20-foot indoor antenna woks well here in “city-mouse” territory.

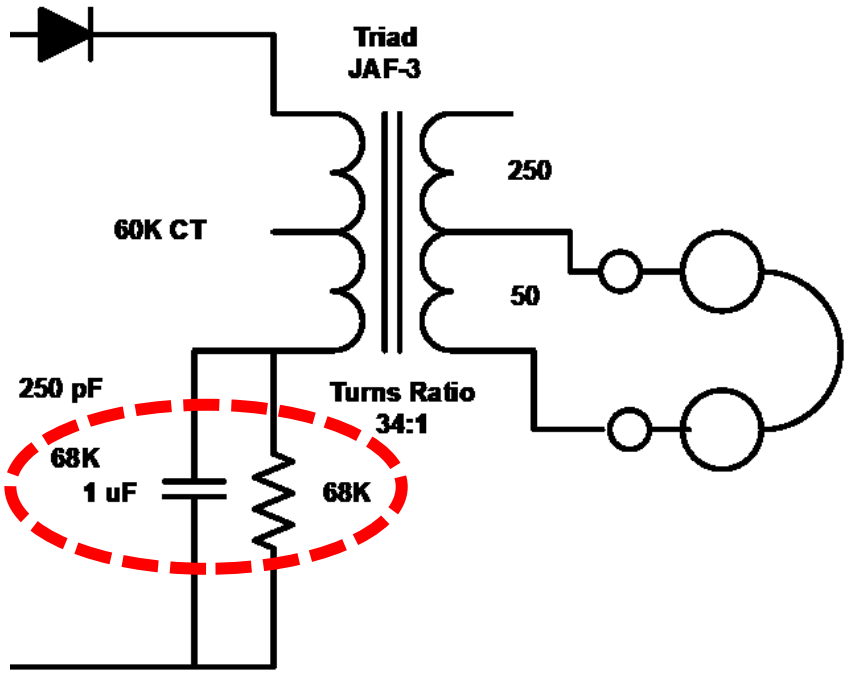


Cheater switch selects germanium diode.

HOMEBREW DETECTOR STAND

The “Benny” Resistor

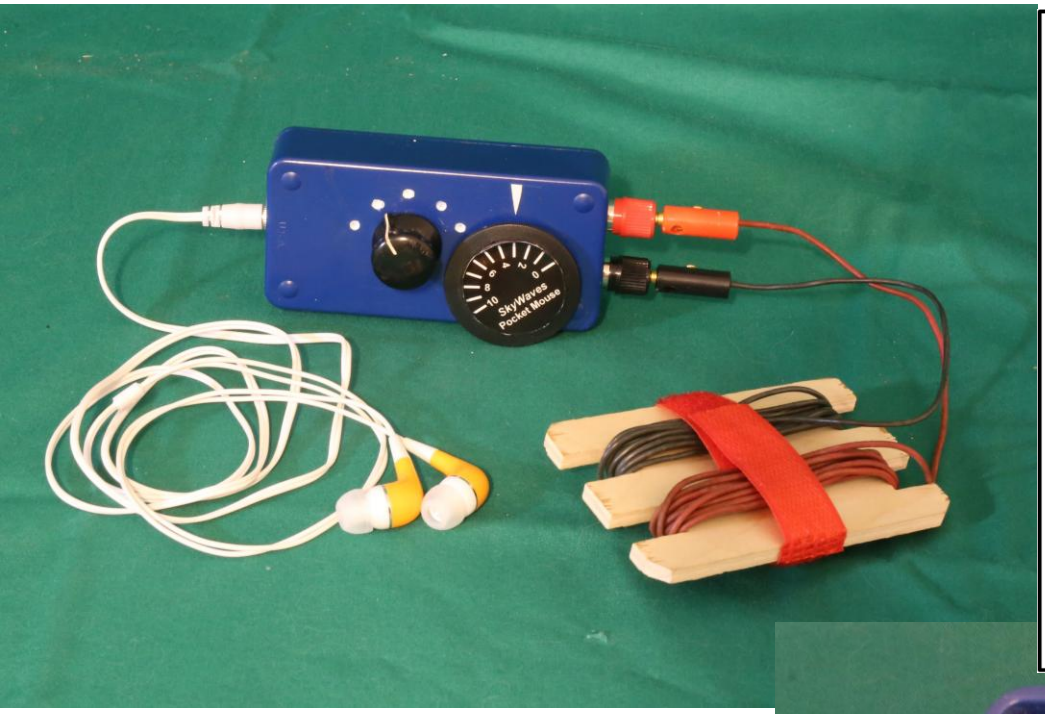
- Pointed out by the late Ben Tongue, captain-of-industry, electrical engineer and crystal-set maven.
- The DC resistance of a matching transform primary is much smaller that the AC impedance.
- The heavy DC load on the diode detector causes distortion and loss.
- Bypassed resistor in series with the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

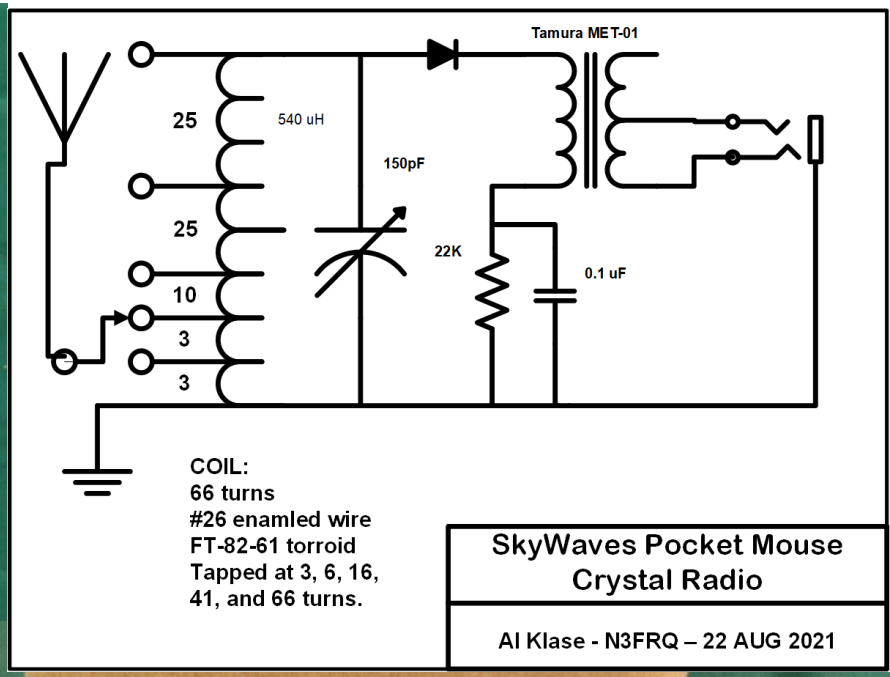


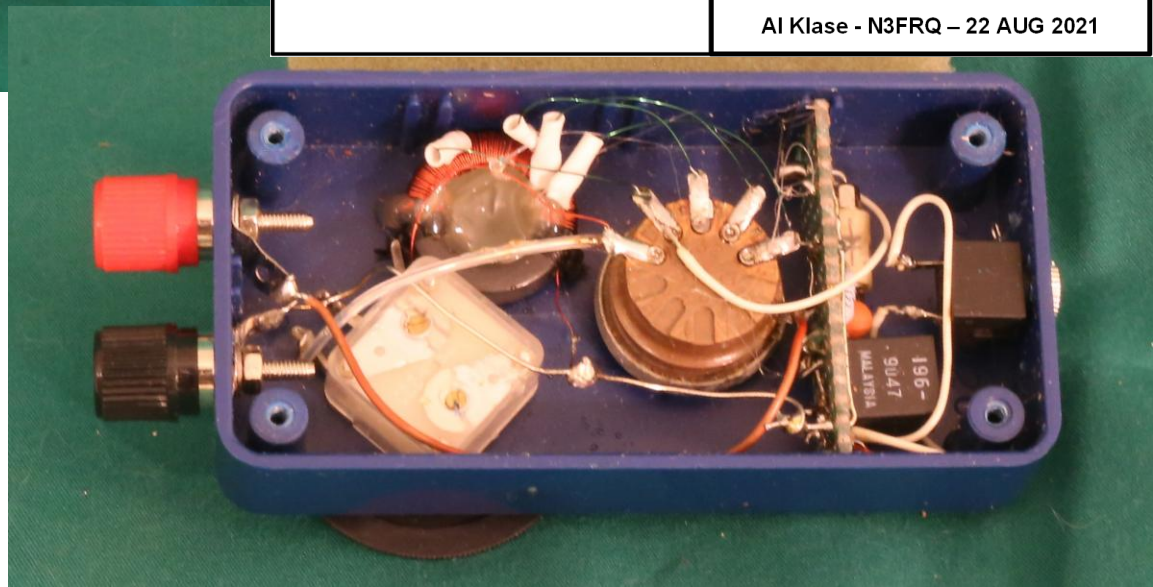
Ben Tongue on Crystal sets

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

The Skywaves Pocket Mouse



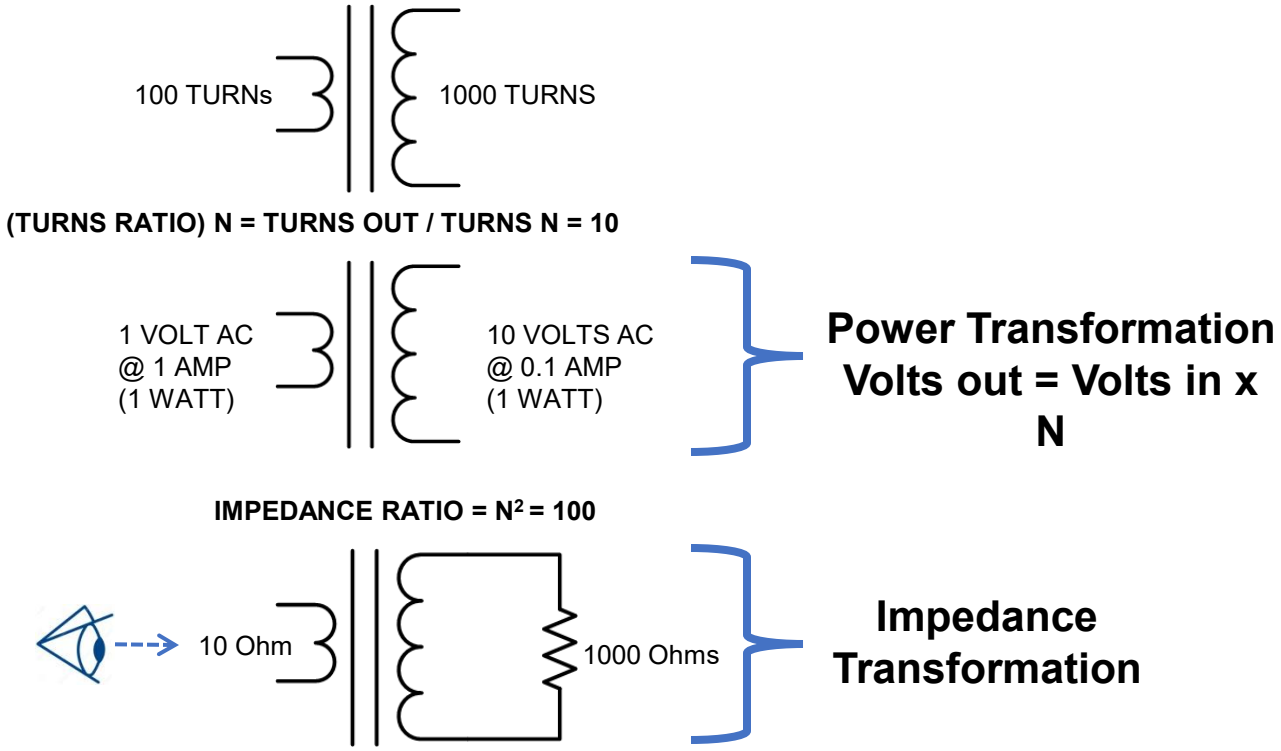




TRAVELING WITH A CRYSTAL SET

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.**

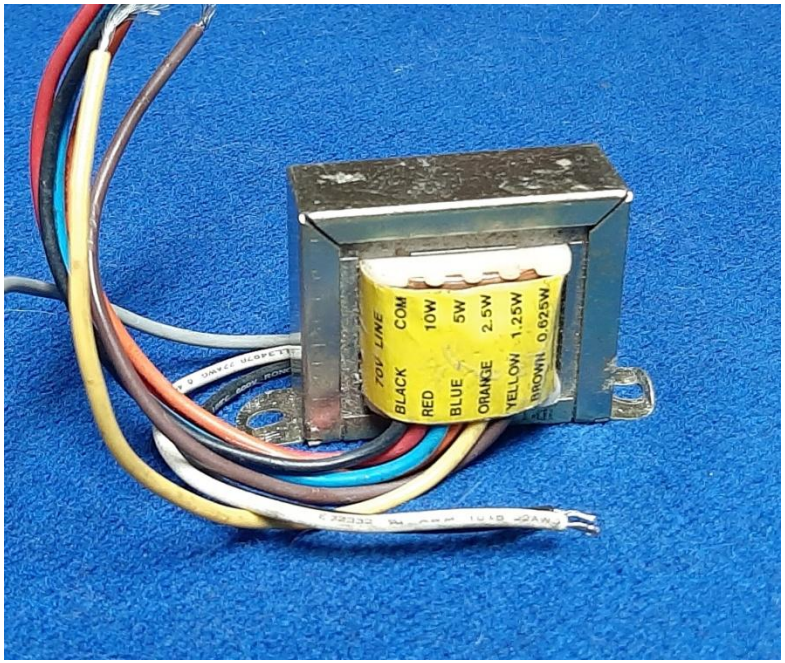


Microphone Input Transformer

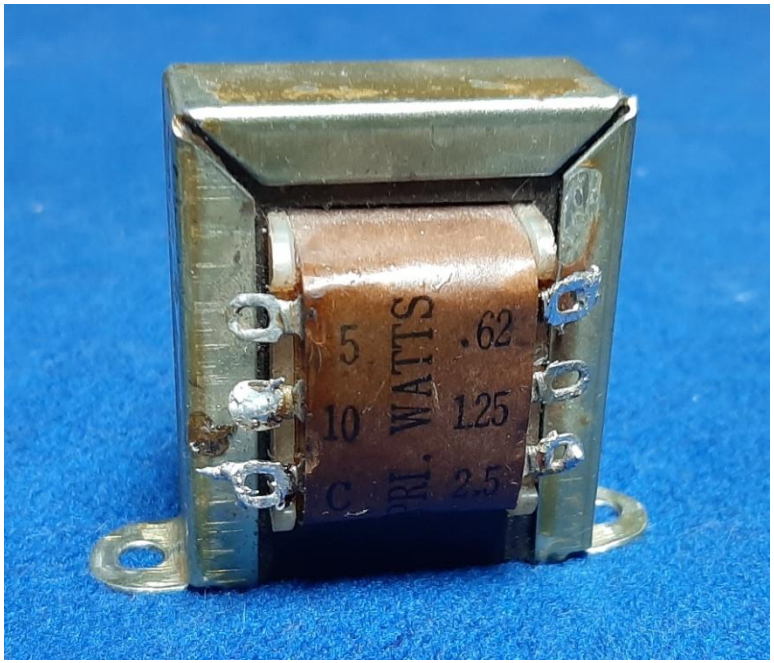
Hi-Fi Frequency Response

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

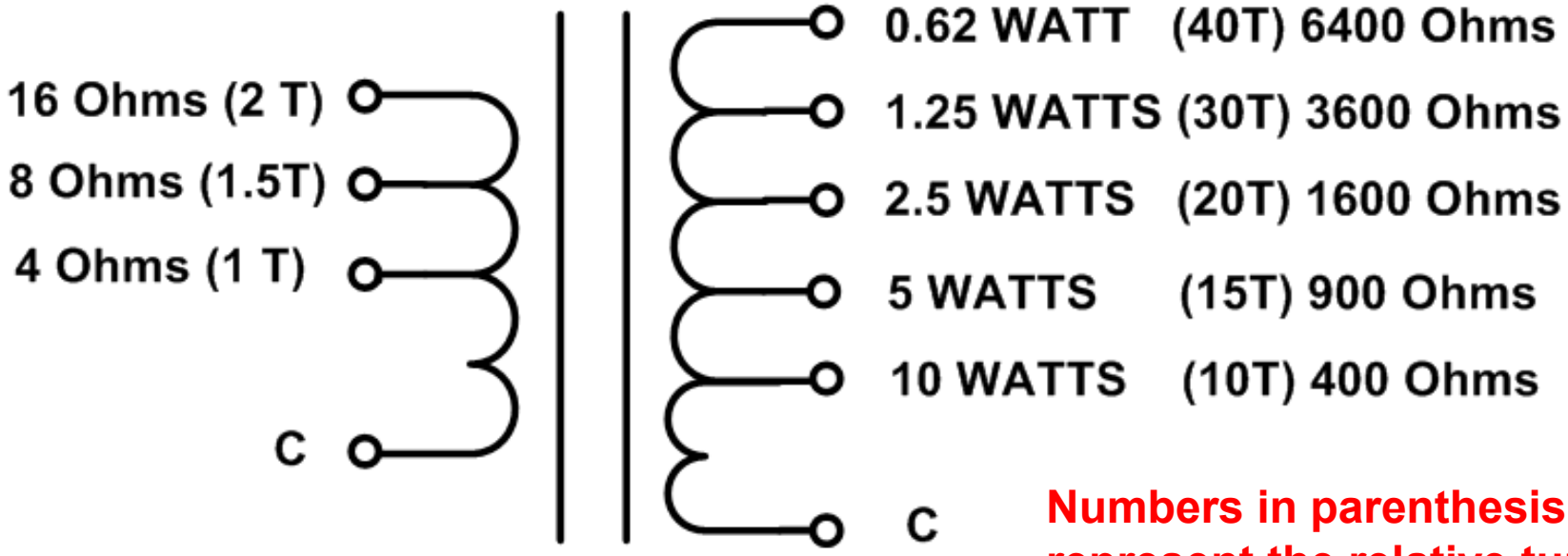


Realistic 32-1031
Made in Taiwan

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.

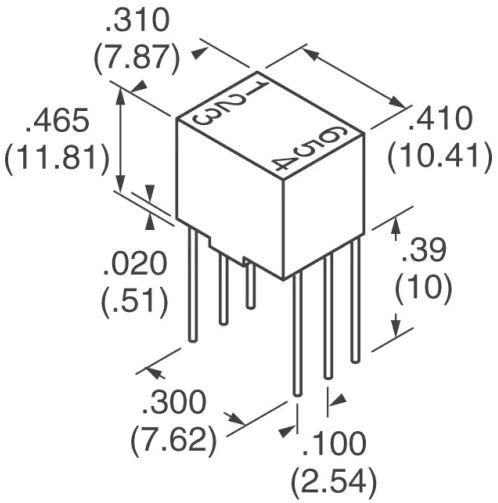


Line-to-Voice Coil Transformer
Radio Shack (Realistic) 32-1031 is typical.

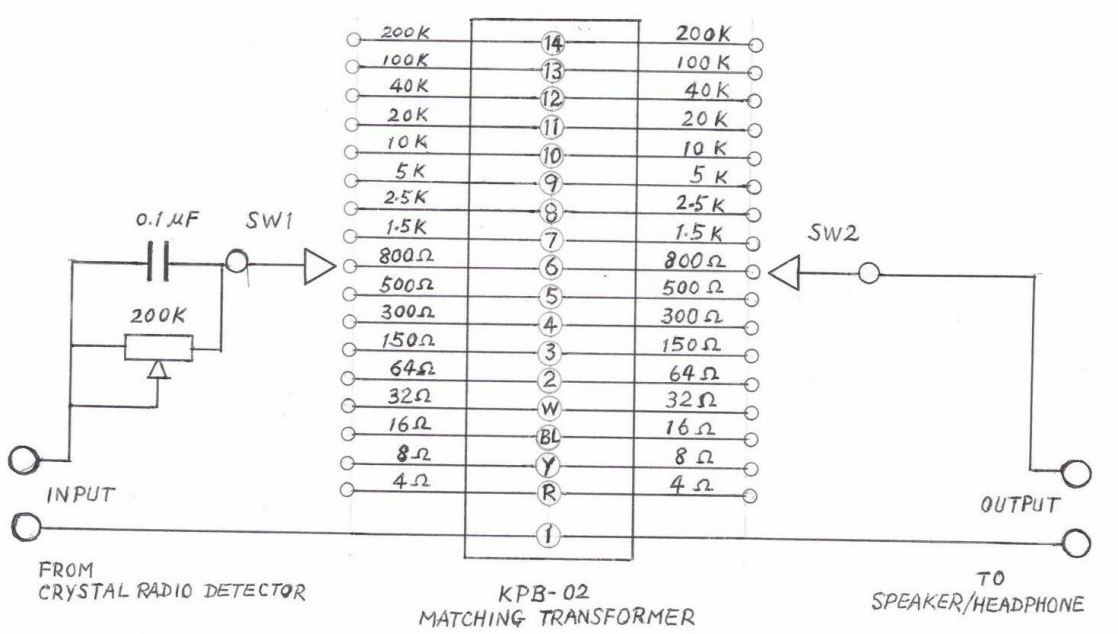
Numbers in parenthesis represent the relative turns count measured by applying 1 Volt AC to the 4-ohm winding.

Currently Available Transformers

- Tamura MET-01
  - 200K CT to 1K CT
  - Mouser $13



- Transformer KPB-02 200KΩ to 4Ω Selectable
  - Ebay $20

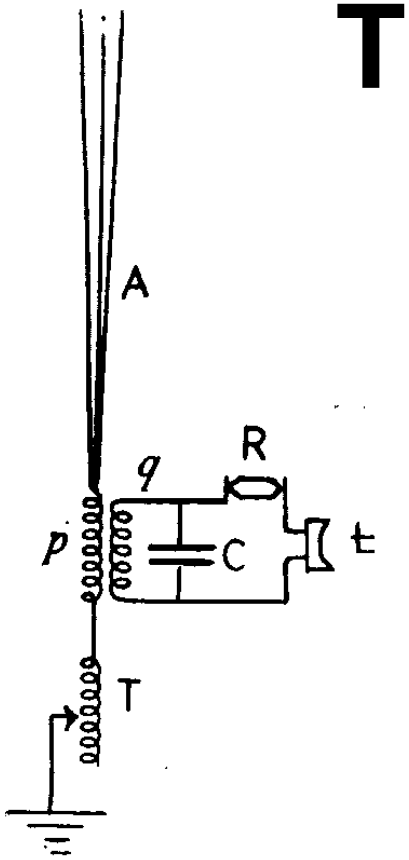


High Performance
Really Good Crystal Sets

- **Double-Tuned Circuits**
  - Improved Selectivity
  - Improved Sensitivity
  - See Classic Communications Receiver for Inspiration
- **More Sensitive Headsets**
  - “Sound-Powered ‘Phones”
  - Modern alternatives

Marconi 101 ca. 1913

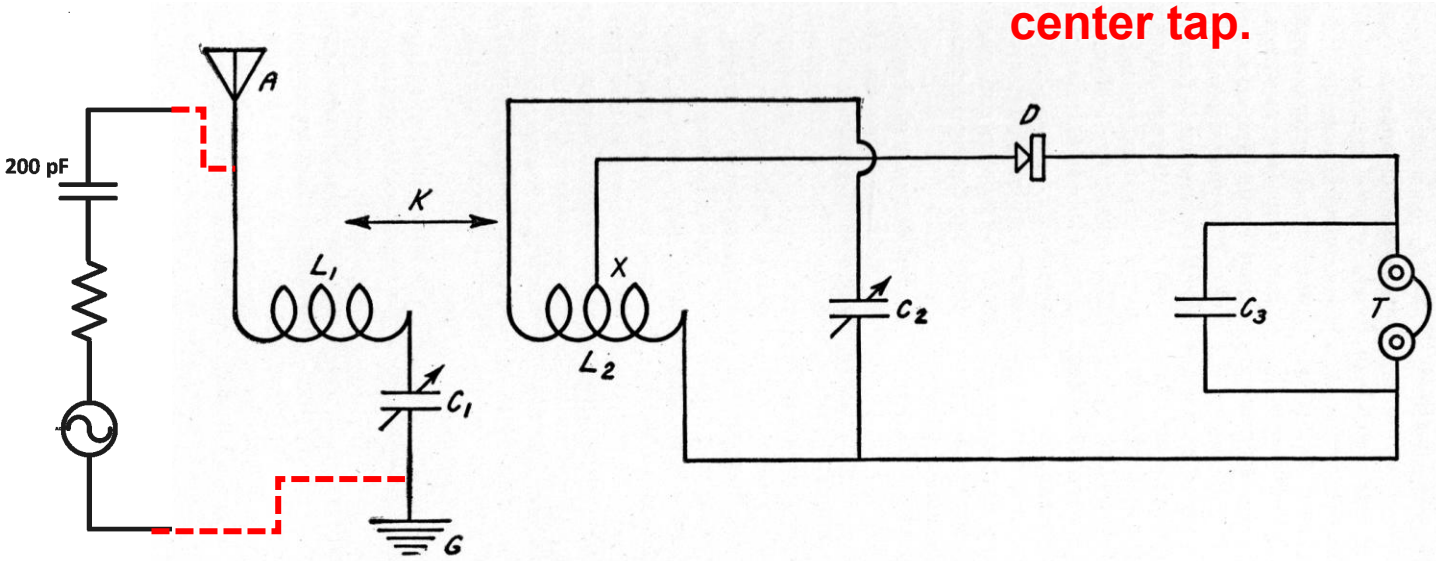
The Two-Circuit Tuner



Marconi 4- sevens patent
1900

Open Circuit **Closed Circuit**

Note: detector connected to center tap.



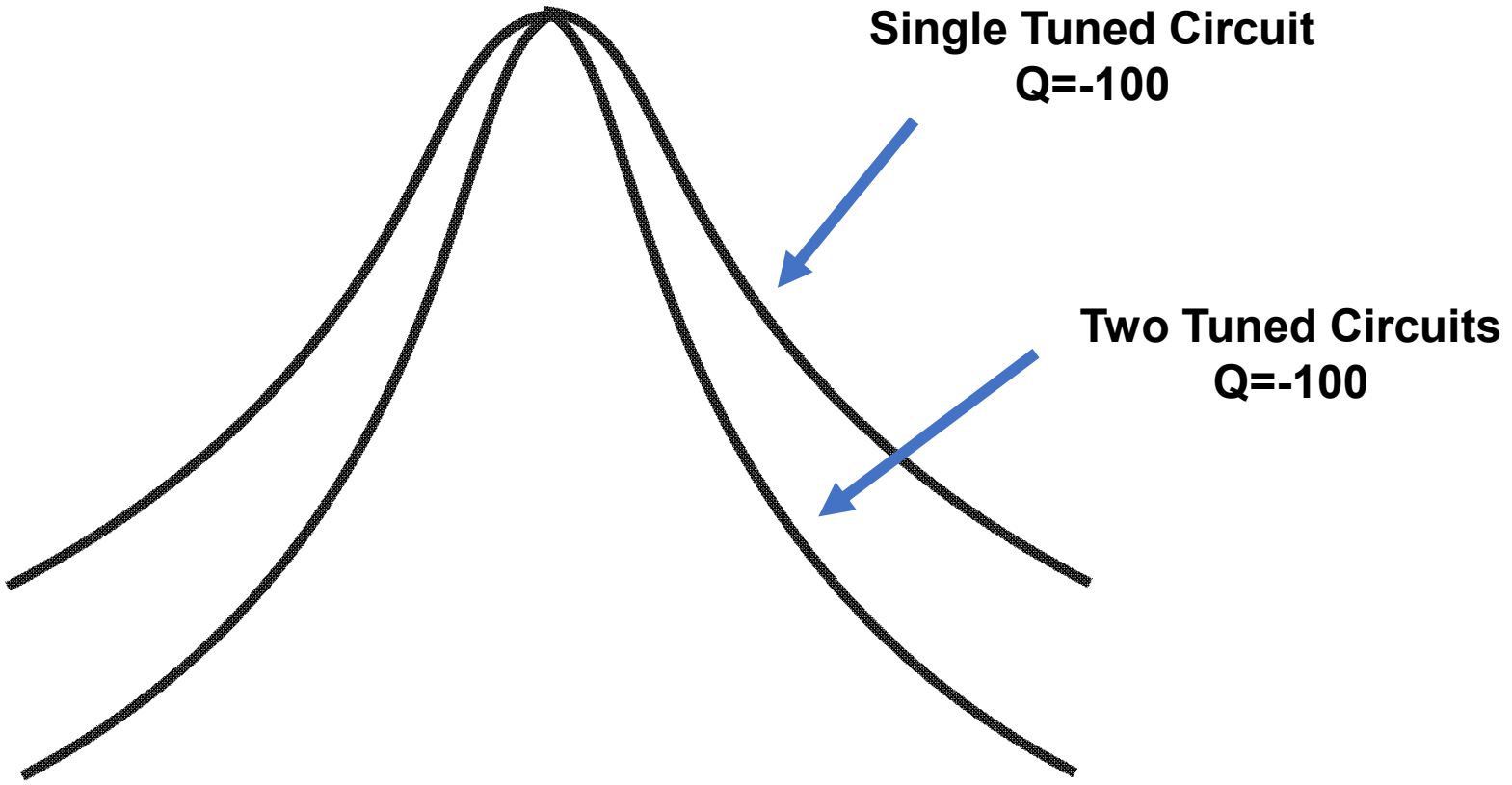
A CIRCUIT THAT WILL IMPROVE THE CRYSTAL RECEIVER

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.

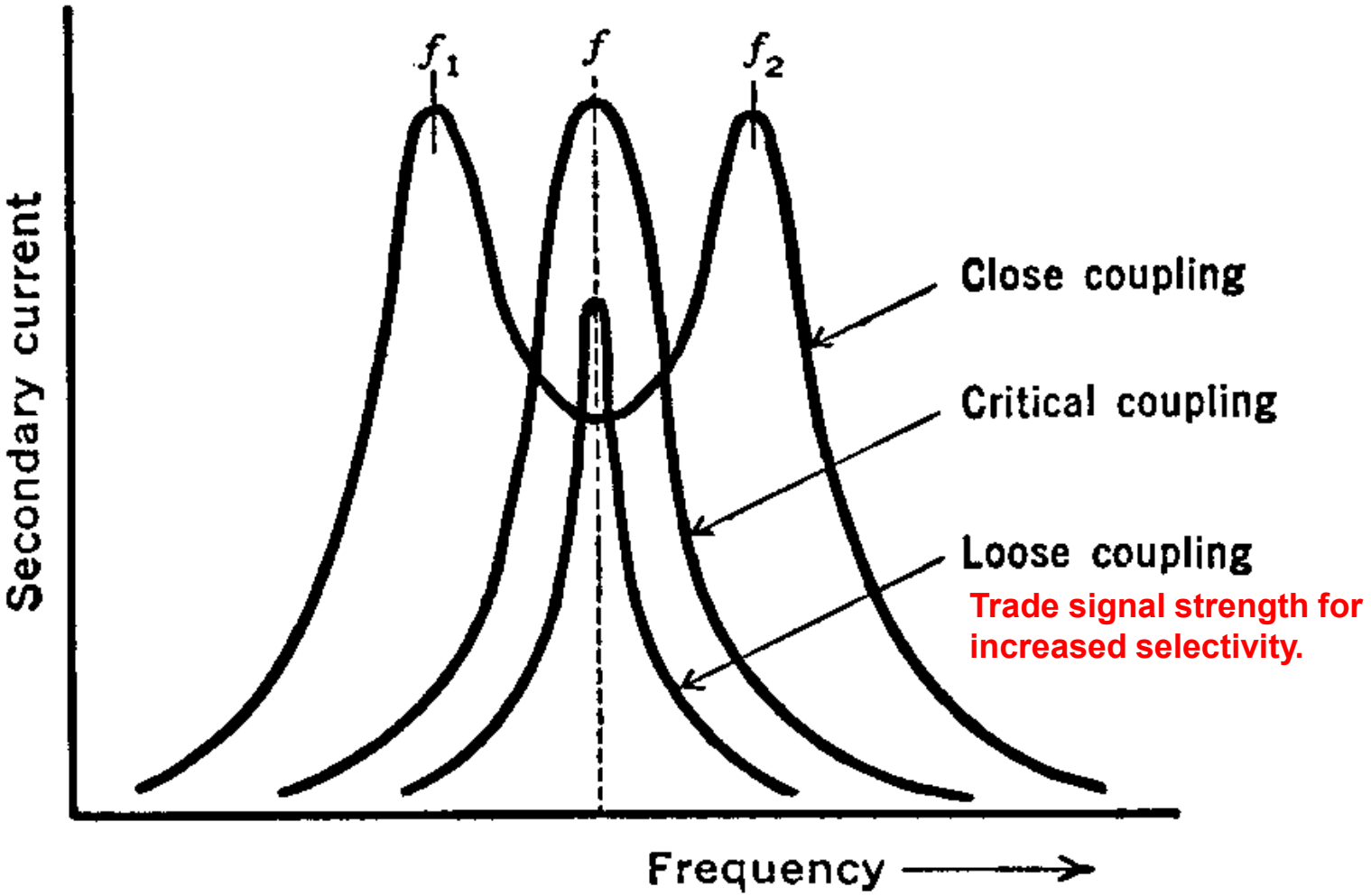
"Conjugate Match"
Maximum circulating current and energy transfer.

Every man's Guide to Radio - 1926

Multiple Tuned Circuits
Improve Selectivity



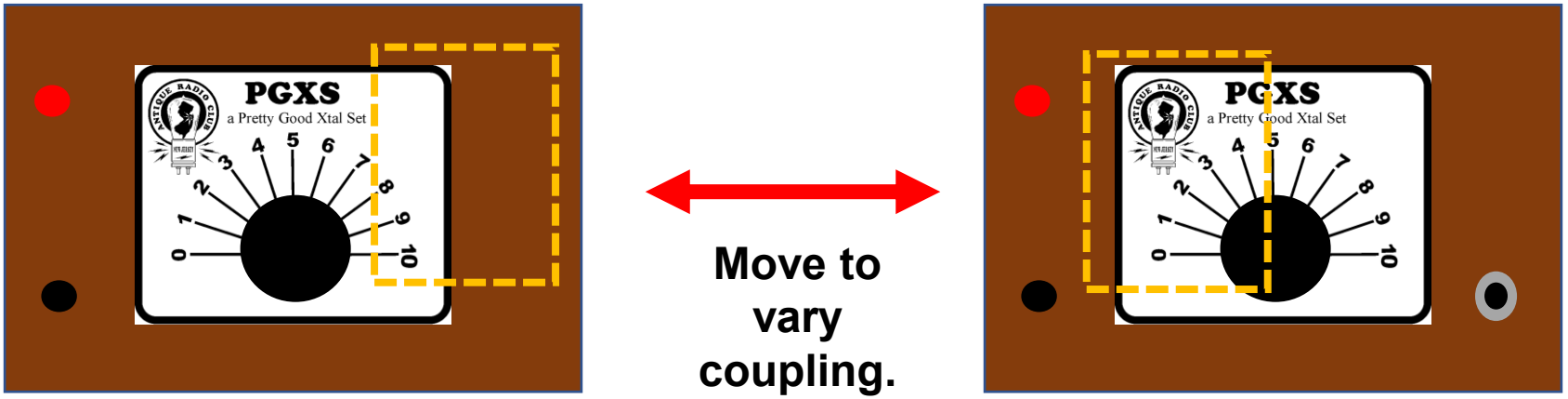
Effects of Loose Coupling



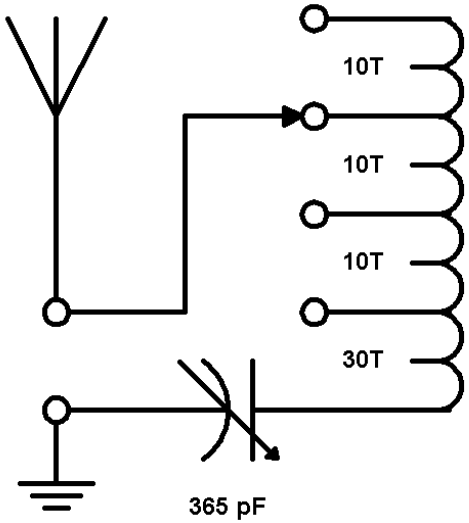
Trade signal strength for increased selectivity.

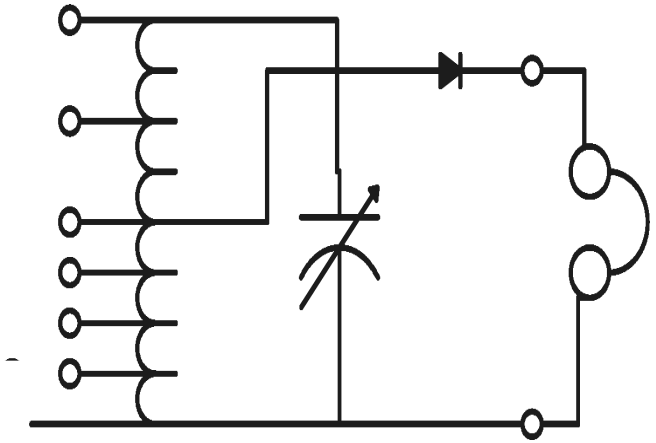
Double-Tuned The Easy Way

Build a second PGXS!



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

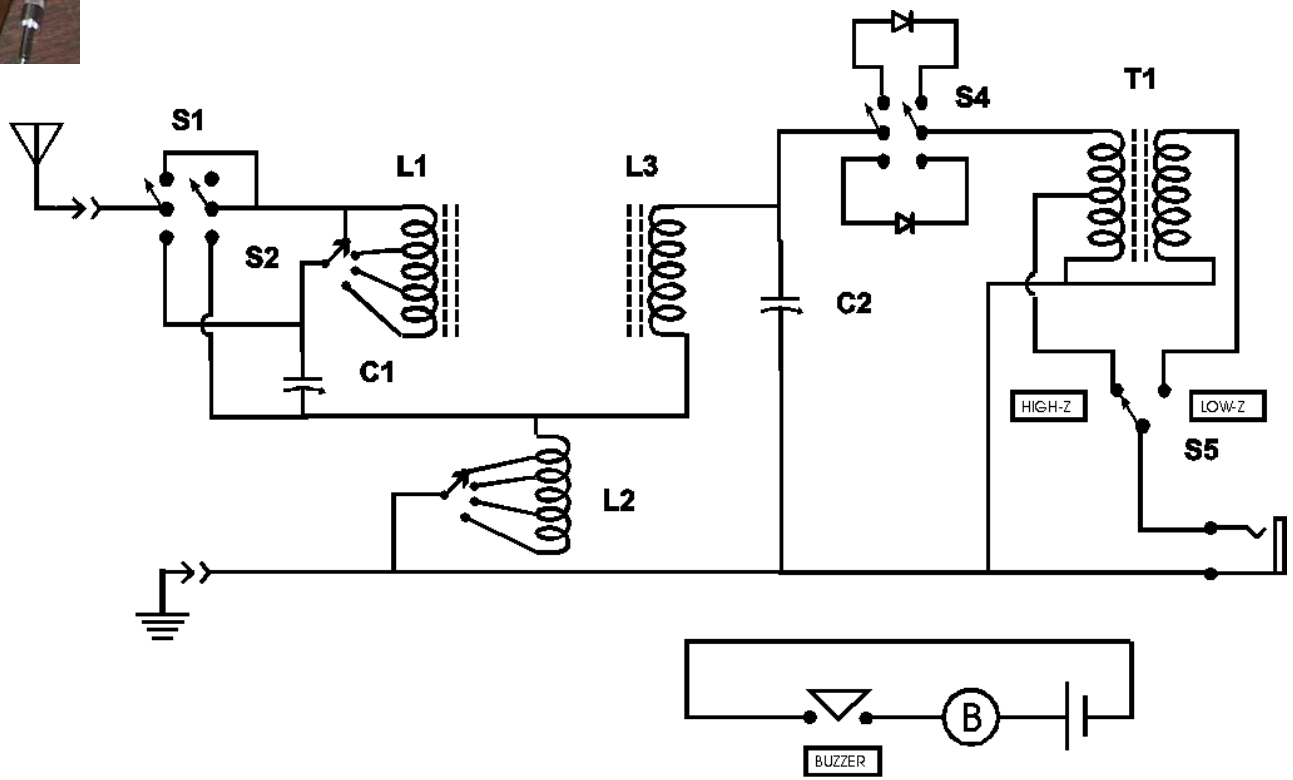
NAME: Al Klase
ADDRESS: 22 Cherryville-Stanton Rd.
Flemington, NJ 08822
PHONE 908-782-4829

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		WMVP	CHICAGO	708 Mi.*
2/19/2001	02:03Z	670		WMAQ	CHICAGO	708 Mi.*
2/19/2001	02:58Z	720		WGN	CHICAGO	708 Mi.*
2/19/2001	03:07Z	760		WJR	DETROIT	482 Mi.
2/19/2001	03:10Z	750		WSB	ATLANTA	717 Mi.*
2/19/2001	03:17Z	650		WSM	NASHVILLE	736 Mi.*
2/19/2001	03:22Z	840		WHAS	LOUISVILLE	630 Mi.
2/19/2001	04:30Z	890		WLS	CHICAGO	708 Mi.*
2/19/2001	04:38Z	1110		WBT	CHARLOTTE	501 Mi.
2/19/2001	05:03Z	530		RVC	SOUTH CAICOS	1309 Mi.* RADIOVISION CRISTIANA
2/19/2001	05:25Z	570		R. RELOJ	CUBA	1279 Mi.* TIME SIGNAL
2/19/2001	06:00Z	870		WWL	NEW ORLEANS	1128 Mi.*
2/19/2001	06:07Z	890		WLS	CHICAGO	708 Mi.*
2/19/2001	06:30Z	1170		WWVA	WHEELING, WV	
				TOTAL MILES FOR 10 BEST STATIONS: 8709		

SkyWaves HP-002

Double-Tuned with ferrite cores
Ca. 1999

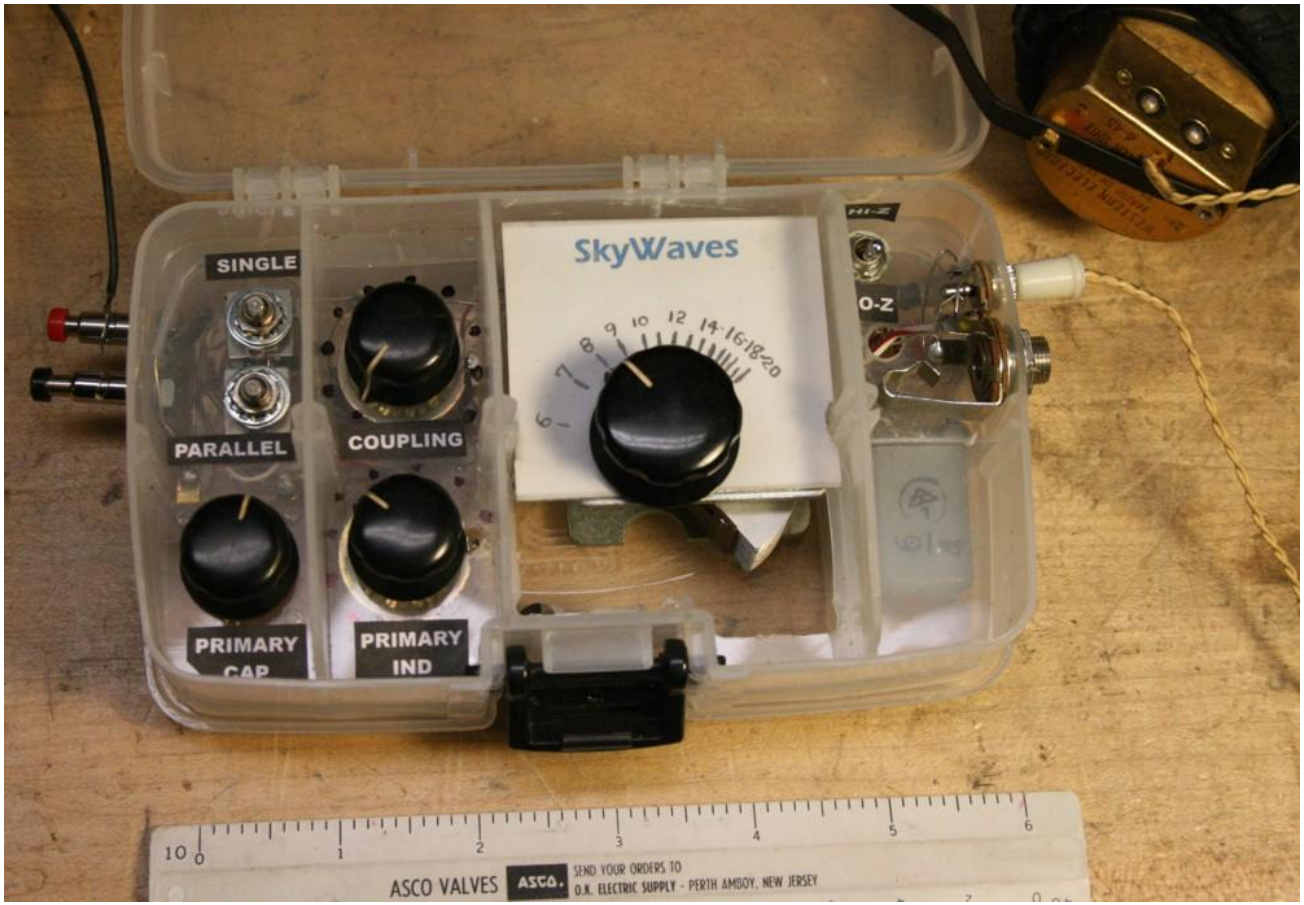


HP-002

Inside

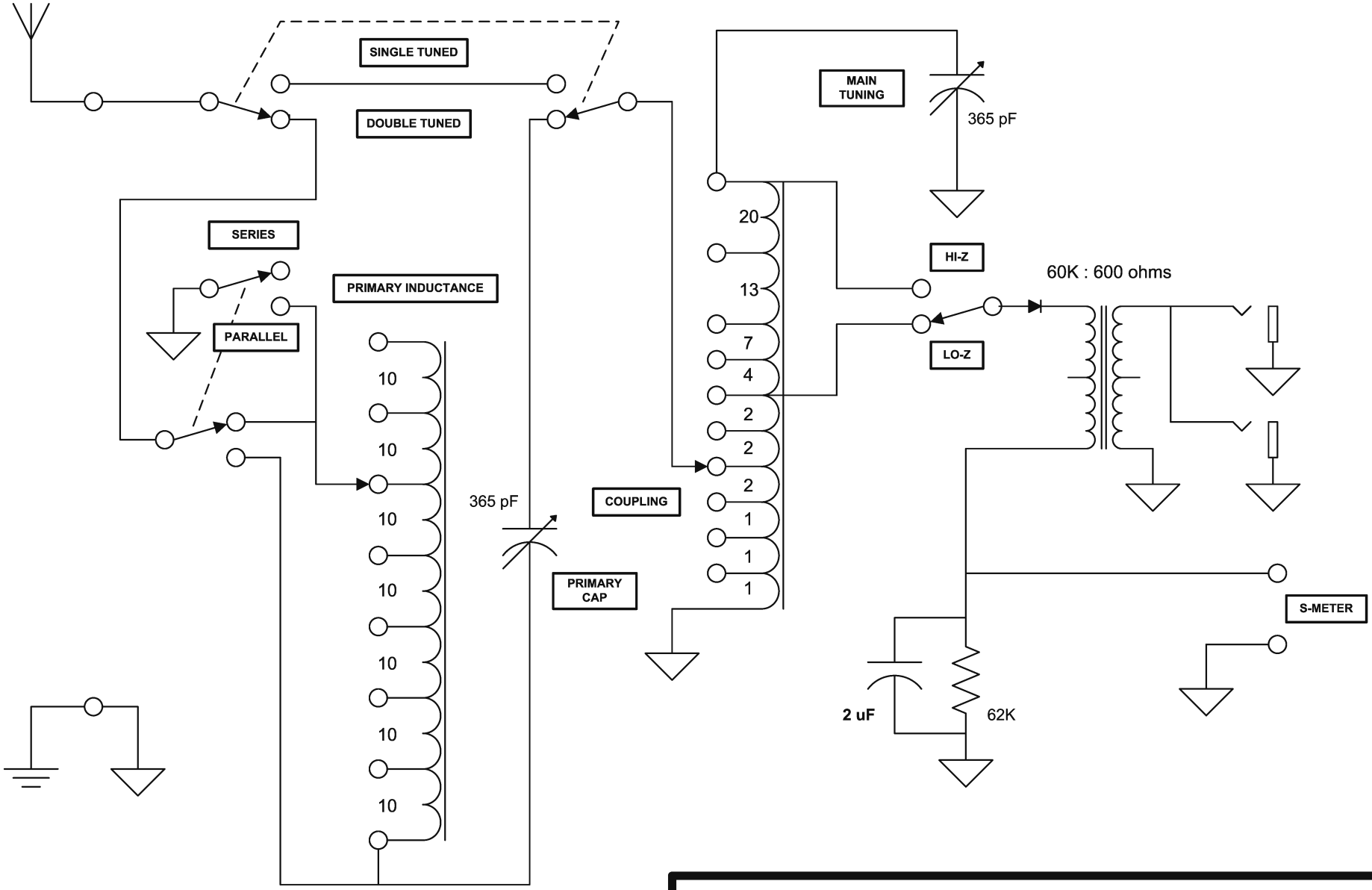
Skywaves Portable

ca. 2010



Repurposed Plastic Tackle Box

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

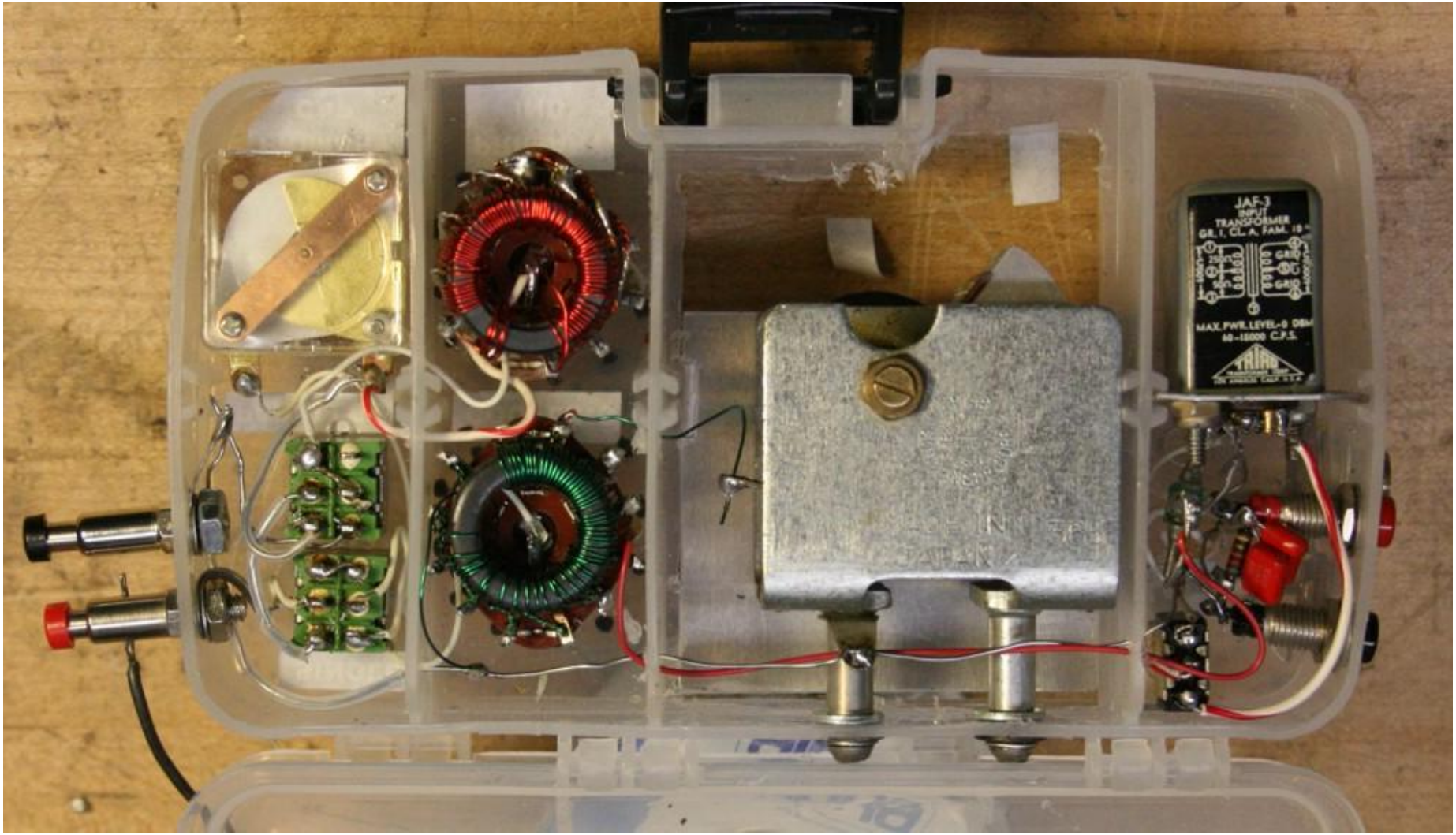


Both coils;
#26 wire on FT-82-61 cores.

SkyWaves Portable Research Crystal Radio

Al Klase - N3FRQ – 3/9/2010

Skywaves Portable - Back



Travel Kit

One more N3FRQ design

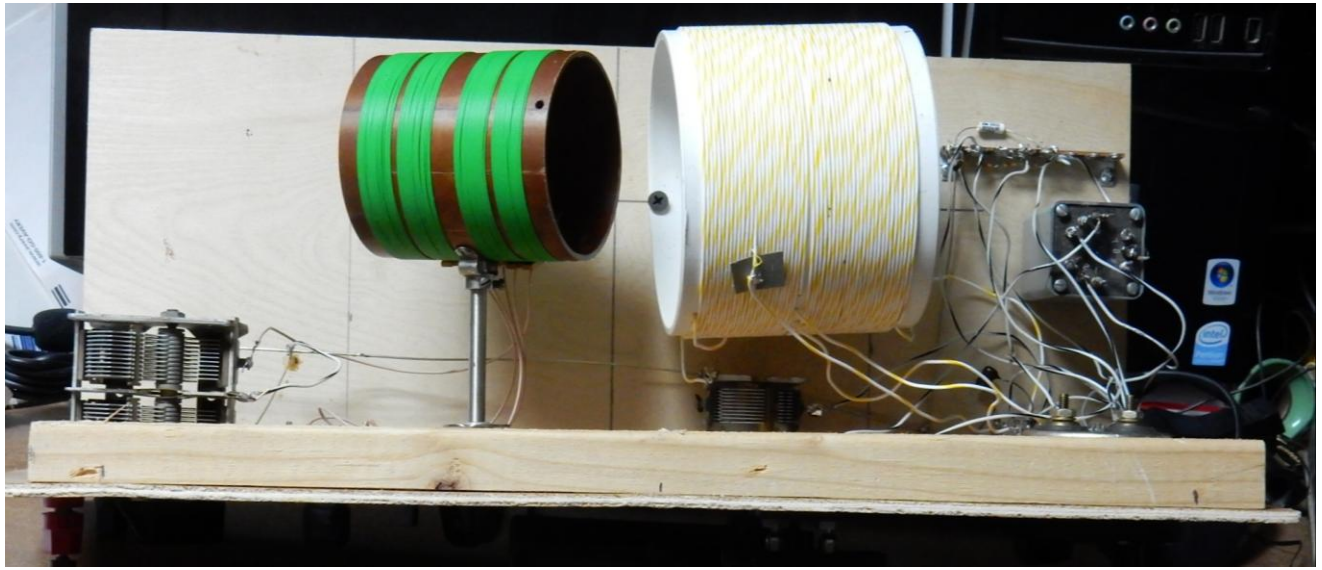
The Jersey City Special

WWI Telefunken field set served as inspiration.

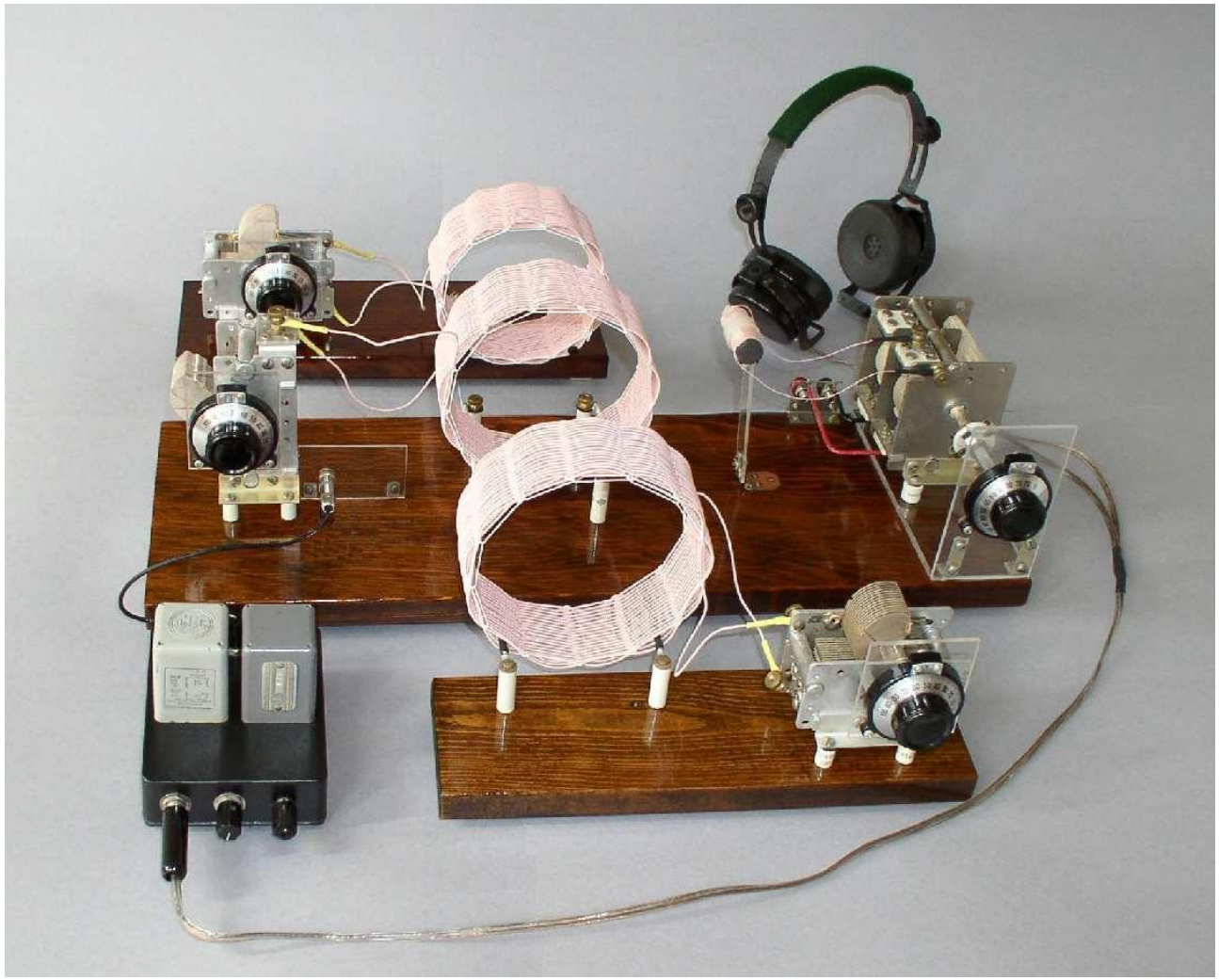
[The Jersey City Project]

[Video discussion of this set.]

The Jersey City Special

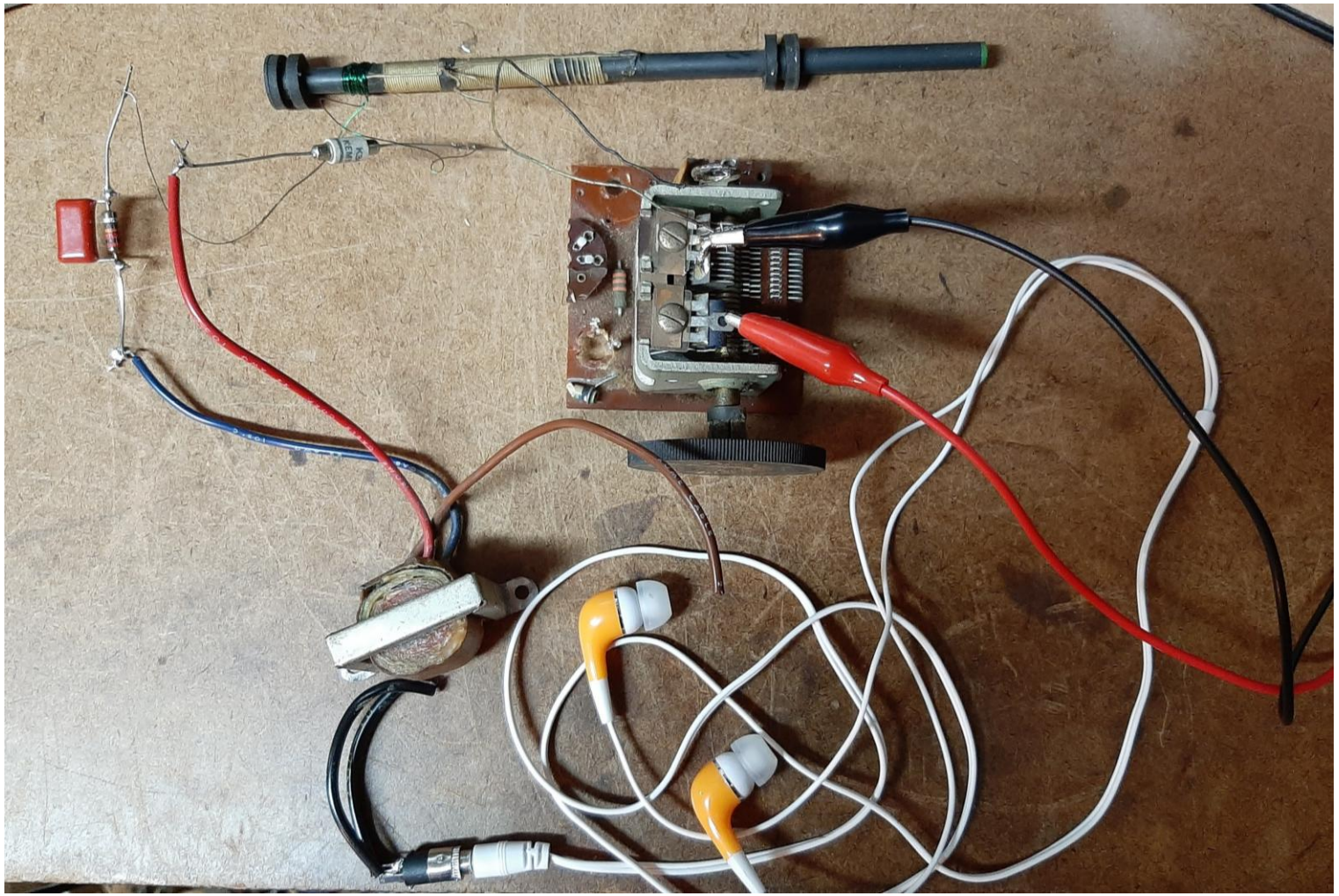


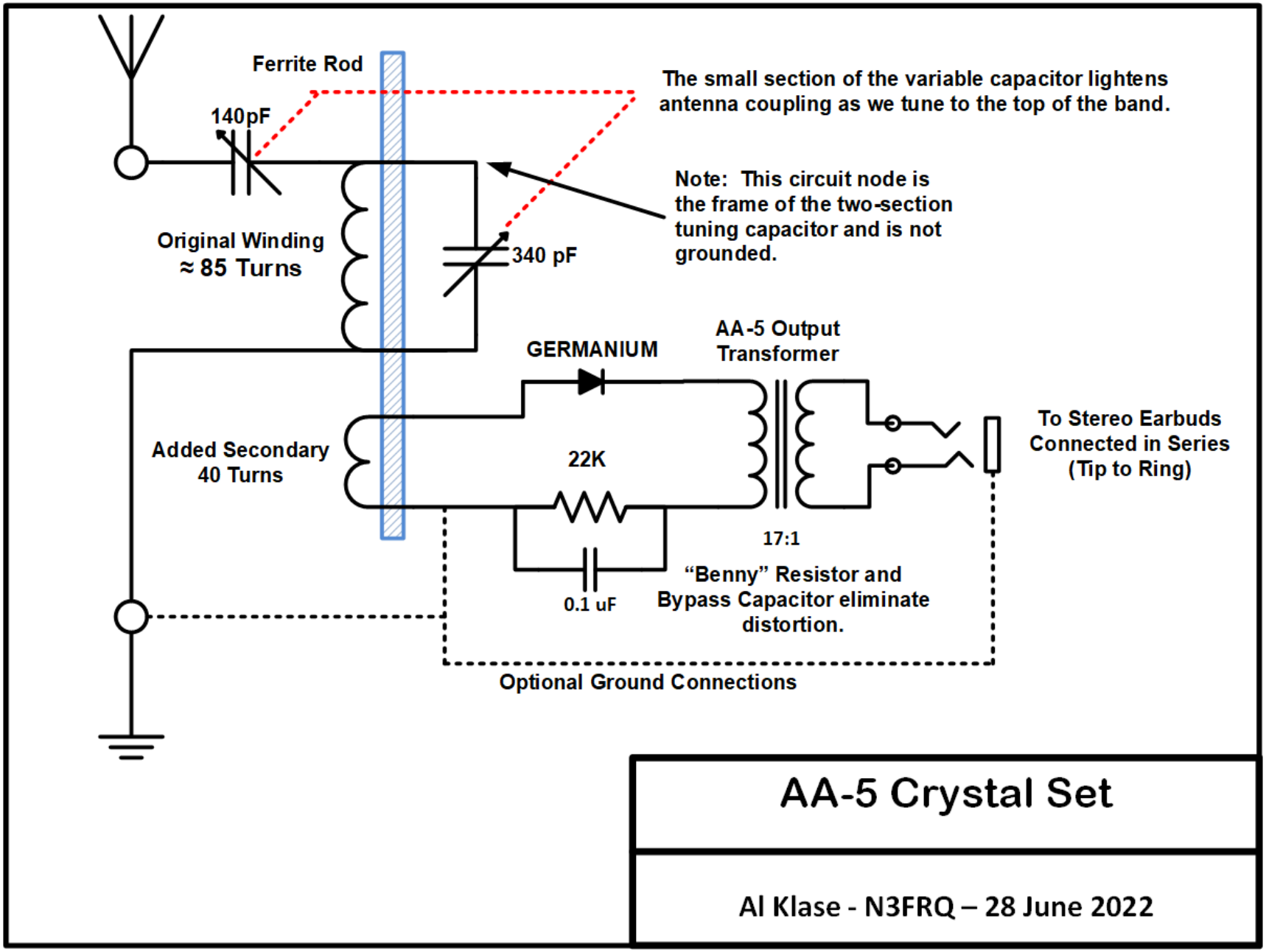
Lyonodyne Version 17 Crystal Set - Mike Tuggle



[Lyonodyne 17]

A Beginner's Crystal Set for the Antique Radio Guy



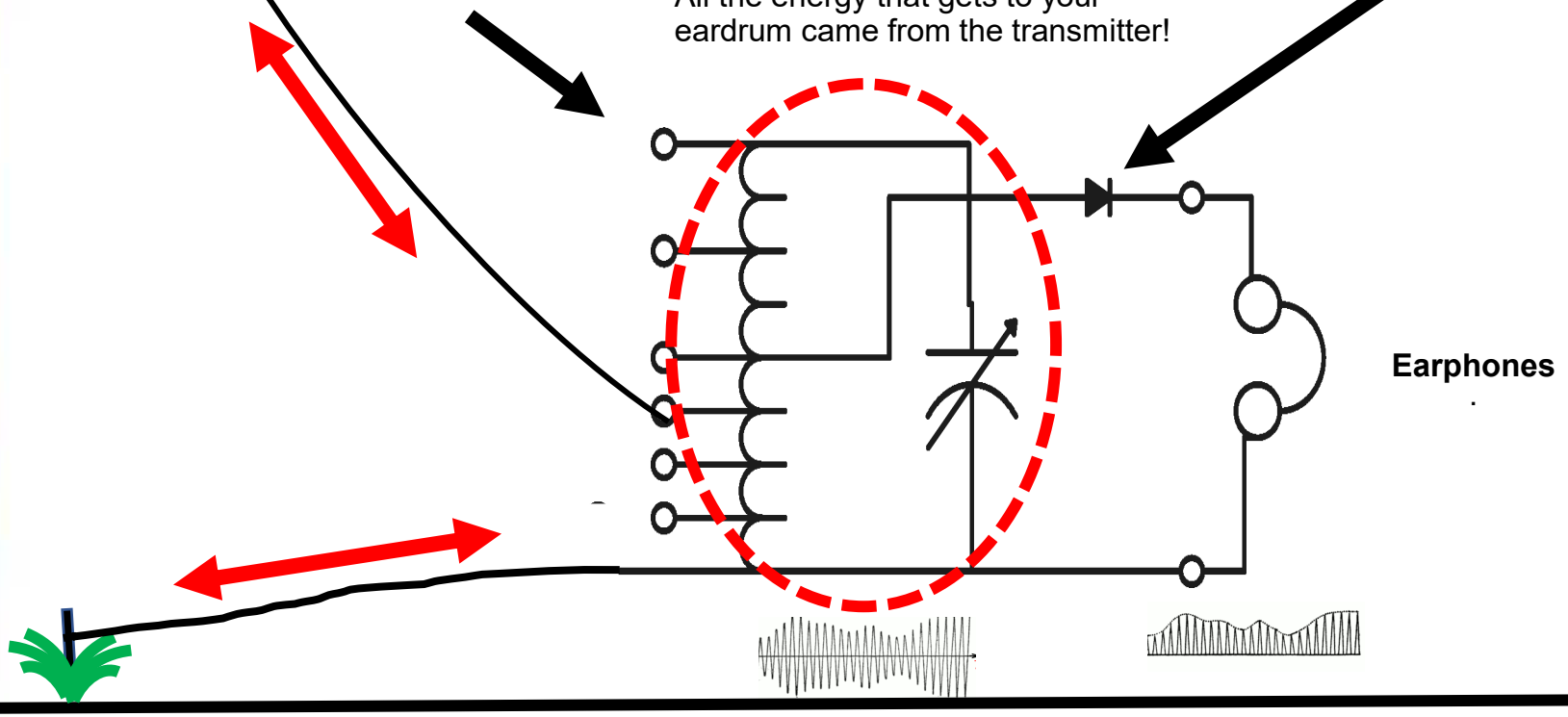

Ferrite Rod
140pF
The small section of the variable capacitor lightens antenna coupling as we tune to the top of the band.
Note: This circuit node is the frame of the two-section tuning capacitor and is not grounded.
Original Winding
≈ 85 Turns
340 pF
GERMANIUM
AA-5 Output Transformer
To Stereo Earbuds Connected in Series (Tip to Ring)
Added Secondary
40 Turns
22K
17:1
0.1 uF
"Benny" Resistor and Bypass Capacitor eliminate distortion.
Optional Ground Connections
AA-5 Crystal Set
Al Klase - N3FRQ – 28 June 2022

Build a Crystal Set!
It's good for your karma!

- A passive radio receiver.
  - No Power Supply
  - No Batteries
- All the energy that gets to your eardrum came from the transmitter!

Tuned Circuit
Selects
the desired station

Detector
Solid-State Rectifier
Converts radio-frequency
signals to audio.



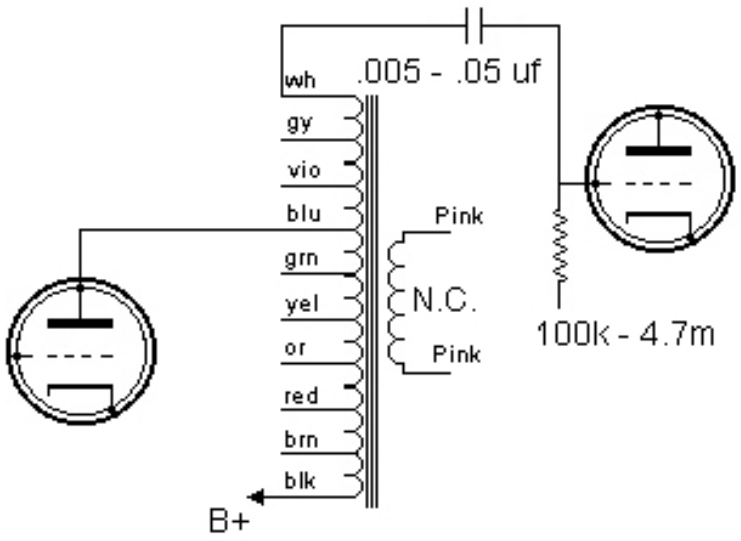
Earphones

Replacing Transformers in Battery Sets

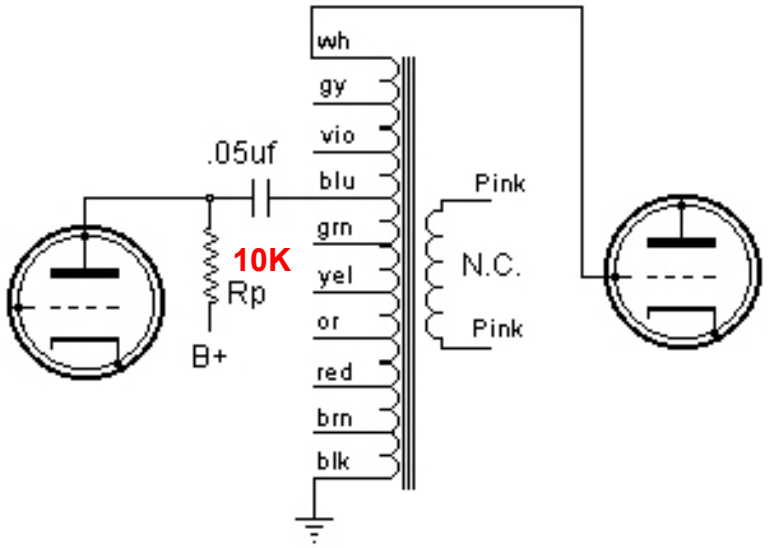
Visit Dave's Homemade Radios

Dave Schmarder

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



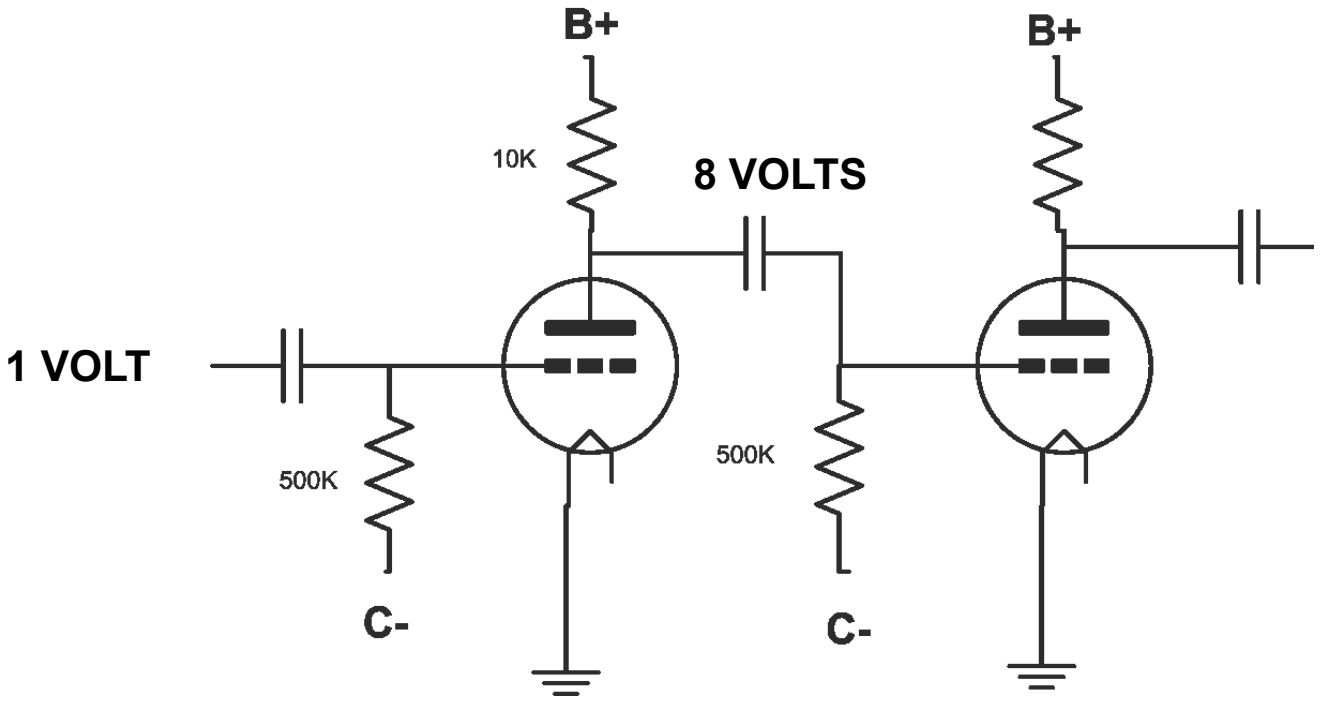
Bogen T-725 as an Interstage Auto-transformer



Bogen T-725 as an Interstage Auto Transformer Version 2

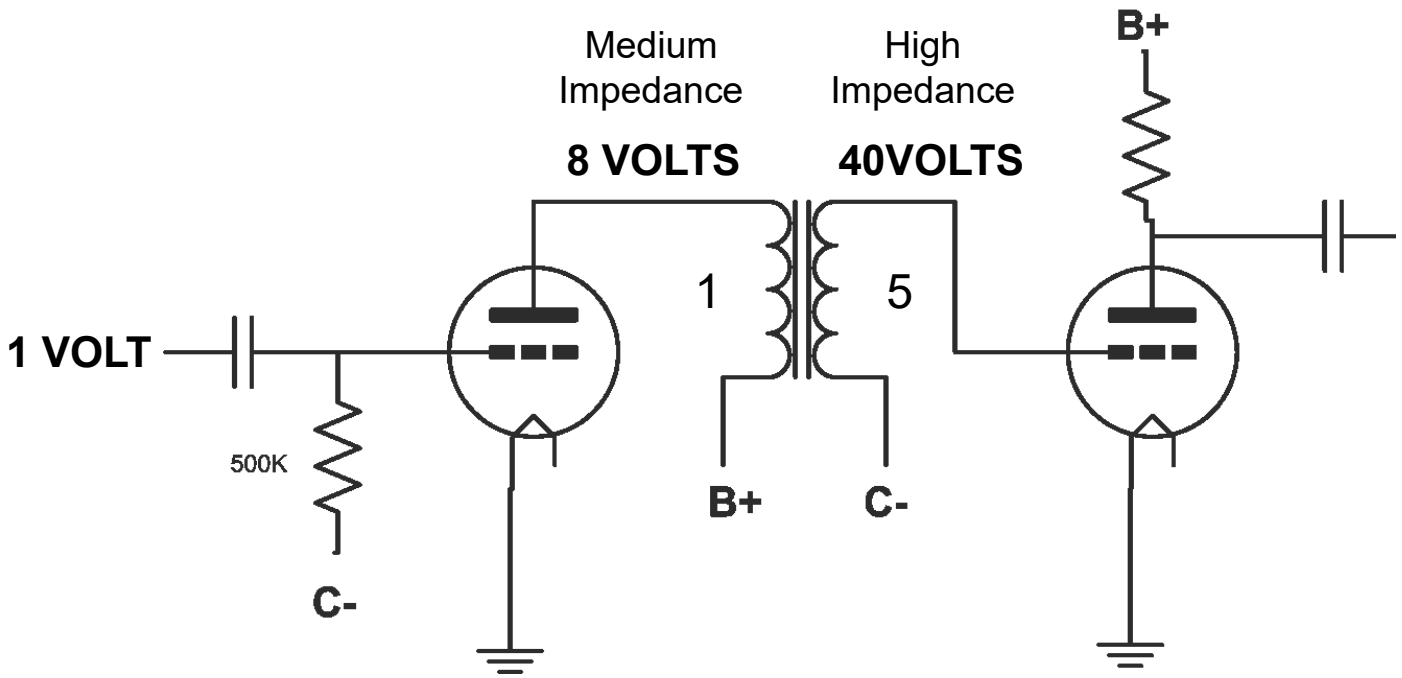
This arrangement keeps plate current out of the transformer. A good thing to do.

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