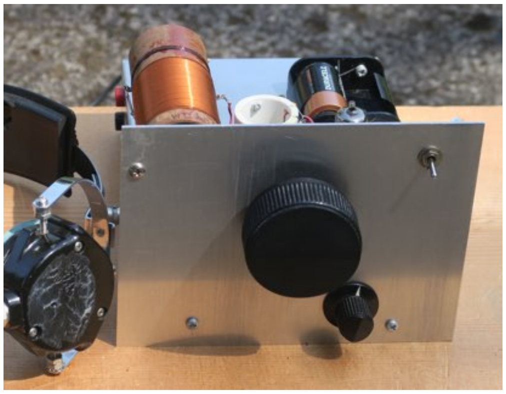
Experiments with a Single Vacuum Tube Regenerative Receiver

Wes Hayward, w7zoi April 28, 2022 ...



Abstract

A single tube receiver originally built over a half century ago is re-examined with up-to-date techniques. Although early 1950s technology is generally used, the design methods are recent. A two-coil Hartley oscillator circuit proves useful. This is enhanced when one of the coils becomes a bifilar element akin to a modern common mode choke.

Introduction

It's often fun and even informative to examine projects from the far past. Why did they work? What could I have done to enhance performance if they did not work as well as desired? I built a one tube AM broadcast band receiver about 70 years ago, a design extracted from the Bear Cub Scout Book, pictured in Fig 1 below. A schematic is presented in Fig 2. Although the radio worked, providing more volume than a previously built crystal set, only three local stations were heard. The distant stations were never found. I tried with marginal success to add regeneration.

Fig 1. The Bear Book

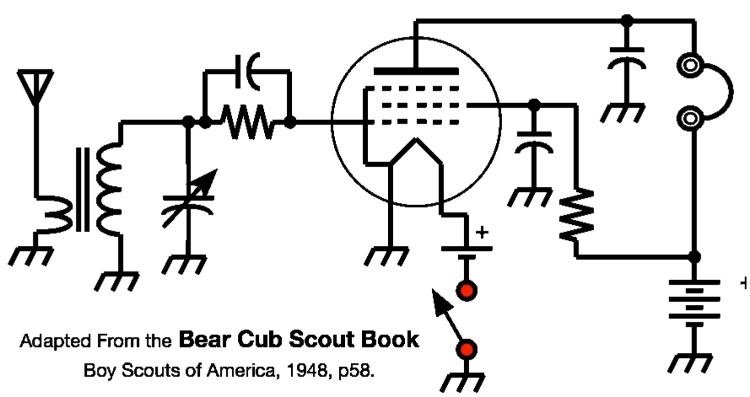


Fig 2. Schematic of the basic 1 tube receiver.

There is, of course, a wealth of information available about single tube radio designs that work well. See "Regenerative Circuit" in Wikipedia. I used some of the old methods in the past but also wondered if some newer tricks might be useful when applied to the old problem. It seemed like it might be interesting to rebuild a classic retro vacuum tube receiver, but apply some newer methods. This article describes these experiments.

Figure 3 shows a schematic of the updated, bare bones Bear Cub Scout receiver. This is a Tuned Radio Frequency (TRF) detector radio. Signals from a tuned circuit are detected in the grid-cathode diode of a pentode tube. The resulting audio is then amplified and applied to headphones.

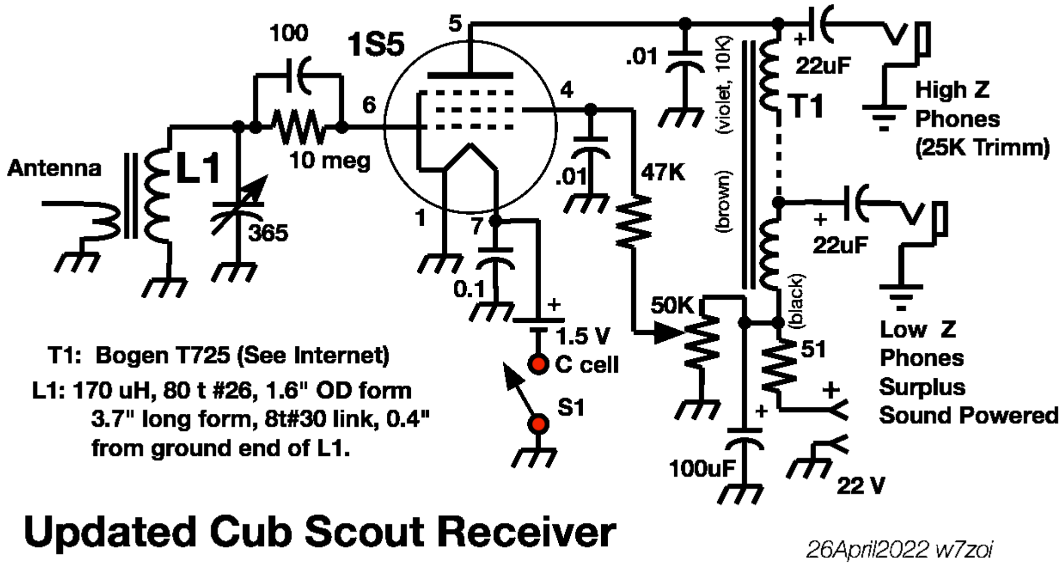


Fig 3. TRF Schematic

The original Cub Scout circuit was enhanced with an aluminum panel and chassis, a potentiometer to control the screen grid voltage (to be used later for regeneration control), provision for both low and high impedance headphones, and a really large knob to improve tuning resolution. Two headphone types were available. One was a classic high impedance set of Trimm Featherweight phones with a 25K impedance. The other was a set of WW-II era "sound powered" headphones for use on Naval ships. (Thanks to Jack, KE4ID) These headphones were so sensitive that a wire connection to a remote microphone required absolutely no amplification. The sound powered phones are revered by crystal set enthusiasts. I've not found any modern phones that even approach them for sensitivity.

The tank inductor was something I found in my junk box, source unknown. The 160 uH inductance was lower than needed to tune the entire AM broadcast band with a standard 365 pF variable capacitor, but was close enough for an experiment. I measured inductor Q of 150 at 1 MHz using a HP-4342A Q-Meter.

The Bogen T-725 audio transformer is another part familiar to the crystal set experimenter. It has a low impedance (8 ohm) secondary for a speaker or phones and a higher impedance primary that has taps for 150, 300, 600, 2500, 5K, 10K, 20K, and 40K ohms. I used the primary as an auto transformer to match the 150 ohm sound powered phones to 10K that was applied to the pentode plate. Unused taps are soldered to a scrap PC board with isolated pads to prevent accidental short circuits. The 25K Trimm phones connect directly to the plate with a blocking capacitor.

Performance for this receiver is better than I remembered from the original. Selectivity is improved owing to greater care in winding the RF input transformer.

Adding Regeneration

One model of a regenerative detector is that it is an oscillator with external RF injected. The classic circuit uses a tickler coil in series with the plate, a primitive form of oscillator. The Hartley oscillator is another circuit that can be used to convert a simple TRF to a regenerative receiver. Fig 4 shows three forms of this evolving circuit.

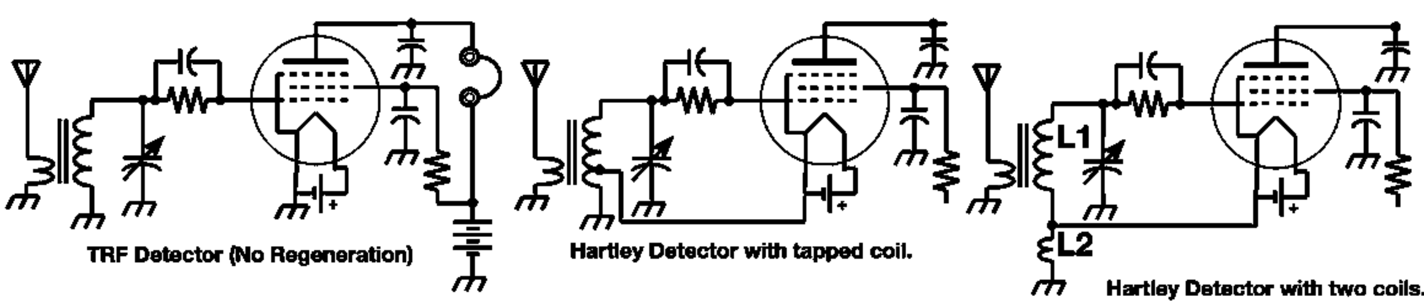


Fig 4. Regenerative detectors based upon the Hartley oscillator.

The classic Armstrong regenerative circuit used a plate tickler winding that was magnetically coupled to the main coil. We used a similar Hartley oscillator circuit. The first part of the figure is merely a repeat of Fig 3 for the Bear TRF receiver. The middle part shows the addition of a tap on the tuning coil. This is the usual form for a Hartley circuit. Typically, the tap is from 5 to 25 % of the number of turns up from the ground end of the coil. Experimentation is required. If the tap is too far up from the ground end of the coil, the oscillator starting gain is very high. This means that the screen voltage must be decreased significantly to cause the detector to stop oscillating. But this leads to audio distortion.

The right hand side of Fig 4 shows a variation of the Hartley oscillator where RF feedback results from the addition of a small inductor that is in series with the main coil. A detailed analysis shows that transformer action is not required for oscillation in the Hartley circuit. Indeed, if a Hartley oscillator is built with two isolated inductors (no shared magnetic field), it is the exact dual of the Colpitts, the popular oscillator with two capacitors.

A tapped inductor is not difficult to build. However, the two inductor Hartley form is handy as a coarse adjustment of the starting gain. It's also a useful tool to have when building and debugging a circuit.

The two inductor Hartley regenerative receiver is shown in Fig 6. The second inductor was wound on a plastic pill bottle. The initial inductance was 16 uH with a Q of 115 at 2 MHz. This turned out to be too much feedback. The coil was reduced to 13 turns, yielding an inductance of 11 uH. Smooth regeneration control was possible with screen voltage still up at half that of the plate. A photo is shown in Fig 6.

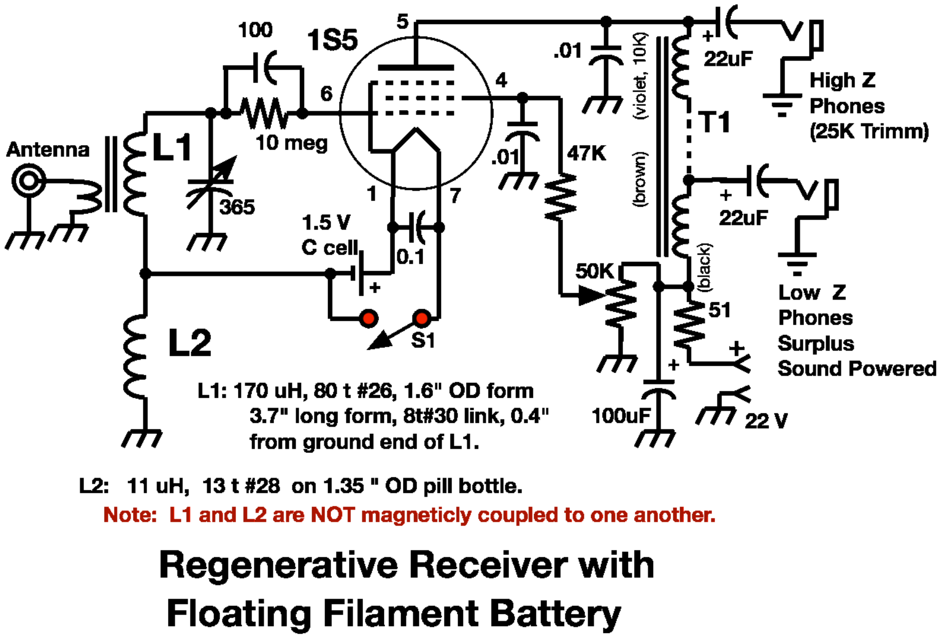


Fig 5. Detector with a Floating Filament "A" Battery.

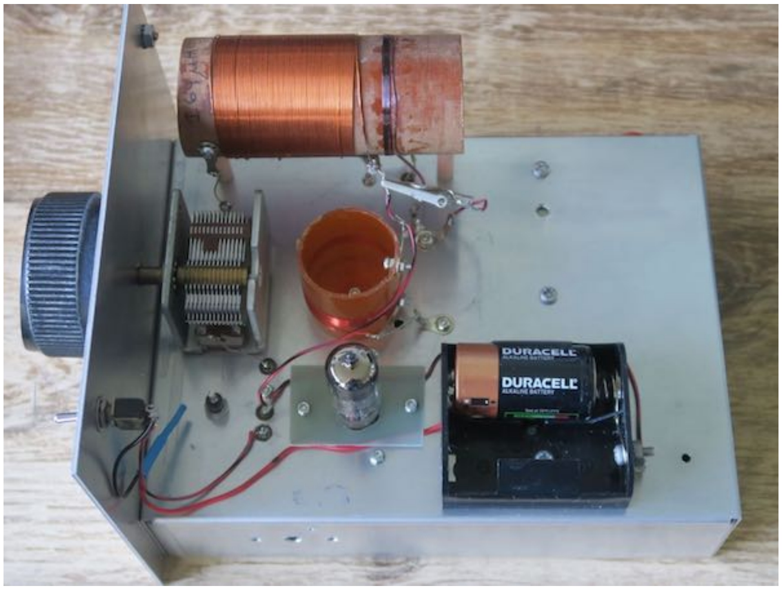


Fig 6. Photo of the floating A battery detector.

The performance was generally good for this receiver. Some out of town stations could be heard among the numerous local signals in the greater Portland, OR area.

The 1.5 volt filament battery and the related switch are attached to the connection between the two inductors. This hardware will add stray capacitance. It's not an issue at the low frequencies of the broadcast band, but it may become troublesome in the HF spectrum. This problem would disappear if a vacuum tube with an indirectly heated cathode had been used. The cathode is then a separate element with a filament that is just a heater.

The 1S5 tube used in our receiver has a directly heated cathode. Directly heated cathodes are still familiar circuit elements in ham radio designs, even in 2022. A prime example is the popular grounded-grid power amplifier using vacuum tubes such as the 811. The filament is usually powered through a bifilar wound choke. One end is at RF ground while the other is at the filament. RF drive is then applied to the cathode through a blocking capacitor. The choke is often wound on a ferrite rod, necessary when a wide frequency range must be covered. We apply the same idea to our broadcast receiver, now shown in Fig 7, but with the bifilar coil wound to provide the inductance needed for smooth regeneration.

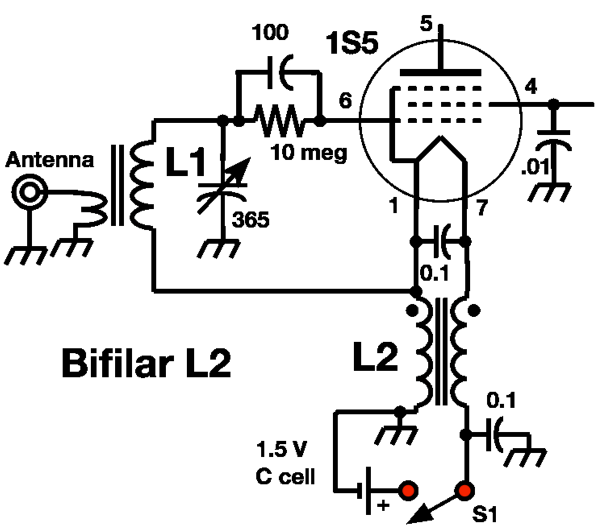
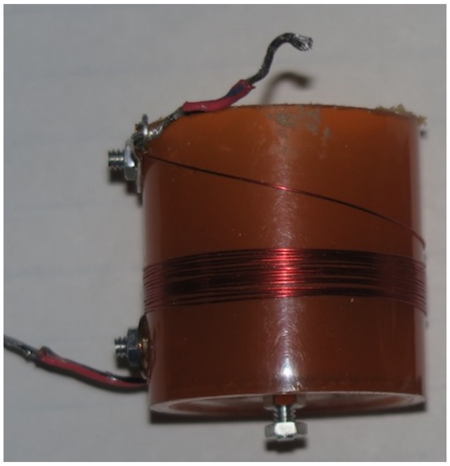


Fig 7. Regenerative receiver with bifilar inductor in a Hartley detector. Only the L2 and vacuum tube details are show; the rest of the circuit is the same as Fig 5.

The bifilar L2 coil was wound on a piece of 1.3 inch diameter PVC pipe. 16 feet of #28 enamel coated wire was doubled and then twisted with a hand drill to a non critical pitch of about 5 turns per inch. 20 turns of the 8 foot wire was then wound on the form. Photos of both coil types are shown in Fig 8. The dots next to the coil windings in Fig 7 correspond to the two wires attached to the filament. The common mode inductance, shown in Fig 9, was 11.2 uH, about the same as L2 for the floating filament battery receiver. Common mode L is measured with the two windings soldered together at each end. The soldered connections are removed after measurement. Q was not measured for this variation although it should not be critical.

A so called common mode choke or inductor has two modes. The common mode displays inductance, shown in Fig 9. The differential mode relates to the load that is connected between the two wires. In the case of L2, the load is the 30 ohm filament resistance (1.5 volt with 50 mA). This is the resistance seen at the other end. There is little inductance seen owing to the transmission line like properties where current in one wire will be matched by an equal current of opposite polarity current in the other, leaving no magnetic field, and hence no inductance. Common mode chokes are frequently used as antenna baluns.



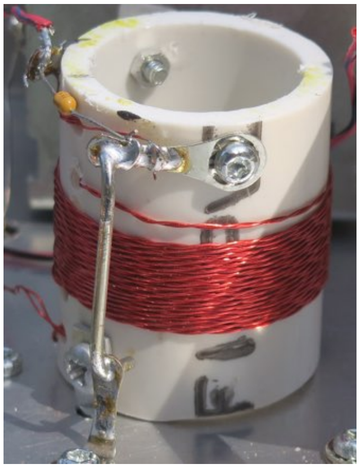


Fig 8. Bifilar version of L2. The left figure shows L2 from the floating battery version of the receiver in Fig 5 and Fig 6. The right photo is the bifilar L2. Both have an inductance of about 11 uH.

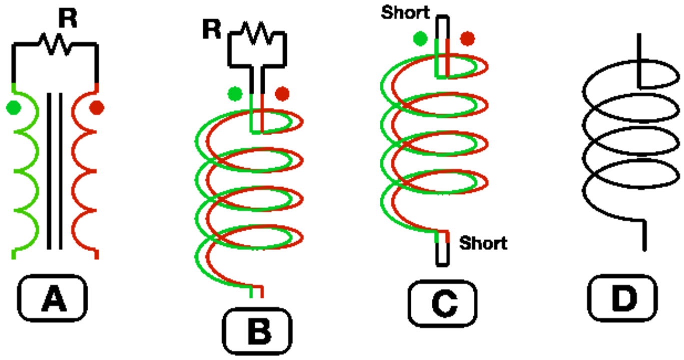


Fig 9. Schematic and sketch of a common mode choke or inductor. Part A shows the schematic for the common mode choke while B is a sketch of the coil. Colors illustrate the bifilar winding, without the twist. A resistor is a load at the top of the coil. This load is between the two wires; it a differential load. Part C shows the connection used to measure common mode inductance. When both ends are short circuited as shown, the structure behaves like a simple inductor, Part D. This L is the common mode inductance that becomes L2 in the composite tuned circuit. This inductance is very close in value to that of one wire with the other open circuited.

The 1S5 tube filament consumes 50 mA, so an alkaline C cell will last a long time. The filament function was formerly termed the “A Cell” battery and the high voltage was supplied by the “B Cell,” 22.5 volts for this design. Batteries with ratings of 22.5, 45, and 90 volts used to be readily available. Three 9 volt cells can be snapped together to form a 27 volt substitute. Higher voltage for the B cell should be avoided unless the electrolytic capacitors are replaced with 50 or 100 volt rating. I used an available bench supply for my experiments. Fig 10 shows a photo of the receiver.

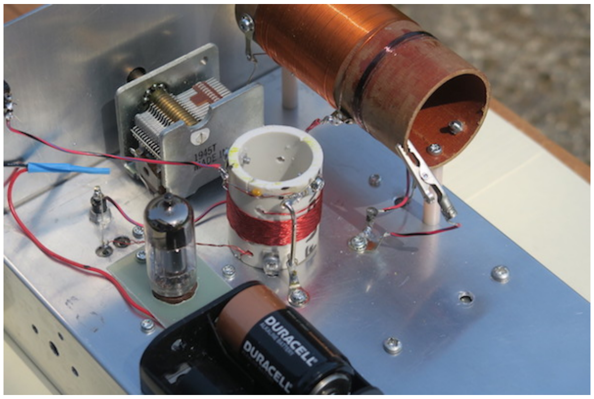
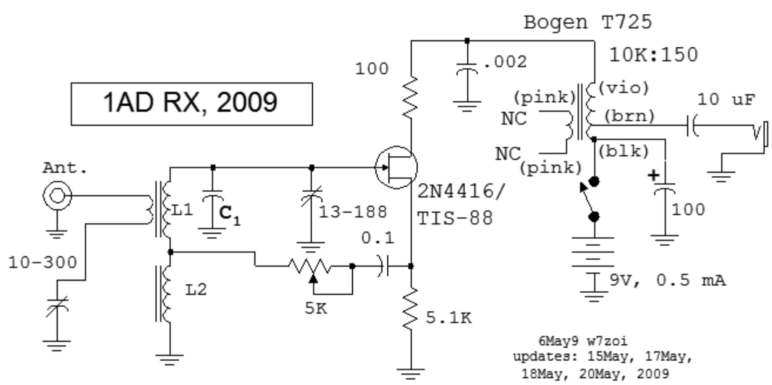


Fig 10. View of the top of the receiver. A grounded alligator clip is attached to a short wire near the end of the main coil. This allows the user to short circuit L2, converting the regen receiver to the original TRF form. This is essentially nothing more than experimental convenience. Be careful to attach only to the filament terminal that has been wired to DC ground. Clipping to the wrong wire could place a short circuit across the battery. See Fig 7.

One enhancement that would be worthwhile is a variable capacitor in series with the antenna link coil. This is common with regenerative receivers or crystal receivers. When adjusted for reduced capacitance, the receiver becomes more selective.

A ham band version of this receiver would be an interesting extension. The two coil approach, especially with a bifilar L2, may be a useful design tool. A two coil Hartley regen is shown in Fig 11.




```
BCB    L1: 420 uH, 52t#22 on FT-114A-61, 3t link
   L2: 2.7 uH, 7t#22 on FT-37-61. No C1.
SW1:  5.8 to 15 MHz.
    L1: 3.9 uH, 30t#28 (compressed) on T50-6, 2t link
    L2: 0.5 uH, 13t#22 on T37-6.No C1.
SW2:  5.8 to 7.3 MHz.
    L1: 1.4 uH, 16t#28 (compressed) on T50-6, 2t link
    L2: 0.25 uH, 7t#22 on T30-6. C1=280

The Bogen T725 transformer is available from numerous web sources.

   Almost any N-Channel JFET will work in this design.
```

Fig 11. A "One Active Device" regenerative receiver using a JFET. This circuit was built in the chassis of an old BC-221 Frequency Meter that has been used for numerous experiments.

Conclusions

The project provided a fun diversion, reminding me of earlier times. The radio from 70 years ago was close to being a functional project. The most interesting thing to emerge from the 21st century version was the realization that it can be very productive (and fun) to apply modern design methods to very old problems.