An Active Ferrite Rod Antenna with Remote Tuning

by

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Introduction

Active antennas are of interest to a wide range of users, from shortwave listeners (SWLs) and radio amateurs to designers of aircraft radios. SWLs and radio amateurs living in confined areas such as apartments or in communities having antenna restrictions find small antennas and especially active antennas to be a practical solution. Antennas that incorporate ferrite rods are of particular interest and practical usefulness as they have the potential of offering reasonably good performance for a very small physical size.

However, many commercial ferrite rod antennas and published hobby articles fail to take advantage of the performance capabilities that are possible with a thorough design, and these antennas are generally untuned wideband designs which, when the wide bandwidth of signals are introduced to the active portion of the antenna, result in often unacceptable intermodulation distortion (IMD) performance.

The purpose of this design is to demonstrate that an active ferrite rod antenna can be designed that incorporates high-Q remote tuning prior to the active portion of the antenna, and which also has sufficient sensitivity so as to be part of a receiver system that has good inherent signal-to-noise (SNR) performance.

Ferrite Rod Antennas

There is more than enough literature available about ferrite rod antennas that the basic theory really does not need to be repeated here, and very thorough treatments are available from Snelling (1), Burrows (2), and others (3, 4, 5). Since ferrite rod antennas respond primarily to the magnetic field component of a signal, they offer a good degree of immunity from electrostatic noise sources such as flourescent lighting, faulty mains transformers, and lightning, which is highly desireable and which makes the pursuit of this design worthwhile.

Ferrite rod antennas work best when they are unloaded, meaning they are conducted to a high impedance load. When so configured, the generation of IMD products has proven to be satisfactory, as the various losses associated with the ferrite material are minimized due to the fact that there is little or no signal current in the antenna winding(s).

For the prototype to be described here, the antenna consists of an RMX 1000 ferrite antenna rod (1.0"D x 7.5"L, Fair-Rite 61 material, available from ByteMark) with 200 turns of #34 wire, closely spaced at the centre of the rod. The overall performance of the antenna can be improved by spacing the windings and adjusting the overall length along the rod (6, 7), however the approach used here has proven to be adequate for the purpose of this design.

Other antenna configurations of ferrite rods and windings are usable and will have little effect on the remote tuning as that portion of the design is dependent upon a small inductor that is in parallel with the antenna, which will be discussed in the next section.

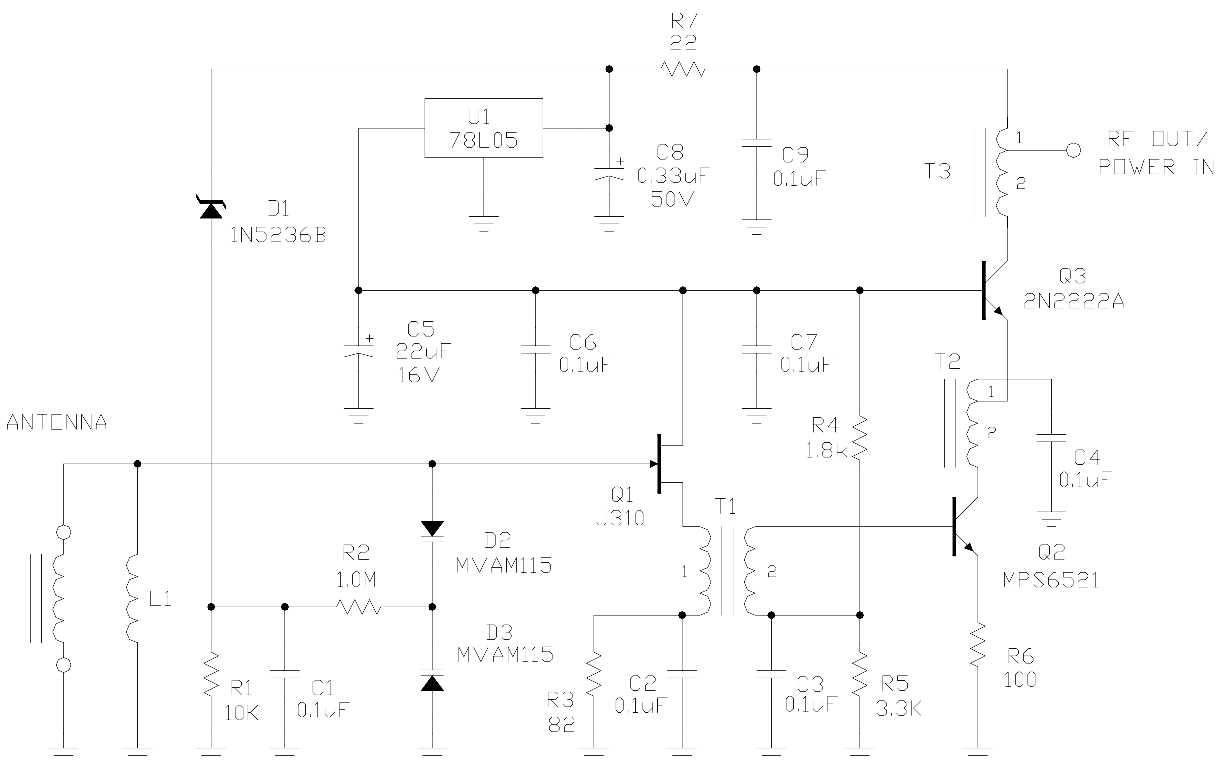
Amplifier Topology and Description

The schematic diagramme of the active ferrite rod antenna amplifier is shown in Fig. 1. Here, the antenna consists of a single winding on a ferrite rod, which is connected to a tuning network consisting of inductor L1 and the varactors D2 and D3. This is followed by a high input impedance voltage-to-current converter, which in turn is followed by a transimpedance current amplifier. Biasing is stabilized by way of a voltage regulator IC.

Remote tuning is applied as a voltage across resistor R1, which is derived from the amplifier power and tuning voltage that varies from 8V to 22V from a control unit. The zener diode D1 provides a voltage drop of 7.5V so that the supply voltage to the amplifier is always greater than 8V while the tuning control voltage varies from 0.5V to 14.5V.

The resonant frequency of the tuning network is determined by the varactor diodes D2 and D3 and the parallel combination of inductor L1 and the antenna winding. This arrangement allows for placing a large number of turns on the ferrite rod, which will then provide a higher signal voltage than if the ferrite rod winding was designed to accomodate the tuning varactors. With the value of L1 being 3.5uH, the tuning range for the network can be varied from 5.5MHz to almost 15MHz with 0.5V to 14.5V of tuning voltage applied to the MVAM115's. For different tuning ranges, the value of L1 can be adjusted as needed.

The varactor diodes D2 and D3 are depicted in Fig. 1 as being MVAM115's, however a variety of varactor diodes are available for this design, such as the MVAM109 and the



Parts List

C1, C2, C3, C4, C6, C7, C9 - 0.1uF
C5 - 22uF 16V electrolytic
C9 - 0.33uF 50V electrolytic

D1 - 1N5236B
D2, D3 - MVAM115 (see text)

L1 - 3.5uH (see text)

Q1 - J309 or J310 (preferred)
Q2 - 2N2222 or MPS6521 (preferred)
Q3 - 2N2222

R1 - 10K
R2 - 1.0M
R3 - 120 ohms (see text)
R4 - 1.8K
R5 - 3.3K
R6 - 22 ohms

T1 - 1:2 Transformer (see text)
T2, T3 - 3:1 Autotransformer (see text)

U1 - 78L05

Fig. 1 - Active Ferrite Rod Antenna Amplifier with Remote Tuning

NTE618 (available from Mouser). Hyperabrupt varactors of this capacitance range tend to be a bit expensive, and their availability is a bit limited, however they are necessary if electronic tuning over a wide range at MF and HF frequencies is desired.

At the resonant frequency of the tuning network, the ferrite antenna sees the only the high load impedance of the gate of Q1. Together with transformer T1, transistor Q2, and resistor R6, this portion of the amplifier circuitry forms a voltage-to-current converter of approximately 20uA/uV, or 20 Siemens (20S). Since the J310 source follower sees a rather large load resistance (about 10K) and the MPS6521 has fairly high current gain, there is very little in the way of IMD products.

Resistor R3 is depicted as being 82 ohms, however the value should be chosen such that the bias current for Q1 is in the vicinity of 15mA to ensure good linear performance. This value is not critical, but is rather a one-time adjustment needed to accomodate the range of biasing characteristics of the J310.

Transformers T2 and T3, together with transistor Q3, form a transimpdeance current amplifier having a power gain of 19dB, as each transformer provides a current gain of three. Amplifiers of this nature add very little in the way of IMD products as the amplification is a result of the current gain provided by the transformers and the transistor is basically performing the function of a current-controlled current source with a gain of slightly less than unity.

The 5V regulator U1 provides a stable bias voltage for the amplifier stages while the supply voltage is varied from 8V to 22V for the remote tuning. The small value for the electrolytic capacitor C8 (0.33uF) is prescribed in the manufacturer’s datasheet for applications where the device is located at an appreciable distace from the power source.

Transistor Selection

There is little that needs to be said about the use of a J309 or J310 (preferred) for the input stage. This device provides the high impedance needed to realize a usable signal voltage from the ferrite rod antenna and to provide a high degree of tuning selectivity from the tuning network. The J310 is known to provide a

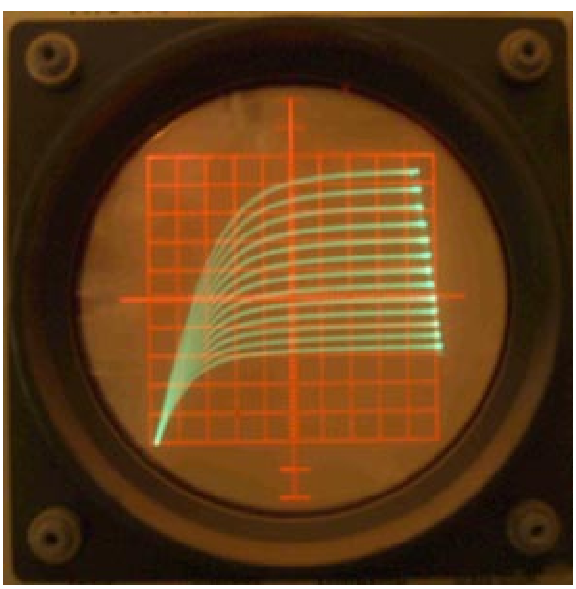


Fig. 2 - J310 Characteristic Curves (horizontal 1V/div, vertical 5mA/div, 0.2V/step)

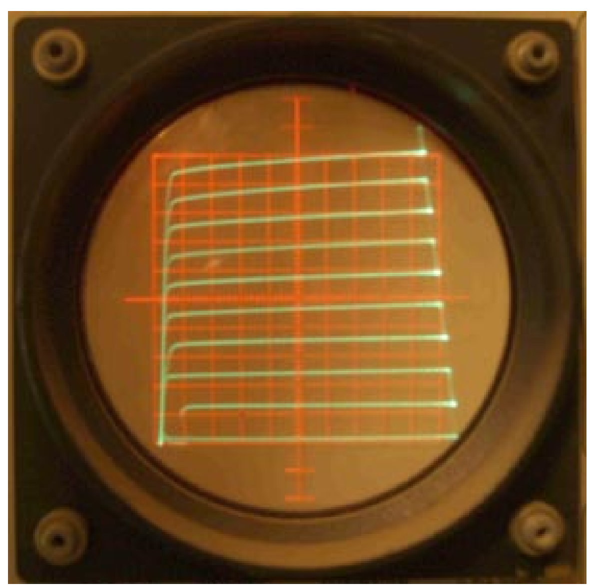


Fig. 3 - MPS6521 Characteristic Curves (horizontal 1V/div, vertical 2mA/div, 5µA/step)

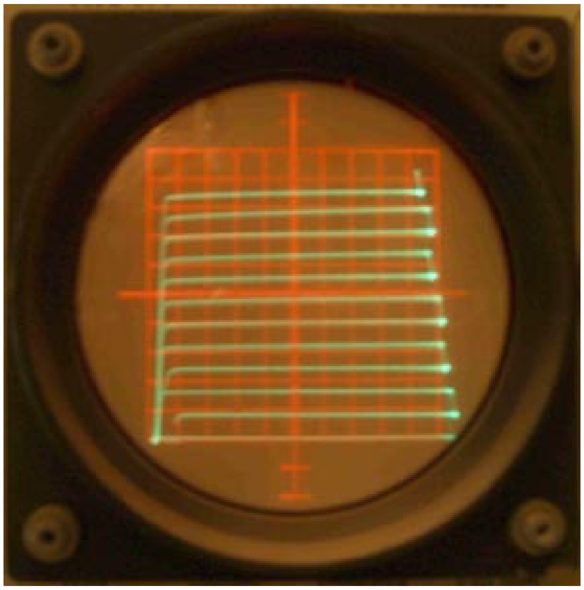


Fig. 4 - 2N2222 Characteristic Curves (horizontal 1V/div, vertical 2mA/div, 10µA/step)

slight edge in terms of IMD performance over the J309 when used as a source follower, though other devices such as the 2N3819 and 2N4416 will deliver better IMD performance in common-source applications. Fig. 2 shows the transfer characteristics of the J310.

The MPS6521 was chosen for the emitter follower Q2 as it has acceptable characteristics (primarily capacitances and f_T) for HF applications together with a fairly high gain (h_{fe}). The 2N2222 may also be used for Q2, though the IMD products may be a bit higher due to the lower h_{fe}. Both devices have very good linearity characteristics, especially in the saturation region, as shown in Fig. 3 and Fig. 4.

The 2N2222 was chosen for Q3 as it is better suited for the fairly high voltage that will exist on the supply line when tuning the amplifier to higher frequencies.

Transformer Construction

The transformers are key elements in the overall performance of the amplifier as they provide linear voltage gain (T1) and current gain (T2 and T3). They need to be constructed in such a manner as to minimize parasitics such as leakage inductance and intrawinding capacitance which affect the high cutoff frequency, but at the same time maximize the coupling coefficient, which affects the low cutoff frequency and the overall amplifier gain. Commercially available transformers such as those available from Mini-Circuits are convenient, however their overall performance is insufficient for high performance applications such as this.

Despite some unfortunate remarks made in the Technical Topics column of RF Communications some years ago (8), it is entirely possible for hobbyists of average ability to construct wideband transformers that will easily have performance equal to and even surpassing that of most commercial offerings, provided that simple guidelines concerning the design and construction as well as the selection of materials are adhered to (9, 10, 11).

One of the leading causes of poor transformer performance is the construction of the windings. Many designs, including most commercial products, make use of monofilar (meaning single-wire) windings, which results in less than ideal coupling coefficients, regardless of how they are arranged. Twisted wires, either bifilar (two wires) or trifilar (three wires) offer the best possible coupling, and one only has to learn how to design transformers using combinations of wires with 1:1 or 1:1:1 ratios. With twisted wires, coupling to the core is minimized, which results in lower losses, lower intrawinding capacitance, and lower IMD products that result from magnetic field nonlinearitites in the core material.

To that effect, all three transformers are constructed using a trifilar twist of #34 enameled wire. Eight turns are wound through the holes of a Fair-Rite 2843002402 binocular (aka balun or multiaperature) core. For lower frequencies, a core made from Fair-Rite 73 material should be used, and for higher frequen-

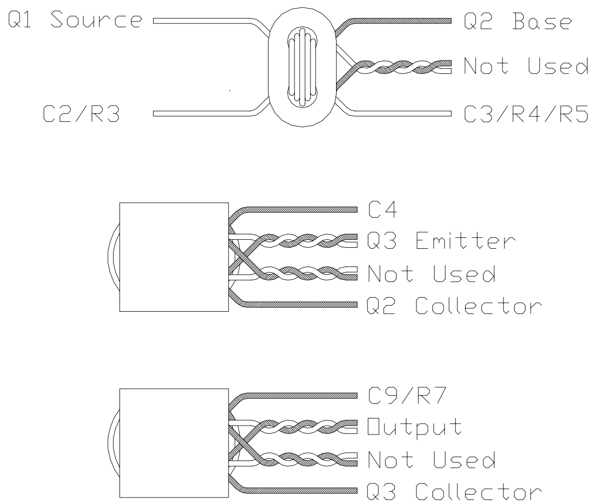


Fig. 5 - Transformer Construction Details for T1 (top), T2 (centre), and T3 (bottom)

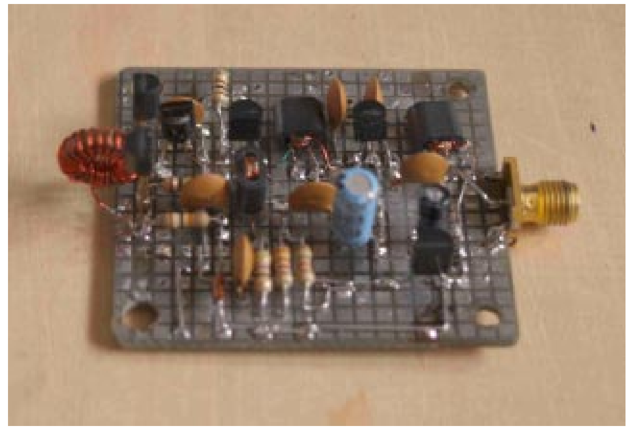


Fig. 6 - Amplifier Protype

cies cores made with either Fair-Rite 61 material or a Micrometals powdered iron material such as Carbonyl E (mix 2) or Carbonyl GQ4 (mix 8) should be considered. And for lower frequencies where more turns will be required, a smaller size of wire will be required.

With the wires of the three transformers being a trifilar twist, the free ends will all exit from one end of the core, and Fig. 5 illustrates how the various wires are arranged in this construction of the three transformers for the amplifier, though other arrangements are possible.

Prototype Construction and Testing

A prototype amplifier was constructed on a 1.7"x2.2" piece of Ivan board (0.80" squares, 0.10" apart on 1/16" G-10 epoxy fiberglass, similar to FR-4), as shown in the photograph of Fig. 6. Preliminary IMD measurements show the OIP3 and OIP2 to be >+30dBm and >+70 dBm, respectively.

Control Unit

The antenna amplifier and tuning can be easily powered and controlled by way of a simple bias tee, such as that described by Roelof Bakker (12), and a variable power supply. However, the amplifier was designed to make use of the control unit that was described in my September/October 2003 QEX article on active loop antennas (13, 14) as a matter of convenience since this control unit has been serving me well for various active antenna designs, and I have come to rely on it for trouble-free operation.

Referring to the schematic of Fig. 7, the unit begins with a DC power supply consisting of a 24V control transformer T1, a full-wave rectifier consisting of diodes D1 through D4, and the electrolytic capacitor C1, which provides about 30VDC. The LM317 regulator U1 provides a fixed 26V for the system, and LED D5 is simply a pilot light.

Transistors Q1 and Q2 and their related components form a current limiting circuit with LED D6 providing an indicator that the unit is in current limiting. Resistor R7 determines the maximum current that the unit will provide, with the value shown (15 ohms) limiting the current to approximately 50mA.

Potentiometer R10 is the antenna tuning control, and given the tuning sensitivity of the antenna it should be of the 10-turn variety. Meter M1 is the tuning indicator, and potentiometer R8 is a full-scale adjustment which is set by ad-

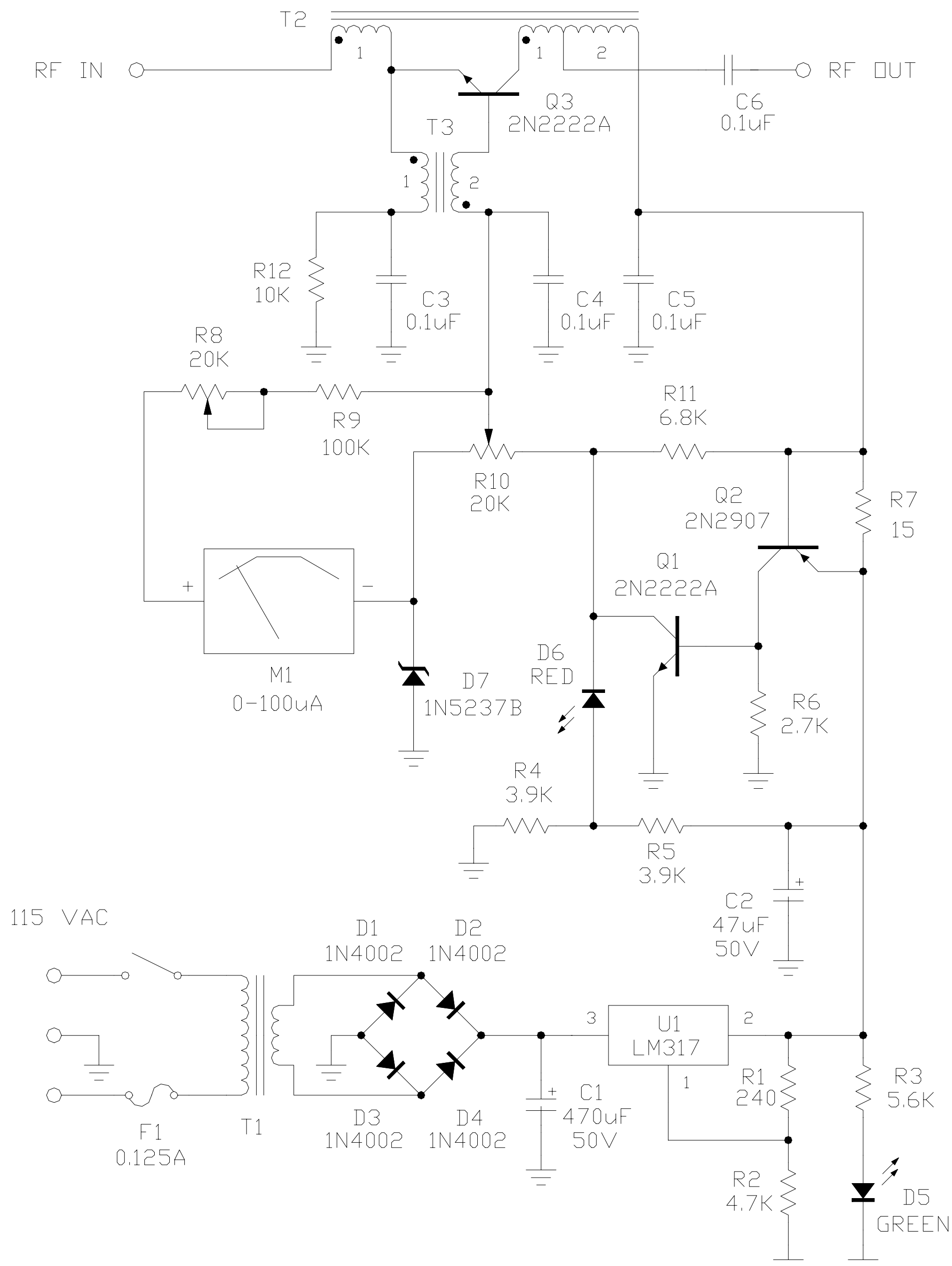


Fig. 7 - Active Antenna Power and Control Unit Schematic (from reference 14)

justing R10 to it's maximum setting and then adjusting R8 for a full-scale reading on M1.

Transistor Q3 together with transformers T2 and T3 comprise an augmented lossless feedback amplifier (15, 16), and the amplifier transistor Q3 also acts as the pass device for controlling the supply and tuning voltage to the antenna ampifier.

The construction of the amplfier transformers T2 and T3 is not necessarily obvious. Transformer T3 is identical in construction to transformer T1 of the antenna amplifier, the details of which are shown in Fig. 8.

The construction of transformer T2 is a bit more demanding, and it is necessary to have to violate the "no monofilar windings" rule For this transformer, you begin with six turns of #34 wire, with the ends exiting from one end of the binocular core (the left end, as shown in Fig. 8). Then, you wind six turns of #34 trifilar wire, with the ends exiting from the opposite end of the binocular core (the right end of Fig. 8). The wires of the trifilar winding are then interconnected so as to form the 1:2 output winding of the transformer, and the various ends are connected to the other circuitry as shown in the labeling in Fig. 8.

The completed protype of the control unit is shown in the photographs of Fig. 9 on the next page.

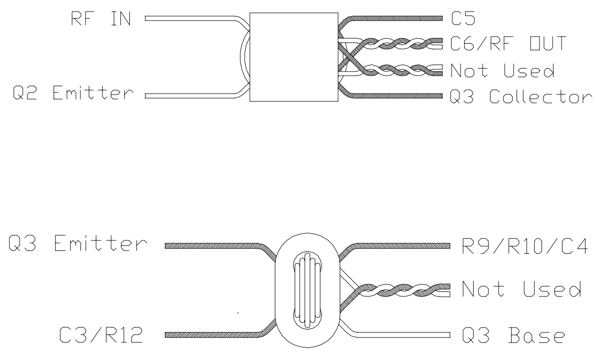


Fig. 8 - Control Unit Transformer Construction Details for T2 (top), and T3 (bottom)

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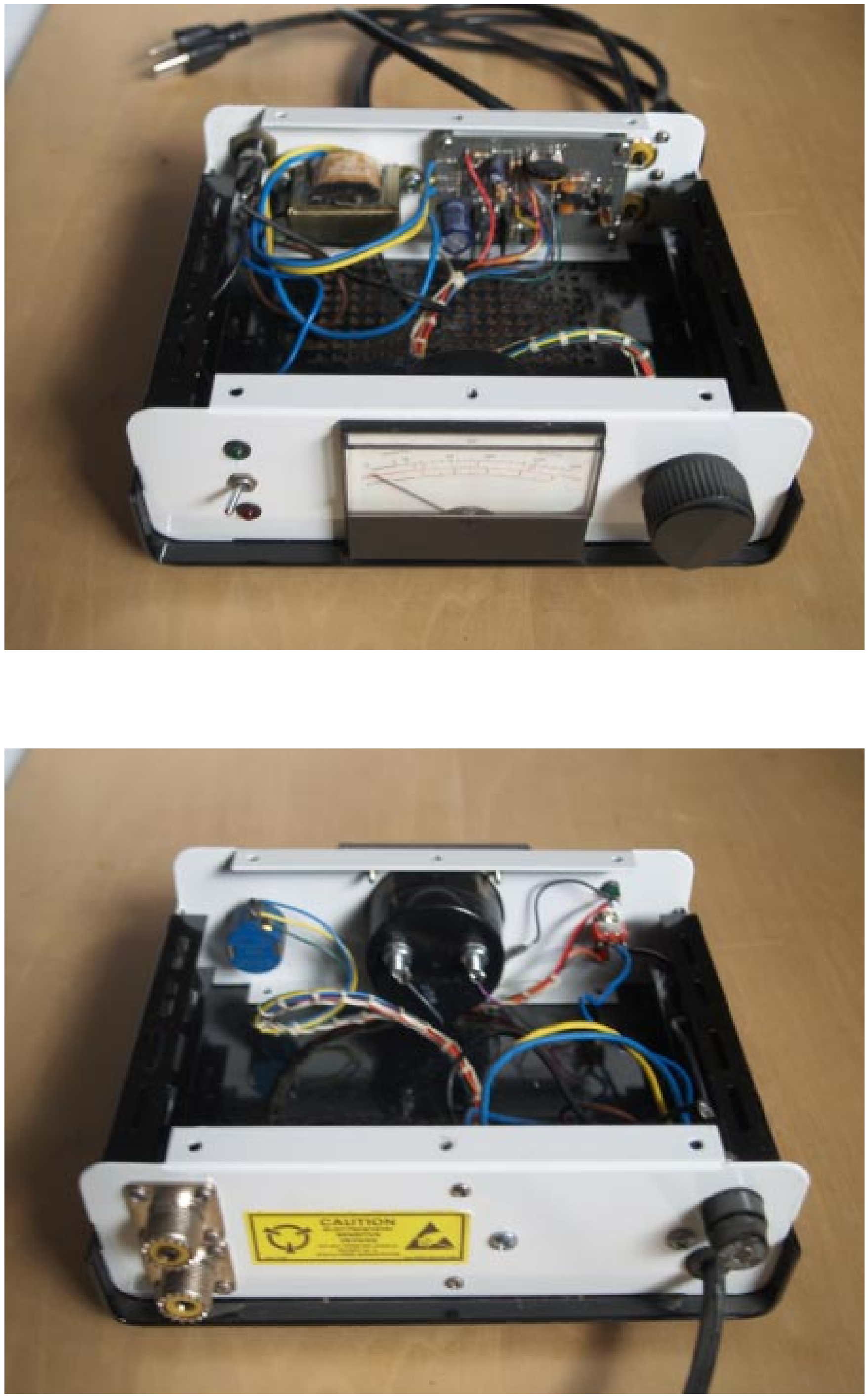

Fig. 9 - Active Antenna Power and Control Unit Prototype
Front View (top) and Rear View (bottom)