An Active Short Dipole 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.

Physically small antennas that have a directional radiation pattern can be very useful when nulling out interference is desired. Small loop antennas have this characteristic, and small shielded loop antennas provide a good degree of immunity from low frequency electric field noise, which is highly desireable in urban environments. Both forms of loop antennas require some form of tuning in order to accomodate the high inductive reactance of the terminal impedance. Designs that employ parallel tuning require an amplifier to couple the resultant high antenna impedance to the feed line, while those that employ series tuning can be passively matched to the feedline and have exceptional noise figure (NF) and intermodulation distortion (IMD) performance.

The purpose of this paper is to present an alternative small directional antenna that is capable of both wideband and tuned narrowband perfromance and which can be made with readily available and inexpensive parts and materials.

Short Active Dipole Antennas

Dipole antennas share radiation pattern characteristics that are similar to those of loop antennas. Typically, dipoles are designed such that their length is a half wavelength of the desired operating frequency although other lengths, although other lengths such as that for the Zepp (short for Zeppelin) are found as they have a narrower major radiation pattern.

A half-wavelength dipole has a terminal impedance of roughly 72 ohms. As the antenna becomes shorter with respect to wavelength, the impedance increases and is best represented as a large resistor in series with a small capacitor. This is in direct contrast with the terminal impedance of a loop antenna, which is often represented as a small resistance in series with a large inductor. Also, as the dipole becomes smaller with respect to wavelength the efficiency and gain decreases, however the directional characteristics are retained, much the same as with a small loop.

The high terminal impedance of a short dipole antenna requires that an amplifier with a similarly high input impedance be employed in order to conduct the antenna signal voltage to a suitable feedline, which is typically 50-ohm or 75-ohm coaxial cable. The NF and IMD performance of such an amplifier constitutes the Achilles Heel of active dipole antennas, and a considerable amount of attention to detail is required in order to arrive at a suitable design the provides a high degree of dynamic range,

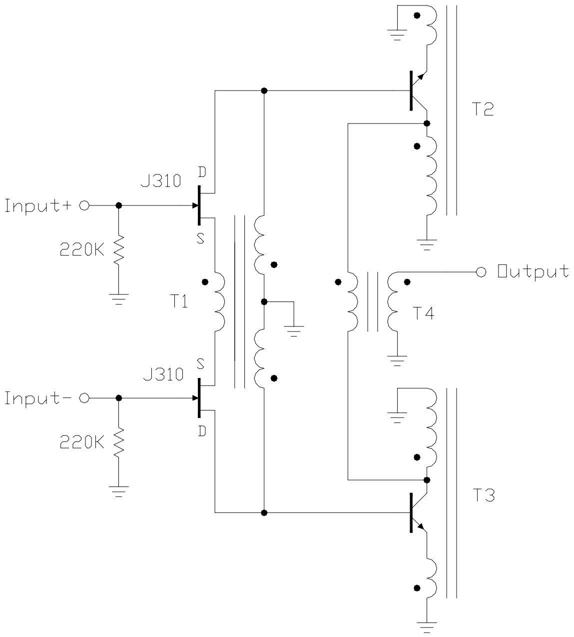


Fig. 1 - The Datong AD270/370 Active Dipole Antenna Amplifier

meaning low NF and high IMD performance, while at the same time keeping cost and power consumption to a minimum.

The Datong AD270/370 Active Dipole Antenna

One of the more popular commercially available active dipole antennas was the Datong AD270 and AD370, the former intended for indoor useage and the latter for outdoor. The amplifier consisted of a balanced JFET input stage using transformer-couple drain-to-source feedback, followed by a pair of bipolar transistor amplifiers using transformer-coupled collector-to-emitter feedback and then a balanced-to-unbalanced (BalUn) transformer. DC power for the antenna was conducted through the coaxial cable feedline. The overall design of the amplifier shows that a good amount of attention was given to both NF and IMD performance, however it does have a somewhat critical flaw.

The JFET input stage is shown in abbreviated form in Fig. 1. The two antenna elements are connected to the JFET gates through a series of coupling capacitors together with some static voltage suppression circuitry, which, together with other details is not shown here for reasons of clarity. The transformer provides a means of drain-to-source negative feedback, a configuration that was made popular by Burhans (1, 2) as well as others (3, 4)

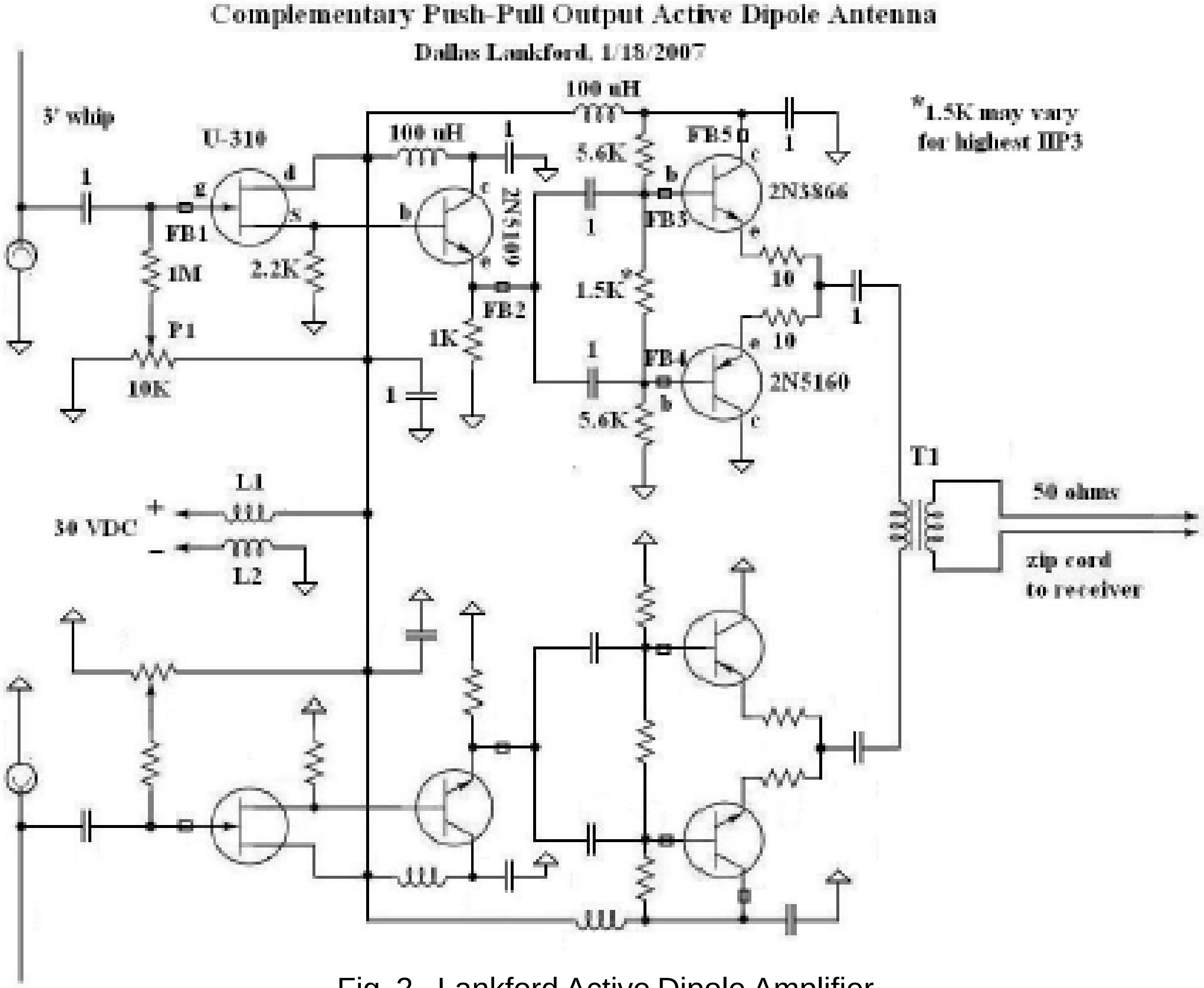


Fig. 2 - Lankford Active Dipole Amplifier

and which was used in the design of the North Country active short monopole antenna (5) which used a $US20 transistor and consumed a large amount of DC power, both aspects of which detracted from the desirable high dynamic range performance of the design.

Those who are experienced in the design of active antennas will undoubtedly recognize that there is no common signal path between the two antenna elements, nor is there any provision for providing immunity from strong common-mode signal voltages that can occur when in close proximity to high-power broadcast stations as well as high intensity noise sources such as lightning. This is an aspect of active dipole design that is often overlooked (6, 7, 8).

One could argue that the balanced nature of the amplifier provides for some common-mode immunity on the output side, however the much preferred approach to the problem is to provide such immunity at all instances, and it is essential that it be applied at the earliest opportunity. This aspect of the design will be discussed at length later.

The Lankford Active Dipole Antenna

An additional active dipole design worth mentioning is that of Dallas Lankford (8), the full schematic of which is shown in Fig. 2. Just as with the Datong amplifier, the Lankford design lacks a common signal path between the two elements. More seriously, the design lacks any provision for immunity from common-mode signals, the output coupling transformer T1 notwithstanding. The design is essentially a pair of monople amplifiers in parallel and undoubtedly has very poor common-mode performance.

In addition to the lack of common-mode signal immunity, the Lankford design requires the use of a pair of obsolete transistors (2N5160) which cost $US10 each. Further, the use of table lamp zip cord for transmission line is highly questionable if for no other reason than the very high dielectric losses in the insulation material. It also requires that a separate conductor be provided for supplying DC power, which is an unnecessary installation burden.

An Improved Balanced Active Dipole Antenna Amplifier

The Lankford circuit has little if anything to offer as a basis for an efficient and effective design, however the balanced feedback topology of the Datong circuit shown in Fig. 1 is a very good place to begin. To start with, we add a BalBal transformer between the antenna input terminals and the JFET gates, as shown in the functional schematic of Fig. 3. This provides the best possible immunity from strong common-mode signals and also allows for the elimination of the 220K gate biasing resistors, which in turn provides a very high load impedance for the short dipole antenna. For wideband operation, the added input transformer can be a simple 1:2CT (aka 1:1:1) transfomer made with four or more turns of a trifilar twist of enameled wire through the holes of a suitable binocular core, such as a Fair-Rite 2843002402. This turns ratio provides a noise- and distortion-free voltage gain of 2.

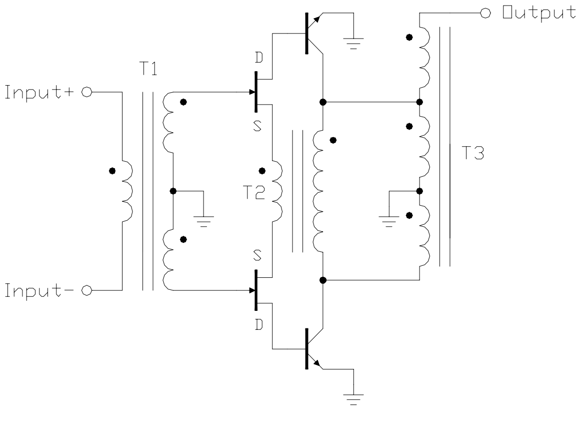
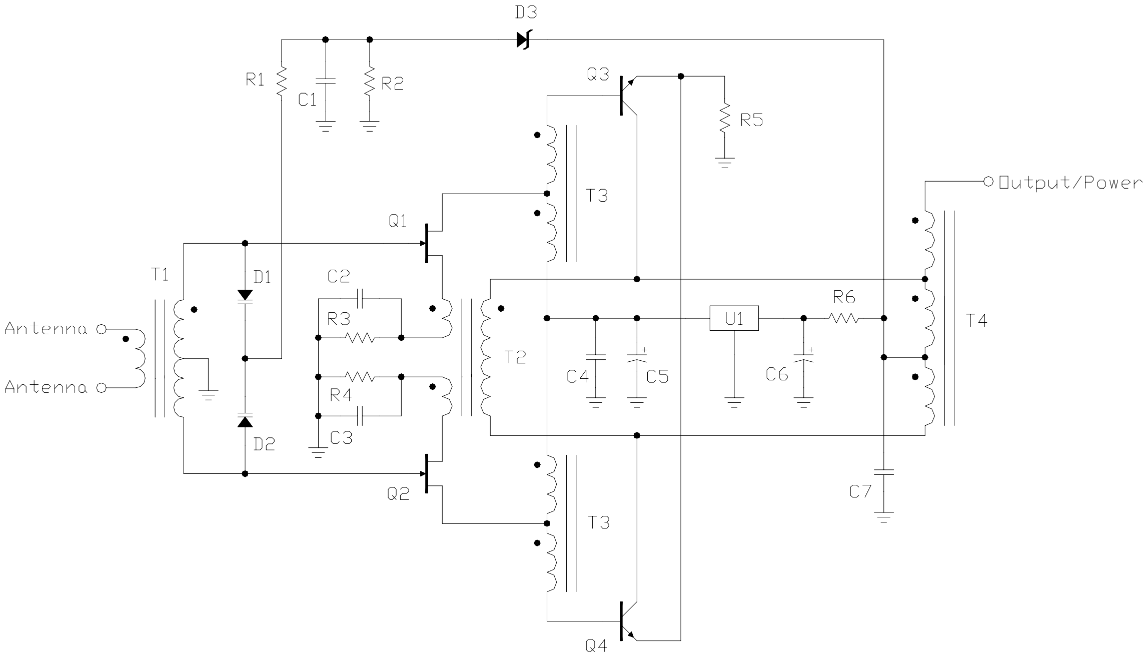


Fig. 3 - Basic Balanced Active Dipole Amplifier

The JFET biasing resistors R3 and R4 are chosen to provide about 5-10mA of bias current for each device. These may be changed as desired if a different bias condiciton is desired

Rather than have two separate gain stages as with the Datong amplifier, the JFET and bipolar devices are combined into a single non-inverting stage having a very high transconductance. The output impedance characteristics of the amplifier remain essentially the same as before, however the higher open loop gain provides significantly better IMD characteristics for the JFET input stage. The amplifier gain is now controlled by the turns ratio of transformer T2. This approach eliminates the bipolar stage feedback transformers T2 and T3 of Fig. 1, which further simplifies the design.

Transformer T3 is a familiar 1:1 BalUn which establishes the balance of the output side



Parts List

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

D1, D2 - MVAM109 or MVAM115 (see text)
D3 - 1N5236B

Q1, Q2 - J309 or J310 (preferred)
Q3, Q4 - 2N2222 or MPS6521 (preferred)

R1 - 1.0M
R2 - 10K
R3, R4 - 100 ohms (see text)
R5 - 220 ohms
R6 - 12 ohms

T1 - 1:2CT Transformer (see text)
T2, - 2:2:12 Transformer (see text)
T3 - 1:2 Balanced Autotransformer (see text)
T4 - 1:1 Balun Transformer (see text)

U1 - 78L05

Fig. 4 - Active Short Dipole Antenna Amplifier with Remote Tuning

of the amplifier as well as providing a convenient means of conducting the DC power from the coaxial cable feedline.

An Active Dipole Antenna with Remote Tuning

The basic active dipole antenna amplifier of Fig. 3 is now further modified to include additional gain and remote tuning, as shown in Fig. 4. Here, a pair of varactor diodes D1 and D2 provide a means of adjusting the parallel resonant frequency of a tank circuit. This feature requires that the input transformer T1 now be made so that it has an inductance value that will provide tuning over a desired range.

For coverage of the more popular shortwave broadcast band (SWBC) frequencies, the inductance of the secondary side of T1 is approximately 3.5uH, and for this value T1 is constructed using 15 turns of #34 trifilar enameled wire on a Micrometals T50-6 toroid core. For different tuning ranges, the value of T1 can be adjusted as needed. For wide tuning ranges hyperabrupt varactor diodes should be used and may be MVAM109, MVAM115, NTE618 (available from Mouser), or any suitable equivalent.

Remote tuning is applied as a voltage across resistor R2, which is derived from the amplifier power and tuning voltage that varies from 8V to 22V from a control unit, which will be described later. The zener diode D3 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. With the parts described for T1, D1, and D2 this provides a tuning range from 5.5MHz to almost 15MHz. For wideband usage, these components may be set aside and T1 constructed as a wideband transformer, as was discussed earlier

Transformer T3 is added to provide additional open-loop voltage gain of the amplifier as well as a convenient means of power supply decoupling. Although not obvious in the schematic, T3 is actually a Guanella 4:1 BalBal impedance transformer (9, 10, 11).

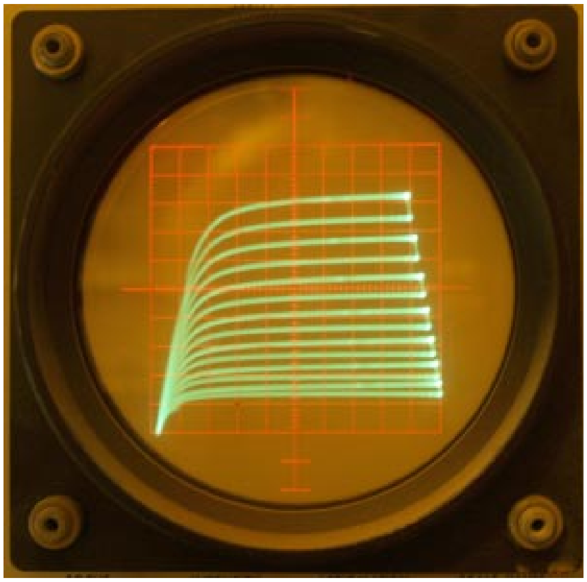


Fig. 5 - J309 Characteristic Curves (horizontal 1V/div, vertical 2mA/div, 0.1V/step)

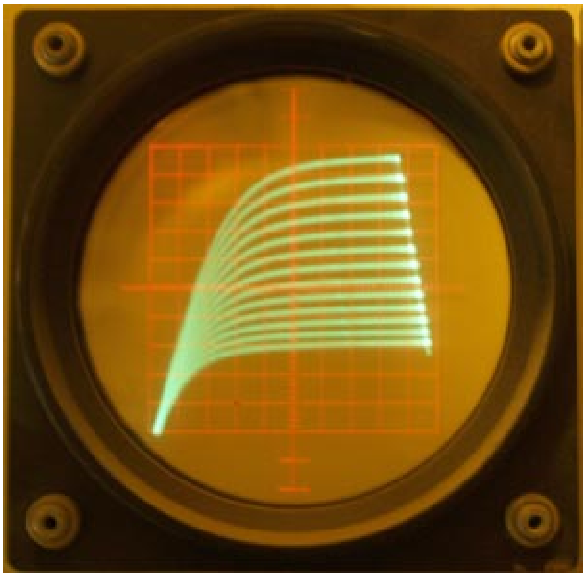


Fig. 6 - J310 Characteristic Curves (horizontal 1V/div, vertical 5mA/div, 0.2V/step)

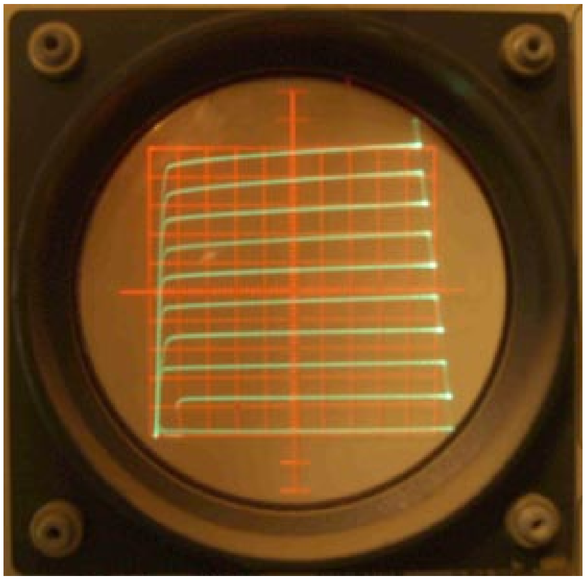


Fig. 7 - MPS6521 Characteristic Curves (horizontal 1V/div, vertical 2mA/div, 5µA/step)

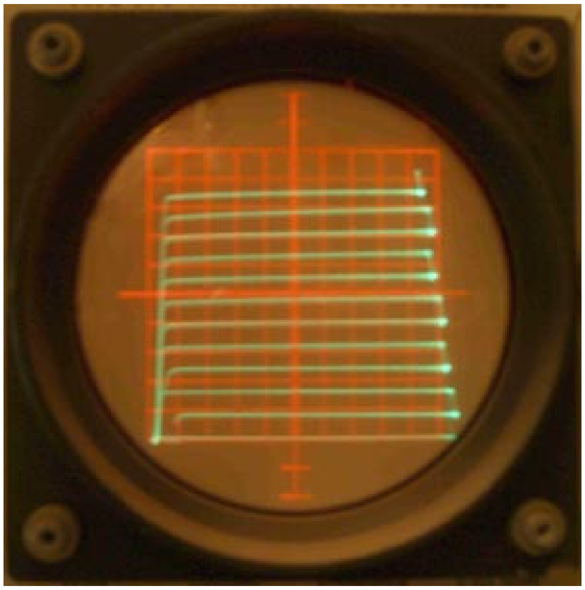


Fig. 8 - 2N2222 Characteristic Curves (horizontal 1V/div, vertical 2mA/div, 10µA/step)

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 Q1 and Q2 in the input stage. Either of these devices will provide the high impedance needed to realize a usable signal voltage from the short dipole antenna and to provide a high degree of tuning selectivity from the tuning network. The J310 is known to provide a 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. 5 and Fig. 6 show the transfer characteristics of the J309 and J310, respectively.

The MPS6521 was chosen for the NPN bipolar devices Q3 and Q4 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 Q3 and Q4, 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. 7 and Fig. 8, and are readily available from a number or sources.

Transformer Construction

The transformers used in this design are key elements in the overall performance of the amplifier as they provide linear voltage gain (T1 and T2), feedback coupling (T3), and output signal combining (T4). 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

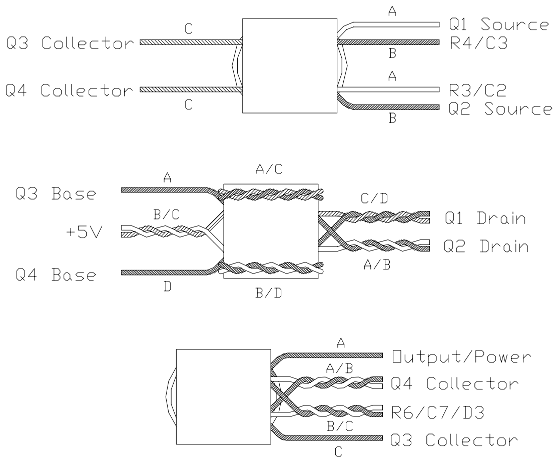


Fig. 9 - Transformer Construction Details for T2 (top), T3 (centre), and T4 (bottom)

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 Radio Communications (RADCOM) some years ago (12), 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 (13, 14, 15, 16).

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 some form of twisted wire where it is convenient. The construction of the input transformer T1has been discussed earlier for both wideband and tuned applications.

Transformer T2 requires a turns ratio that is not convenient for having all wires twisted together. However, the split primary winding is best realized with a twisted bifilar pair to ensure good balance, while the secondary winding is monofilar. Since the DC bias current passing through the two halves of the primary winding is essentially balanced, there is very little if any bias flux in the transformer core, which relieves most of the concerns of distortion due to flux compression in the core material. Therefore, T2 is constructed first with two turns of #34 bifilar twisted wire with the free ends exiting from one end of a Fair-Rite 2843002402 binocular core, followed by eight to twelve turns (depending on the amount of signal gain desired) of #34 wire exiting from the opposite end, as is shown in Fig. 9.

Transformer T3 is also constructed on a Fair-Rite 2843002402 binocular core, this time winding four turns of #34 biifilar wire through the two holes and along the outside, as shown in Fig. 9. Finally, a third such binocular core is used for constructing T4, this time winding four turns of #34 trifilar wire between the two holes, which is also shown in Fig. 9.

For lower frequencies, a core made from Fair-Rite 73 material should be used, and for higher frequencies 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

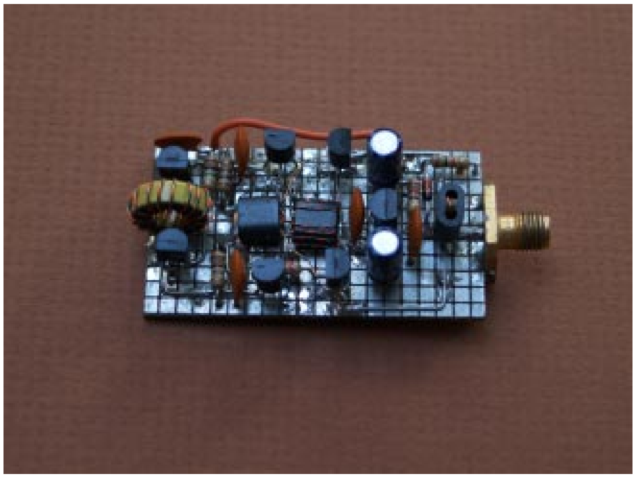


Fig. 10 - Amplifier Protype

for lower frequencies such as LF and VLF where more turns will be required, a smaller size of wire will be required.

Prototype Construction and Testing

A prototype amplifier was constructed on a 1.1"x2.0" 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. 10. In the photo, transformer T1 is the toroid core on the far left, followed by transformers T2, T3, voltage regulator U1, and then transformer T4 going from left to right. The SMA connector was later removed when the assembly was installed in a 1 1/8" x 2 1/8" x 3 1/4" aluminum enclosure together with an SO-239 connector for attaching the coaxial feedline.

Fig. 11 shows the completed amplifier housing assembly attached to a pair of 1 meter long antenna elements made from 1/2" copper pipe. A pair of PVC electrical conduit nipples with a filler sleeve made from 1/2" PVC pipe are used to attach the antenna elements to the aluminum enclosure. Fig. 12 then shows a waterproof housing made from PVC plumbing components that the assembly of Fig. 11 is mounted in.

Control Unit

The active dipole antenna described here was designed to make use of the control unit that was described in my September/October 2003 QEX article on active loop antennas (17, 18) 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. 13, 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 adjusting 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 (19, 20), 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 trans-

Fig. 11 - Active Dipole Antenna Assembly

Fig. 12 - Active Dipole Antenna Housing

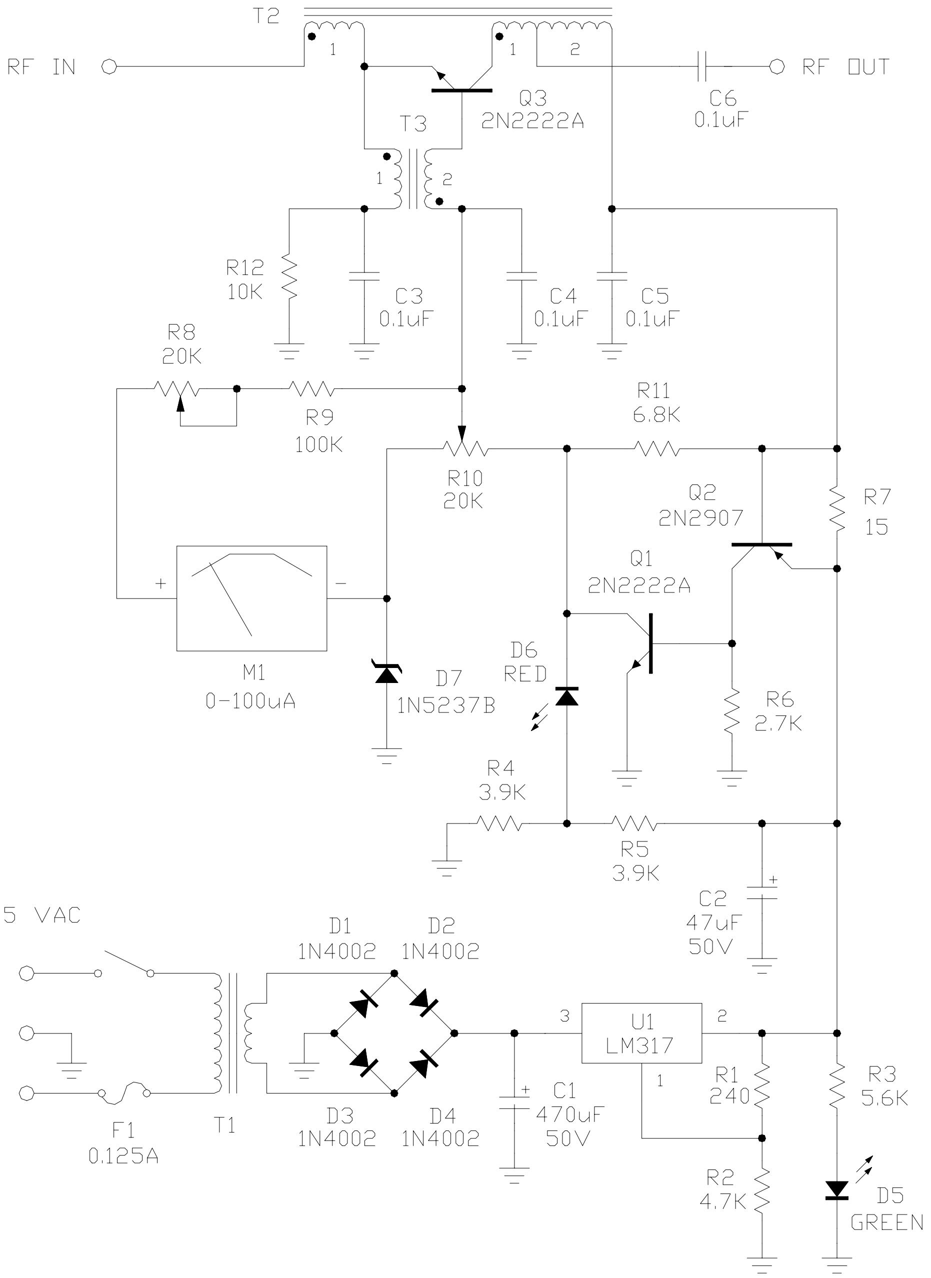

T2
RF IN
1
1
2
RF OUT
Q3
2N2222A
C6
0.1uF
T3
1
2
R12
10K
C3
0.1uF
C4
0.1uF
C5
0.1uF
R8
20K
R9
100K
R11
6.8K
R10
20K
Q2
2N2907
R7
15
Q1
2N2222A
+
−
M1
0-100uA
D7
1N5237B
D6
RED
R6
2.7K
R4
3.9K
R5
3.9K
+
C2
47uF
50V
115 VAC
D1
1N4002
D2
1N4002
3
U1
LM317
2
1
R1
240
R3
5.6K
+
C1
470uF
50V
F1
0.125A
T1
D3
1N4002
D4
1N4002
R2
4.7K
D5
GREEN

Fig. e 13)

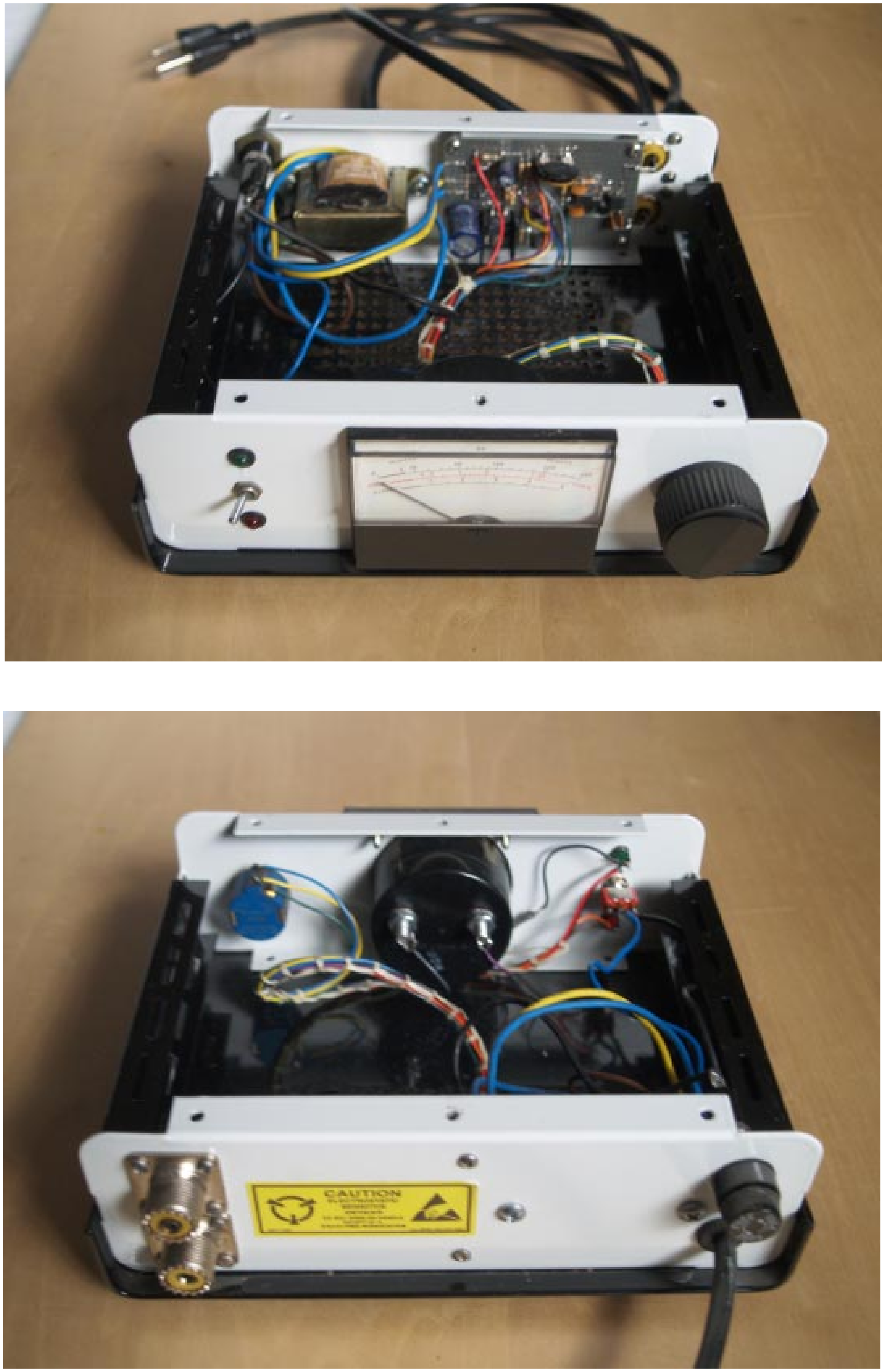


Fig. 14 - Active Antenna Power and Control Unit Prototype
Front View (top) and Rear View (bottom)

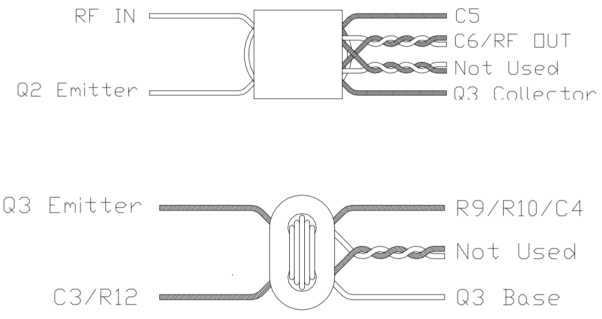


Fig. 15 - Control Unit Transformer Construction Details for T2 (top), and T3 (bottom)

former 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.15). 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. 15. The completed protype of the control unit is shown in the photographs of Fig. 14.

The antenna amplifier and tuning can be easily powered and controlled by way of a simple bias tee, such the one depicted in the schematic of Fig. 16. Here, the transformer T1 is made with 6 turns #26 AWG bifilar wire on a Fair-Rite 2843000102 or similar balun core. As shwon in Fig. 17, this bias tee fits comfortably inside a 1 1/8” x 2 1/8” x 3 1/4” aluminum enclosure and is very convenient for other applications such as powering mast-mounted preamplifiers.

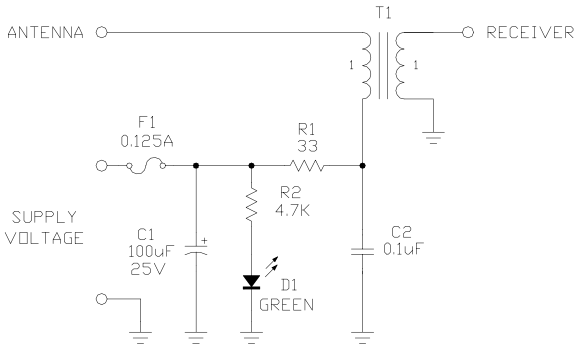


Fig. 16 - Biasing Tee Schematic (see terxt)

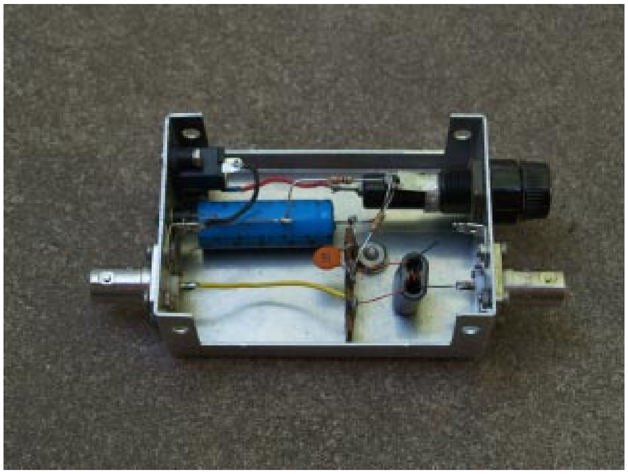


Fig. 17 -Bias Tee Assembly

Synopsis

The active dipole antenna described here was designed to make things as simple as possible and yet retain a high degree of dynamic range. The addition of a transformer to the input provides noise-free voltage gain that improves the NF, while at the same time providing much-needed initial immunity from strong common-môde signals. The combining of two gain stages into a single negative feedback amplifier with a high degree of open-loop gain serves to improve the IMD performace of the Datong amplifier, from which this design is derived. Both tuned and wideband (untuned) versions are available, which gives the user a good degree of flexibility. The performance compares well with that of active loop antennas, though passively tuned loops perform better.

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