A High Dynamic Range Amplifier for Active Short Monopole Antennas

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 of particular interest. However, many commercial active antennas and published hobby articles fail to take into consideration the aspects of noise figure (NF) and intermodulation distortion (IMD) in their designs, resulting in poor performance and a feeling of disdain for active antennas in general.

A couple of designs offered for SWLs online have proven to be worthwhile as they overcome the performance shortcomings of earlier designs. One of these is an active whip antenna design by Dallas Lankford that uses a complementary push-pull output (also called totem-pole) using the 2N3866 and 2N5160 transistors, shown in Fig. 1 (1), which has an IIP3 of +50dBm. Although NF was not published, the circuit has a NF of at least 6dB owing to the 3dB NF of the J310/U310 transistor and the 3-4dB of signal loss from the input to the output, and this does not take into account the NF of the 2N3866 and 2N5160 transistors. For MF and HF frequencies, this is not a considerable concern.

The almost \$10 per unit cost of the 2N5160 transistor detracts from the overall attractiveness of the circuit's performance, and it was felt that a suitable circuit alternative should be pursued that would provide comparable performance and which would use transistors that are more readily available at a far lesser cost than that of the 2N5160.

Amplifier Topology

As mentioned just now, the point of this effort was to devise an amplifier having performance similar to that of Lankford's complementary push-pull design but which negates the need for the 2N5160 PNP transistor, which is somewhat difficult to obtain and which is prohibitively expensive.

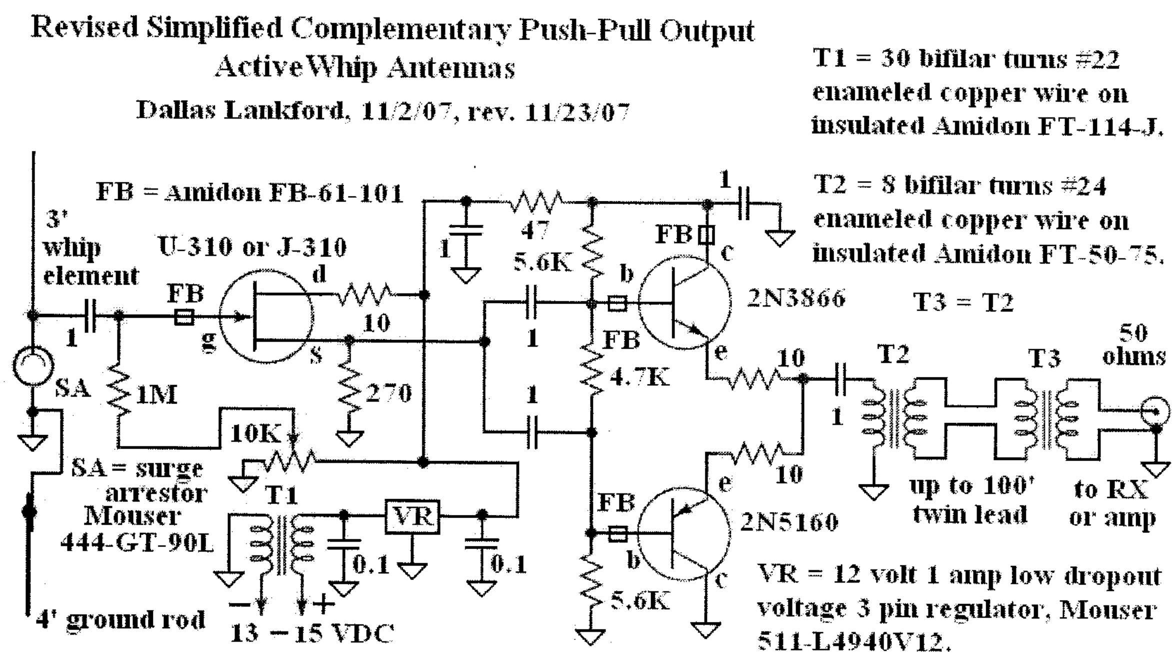


Fig. 1 - Complementary Push-Pull Active Whip Antenna as Designed by Dallas Lankford (from Reference 1)

The first topology that comes to mind here is that of a transformer-coupled push-pull emitter follower, which is shown in functional form in Fig. 2. Here, the first transformer divides the input signal into a balanced pair of signals which are conducted to the bases of the two NPN transistors. The emitters of the transistors are then connected to the split secondary of the second, or output transformer, which then combines the two balanced emitter signals to a single output signal. Although this will require the use of a pair of transformers, the transistors now become far less expensive and readily available from popular sources such as Digi-Key and Mouser.

I am somewhat prejudiced in my active amplifier designs in that I prefer to have a transformer as the last circuit element. This allows me to pass the supply voltage, and sometimes even the tuning control voltage through the centre conductor of a coaxial cable (2). This produces a design that requires just a single cable going to the active antenna, and all that is additionally required is a bias tee of some sort to couple the supply voltage to the cable.

Transistor Selection

There is little that needs to be said about the use of a J310 or U310 (preferred) for the input stage. This device provides the high impedance needed for a short wideband monopole aerial, and the high transconductance makes it ideal for use as a source follower as this characteristic will result in lower IMD products.

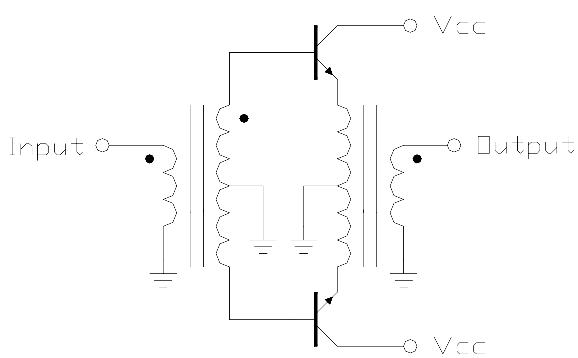


Fig. 2 - Transformer-Coupled Push-Pull Emitter Follower

There are a number of transistors that are suitable choices for this configuration, such as the 2N3866, 2N5109, and the NE46134. All three of these are available from Mouser for about the same price (less than $2 each), and the last one is also available from Digi-key. This is a matter in the design which will make the construction of such an amplifier more acceptable in terms of both cost and convenience.

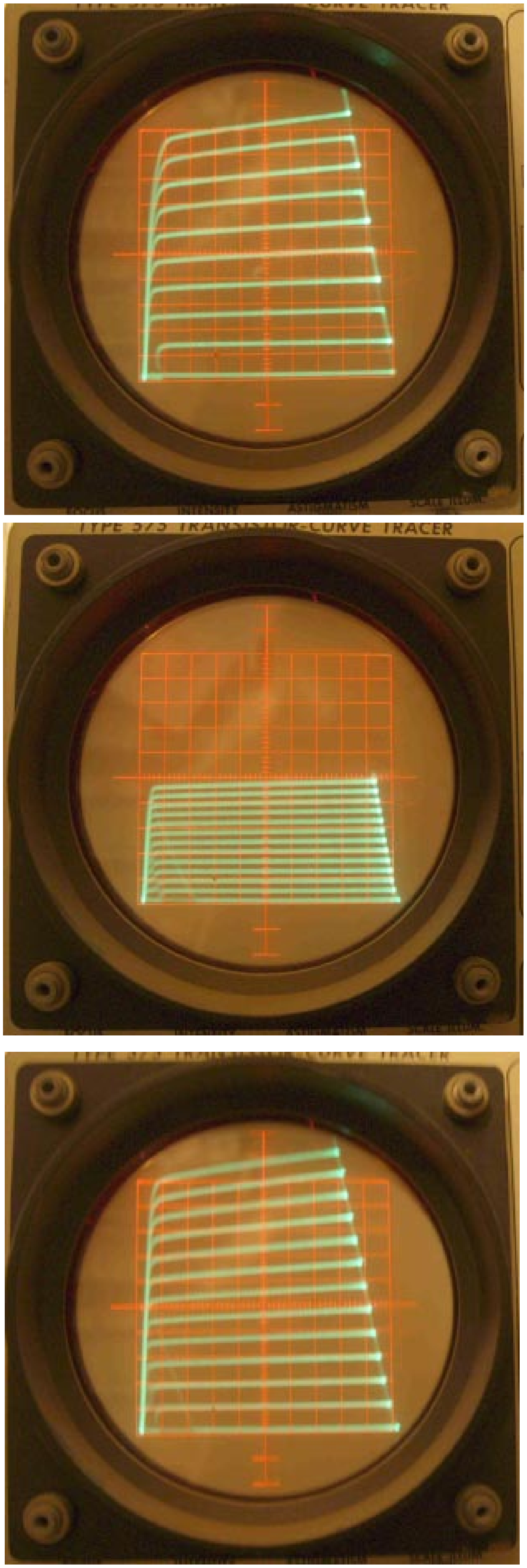
A quick review of some important parameters of these transistors reveals that the NE46134 has a considerable edge in terms of the transition frequency (f_T). It also has a much better NF than the 2N5109, and both of these parameters make the NE46134 attractive.

In Fig. 3, the transfer characteristics of these three transistors can be seen on a curve tracer. The 2N3866 has the highest gain, whereas the 2N5109 has the least. All three devices exhibit good linearity characteristics, especially in the saturation region. Adding these measurements to the parameters of Table 1, the NE46134 would be a suitable choice in terms of gain, NF, f_T, and linearity.

A full schematic of the amplifier appears in Fig. 4. Here, the secondary winding of the output transformer T2 has been split into a pair of independent windings so as to facilitate the biasing of the two output transistors Q2 and Q3.

Table 1 - Transistor Parameters

Device	hfe	f_T	NF
2N3866	10-200	800MHz	N/A
2N5109	40-120	1200MHz	3.0dB
NE46134	40-200	5600MHz	1.5dB



Using a the transformer T1 to couple Q1 to Q2 and Q3 allows for moving the bias control for the input transistor Q1 fro the gate, as shown in Fig. 1, to the source, which eliminates a possible vector for power supply noise to degrade the NF. Adjustment of this contol is the same as that described by Lankford (1).

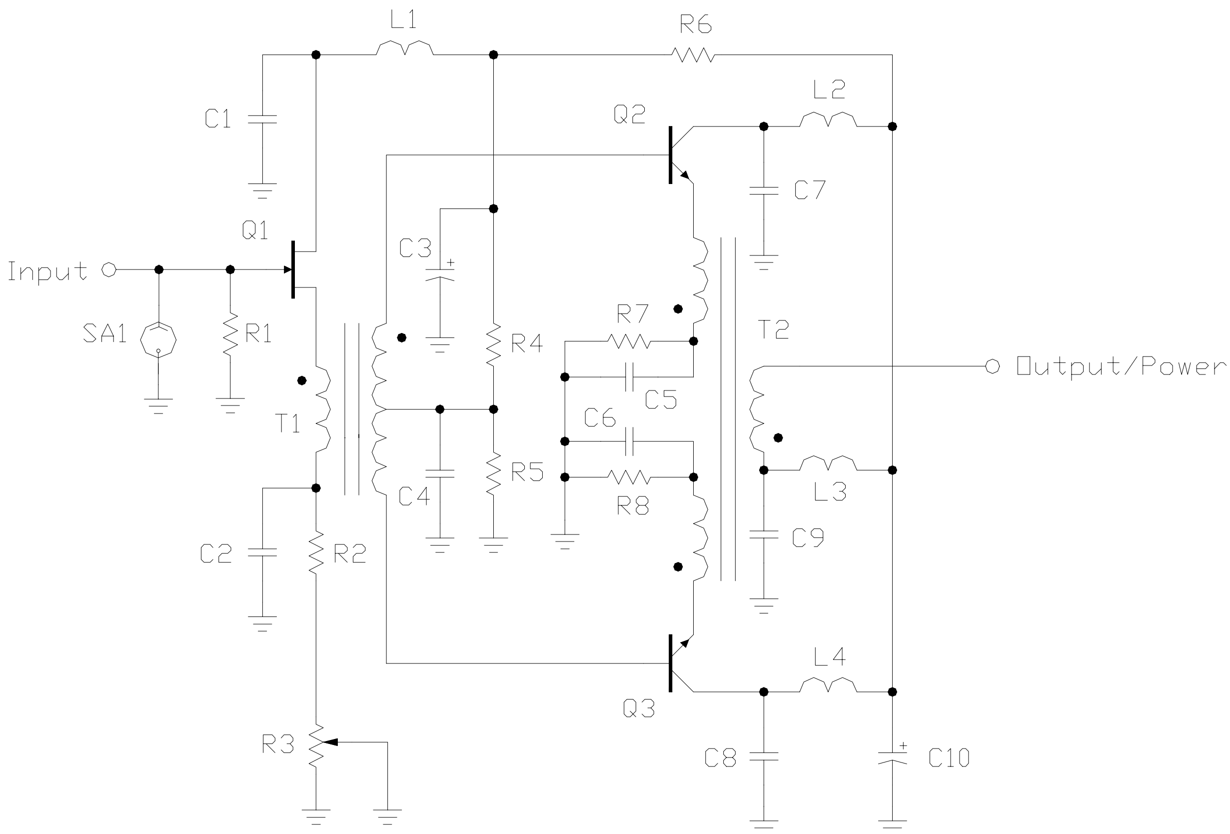
Additonal noise improvement can be obtained by using a low noise 1.5V voltage regulator such as the LT1761ES5-1.5 (Linear Technology) or the NJM2871BF15 (New Japan Radio Co.) to supply the base bias voltage for the two output transistors rather than the voltage divider of R4 and R5.

Transformer Construction

Together with the transistors, transformers T1 and T2 are key elements in the overall performance of the amplifier. 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, howerver 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 (3), 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 are adhered to (4, 5).

Figure 3 - Transistor Curve Familes for 2N3866 (top), 2N5109 (centre) and NE46134 (bottom) (vertical = 5mA/div, horizontal = 10V/div, 0.05mA/step)



Parts List

C1, C2, C4, C5, C6, C7, C8, C9 - 0.1uF
(see note)
C3, C10 - 4.7uF 25V Tantalum
(Vishay/Sprague
293D475X0025C2TE3 or equivalent)

L1, L2, L3, L4 - Ferrite bead
(Murata BLM31PG121SN1L or equivalent, see note)

Q1 - J310 or U310 (preferred)

Q2, Q3 - NE46134

R1 - 100K
R2 - 68 ohms
R3 - 200 ohm 10-turn potentiometer
R4 - 1.0K
R5 - 150 ohms
R6 - 100 ohms
R7, R8 - 18 ohms

SA1 - Gas Tube Surge Arrestor
(Xicon 444-GT-90L)

T1, T2 - 1:1:1 consisting of eight turns of #34
trifilar wire on Fair-Rite 2843002402
core (see text)

Note: Passive components are SMT size
1206 except for C3, C10, and R3.

Fig. 4 - Active Monopole Antenna Amplifier Schematic and Parts List

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 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, transformers T1 and T2 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 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 for lower frequencies where more turns will be required, a smaller size of wire will be required.

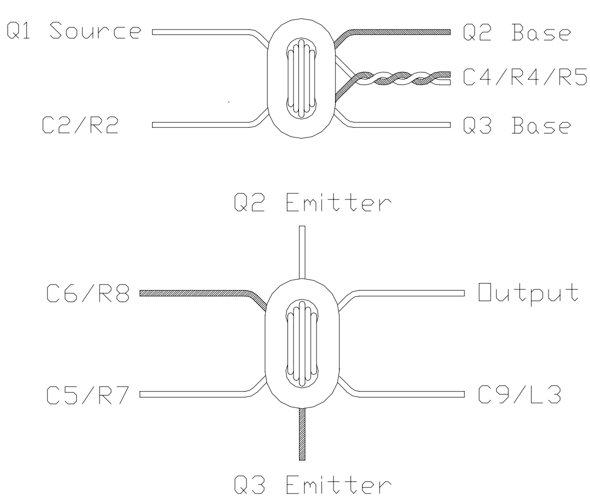


Figure 5 - Construction Details for Transformers T1 (top) and T2 (bottom)

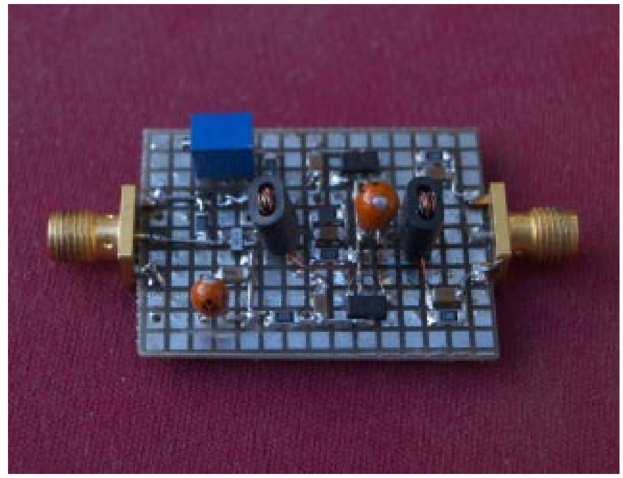


Figure 6 - Active Monopole Amplifier Prototype

With the wires of the two 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, though other arrangements are possible.

Prototype Construction and Testing

A prototype was constructed on 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. The prototype is a slight departure from the schematic of Fig. 4 as the ferrite beads were omitted for convenience. At 10MHz the gain was -0.7dB and the NF was determined to be about 3.84dB. The 3dB bandwidth is 150kHz to 55MHz. Preliminary IMD measurements show the OIP3 and OIP2 to be +48dBm and >+70 dBm, respectively.

The IMD performance is comparable to the original circuit by Lankford, while the gain and NF are both improved. While this circuit is a bit more complicated and requires the construction of a pair of transformers, it does do away with the objectionable price and limited availability of the 2N5160 transistor.

References

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