

The Crashcup 1V40 1W Transmitter

by

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Introduction

This project was the result of a desire to design a 1W HF transmitter using nothing more than the 2N2222 transistor and the 1N4148 diode. Numerous other designs already exist, and the popularity of these devices has prompted design contests which have yielded many good and innovative designs as well as some really bad ones. A goal in this design was to come up with a robust design that was both cost-effective and bullet-proof, keeping the number of devices to the essential minimum but at the same time retaining the qualities of a good design, by which is meant that performance was not to be compromised and design margins such as power dissipation were to be kept reasonably high.

Transmitter Block Diagram

The transmitter consists of three blocks of circuitry, being a variable frequency oscillator (VFO), a variable-gain driver amplifier (VGA), and a power amplifier (PA).

The Variable Frequency Oscillator

In the schematic of Fig. 1, transistor Q1 is the variable frequency oscillator while transistors Q2 and Q3 comprise a cascode follower amplifier which provides about 60dB of isolation from the driver amplifier.

Diode D2 stabilizes the bias point of Q1 over temperature while diode D2 keeps the V_{CE} of Q1 constant over temperature, both of which are necessary in order to minimize the frequency drift over temperature. Capacitors C6 (negative temperature coefficient) and C8 (positive temperature coefficient) and differential variable capacitor C7 provide additional compensation for temperature drift, but these three components can be left out if desired. The adjustment of C7 will be discussed later.

Variable capacitor C5 is the tuning control, while trimmer C9 is used to centre the tuning range.

Inductor L1 is approximately 3.3uH for 40m operation, and initially consists of 35 turns of #28 AWG enameled wire on a Micrometals T37-10 toroid core. Some variation in the number of turns is to be expected due to the variation in the initial permeability of the powdered iron material, as well as the need to adjust the value due to variations in construction practices, and that aspect of the design will be discussed later.

The Variable Gain Driver Amplifier

Again referring to the schematic of Fig. 1, transistors Q4 and Q5 are the variable gain driver amplifier. In the beginnings of this design, the output power of the transmitter was controlled by varying resistor R5 in the VFO, but this method caused the frequency to vary as the power level was changed. The frequency also varied as the power amplifier was keyed, so it was decided in the best interest of the design goals to add the additional two transistors so as to not degrade the frequency stability.

Transformer T1 is a 1:2CT balun, and a MiniCircuits TT4-1A may be used here, although a far less expensive and better performing transformer can be made by winding four turns of #32 trifilar wire through the holes of a Fair-Rite 2861002402 binocular core, the necessary details of which are shown in Fig. 2 below.

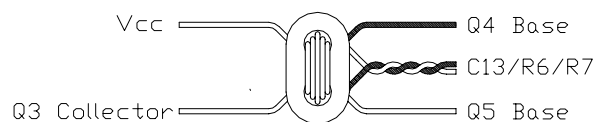
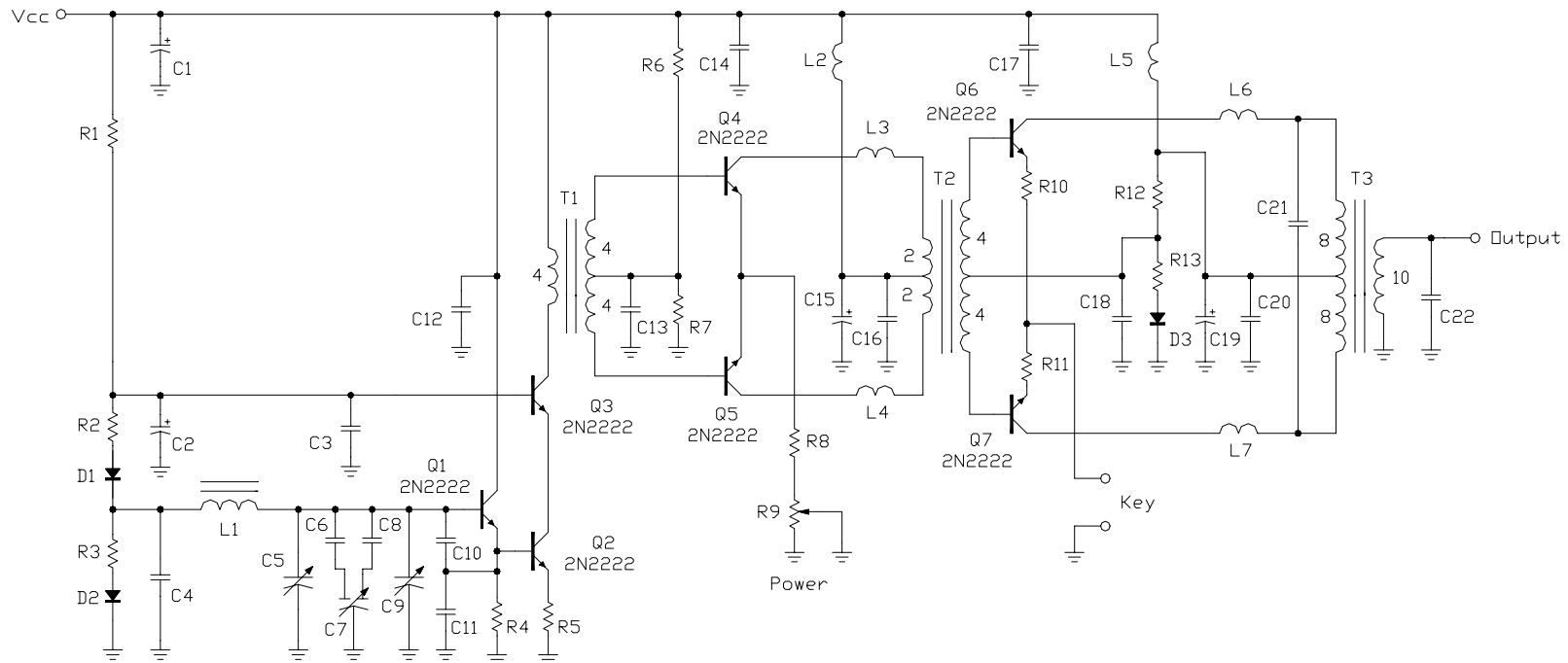


Figure 2 - Construction Details for Transformer T1



C1, C2, C15, C19 - 22uF 25WVDC
 C3, C4, C12, C13, C14, C16, C17, C18,
 C20 - 0.1uF
 C5 - 140pF variable
 C6 - 47pF mica (optional)
 C7 - 50pF differential variable (optional)
 C8 - 47pF N750 (optional)
 C9 - 50pF trimmer
 C10 - 1000pF mica
 C11 - 220pF mica

C21 - 120pF mica
 C22 - 470pF mica
 D1, D2, D3 - 1N4148
 L1 - 3.0uH (see text)
 L2, L3, L4, L5, L6, L7 - ferrite bead
 (see text)
 Q1 - Q7 - 2N2222

R1 - 1.2K
 R2, R3, R5 - 470 ohms
 R4, R12 - 2.2K
 R6, R7 - 3.3K
 R8 - 270 ohms
 R9 - 5K potentiometer
 R10, R11, R13 - 4.7 ohms

T1 - 1:2CT transformer (see text)
 T2 - 2CT:4CT transformer (see text)
 T3 - 4:4:5 transformer (see text)

Figure 6 - Crashcup 1V40 1W 2N2222 Transmitter Schematic and Parts List

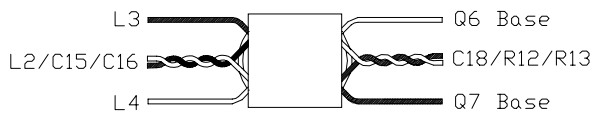


Figure 3 - Construction Details for Transformer T2

The transmitter output power level is adjusted by way of potentiometer R9, while resistor R8 sets the upper limit. With the values shown, the output power level can be continuously adjusted from about 50mW to the full design 1W.

Transformer T2 is a 2CT:4CT balbal, and a MiniCircuits TT4-1A may also be used here as well, although a far less expensive and better performing transformer can be made by winding two turns of #32 bifilar wire through the holes of a Fair-Rite 2861002402 binocular core for the primary, followed by four turns for the secondary, the necessary details of which are shown in Fig. 3 above.

What's All This Push-Pull Class B Stuff, Anyhow?

The power amplifier for the transmitter is operated in push-pull class B, which has many advantages, the first of which is the substantial suppression of even-ordered harmonics. Since these harmonics will have the same phase for the two sides, they will be cancelled out by way of the the output balun transformer T3, and the degree of cancellation will depend on the balance of the two amplifier halves and the construction of T3.

An additional advantage is the output, or collector power efficiency. In a class B amplifier, the device conducts for just one-half, or rather 180° of the signal cycle. A class C amplifier conducts for less than 180°. An additional class specific for linear amplifiers, class AB, conducts for slightly more than 180° and is used

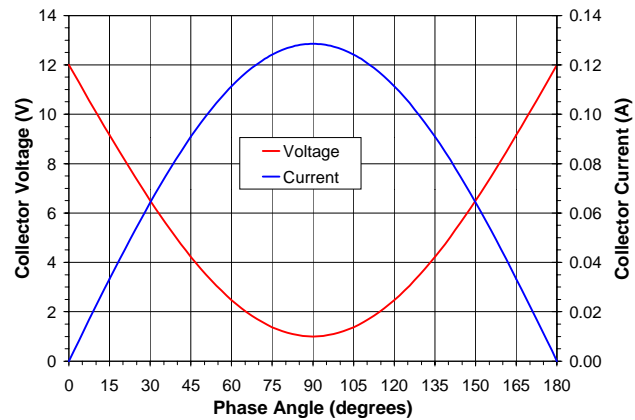


Figure 4 - Collector Voltage and Current for 1W Class B Power Amplifier

to overcome the gain compression that takes place in tubes and transistors as they approach cutoff. Classes AB1 and AB2 are used for describing tube amplifiers and depend on whether or not the grid is drawing current (1).

Typically, a class B amplifier is biased so that the quiescent current is 5% or less of the peak current. The result is that little, if any quiescent bias current is required, so little DC power is used when no transmission is taking place. In addition, the amount of power that is dissipated by the amplifier devices is much less than would be dissipated in class A, which is generally more than the peak power delivered to the load and often 120% or more so as to overcome the saturation margin of the device and maintain the linearity. In the schematic of

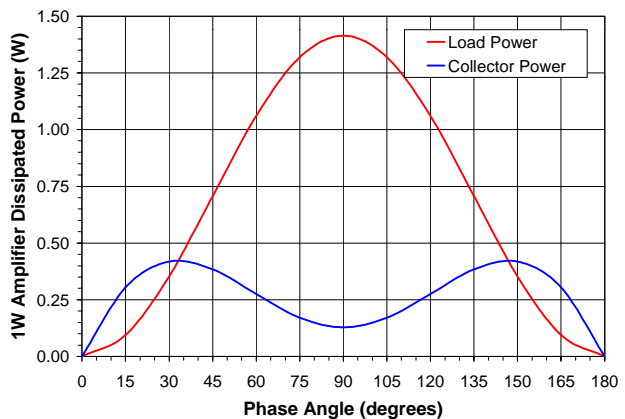


Figure 5 - Collector and Load Dissipated Power for 1W Class B Power Amplifier

Fig. 1, diode D3 serves to maintain the quiescent bias current over temperature, while resistors R10 and R11 provide a slight improvement in linearity and together with R13 provide additional stabilization of the bias current.

Looking first at Fig. 4, the voltage and current at the collector of Q6 and Q7 varies as they conduct the signals through its respective 180°. Looking now at Fig. 5, the power dissipated by the collector peaks both early and late in the cycle, then decreases to less than half that amount at the 90° point, while the power delivered to the load is far greater. For this PA, the peak power dissipated by the devices is slightly more than 0.4W, about 35% less than the maximum allowed for the 2N2222 in the plastic TO-92 package. And the dissipated power at the 90° point is less than 0.15W. Since each device only conducts for half of the signal cycle, the total average power dissipated by the collector is less than 0.2W.

Those who are familiar with the theory of switching amplifiers (classes D, E, F, and S) will recognize this as being the fundamental reason why switching transistors used in such amplifiers run surprisingly cool while delivering large amounts of power to the load. In designing power amplifiers that achieve this degree of efficiency, it is necessary to carefully tailor the collector load impedance with the supply voltage and the transistor collector-emitter saturation voltage ($V_{CE(sat)}$). In the case of this design, the supply voltage is 12V and $V_{CE(sat)}$ is estimated to be 1V. The desired average output power is 1W, which makes the peak power 1.414W, therefore the collector load impedances should be about 42.8 ohms (85.6 ohms total), which makes the turns ratio for T3 to be 13CT:10, but is rounded up to a more convenient 16CT:10.

Harmonics and Filtering

Any amplifier that conducts for less than the full 360° of the signal cycle will generate an



Figure 6 - Construction details for Transformer T3 and Ferrite Beads

increasing level of even-ordered harmonics as the amount of cycle conduction is decreased, and single-sided class C and B amplifiers make wonderful comb generators. Many inexpensive CW transmitter designs use such an approach and make up for the excessive harmonics by applying a fairly high degree of filtering at the output. In this design, the even-ordered harmonics are substantially reduced by virtue of the push-pull arrangement, however the odd-ordered harmonics are still present and some degree of filtering is required, though not as intensive as would be needed for a single-sided amplifier.

Capacitors C21 and C22, together with the inductances of transformer T3, comprise a 3-pole lowpass filter (2). The ratio of the values for C21 and C22 is equal to the square of the turns ratio of transformer T3. The inductances of T3 determine the maximum frequency for the lowpass filter function (2), and therefore T3 needs to be constructed with this aspect in mind.

For the 40m band, transformer T3 consists of two windings of eight turns and one winding of ten turns of #26 AWG enameled wire on a Micrometals T50-10 toroid, which was cho-

sen for its permeability so as to have about 24 turns total and at the same time have the proper inductance for a low-pass filter section for 40m. The first two windings are constructed by winding them in parallel so that they begin and end on one side of the core. The third winding is then constructed starting and ending on the opposite side, with the two extra turns placed between the start and finish ends of the first two windings. The photograph of Fig. 6 is provided to clarify this construction practice. In the photo, the green and red coloured wires are the first two windings of eight turns, and the natural coloured wire is the third winding of ten turns.

Construction and Adjustment

The prototype for this transmitter was constructed on a 2" x 4" piece of 1/16" FR-4 PC board material using leaded components and Manhattan-style traces cut out with a Dremel tool. There is plenty of room left on the board to later accommodate a small audio amplifier for including AM capability.

Inductors L2 through L7 consist of a single ferrite bead on a short piece of bare wire, such as a component lead, one of which can be seen in Fig. 6. Surface-mount ferrite beads may also be used.

After construction, increase the supply voltage slowly so as to check for any shorts due to solder splashes. Rotate capacitors C5, C7 (if used) and C9 to their mid-positions. With a frequency counter and a high-impedance probe, check the frequency at the emitter of Q2 and adjust the turns of inductor L1 as needed to get the frequency close to the centre of the desired band. Once that is done, adjust trimmer C9 to fine-tune the centre frequency.

If C6, C7, and C8 are used, monitor the frequency as the transmitter warms up and adjust C7 to reduce the amount of frequency drift as required. This will take a good deal of time and patience, but the end result is worthwhile.

Modifications for Other Bands

The prototype for this transmitter was built for the 40m band as it was convenient. It may, however, be modified to operate on any of the HF bands, including 10m, as well as VLF/LF frequencies by changing the tuning components in the VFO and the components C21, C22, and T3 in the output transformer/filter. The two capacitors can be scaled or the desired operating frequency band, while the transformer will require that a different core material be chosen and the number of turns adjusted so as to have the needed inductance.

For low HF frequencies and especially VLF/LF frequencies, a toroid made of ferrite material rather than powdered iron will be required for T3. Also for the lower VLF/LF frequencies, the material used for transformers T1 and T2 will need a higher permeability, such as Fair-Rite mixes 43 (below 10MHz) or 77 (below 1MHz).

Synopsis

This was a fun project as it had some design challenges in squeezing more performance from the immortal 2N2222 and 1N4148. It also provided an opportunity to demonstrate the distinct advantages of push-pull class B operation as well as designing wideband transformers so that they can additionally be used as lowpass filter section inductors.

Enjoy.

References

1. Krauss, H.L., C.W. Bostian, and F.H. Raab, *Solid State Radio Engineering*, John Wiley & Sons, 1980.
2. Trask, C., "Wideband Transformers: An Intuitive Approach to Models, Characterization and Design," *Applied Microwave & Wireless*, Vol. 13, No. 11, November 2001, pp. 30-41.