

If you want to use a modern synthesized VFO with a tube-type “boatanchor” transmitter, you might have trouble producing enough output from the solid-state VFO to drive the tube rig’s circuitry. WA1FFL has a project to solve that problem.

## An Improved VFO Driver Amp for Tube Rigs

BY JAMES D. HAGERTY,\* WA1FFL

I have had many discussions with other radio amateurs regarding the suitability of using a direct-digital synthesis (DDS) VFO with a vintage tube-type transmitter. The stability, precision, and software flexibility of DDS VFOs make these devices an attractive option to keep vintage gear on the air. However, some interfacing is required. The output of DDS VFOs tends to be relatively low because of the very low operating voltages of the chips themselves (1.8–5 volts). My own VFO design (published in 2008 in *QEX*<sup>1</sup>) puts out 0.5 volts peak across 50 ohms after filtering and a 20 dB gain stage. Its AD9951 DDS IC runs on a mere 1.8 volts.

One classic reference on this subject is the Doug DeMaw *CQ* article “VFO Interfacing: Using Solid-State VFOs to Drive Vacuum-Tube Transmitters.”<sup>2</sup> This article, which was published nearly 20 years ago, is one of the few treatments of a subject which has been the focus of discussion for many vintage-equipment users’ groups.

I eventually built the DeMaw circuit (see fig. 1; this was called figure 2 in the original article), which consisted of a 1-stage 2N3866 circuit with a tuned transformer output. There was little design data for the output matching circuit, for which it was only stated, “T2 is wound for the operating frequency.” The circuit was stable and gave over 10 volts peak output at the lower HF frequencies, but it rolled off much too quickly to be useful over the entire HF spectrum. The reason is that T2, when wound with the specified 1:8 turns ratio (in my case, 5 turns to 40) acquired a secondary inductance so large that for practical values of variable capacitor C1, the res-

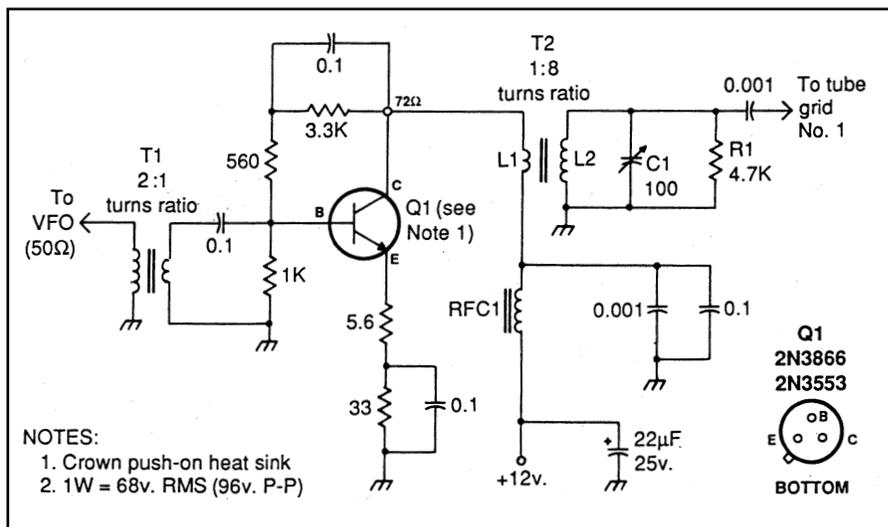


Fig. 1—Schematic of Doug DeMaw, *W1FB*’s, solid-state VFO amplifier circuit, as published in the September 1991 issue of *CQ*.

onant frequency of the tuned secondary was only in the region of 2 MHz or so. I then turned my attention to developing a better approach. I needed to know what VFO drive level was actually required for the older rigs. It will certainly vary from one tube to another, but some basics may be stated.

### Assessing the Needs

For a VFO, driving a vacuum-tube grid requires volts, but not enormous amounts of power. Recall that we are replacing a very high-Q device (i.e., a crystal) that will shatter at low power levels, but that nonetheless is capable of significant voltage excursions. The subject of input impedance for the grid of a common-cathode tube circuit is non-trivial and generally has been oversimplified. It is important to consider here for the purpose of knowing how to

match the VFO output for a drive level that will actually work.

One interesting window into this subject was the specification for the VFO drive requirements of the original E.F. Johnson Adventurer, a classic tube transmitter from the 1950s and ’60s. According to the original product flyer/data sheet, this is “8–10 volts across 22K ohms.”<sup>3</sup> That is less than 5 milliwatts! The spec for the Heath HG-10 VFO, which is known to work well with the vintage DX-40 and DX-60, states an output of 5V RMS or more, only with no load specified. Many years ago I tried driving my Hallicrafters HT-40 with this VFO, but the drive was insufficient. I later used a Hallicrafters HA-5 VFO with approximately 10 volts output to do the job. The capacities of the older tube VFOs from the 1960s have thus been specified in various ways, but with little consistency.

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The 2011 *ARRL Handbook*<sup>4</sup> explains the tube grid input impedance situation this way (page 17.5): “The input impedance of a vacuum tube amplifier is directly related to the grid current. Grid current varies with grid voltage, increasing as the voltage becomes more positive. When the grid voltage is negative, no grid current flows and the input impedance of a tube is nearly infinite.” However, with grid current flowing,

and adding in the inter-electrode capacitances of the tube, the input impedance drops dramatically.

Written during the heyday of vacuum-tube gear, the 1965 *Handbook*<sup>5</sup> (page 157) states, “... the grid-current flow that results when the grid is driven positive in respect to the cathode over a portion of the excitation cycle represents an average resistance across which the exciting voltage must be

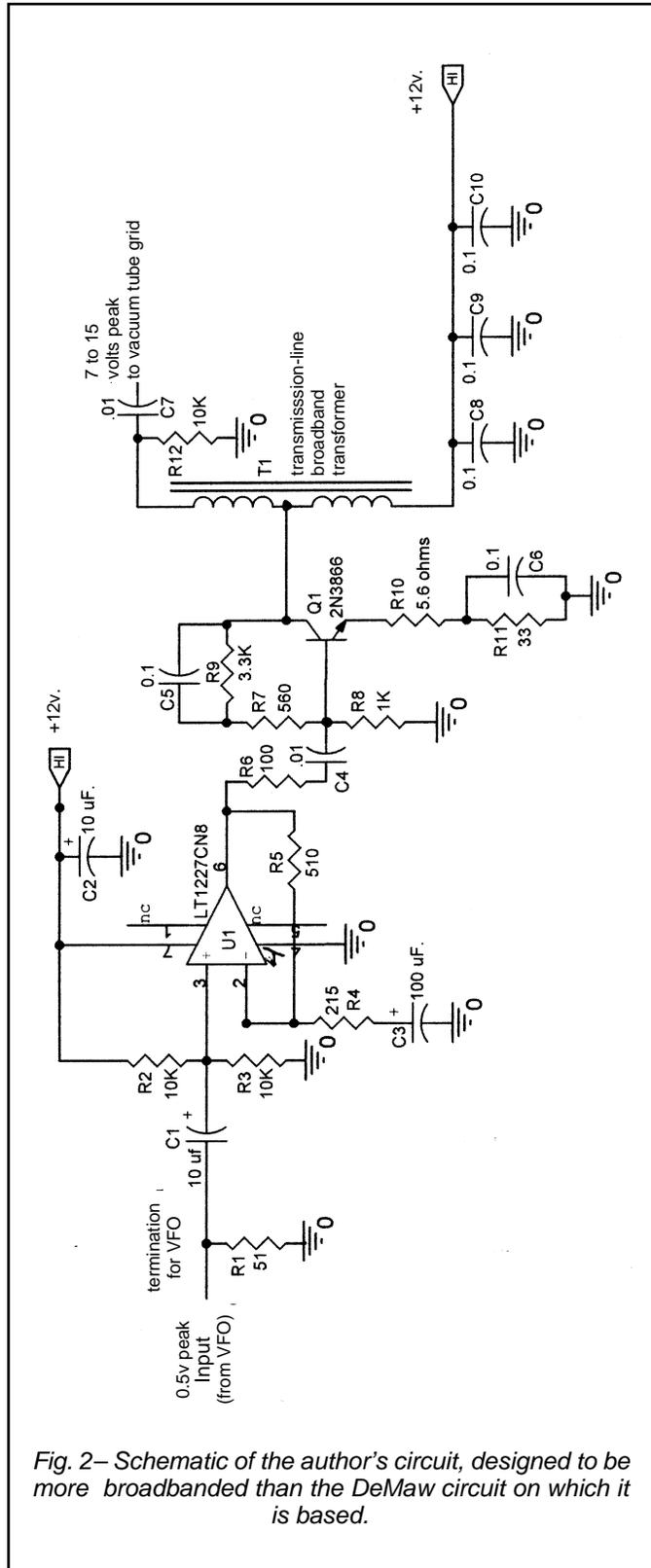


Fig. 2— Schematic of the author's circuit, designed to be more broadbanded than the DeMaw circuit on which it is based.

### Parts List and Construction Notes for Broadband Driver Amplifier for Use with Vacuum-Tube Rigs

- R1: 51 ohms, 1/4 watt, metal film, 1%
- R2, R3: 10K ohms, 1/4 watt, metal film, 1%
- R4: 215 ohms, 1/4 watt, metal film, 1%
- R5: 510 ohms, 1/4 watt, metal film, 1%
- R6: 100 ohms, 1/4 watt, metal film, 1%
- R7: 560 ohms, 1/4 watt, metal film, 1%
- R8: 1K ohms, 1/4 watt, metal film, 1%
- R9: 3.3K ohms, 1/4 watt, metal film, 1%
- R10: 5.6 ohms, 1/4 watt, metal film, 1%
- R11: 33 ohms, 1/4 watt, metal film, 1%
- R12: 10K, 20%, carbon, 1/2 watt rating.
- C1, C2: 10  $\mu$ F, tantalum, 15 volt rating
- C3: 100  $\mu$ F, tantalum, 15 volt rating
- C4, C7: 0.01  $\mu$ F, ceramic; 25 volt minimum rating for C4; 500 volt rating for C7
- C5, C6, C8, C9, C10: 0.1  $\mu$ F, ceramic, 25-volt rating or higher
- Q1: 2N3866 (RF Parts, use genuine Motorola)

U1: RF op amp, Linear Technology #LT1227CN8. (For convenient mounting use a 4-pin wire-wrap socket). Solder pin 4 (ground) to ground plane on proto-board.

Heat sink: TO-39 clip-on unit for Q1 (Aavid part number 578305B00000G)

T1: Transmission-Line Broadband Transformer; 10 bifilar turns #26 enameled wire on an FT50-43 core, or 10 bifilar turns #24 insulated solid wire on an FT82-43 core.

Twist the two wires together using a manual drill, holding one end of the bundle in a vise and the other end in the drill chuck. Obtain about 5–8 twists per inch. Then wind the twisted pair of wires on the toroid, counting the number of turns going through the center of the toroid. Connect one free end of each separate wire together in the middle and then to Q1's collector; the remaining two free ends connect as shown on the schematic.

For more detailed winding notes consult any edition of the *ARRL Handbook*.

Note: All cores are available from Amidon, Inc., <www.Amidoncorp.com>; they take direct phone orders).

*Miscellaneous*: Vector 8004 or other perforated ground-plane prototyping board (2.5"  $\times$  4.5") with holes 0.1" apart. Use #4-40 standoffs.

Chassis-type (i.e., bulkhead) BNC connectors with solder lugs (e.g., Jameco #355178 or Jameco #658427)

**Construction Notes:** Construct the amplifier on perforated ground-plane prototyping board, such as Vector part #8004. To accommodate the 4-pin wire-wrap socket for U1, the board perforation holes should be spaced 0.1" apart. Push through the socket so that the pins stick through to the ground plane side.

Solder the ground pin (IC pin 4) to the ground plane. Components are mounted “ugly-style” to the ground plane. An input and output BNC connector can be mounted on the board with a ground lug. Bend the ground lug at 90 degrees and solder to the ground plane. First solder the lugs on by themselves, and then attach the BNC connectors after cooling. Jameco has affordable RG58/U BNC cables that are 1–3 feet long.

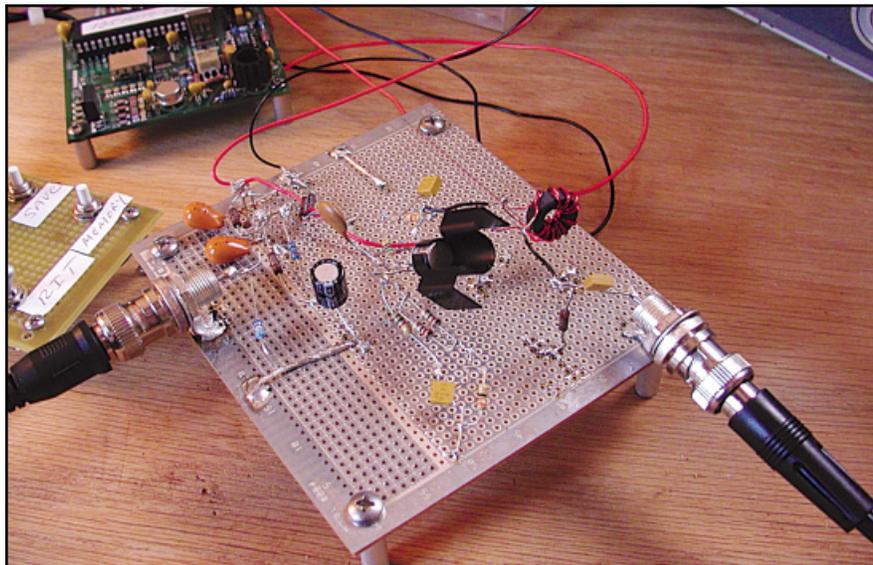


Photo A— Here is the author's amplifier circuit built "ugly style" on a Vector prototyping board.

developed by the driver ... the grid input resistance is a matter of a few thousand ohms..." In the same section, an approximate expression for the grid input impedance is given by:  $\text{Input impedance (ohms)} = \{ \text{driving power (watts)/d.c. grid current (ma)}^2 \} \times 620,000$ , with the driving power and grid current (for normal operation) taken from the tube tables.

Finally, I quote the 1990 *Handbook*<sup>6</sup> on this subject (page 5-8): "If the tube is driven into the grid-current region, there is in addition a resistance component in the input impedance. The resistance has an average value equal to  $(E^2)/P$ , where E is the RMS driving voltage and P is the power in watts consumed by the grid. The resistance will usually vary during the a.c. cycle, because grid current may flow only during part of the cycle ... the grid voltage/grid current characteristic is seldom linear."

Putting together all of the above, it is obvious that we will need a step-up impedance transformer in our VFO buffer output stage, and that the impedance we need to drive will be well above 50 ohms and certainly at least 1K ohms (if we assume 10 volts RMS drive level at less than 0.1 watts).

### Making it Broadbanded

A broadband solution was then investigated. Broadband transmission-line matching transformers are universal in transistor circuits. All recent ARRL *Handbooks* have extensive winding information about these devices (see page 20.22 of the 2011 ARRL *Handbook*, for example). Starting with

the basic 1:4 configuration, I wound a conventional transformer with #26 enameled wire on an Amidon FT-50-43 toroid. The "50" means 0.5-inch diameter; the "43" is the core material type and each type has a specific value of magnetic permeability associated with it. Using the original one-stage circuit I then connected the center (Low-Z terminal) of the new broadband transformer to the 2N3866 collector, replacing the original tuned transformer. See fig. 2 for a schematic of the new circuit. Then, 12 volts d.c. was fed in through one free transformer end. The transformed, High-Z output (a.c. coupled) was taken at the other end. The transformer winding itself acts as an RF choke for the d.c. feed.

To give the output circuit a resistive termination for load stability I used 10K, knowing this would not excessively load down the grid circuit that followed. (I have actually loaded this circuit down to 1K.) A pre-driver stage was then added using a Linear Technology RF op amp, the LT1227CN8. This allowed me to direct-couple its output to the 2N3866 stage, eliminating the input transformer in the original DeMaw circuit. It also allowed me to tailor the overall gain more easily, as well as providing a 50-ohm termination for the preceding DDS VFO output filter. The LT1227 is a robust, general-purpose RF op amp that is available from Digi-Key and it costs only a few dollars. It may also be used as a driver for mixers.<sup>7</sup> The gain resistor and other component values of the LT1227 were adjusted to produce the best-quality waveform at the output of the 2N3866 stage. The 100-ohm resistor in series

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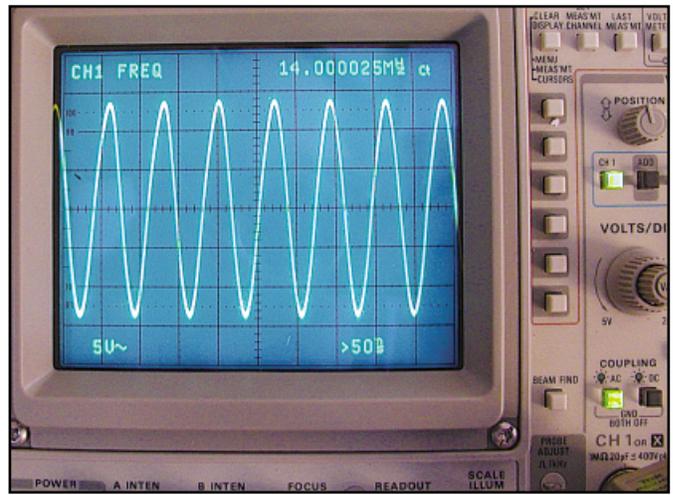
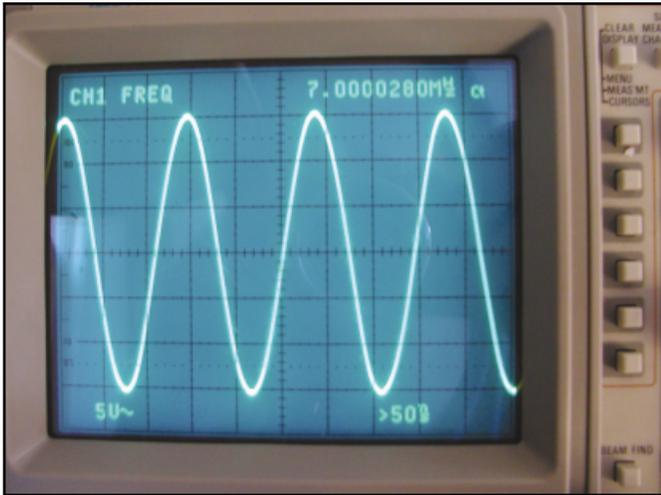
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Photos B & C— Typical measured output waveforms on 7 and 14 MHz, respectively, showing 15 volts peak output on 40 meters and 13.5 volts out on 20 meters—enough to satisfy the drive requirements of most tube-type transmitters.

with U1's output is referred to as a "back termination" and its main purpose is for load stability; a minimum value of 50–75 ohms is recommended for this part.

The entire two-stage amplifier was built "ugly-style" on a slice of Vector 8004 prototyping board, which has a ground plane as well as the 0.1 hole spacings required for the socket that housed the LT1227. This method of construction allows for easy experimentation with different transformer types, transistor substitutes, and trimming of component values. For input and output connectors, I used bulkhead BNC types with the solder lug bent 90 degrees and soldered right to the ground plane. This technique allowed for easy cabling with BNC cables. Jameco Electronics has such cables from 1 to 3 feet in length. Mouser Electronics has Vector #8004 board stock. A 2.5" × 4.5" slice of this material is sufficient to build the circuit. Photo A shows the working amplifier board.

### Initial Results and More Experimenting

The results were more than encouraging. Over most of the HF band I obtained 10–15 volts peak, dropping to about 10 volts peak at 21 MHz. The broadband transformer did indeed widen the response from the previous version and provided (across the much larger impedance) the signal swing I needed to drive a tube rig. The circuit is economical and very easy to build. See photos B and C for typical measured output waveforms from the amplifier, measured at C7. For example, at 7 MHz there was 15 volts peak, with about 13.5 volts peak observed at 14 MHz.

As an experiment, I wound another transformer on a larger (FT-82) core with insulated, #24 solid wire; its performance was identical to the smaller unit and the insulated wire (vs. enameled) was easier to work with. Increasing the number of core turns from 10 to 14 resulted in no observable difference in the output.

I also tried substituting hand-wound, 1:9 and 1:16 transformers, but the larger inductive load that they placed on the 2N3866 collector caused distortion. The original 1:4 unit delivered the volt-

age I needed with a minimum amount of distortion from the magnetic core.

In another experiment I used an Amidon type 61 core material instead of type 43 for the transformer; the result was improved signal fidelity at 14 MHz, with a penalty of more distortion below 3.5 MHz. If you are a 160- or 75-meter phone operator, the type 43 core material is definitely the way to go! It gave good results down to 1 MHz.

The final step was to drive my 1965 HT-40 transmitter with the DDS-VFO and buffer-amp combination. After

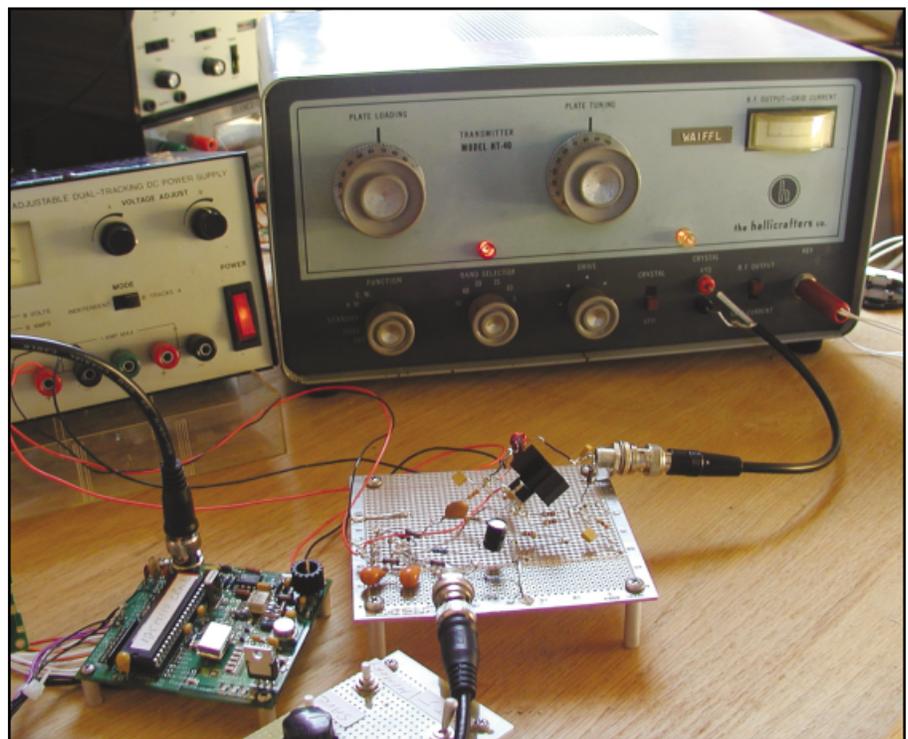


Photo D— WA1FFL's complete setup, with his DDS VFO (left) and amplifier (center) connected to his Hallicrafters HT-40 transmitter.

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some protective restoration work (replacement of paper capacitors, electrolytics, and addition of a 2-amp line fuse), the HT-40 was ready to be re-energized.

Lacking a compatible FT-243 crystal socket plug, I made up a cable with surplus connector pins that fit into the crystal socket with a push fit. See photo D of the entire system connected together. A 12-volt bench supply was used to power the VFO and buffer amp.

## Ready to Rock ... Without the "Rock"

After a 10-minute warm-up, the HT-40 was loaded up with the DDS-VFO and buffer amp driving the rig. With the buffer amplifier in the circuit there was plenty of VFO drive to obtain 35 watts output from the HT-40 on 80 and 40 meters. The output on 20 meters was 33 watts and on 15 it was 25 watts, with 20 watts on 10 meters. All of these results were obtained while using a 50-ohm dummy load at the HT-40 output. The HT-40 tubes were the originals, and the readings were very typical of what I remember getting from the rig after its last use some 35 years ago.

*Important:* it should be noted that the length of cable between the buffer amplifier and the HT-40 (10 inches of RG58/U) should be kept very short to avoid unacceptable roll-off on the higher bands, resulting in insufficient drive on 10 meters. An earlier (2-foot) cable made from miniature coax exhibited this problem; it had 55 pF of measured capacitance. The new 10-inch cable measured only 17 pF and worked significantly better, easily driving the rig up at 28 MHz. As a check against false resonance, the output was put on the author's scope/counter (Tektronix 2247A) and it showed a stable 28.000-MHz carrier reading.

A complete parts kit is available for the buffer amplifier at <[www.WA1FFL.com](http://www.WA1FFL.com)>. I hope you will try this amplifier

with your favorite vintage-tube rig. I will have the HT-40/DDS-VFO/driver amp set up at the Hagerty Radio Company booth at the Dayton Hamvention® so that you can see them working.

## Acknowledgements

The author would like to thank Mitchell Lee, KB6FPW, Senior Applications Engineer with Linear Technology Corp., for his valuable suggestions and insight. I also am grateful to Bruce Muranko, WD8BPD, for testing the circuit with his vintage Heathkit DX-40. His photos and correspondence indicated success.

## Notes/References

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