<u>D104 FET TRANSFORMER</u>

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I. INTRODUCTION

The Astatic D104 is a very popular, but now obsolete microphone that has a 75+ year manufacturing history. From my research, the first D104 ads appeared in 1935. The D104's crystal element and mechanics have evolved little since its first introduction in the mid-1930s. However, as the D104 evolved, the "grip-to-key" arm was added in 1938, and the 2-transistor amplifier in the TUG8/TUG9 style base was added in the late 1960s.

Presumably, the 2-transistor amplifier was implemented to meet the needs of evolving technology as manufacturers shifted away from vacuum tubes toward solid-state devices. Although the initial intent was likely an impedance transformation device for use with low-impedance, solid-state input circuits, the D104 with its adjustable preamp became widely known as a “power mic” during the peak of the U.S. citizens band activity in the mid-1970s. Finally, the Silver Eagle version included an additional PTT arm in the mic base.

The new *D104 FET Transformer* circuit board is an easy, direct drop-in replacement for the 2-transistor power mic board. In *non-amplified* D104 mics, the board can be mounted into the base using double-sided tape -- or it's possible to fasten the board using one of the mounting tabs and an existing base screw. When practical, the two mounting tabs can be broken off with diagonal cutters if the board will be fastened in place with double-sided tape.

If you conduct a web search, you will see many D104 buffer circuits. In almost every case, something is neglected in the design. My goal was to address these shortcomings with a high-performance circuit. Fortunately, an FET configured as a source-follower is quite forgiving of its designer, even when the source and drain leads are reversed. The new board is a very high quality CAD design with “via stitching” and a ground plane pour.

II. INSTALLATION

<u>[Important Notes before proceeding with installation:</u>

(i) ***<u>The new circuit is a fixed source-follower; after installation, the D104’s base gain control is normally bypassed. However, a schematic representation is attached showing an optional level control by using an amplified D104’s 5K gain control;</u>***

(ii) ***<u>Components R3 and C5 are NOT normally used and are left open on the board. [Details below]</u>***

1) Access to the base of the D104 is accomplished by removing three (3) screws from the bottom plate. Set them safely aside as you remove the bottom plate from the mic base.

2) In D104 mics with the existing 2-transistor circuit board (e.g., T-UG base), removal of the board is accomplished by unscrewing a pair of #6 metal screws. The board in *newer D104s* is held in place with two #6 Nylon screws. In either case, use these screws to hold the new board in place. **The board is inserted with the components facing down and away from you (only the bottom soldered connections showing).** You may leave the gain pot mounted or remove it; the control is not normally used with the new circuit (see paragraph 3 below). As stated earlier, the new circuit uses a "source follower" configuration with unity gain. A typical unloaded crystal element produces far more voltage than is normally required for all transmitters and transceivers and as such, level boost is almost never required. In the event you have a stock D104 mic *without* the existing 2-transistor board, *some* D104 versions *may* need to be installed with double-sided tape. In these instances, look for two screws holding the terminal strip to the base. If these screws are missing, then two-sided tape will be required.

3) The attached schematic shows the old gain control in an optional block. In amplified D104s, it's possible to re-wire the existing gain control to vary level into the transmitter but at the expense of raising the source impedance. The source impedance then becomes a function of the control setting. For normal mic cable lengths (i.e., under 10 ft), this will not present a problem if the added utility of a level control is desired.

4) There are four leads coming from the new FET Transformer board: (1) the **green wire** is soldered to the **hot mic element** terminal in the base. This lug should have an existing green wire going up to the mic head through the vertical mic stand; (2) **white** is the **audio output** lead. It may connect to the existing white lead or connected to the mic switch. I do not use the mic switch to open/close the audio output since that precludes VOX operation. If your D104 has a mic diagram affixed to the base, follow the output lead; (3) **red and brown** are paired. These are used to **power** the new board from a +9V battery or through a +8V source from a transceiver's 8-pin mic jack. Red is positive (+), and brown is negative (-). The red lead goes to the same base power source lug. The brown lead is soldered to the existing base ground lug. Again, refer to your D104's mic base diagram as well as the attached mic base diagrams that show 'before and after" schematics of the most common D104 base wring arrangements. As the D104 changed over time, so did base wiring. If it's not practical to obtain +9V or +8V on the mic cable, most any voltage source from +5V to +15V will work fine with the new circuit – including a common +9V "transistor radio" battery.

5) The FET Transformer board is normally shipped with circuit ground strapped from one of the mounting holes. This is to give the owner freedom to experiment with any isolated buzz, hum, or RF issues. The default arrangement is for the jumper to be in place.

6) ***You'll notice that R3 and C5 are not used in the new board.*** These are optional and only used to alter the frequency response for low-end roll-off. However, a 4.7 meg resistor can be used at R3 for FET gate static protection in **low humidity areas**. *The widest audio response will be produced by leaving these two parts out of the circuit.* If desired, C5 can be used to roll off the high-end. C5 is in parallel with a very high output impedance from the crystal element. So, small values less than 200 pF should be sufficient. Again, these parts are not normally used in the new circuit.

7) The FET is a MPF-102, J310 JFET, or equivalent. You may want to keep a small supply of these available, especially as leaded transistors continue to go obsolete.

8) The FET Transformer circuit has adequate RF bypassing and is completely de-coupled from its power source. Also, the board has a via-stitched ground plane "pour" to assist with RFI mitigation.

9) After installation of the FET Transformer board, cartridge loading Z is greater than 10 meg-ohm. The circuit's output Z to the transmitter is just under 300 ohms.

III. THEORY OF OPERATION

The FET Transformer is configured as a classic source-follower (common drain amplifier) where gain is less than unity. It uses either a J310, MPF-102, or equivalent n-channel JFET transistor. Note that the JFET as a source-follower is self-biased and *does not require* a "leak" resistor (R3) between the gate and circuit ground. However, notice that R3 is shown as an option in the attached schematic diagram. A ¼-watt, 10 meg resistor may be used at R3 when using the D104 FET Amplifier in low humidity areas to prevent JFET gate damage from static electricity. Alternatively, R3 can be reduced in value to deliberately form a simple 6 dB/octave high-pass filter. An R3 value of 100K will result in a -3dB turnover point close to 250 Hz.

Self-bias stabilizes the quiescent operating point against changes in JFET parameters (e.g.,Idss, gfs, etc.). Here's the idea: Suppose we substitute a JFET with a forward transconductance (gm or gfs) value that's twice as large. Then, the drain current will try to double. But since the drain current flows through R(s), the gate-source voltage V(gs) becomes more negative and reduces the original increase in drain current. A gate voltage equal to 1/4 of V(gs-off) results in drain current equal to approximately 1/2 of Idss. To set-up the mid-point bias "Q point," R(s) is computed simply by taking the *reciprocal of the JFET's forward transconductance value*. This value creates a drain current equal to 1/2 of Idss.

With some difficulty, FET transconductance can be measured. In the alternative, simply research the range of gm or gfs values from the manufacturer's data sheet and compute the geometric mean. For the Motorola MPF-102, the computed R(s) value is approximately 300 ohms. This becomes the driving source impedance to the transceiver. And so, the input impedance of the FET transformer circuit is greater than 10-megohm while the output impedance is less than 300 ohms. Within limits, R1 can change in value based on the JFET's gfs value. As the value is lowered, one benefit is the source Z decreases, but at the expense of greater current and a shift of the Q point along the FET Transformer's bias curve. Keep this in mind if powering the circuit from a 9V battery.

Output coupling capacitor C4 is 4.7 uF and is adequately large enough to pass a low-end response below 100 Hz as the typical mic input impedance of most transmitters and transceivers is > 1K-ohm.

The FET Transformer Circuit is also an excellent choice when using a crystal (or ceramic) mic element on a long mic cable run into the grid of an audio triode, for example. Many owners of older vacuum tube-based transmitters incorrectly assume that the extremely high input impedance of the control grid is enough to offset the crystal element's Hi-Z source impedance. However, a recipe for disaster is set up any time a high parallel capacitance exists across a Hi-Z source impedance. Since the source Z of the crystal element is mostly a capacitive reactance, the cable capacitance creates a uniform voltage divider across all audio frequencies. To mitigate the effect of distributed cable capacitance from the D104's Hi-Z mic element, the *D104 FET Transformer Circuit* will convert the Hi-Z mic output into a Lo-Z source at a point where it matters most*: the input end of the mic cable*. In doing so, the low output impedance from the FET Transformer is set up by R(s) and swamps out the detrimental attenuation caused by a combination of cable capacitance in parallel with a series capacitive source. A low driving source Z also minimizes noise pick-up on the mic line.

Attached are several wiring diagrams for use with the *D104 FET Transformer* circuit. *This is not an all-inclusive set of diagrams.* For example, I do not yet have a wiring diagram of the non-amplified D104 with the grip-to-key arm. Also, very early D104s have no PTT switching whatsoever: the mic cable is connected to the mic element, runs through the stem and out the base to the transmitter. So, some brain power will be required when using the FET Transformer in these D104 variations.

IV. SPECIFICATIONS

- Input impedance: Greater than 10 meg-ohm.
- Frequency response: +/- 0.5 dB, 50 Hz - 10 kHz (incl. crystal element equivalent source Z of 1000pF in series with 10K resistance);
- Audio filtering: On-board provision for optional 6dB/octave HP filter by adding two components;
- Output impedance: Less than 300 ohms and will drive both Lo-Z and Hi-Z terminations;
- THD, ref. 1 kHz at -10 dBu input level: 0.1%;
- IMD (SMPTE): at -10 dBu input level: 0.15%
- SNR, no weighting, > -80 dB ref. 0 dBu;
- Gain: Less than unity as a source-follower. Generally, no amplification required as the high-output-voltage crystal element is completely unloaded;
- Output level: Adjustable with external control as shown on our schematic and circuit description. The existing Astatic 5K potentiometer may be used to control output level;
- Powered from +5V to +15V and only 2 mA of idle current with the J310 and MPF-103; approx. 1 mA with the J201.

V. PARTS LIST

- C1, C2 0.1 uF film 50 WVDC, radial leads
- C3 47 uF Electrolytic 25 WVDC, radial leads
- C4 4.7 uF Electrolytic 25 WVDC, radial leads
- C5 normally left open. Optional to form LP filter (see text)
- C6 0.001 uF film 50 WVDC, radial leads
- R1 100 ohms 1/4 W carbon film
- R2 1K 1/4W carbon film
- R3 normally left open. Use for Q1 static gate protection or to form a HP filter. (see text)
- R4 100 Ohms 1/4 watt carbon film
- Q1 J310, MPF-102, or other N channel JFET transistor

VI. CONCLUSION

When considering cost, circuit simplicity and performance, it's difficult to beat *the D104 FET Transformer* circuit. In the future, another set of boards will be available that use the common-source configuration. This will allow for adjustable mic gain through the use of, for example, the existing D104 gain control.

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