The SHARC Audible Current Meter

When Raymond Andrews, K0LZR, president of the Sand Hills ARC, suggested that club members design a special radio aid for blind amateurs, he got results.

By Leroy J. Stockemer,* K0WOL

The audible current meter described in this article originally was designed for a fellow radio amateur who is blind, but it may also be of special use to those blessed with sight. My friend needed a device to enable him to tune his transmitter to resonance. He also wanted very much to have a means of knowing the relative power input to the final rf stage. We reasoned that the latter could be accomplished by monitoring different current levels.

Other devices used previously by my fellow amateur proved undesirable because they tended to give false indications of resonance. Furthermore, they lacked a method of showing the power input or output of the rf stage. False indications, needless to say, can cause detrimental effects to the rf power tubes in the final amplifier. That misfortune befell my friend several times, a result of misadjustment.

As I thought over his situation, these criteria came to mind. There existed a need for a device that would track and indicate the movement of the existing current meter. Such a unit should have a means of indicating different current levels for adjusting the bias level and relative power input to the rf power amplifier. I rationalized also that the device must combine practicality, effectiveness and low cost. The practical aspect seemed to dictate that the unit would be of small physical size, have a minimum of operating controls and require only simple calibration techniques.

Initial efforts to produce a satisfactory device were rather disappointing. Several circuits were tried. They all involved too many components, along with a lack of simplicity. Determination, however, led to a design that seemed well suited for meeting the criteria.

Block Diagram Explanation

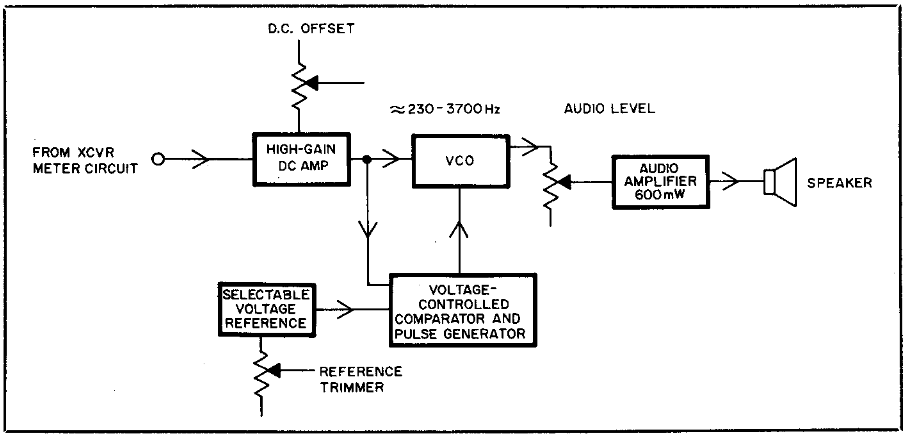
The block diagram (Fig. 1) illustrates the basic configuration of the audible current meter (ACM). It consists of a high-gain dc amplifier (40 dB) which feeds a voltage-controlled oscillator (VCO) and combination voltage-controlled comparator/pulse generator. A switch-selectable voltage reference is used in conjunction with the voltage-controlled comparator. The output of the VCO feeds a 600-mW audio amplifier which drives a small 8-ohm speaker.

The input terminals of the high-gain dc amplifier are connected to the meter terminals of the transceiver. The input voltage range is 0 to 50 mV, representing a meter deflection of 0 to 1 mA for the meter in a Swan 350 ssb transceiver. The meter current (0 to 1 A) is indicative of the input current to the final rf amplifier of the transmitter.

The ACM dc amplifier output voltage ranges from 1 to 5 volts. This variable-voltage output causes the VCO to vary in frequency from approximately 230 to 2100 Hz, representing a change in transmitter input current from 0 to 1 ampere.

When the transmitter is tuned through resonance (indicated by a dip in meter

Fig. 1 — Block diagram of the audible current meter.



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current) the audible pitch generated by the VCO goes from high to low to high. At the point where a dip is reached (the lowest pitch sound indicating resonance), the selectable-voltage reference may be set to a level representing a specific transmitter-input current. This enables the operator to load the power amplifier for the desired power input.

During operation, as the transmitter is adjusted for more input power, the voltage at the output of the dc amplifier increases; the tone goes higher in pitch until the selected current level is reached. (Of course, this current level must coincide with a dip in meter current, as mentioned above.) When it reaches a value equal to that selected by the voltage reference, the comparator becomes a pulse generator which gates the VCO *off* and *on* at a variable rate. Then the tone gates *off* and *on* at approximately a 2-Hz rate. If the current is increased further, the rate will rise to about 13 Hz, indicating the desired current level has been surpassed by an appreciable amount. The proper level is attained when the tone just begins to gate *off* and *on*.

The selectable voltage reference is designed to compare transmitter current levels representing 50 mA (to enable setting the idling current for the rf power amplifier) and 100, 200, 300, 400, 500 and 600 mA (for setting the desired power input). This arrangement seems to serve the purpose well.

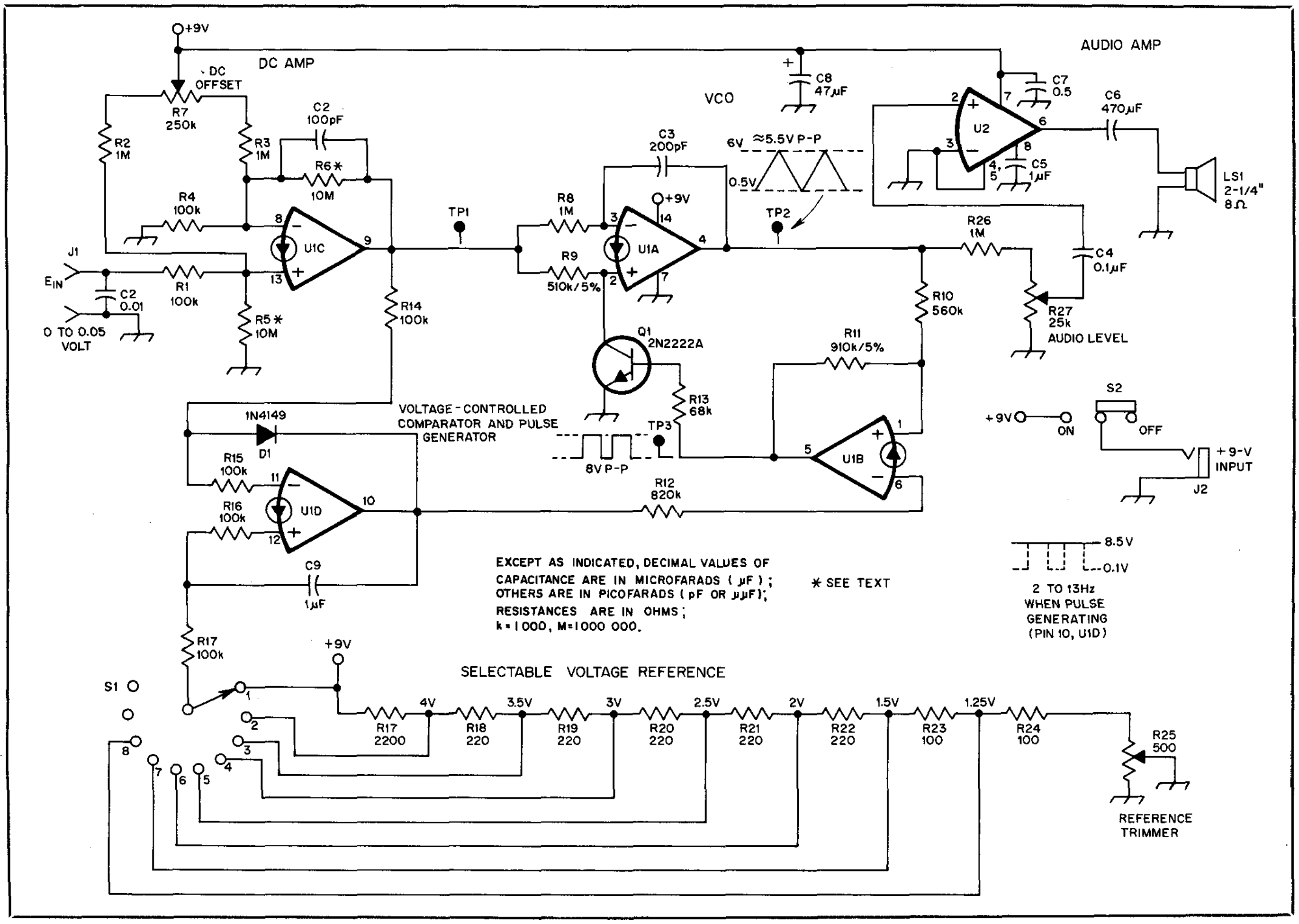
We originally tried the circuit on a Swan 350 transceiver. Later it was modified to function with a Swan 700-CX. Results with both transceivers were remarkably good. The audible current meter can be used with nearly any type of meter that indicates current as long as the negative side of the meter is near ground potential. Other uses for the audible method, apart from those explained in this article, might be for an rf power-output indicator, an SWR monitor, or a remote monitoring device.

The Circuit

Our ultimate design incorporated the use of a low-cost LM3900 quad-amplifier IC using four Norton operational amplifiers. This amplifier seems rather unusual. Most op amps make use of differential input voltages, whereas the Norton amplifier differentiates between input currents. This allows the use of high-value resistors to convert input voltages to input currents. Another feature is that the Norton amplifier uses a current mirror to mirror the noninverting input current about ground. This allows the use of a single power supply voltage. Most of the circuitry consists of variations of the basic configurations given in applications manuals.[1]

The audible current meter utilizes two integrated circuits and one transistor, as shown in the schematic diagram of Fig. 2. To some people the diagram may seem rather complicated at first glance. It really isn't, however. U1A and U1B are the main components of the VCO, whereas U1C functions as the dc amplifier and U1D serves as a combination voltage-controlled comparator/pulse generator. U1 is an LM3900 14-pin DIP quad amplifier. Q1 performs as a switch in the VCO circuit. U2 is an LM380-8 (8-pin DIP) 600-mW audio amplifier. U1C, the dc amplifier, has a gain of approximately 100. Offset-control R7 is adjusted to pro-

Fig. 2 — Schematic diagram of the SHARC audible current meter. U1 is a type LM3900 quad-operational amplifier. U2 is a type LM380-8 600-mW audio amplifier. S1 provides a choice of voltage ranges furnished through the selectable voltage reference divider circuit. C9 is nonpolarized.



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[1] *Linear Applications Manual* (AN72), National Semiconductor Corp., February 1973.

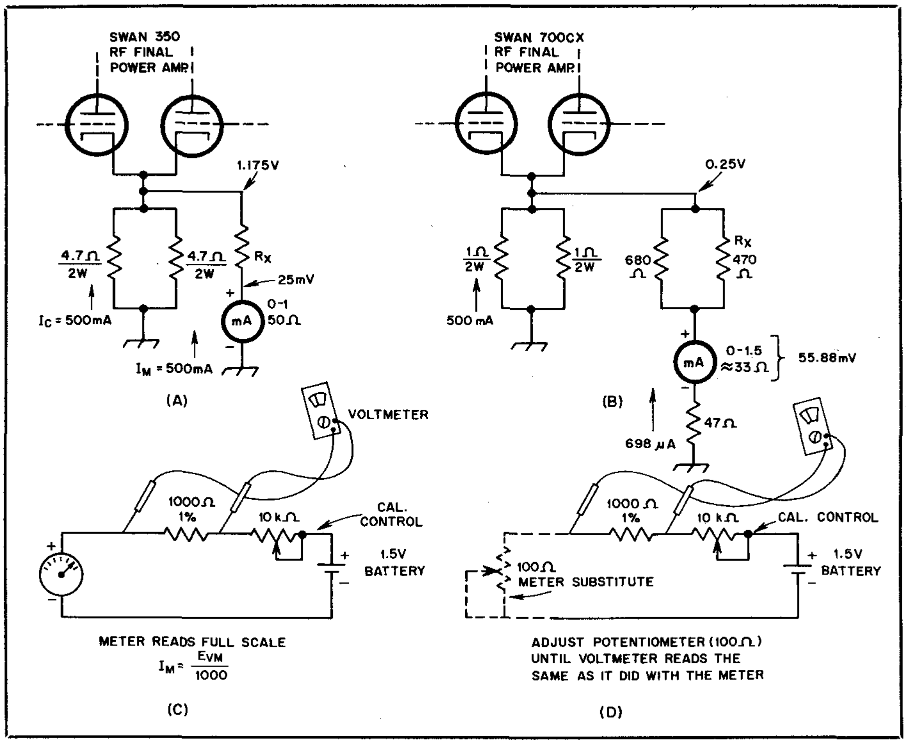


Fig. 3 — These drawings suggest how you would proceed to apply an audible meter circuit to a Swan 350 or Swan 700-CX. A simplified Swan 350 meter circuit is shown at A. The diagram at B is for the Swan 700-CX meter circuit. In both cases the cathode current is measured. Drawing C is for determining the full scale current of a milliammeter. Drawing D is for a circuit to determine the internal resistance of a milliammeter after the full scale current is ascertained.

vide 1 volt at the test point (TP1) with the input at J1 shorted to ground. This 1 volt applied to the input of integrator U1A causes this voltage to be changed to an input current charging C3, effecting a ramp-up voltage at TP2. When this ramp reaches approximately 6 volts, it causes the Schmitt trigger U1B to trip. The output of U1B goes positive, turning on Q1 and causing pin 2 of integrator U1A to be grounded. By grounding pin 2, the integrator ramps down to approximately 0.5 volt. U1B then reverts back to the initial state (pin 5 low), turning off Q1. The cycle then repeats itself, thus generating an output waveform which is triangular. U1A and U1B, along with Q1, form the VCO. The frequency change of the VCO may be understood from the following relationship:

$$f_o = \frac{V_{in} - V_{be}}{2RC\,(\Delta V_o)} \qquad \text{(Eq. 1)}$$

where

f_o = frequency
V_{in} = input voltage to integrator
V_{be} = base-to-emitter voltage ($\approx$0.5 V) of the integrator
R = R8 in the diagram = 1 MΩ
C = C3 = 200 pF
ΔV_o = ramp voltage = 6 V − 0.5 V = 5.5 V.

Since R, C, ΔV_o and V_{be} are essentially constant, Eq. 1 indicates that the frequency is directly proportional to V_{in}. Increasing the input voltage causes the frequency to increase.

U1D acts as a combination voltage comparator and pulse generator. With S1 in position no. 1, a 9-volt input is applied, holding the output of U1D (pin 10) high (8.5 V). This voltage is applied as an input to the inverting side of U1B, enabling the VCO. If S1 is set to position 3, a 3.5-volt input is applied to the noninverting input of U1D, still enabling the VCO. Now suppose that at the same time a 25-mV level is present at the input of J1. This would produce a 3.525-V output from the dc amplifier. Because this input to the inverting side of U1D is slightly greater than the 3.5 volts to the noninverting side, the output of U1D drops to approximately 0.1 volt. When the output of U1D goes low, the enable voltage to the VCO is removed. U1B ramps down to a low level and holds. At the same time, C9 is discharging, holding the output of U1D to a low level. D1 is also conducting, effectively removing the inverting input voltage to U1D. U1D remains low until C9 has discharged to a lower level. After C9 reaches a predetermined lower level, the U1D output again goes positive. This enables the VCO to operate again, generating an output tone. The positive transition at the output of U1D also reverse biases D1, allowing the comparison voltage to be sensed at the inverting input. C9 also couples this positive input to the noninverting input, holding the output of U1D high. After a period of time, C9 becomes charged and the voltage at the inverting input again drives the output low and the cycle repeats. From the above explanation, you can see how different settings of S1 can be used to compare the input voltage taken from a milliammeter to provide a means of determining representative current levels.

Metering

Because there are various methods of metering current in different brands of equipment, use of a different gain figure for dc amplifier U1C may be necessary in some cases. As stated previously, the circuit shown was applied to a Swan-350 transceiver and later modified to accommodate a Swan 700-CX transceiver. Amateurs who may be considering the construction of an audible current meter are advised to study the metering circuit of the transmitter with which the audible meter is to be used. The two units must be electronically compatible. In many instances one will find that the manufacturer has installed a 0-1 milliammeter associated with various combinations of shunt and series resistors.

Fig. 3 provides some examples of metering arrangements. Circuit A is for the Swan 350 transceiver. The meter internal resistance is nominally 50 ohms. With 500 mA flowing in the final amplifier cathode circuit, a 0-1 milliammeter should have 500 μA flowing through it to register the 500-mA cathode current. Although the meter current is only 500 μA, the scale is calibrated in milliamperes. This 500-μA current causes a voltage drop of 25 mV across the internal resistance of the meter. By applying Ohm's Law and using the values just given, we can arrive at these results: E = IR = 500 μA × 50 ohms = 0.025 V = 25 mV. In this case the value of R_x would have to be 2300 Ω, but don't look for a 2300-Ω resistor in the meter voltage-divider circuit. There may be two or more resistors in parallel to make R_x the value needed to have the milliammeter register properly. One must compensate for circuit tolerances, meter error and all that good stuff put there seemingly to confuse the uninitiated. This arrangement yields a value of 50 mV across the meter for full-scale deflection.

Fig. 3B shows the meter circuit for the Swan 700-CX transmitter. In this case the voltage across the meter and 47-ohm series resistance is approximately equal to 56 mV. Here a current through the meter and voltage divider circuit of 698 μA represents 500 mA of transmitter current. Of course, the meter scale is marked to represent 500 mA. The important part of all this is being able to determine (1) the voltage across the meter circuit for a certain amount of representative transmitter current and (2) how to change the gain of the dc amplifier in the audible current meter in order to obtain the desired results. If you know the resistance of the meter and the full-scale current reading, then calculating the maximum expected voltage across the meter for any current through it is simple. If you should be fortunate enough to have a good millivoltmeter then the voltage across the meter should be read and if the range of the meter is known, then the current may be read on the meter. A good millivoltmeter, however, is not likely to be found in most amateur stations.

Table 1

I_t, A	E_x, V	ΔE, V	R_x, Ω
$I_1 = 1.2$	$E_1 = 6.376$	$V_{cc} - E_1 = 2.624$	R17 = 1200
$I_2 = 1.0$	$E_2 = 5.48$	$E_1 - E_2 = 0.896$	R18 = 410
$I_3 = 0.8$	$E_3 = 4.584$	$E_2 - E_3 = 0.896$	R19 = 410
$I_4 = 0.6$	$E_4 = 3.688$	$E_3 - E_4 = 0.896$	R20 = 410
$I_5 = 0.4$	$E_5 = 2.792$	$E_4 - E_5 = 0.896$	R21 = 410
$I_6 = 0.2$	$E_6 = 1.896$	$E_5 - E_6 = 0.896$	R22 = 410
$I_7 = 0.1$	$E_7 = 1.448$	$E_6 - E_7 = 0.448$	R23 = 205
		$E_7 - 0 = 1.448$	R24 = 412

Checking a Meter for Full-Scale Current

A simple method of checking a meter for full-scale current value and internal resistance is shown in Fig. 3C. All that is needed are a voltmeter, a 1000-Ω resistor (1-percent tolerance), a 100-Ω and a 10-kΩ potentiometer, plus a 1.5-volt battery. Connect the meter as shown in Fig. 3C with the potentiometer set for full resistance. Then decrease the resistance of the potentiometer until the meter just reads full scale. Measure the voltage across the 1000-Ω resistor and calculate the current through the meter by means of Ohm's Law.

$$I = \frac{E}{R} = \frac{\text{voltage across 1000-}\Omega\text{ res.}}{1000\ \Omega}$$

Leave the potentiometer set for full-scale indication on the meter. Next remove the meter from the circuit, replacing it with a 100-Ω potentiometer as shown in Fig. 3D. Adjust the 100-Ω potentiometer until the voltmeter reads exactly the same as when the meter was in place. Remove the 100-Ω potentiometer from the circuit and measure the adjusted resistance of the potentiometer. This resistance is the same as the internal resistance of the meter. Now calculate the full-scale voltage of the meter. The following steps illustrate how to perform the calculation. As an example:

1) Current calculated through the 1000-Ω resistor = 1 mA = 0.001 A = I_m.

2) Resistance of the potentiometer across the circuit measured 50 ohms = R_m.

3) Then $E_m = I_m R_m = 0.001 \times 50 = 0.05 = 50$ mV.

This example is well suited for the audible current meter shown schematically in Fig. 2.

If the transmitter to be used with the audible meter has a circuit such as illustrated by Fig. 3B, the full-scale reading will provide a voltage across the meter circuit of 168 mV. In a case such as this, the gain of the dc amplifier would need to be changed. If the circuit were left as it appears in Fig. 2, the amplifier would be driven into saturation before a full-scale meter reading occurred. Also, the current-comparison scale would not agree with the current readings of the meter. In order to avoid saturation, the gain to the amplifier is changed as follows.

Step 1: Since the maximum (full-scale current) meter-circuit voltage is 168 mV and the maximum positive voltage available from the amplifier is 8 volts and the offset voltage at TP1 is 1 volt, the maximum allowable swing is 7 volts, or the output should not swing more than 7 volts for an input of 168 mV. The required gain for the amplifier is therefore

$$A_v = \frac{E_{out}}{E_{in}} = \frac{7\text{ volts}}{168\text{ mV}} = 41.67$$

We can then calculate the value of R5 and R6, using these values to change the gain of the dc amplifier and balance the input currents.

$$\text{R5 and R6} = (A_v - 1)\text{R4} = (41.67 - 1)100\text{ k}\Omega = 4.067\text{ M}\Omega$$

Since this is not a standard value, we select the nearest standard value (3.9 MΩ). This value provides a gain of

$$A_v = 1 + \frac{R6}{R4} = 1 + \frac{3.9\text{ M}\Omega}{100\text{ k}\Omega} = 40$$

Step 2: Calculate $E_{out} \cdot E_o = E_{in} \times A_v = 168\text{ mV} \times 40 = 6.72$ V

Step 3: Determine the maximum comparison current for the particular transmitter. (We'll use 1.2 A here to illustrate.) Since 1.5 A is full scale, the ratio of maximum desired comparison (1.2 A) to maximum full scale meter current (1.5 A) times the maximum input voltage of 168 mV provides:

$$E_{in} = \frac{I_m E_m}{I_{max}} = \frac{1.2 \times 168\text{ mV}}{1.5}$$

$$= 134.4\text{ mV}$$

134.4 mV will represent the maximum voltage into the dc amplifier to be used for current comparison.

Step 4: Calculate the output voltage of the dc amplifier with 134.4 mV input.

$$E_o = E_{in}A_v + 1 = (134.4\text{ mV} \times 40) + 1 = 6.376\text{ volts}$$

Step 5: Determine the resistance of R17 for the selectable voltage reference. (See Fig. 2.) Let the current through the voltage divider equal 1.5 to 2.5 mA. Therefore

$$R17 = \frac{V_{cc} - E_o}{I_{ref}} = \frac{9\text{ V} - 6.376\text{ V}}{2\text{ mA}}$$

$$= 1312\ \Omega$$

where

V_{cc} = power supply voltage

E_o = 6.376 volts (calculated in step 3)

I = 2 mA (voltage-divider current)

Since 1312 Ω is not a standard value, we'll use the nearest standard value and re-establish the voltage divider current. Using 1.2 kΩ,

$$I_{ref} = \frac{E_{R17}}{R_{17}} = \frac{2.624}{1.2\text{ k}\Omega} = 2.187\text{ mA}$$

Step 6: Now determine the rest of the resistances in the selectable voltage reference. First, determine the desired comparison currents. Then start a table, similar to Table 1, listing these current values and compute E_x, ΔE and R_x. Fill in the rest of the table. The computation procedure is

1) $E_x = \frac{(E_1 - 1)I_x}{I_1} + 1$

For example,

$$E_2 = \frac{(6.376 - 1)\ 1.0}{1.2\text{ A}} + 1 = 5.48$$

where

$I_x = I_1, I_2, I_3, \ldots$

$E_x = E_1, E_2, E_3 \ldots$

2) $\Delta E = E_1 - E_2, E_2 - E_3 \ldots$

3) $R_x = \frac{\Delta E}{I_{ref}}$

For example,

$$R18 = \frac{E_1 - E_2}{I_{ref}} = \frac{0.896}{2.187\text{ mA}}$$

$$= 409.69\ \Omega$$

where I_{ref} was determined in step 5.

4) $R_{24} = \frac{E_7}{I_{ref}} - 250$

where $250 = \frac{R25}{2}$

As can be seen from the table, if the

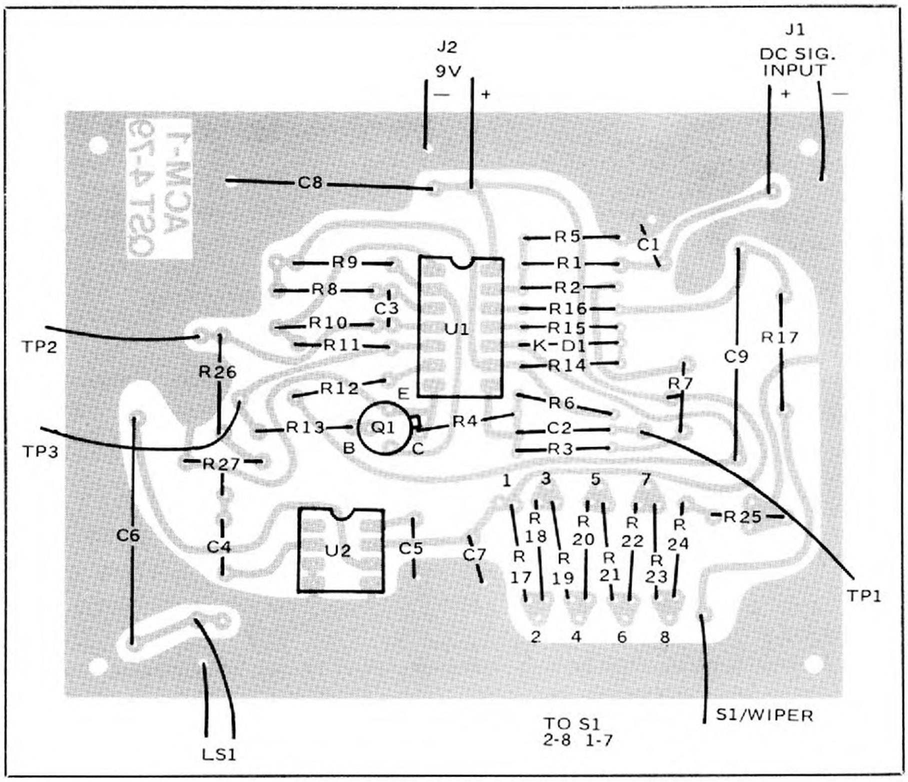


Fig. 4 — Parts placement guide for the audible current meter. Parts are placed on the nonfoil side of the board; the shaded area represents an X-ray view of the copper pattern. (The etching pattern appears in the "Hints and Kinks" section of this issue.)

values of transmitter current selected for comparison have a constant difference, the resistors R18 through R22 will be the same value. The formulas included allow for any desired current variable.

Whereas the resistors R18 through R24 are not standard values, I recommend that standard values be used instead. For example, for R18 through R22 use 430 ohms, for R23 use 220 ohms, and for R24 use 430 ohms. Although the accuracy will be somewhat affected by the substitution, an accuracy of 1.5 percent should be obtainable by adjusting R25. Of course one could make up the proper resistance values by paralleling combinations of resistors or by purchasing precision resistors. However, I do not suggest the use of precision resistors because they are more expensive and rather difficult to obtain.

Other Considerations

Other transmitter metering circuits may exist for which the foregoing information may not be applicable. However, the required input voltage and selectable voltage reference calculations should still apply. In some situations it may be advantageous to utilize a separate voltage divider in the transmitter in order to obtain the drive to be used with the audible current meter.

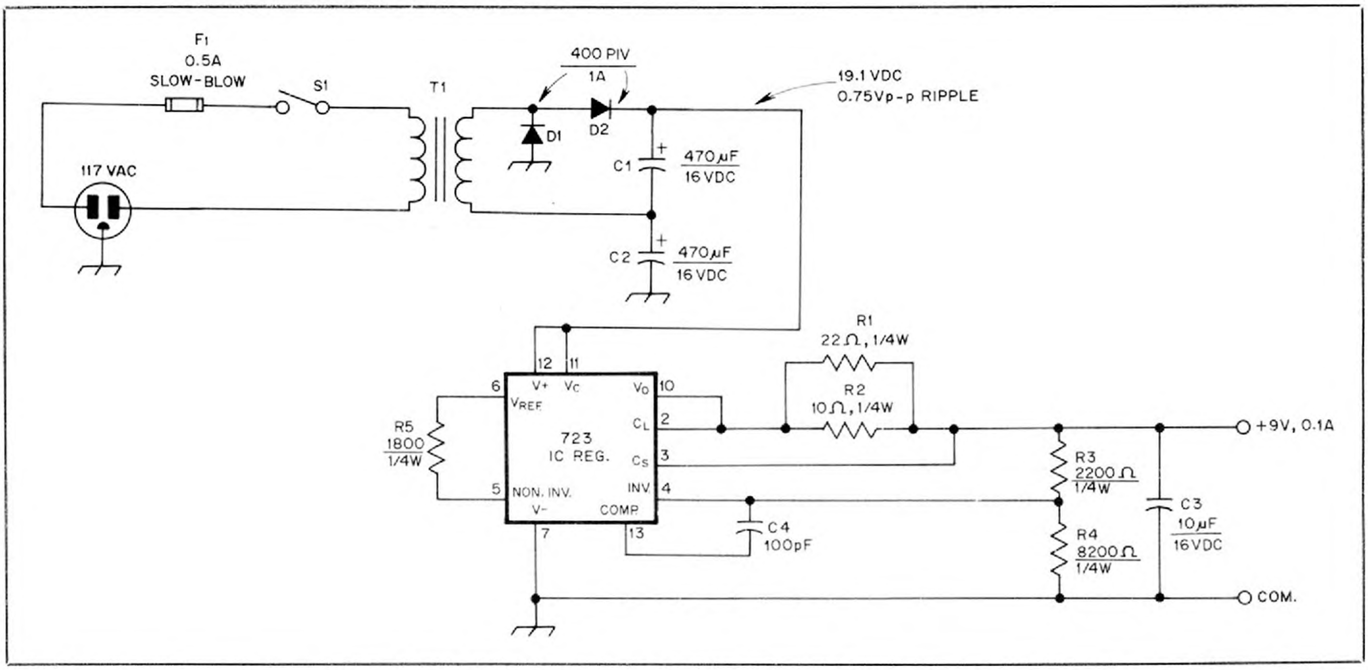
Although the device described in this article is used to monitor the current through the final amplifier of a transmitter, it could just as well be used to measure the SWR or rf power output. If the SWR were to be monitored, the selectable voltage reference resistors could be proportioned so that the no. 2 switch position could be used to calibrate the full-scale meter reading (maximum forward power) while the other positions would represent various levels of reflected power.

Construction

Construction of the audible current meter is facilitated by use of the circuit board pattern and the component placement guide, Fig. 4. Use of 1/4-watt 5-percent resistors is suggested. C3, the 200-pF capacitor in the integrator circuit, should be a silver-mica or other good-quality capacitor. C9, a 1-µF capacitor, is nonpolarized.

In choosing other components for the

Fig. 5 — Power supply diagram for the SHARC audible current meter.



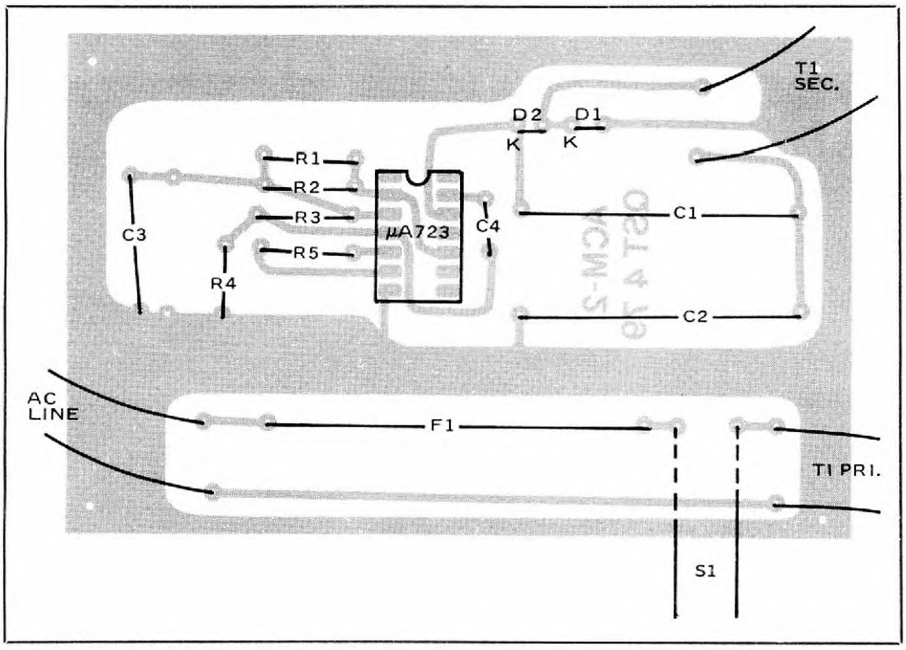


Fig. 6 — Parts placement guide for the audible current meter, shown from the component side of the board. The shaded area represents an X-ray view of the copper pattern (see "Hints and Kinks" section of this issue).

audible meter I selected a 10-position single-pole phenolic rotary switch for S1. OFF-ON switch S2 is a miniature single-pole slide switch. J1 is a 2-terminal phenolic pan-head screw-type terminal board. J2 is a miniature phone jack and R7 and R27 are (CRL) cermet vertical-mount printed-circuit potentiometers.

A 3-1/2 × 5 × 3-1/2-in. (89 × 127 × 89-mm) Minibox provides a suitable housing for the circuit-board assembly and the speaker, in addition to S1 and S2. A small square Minibox may be used to enclose the external power supply. A diagram and the printed circuit-board layout for a 9-V power unit to be used with the audible current meter are shown in Figs. 5 and 6.

Calibrating and Using the ACM

To calibrate the audible current meter, set the audio level control, R27, to approximately midposition. Connect a voltmeter to TP1 and short the J1 input to ground. Adjust the dc offset with R7 so that the voltage at TP1 measures 1 volt. This should produce a relatively low-pitched sound from the speaker. Remove the short from J1 and the sound from the speaker should become very high-pitched. Next, the voltmeter is connected to the common terminal of S1. R25 (the reference trimmer) is adjusted for the proper voltage at different positions of S1 with the adjustments set as near as possible to the voltage values calculated as E_X in Table 1.

The next step is to connect the audible meter to the metering circuit with which it is to be used. Switch S1 to the no. 1 (9-volt) position. Note that the pitch of the tone generated increases as the meter current increases. Set S1 to the desired position. Note that the tone begins to pulsate when the current through the meter equals the current level selected by S1. When the current is less than this value, the tone will be steady and lowers in pitch as the current through the meter decreases. If the current selected does not agree with the meter reading, it may be necessary to make a slight adjustment to the offset control, R7, to make the audible meter start pulsating at the selected current value and that of the meter. This completes the calibration.

When using the device while tuning a transmitter, a good suggestion is that the range switch, S1, be placed in the no. 1 (9-volt) position with the transmitter being tuned for the lowest pitch sound indicating resonance. Set S1 to the desired current position and increase the loading until the tone starts pulsating. The tone will be steady, or will increase and decrease in pitch as long as the meter current does not equal the value selected. This facilitates resonating the final amplifier (dipping the plate current) as the transmitter is loaded.

If the rf output power is being monitored, then one tunes the transmitter to obtain the highest pitched sound. A value one seeks to monitor is selected and the transmitter output is increased until the tone begins to pulsate.

The audible current meter is indeed a simple yet effective device. The ACM concept may be applied to measuring rf output, the SWR, or just the current in a circuit. I believe it is fair to say that the application of the audible current meter is limited only by the user's imagination.

Feedback

☐ An error exists in "A Noise Blanker for the Collins S/Line," by Doc Lask, K6CUF (February 1979 *QST*). On page 30 under the subhead, "Modifying the Noise Blanker," the second paragraph states that two coils are padded. The sentence should read as follows: "By padding *L2 and L3* on the blanker with 36-pF capacitance . . ." L4 is not used.

☐ In "Upgrading the SB-220 Linear Amplifier," February 1979 *QST*, R1 shown in Fig. 1 has an effective resistance of 50 ohms, not 100 ohms as is indicated in the text. The 50-ohm value works satisfactorily when the amplifier is being operated on 117-V house current, but on 234 V ac a value of 200 ohms at R1 provides better in-rush current control. It is also necessary to use contacts K1B for both 117 V and 234 V ac.

☐ The helium-neon laser pictured in February *QST*, page 42, operates on 474.0834 THz, not 474.0834 GHz. One THz equals 1,000,000 MHz or 1000 GHz.

☐ In "*El Hombre Y La Mar* Expedition" (November 1978 *QST*) the net control station in Spain was Manuel Vega Torregrosa, EA1TI, not Manolo Estavez.

☐ The "Roadeo Hams" (October 1978 *QST*, page 29) was written by K9BIL not K9ZZ.

Strays

W1AW WORKS THE WORLD

☐ If you were on the air during the weekend of December 2-3, you may have worked W1AW; nearly 2000 hams did. Members of the Western Connecticut Traffic and Emergency Net (WESCON) spent the daylight hours of that weekend at the Maxim Memorial Station contacting hams throughout the world on 10 through 80 meters. And they plan to do it again.

On May 12 and 13, the group will be providing everyone with another opportunity to work the ARRL headquarters station. The operation will begin at approximately 1400Z and end at 2100Z each day. (There may also be activity in between the regular Saturday evening W1AW transmissions.) All QSL cards will be answered. The WESCON crew hopes to be able to work you all. — *Stan Horzepa, WA1LOU*