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QST Issue: Dec 2003
Title: A Homebrew Condenser Microphone
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By Sam F. Kennedy Jr, KT4QW

A Homebrew Condenser Microphone

Build a condenser microphone that will perform like the costly commercial units...plus, you won't need an expensive equalizer. Sounds good!

With modern commercial amateur transceivers becoming increasingly difficult to work on, most ham builders have turned to other endeavors. Looking around for a fresh project, and one that had a reasonable chance of success, I decided to build a "scratch-built" condenser microphone. One of my friends had been working on piezoelectric homebrew microphones, so the condenser microphone seemed like a good choice. I know that this is 1920s technology and that you can buy a very good microphone reasonably, but it is interesting, challenging and educational to retrace some of the development processes of those "times gone by." I set the following objectives for my new homebrew microphone:

- Sound as good or better than the Heil Goldline microphone
- Work directly into a transceiver without external equalization or processing
- Require no special tools to fabricate
- Use no manufactured microphone parts
- Use no special materials—only those found in the "junk box" or local store
- Be attractive and complementary to my station
- Be inexpensive

I'll not bore you with all the things I tried that didn't work—I will simply explain the final model that met all my objectives. The final product, pictured here, is the result—a condenser microphone with a very large diaphragm (1.6 inch diameter). The coarse screen mesh "cricket cage" serves as a combination windscreen and Faraday shield for the element. Adequate shielding is very important to ensure that no RF enters the audio stream. Because of the high gain required to amplify a condenser element, RFI can be a problem, so I shielded all the components thoroughly.

Some Basic Theory

Condenser microphones use a thin lightweight conducting membrane as a diaphragm and a fixed plate closely spaced behind it. The two facing surfaces become the plates of an air dielectric condenser (or capacitor if you prefer). Sound pressure against the thin membrane causes it to move. This movement changes the spacing between the plates and therefore the capacitance. When the condenser is polarized (charged or biased) with an external voltage, it causes a changing electrical output proportional to the sound pressure. The source impedance of the condenser element is very high, several megohms being typical. A built-in field effect transistor furnishes the impedance step-down necessary to deal with input to typical solid-state amplifiers. The FET has the capability of accepting a very high impedance input and producing a reasonably low output impedance of 1-2 kΩ, while producing moderate gain.[1]

When considering commercial studio type condenser microphones, "phantom power" is the term normally used for an externally supplied bias or polarizing voltage. A microphone of this type is said to be a "pure condenser" type as contrasted with an "electret condenser" microphone, which requires no external polarizing voltage.[2] The homebrew microphone under

[1]Notes appear on page 32.

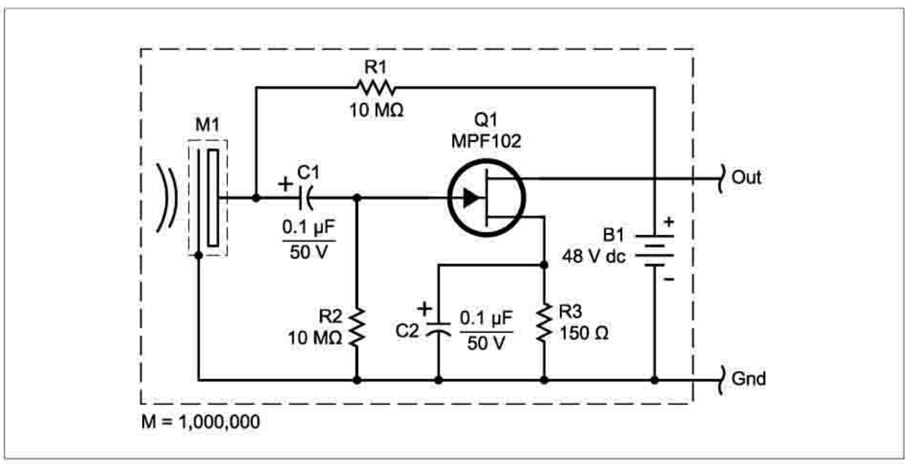

Figure 1—The microphone amplifier schematic together with the parts required for construction. Note that the polarizing or bias battery is fabricated from multiple cells, as described in the text. R1 and R2, the 10 MΩ resistors, can be made of two 4.7 MΩ, 1/4 W resistors if 10 MΩ resistors prove difficult to locate. C1 is used to keep the microphone polarizing voltage from appearing at the FET gate and C2 is used to bypass the FET source resistor. M1 is the microphone element and its construction is described in the text.

B1—48 V battery (see text).
C1, C2—0.1 µF, 50 V capacitor.
M1—Fabricated element (see text).
Q1—MPF-102 JFET, RadioShack 276-2062.
R1, R2—10 MΩ, 1/4 W resistor.
R3—150 Ω, 1/4 W resistor.

discussion uses a polarizing voltage derived from a very small internal 48 V battery mounted within the microphone housing. It does not use an external phantom power system. As is the case with an electret microphone, it does require a small voltage for the FET impedance transforming circuit inside the microphone. And, as in many electret microphones, the FET's drain load resistor and voltage source are located downstream, in the amplifier. No specific power supply is therefore necessary when operating this microphone with an electret-compatible circuit, such as that used by ICOM. As an example, this operating mode provides adequate microphone drive to satisfy the IC-756PRO transceiver. Figure 1 is the schematic of the microphone amplifier and the parts required.

In critical sound applications, the condenser microphone is often preferred for its uniform frequency response and its accurate response to transient sounds. The natural design of a condenser microphone ensures an outstanding low-frequency response, and the low mass and high tension of the diaphragm allows a smooth high-frequency response. This results in a clean, natural and clear sound. It is said to produce outstanding "transparency and detail." These characteristics make the condenser microphone a natural choice for professional use or other demanding applications.

Some manufacturers produce condenser microphones with diaphragms that are less than 1/10,000th of an inch thick. For amateur service use, not all of these characteristics are relevant. Since most amateur transmitters roll off most audio frequencies above 3 kHz, the high frequency characteristic of the microphone is not overly important. Condenser microphone design does provide the opportunity to shape the audio response without the use of external equalizers and processors. In the case of the homebrew micro-

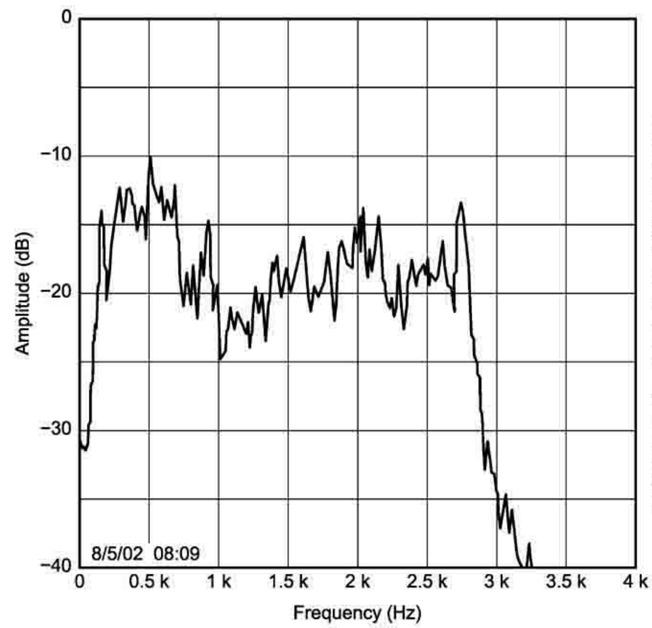

Figure 2—The overall frequency response of the homebrew condenser microphone as transmitted by an ICOM IC-756PRO and received by a Ten-Tec Pegasus transceiver. Note that the frequency response ranges from 100 Hz to 2750 Hz. The hump at the low frequency end is a typical ICOM transmitter characteristic. See editor's note in text.

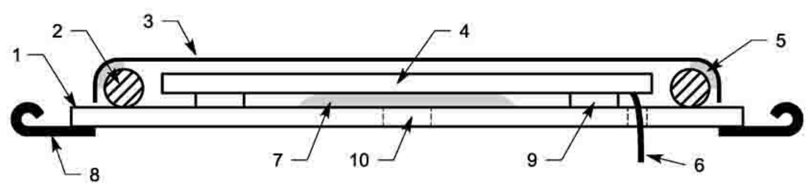

Figure 3—The microphone element mechanical details and basic construction steps. More detail can be found in the text.

1. The microphone base is made of a round disk of 1/16 inch double-sided PC board.
2. The spacer ring is made of 1/8 inch brazing rod, bent into a 1.6 inch diameter circle and soldered to surface of the base.
3. The diaphragm is 0.001 inch aluminum foil (lightweight household foil).
4. The condenser plate (inner) consists of 1/16 inch double side PC board and positioned 0.002-0.003 inch below the diaphragm.
5. The diaphragm is attached to spacer ring with epoxy cement. Stretch foil as tightly as possible without tearing. The foil must make good electrical contact with the spacer ring.
6. Flexible wire is connected to front surface of the condenser plate. Connects to the input coupling capacitor and to the JFET transistor and the polarizing voltage (bias) resistor.
7. Epoxy mix holds inner condenser plate in position.
8. Dress hooks soldered in place for elastic band suspension of the microphone element (4 hooks soldered with 90° spacing around element perimeter).
9. Foam rubber doughnut (see text).
10. Pour hole, 1/4 inch, for pouring epoxy mix into cavity to hold the condenser back plate in position.

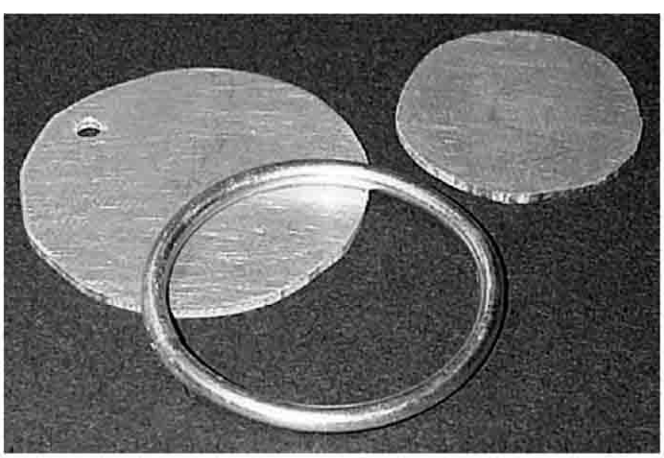

Figure 4—The main parts of the microphone element.

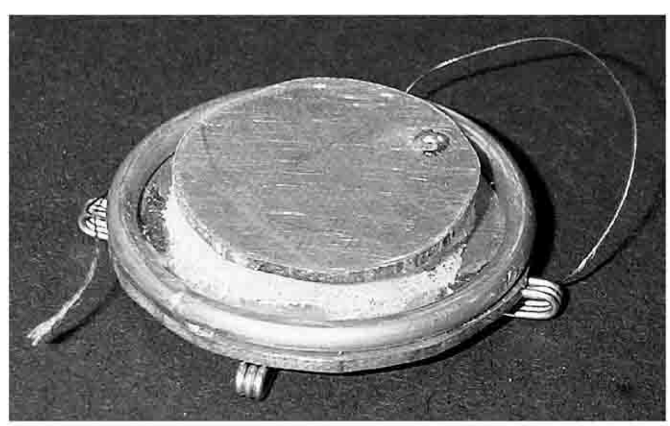

Figure 5—The assembled microphone element.

phone under discussion, a very large diaphragm (1.6 inches) is made of 0.001 inch thickness aluminum foil. The large diaphragm increases the low frequency response and the thickness of the material does limit the high frequency response, but the microphone operates very well within the frequency range we are concerned with.

Transmitted Spectral Content

Using a *HamAlyzer*[3] FFT audio spectrum analyzer on my notebook computer, I was able to test for frequency response and to "tweak" the microphone to achieve best results. Figure 2 shows a *HamAlyzer* trace of the microphone's over-the-air response when used with my ICOM IC-756PRO transceiver. This trace was captured by W5TOM, using his Ten-Tec Pegasus.

[Editor's Note: A bit of caution here. The *HamAlyzer* records a *system* spectral response that includes both the transmitter modulation and the receiver demodulation characteristics. If that measurement is taken by a distant station, it will also include any RF path characteristics that affect the transmit/receive audio frequency response. It includes, too, the sound card characteristics of the particular computer used, unless that is taken into account in the calibration procedure. Additionally, the output impedance variations of the microphone over frequency can contribute to audio "coloring" with a particular transceiver. And, the sonic characteristics of the room will further influence the measurement results. For accurate objective spectral response measurements of a microphone, an audio spectrum analyzer with an accurate audio frequency transducer driven by a calibrated audio sweep generator is required. The microphone should be tested in an anechoic chamber (a test chamber free of echoes and reverberation). Commercial microphone manufacturers do extensive measurements on their products, using sophisticated audio test equipment in laboratory environments. While relative basic measurements can be interesting, the fact that a microphone "sounds" good or bad with one transceiver may, in fact, be misleading, unless accurate testing is done under carefully controlled and calibrated conditions.]

After extensive testing, I discovered that this microphone had the best "presence" and overall sound quality when the element was suspended in air with no enclosure other than the element itself. It produces a cardioid pattern over the whole frequency range, but the pattern is less pronounced at low frequencies. It does pick up room noise and it shows less "proximity" effect than other microphones I have used. I did not concern myself with frequencies above 4 kHz, in that my transmitter cuts off everything above about 3 kHz anyway.

Building the Element

By referring to Figures 3, 4 and 5 you can see that the element is constructed by building four main subassemblies, then combining them. These are:

1. The base plate, a circular, 1.7 inch diameter disk of double sided $^1/_{16}$ inch printed circuit board. I used a school-type compass for layout and sawed the base plate out using a small jigsaw. Note that a $^1/_8$ inch hole is drilled into this part. This serves two purposes. One is to furnish an exit path for the wire that connects to the inner condenser plate and the second is to relieve some of the acoustical back pressure. It is important that the element is vented to atmospheric pressure to avoid an internal pressure differential and thus distort the diaphragm. The hole in the center of the back plate is $^1/_4$ inch in diameter. This hole is for pouring in epoxy behind the condenser back plate and is filled in later.

2. A 1.6 inch diameter brass ring is made of $^1/_8$ inch brazing rod. It is formed into a circle by wrapping it around a $^3/_4$ inch schedule 40 PVC pipe coupling which is clamped in a vise. The coupling is only 1.3 inch OD, but the rod springs back to form a somewhat larger circle. It is formed around the coupling for about a turn and a half and then adjusted so that it forms a 1.6 inch circle. The brazing rod behaves much better if you anneal it by heating it with a propane torch to discoloration and then letting it air cool. After the bending operation, clamp the loop in a vise and cut the both ends at the same time with a hacksaw. Solder it together being very careful to align the two ends to ensure a smooth circle.

3. The back plate of the condenser is a circular 1.25 inch diameter disk made of double sided $^1/_{16}$ inch printed circuit board. The layout for this was also done with a simple school-type compass and then the back plate was sawed out using a small jigsaw. Since most of the diaphragm motion is in the center, there is very little advantage realized by using all the outer space under the diaphragm. The 1.25 inch diameter leaves plenty of room around the edges for assembly and alignment.

4. A foam rubber doughnut the same OD as the back plate is required. While not critical, the doughnut's center hole should leave about $^1/_4$ inch of foam and the height should be about $^1/_4$ inch. This will allow it to be compressed to approximately $^1/_8$ inch in the final assembly. This doughnut, or "O-ring," serves to contain the epoxy poured in from the back and produces pressure on the back plate so that it will align with the brass ring when clamped to a hard smooth surface.

Smooth the edges and the flat surfaces

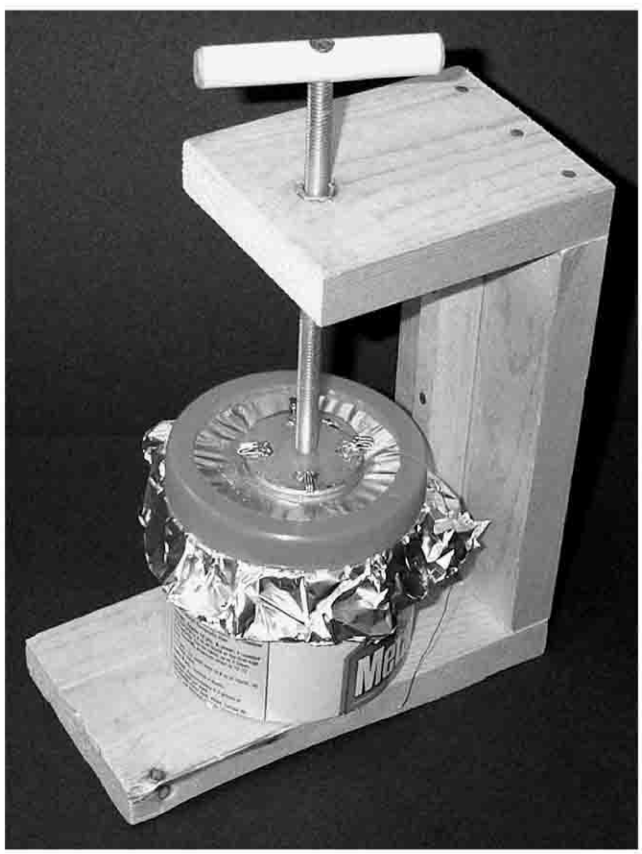

Figure 6—Applying the aluminum foil diaphragm to the element using a homebrew test fixture. Notice the bead of epoxy cement around the edge of the spacer ring. The diaphragm is held in this position until the glue dries fast. It is then trimmed, close to the ring.

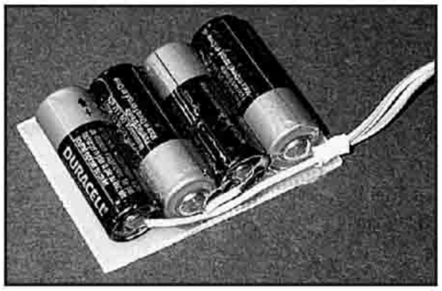

Figure 7—The 48 V polarizing (bias) battery assembly and parts list.

2 each, 12-V packs (RadioShack Keyless Entry System, RS 23-279 [GP27A]. Each pack contains two batteries for a total of four).
1 each, fiberglass board, 1.25×1.75×1/16 inches.
1 each, Velcro patch 3/4×3/4 inch. Apply to back of board for mounting.
Misc
Short length of very small gauge stranded hookup wire for interconnects and external leads.
Small quantity of 5 minute epoxy to affix the batteries to the board and to clear coat the finished unit for insulation.
Small section (0.5 inch) of shrink tubing to contain the two battery wires.

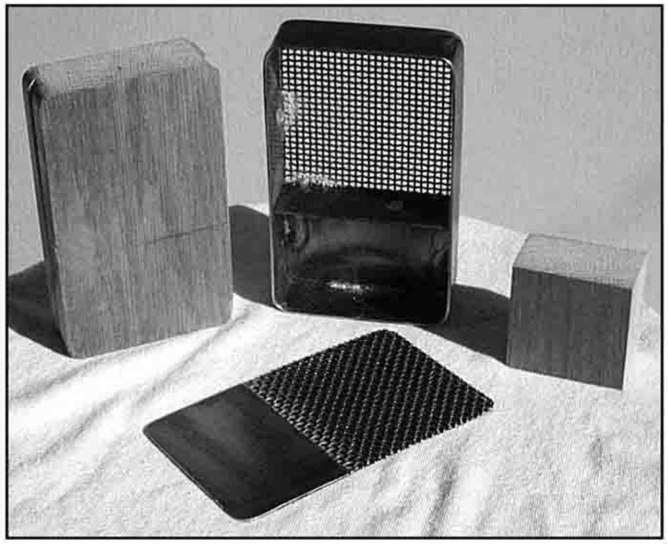

Figure 8—An example of a typical microphone housing, with parts and fixtures.

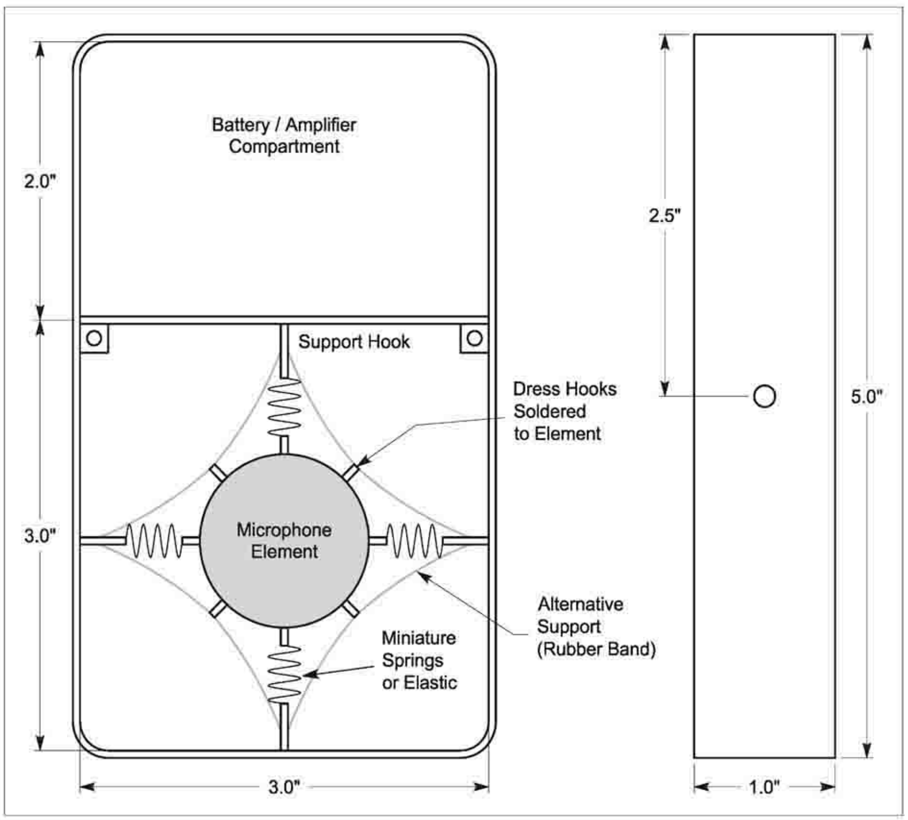

Figure 9—The dimensions of the microphone housing example. Note that the element is suspended by hooks and elastic. An alternative element support can be a rubber band, also shown. Use either method for support.

with 400 grit wet-dry sandpaper. Place the sandpaper on a firm, flat surface and lap the surfaces carefully to make certain they are flat and have no rough spots or burrs.

The following steps are necessary to assemble the element:

1. Solder a small, flexible insulated wire to the condenser back plate. This connection must be made to the front surface of the disk in such a manner so as to avoid disturbing the flatness of the front surface. I drilled a 1/16 inch hole from the back but not all the way through the front copper. Then press a dimple in the copper over the hole and drill a hole through the copper large enough to terminate the small connecting wire. Carefully sand the surface to make certain the solder does not protrude above the back plate front surface.

2. Solder the brass ring to the base plate (large disk) in three places. Use a large soldering iron and a minimum amount of solder and make sure that the solder flows to both ring and plate. See Figure 6 for the proper position of the ring.

3. The most critical operation of the entire project is mounting the condenser back plate so that it is 0.002-0.003 inch below the plane of the lip formed by the brass ring. This is done by temporarily using a piece of transparency film (used to make overhead graphics) as a shim between the front surface of the condenser back plate and the diaphragm. This shims the surface of the plate a controlled distance behind the plane of the lip. When both surfaces are pressed firmly onto a flat surface and glued in place, the proper spacing will have been established. The objective of this operation is to establish the minimum spacing possible while ensuring enough clearance, to avoid shorting of the condenser plates when stimulated with high sound pressure levels. The closer the spacing, the higher the microphone's output level and the better the signal to noise ratio. [A higher polarizing (bias) voltage might work to advantage here.—*Ed.*]

Application of the Diaphragm

Initially, I had difficulty applying the aluminum foil diaphragm to the base ring of the element. Figure 6 illustrates a fixture I built to make the task easy. Remember that the foil must be tensioned to the maximum extent possible without bursting. The following procedures will make this critical operation easy. Note that it is not essential to use a special fixture. A drill press that can be locked into position or a similar device will work equally well.

The fixture allows a larger than needed piece of foil (lightweight aluminum foil from the kitchen) to be held smoothly and tightly while the element is pressed into it. A large-mouth plastic jar with a threaded top is used to hold the foil. The center portion of the jar top is removed with a sharp pocket knife. With a little care and experimentation, it becomes a very simple operation to form a "drum head" with the jar. The foil need not be tensioned, just clamped into place smoothly with no ripples. Lubricate the threads on the jar and the lid with a very light application of non-staining oil or petrolatum. This makes it much easier to get the foil in place. Make certain that the lubricant does not get on the foil in the center area or it will interfere with the cementing operation.

Once the element is pressed into the center of the "drum head," apply a light coat of epoxy cement around the edge with a small brush. Just a few bristles of an old brush held together with a piece of masking tape works fine and can be discarded when finished. Allow the epoxy to set (I used fast set epoxy but you may need more working time to avoid rushing) and then remove the excess foil by simply rough-cutting the excess foil from around the element. When it's removed, carefully trim the edges, being careful not to injure the tensioned diaphragm. Verify that the foil has a stable electrical contact with the ground portion of the element and that it does not make contact with the back plate of the condenser.

Polarizing (Bias) Battery

The 48 V battery assembly is made up of four 12 V batteries wired in series and mounted on a small fiberglass board. Since the condenser microphone uses this voltage to furnish only element bias, there is no current drawn from the battery and you should expect many years of full output potential—essentially the normal shelf life of the battery. The internal battery was used rather than an external power supply for economy and simplicity. Figure 7 shows the wired battery assembly.

The Microphone Housing

Because everyone has different mechanical capabilities and facilities at their disposal, I have not attempted to furnish exact mechanical details for construction of a housing. A number of satisfactory designs are possible. The housing shown in Figure 8 was constructed by W5TOM, using no more than simple hand tools and equipment. Figure 9 gives the overall dimensions for the housing. While I didn't intend to furnish exact construction details for the microphone housing, these photos and notes should provide some basic ideas for the construction techniques used to make a suitable housing. Since I use a boom microphone, my construction followed that path. A very nice desk mount could probably be constructed without much difficulty. So, sit back and enjoy your new condenser microphone—you'll be proud to say, "The mic here is totally homebrew!"

Notes

[1]*Editor's Note:* The condenser microphone was invented by Dr Edward C. Wente, of Bell Laboratories, in 1916, with a patent granted on March 16, 1920. The condenser element is a current source, with the current dependent upon the rate of change of capacitance (by sound pressure) multiplied by the applied bias voltage, which is a constant ($Q = C \times V$, so $d[Q]/dt = I = d[C]/dt \times V$). Sensitivity does depend on bias voltage and some commercial units run the bias voltage as high as 200 V dc, depending on diaphragm size, material and structure. The high impedance current source is converted to a voltage by a bias resistor and an impedance converter, which can be a FET or a vacuum tube.

[2]*Editor's Note:* That polarizing voltage comes from a permanently charged electret "battery" which is part of the microphone element. An electret is a solid dielectric material that has a near-permanent electrostatic charge. Electrets are similar to permanent magnets, but they are electrostatic rather than magnetic. They are made by heating certain dielectric materials (special plastics, Teflon compounds and waxes) and then letting them cool while they are in a strong electric field.

[3]**www.hamalyzer.com.**

All photos by the author.

Sam Kennedy, KT4QW, has been interested in radio since the age of 7 (65 years ago) but was actually first licensed in the 1950s as K4DEP. Relicensed in 1996,when he was assigned his current call, he earned the Amateur Extra ticket shortly thereafter. Sam has attended both commercial and US Navy electronics schools and has worked with military radio, radar and navigation equipment. He enjoys the technical aspects of ham radio and, as can be seen from this article, he has a special interest in microphones. You can contact him at 57 Huxley Pl, Newport News, VA 23606 or at **kt4qw@arrl.net**.

NEW PRODUCTS

NEW RADIO KITS FROM KENNEKE COMMUNICATIONS

◊ Kenneke Communications has announced a new line of radio kits. The three band shortwave receiver kit lets you build a radio designed to pull in stations from distant places. This kit will receive local AM radio stations as well.

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Frequency:	1.3-30 MHz (LPF), 49-470 MHz (HPF)
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Isolation:	45 dB
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Price: $69.95. For more information see your local dealer or contact Diamond Antenna, 435 S Pacific St, San Marcos, CA 92069; 760-744-0900; **www.diamondantenna.net**.

DXTREME *STATION LOG—MULTIMEDIA EDITION*

◊ DXtreme Software has released a new logging program in its Amateur Radio product line: DXtreme *Station Log—Multimedia Edition*. Like other logging programs, *Station Log* lets hams log their contacts and import ADIF files from popular contest programs. *Station Log* also provides multimedia and advanced features that can add functionality to Amateur Radio logging activities.

This program features an embedded audio facility that lets hams create and maintain an audio archive of selected contacts. *Station Log* also includes an integrated QSL imaging facility, which lets hams scan the physical QSL cards they receive from regular mail and capture the electronic QSLs they receive from the Internet. Both types of QSLs are saved as compatible digital images that hams can view at any time.

Station Log integrates with Microsoft *Word* to create customized, rich-text-formatted QSL card labels. It also produces ADIF-based electronic QSLs for uploading to Web sites that specialize in the delivery of eQSLs.

To help hams track the performance of their stations, *Station Log* can generate a variety of reports and output them to printers, as well as to the *DXtreme Active Report Viewer*. The viewer lets hams view and sort reports within Microsoft *Internet Explorer*.

Station Log retails for $79.95 in North America and $82.95 elsewhere, including shipping and handling. For more information, see **www.dxtreme.com** or e-mail **bob.raymond@dxtreme.com.**