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Replacing the Klipschorn Tweeter

By John Warren

This project, which offers an alternative tweeter configuration for the Klipschorn, Belle, and LaScala loudspeaker systems, requires no modifications to the existing cabinetry.

The Klipschorn has been in production for close to 60 years, and over much of that time it has been offered with the same tweeter—the Electro-Voice Model T35 Super-Sonax with the Avedon Sonophase Throat. Why this particular horn tweeter has survived for so many years is something of a mystery to me. Regardless of the crossover topology, I do not find them particularly pleasing to listen to.

PHOTO 1: ELECTRO-VOICE AVEDON T35. CERAMIC MAGNET MOTOR VERSION IS SHOWN. FANCIER CHROME-PLATED, "VINTAGE" ALNICO VERSIONS EXIST, TOO.

THE ELECTRO-VOICE T35

The EV T35 tweeter (*Photo 1*) is perhaps the most widely recognizable horn tweeter ever to be manufactured in the United States. I purchased this particular unit from MCM Electronics in 1994 for $40, and—other than changes to the motor structure—it is essentially the same tweeter horn designed in 1957 by Robert Avedon for Electro-Voice[1]. The Avedon design was also available in a smaller-magnet, low-cost, model T35B and a considerably more expensive model, the larger-magnet T350[2].

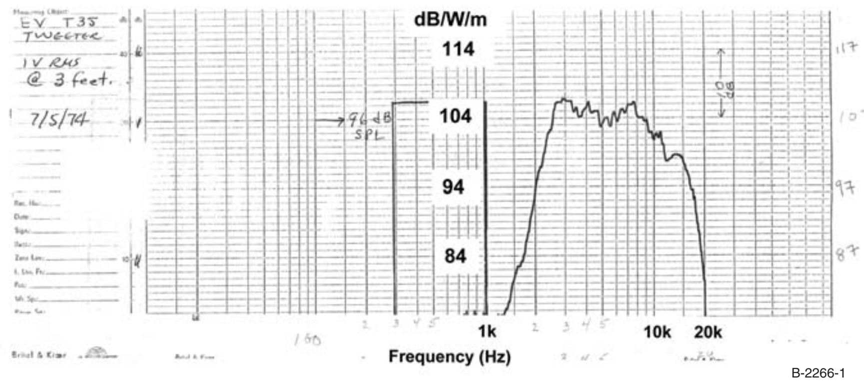
The unit in *Photo 1* has a nominal impedance of 8Ω with a published sensitivity of 104dB/W/m. The steady-state power dissipation capability of the 1″ diameter voice coil is between 5–7W RMS. The 1″ diameter diaphragm is a formed dome made from linen cloth impregnated with phenolic resin.

An anechoic chamber frequency response of a typical 8Ω alnico magnet version of the T35 is shown in *Fig. 1*. The frequency response, estimated to be 3–15kHz (±4.5dB), seems to agree reasonably well with the published response of 3–15kHz (±4dB). The chamber response also gives some information about the tweeter's sensitivity. Between 3–9kHz the unit exhibits an approximate average sensitivity value slightly over 104dB/W/m. The sensitivity then drops to a much lower value of 98dB/W/m at 15kHz.

Interestingly, the response drops off precipitously after 10kHz. For example, the SPL at 12kHz is about 6dB lower than it is at 9kHz. The reduction in acoustic output is associated primarily with the inability of the edge-driven dome to behave as a "linear piston" above 12kHz. The phenomenon is referred to as mass-induced high-frequency rolloff and results in distortion.

The tweeter crossover frequency has historically been 6kHz in the Klipschorn, Belle, and LaScala systems. In the early A-network, a simple first-order

FIGURE 1: ANECHOIC CHAMBER ON-AXIS FREQUENCY RESPONSE OF AN 8Ω ALNICO VERSION OF THE AVEDON T35 SUPER-SONAX. THE RESPONSE WAS MEASURED IN THE ANECHOIC CHAMBER RESEARCH FACILITY LOCATED AT THE CENTRAL INSTITUTE FOR THE DEAF (4560 CLAYTON AVENUE, ST. LOUIS, MO). THE RESPONSE CURVE WAS KINDLY SUPPLIED BY M. HORONZAK (USED WITH PERMISSION).



ABOUT THE AUTHOR
John Warren is a senior staff engineer in the rotor structures Materials Engineering Group at GE Aircraft Engines in Lynn, Mass. He has an MS from RPI and a Ph.D. from the University of Virginia, both in materials engineering. He holds six US patents in the area of materials processing. John has been actively involved in speaker building for over 30 years. He can be reached at Lwarren02@comcast.net.

(6dB/octave) high-pass scheme on the tweeter was used. The network was later revised by Klipsch to a third order (18dB/octave) and was designated the AA-network. Factory modifications to the Klipschorn network have continued and are ongoing to this day. The AA has since been replaced by the AK, AK-2, AK-3, and (current) AK-4 series of designs. The crossover frequency has not changed, however.

SELECTING A REPLACEMENT

In selecting a replacement for the T35, my goal was to reduce the distortion heard in the tweeter at the SPL levels I liked listening to. First I surveyed the available horn tweeter designs in an attempt to understand how design tradeoffs between them affect performance. Considering the aesthetic qualities of the replacement I determined at the outset that it would be easier to simply mount the tweeter and its associated filter on top of the Klipschorn rather than attempt a rework of the existing factory cabinetry.

A few of the listening positions in my room, including my chair, are about 6m away from the corners. For an on-axis SPL of 95dB at 6m from a single tweeter, the voice coil must be able to dissipate a minimum of 5W RMS assuming an average sensitivity of 104dB/W/m. Diaphragm excursion, which varies inversely with the square of the frequency above the tweeter's Fs, has a considerable effect on distortion[3]. Distortion

PHOTO 2: THE DIFFERENCES BETWEEN THE JBL 2404H AND THE EV T35 HORNS (VIEW IS FORWARD LOOKING AFT).

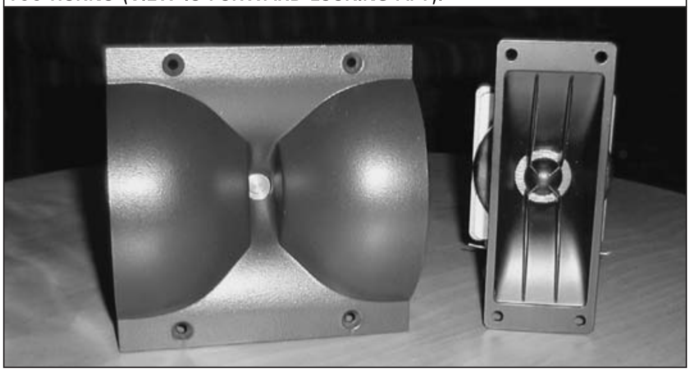
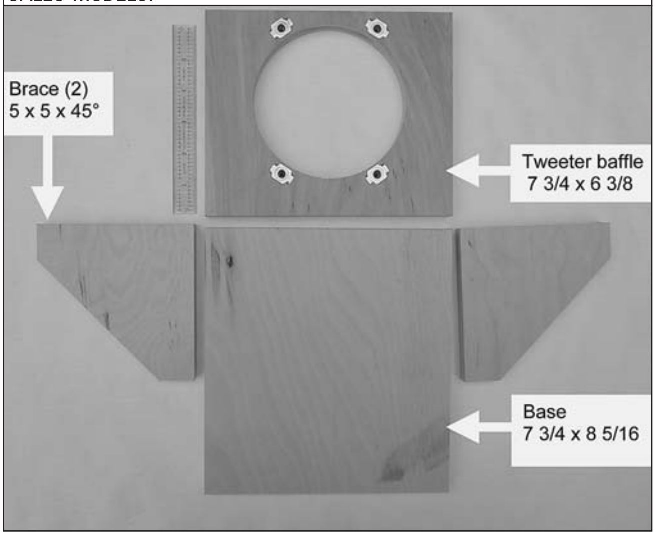


PHOTO 3: DIFFERENCES IN DEPTH BETWEEN THE TWO DRIVERS. THE MOTOR STRUCTURE OF THE JBL (RIGHT-HAND SIDE) TWEETER IS VERY LARGE. A RUBBER-LIKE "MAGNET TIRE" SURROUNDS AND PROTECTS THE MAGNET ON THE JBL TWEETER. MAXIMUM HEAT DISSIPATION IS REALIZED WHEN THE TIRE IS REMOVED.

PHOTO 4: LAYOUT OF THE FOUR ¾″ PLYWOOD PARTS THAT MAKE UP THE TWEETER STAND WITH DIMENSIONS GIVEN IN INCHES. NOTE THAT THE TWEETER HOLE IS POSITIONED TO ACCOMMODATE A BUTT-JOINT AT THE BASE (SEE *PHOTOS 7* AND *8*). YOU CAN FIND A DETAILED DIMENSIONAL DRAWING OF THE JBL 2404H AT WWW.JBLPROSERVICE.COM/PDF/ UNDER THE FOLDER NAMED DISCRETE SALES MODELS.



trends with excursion and, in the case of the T35, increases sharply at these power levels. For example, a "bacon-frying" sound becomes apparent when the T35 is driven to the sound pressure levels described. So, from a qualitative perspective, I favored drivers with relatively large radiating surfaces.

Obviously, the candidate tweeter must be horn loaded and exhibit a sensitivity comparable to the T35. Higher sensitivities are permissible, but might require either a resistor L-pad or an attenuation autoformer. The replacement must also have a better frequency response at 10kHz and above.

The crossover frequency of 6kHz and third-order attenuation response of 18dB/octave is sufficient to allow for a wide range of tweeter types to be considered. In fact, the 6kHz crossover frequency is significantly higher than the lowest recommended crossover frequency for a number of good-quality horn tweeters. Since large diaphragm excursions associated with operating in the lower frequency range are avoided, distortion is minimized.

I also factored adequate power-handling capability for occasional listening levels considered unreasonable into the power requirements. Transient SPLs of 105dB at 6m require a tweeter able to dissipate about 40W under short-term conditions given the 104dB/W/m minimum sensitivity requirement. This provides significant margin since most of the power dissipation in a loudspeaker system is concentrated in the bass and low midrange regions of the acoustic spectrum.

METAL CHOICES

Diaphragm materials are numerous and include phenolic-impregnated fabrics and the engineering alloys that possess high specific modulii (the ratio of elastic modulus/density). The metals in this category include aluminum alloys, pure (elemental) titanium, and pure beryllium. The higher the specific modulus, the closer the diaphragm is able to behave as the "perfect" piston. Of the three, beryllium is the clear standout, possessing a significantly higher specific modulus than either titanium or aluminum.

It is ideal for this application, but the pure metal is exceedingly difficult to form using conventional deformation processing methods. Instead, a process called vapor deposition is used to form the diaphragm from a "gas" composed of beryllium atoms. The atoms condense onto shaped tooling and thus take on whatever form the tool is fabricated to (for example, a dome). Beryllium tweeters and the replacement diaphragms are expensive, but if this is a secondary concern, the high-frequency performance is exceptional; an example of this type of horn tweeter is the Pioneer TAD ET-703.

Since titanium and aluminum alloys can be formed from annealed sheet using conventional forming processes, diaphragm costs are much lower. Commercially pure titanium possesses both the strength and fatigue resistance necessary for midrange and high-frequency transducer diaphragm applications. It's nearly twice as dense as aluminum, but its elastic modulus is greater by an even larger factor, so when the specific modulii of the metals are compared, titanium shows a small advantage. Alternatively, aluminum alloys are quite suitable for home audio applications, having been used for many years.

TWEETER TYPES

When examining horn tweeters, I found quite a few options to choose from. For the replacement I considered bullet, slot, and bi-radial configurations. The Klipschorn, by design, must be placed in the corner of the listening room, which suggests that a horn with 90° horizontal dispersion would provide optimum coverage, especially if the units are positioned in corners separated by the longest room dimension as recommended by Paul Klipsch.

Bullet tweeters provide high on-axis sensitivities resulting in narrow, conical dispersion characteristics, useful in sound reinforcement applications where the tweeter is located far away from the listening audience but, perhaps, less desirable for the home audio

PHOTO 5: SETUP USED TO MAKE THE CUTOUT FOR THE TWEETER OPENING. ROUTER IS A MILWAUKEE. BIT IS ¼″ DIAMETER, SINGLE FLUTE CARBIDE.

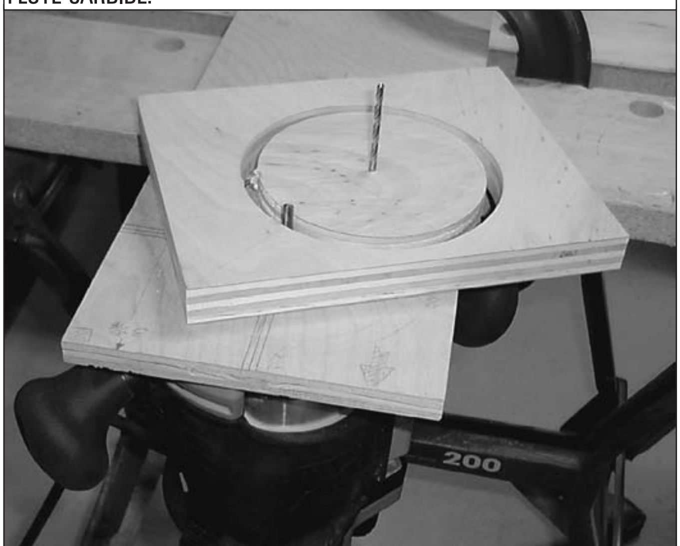


PHOTO 6: PILOT HOLES DRILLED IN BOTTOM OF BASE. THE RUBBER FEET CONTAIN METAL WASHERS THAT ALLOW THE SCREWS TO BE SOCKED DOWN FIRMLY. RUBBER FEET ARE FROM PARTS EXPRESS (PN 260-773). DRILL THE PILOT HOLES BEFORE GLUING THE ASSEMBLY TOGETHER.

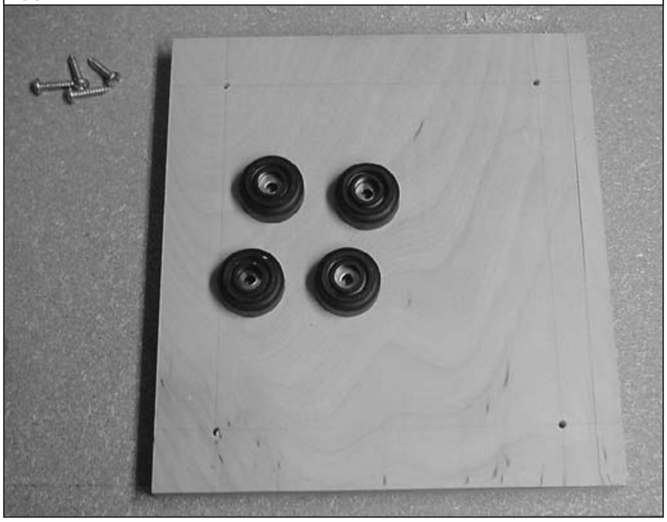


PHOTO 7: FORWARD VIEW SHOWING HOW THE BAFFLE AND BASE BOARDS OF THE TWEETER STAND ARE FIXTURED FOR GLUING.

enthusiast who's trying to achieve good sound reproduction in any number of potential listening positions scattered throughout the room. Examples of bullet-type tweeters include the JBL 2402H and Fostex T500A.

Slot tweeters rely on the principle of diffraction to achieve extremely wide horizontal dispersion characteristics with a corresponding debit in vertical plane dispersion. Given that the tweeter will be placed in the corner, however, wide horizontal dispersion (as high as 140° in some embodiments, for example) is of no real advantage in this application. Examples of slot-type transducers include the JBL 2405H and Beyma CP21F.

Bi-radial horns appear to be quite satisfactory for corner placement, as the dispersion characteristics of the JBL 2404H Bi-radial horn attest. The published specification sheet shows the 2404H to possess 100° horizontal × 100° vertical coverage angles with 1/3 octave polar response plots showing very good horizontal and vertical dispersion characteristics between 3–20kHz[4].

Further examination of the specification sheet shows a sensitivity of

PHOTO 8: AFT VIEW. NOTE THAT BUTT-JOINT IS MADE AGAINST THE AFT FACE OF THE TWEETER BAFFLE. A COUPLE OF DRY ASSEMBLY RUNS ARE NECESSARY TO OBSERVE HOW THE WOOD STRAINS WHEN LOADED BY THE CLAMPS.

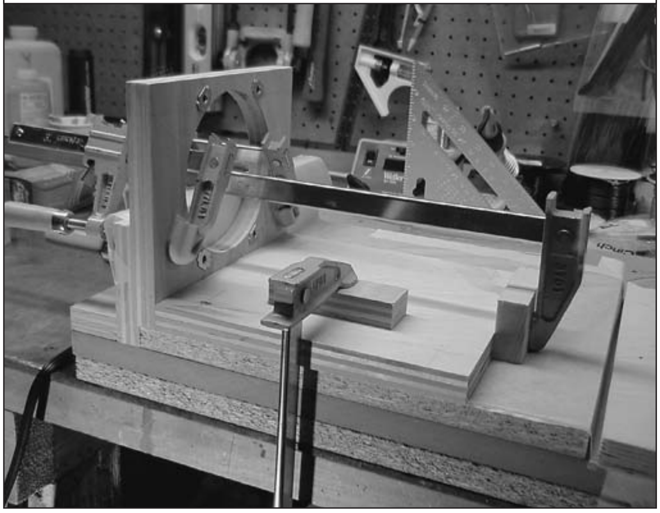
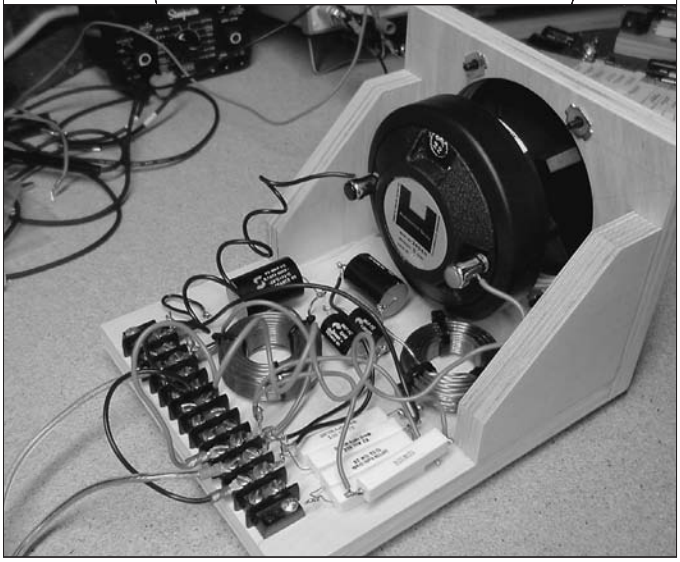


PHOTO 9: FINISHED TWEETER ASSEMBLY, SHOWING HOW NETWORK IS SHOEHORNED INTO STAND. IN THIS PARTICULAR CONFIGURATION, A 1.5DB L-PAD WAS USED. A 10-POSITION CINCH 10-141 TERMINAL BLOCK IS SHOWN SCREWED DOWN TO THE BASE. NETWORK CONNECTIONS TO THE TERMINAL BLOCK ARE FACILITATED BY CINCH Y-141 SOLDER POSTS (CINCH PRODUCTS AVAILABLE FROM DIGI-KEY).



105dB/W/m, a frequency response of 4–19kHz (±3dB), and a continuous power dissipation capability of 40W. Above the crossover frequency of 6kHz, the sensitivity is higher still. The recommended minimum crossover frequency is 3kHz with a 12dB/octave attenuation response, well below the desired 6kHz crossover point necessary for the Klipschorn. The diaphragm is a relatively large 1.75″ diameter annular ring fabricated from an aluminum alloy. Also, as an added bonus, the mounting hardware for the tweeter is included and consists of black oxide machine screws and baffle T-nuts.

FILTER NETWORK

The 2404H is a physically large unit, as you can see in *Photos 2* and *3*. I measured the driver impedance using the test setup described by Pierce[5]. The impedance of the raw driver is shown in *Fig. 2* and is labeled "2404H." At the desired crossover frequency of 6kHz the impedance is about 8.5Ω with a large impedance peak in the vicinity of 4.3kHz. Also shown in the same graph is a curve labeled "2404H + LCR," which is the resultant impedance of the driver with a series notch filter in parallel with it and tuned to 4.3kHz (C = 7µF, L = 200µH, R = 10Ω).

With the notch filter in place, the measured impedance ranged between 5 and 6Ω over 2–10kHz. As expected, attenuation of the signal at and above 6kHz was realized due to the effect of the notch filter. For example, listening to the tweeter on-axis at 6kHz while switching the notch filter "in and out" revealed some attenuation of the signal when the filter was active. I did not consider the attenuation significant, however, since the output at 6kHz of the 2404H with the notch filter had essentially the same loudness as the raw T35.

With the notch filter in place and doing its job, I calculated the component values for a third-order, 6kHz Butterworth network terminated into a 6Ω load. The complete network schematic is shown in *Fig. 3*. The resistor L-pad (should you find one necessary) is inserted between the notch filter and the Butterworth (for resistor values and corresponding attenuation ratings, see *Table 1*). The measured impedance of the driver with LCR filter and 6kHz,

TABLE 1

ATTENUATION (DB)	R1 (Ω)	R2 (Ω)
1.0	0.65	49
1.5	1.0	32
2.0	1.2	23
3.0	1.8	14
4.0	2.2	10

FIGURE 2: IMPEDANCE PLOTS OF THE 2404H, 2404H WITH LCR FILTER IN PARALLEL WITH DRIVER, AND THE 2404H WITH THIRD-ORDER BUTTERWORTH FILTER. THE IMPEDANCE VALUES WERE MEASURED USING A CALIBRATED VOLTAGE DIVIDER WITH THE DRIVER SUSPENDED SUCH THAT A DISTANCE OF 3′ FROM ANY SURFACE WAS REALIZED.

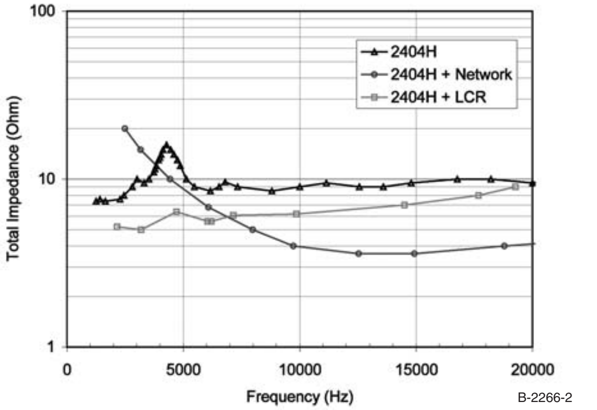
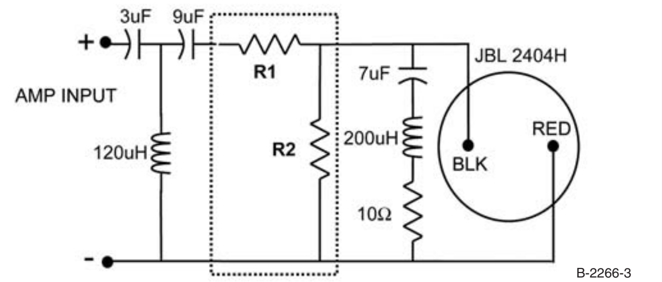


FIGURE 3: SCHEMATIC OF THE TWEETER NETWORK. 16 AWG STRANDED HOOKUP WIRE IS SUITABLE FOR ALL OF THE CONNECTIONS.



third-order Butterworth network is shown in *Fig. 2*. The curve is labeled "2404H + Network."

For the prototypes, I used 14AWG air-core inductors and Solen metallized polypropylene capacitors. Resistors were non-inductive, sand-cast types with 20W RMS power ratings. The supplier was Madisound.

MAKING THE TWEETER ASSEMBLY

With the tweeter and crossover taken care of, the last part of the project is to construct a small housing (a "stand") for placement on top of the speaker system. To take advantage of the dispersion characteristics of the bi-radial horn, I made the tweeter mounting baffle as small as was practical, assuming that the unmounted driver is the ideal mounting configuration. I made the base of the stand deep enough to contain the associated network and terminal block.

I fabricated the tweeter stand prototype from ¾″ thick plywood, using a table saw, router, and a bench top drill press (*Photo 4*). The baffle cutout for the tweeter is a 122mm diameter hole cut using the setup shown in *Photo 5*. The trickiest part of the woodworking is mounting the T-nuts so that they align precisely with the bolt holes on the tweeter mounting flange. When done properly the mounting screws will pass through the tweeter mounting flange and screw down without binding.

Once you have cut all of the parts and pressed in the T-nuts, drill the four pilot holes that will be used to screw the mounting feet down onto the bottom of the base plate (*Photo 6*). Assembly is straightforward but requires a few basic tools which most builders have.

To glue the baffle to the stand, I fabricated a simple right-angle fixture from scrap pieces of MDF and plywood (*Photos 7* and *8*). A sheet of wax paper keeps the assembly from sticking to the fixture. Also, an assortment of clamps similar to the ones shown are very useful to have handy. The finished prototype tweeter stand with all of the components mounted is shown in *Photos 9*, *10*, and *11*.

HOOKUP

Hooking up the new tweeter to the Klipschorn requires that the tweeter filter section in the existing factory network be deactivated. If you have the AK, AK-2, or AK-3, it is relatively straightforward. For illustration purposes, I've included a schematic of the AK-2 network (*Fig. 4*). The tweeter filters in the AK and AK-3 are identical to the AK-2.

Referring to *Fig. 4*, one of the 2µF series caps has a lead that connects directly to the positive amp input terminal block. At the capacitor, unsolder the wire from the capacitor lead to the terminal block connection. Then, at the 125µH inductor, unsolder the connection of the inductor leg that connects to ground. By performing these two steps, the ladder section of the stock tweeter circuit is cut completely from the amp input.

On the A and AA-networks, disconnect the leg of the 2µF capacitor connected to tap #5 on the midrange attenuation autoformer, which is labeled T2A. Again, the best way to do this is to unsolder the connection at the 2µF cap. The AA has a 245µH inductor in parallel with the tweeter with one leg back to ground (the A has no inductor). Unsolder this leg at the inductor.

Figure 5 shows the AA schematic and where the breaks are made. Finally, run a pair of leads from amp input to the input of the new tweeter filter.

Place the 2404H tweeter assembly on top of the Klipschorn cabinet with the tweeter baffle flush with the top-section grille. Run a line of 16 AWG lamp cord from the amp inputs located on the factory network, to the amp inputs on the 2404H tweeter assembly terminal block and make the appropriate connections. To simplify making the connection, crimp #6 (22-16 AWG) insulated fork terminals to the wire ends.

FIRST IMPRESSIONS

The improvement over the T35 is by no means subtle, it is decidedly obvious.

REFERENCES

1. US Patent # 2,873,812 (see www.uspto.gov).
2. Specifications and Instructions Models T35B, T35, and T350 (P/N 53517), Electro-Voice, Inc.
3. Excursion-Limited SPL Nomographs, S. Linkwitz, *Speaker Builder*, 4/84, pp. 24 27.
4. 2404H Product Specification Sheet (see www. jblpro.com).
5. "The Impedometer," D. Pierce, *Speaker Builder*, 8/99 pp. 28 31.

PHOTO 10: TO GIVE SOME IDEA OF THE ACTUAL SIZE OF THE TWEETER ASSEMBLY, A 15″ UNIVERSITY C15W LOW FREQUENCY DRIVER IS SHOWN NEXT TO IT.

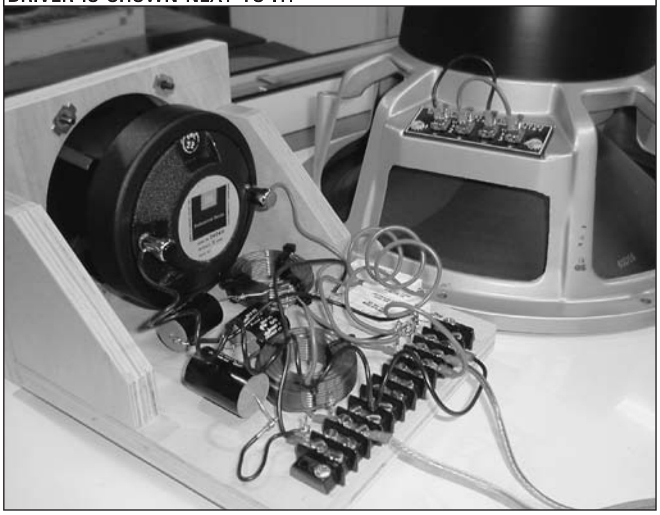


PHOTO 11: FRONT VIEW OF 2404H TWEETER ASSEMBLY NEXT TO 15″ UNIVERSITY C15W LOW-FREQUENCY DRIVER.

High frequencies are reproduced with extreme clarity and detail. The assumed excellent dispersion characteristics of the bi-radial horn configuration are confirmed too, evidenced by a complete lack of "beaming."

SUMMARY

As Mr. Dell himself so eloquently stated, "the long history of the EV T35 is a case of reluctant accommodation," and empirical evidence to support this observation is found in the numerous factory modifications to the tweeter filter section of the network. These were all designed and released to "reluctantly accommodate" the limited power and frequency response capability of the EV T35.

Good horn tweeters are expensive, and the JBL 2404H is no exception. A new pair will set you back about $550. The network components used will cost an additional $40. A better grade of components, of course, will cost more, but, in my opinion, the investment is entirely worthwhile. *aX*

FIGURE 4: SCHEMATIC OF THE AK-2 CROSSOVER USED IN THE KLIPSCHORN. THE AK AND AK-3 TWEETER FILTER SECTIONS ARE IDENTICAL. LARGE XS MARK LOCATIONS WHERE CIRCUIT BREAKS ARE MADE.

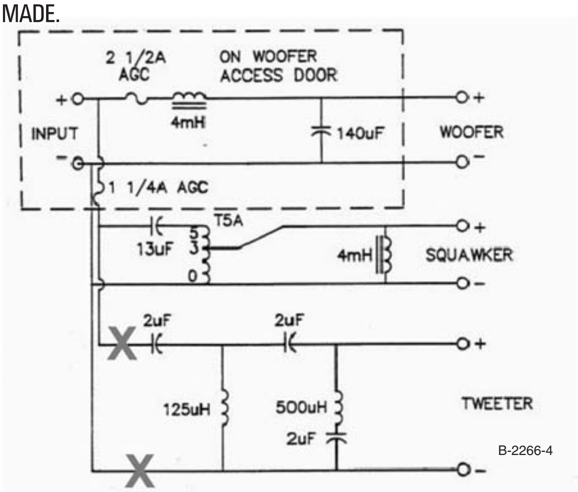


FIGURE 5: SCHEMATIC OF THE AA CROSSOVER USED IN EARLIER KLIPSCHORNS. LARGE XS MARK LOCATIONS WHERE CIRCUIT BREAKS ARE MADE.