Transmission Line ∘ Networks ∘ T & S Sixth's ∘ Taming Table Saws ∘ Calculators

1/1982

SPEAKER BUILDER

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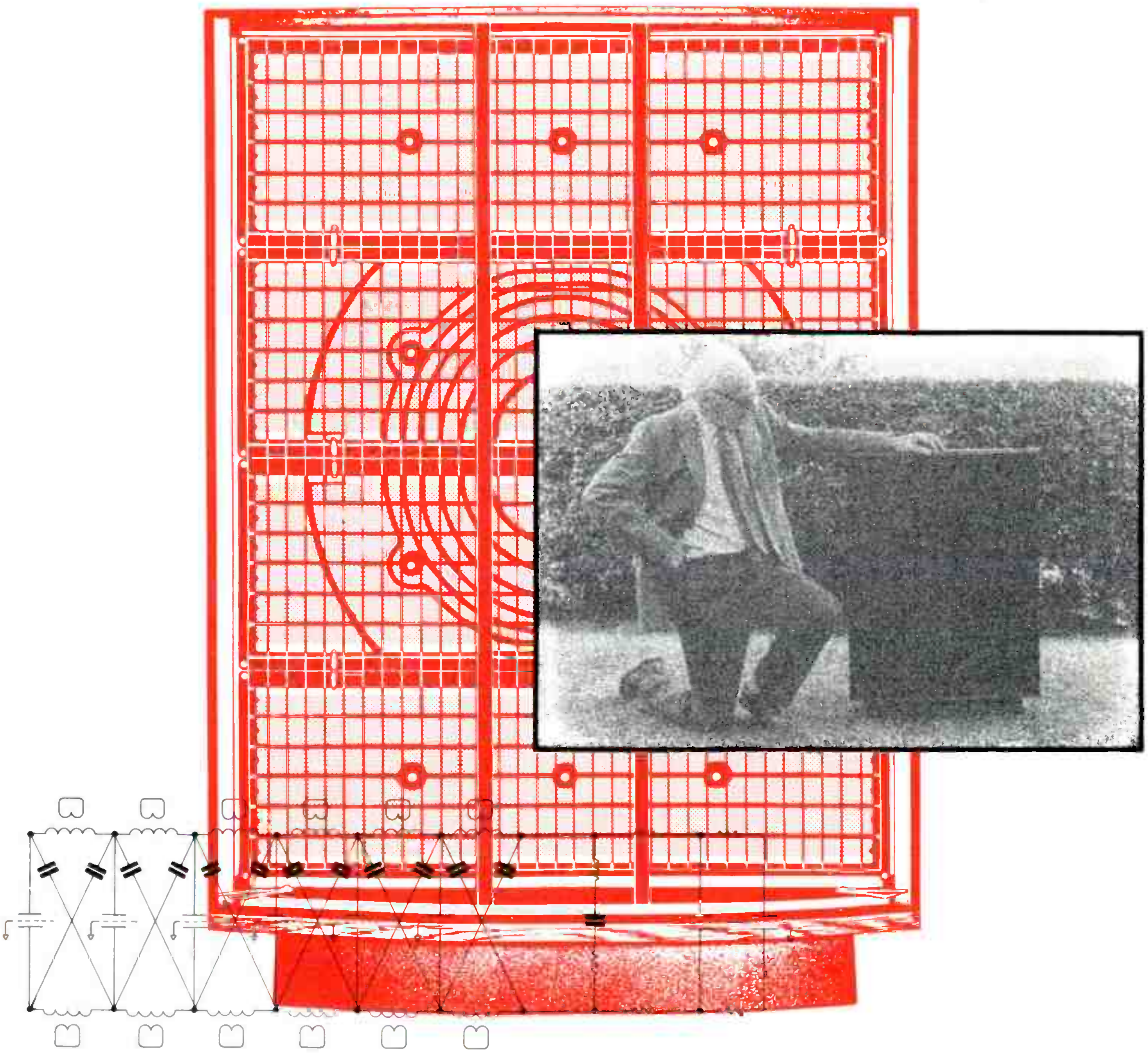
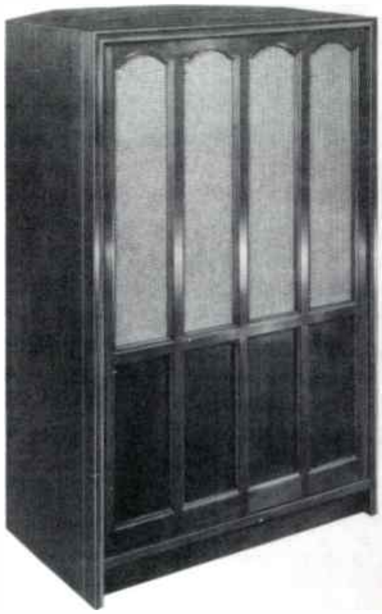


Good News



Electro-Voice has begun again marketing the 1952 designed Patrician 800 in the United States on a very limited basis. Two years ago EV reinstituted production of the Patrician with all output earmarked for Japan, where the Patrician has a large cult following. Suggested retail for the four-way units is $10,000 per pair. The 800 stands close to 4½-feet tall, is finished in walnut veneers with woven cane grilles, and has a 30-inch woofer, the largest low-frequency driver currently in production. The frequency response is 15-23,000Hz, according to EV. If you want a dealer's name write Electro-Voice, Inc., Dept. P-3, P.O. Box 186, Buchanan, Michigan 49107.

Design Acoustics, a new operation of the Audio-Technica company, has a new, three-piece DA-30 Loudspeaker System ($595) featuring a pair of low diffraction miniature loudspeakers and a bass extender with a 12 in dual voice coil, long-throw woofer. The bass unit is 16″x16″20″, and is said to reproduce lows to 40Hz. Recommended amplifier power for the DA-30 is 35 to 250 watts per channel. A brochure is available: Audio Technica, US., Inc., 1221 Commerce Drive, Dept. SB., Stow, OH 44224.

One-to-one duplicated reel-to-reel tapes are a new offering from **Centaur Records, Inc.,** (PO Box 23764, Baton Rouge, LA 70893) whose interests are both classical and jazz. Their record catalog is free for the asking. A technical brochure on their tape offerings is 50¢.

Teledyne's **Acoustic Research** has a new 3-way floor standing or bookshelf speaker, the AR58s. It features: a 12″ woofer, 1½″ liquid-cooled dome midrange, ¾″ liquid-cooled dome tweeter. Specifications include: Voltage sensitivity: 2.83 volts produces 90dB SPL at one meter on axis. Efficiency: 1 watt produces 87dB SPL at one meter on axis. Power requirement: 15 watts per channel minimum. Power handling ability: May be used with amplifiers rated up to 200 watts per channel with amplifier being driven into clipping no more than 10% of the time. System frequency response: −3dB (half power) points at 37Hz and at 25000Hz. System low frequency performance: −3dB at 37Hz with an effective Q at resonance of 0.6. Crossover frequencies: 700Hz, 7500Hz. Suggested retail price is $325.00. For more information write 10 American Drive, Dept. SB, Norwood, MA 02062.

Amateur and professional recordists may be interested in **Crown International's** PZM Challenge, a contest to award excellence in recordings made with Crown's PZMicrophones. Entries must be excerpts from original stereo recordings made using two or more PZMicrophones as the principal pick-ups. Judging is to be based on how the recording reflects the attributes of the PZMicrophones, overall sound quality, and, for multiple microphone recordings, the quality of the mix.

The PZM Challenge is actually two contests, differing in contestant eligibility: one open to persons not affiliated with Crown, called the PZM Open Challenge; and a second open to Crown PZM dealers, their employees and immediate families, called the PZM Dealer Challenge. Winners will be named in each of three categories: classical, pop and environmental sounds. Prizes are to be an array of Crown products. For more details and rules write Crown International, PZM Challenge, Dept. SB, 1718 W. Mishawaka Road, Elkhart, IN 46517.

Pyle Industries has introduced three new hi-fidelity/musical instrument woofers in 10″, 12″, and 15″ versions, suitable for woofers in sealed or bass reflex enclosures, or for musical instrument applications.

All three sizes feature a 2½″ "Power-Proof" voice coil which Pyle claims is one of the most reliable in the industry. The voice coils incorporate the latest in design and technology, featuring high-temperature Kapton forms for continuous play at high power levels. The units have 70 oz. magnets, and 12 lb. motor assemblies and range in price from $100 to $120. Further information is available from Pyle Industries, Inc., PO Box 620, Dept. SB, Huntington, IN 46750, or phone (219) 356-1200.

Henry Kloss has a new version of his projection TV System, (Model 2) that uses any white wall for a screen. The projector folds when not in use and is smaller than many 19″ TV sets. The new Novabeam® costs about $3,000. and uses the tuner in a video cassette recorder. The picture is 5 ft. wide and is twice as bright as any competitive projector system currently available. Info from 145 Sidney St., Cambridge, MA 02139.

Acoustical Physics Labs (151 6th St., NW, Atlanta, GA 30313) has a kit version of its Acoustic Image® loudspeaker system which saves well over half the cost of the finished version. The time aligned satellites are based on Bill Morrison's work at Georgia Tech a few years back. The kits include everything but the cabinets, with full plans provided the woodworker/builder. The manufacturer has a detailed fact sheet on the kit.

VOLUME 3, NUMBER 1 FEBRUARY 1982

SPEAKER BUILDER
MAGAZINE

Editorial and Circulation Offices:
P.O. Box 494
Peterborough, New Hampshire 03458 U.S.A.

ADVERTISING REPRESENTATIVE
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316 St. James Place, Philadelphia, PA 19106
Telephone (215) 627-5326

SUBSCRIPTION RATES
In the United States and Possessions
One Year (four issues) $10
Two Years (eight issues) $18
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FRANCE:
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SPEAKER BUILDER MAGAZINE (US ISSN 0199-7920) is published four times a year at $10 per year; $18 for two years by Edward T. Dell, Jr. at 5 Old Jaffrey Road, Peterborough, NH 03458 U.S.A. Second class postage paid at Peterborough, NH and pending at additional mailing offices.
POSTMASTER: If undeliverable send PS form 3579 to P.O. Box 494, Peterborough, NH 03458.

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SPEAKER BUILDER

About this issue

Gary Galo leads off this time with the first of two articles on transmission line speakers. Next time, full plans for three TL devices.

Reggie Williamson, longtime contributing editor of *Audio Amateur*, took along his camera to Huntingdon, near Cambridge, England and collected material for his report on Peter Walker's new electrostatic speaker (p. 10).

Robert Bullock returns with the fifth part of his series on Thiele/Small (p. 20). This marks the end of the heavily theoretical portion of the series, says Editor Bullock, and from here on the series will detail hands-on construction of examples of closed and vented boxes.

Bruce Edgar gives us a primary course in handling the table saw (p. 25) with guidance on setting it up properly and constructing those handy accessories which every craftsman needs to do a proper job of speaker building.

The Tools, Tips & Techniques section is full of helpful items (p. 30) from readers **John B. Arrango, Vern L. Mastel, R. J. Welsh**, and two from our prolific Contributing Editor **G. R. Koonce.**

Jack Philpot likes Jon Dahlquist's justly famous DQ-10 speakers, but has some customizing suggestions for those who want to modify their units. All the details begin on page 36.

Welcome to the 1982 series which could become our best year to date. Our files are brimming with good material but our pages are fewer than we'd like. Your responses to our advertiser's offerings is the way to more pages. Do let the vendor know you saw his ad in *SB*. It could mean fatter issues in '82.

Bandages

Two heavy, expensively printed manufacturer's brochures arrived at my desk within days of each other recently. In other times when the audio business was strong, exploratory and growing at a satisfying rate, I would have settled down to read the releases with unalloyed interest and admiration. The serious search for good sound in the US is in its fourth decade if we date the beginning of the hunt as Goldmark's announcement of the development of the long playing disk.

I read both announcements with great interest and not a little admiration. One of them concerns *Acoustic Research's* new computerized Adaptive Digital Signal Processor (ADSP). In brief it analyzes the signal, decides how it is deformed or what excesses it contains, including the vital problem of room reflections, and corrects them. I would probably not have thought much about the new machine but that *Nakamichi* also announced a new gadget which is also, in its own way, an adaptive device.

For $7,000 you may have a turntable which has a special movable platter with the spindle in it which is micropositioned by two tiny motors in response to a special sensing arm which determines where the true center of the recorded disk is located. It is all done with a microprocessor, of course.

Now I want it clearly understood that I have the greatest admiration for the work of Messrs. Acoustic Research and Nakamichi. Their accomplishments are impressive. Unfortunately, I think these devices are part of a seriously misdirected trend and that they are working at the wrong end of the problem.

What both these devices do, most of the time, is correct flaws in the reproducing chain and in the "software" of sound reproduction. Are your amplifiers distorting? Not to worry, just buy this complex digital processor and get rid of the problem. Are the holes in your disks off center? No problem, for only $3.50 each for those 2,000 disks you own, you can make sure each one plays with absolute concentricity. No matter how badly the records you buy are made, you have a cure for the shortcoming.

It is certainly fair to add, however, that AR's machine is designed to deal with a problem which thus far no other device, or combination of them, has solved satisfactorily. Rooms distort and unbalance recorded sound. Without hearing one of the new ADSP units in action I cannot know whether it does the corrective adaptation without causing other problems and whether I like what the computer thinks the "ideal" form of the sound ought to be. If the ADSP does deal effectively and unobtrusively with room imbalancing it is a genuine advance for those who love good sound. As a palliative for distortion in recordings or in the reproducing chain, it ought to be unnecessary.

Anyone who came into our little world of high quality sound reproduction from elsewhere and looked at what we are up to would ask the "dumb" question, "Why not get rid of the pollution at the source?" Why not, indeed?

It is profoundly saddening to see the record companies rushing pell mell into the "digital era" without having solved the basic mechanical problems of their technology. And while $7,000 band aids are impressive—they are still band aids. □

Transmission Line Loudspeakers
Part I: Theory

by GARY A. GALO

NEARLY ALL LOUDSPEAKER enclosures used for low frequency reproduction attempt to solve three problems: (1) isolating the loudspeaker's front radiation from the rear radiation to prevent the low bass from being wiped out; (2) controlling the woofer's rise in response and impedance at the resonant frequency; and (3) either losing the rear radiation completely, preferably in a way that will not be detrimental to the sound, or somehow using it to reinforce or dampen the woofer's bass response at specific frequencies. The acoustic suspension (or infinite baffle) and bass reflex enclosures are popular examples of solutions to these problems.

My dissatisfaction with these "conventional" enclosures and search for a superior alternative began several years ago. Bass reflex enclosures are, by definition, "resonant" enclosures; even the best designs are incapable of delivering flat, natural bass, free of peaks and other colorations around the region where bass reinforcement from the port takes place. The best acoustic suspension designs do not suffer from the resonant peaks present in bass reflex designs; however, I have yet to hear an acoustic suspension design completely free of "boxy" colorations caused by internal reflections. Large infinite-baffle enclosures provide no means of controlling cone motion at resonance, so one must use woofers with relatively stiff suspensions, and consequently higher than desirable resonant frequencies.

My interest in transmission line loudspeaker design began many years ago when I heard the "tower" version of the E.S.S. AMT-1 loudspeaker. This was E.S.S.'s only transmission line loudspeaker, and was the first loudspeaker I had heard that achieved acceptable low bass performance without boxy coloration or boomy bass. Unfortunately, E.S.S. ceased producting transmission line woofer systems when they discontinued this model shifting their emphasis to acoustic suspension and, more recently, passive radiator designs.

Even today, only a few commercial manufacturers are marketing transmission line loudspeakers, the most notable being Fried Products and I.M.F. (Both were founded by the same Irving M. Fried, although Mr. Fried is no longer connected with the latter company.) The transmission line loudspeaker simply hasn't enjoyed the kind of commercial success it deserves. Among the reasons are: (1) its relatively complex internal construction compared with "box" enclosures, which adds substantially to manufacturing costs; and (2) the relatively large enclosure needed for a given woofer diameter, when compared with "box" speakers using the same similar woofers.

Fortunately, these difficulties matter little to the home constructor who has moderate electronic and woodworking skills. The difficulty has normally been the lack of available sources on theory and practical models to work from. In the course of my research I found that many of the articles previously written on transmission line loudspeaker design were incomplete, inaccurate, or both. Among the more misleading comments in published articles are: "T.L. systems are designed basically by trial and error";[1] and, "If your T.L. design doesn't work, use the enclosure as a dog house and build a box speaker"?

Even worse, many of these articles contain no workable construction plans of proven designs. This leaves the constructor with little to work from, especially compared with the vast number of theory articles and construction plans available for box-type loudspeakers.

This paper's purpose is two-fold. In Part 1 I shall outline the theory of transmission line loudspeaker design, providing sufficient data for ambitious constructors to base their own designs on, while in Part 2 I'll provide plans for constructing three full range systems using T.L. woofers. These designs are not theoretical models: they are working models built and improved by me and successfully duplicated by many of my friends and colleagues.

THE THEORY

The transmission line loudspeaker is a refined descendant of the acoustic labyrinth invented in the 1930's by Stromberg-Carlson (see *Fig.1*). The labyrinth consisted of a pipe into which the woofer's rear radiation was loaded, where length was one-quarter wavelength (λ) of the woofer's free-air resonance. If the woofer's free-air resonance was 50Hz, the line would be 5.65 feet long (1130 ÷ 50 = 22.6 ÷ 4 = 5.65). The pipe was normally folded

FIG. 1

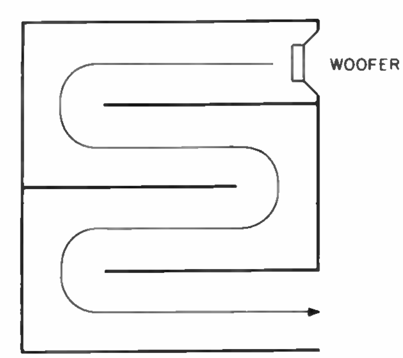


Fig. 1. Typical Acoustic Labyrinth Enclosure.

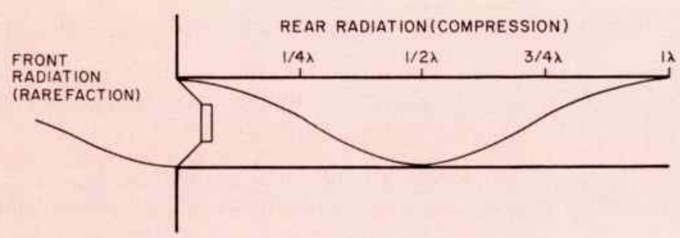
as in *Fig. 1*, to conserve space, and its maze-like appearance led to the name "labyrinth."

The ¼ λ size was chosen for two reasons: (1) to dampen excessive woofer output at resonance; and (2) to reinforce the octave above resonance. A look at *Fig. 2* will clarify this. It shows a woofer loaded into a pipe that is a full λ long at its resonant frequency (whatever it happens to be). The woofer is reproducing a sine wave (which I have drawn in) at this frequency. As the illustration shows, the front and rear radiation are 180° out of phase. (In this case, the woofer has moved backward, producing a rarefaction in front and a compression in the rear.)

fiberglass to dampen internal reflections.

Although a step in the right direction, the acoustic labyrinth has several inherent weaknesses. First, it provides no adequate means of controlling the woofer's excessive cone motion at resonance. The pipe's output does cause partial acoustic cancellation in the listening area, but the woofer excursions can still be excessive, causing the driver to operate in its non-linear region at higher playback levels. The result of this non-linear operation is, of course, excessive distortion at all frequencies in the woofer's operating range. We can control this by using woofers with relatively stiff suspensions, but the result is poor deep-bass response due to high resonant frequencies for these types of woofer.

FIG. 2



Phase Relationship of Rear Radiation to Front Radiation at Resonance:
At 1λ—180°out—No Good
At ¾λ—90° out—O.K. but the line is too long to be practical
At ½λ—in phase—No Good
At ¼λ—90° out—**Correct Length**

Fig. 2. Phase relationship of front radiation to rear radiation for labyrinths of various lengths.

The phase relationship between the front radiation and the output of the pipe will determine whether cancellation or reinforcement takes place. Considering the first requirement, damping of the excessive output at resonance, turn again to *Fig. 2*. If the pipe is one λ of the resonant frequency, the pipe's output is 180° out of phase with the woofer's front radiation, causing total cancellation at this frequency. Obviously this is undesirable. At ¾ λ, the output is 90° out of phase with front radiation. This is what we are looking for since the pipe's output will cause partial (not complete) cancellation of the output at resonance. Unfortunately, a pipe ¾ λ long would be unmanageably large; so we must find another length.

At ½ λ, the pipe's output is in phase; again, not good. At ¼ λ, the pipe's output is again 90° out of phase (270° actually, but the effect is the same), and again we have partial cancellation of the output from the front of the woofer. This, therefore, is the length the labyrinth should be. At one octave above resonance, our labyrinth is now ½ λ long. The pipe's output is in phase with the front radiation at this frequency, causing a reinforcement in this region. The pipe is usually lined with

Secondly, the reinforcement at the octave above resonance is usually excessive, resulting in boom-box characteristics at this frequency. (This is similar to bass reflex action.) The result of all this is that a labyrinth will have either excessively high distortion at high levels due to poor woofer control, or poor deep-bass response. The excessive output at the octave above resonance may please some "West Coast" speaker fans, but it is not accurate. Old-fashioned labyrinths are *not* non-resonant designs.

The modern transmission line loudspeaker is theoretically non-resonant, and in the real world we can for all practical purposes achieve this theoretical ideal. The transmission line bears a superficial resemblance to the acoustic labyrinth, but they are quite different in operation. The purpose of a transmission line design is to completely lose the woofer's rear radiation in the pipe (henceforth referred to as the "line"). An ideal transmission line has no acoustic output from the end of the line ("line exit"). Such a line would be infinite length; since this is an obvious impossibility, the designer must select an appropriate finite length, which will normally be ¼ λ on the driver's resonance.

Since total absorption of the rear wave is the design goal, the line must be filled, not lined, with a suitable damping material. Long-fiber wool has proven to be best for this purpose.[3,4]

The line is loosely filled with the wool, at the rate of half a pound per cubic foot of line volume. The wool's purpose is two-fold. Of course it must absorb the rear radiation of the loudspeaker so no sound will emerge from the line exit, but it also has another interesting characteristic: it acts as an acoustic low-pass filter. This is extremely important, for controlling woofer cone motion (and impedance) at resonance. At higher frequencies, above two or three times resonance, the wool absorbs all rear radiation. At these frequencies, the movement of air inside the line is confined to a small area behind the woofer, i.e., the woofer "sees" a very short line. As the woofer operates at lower frequencies, movement of air in the line occupies a much larger portion of the line length. At the woofer's resonant frequency, the woofer "sees" the entire length of the line. This increased amount of air adds mass to the woofer cone, restricting excessive motion at resonance.

Note that at very low frequencies there will be a small amount of output from the line exit; but its amplitude at this point is so low that, unlike reflex action, it has virtually no effect on the woofer's front radiation. For all practical purposes, the rear radiation has been lost in the wool-filled line. Several builders have asked me what would result if the line exit were closed off. If one did this, the line would act more like an acoustic suspension system at very low frequencies. One of the reasons for a T.L. system's non-resonant characteristics is the complete freedom from internal pressure at low frequencies, eliminating the "bass in a box" character found in acoustic suspension systems.

As a serious audio constructor, you may wish to design your own T.L. system to suit your particular needs. Observe the following guidelines:

1. The line length should be ¼ λ (wavelength) of the woofer's free-air resonance. If this frequency makes the line impractically long, you can use ¼ λ of a pre-determined (higher) cut-off frequency. If the line is a full ¼ λ of the woofer's resonance, you may expect flat bass down to the woofer's free-air resonant frequency; it will usually be around 3dB down at this point. Since woofer resonance is not raised in a full ¼ λ line, a good 10″ woofer will provide flat low bass which acoustic suspension systems normally can't equal with 12″ or 15″ drivers.

2. The line's cross-sectional area

should be greater than the woofer cone's rear area. You may taper the line to conserve space, but I recommend that the line's cross-sectional area remain at least equal to the woofer cone area at all points.

3. Line the parallel surfaces immediately behind the woofer with carpet felt or fiberglass (1" thick or so) to prevent reflections back to the woofer cone.

4. Woofers should have butyl rubber or P.V.C. surrounds. Give preference to Bextrene or other non-paper cone materials. Drivers by Audax, KEF, and Dalesford are excellent. Philips paper cone woofers are very good, but their performance does not equal that of the Audax Bextrenes. Foam surrounds are not as good.

5. Make the enclosure of ¾" particle board, Titebond glue, and screws. Extensive internal bracing is unnecessary, due to the absence of internal pressure.

6. Install 45° angle pieces at corners near the woofer; they are unnecessary in the last half of the line.

7. Long-fiber wool is the preferred damping material (one half pound per cubic foot). Dacron-polyester is cheaper, but its performance unfortunately matches its cost. Fiberglass is out of the question, since it is highly reactive, rather than moderately resistive, at low frequencies: it acts more like a "no-pass filter" than a low-pass filter.

Following these guidelines will produce a woofer system free of resonant or boxy characteristics, with true low bass fundamentals unmasked by upper bass boom. If upon first hearing you find that a well-designed T.L. system is bass deficient, maybe you need a trip back to the concert hall. Many listeners are used to overly fat upper bass in reproduced sound; some even prefer it. Live music doesn't sound like this, however. A transmission line system will reproduce what has been recorded on the disc or tape, no more and no less.

In Part 2, to be published in the next issue of *Speaker Builder*, I'll discuss the construction details of my three full-range systems. Transmission line designs also make superb sub-woofer systems to extend the bass of an existing speaker. A transmission line woofer system is ideal for use with full-range electrostatic systems: since an electrostatic loudspeaker is free of enclosure-related resonances, a T.L. woofer will provide a seamless blend at the selected crossover frequency. Roger Sanders' system[5] is an excellent example of this application. ☐

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ABOUT THE AUTHOR

Gary Galo is an electronics technician/recording engineer at the Crane School of Music, State University College of Arts and Sciences, Potsdam, N.Y., where he teaches a course in Fundamentals of Audio. He is also an instructor of music at the State University Agricultural and Technical College, Canton, N.Y. He was previously a marine electronics technician for Seatronics, Inc. of Greenport, L.I., N.Y., and taught music in the Rockville Center, L.I., N.Y. public schools. He holds a B.A. in Music Education and an M.A. in Music History and Literature from the State University College at Potsdam, N.Y. He is a member of the Audio Engineering Society.

The Quad 63

by Reg Williamson

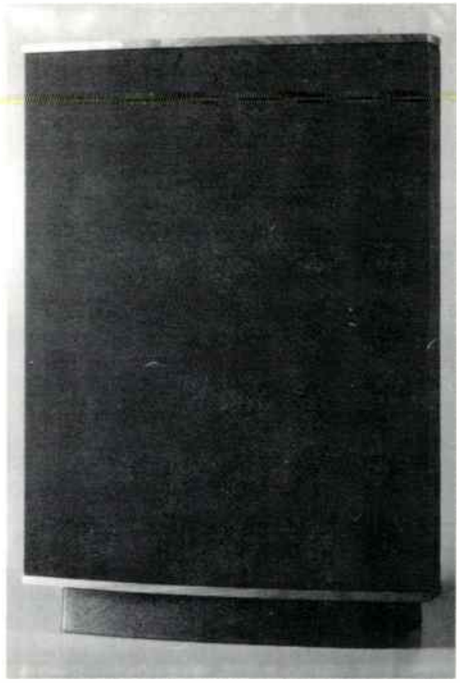

Fig. 1. Quad's new ESL-63 full range electrostatic speaker.

A regular feature of our major hifi show in the UK, is the panel "of experts," who are persuaded to come together and answer questions from an audience of exhibition visitors. Mostly, the panel is drawn from contributors to the hifi press rather than those who do the work (!); but occasionally, it will include someone such as my iconoclastic self and one can only assume, for the reason that I can be relied upon to say something reactionary and add spice to the proceedings. However, one question came up at the last show which gave me little difficulty and my answer was accepted with general accord by my colleagues on the team.

We were asked to suggest which were the three major audio developments over the past 50 years. For my part, I interpreted the question to mean genuine innovations that had advanced the science of audio to a significant degree; and my answer was swift and unequivocal. First, the invention of the transistor. Second, the invention of the analogue to digital concept (and this one just made it, since Reeves' patents were filed in the mid-1930's). Finally, and here my answer provoked a mutter from the knowledgeable afficionados in the audience, the successful development of the world's first commercial, full range electrostatic loudspeaker 25 years ago.

It was back in the mid-fifties, before commercial hifi as we now know it had got off the ground, that most serious development work was in the hands of a enthusiastic few. They were often professional engineers in other, unrelated disciplines whose interest in high quality audio was primarily a part-time activity. These were halcyon years which saw the development of many basic concepts, such as the well-known Baxandall tone control that for a very long while was one of the basic "bricks" of preamplifier circuitry. At about the same time, a series of articles appeared in the august (and then, much respected) periodical *Wireless World* under the names of Peter Walker[1] and my distinguished namesake, D.T.N. Williamson. They examined in great detail, many of the possible design approaches for a new loudspeaker using the electrostatic principle. For anyone interested in the subject, it is mandatory reading.

HISTORY

ES speakers, of course, were not new; the principle was known prior to the work of Rice and Kellogg on the moving coil speaker. Various practical examples had appeared before, usually as simple tweeter units with their function confined to handling the frequency spectrum above, say, 1 or 2kHz. To go much below that presented, so it was thought, too many theoretical and practical design problems. Those available commercial examples suffered from many shortcomings, such as poor efficiency, non-linear distortion and unreliability.

Yet, to design engineers of Walker's and Williamson's calibre, these unsolved problems presented a fascinating challenge, with ultimate solutions to them promising an exciting prospect since the electrostatic concept had one particular attraction over conventional speakers using moving coil driver units. It held out the tempting possibility of being predictable to a far greater degree than hitherto considered feasible, and offered designers a reliable preview of how a high quality loudspeaker would perform at the design stage long before prototype construction. This is in contrast to the "try it and see" approach that even today is often the dominant technique for designers of moving coil or dynamic speaker systems.

Since Peter Walker is, as then, the major driving force behind other highly successful audio products under the Quad trade name, it was inevitable that any results of this research would find a practical outlet and indeed, they did. In 1956, his Acoustical Manufacturing Company announced the production of the world's first full range electrostatic loudspeaker. I well remember the enormous stir it created at the time, with long lines of enthusiasts at the audio show to hear the wonder speaker. My chance didn't come until some months later at a private hearing in my home town. My memories of that event are as vivid now as they were then. Even the first recording I heard remains with me—Rita Streich singing "The Last Rose of Summer" from Flotow's opera *Martha*. Not a very distinguished piece of music, but I had never before heard anything remotely equalling the sound quality.

Interestingly enough, a Voigt horn system I once heard in a BBC studio came very close. It is not without significance that Walker regarded Voigt's "open window" concept as one of the basic tenets of his design philosophy. Voigt believed the reproduced sound should be close to that which one would hear when listening to the real thing through an open window. That idea was well to the fore in my first impression of the first Quad ESL. It seemed as if Rita Streich's lovely soprano with her accompanying music were coming from somewhere behind or through the loudspeaker, with a freedom from coloration and distortion that raised new standards.

LONGEVITY

At the time, I had begun to be interested in, and responsible for the record playing gear of my local gramophone (or recorded music) society. It was obvious we were going to have to have this new speaker, where it also established the standard for us for many years to come. We acquired our first Quad ESL in 1957 and some four or five years later, when stereo reared its two heads we bought the second. Right up to mid-1981, these two speakers have served us well with only infrequent servicing needs. Our standards of record reproduction at weekly meetings throughout the year have always been high and have attracted favorable comment from visiting guests. Peter Walker was himself a very welcome guest contributor in our early days, providing one of the most entertaining programs in the Society's history. He is, like all first class audio engineers, a lover of good music and an enthusiastic, active performer on the flute.

The basic Quad ESL design has remained fundamentally unchanged in 25 years and this alone must be some sort of record. For how many mass produced loudspeakers can claim uninterrupted production for the same period and to have enjoyed commercial success right up to the time that its replacement is contemplated? Not many, I wager. All designs involve acceptance of some compromise and the Quad ESL was no exception. Its shortcomings were never concealed by the company and any potential user had to be ready to accept them. One was its power handling capacity, which proud owners of half kilowatt amplifiers soon discovered was limited in comparison to conventional moving coil systems. If this was coupled with a predeliction for hard rock or pipe organ recordings at high level, the first casualties were the speakers. On the other hand, those users who sensibly matched it with Quad's own excellent power amplifier or alternatively, read and observed the details in the comprehensive specification that came with it, at least in terms of power handling capability, encountered no problems. Quad owners also accepted that their ESLs would not comfortably handle the 32 foot open wood of a pipe organ. Yet despite these limitations, it could give sustained pleasure for many years—and did, for many thousands of owners.

Quad ESLs had another important failing. They were not ideal for stereo due to certain radiation pattern deficiencies. Thus Peter Walker continued his work on a possible Mk 2 version in the early sixties; in 1963 to be exact since his first notes on the basic concepts appear in the laboratory note book of that year. To appreciate what he set out to do, it is essential to remind ourselves about the very nature of sound and how it is generated and propagated.

THEORY

Imagine what happens when you cast a stone into a pool of water. Concentric ripples, perfectly circular, radiate out from the point of impact. This is what happens when a source of sound radiates into the surrounding conduction medium—in our case, air. We live, in fact, in a pool of air. If we could make these sound waves visible, we would also see them radiating out from the source; again, perfectly circular. If the frequency of the sound is of a periodicity high in the spectrum, then these concentric rings are tightly compressed together; low frequency sounds have their maximum and minimum layers of compression and rarefaction spaced much wider apart.

FIG. 2

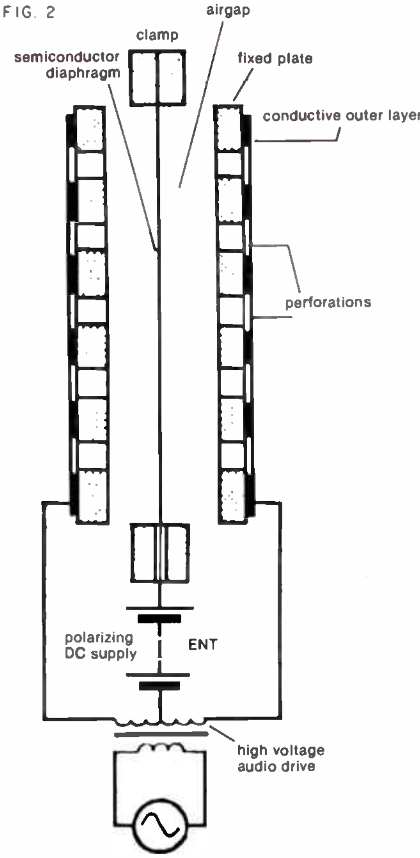

Fig. 2. Cross section of a typical electrostatic drive unit with external circuit.

From this it follows that the ideal reproducer of these radiation patterns is a pulsating sphere—or alternatively, a generator that would simulate the same patterns; moreover, one that would accomodate all the frequencies of the spectrum with equal efficiency. Such an ideal radiator would have been thought impractical a couple of decades ago. So in the world of orthodox speakers, the design approach had to be one of variations on a large number of compromises. Multiple unit systems to cover the spectrum adequately and shaped cones to tailor the radiation pattern; all familiar techniques achieving varying degrees of success. Peter Walker decided to tackle the impossible and found the answers; but it took 18 years.

Go back to that original ESL design, which in the process created a large number of highly difficult manufacturing problems, none of which had arisen before and yet, had to be solved before a speaker could be made at all. The basic design consisted of a light, thin diaphragm of plastic which was made *weakly* conductive and suspended centrally between two outer electrodes. The diaphragm was, in fact, so light it weighed less than the air layers on either side to which it imparted the sound vibrations (*Fig. 2*). The diaphragm is also given a constant charge from a high voltage polarizing source, the equivalent of the permanent magnet in a moving coil unit. The driving signal is fed across the two fixed electrodes, so when one is negative and the other is positive, the diaphragm will move towards one by attraction any by repulsion from the other. Reverse the phase, as with an audio signal, and the movement is the other way; a genuine push-pull system, and fully symmetrical.

ADVANTAGES

Now we come to some of the electrostatic speaker's many advantages. Since the diaphragm is driven over its entire surface, it need not be very stiff and thus, has little stored energy in itself. Also, because of an excellent impedance match with the air, the system requires no load in any form of acoustic chamber, thus many of the problems associated with cabinets never arise.

The laws of physics, however, must be considered, because if the size of the radiating area is comparable with the wavelength of frequencies being reproduced, spurious and unwanted multiple lobes will also be generated over the vibrating surface and in direct proportion to frequency. These tend to interfere with the desired radiation pattern and in stereo, militate against a firm and coherent image. Finally, a perfectly flat radiator will not produce ideally circular wave fronts.

Fortunately, most of these phenomena are mathematically predictable. In the original design some of these problems were solved by using two separate radiating panels. The higher frequencies were handled by a narrow strip in the center and the bass by two rather wider strips on either side. In the first production models, the crossover point, around 1kHz, was mechanical and relied upon the inherent inability of the center diaphragm unit to reproduce frequencies below the nominal X-over point. However, since the entire full spectrum signal was fed to the whole speaker and the gap spacing on the treble unit was smaller, it was more prone to overload and to subsequently fail. So post-1966 production models incorporated a simple high pass electrical filter in the signal path to the center unit. Finally, to improve the waveshape, the entire speaker unit was curved gently in the vertical plane.

So this was the ultimate production model which in essence changed little over the 25 years it enjoyed success with its loyal devotees. Aesthetically, it left much to be desired, but in many important areas of *performance* it has reigned unchallenged and set the standard by which others are often judged.

Yet, it was a 25 year old design with many shortcomings recognized by its creator; so a much improved successor was, in time, inevitable. As one who knows the company and has enjoyed the friendship of the designer for many years, however, it was evident that unless the successor was a significant advance on the first model, it would never see the light of day commercially. Mere cosmetic catering for the marketplace has never been the Quad company's style.

NEW MODEL

The new speaker's existence became strong rumor after the mid-sixties and a few friends, including our editor, were privileged under a pledge of discretion to see and hear it. In 1981, the secret became reality with demonstrations of the new speaker at the Audio Engineering Society in London and Los Angeles. Never before has a new audio product had such a keenly anticipated and prestigious start in life. With commercial production starting in mid-1981, already a long waiting list of eager customers outstrips production capability by many months.

Now, what is so startlingly different about the new speaker? Well, all of the best characteristics of the old model have been carried over into the new, with improvements wherever practicable to take account of new materials and techniques. It is, as before, a push-pull design so again, compared with the very best of moving coil systems, is virtually free from generated harmonic distortion. As one might expect from an electrostatic, it has also an exceptional linear frequency response that extends right up to 20kHz both on, and to a substantial degree, off axis. Bass end performance carries a claim of only −6dB at 35Hz, sensitivity up by 3dB and power handling similarly improved. Most important of all, the unique characteristic of a bidirectional radiating pattern has been retained.

The original design was an innovation in this respect, in that being a dipole radiating source, it carries with it significant benefits in terms of room placement and stereo imagery. With a sound dispersion pattern that resembles a "figure of eight," a dipole (or "doublet") (*Fig. 3*) radiates no energy in the plane of its diaphragm and so, does not excite room resonances that lie in the plane of these axes. The front

FIG. 4

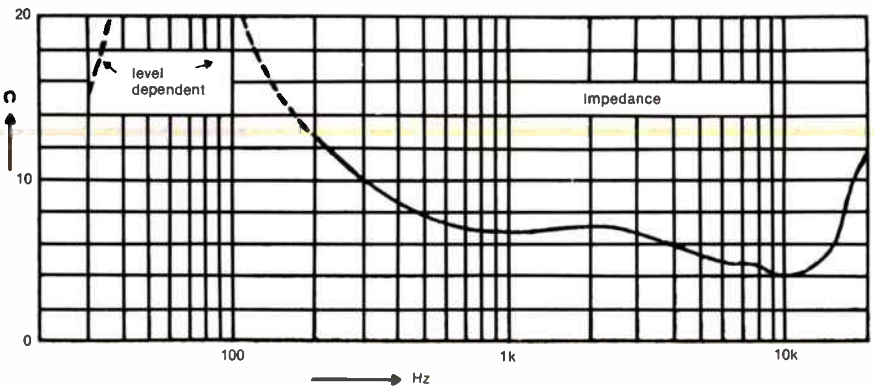

Fig. 4. Input impedance of the ESL-63.

FIG. 3

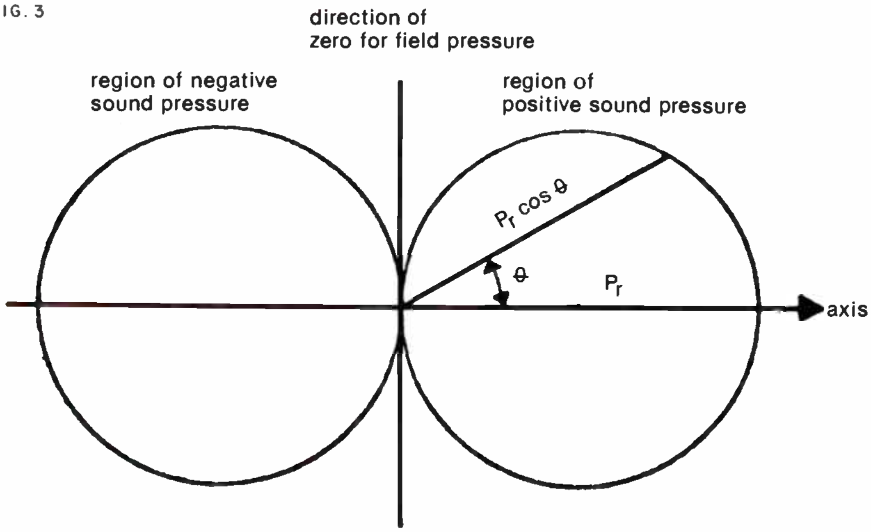

Fig. 3. The radiation pattern of a doublet.

PARTS LIST FOR FIG. 5.—

QTY	REF NO.	DESCRIPTION
4	R_{1ab} R_{2ab}	3R3Ω
4	R_{3ab} R_{4ab}	150k
4	R_5-R_8	360k
1	R_9	100Ω
2	R_{10} R_{11}	4k7
1	R_{12}	10M
2	R_{13} R_{14}	180k
1	R_{15}	1R5Ω
1	R_{16}	2k2
1	R_{17}	680Ω
1	R_{18}	120Ω
1	R_{19}	1M
1	R_{20}	10k
1	RV_1	Pre-set resistor 10k
2	VDR_1 VDR_2	Voltage dependent resistor E298-22-06
10	C_1-C_{10}	22pF
2	C_{11} C_{12}	10pF
4	C_{13abcd}	220pF
1	C_{14}	1μ5F
1	C_{15}	47nF
8	C_{16}-C_{23}	20nF
1	C_{25}	220μF
1	C_{26}	10nF
1	C_{27}	330nF
1	C_{28}	1000μF
1	C_{29}	150nF
1	D_1	Bridge rectifier by 225-100
1	D_2	Zener Diode BZY 88C 15V
8	D_3-D_{10}	Diode 1AV30
2	D_{11} D_{12}	Diode 1S920
1	D_{13}	LED XC5053
1	D_{14}	Bridge rectifier VM18
1	TR_1	Transistor 2N6489
1	TR_2	Transistor MPSU45
1	TR_3	Transistor E5270
1	T_1	Traic T6000B
1	T_2	Diac 2N4992
1	T_3	Triac MAC 92 3
12	L_1-L_{12}	Coil
1	L_{13}	Choke 22μH
2	L_{14} L_{15}	Audio transformer
1	L_{16}	Mains transformer
1	FS_1	Fuse T100mA

FIG. 5

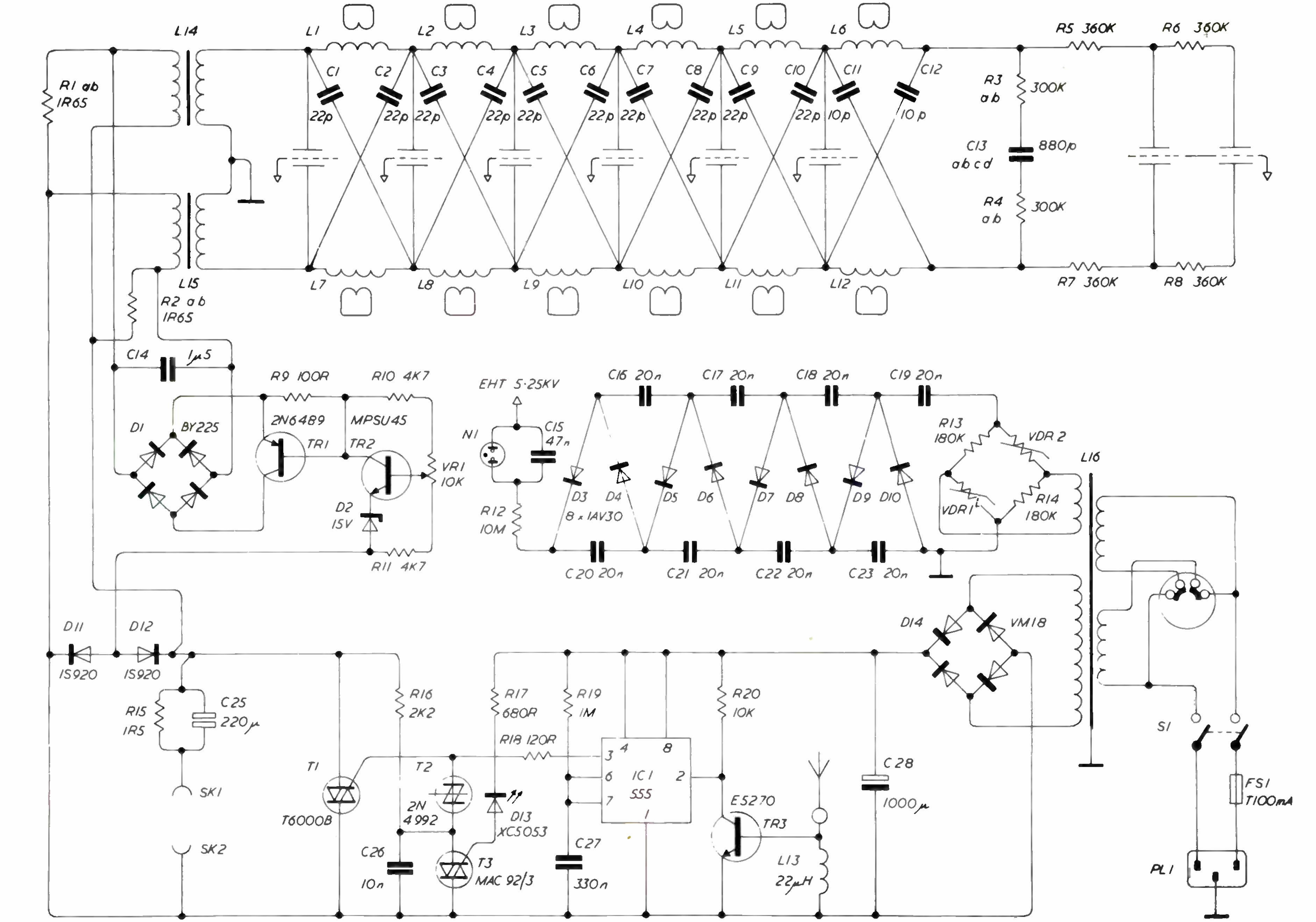

Fig. 5. Complete circuit of the ESL-63.

and rear lobes are also 180 degrees out of phase with one another, rather like a ribbon microphone. In the new speaker, the front and rear patterns are identical so an audience both in front as well as behind hear the same sound—except the channels will appear reversed for those behind.

PATTERNS

With the speakers in a stereo set-up, they will normally be placed at an angle to the horizontal axes of the listening room and excitation of both horizontal axial modes is 3dB less than one would get with omnidirectional sound sources—whilst vertical modes are discriminated against. The ratio of direct to reflected sound is much greater with a dipole source, giving greatly improved location characteristics to the stereo image.

Further improvements are extensive. The old design presented to the amplifier a somewhat awkward load and wasn't far from looking like a pure 2μF capacitor. Understandably, some amplifiers—especially those whose feedback designs were not unconditionally stable—just didn't like it. In fact, during the time I was doing amplifier reviews, one of the mandatory tests was how it behaved on an equivalent simulated load as presented by a Quad ESL. The new one, whilst still exhibiting some variations in load around a nominal 8 ohms (*Fig. 4*) is really now no worse than many conventional systems and more importantly, is substantially resistive; so should present no problems to a modern amplifier design.

PROTECTION

Incorporated now is a complex protection mechanism, for the designer has apparently accepted as a fact of life that users of the new speaker are not going to do what might seem the sensible thing and complement it with a Quad amplifier. The protection circuitry (*Fig. 5*) operates in progressive stages via two independent circuits. One limits the maximum voltage that may be fed into the speaker and another detects an imminent failure mode, immediately short circuiting the input signal, the so-called "crowbar" technique. It follows, naturally, that the amplifier itself must have reliable overload protection circuitry and be able to tolerate a short circuit across the speaker outputs.

The first mechanism is the detection of peak input voltages above a recommended maximum, in this instance, set at 40V. This brings in a "soft" limiter whose operation is obvious to the listener by the presence of audible nonlinear distortion and is the first warning of impending trouble, of too high input signal to the speaker. Assuming the situation is uncorrected, then persistent peaks of excess voltage across the fixed electrodes eventually provokes ionization of the air in the gaps. The high frequency noise that accompanies the onset of ionization is sensed by an antenna wire within the speaker and running around the high voltage circuitry. TR_3 detects this and in turn, fires the 555 monostable for a fraction of a second. Triac 71 fires to slap the "crowbar" directly across the input and if the overload persists, stays there as a steady short circuit. If an attempt is made to operate the speaker without the internal power supply on, there is still the risk of excess signal volts across the internal electrodes. In these circumstances, the crowbar function is triggered by breakover diode T_2 and triac T_3.

SPHERICAL WAVES

Finally, the most remarkable innovation of all: that trick of persuading a flat diaphragm to behave as if it is a perfect pulsating sphere, as theory demands, and so producing the optimum radiating pattern for domestic listening conditions. In those classic series of articles to which I referred at the beginning, Peter Walker acknowledged the problem of the reactive current that would flow in the plate-to-plate capacitance at high working frequencies and suggested this might be solved by using several speaker elements as the shunt C component in a LC delay line. A patent published in 1971 subsequently described how this matching arrangement might also be used to deliberately tailor the radiation pattern of a large diaphragm ES speaker.

Then, a paper to the AES in 1979 made it apparent what was coming. My diagram shows the ingenious design technique that saw germination as an idea 18 years ago. The fixed electrodes are now subdivided concentrically into six rings, (*Fig. 6*), separating a small center area and the outer remaining section of the diaphragm. The signal is fed to the center first; then via an inductor to the first ring, and then another five inductors, each tapped off at each succeeding five rings. The capacitance of each speaker element plus the inductors simulates a tapped delay line, with each section delaying the sound to each concentric ring in turn, moving outwards, by 20μSeconds. The effect will, I'm sure, be fairly obvious.

The sound leaves the center area first, then by the first inner ring 20μSecs later, the next ring 20μSecs later still and so on.... So the sound plane wave generated at the surface assumes a domed shape (*Fig. 7*) simulating a pulsating sphere that if it actually existed, would occupy a position some 30cms *behind* the speaker. Another clever trick is to make the coils of the delay line deliberately lossy by means of shorted turns during manufacture. This helps to preserve the waveshapes as will be seen from the plotted radiation pattern right up to the highest part of the spectrum. One assumes as well, that this intentional tapering of the signal's amplitude also inhibits the production of secondary lobes at high frequencies.

FIG. 6

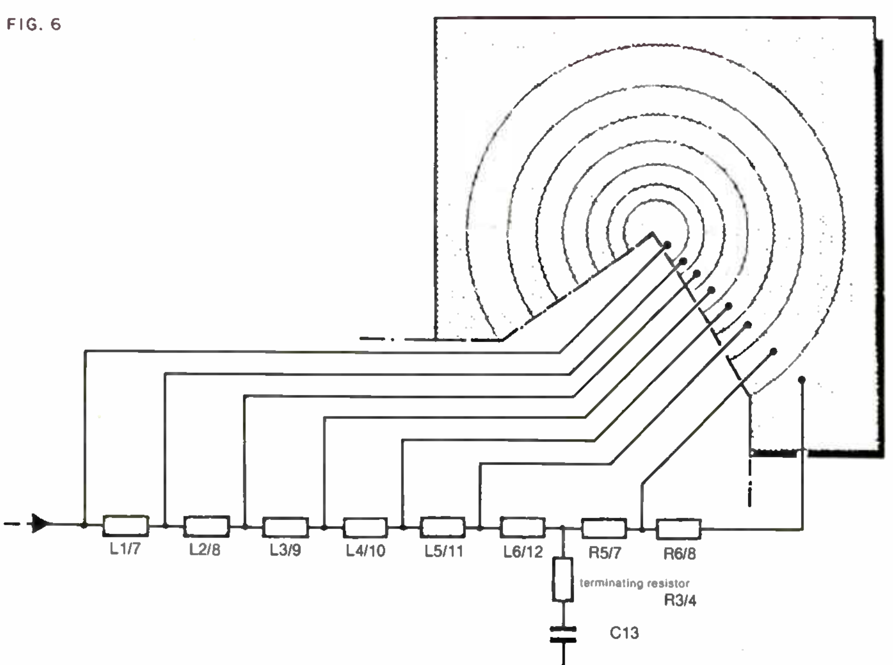

Fig. 6. How the ESL-63 radiates a curved waveform.

FIG. 7

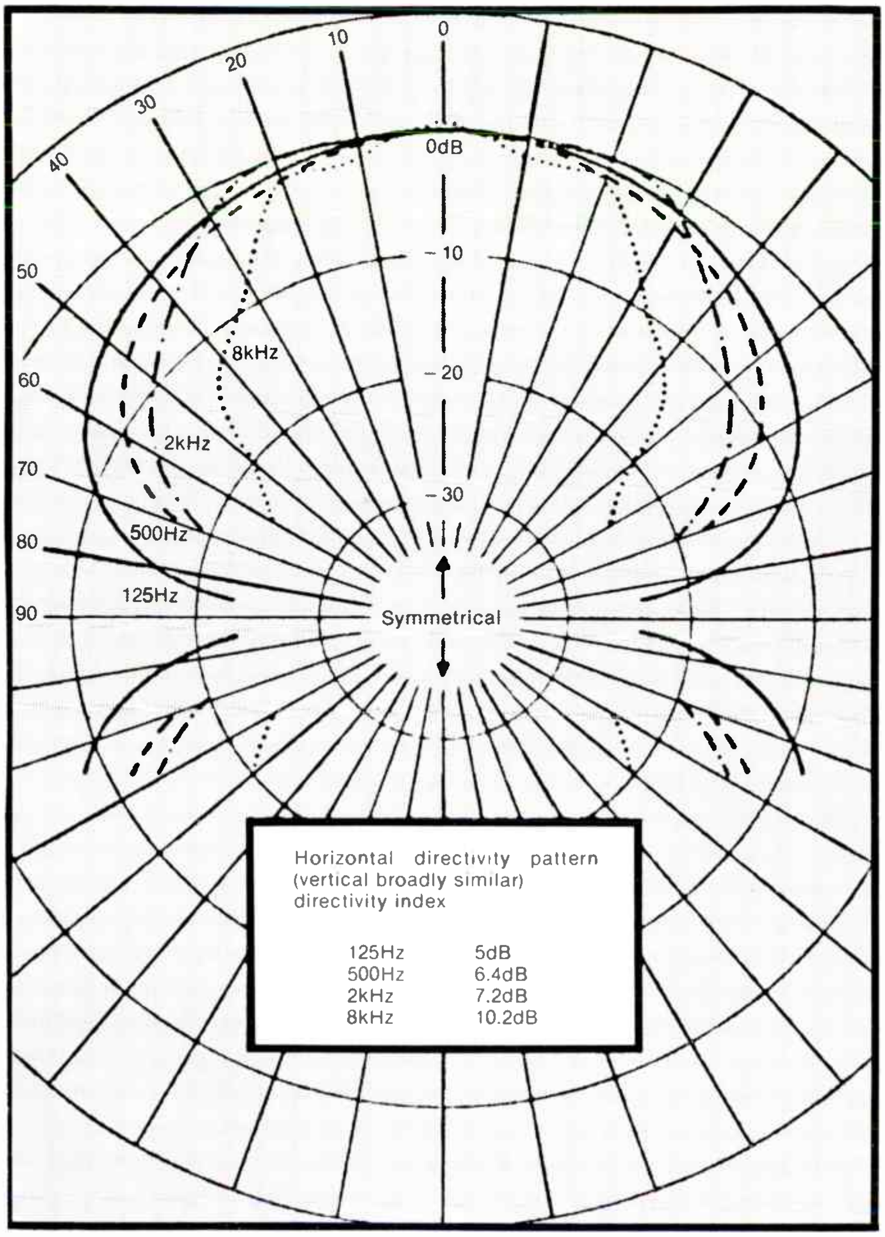

Fig. 7. Measured radiation patterns of the ESL-63.

ESL-63 Loudspeaker Specification
Manufacturer Source:

Dimensions	Height 92.5cm (36.4″) Width 66cm (26″) Depth 27cm (10.6″) including 15cm (6″) base	
Weight	Nett 18.7 kgs. (41.2 lbs.) Gross 23 kgs.	
A.C. Supply	240/200V 120/100V 50-60Hz 5VA	
Impedance	8Ω nominal	
Sensitivity	1.5μbars per volt referred to 1M. (i.e. 86dB/2.83Vrms).	
Max. Output	Continuous input voltage 10Vrms Programme peak for undistorted output 40V Permitted peak input 55V	
Max. Output	2N/m² at 2m on Axis	
Dir. Index	125Hz	5dB
	500Hz	6.4dB
	2kHz	7.2dB
	8kHz	10.6dB
Axis Band Limits (low level)	−6dB at 35Hz 3rd order −6dB > 20kHz	

FIG. 8

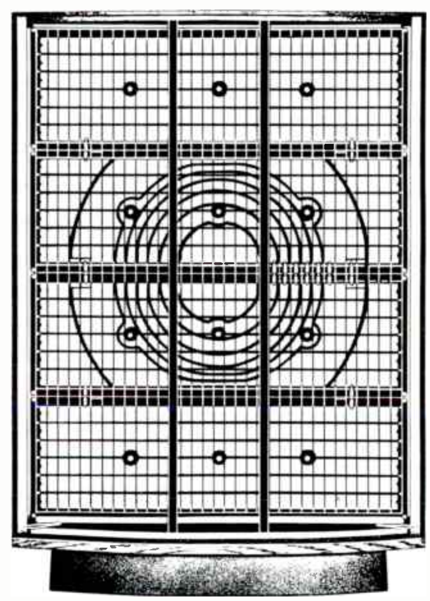

Fig. 8. The ESL-63's fixed plates are concentric ovals. The dark lines are the boundaries of the rings.

So this outstanding example of *thinking* about design problems as opposed to the traditional "cut and try it" techniques with orthodox speaker systems has led to a solution of a seemingly impossible problem. It has involved the application of techniques from many sciences—chemistry, physics as well as electronics. Moreover, the problems have, as before, been substantially solved before the prototype stage. Not, as is so often the case, on the production line.

TESTING

Final testing of the production speaker is a perfect illustration of this and is confined to ensuring that its principal parameters match up with a reference unit. My photos show the two main tests at the end of the production line, the first being a straightforward one of comparing the Z curves (*Fig. 16*). The second is one I suspect no other speaker manufacturer would dare attempt (*Fig. 17*). The reference speaker is fed with a pulsed square wave and close by, the test speaker is fed with the same signal but inverted in phase. A high grade probe microphone is placed centrally between the two and its output displayed on a 'scope. It follows that if the signal level is identical from both speakers, with uniformity of frequency response—and the probe mike is equidistant from both speakers—then the signals at the mike will be identical, but cancel one another by virtue of being out of phase. That is what happens and all one can see on the 'scope face is a straight line, with some noise.

I suggested that perhaps the final test ought to include listening to some music. "Whatever for? Oh, dear me, no. No point. We leave our customers to do that...." And as a customer, I have now listened extensively and just as with its forerunner of 25 years ago, there is no doubt in my mind it is destined to set the standard again by which all true high fidelity speakers are going to be judged for many years to

Text continued on page 18

How Quad's people make the ESL-63...

Fig. 9. Lilian Smith assembles a mandrel preparing to wind one of the 14 delay inductors in the Quad-63 speaker.

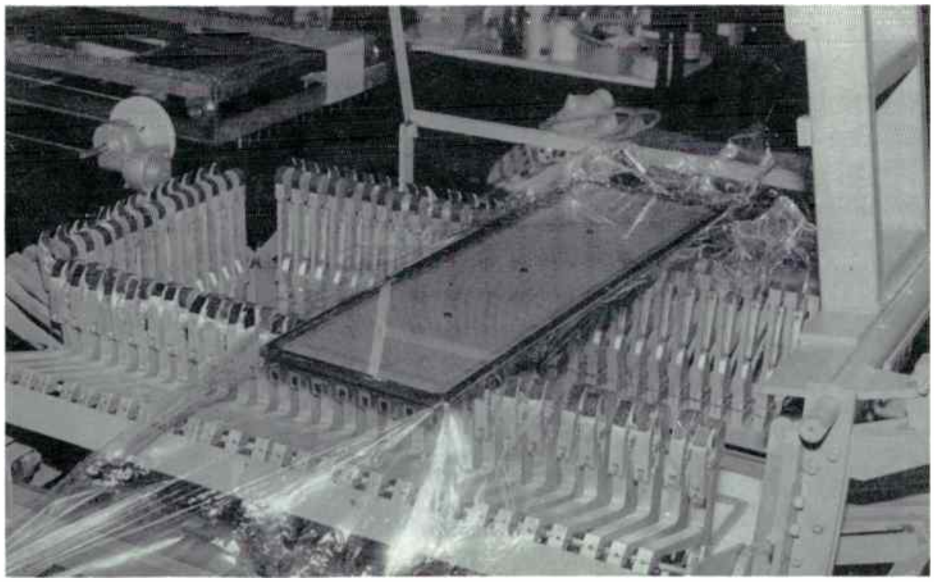

Fig. 12. One diaphragm sits atop the custom made jig which stretches the film evenly over the frame before being bonded to it.

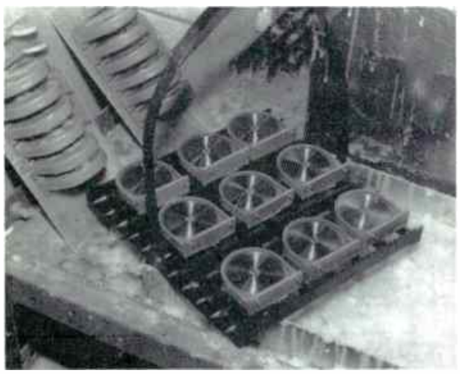

Fig. 10. A set of inductors just ready for potting.

Fig. 13. Nancy Kelly assembles a radiator panel.

Fig. 11. Lesley Richmond spreads a graphite slurry over the film before bonding it to its frame. The liquid makes the diaphragm slightly magnetic.

Fig. 14. Joan Lawson uses a heat gun to remove wrinkles from the dust cover of the speaker's diaphragm.

Fig. 15. Judy Taylor does a final check on the electronics.

Fig. 16. Testing the ESL-63 for impedance.

Fig. 17. Richard Ramsey does the "cloning" test where the production line model is tested against a measured standard speaker using a square wave, inverted in one, and both equidistant from a probe mike. A good speaker "cancels" the standard one.

Fig. 18. Peter Walker poses outside the Huntingdon plant with the new speaker.

THE QUAD 63
Continued from page 15

come. I use the term "high fidelity" advisedly and with its exact dictionary meaning very much in mind: faithfulness. In complete contrast with what seems to be a popular trend in hifi speaker design, the new Quad ESL has no personality of its own to impose upon the reproduced sound and one can only recognize its unique characteristics by the sheer lack of them. One of the most difficult sounds to reproduce with perfect fidelity is the human voice and is one of the first tests I always perform. The new speaker does it with unnerving accuracy and with one's back to it, one can easily be fooled into confusing reproduced sound with the real thing.

REVELATIONS

Peter Walker once commented about his speaker, that if you didn't like what was coming out of it, worry about what was going in. And he is right. The ESL-63 is quite ruthless in exposing less than ideal recording balance and particularly in revealing the deficiencies inherent in multimike, multi-tracking techniques now all too prevalent in the recording industry. A multimike balance sounds exactly like a gaudy picture postcard, just as thin and artificial with individual instruments sitting in their own individual little compartments in the sonic stage. One the other hand, a simple coincident set-up, or one using minimum miking, usually yields a beautiful, natural sound with depth and spaciousness. A good live broadcast oftens gives the impression of actually being there in an ideal seat in the concert hall.

The ESL-63 is a totally homogeneous sound source, phase free and very aperiodic; and unlike that which is quite unavoidable with multiunit speaker systems, the frequency response both on and off axis is completely free from major irregularities.

It is no accident that one of the early users of the new speaker is a major European record company. Judging by their issues since the new speaker came into use as a quality monitor, its influence is going to be highly beneficial. This enthusiast is left in no doubt, the development of the Quad ESL-63 is the most exciting audio event for over two decades.

At the time of writing, I am also prepared to predict that the genius behind it will be recognized by a number of prestigious awards during 1982. All richly deserved too. □

REFERENCE

1. Walker, P.J., " Wide Range Electrostatic Loudspeakers," *Wireless World*, May, June, August, 1955.

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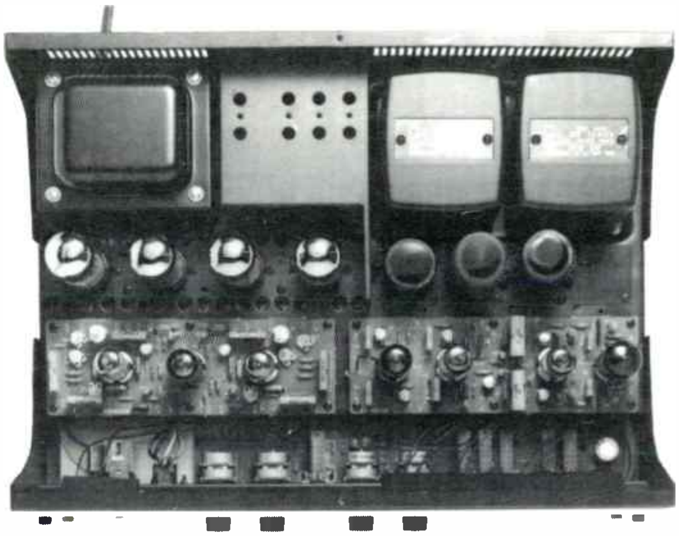

SPECIFICATIONS

Tube Compliment:	6CA7(4), 12AU7(2), 6AQ8(1), 12AX7(4)
Power Output (UL Mode)	30W x 2(4Ω, 8Ω), 25W x 2 (16Ω). Both channels driven
(Triode Mode)	15W x 2(4Ω, 8Ω), 11W x 2(16Ω). Both channels driven
THD:	Below 0.4% (8Ω, 1kHz, 30W)
Intermodulation Distortion	Below 1% (8Ω, 30W, 60Hz:7kHz=4:1)
Frequency Response	30~30,000Hz (within −1dB, 8Ω, 1W)
Input Sensitivity	Phono: 2.2mV, TUNER AUX, Monitor −1, 2;190mV
SN Ratio (1HF-A weighted)	Phono: 72dB, TUNER AUX, Monitor −1, 2;92db

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Thiele, Small & Vented Loudspeaker Design
Part V: Sixth Order Alignments

by Robert M. Bullock III

A loudspeaker system's response curve is often modified by the use of electronics, such as rumble filters or graphic equalizers. If the modification component is a high pass filter especially tailored to the loudspeaker characteristics, then the loudspeaker/filter combination is called a higher order speaker system. The order of the system is that of the speaker (closed box = 2, vented box = 4) plus that of the filter. In his famous paper on vented boxes, Thiele[1] introduced the notion of a higher order system and tabulated several fifth and sixth order alignments for vented boxes. In reference 2 he gave a convincing argument for their superiority over the usual fourth order alignments.

This led me to generate an extensive set of sixth order alignments using Small's[3] vented box model so that box losses (Q_L) could also be incorporated into the design. With these tables it is quite practical for you to design and construct your own sixth order vented system. Why should you want to use a more complicated system? My experience has been just as Thiele predicted: the result gives an obvious improvement in sound quality. Surely you would like to verify this yourself.

THIELE'S ARGUMENT

Why does a higher order vented system perform better? According to Thiele[2], it is because the filter will reject subsonic frequencies. Most of the information in this band is not part of the program material but noise from a variety of sources. Vented loudspeakers are very sensitive to this noise, which causes large random cone excursions apparently unrelated to the program. Even though the noise is inaudible, it causes distortion at audible frequencies and reduces the potential power handling ability of the system.

Those of you who use vented boxes are probably well aware of this deficiency and have found that the use of a rumble filter will eliminate the cone flapping and clarify low frequency reproduction. A higher order vented system includes its own rumble filter, designed specifically to complement the box response.

Thiele indicates that the low frequency noise problem can be adequately solved in vented systems by using either a fifth or sixth order alignment, so that there is no need to consider higher orders. It would appear then that the fifth order system is the natural choice, since it uses the simplest filter. Why did I choose to concentrate on sixth order alignments? They do offer additional noise reduction over the fifth, but that was not the deciding factor. Fifth order responses are much like fourth in that each possible response corresponds to only one possible alignment. But, because of the mathematical nature of sixth order responses, each can be realized by any one of three different alignments. This increased richness in alignment possibilities sold me.

POSSIBLE RESPONSES

In deciding what responses are desirable, it is natural to consider the sixth order versions of the fourth order responses I have described in earlier articles, i.e., quasi-Butterworth, Chebyshev, Boom-Box, etc. Qualitatively, the sixth order responses resemble their fourth order counterparts quite closely. As *Fig. 1* illustrates, the main difference is that sixth order responses will typically remain more nearly flat in the pass band but will eventually roll off faster.

Since each sixth order response yields three alignments, I felt there was no need for alternatives and considered only the sixth order quasi-Butterworth (QB_5)-sixth order Chebyshev (C_6) response series. So you may think of these alignment tables as the sixth order analogues of the tables in my first article.

THE ALIGNMENTS

To distinguish between the three alignments obtained from a given sixth order response I will follow Thiele[1] and refer to them as class I, II and III. *Tables 1* through *6* list class I alignments, *Tables 7* through *12*, class II and 13 through 18, class III. As in the past, tables are given for the box loss values (Q_L) of 3, 5, 7, 10, 15, 20.

From the tables themselves, it is not clear which alignments come from the same response. To give you some idea of this relationship, consider the Q_L = 7 tables and let's take the sixth order Butterworth response. Remember, this response marks the transition from QB_5 to C_6. The class I (*Table 3*) alignment closest to this response is Q_T = .31, while the class II (*Table 9*) is Q_T = .43 and the class II (*Table 15*) is Q_T = .55. Thus, it is possible to get the same Butterworth response from drivers with any one of these Q_T values, as long as they all have the same resonant frequency f_{SB}. In other words, the same response can be realized from three distinct vented boxes. Of course the filter requirements will also be different in each case.

THE BOX

The first four columns in the tables are used exactly as those in the earlier fourth order tables. With this information you should now have no trouble designing, building and adjusting the loudspeaker. All the necessary information is contained in the first three parts of this series. I should point out that the f_3 value determined from the table will be the cut-off frequency of the system including the filter and not that of the box operating alone.

THE FILTER

The columns headed f_a/f_S and A give the necessary information for realizing the filter. For those of you familiar with filter theory, build an active, second order high pass filter with $Q = 1/A$ and characteristic frequency $f_a = (f_a/f_S)\cdot f_{SB}$ where f_{SB} is the driver resonant frequency in the enclosure.

For those of you like myself without the electronic expertise to scratch build your own filter, I have included a filter design supplement. It contains step by step instructions for building the filter using an Old Colony kit [KF-6]. This method is very easy to use and gives dependable results.

The completed filter is placed between the preamplifier and amplifier in a monoamplified system. If you multi-amplify place it after the active crossover if $A < \sqrt{2}$ and before it if $A > \sqrt{2}$. The reason for this is that if $A > \sqrt{2}$ then the filter attenuates all frequencies to some extent and so will decrease the demands on the crossover. If $A < \sqrt{2}$ then the filter provides lift over a certain frequency band. Placing it before the crossover in this case would increase crossover demands unnecessarily.

THE RESPONSE TYPE

The information in the ripple column serves two purposes. First, if the column is empty the response will be QB_5, while an entry denotes a C_6. Second, all C_6 responses exhibit some amount of ripple in the pass band. An asterisk in this column means the ripple is less than .01dB, while a number is the actual ripple value. The ripple values reach their highest levels in the class I alignments. Even here, I doubt the response variation would be audible.

The driver constraints for sixth order alignments are much the same as in the fourth order case. Any driver with Q_T($=Q_{TS}$ adjusted for series resistance and amplifier damping) between .2 and .75 can be used, with two alignments possible for the Q_T range between .3 and .5.

Those of you hoping that a sixth order alignment will necessarily allow significant decrease in box volume will be disappointed, since it depends on the alignment. All class III and high Q_T class I alignments use smaller boxes, but the rest do not.

COMPARISONS

A class I alignment offers a lower cut-off frequency than a fourth order system of the same Q_T because of bass

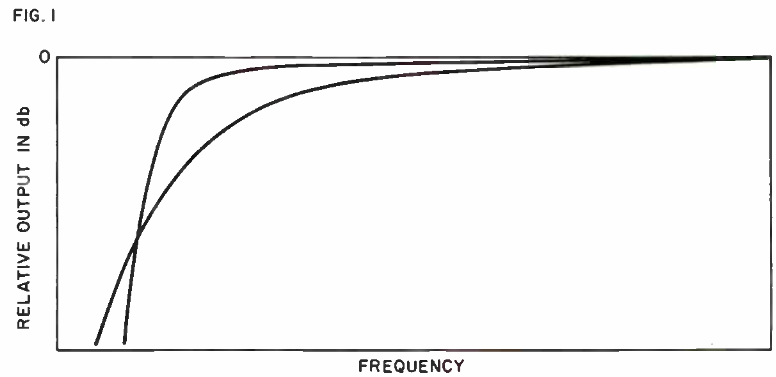

Fig. 1. Comparison of hypothetical sixth (top) and fourth (bottom) order responses.

TABLE 1
QB_5 AND C_6 ALIGNMENTS—CLASS I
$Q_L = 3$

Q_T	h	α	f_3/f_S	f_a/f_S	A	ripple
.20	1.4228	6.3491	2.0001	1.9995	.6162	
.21	1.3643	5.6715	1.8951	1.8944	.6157	
.22	1.3118	5.0843	1.7988	1.7979	.6150	
.23	1.2647	4.5722	1.7098	1.7087	.6141	
.24	1.2223	4.1230	1.6271	1.6258	.6130	
.25	1.1842	3.7268	1.5498	1.5482	.6114	
.26	1.1499	3.3757	1.4770	1.4751	.6094	
.27	1.1193	3.0633	1.4080	1.4057	.6067	
.28	1.0919	2.7841	1.3420	1.3392	.6030	
.29	1.0677	2.5338	1.2781	1.2748	.5977	
.30	1.0466	2.3087	1.2155	1.2116	.5902	
.31	1.0285	2.1059	1.1527	1.1484	.5787	
.32	1.0135	1.9228	1.0876	1.0836	.5101	
.33	1.0017	1.7575	1.0162	1.0147	.5279	
.34	.9919	1.6073	.9389	.9438	.4785	*
.35	.9798	1.4679	.8754	.8843	.4374	*
.36	.9657	1.3397	.8218	.8334	.4026	*
.37	.9500	1.2227	.7758	.7891	.3727	*
.38	.9332	1.1167	.7357	.7501	.3468	*
.39	.9155	1.0213	.7005	.7156	.3242	*
.40	.8973	.9360	.6692	.6848	.3042	.01
.41	.8790	.8599	.6415	.6573	.2866	.01
.42	.8607	.7923	.6166	.6326	.2709	.02
.43	.8427	.7323	.5943	.6103	.2569	.03
.44	.8252	.6790	.5741	.5902	.2444	.04
.45	.8082	.6316	.5560	.5719	.2331	.06
.46	.7918	.5895	.5395	.5554	.2229	.08
.47	.7760	.5519	.5245	.5403	.2137	.11
.48	.7610	.5182	.5108	.5265	.2054	.13
.49	.7466	.4878	.4982	.5139	.1977	.16
.50	.7329	.4605	.4867	.5023	.1907	.20

TABLE 2
QB_5 AND C_6 ALIGNMENTS—CLASS I
$Q_L = 5$

Q_T	h	α	f_3/f_S	f_a/f_S	A	ripple
.20	1.3625	6.6952	1.9201	1.9195	.6159	
.21	1.3081	5.9843	1.8179	1.8170	.6153	
.22	1.2595	5.3684	1.7237	1.7227	.6144	
.23	1.2161	4.8314	1.6365	1.6352	.6133	
.24	1.1772	4.3605	1.5551	1.5536	.6118	
.25	1.1425	3.9453	1.4786	1.4767	.6097	
.26	1.1117	3.5776	1.4061	1.4038	.6069	
.27	1.0843	3.2506	1.3367	1.3339	.6029	
.28	1.0604	2.9587	1.2694	1.2660	.5972	
.29	1.0397	2.6974	1.2029	1.1990	.5886	
.30	1.0223	2.4631	1.1356	1.1313	.5749	
.31	1.0083	2.2527	1.0640	1.0605	.5512	
.32	.9980	2.0640	.9814	.9830	.5057	*
.33	.9872	1.8906	.9051	.9123	.4563	*
.34	.9741	1.7304	.8426	.8533	.4154	*
.35	.9591	1.5838	.7900	.8030	.3808	*
.36	.9427	1.4507	.7451	.7594	.3512	*
.37	.9253	1.3310	.7061	.7213	.3257	*
.38	.9074	1.2239	.6720	.6877	.3034	.01
.39	.8892	1.1288	.6421	.6581	.2839	.01
.40	.8712	1.0445	.6155	.6317	.2667	.02
.41	.8536	.9700	.5920	.6082	.2515	.04
.42	.8364	.9043	.5710	.5872	.2380	.05
.43	.8200	.8463	.5522	.5684	.2259	.08
.44	.8043	.7950	.5354	.5515	.2151	.10
.45	.7893	.7496	.5202	.5362	.2054	.13
.46	.7752	.7093	.5065	.5224	.1965	.17
.47	.7618	.6733	.4940	.5099	.1885	.21
.48	.7491	.6412	.4827	.4985	.1812	.25
.49	.7372	.6123	.4724	.4881	.1746	.30
.50	.7260	.5862	.4630	.4786	.1685	.34

TABLE 3
QB_5 AND C_6 ALIGNMENTS—CLASS I
$Q_L = 7$

Q_T	h	α	f_3/f_S	f_a/f_S	A	ripple
.20	1.3391	6.8392	1.8878	1.8871	.6158	
.21	1.2864	6.1148	1.7865	1.7856	.6151	
.22	1.2394	5.4872	1.6931	1.6920	.6141	
.23	1.1974	4.9401	1.6065	1.6051	.6129	
.24	1.1600	4.4604	1.5254	1.5238	.6111	
.25	1.1267	4.0376	1.4491	1.4471	.6088	
.26	1.0972	3.6632	1.3764	1.3739	.6055	
.27	1.0713	3.3304	1.3065	1.3034	.6007	
.28	1.0488	3.0336	1.2380	1.2344	.5937	
.29	1.0297	2.7682	1.1696	1.1655	.5827	
.30	1.0140	2.5305	1.0987	1.0945	.5642	
.31	1.0021	2.3178	1.0196	1.0181	.5294	
.32	.9922	2.1256	.9341	.9394	.4751	*
.33	.9799	1.9474	.8645	.8741	.4295	*
.34	.9656	1.7838	.8068	.8192	.3915	*
.35	.9496	1.6350	.7581	.7720	.3592	*
.36	.9325	1.5008	.7162	.7312	.3315	*
.37	.9148	1.3807	.6798	.6955	.3076	.01
.38	.8967	1.2740	.6480	.6640	.2867	.01
.39	.8787	1.1795	.6201	.6363	.2684	.02
.40	.8610	1.0962	.5954	.6117	.2523	.04
.41	.8439	1.0228	.5735	.5898	.2380	.05
.42	.8275	.9582	.5541	.5703	.2253	.08
.43	.8119	.9013	.5367	.5529	.2139	.11
.44	.7971	.8511	.5211	.5372	.2038	.14
.45	.7832	.8066	.5071	.5231	.1946	.18
.46	.7701	.7671	.4945	.5104	.1863	.22
.47	.7577	.7320	.4830	.4989	.1788	.27
.48	.7461	.7005	.4726	.4884	.1719	.32
.49	.7352	.6723	.4632	.4789	.1656	.37
.50	.7250	.6468	.4545	.4702	.1598	.43

TABLE 4
QB_5 AND C_6 ALIGNMENTS—CLASS I
$Q_L = 10$

Q_T	h	α	f_3/f_S	f_a/f_S	A	ripple
.20	1.3225	6.9456	1.8642	1.8634	.6157	
.21	1.2709	6.2113	1.7635	1.7626	.6149	
.22	1.2250	5.5753	1.6707	1.6695	.6139	
.23	1.1842	5.0208	1.5844	1.5830	.6125	
.24	1.1478	4.5347	1.5036	1.5018	.6106	
.25	1.1156	4.1063	1.4272	1.4250	.6080	
.26	1.0871	3.7272	1.3543	1.3516	.6043	
.27	1.0623	3.3903	1.2837	1.2805	.5988	
.28	1.0409	3.0900	1.2142	1.2104	.5905	
.29	1.0230	2.8217	1.1439	1.1396	.5771	
.30	1.0087	2.5819	1.0691	1.0655	.5534	
.31	.9982	2.3678	.9821	.9837	.5061	*
.32	.9874	2.1715	.9016	.9091	.4537	*
.33	.9741	1.9902	.8363	.8473	.4107	*
.34	.9590	1.8244	.7818	.7951	.3746	*
.35	.9424	1.6743	.7356	.7502	.3439	*
.36	.9249	1.5396	.6959	.7113	.3176	*
.37	.9069	1.4196	.6614	.6773	.2947	.01
.38	.8889	1.3134	.6312	.6474	.2748	.02
.39	.8711	1.2197	.6047	.6210	.2574	.03
.40	.8539	1.1373	.5814	.5977	.2420	.05
.41	.8373	1.0648	.5607	.5770	.2284	.07
.42	.8215	1.0012	.5423	.5586	.2163	.10
.43	.8066	.9451	.5259	.5421	.2054	.13
.44	.7925	.8957	.5113	.5274	.1957	.17
.45	.7793	.8520	.4981	.5141	.1870	.22
.46	.7670	.8132	.4862	.5022	.1790	.26
.47	.7554	.7786	.4755	.4914	.1718	.32
.48	.7446	.7477	.4658	.4816	.1652	.37
.49	.7345	.7199	.4569	.4727	.1592	.43
.50	.7251	.6949	.4468	.4645	.1536	.50

lift supplied by the filter. The peak amount of lift is given by

$$\text{peak lift (dB)} = 10 \log(4/(4A^2 - A^4))$$

and it occurs at a frequency f_p given by

$$f_p = \sqrt{2/(2-A)^2}\,(f_a/f_S) f_{SB}$$

The formulas are valid if $A < \sqrt{2}$. Otherwise the filter attenuates all frequencies. The peak lift of class I filters ranges from 4.6 to 16.7dB and occurs at a frequency near f_3. This means that the low frequency demands on the amplifier will be greater than they would be in a fourth order system. Consequently, it may not be possible to achieve acceptable sound levels at higher frequencies. The filter lift may also increase cone excursion requirements in the pass band, even though they are greatly reduced at subsonic frequencies. For this reason class I excursion requirements could exceed those found in the pass band of a fourth order system for the same driver.

These problems can occur only when the program spectrum actually contains frequencies around f_p. So, if the peak lift is at a low enough frequency they should appear only when playing unusually wide spectrum material. As a practical matter, I have never been able to identify any amplifier clipping in my system, which uses a class I subwoofer. However, I have heard driver bottoming on occasion. Even when it doesn't bottom it can rattle quite loudly. My cure is to decrease the volume and be satisfied with lower output levels. Another cure is to use a driver with larger excursion and/or cone area.

For drivers with Q_T between .3 and .5, the alternative class II alignment can be used to eliminate the above problems. In many of these alignments $A > \sqrt{2}$ so the filter attenuates, but even when it lifts the amount is never more than 3.5dB.

You may object to the fact that class II cutoff frequencies are higher, but so also are its potential sound pressure levels. The maximum SPL capability of my present class I subwoofer system could be increased by about 8dB if I converted it to class II. This figure is based on large signal behavior as analyzed by Thiele[1] and Small[3].

Finally, a comment about class III alignments. When compared to fourth order alignments of the same Q_L, Q_T, they seem to offer less since the system cutoff is higher. But, because of this and the fact that A is always greater than $\sqrt{2}$, class III systems should produce much higher sound levels. Also, the box volume averages about 20% less.

A CONVERTIBLE SYSTEM

As I mentioned in my *SB* (2/81) article some fourth order alignments can be changed to sixth order if the box is oversized. I offer a refinement of this idea in which three different alignments can be realized from the same driver and box size.

For this option, choose a driver whose Q_T is between .3 and .4. Determine the box sizes needed for the standard fourth order, class I sixth order and a class II sixth order alignments. Then build a box whose size is midway between the largest and smallest of these. Now, the actual α will be in error in all three alignments, but never by more than 7%, even including the space taken up by the vents. This amount of error in α will cause at most a negligible .5dB response variation. In other words, for all practical purposes, the box volume will be correct for all three alignments. Then, with the necessary vent and/or filter, the system will be standard fourth order, sixth order class I or sixth order class II.

I am in the process of completing a subwoofer system designed in this way. I expect to use the class II mode to produce high sound levels and the class I to reach very low frequencies. For example, on organ music, I would operate class I but would convert to

TABLE 5
QB_5 AND C_6 ALIGNMENTS—CLASS I
$Q_L = 15$

Q_T	h	α	f_3/f_S	f_a/f_S	A	ripple
.20	1.3100	7.0275	1.8461	1.8454	.6156	
.21	1.2594	6.2857	1.7460	1.7450	.6148	
.22	1.2143	5.6432	1.6535	1.6523	.6137	
.23	1.1743	5.0831	1.5674	1.5660	.6122	
.24	1.1387	4.5922	1.4867	1.4849	.6102	
.25	1.1073	4.1597	1.4103	1.4080	.6073	
.26	1.0797	3.7769	1.3371	1.3343	.6032	
.27	1.0556	3.4369	1.2660	1.2626	.5971	
.28	1.0351	3.1340	1.1955	1.1914	.5876	
.29	1.0182	2.8637	1.1232	1.1189	.5718	
.30	1.0050	2.6255	1.0445	1.0417	.5425	
.31	.9951	2.4066	.9541	.9579	.4879	*
.32	.9834	2.2072	.8778	.8867	.4379	*
.33	.9695	2.0236	.8155	.8275	.3967	*
.34	.9537	1.8564	.7634	.7772	.3621	*
.35	.9368	1.7056	.7190	.7341	.3325	*
.36	.9190	1.5707	.6809	.6966	.3071	.01
.37	.9010	1.4510	.6477	.6638	.2851	.01
.38	.8831	1.3453	.6188	.6351	.2660	.02
.39	.8655	1.2523	.5934	.6098	.2491	.04
.40	.8486	1.1706	.5710	.5874	.2343	.06
.41	.8325	1.0990	.5513	.5676	.2212	.09
.42	.8172	1.0361	.5337	.5500	.2095	.12
.43	.8029	.9808	.5181	.5343	.1991	.16
.44	.7894	.9320	.5041	.5202	.1897	.20
.45	.7768	.8889	.4915	.5076	.1812	.25
.46	.7651	.8506	.4083	.4962	.1736	.30
.47	.7541	.8164	.4701	.4860	.1666	.36
.48	.7439	.7859	.4608	.4767	.1602	.42
.49	.7344	.7586	.4524	.4682	.1544	.49
.50	.7255	.7339	.4448	.4605	.1490	.56

TABLE 6
QB_5 AND C_6 ALIGNMENTS—CLASS I
$Q_L = 20$

Q_T	h	α	f_3/f_S	f_a/f_S	A	ripple
.20	1.3039	7.0682	1.8372	1.8365	.6155	
.21	1.2537	6.3227	1.7373	1.7364	.6147	
.22	1.2091	5.6770	1.6450	1.6438	.6136	
.23	1.1695	5.1142	1.5590	1.5576	.6120	
.24	1.1343	4.6209	1.4784	1.4765	.6099	
.25	1.1033	4.1863	1.4019	1.3996	.6069	
.26	1.0760	3.8017	1.3285	1.3257	.6026	
.27	1.0524	3.4602	1.2571	1.2536	.5962	
.28	1.0324	3.1561	1.1860	1.1819	.5860	
.29	1.0159	2.8848	1.1126	1.1083	.5688	
.30	1.0033	2.6430	1.0315	1.0292	.5360	
.31	.9935	2.4259	.9406	.9455	.4792	*
.32	.9814	2.2250	.8663	.8758	.4303	*
.33	.9671	2.0404	.8054	.8178	.3899	*
.34	.9511	1.8725	.7544	.7686	.3560	*
.35	.9339	1.7214	.7110	.7262	.3270	*
.36	.9161	1.5866	.6736	.6894	.3021	.01
.37	.8981	1.4670	.6411	.6573	.2805	.01
.38	.8802	1.3616	.6128	.6291	.2616	.03
.39	.8628	1.2690	.5879	.6043	.2451	.04
.40	.8461	1.1878	.5661	.5824	.2306	.07
.41	.8302	1.1166	.5467	.5631	.2177	.10
.42	.8152	1.0541	.5296	.5458	.2062	.13
.43	.8011	.9991	.5143	.5305	.1960	.17
.44	.7880	.9507	.5006	.5168	.1868	.22
.45	.7757	.9078	.4884	.5045	.1785	.27
.46	.7642	.8698	.4774	.4934	.1709	.32
.47	.7536	.8359	.4675	.4834	.1641	.39
.48	.7437	.8056	.4585	.4743	.1578	.45
.49	.7345	.7784	.4503	.4661	.1521	.52
.50	.7259	.7539	.4428	.4586	.1468	.59

TABLE 7
QB_5 AND C_6 ALIGNMENTS—CLASS II
Q = 3

Q_T	h	α	f_3/f_S	f_a/f_S	A	ripple
.30	2.0450	2.1652	2.2706	2.2633	1.6152	
.31	1.9684	1.9734	2.1790	2.1707	1.6146	
.32	1.8960	1.7992	2.0921	2.0825	1.6139	
.33	1.8272	1.6406	2.0093	1.9984	1.6131	
.34	1.7616	1.4957	1.9301	1.9178	1.6121	
.35	1.6989	1.3631	1.8543	1.8401	1.6109	
.36	1.6387	1.2412	1.7812	1.7651	1.6094	
.37	1.5806	1.1290	1.7106	1.6922	1.6075	
.38	1.5244	1.0253	1.6420	1.6210	1.6052	
.39	1.4696	.9293	1.5749	1.5510	1.6021	
.40	1.4159	.8399	1.5090	1.4817	1.5982	
.41	1.3627	.7565	1.4437	1.4124	1.5928	
.42	1.3094	.6780	1.3781	1.3425	1.5854	
.43	1.2551	.6037	1.3113	1.2712	1.5745	
.44	1.1985	.5320	1.2419	1.1977	1.5577	
.45	1.1380	.4611	1.1679	1.1228	1.5301	
.46	1.0736	.3882	1.0896	1.0535	1.4850	
.47	1.0133	.3134	1.0163	1.0072	1.4279	
.48	.9623	.2435	.9549	.9804	1.3753	*
.49	.9112	.1846	.8970	.9517	1.3224	*
.50	.8610	.1355	.8431	.9213	1.2697	*

TABLE 8
QB_5 AND C_6 ALIGNMENTS—CLASS II
$Q_L = 5$

Q_T	h	α	f_3/f_S	f_a/f_S	A	ripple
.30	1.8132	2.6146	2.0653	2.0566	1.6142	
.31	1.7465	2.3840	1.9801	1.9700	1.6134	
.32	1.6832	2.1746	1.8989	1.8873	1.6124	
.33	1.6230	1.9837	1.8213	1.8079	1.6112	
.34	1.5655	1.8092	1.7467	1.7313	1.6096	
.35	1.5102	1.6492	1.6748	1.6570	1.6077	
.36	1.4568	1.5019	1.6049	1.5844	1.6051	
.37	1.4049	1.3658	1.5368	1.5130	1.6018	
.38	1.3540	1.2396	1.4696	1.4422	1.5974	
.39	1.3036	1.1219	1.4028	1.3711	1.5912	
.40	1.2529	1.0112	1.3354	1.2988	1.5822	
.41	1.2007	.9060	1.2659	1.2244	1.5682	
.42	1.1453	.8038	1.1922	1.1473	1.5450	
.43	1.0849	.7010	1.1123	1.0713	1.5040	
.44	1.0249	.5963	1.0320	1.0144	1.4424	
.45	.9728	.4980	.9644	.9859	1.3819	*
.46	.9218	.4139	.9016	.9572	1.3212	*
.47	.8708	.3436	.8427	.9256	1.2598	*
.48	.8215	.2858	.7887	.8927	1.1991	*
.49	.7751	.2384	.7399	.8595	1.1408	*
.50	.7322	.1995	.6965	.8272	1.0857	*

TABLE 9
QB_5 AND C_6 ALIGNMENTS—CLASS II
$Q_L = 7$

Q_T	h	α	f_3/f_S	f_a/f_S	A	ripple
.30	1.7333	2.7672	1.9902	1.9808	1.6138	
.31	1.6699	2.5234	1.9070	1.8961	1.6128	
.32	1.6097	2.3018	1.8276	1.8149	1.6116	
.33	1.5523	2.0998	1.7515	1.7368	1.6101	
.34	1.4974	1.9150	1.6782	1.6612	1.6082	
.35	1.4445	1.7453	1.6071	1.5875	1.6058	
.36	1.3932	1.5890	1.5379	1.5150	1.6026	
.37	1.3430	1.4442	1.4698	1.4432	1.5982	
.38	1.2934	1.3094	1.4022	1.3712	1.5921	
.39	1.2436	1.1830	1.3339	1.2979	1.5831	
.40	1.1923	1.0630	1.2635	1.2224	1.5690	
.41	1.1379	.9464	1.1886	1.1438	1.5452	
.42	1.0783	.8294	1.1070	1.0665	1.5021	
.43	1.0184	.7109	1.0253	1.0108	1.4370	
.44	.9677	.6014	.9566	.9831	1.3738	*
.45	.9165	.5080	.8921	.9537	1.3094	*
.46	.8653	.4301	.8319	.9212	1.2440	*
.47	.8159	.3663	.7768	.8872	1.1795	*
.48	.7696	.3145	.7273	.8531	1.1175	*
.49	.7270	.2725	.6836	.8200	1.0592	*
.50	.6887	.2384	.6452	.7888	1.0053	.01

class II when playing material such as Telarc's 1812 Overture. Some low frequency information in the cannon shots would surely be lost, but I expect to be able to reach more realistic sound levels. I hope to report later on how well my expectations were met.

FILTER DESIGN SUPPLEMENT

The Old Colony 30Hz Rumble Filter Kit (KF-6, $19.75) can be easily adapted for use as a filter in a sixth order system. The circuit on which the kit is based was designed and thoroughly explained by Jung in *Audio Amateur* 4/75. I strongly recommend that you read the article to familiarize yourself with the circuit and its ver-

Text continued on page 24

TABLE 10
QB_5 AND C_6 ALIGNMENTS—CLASS II
$Q_L = 10$

Q_T	h	α	f_3/f_s	f_c/f_s	A	ripple
.30	1.6791	2.8705	1.9377	1.9277	1.6133	
.31	1.6179	2.6177	1.8557	1.8441	1.6123	
.32	1.5598	2.3879	1.7774	1.7639	1.6109	
.33	1.5043	2.1782	1.7022	1.6865	1.6092	
.34	1.4510	1.9863	1.6296	1.6113	1.6070	
.35	1.3996	1.8099	1.5590	1.5377	1.6041	
.36	1.3496	1.6471	1.4899	1.4650	1.6001	
.37	1.3004	1.4960	1.4214	1.3923	1.5947	
.38	1.2513	1.3549	1.3527	1.3187	1.5867	
.39	1.2012	1.2215	1.2824	1.2430	1.5744	
.40	1.1484	1.0932	1.2082	1.1642	1.5537	
.41	1.0908	.9656	1.1273	1.0842	1.5159	
.42	1.0302	.8358	1.0425	1.0197	1.4527	
.43	.9783	.7133	.9698	.9888	1.3860	•
.44	.9272	.6078	.9030	.9598	1.3192	•
.45	.8756	.5194	.8404	.9273	1.2509	•
.46	.8254	.4470	.7829	.8927	1.1829	•
.47	.7781	.3885	.7313	.8578	1.1173	•
.48	.7347	.3415	.6857	.8237	1.0555	•
.49	.6957	.3037	.6459	.7916	.9984	.01
.50	.6609	.2731	.6114	.7618	.9462	.01

TABLE 11
QB_5 AND C_6 ALIGNMENTS—CLASS II
$Q_L = 15$

Q_T	h	α	f_3/f_s	f_c/f_s	A	ripple
.30	1.6398	2.9453	1.8987	1.8883	1.6130	
.31	1.5802	2.6859	1.8177	1.8055	1.6118	
.32	1.5236	2.4500	1.7401	1.7259	1.6103	
.33	1.4694	2.2348	1.6655	1.6489	1.6084	
.34	1.4174	2.0376	1.5933	1.5739	1.6059	
.35	1.3670	1.8562	1.5228	1.5001	1.6025	
.36	1.3178	1.6885	1.4535	1.4268	1.5979	
.37	1.2691	1.5326	1.3844	1.3532	1.5913	
.38	1.2200	1.3862	1.3145	1.2779	1.5813	
.39	1.1691	1.2469	1.2417	1.1998	1.5650	
.40	1.1144	1.1108	1.1634	1.1186	1.5361	
.41	1.0544	.9728	1.0777	1.0428	1.4825	
.42	.9984	.8369	.9977	.9992	1.4121	
.43	.9480	.7167	.9283	.9719	1.3445	•
.44	.8962	.6151	.8626	.9403	1.2742	•
.45	.8450	.5313	.8019	.9058	1.2034	•
.46	.7961	.4634	.7470	.8702	1.1342	•
.47	.7510	.4092	.6985	.8350	1.0685	•
.48	.7103	.3660	.6561	.8016	1.0075	.01
.49	.6741	.3315	.6194	.7705	.9519	.01
.50	.6422	.3037	.5878	.7422	.9015	.02

TABLE 12
QB_5 AND C_6 ALIGNMENTS—CLASS II
$Q_L = 20$

Q_T	h	α	f_3/f_s	f_c/f_s	A	ripple
.30	1.6211	2.9810	1.8798	1.8691	1.6128	
.31	1.5623	2.7185	1.7992	1.7867	1.6118	
.32	1.5063	2.4797	1.7220	1.7074	1.6100	
.33	1.4528	2.2617	1.6476	1.6305	1.6079	
.34	1.4013	2.0620	1.5755	1.5555	1.6053	
.35	1.3513	1.8781	1.5050	1.4816	1.6016	
.36	1.3024	1.7080	1.4356	1.4080	1.5966	
.37	1.2539	1.5496	1.3661	1.3337	1.5893	
.38	1.2047	1.4006	1.2953	1.2574	1.5780	
.39	1.1533	1.2580	1.2210	1.1780	1.5590	
.40	1.0973	1.1173	1.1401	1.0961	1.5245	
.41	1.0368	.9741	1.0532	1.0259	1.4627	
.42	.9839	.8375	.9769	.9918	1.3924	•
.43	.9329	.7191	.9079	.9630	1.3228	•
.44	.8809	.6197	.8429	.9301	1.2509	•
.45	.8301	.5383	.7833	.8948	1.1791	•
.46	.7822	.4728	.7299	.8588	1.1096	•
.47	.7383	.4208	.6829	.8238	1.0441	•
.48	.6990	.3795	.6422	.7908	.9838	.01
.49	.6643	.3467	.6071	.7604	.9290	.02
.50	.6338	.3202	.5769	.7329	.8796	.03

TABLE 13
QB_5 AND C_6 ALIGNMENTS—CLASS III
$Q_L = 3$

Q_T	h	α	f_3/f_s	f_c/f_s	A	ripple
.53	1.0026	.3653	1.0113	.6326	2.2013	
.54	1.0144	.3356	1.0210	.6923	2.1150	
.55	1.0205	.3181	1.0294	.7822	2.0300	
.56	1.0235	.3018	1.0334	.8419	1.9916	
.57	1.0240	.2859	1.0339	.8851	1.9703	
.58	1.0224	.2701	1.0316	.9179	1.9570	
.59	1.0192	.2544	1.0272	.9436	1.9481	
.60	1.0149	.2388	1.0211	.9640	1.9418	
.61	1.0096	.2232	1.0136	.9804	1.9371	
.62	1.0036	.2078	1.0051	.9937	1.9335	
.63	.9971	.1926	.9970	1.0047	1.9373	•
.64	.9907	.1783	.9881	1.0152	1.9345	•
.65	.9844	.1651	.9795	1.0255	1.9316	•
.66	.9783	.1529	.9714	1.0357	1.9288	•
.67	.9724	.1415	.9636	1.0458	1.9259	•
.68	.9666	.1310	.9562	1.0556	1.9231	•
.69	.9609	.1211	.9491	1.0654	1.9202	•
.70	.9554	.1120	.9423	1.0749	1.9173	•
.71	.9501	.1034	.9359	1.0844	1.9143	•
.72	.9448	.0954	.9296	1.0937	1.9114	•
.73	.9397	.0880	.9237	1.1028	1.9085	•
.74	.9347	.0809	.9179	1.1118	1.9055	•
.75	.9298	.0744	.9124	1.1207	1.9026	•

TABLE 14
QB_5 AND C_6 ALIGNMENTS—CLASS III
$Q_L = 5$

Q_T	h	α	f_3/f_s	f_c/f_s	A	ripple
.50	1.0091	.5674	1.0150	.6352	2.1915	
.51	1.0162	.5425	1.0261	.7601	2.0466	
.52	1.0197	.5190	1.0313	.8340	1.9951	
.53	1.0201	.4958	1.0319	.8846	1.9697	
.54	1.0183	.4725	1.0291	.9217	1.9550	
.55	1.0148	.4492	1.0237	.9499	1.9456	
.56	1.0102	.4259	1.0163	.9719	1.9392	
.57	1.0046	.4027	1.0074	.9894	1.9345	
.58	.9984	.3798	.9985	1.0034	1.9377	•
.59	.9921	.3582	.9886	1.0165	1.9344	•
.60	.9861	.3383	.9792	1.0294	1.9310	•
.61	.9803	.3198	.9704	1.0421	1.9277	•
.62	.9747	.3026	.9621	1.0547	1.9242	•
.63	.9693	.2867	.9542	1.0672	1.9208	•
.64	.9641	.2718	.9467	1.0795	1.9173	•
.65	.9590	.2580	.9396	1.0917	1.9138	•
.66	.9542	.2451	.9329	1.1038	1.9103	•
.67	.9495	.2330	.9265	1.1157	1.9068	•
.68	.9449	.2218	.9204	1.1274	1.9032	•
.69	.9405	.2112	.9146	1.1391	1.8996	•
.70	.9362	.2013	.9090	1.1506	1.8960	•
.71	.9321	.1920	.9038	1.1619	1.8923	•
.72	.9281	.1832	.8987	1.1732	1.8887	•
.73	.9242	.1750	.8939	1.1843	1.8850	•
.74	.9204	.1672	.8892	1.1952	1.8814	•
.75	.9168	.1599	.8848	1.2061	1.8777	•

TABLE 15
QB_5 AND C_6 ALIGNMENTS—CLASS III
$Q_L = 7$

Q_T	h	α	f_3/f_s	f_c/f_s	A	ripple
.50	1.0171	.6354	1.0286	.7983	2.0172	
.51	1.0189	.6086	1.0315	.8625	1.9798	
.52	1.0180	.5817	1.0300	.9073	1.9602	
.53	1.0151	.5546	1.0253	.9405	1.9485	
.54	1.0108	.5275	1.0182	.9659	1.9408	
.55	1.0054	.5005	1.0092	.9858	1.9354	
.56	.9994	.4738	1.0000	1.0015	1.9382	•
.57	.9932	.4483	.9896	1.0157	1.9346	•
.58	.9872	.4248	.9798	1.0297	1.9311	•
.59	.9815	.4031	.9706	1.0437	1.9275	•
.60	.9759	.3829	.9620	1.0574	1.9238	•
.61	.9706	.3642	.9538	1.0711	1.9201	•
.62	.9655	.3468	.9461	1.0846	1.9164	•
.63	.9606	.3306	.9388	1.0979	1.1926	•
.64	.9559	.3155	.9319	1.1111	1.9088	•
.65	.9513	.3014	.9254	1.1242	1.9049	•
.66	.9470	.2882	.9192	1.1372	1.9011	•
.67	.9427	.2758	.9133	1.1500	1.8972	•
.68	.9387	.2642	.9077	1.1626	1.8932	•
.69	.9348	.2533	.9024	1.1752	1.8893	•
.70	.9310	.2431	.8973	1.1876	1.8853	•
.71	.9273	.2335	.8925	1.1999	1.8813	•
.72	.9238	.2244	.8879	1.2120	1.8773	•
.73	.9204	.2158	.8835	1.2241	1.8732	•
.74	.9171	.2078	.8793	1.2360	1.8692	•
.75	.9139	.2001	.8753	1.2477	1.8651	•

TABLE 16
QB_5 AND C_6 ALIGNMENTS—CLASS III
$Q_L = 10$

Q_T	h	α	f_3/f_s	f_c/f_s	A	ripple
.50	1.0181	.6886	1.0311	.8670	1.9774	
.51	1.0169	.6567	1.0291	.9122	1.9582	
.52	1.0137	.6266	1.0238	.9454	1.9468	
.53	1.0092	.5964	1.0160	.9707	1.9394	
.54	1.0036	.5664	1.0064	.9904	1.9342	
.55	.9974	.5369	.9966	1.0062	1.9370	•
.56	.9913	.5093	.9861	1.0212	1.9333	•
.57	.9855	.4838	.9762	1.0361	1.9295	•
.58	.9799	.4602	.9669	1.0509	1.9257	•
.59	.9745	.4383	.9583	1.0655	1.9218	•
.60	.9694	.4180	.9501	1.0799	1.9179	•
.61	.9644	.3991	.9424	1.0943	1.9139	•
.62	.9597	.3815	.9351	1.1085	1.9099	•
.63	.9551	.3650	.9283	1.1225	1.9059	•
.64	.9508	.3497	.9218	1.1365	1.9018	•
.65	.9466	.3354	.9157	1.1503	1.8977	•
.66	.9426	.3219	.9099	1.1639	1.8935	•
.67	.9387	.3093	.9044	1.1775	1.8893	•
.68	.9350	.2975	.8991	1.1909	1.8851	•
.69	.9314	.2864	.8942	1.2041	1.8809	•
.70	.9280	.2759	.8894	1.2173	1.8766	•
.71	.9247	.2660	.8849	1.2303	1.8723	•
.72	.9215	.2567	.8806	1.2432	1.8680	•
.73	.9184	.2479	.8765	1.2559	1.8636	•
.74	.9154	.2396	.8726	1.2686	1.8592	•
.75	.9126	.2317	.8689	1.2811	1.8548	•

TABLE 17
QB_5 AND C_6 ALIGNMENTS—CLASS III
$Q_L = 15$

Q_T	h	α	f_3/f_s	f_c/f_s	A	ripple
.50	1.0166	.7253	1.0293	.9059	1.9605	
.51	1.0137	.6927	1.0243	.9417	1.9479	
.52	1.0092	.6601	1.0165	.9687	1.9399	
.53	1.0038	.6275	1.0068	.9895	1.9344	
.54	.9976	.5955	.9968	1.0061	1.9370	•
.55	.9915	.5655	.9860	1.0218	1.9332	•
.56	.9857	.5378	.9759	1.0374	1.9293	•
.57	.9801	.5123	.9664	1.0528	1.9253	•
.58	.9748	.4885	.9576	1.0681	1.9213	•
.59	.9697	.4665	.9492	1.0883	1.9172	•
.60	.9648	.4461	.9414	1.0983	1.9130	•
.61	.9602	.4270	.9341	1.1132	1.9089	•
.62	.9557	.4093	.9272	1.1280	1.9046	•
.63	.9514	.3927	.9206	1.1427	1.9003	•
.64	.9474	.3772	.9145	1.1572	1.8960	•
.65	.9434	.3627	.9086	1.1715	1.8917	•
.66	.9397	.3491	.9031	1.1858	1.8873	•
.67	.9361	.3363	.8979	1.1999	1.8828	•
.68	.9326	.3242	.8929	1.2139	1.8784	•
.69	.9293	.3129	.8882	1.2278	1.8739	•
.70	.9261	.3022	.8837	1.2415	1.8694	•
.71	.9231	.2922	.8795	1.2551	1.8648	•
.72	.9201	.2827	.8754	1.2686	1.8602	•
.73	.9173	.2736	.8715	1.2819	1.8556	•
.74	.9146	.2651	.8678	1.2951	1.8510	•
.75	.9120	.2571	.8643	1.3082	1.8463	•

TABLE 18
QB_5 AND C_6 ALIGNMENTS—CLASS III
$Q_L = 20$

Q_T	h	α	f_3/f_s	f_c/f_s	A	ripple
.50	1.0153	.7742	1.0275	.9222	1.9544	
.51	1.0177	.7102	1.0211	.9543	1.9440	
.52	1.0067	.6763	1.0123	.9788	1.9372	
.53	1.0009	.6426	1.0016	.9977	1.9324	
.54	.9947	.6101	.9914	1.0139	1.9352	•
.55	.9887	.5802	.9808	1.0299	1.9312	•
.56	.9831	.5525	.9710	1.0457	1.9272	•
.57	.9776	.5268	.9617	1.0615	1.9231	•
.58	.9724	.5030	.9531	1.0770	1.9190	•
.59	.9675	.4810	.9449	1.0925	1.9148	•
.60	.9628	.4605	.9373	1.1078	1.9105	•
.61	.9582	.4413	.9301	1.1230	1.9062	•
.62	.9539	.4235	.9234	1.1381	1.9019	•
.63	.9498	.4068	.9170	1.1530	1.8975	•
.64	.9458	.3912	.9110	1.1679	1.8930	•
.65	.9420	.3766	.9053	1.1825	1.8885	•
.66	.9384	.3629	.8999	1.1971	1.8840	•
.67	.9349	.3500	.8948	1.2115	1.8795	•
.68	.9316	.3379	.8900	1.2258	1.8749	•
.69	.9284	.3265	.8854	1.2399	1.8702	•
.70	.9254	.3157	.8810	1.2540	1.8656	•
.71	.9224	.3055	.8769	1.2679	1.8609	•
.72	.9196	.2959	.8729	1.2817	1.8562	•
.73	.9169	.2668	.8692	1.2953	1.8514	•
.74	.9143	.2782	.8656	1.3088	1.8466	•
.75	.9118	.2700	.8621	1.3222	1.8418	•

Acknowledgement: The tables in this article were prepared using the computer facilities of Miami University, Oxford, Ohio.

satility. In particular, you may find the gain options useful. [Article reprints are available with the KF-6 kit or by sending a stamped, addressed #10 envelope to Old Colony, Dept. RB.—Ed.]

One kit will yield a stereo pair of filters, each of which can be individually adjusted so the channels can be independently aligned. The kit supplied parts are described in Parts List I. The first step is to discard the kits parts R_1, R_2, R_3, R_6, R_8 and C_3. Next, install the remaining parts on the circuit board using the parts placement guide, *Fig. 2*.

Now refer to Parts List II for the remaining components. After installing jumpers in the indicated positions, calculate the values of R_A and R_B from

$$R_A = 795800A/(f_a/f_S)f_{SB}$$

$$R_6 = R_B = 3183000/A(f_a/f_S)f_{SB},$$

where f_{SB} is the driver resonant frequency in the enclosure and A, f_a/f_S are listed in the alignment tables. I usually use the closest 1% values for R_6, R_A and R_B. Now install R_6. At this stage all parts are in place except R_A and R_B which determine the response shape of the filter.

Connect one end of R_A between C_1 and C_2 at the vacant point A_1. Connect the other end to the filter output at point A_2 which is available because R_2 is not used. Connect one end of R_B at point B_{11} also vacant because R_2 is not used. Finally, attach the other end to signal ground at point B_2 which is open because R_3 is not used.

FIG. 2

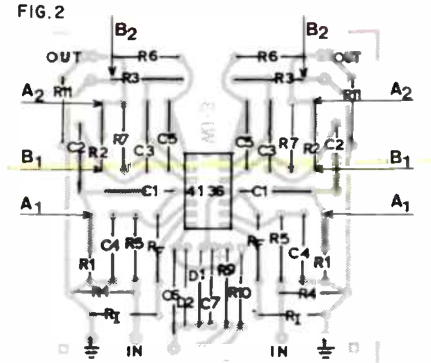

Fig. 2. Parts placement guide for filter board.

Mount the completed card in cabinet and install interconnecting wiring and jacks. The filter operates from a ±15 volt power source which you must supply. Remember to join power and signal grounds at some point.

REFERENCES

1. A.N. Thiele, "Loudspeakers in Vented Boxes," *JAES*, Vol. 19, 1971, pp. 382-391, 471-483.
2. A.N. Thiele, "Loudspeakers, Enclosures and Equalizers," Proceedings of the IREE, November, 1973, pp. 425-447.
3. R.H. Small, "Vented-Box Loudspeaker Systems, Part I," *JAES*, Vol. 21, 1973, pp. 363-372.

PARTS LIST I (*kit supplied*)

R_1	39k ±2%, 0.4W met. film
R_2	15k ±2%, 0.4W met. film
R_3	270k ±2%, 0.4W met. film
R_4	100k
R_5	1k
R_6	270k
R_7	100Ω
R_8	2.2k ±2% 0.4W metal film
R_9	470Ω
R_{10}	470Ω
R_{11}	4.7k ±2% 0.4W metal film

Resistors are ⅛W, ±5% carbon film unless specified otherwise.

C_1,C_2,C_3,C_5	0.1µF ±5%, 100V polycarbonate Siemens MKM
C_4	1000pF ±5%, 160V polystyrene
C_6,C_7	22µF 35V, tantalum Siemens
D_1,D_2	6.8V 0.5W Zener ±5%
IC	Quad op amp RC4136P (or RC4136D) Raytheon
Circuit board	
Molex pins	

PARTS LIST II (*user supplied*)

R_3,R_8	leave out
R_A	see text for sizing
R_B,R_6	see text for sizing
R_I	leave out
R_F	jumper
C_3	jumper

Table Saw Basics

by Bruce C. Edgar

Eighty percent of all woodworking operations, according to Rockwell's Power Tools Division[1] can be accomplished with a table saw. For building speaker enclosures that percentage may be even higher, so the aspiring loudspeaker designer-constructor had better pay close attention to the careful alignment of his table saw.

To begin with, obtain some plastic drafting triangles (45°- 45° and 30°-60°) and a large metal carpenter's square. Drafting triangles are probably the most reliable angle gauge available to the individual constructor. Stand the long end of the 30°-60° triangle up on the saw table. Then take the carpenter's square and stand it also on the saw table. If the carpenter's square is true, the vertical edges of the triangle and the square should meet evenly when brought together on the saw table. If a gap appears, buy a new square; they do go out of alignment if you drop them enough times on concrete floors.

Now go out and buy a multi-tooth tungsten carbide saw blade. I recommend any blade in the 20-40 tooth range: one with more teeth will tend to slow the motor down too much, and you will not obtain as smooth a cut with coarser blades. Tungsten-carbide blades do not warp as readily as cheaper setsaw blades do[2]

FIG. 1

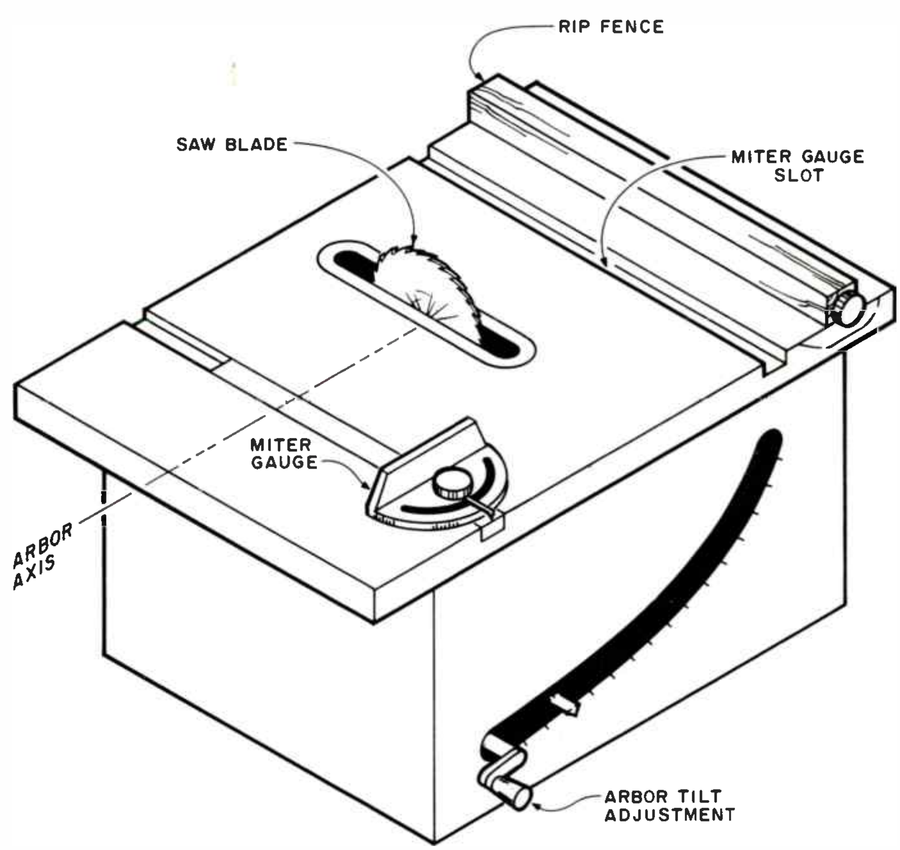

Fig. 1. A typical table saw, showing the miter gauge, rip fence, and arbor axis.

THE TABLE SAW

Let's assume you have a typical small 9″-10″ table saw as sold by Sears, Wards, Rockwell, etc., and have aligned it according to the instructions. If you don't have such a saw, *Fig. 1* shows a table saw schematic with the three features to be discussed in this article.

The saw blade is mounted on a rotating shaft called the arbor. On cheaper saws the motor shaft directly drives the arbor, but on more expensive models the motor couples to the arbor by means of pulleys and a belt. The miter gauge helps perform crosscuts; its rod rides in a slot in the saw table and allows the operator to push a piece of wood across the blade. It has a protractor setting to allow crosscuts at angles up to 45°, but usually it is set at 90° to give square crosscuts. The rip fence is a long bar which can be clamped to the table top to give a guide parallel to the saw blade; it is most useful for producing parallel cuts.

If you follow your manual's procedures for aligning the arbor, miter gauge, and rip fence, you will obtain a reasonable alignment. But after constructing several projects, you may find annoying little errors creeping in. The next sections will outline several techniques for correcting those errors.

TRUEING THE MITER GAUGE

The usual procedure for trueing the saw blade with the miter gauge is to lay a square on the table against the miter gauge and saw blade and adjust the gauge until you see no gaps. With planar blades this procedure works well, but with a 40-tooth or more tungsten carbide blade, the teeth interfere with the square to prevent a good alignment. The following procedure, which I ran across in *Fine Woodworking*[3] Magazine, solves this problem.

First you take a several foot length of 1″ x 6″ stock without warps and make what you think is a good square cut, as shown in *Fig. 2A*. Fit the two cut pieces together as shown in *Fig. 2B*. Then flip one piece and place the two pieces together again as demonstrated in *Fig. 2C*. The gap between the boards is twice the angular deviation from 90°.

Now make a slight correction to the miter gauge and make another cut. If the gap is larger, you have made a correction in the wrong direction. If the gap appears at the other end, you have overshot the 90° position. When you can cut the 1″ x 6″ board and see no gaps when one board is flipped over and over, your miter gauge is set exactly at 90°. You may use up a good 1″ x 6″ board this way, but you will wind up with an accurately set miter gauge.

Since my Sears miter gauge has no stop for 90°, I usually go through this alignment procedure before I do any square cross cuts. The Rockwell miter gauge has adjustable set screws which allow one to do the trueing operation once and return accurately to 90° after other angular cuts.

This is a good time to check the alignment of the arbor with the saw table. You were supposed to do this when you first set up the saw out of the box. If laying a square against the miter gauge and the slot in the saw table yields a gap, the arbor is not aligned accurately. However, unless the gap is more than a degree, trying to readjust the arbor may be more trouble than it is worth. There are better ways of compensating for arbor misalignment, as I will show in the next section.

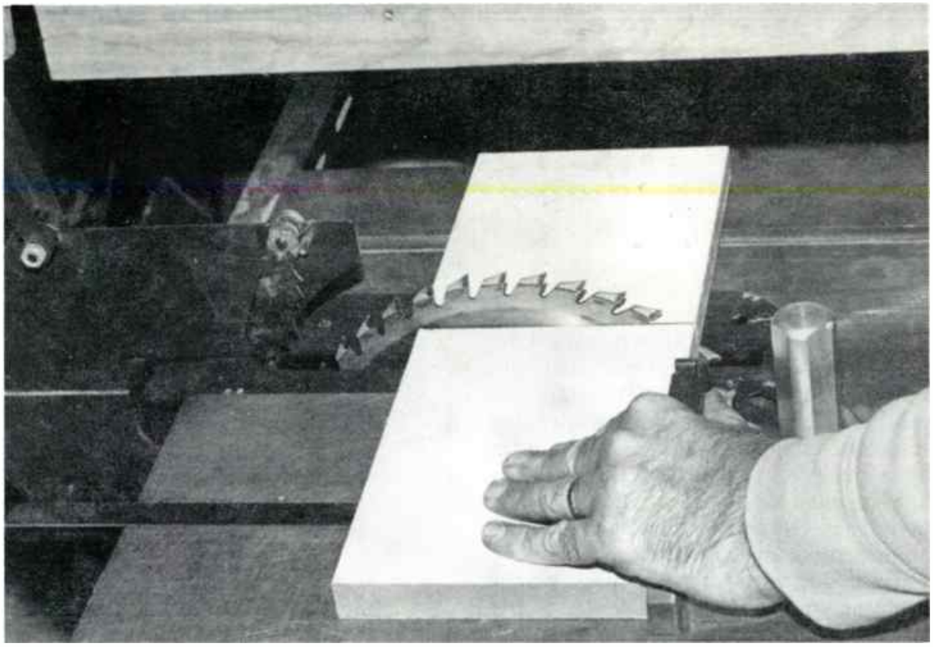

Fig. 2(a) To true the miter gauge, first cut a 1" x 6" board. Note: the saw blade guard is shown in the "up" position only for the sake of illustration. *The guard should be down for safety reasons.*

FENCE ALIGNMENT

The usual rip fence alignment calls for checking to see whether it is parallel to the miter gauge slots in the table. However, this method assumes that the arbor is correctly aligned. The previous method of trueing the miter gauge compensates for any arbor misalignment. A better procedure is to ignore the slight arbor misalignment and construct an auxiliary fence with shims to help the alignment. You can now obtain an idea of the miter gauge/fence system's relative squareness by placing the large carpenter's square against the miter gauge and the fence as shown in *Fig. 3A*.

At this point it is useful to talk about auxiliary fences. In *Fig. 3A* the fence is shown as 6" x 20" piece of ¾" birch veneer plywood. The hard birch gives a slick surface for wood to slide against. The auxiliary fence extends out several inches beyond the table so one can align a long piece against it before the piece meets the saw blade.

The auxiliary fence also allows you to make rabbet cuts (see your manual for a description of a rabbet joint). For accurate rabbet cuts, the fence must be square to the table; you may find it is not when you check this angle as shown in *Fig. 3B*. The offset can be corrected by adding appropriate shims as shown in *Fig. 3C*. In my case, two thicknesses of cardboard from a sandpaper wrapper were sufficient. *Figure 3C* also shows a 2" x 3" length of wood attached to the metal fence, which gives some latitude for attaching the auxiliary fence.

If the miter gauge/rip fence squareness test of *Fig. 3A* indicates the arbor is slightly misaligned, you can add a shim to the appropriate end of the auxiliary fence as shown in *Fig. 3C*. Mine needed a piece of ⅛" masonite (I always keep a collection of cardboard pieces, metal cuttings, circuit board pieces, etc., for shim material). The auxiliary fence is attached with two flathead screws to the 2" x 3". At the place where you determine the large shim should be located, the mounting screw should also be; otherwise the auxiliary fence can become warped.

There is always a good chance that the auxiliary fence shim was too large or in the wrong position. First check to see if a 2" x 4" will slide easily between the blade and fence with the saw motor turned *off*. If you observe no binding or gaps, the auxiliary fence is probably very near the correct position. Then rip an edge off the 2" x 4"; if burn marks appear on the cut, the blade is binding.

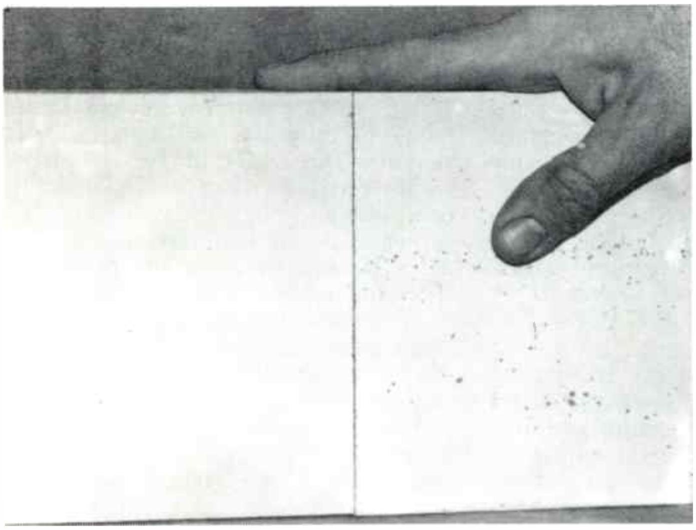

Fig. 2(b) After cutting the board, join the two sections together to test the straightness of the board and table top. There should be no gaps.

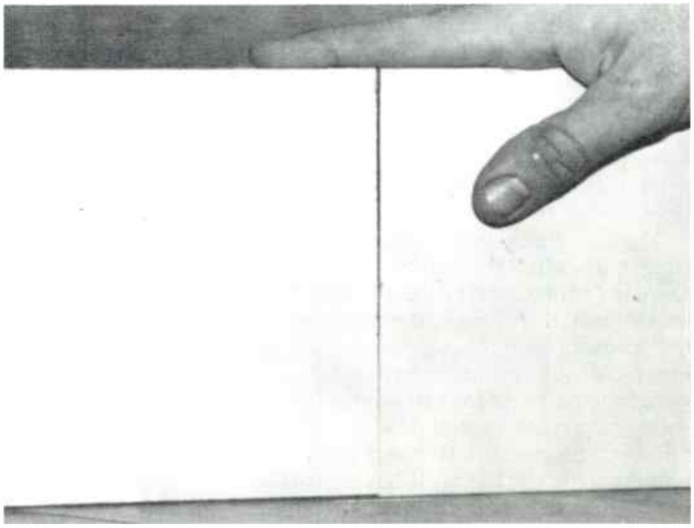

Fig. 2(c) Flip one section over and join the two sections together again. If there is a gap as shown, the miter gauge is not true with the saw blade. It is not true unless you can flip one section over and over and not see any gaps between the boards.

If the fence tends to push the material into the blade, you must move the shim and the mounting screw to a point where binding does not occur.

The acid test for the fence is to square off one end of a piece of 1" x 6", using the trued miter gauge, and place that end against the fence. Push the piece through the saw, and perform the "flip" test of *Fig. 2* to check squareness. At this point small adjustments should suffice to bring the fence into excellent alignment.

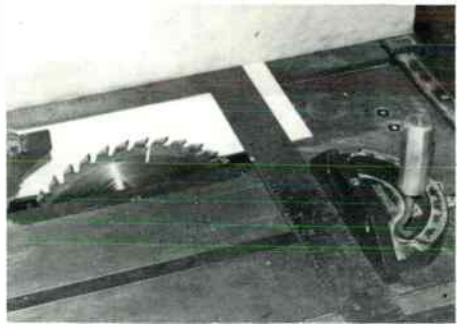

Fig. 3(a) Checking to see if the rip fence is square with the miter gauge.

Fig. 3(b) Checking the vertical squareness of the auxiliary fence with the table top.

AUXILIARY TABLES

It is a nuisance to keep trueing up the miter gauge, so I recommend constructing a small sliding table as shown in *Fig. 4A* from a scrap piece of plywood. The secret to this item is to make sure you cut the piece that slides the miter slot to fit almost snug but without binding in the slot. To build the table (see *Fig. 4B*), crank the saw blade all the way down; place the slide piece in the slot and the plywood scrap on the table slightly overlapping the blade. Nail the plywood piece to the slide and take it off the table, raise the saw blade, and replace the sliding table on the saw table so you can push it through the saw blade, cutting off the excess.

Nail a piece of 1" square stock at one end to provide a stop. Square the sliding table using the *Fig. 2* procedure for trueing the miter gauge; only this time you use the nailed end of the 1" x 1" stop as a pivot point and temporarily nail the other end. After cutting the 1" x 6" stock, you can fix the stop with several nails along its length to achieve the true square position.

For cutting large or long stock, build a shuttle or "shute" table as shown in *Fig. 5A* from two 2' x 3' plywood pieces and some reasonably true 2" x 4" stock. Rip the slides out of hardwood stock such as oak or birch, taking care to make sure they exhibit no play in the slots, and assemble the shuttle table on the saw, this time with the blade up.

As you will see from *Fig. 5B*, the gap between the plywood pieces should be wide enough to accommodate a set of dado blades. Once the gap is even and parallel, clamp the plywood boards to the slides and nail together. Then screw

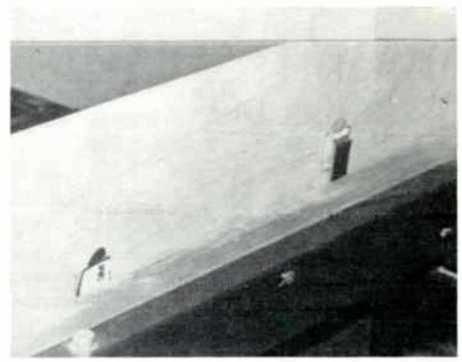

Fig. 3(c) Shims for the auxiliary fence.

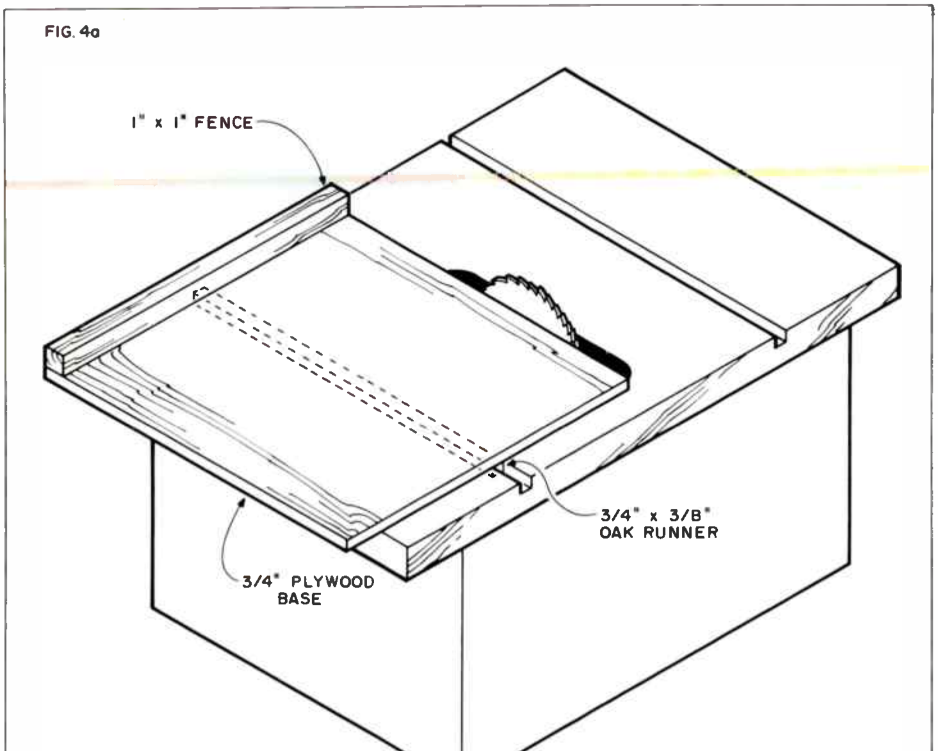

Fig. 4(a) Schematic of the sliding table.

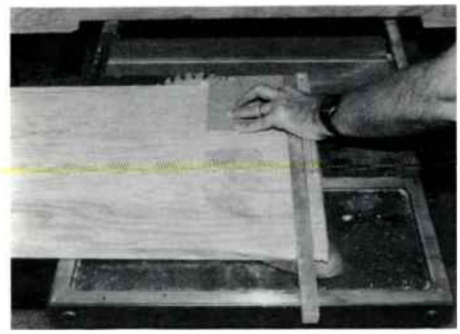

Fig. 4(b) Sliding table in operation. A plastic sheet stapled to the bottom reduces sliding friction.

a 2" x 4" piece to the end of the shuttle table furthest from normal operating position. For the stop closest to you, screw a 2" x 4" to one end to act as a pivot point. Clamp the other end of the 2" x 4" and perform the *Fig. 2* trueing operation all over again. (You use up many 1" x 6" boards this way.) Once you reach a square cut condition screw or nail the 2" x 4" into permanent position. Some of my woodworking friends actually have several sizes of shuttle tables, some large enough to handle 4' x 8' sheets of plywood or particle board.

Instead of a table large enough for cutting such sheets, I sometimes use the setup in *Fig. 6*. I am partially handicapped and do not have the strength to manhandle a 4' x 8' sheet, so I usually have the lumber yard cut my 4' x 8' sheets into 4' x 4'. With a longer auxiliary fence temporarily clamped to the smaller fence of *Fig. 3* and with the help of the following feed roller, I can easily rip the 4' x 4' pieces into the desired sizes.

FEED ROLLER

A very useful item for a table saw is the feed roller shown in *Fig. 7*. When you use a shuttle table or rip a long plank, you need support behind the saw so the table, plank, etc., does not tip over as you finish the cut. This model is based on an idea from *Fine Woodworking*[4] and uses an ordinary kitchen rolling pin in a 2" x 4" base.

I selected my rolling pin size to fit in between the miter gauge slots in the saw table and thus support the shuttle

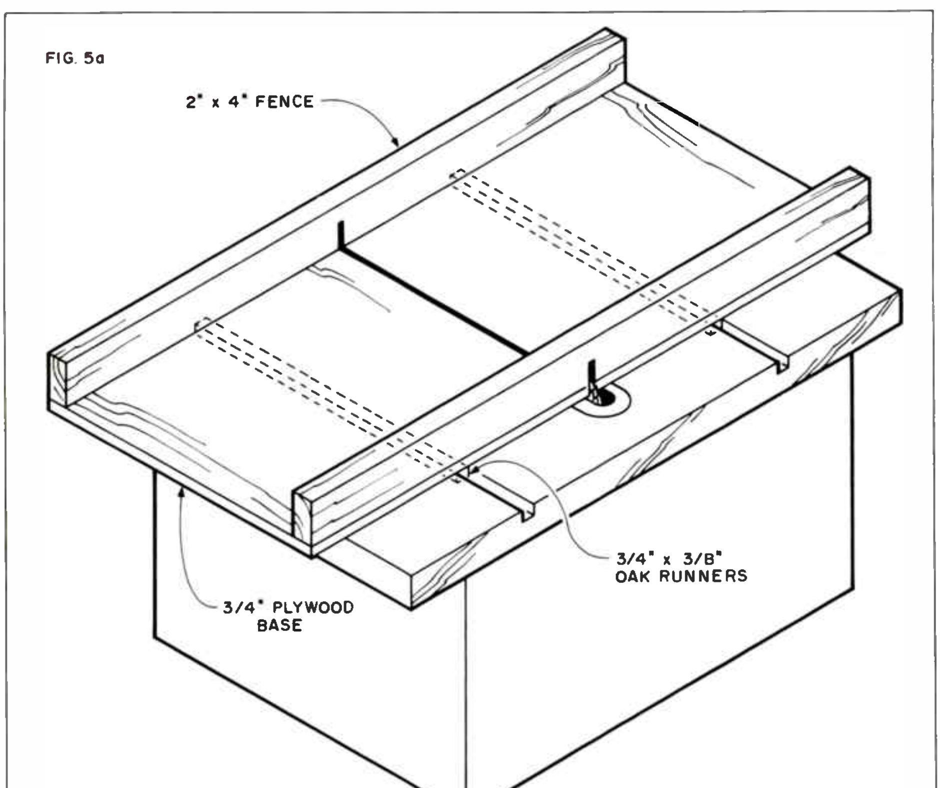

Fig. 5(a) Schematic of the shuttle table.

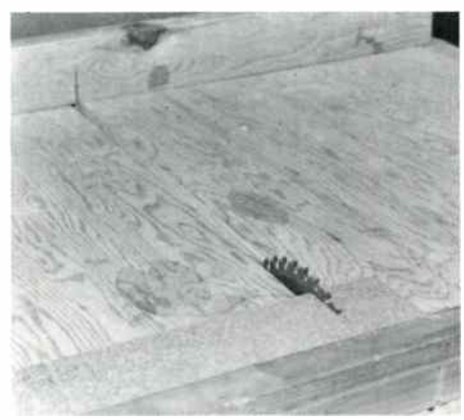

Fig. 5(b) Shuttle table in operation.

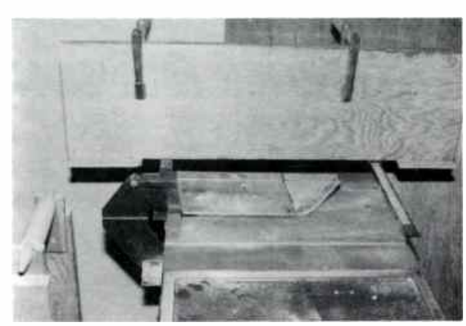

Fig. 6. Table saw setup for cutting large pieces of plywood or particle board.

table between the hardwood slides. Put the triangular base together with corrugated fasteners. Cut "vee" notches into one end of two 5" lengths of 1" x 3" stock; clamp them to the support 2" x 4" and adjust them, with the rolling pin in place, till the top of the roller is level with the saw table. Then screw the 1" x 3"'s in place. You can assemble this item from scrap pieces in less than an hour.

VACUUM ATTACHMENT

My table saw has to share our garage with washer, dryer, bicycles, electronic gear, etc. To keep sawdust from these items, I devised the vacuum attachment of *Fig. 8*. Screwed to the bottom of the saw is a shallow pan, to which I epoxied a small collector from the shopvac accessories after cutting out a suitable hole with an Xacto® knife. I found I needed a large Sears Shopvac for effective dust collection; Sears now market a dust collector for their larger table saws.

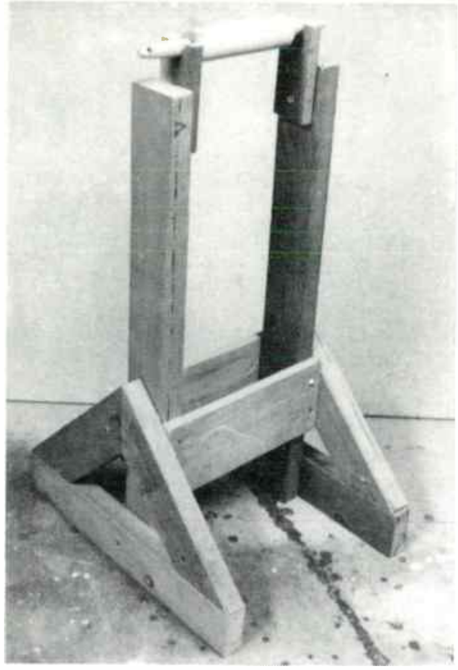
Fig. 7. Feed roller.

OTHER TIPS FOR PRECISION CUTS

Several authors[3,5] recommend using sharp pointed instruments such as a hard lead pencil, an Xacto® knife, or a sharp point scribe to make lines or marks on materials. So throw away all your soft lead #2 pencils, or at least remove them from the vicinity of your work area.

As helpful as many of these tips are, they are only as good as the operator. When you set up a cut or make a mark, take another look at the plans and remeasure. I don't know how many pieces I have goofed up because I did not follow this rule. Another rule is, stop when you become fatigued. It is only a hobby. You make fewer mistakes when you are fresh, and are less likely to have an accident. When I ask a carpenter with a missing finger or joint how it happened, he usually says it was at the end of a long day when he was tired and not watching.

READING MATERIAL

I recommend the Rockwell saw manual[1] as a general reference. Most of the woodworking joints you will ever want to use are very well explained. The other references[3,4,5] contain many tips I was not able to include in this article. In general the bi-monthly *Fine*

Continued on page 40


Fig. 8. Vacuum attachment for the table saw.

Tools, Tips & Techniques

DRIVER SUSPENSIONS

You can noticeably improve the performance of most speaker systems by remounting the woofer and mid-range drivers in a compliant suspension made with rubber grommets and butyl caulk. Steps:

1. Remove the drivers. Check that the T-nuts (or other hardware) that held the mounting screws are still securely in place.
2. Since the grommets will generally raise the top of the drivers' baskets above the mounting board, causing undesirable defraction, cut the area on which the baskets rest down 1/16"-1/8", using a router. If this can't be done, take a chisel and cut down the area within 3/8" of each mounting screw.
3. Cut grommets from an old inner tube with tin-snips. They should be roughly ½" in diameter; if they are larger, they tend to be dragged into the cabinet when the drivers are inserted. Cut holes for the mounting screws by folding the grommets in half and cutting a wedge at the fold with nippers. Two layers of inner tube are sufficient for all but the largest drivers.
4. Run a bead of butyl caulk completely around the driver opening. Be sure the area around each mounting screw is covered. The bead should be roughly twice the thickness of the rubber grommets. Proceed with care: butyl is extremely messy. Clean up with mineral spirits or turpentine.
5. Press the grommets into the caulk. Gradually lay the speaker over the grommets and into the caulk. Use a nail to check that the basket screwholes and the grommets are exactly above the mounting holes in the cabinet. Insert screws and *gently* find the thread on the T-nut in the cabinet; pushing hard will make the T-nut drop into the cabinet.
6. Tighten the screws until the driver basket presses on the grommets. Then tighten slightly more.

Compliant suspension should result in (1) better side-to-side imaging, and (2) cleaner mid-range (no bass "undertones" around voices and instruments). Bass fundamentals should be unaffected, although eliminating upper bass panel vibration may initially give you the impression of "less bass."

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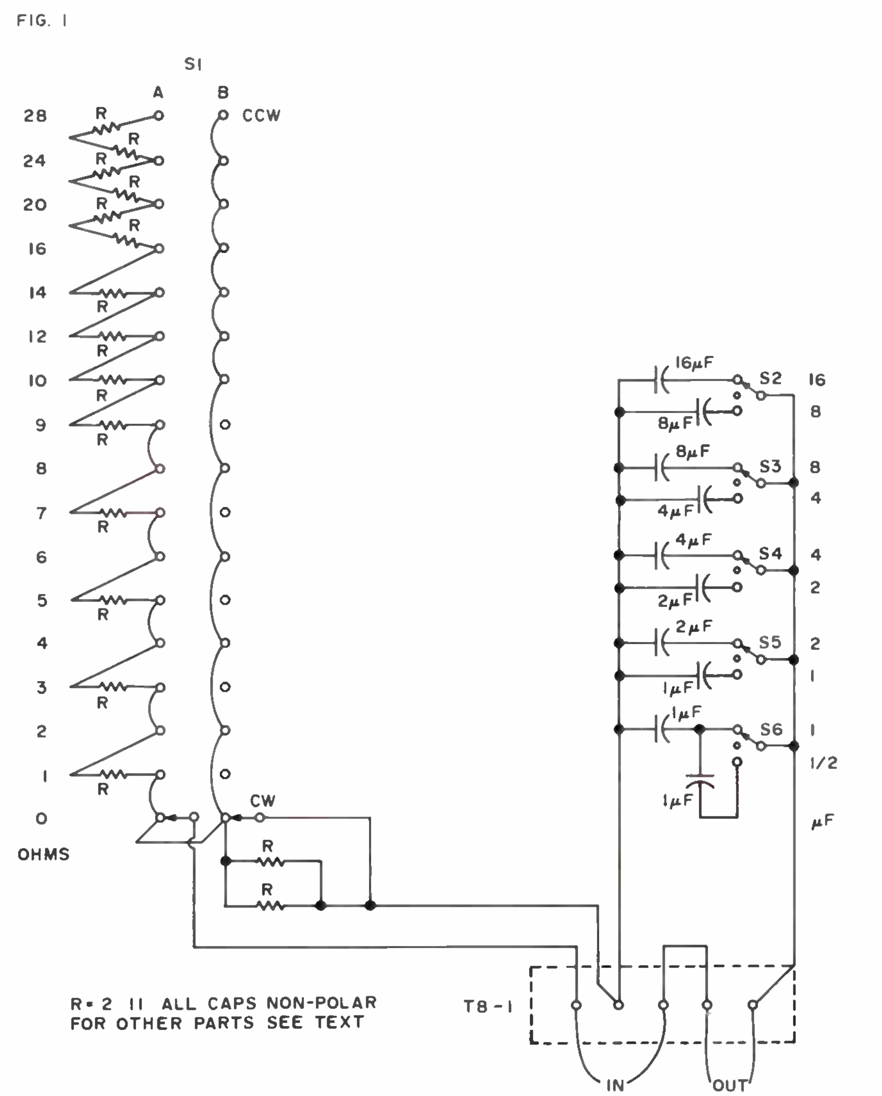

Fig. 1. Schematic for simple series R-C crossover.

A SERIES PADDED SIMPLE CROSSOVER

When testing two way speaker enclosures after initial construction I like to investigate the effects of series padding of the tweeter to "push" the high end response limit. The simple crossover test box shown schematically in *Fig. 1* allows this. It is only a series resistor-capacitor circuit, but it covers the value range I have found needed and in a way that is convenient. The resistor portion is composed of sixteen 2Ω 11W resistors (Ohmite Stock No. 4737) and an old two layer 18 position (can only use 17 actually) rotary switch (S_1). I had all these parts on hand but any substitutes would be O.K. The switch can be shorting or non-shorting and the resistors can be a lower wattage with no problems. With the wiring shown in *Fig. 1*, the resistance can be varied from 0 to 10Ω in 1Ω steps, 10 to 16Ω in 2Ω steps and 16 to 28Ω in 4Ω steps. This has proved to be sufficient range and resolution for anything I have done to date.

I implemented the capacitive section somewhat differently. A rotary switch would have required many switch poles or lots of precious crossover capacitors and not really have been functionally what I wanted. While attenuation should be changeable in tiny steps, functionally you sometimes want to jump the crossover frequency in reasonably large steps. Thus I wanted to be able to make large capacity changes from any dialed capacity value, so the unit was implemented with five SPDT, center-off miniature toggle switches (S_2–S_6) wired as shown in *Fig. 1*. This allows any 0.5μF increments from 3 to 31μF. One more switch and two capacitors would halve this increment, but I have not found it needed. The capacitor value is the sum of the values of the "on" switch positions.

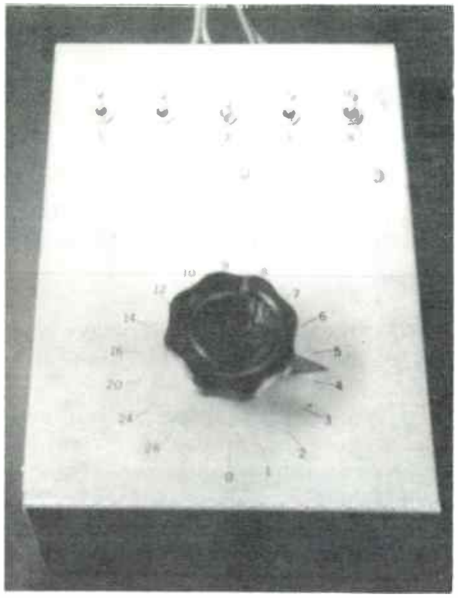

Fig. 2. Simple crossover unit. Capacitor switches are at top, multi-selector resistor switch is below.

The unit is constructed in a 7 x 5 x 3" chassis as shown in *Fig. 2*. A five terminal barrier strip allows me to bring the junction of the resistive and capacitive sections out for individual use. The remaining two terminals are tied together to provide a "common" for input and output wiring. The various resistors and capacitors are mounted on "knife-cut" P.C. boards (see *SB* 1/82, p. 34) and wired to the switches. Marking was done with black transfers right on the chassis.

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ADAPTING HEATH'S RCL TO MEASURE Z

Measuring speaker impedance usually requires specialized equipment or the use of several pieces of equipment ('scope, AC VTVM, sine generator) at one time. When I recently acquired a Heath IB-5281 RCL bridge, I found some simple modifications enable it to make this type of measurement.

1. The internal oscillator operates on only three frequencies: 1, 10, 100kHz. I added an extra jack and switch to select between this internal source and an outboard signal generator covering 10Hz-100kHz see *Fig. 1* for circuit modification. *Photo #1* shows the jack's location on the front panel. Note that the photo was taken before I added the switch, which I did when I realized the unit's portability suffered if

I couldn't also use the internal oscillator.

2. The bridge amplifier's input coupling capacitor is only .001μF which will not pass low frequencies when the external oscillator input is being used. Change this capacitor to at least 1μF. Larger values create a problem because they will not fit the space on the circuit board. *Photo #2* shows the new capacitor installed in the unit.

To measure impedance, connect a 10Ω resistor to the Z_s terminals. Set the range switch to the Z_s position. In this mode the ratio of the known to unknown impedance is read out on the dial over a range of 1-100Ω. You can make a complete plot by checking the impedance over the usual working range of 10Hz-2kHz (or higher if you wish).

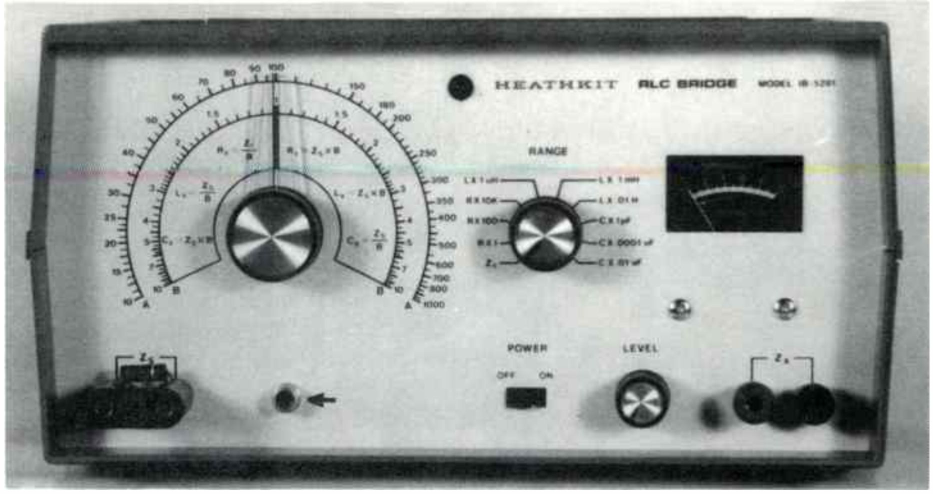

Photo 1. Arrow shows input jack added to front panel.

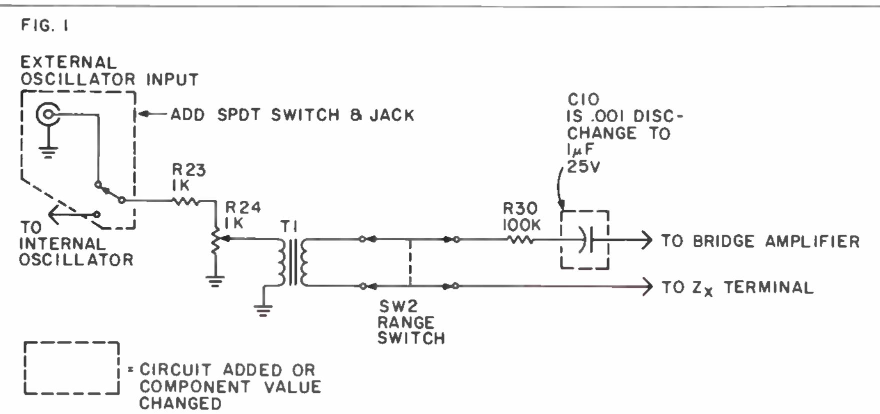

Fig. 1. All component notations are from Heathkit schematic.

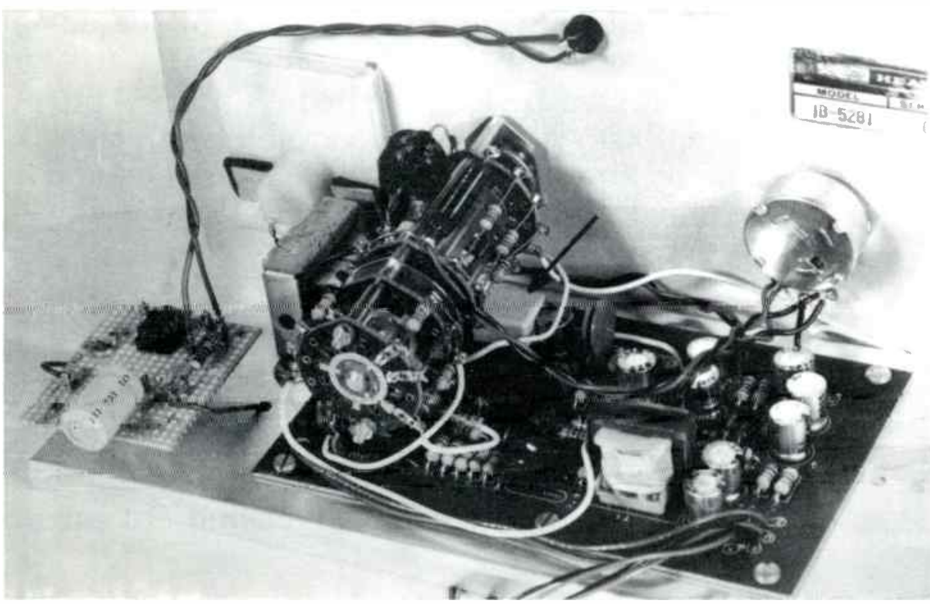
Photo 2. Arrow shows location of new C_{10} capacitor.

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PASSIVE CROSSOVER NETWORKING

THE HYBRID BUTTERWORTH crossover design for multi-driver systems is an interesting one for those who refuse to invest in multiple amplifier systems. Its series/parallel arrangement utilizes an initial center split of 18dB/octave and 6dB/octave series high and/or low sections.

Figures A and *B* respectively illustrate three- and four-way networks which derive their component requirements from the values in *Tables 1* and *2* or *3*. The quasi-second order values in *Table 3* allow the designer considerable latitude in choosing high values of either $L_{4,5}$ or $C_{4,5}$ with very little effect on the final product.

Phasing through the networks is complex but coherent. Try to place the secondary (series) crossover points in the prime section's middle bandwidth. Note that connection to a series arrangement section should be as shown in *Fig. C*.

Reversing the component order in the series section on the initial split's high and low pass legs allows some correction of electrical phasing through the network. This compensates for the

Continued on page 34

TABLE I

	MH			μF			
f_c(Hz)	L_1	L_2	L_3	C_1	C_2	C_3	C_B
100	19	6	9.5	270	130	400	2μF
125	15	5	7.6	210	105	316	2μF
160	12	4	6	170	84	250	2μF
200	9.6	3.2	4.75	133	66	200	2μF
250	7.5	2.5	3.8	105	53	160	2μF
315	6	2	3	84	42	126	2μF
400	5	1.5	2.5	67	33	100	2μF
500	3.8	1.3	2	53	26	80	2μF
650	3	1	1.5	42	21	63	1μF
800	2.5	.8	1.2	33	17	50	1μF
1000	2	.65	1	27	13	40	1μF
1260	1.5	.5	.75	21	11	32	1μF
1600	1.2	.4	.65	17	8	25	1μF
2000	1	.3	.50	13	7	20	1μF
2500	.75	.25	.40	11	5	16	.47
3150	.60	.20	.30	8	4	13	.47
4000	.50	.15	.25	7	3	10	.47
5000	.40	.125	.20	5	2.5	8	.47
6300	.30	.10	.15	4	2	6	.1
8000	.25	.075	.125	3	1.5	5	.1
10,000	.20	.05	.10	2.5	1.2	4	.1

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speaker polarity reversal which would be necessary without the series sections.

I have approximated the value of C_6, a bypass capacitor to improve transient response, for 8Ω drivers. The last column in *Table 1* shows this value for the crossover points given in the table.

	1st Order TABLE 2		Q 2 Order TABLE 3	
f(Hz)	L	C	L	C
100	9	280	6	400
125	7	225	5	316
160	5.5	180	4	250
200	4.5	140	3	200
250	3.5	110	2.5	160
315	3	90	2	125
400	2.25	70	1.6	100
500	2	60	1.3	80
650	1.5	45	1	65
800	1.2	35	.8	50
1000	.9	30	.65	40
1260	.75	22	.5	32
1600	.6	18	.4	25
2000	.5	14	.3	20
2500	.36	11	.25	16
3200	.25	9	.2	13
4000	.20	7	.16	10
5000	.18	6	.13	8
6300	.15	5	.1	6
8000	.12	4	.08	5
10,000	.10	3	.06	4

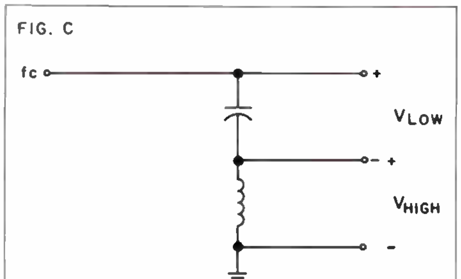

Fig. C. Series connection.

I used these suggestions and networks to design a 116 liter bass reflex system using the KEF B139, Realistic 5¼", Yamaha 80mm. beryllium domes, and Decca London ribbon horns. I limited all the drivers to piston operation, and set the crossover frequencies at F_c = 650Hz, f_L = 160Hz, and f_h = 3000Hz. The sound is remarkably coherent, avoiding both the dull lower midrange so common in current loudspeaker designs and the vicious impedances found in true third order bandpass sections.

R. J. Welsh
Bogota, NJ 07603

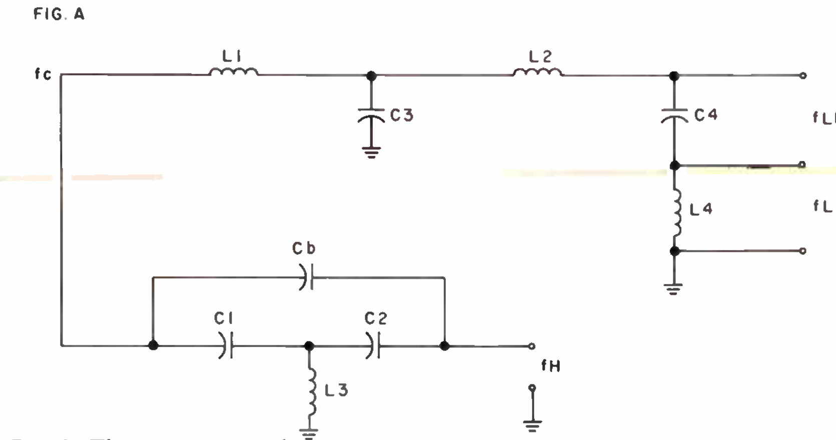

Fig. A. Three-way network.

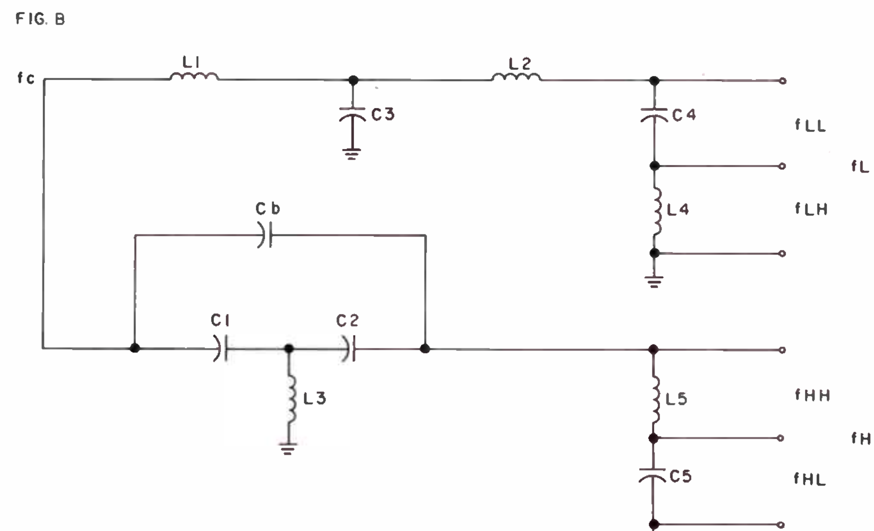

Fig. B. Four-way network.

CIRCUIT BOARDS FOR CROSSOVERS AND DUMMY LOADS

WHEN YOU MENTION circuit boards, most people think long delays and high costs. This is likely to be true with boards for complicated electronic circuitry, but boards for simple circuits such as crossovers and dummy loads can be made with a sharp knife in about 10 minutes. *Figure 1* shows some examples of what can be built.

Top left shows a crossover PC board packaging three air core coils and two caps. The board makes a convenient way to mount the parts (brass hardware for the coils please) and interconnect them. Top right in *Fig. 1* is a simple board mounting eight of the Ohmite 2Ω, 11W resistors. This quick board mounted to a surplus piece of chipboard is a convenient dual channel 8Ω, 44W dummy load. The PC board shown bottom left, component side up, gives an idea of the capacitor density. This approach will mount and interconnect easily. This particular board is part of a switchable passive crossover unit I use in testing.

The board in the bottom center has to be nearly the simplest board possible, two copper runs separated by a straight gap! It can be made with a knife, a hacksaw or a file. I use them to make large plastic film capacitors from a group of small ones. For example, I purchased a bunch of 1μF, 50W polypropylene stand-up capacitors for 7¢ each (doesn't matter where, I bought all they had!). I can put ten of these together on one of these simple PC boards for a compact and robust 10μF polypropylene capacitor for 70¢,

Continued on page 41

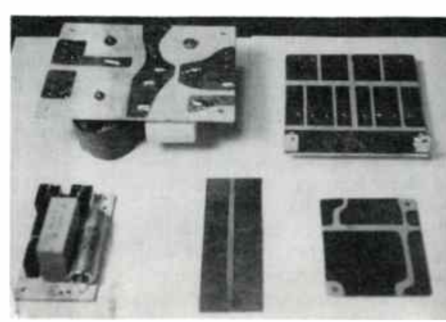
Fig. 1. A group of knife-cut circuit boards.

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Craftsman's Corner

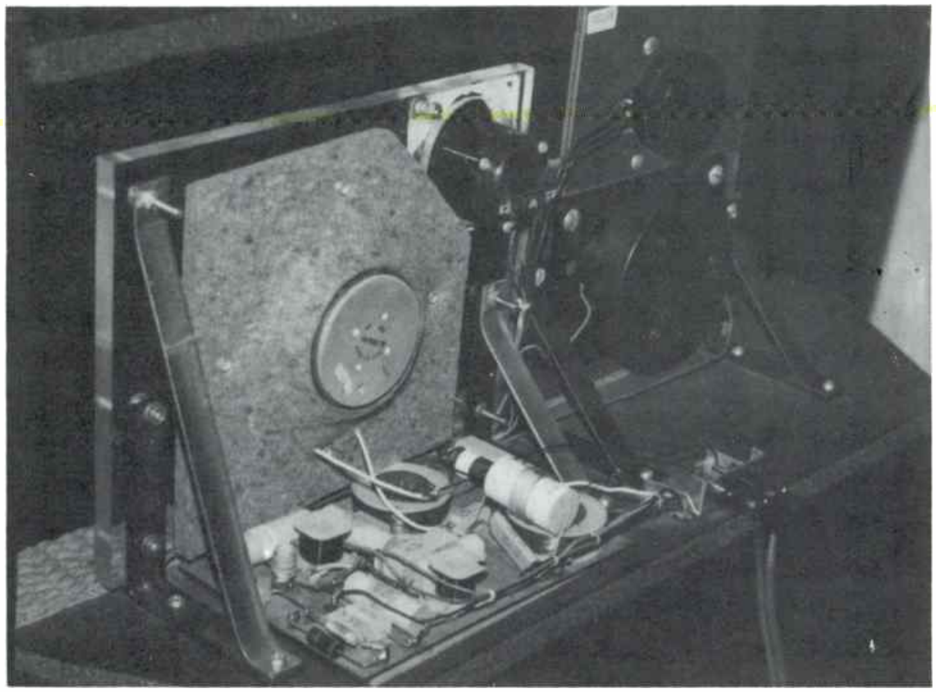

Fig. 2. Back view of the altered mid-woofer crossover mount and new input terminals.

DQ-10 REDUX

MANY YEARS DOWN THE LINE, the Dahlquist DQ-10 speakers will, I believe, be viewed as one of the truly classic speakers in much the same way we think of the original AR-3a system. The DQ-10 was one of the first full-range speakers to employ low diffraction and phase alignment. Perhaps the DQ-10 is as good a dynamic speaker as possible with standard drivers (non-exotic cone material and a reasonable price tag).

I would like to pass along several simple modifications aimed at achieving maximum performance from the DQ-10's. (Several of these ideas can be applied to other speakers.)

First, and most importantly, every owner of Dahlquist's speakers should be aware of the two factory authorized updates. These are mylar capacitors in the crossover (easily identified by their large size and bright yellow jackets), and mirror imaging. These modifications are a must. Contact the Dahlquist Company for parts and instruction.

The next modification, which to my ears, is at least as significant as the first two, is called bi-wiring (not bi-amping). The DQ-10 crossover can be *electrically* divided into two sections. One section involves the woofer and the mid-woofer cone drivers. The remainder of the crossover deals with the mid-range, tweeter and supertweeter. The modification consists of electrically separating the two sections and wiring each section back to the same amplifier terminals via their own speaker leads. (See *Fig. 1.*) A second set of terminals must be provided on the speakers by cutting a "window" in the rear screen and mounting a dual banana terminal on a bracket. (See *Fig. 2.*) (If you have big doubts about this modification, wire it up temporarily and audition it.) In either case, the following precautions apply:

1. Don't reverse the phase of the two sections.

2. For long runs (over 15 feet) use at least 12 gauge wire. (After you audition the improvement with double runs of your present wire.)

3. Be sure both crossover sections are separated at *ground* and *hot* lead; i.e., they do not come together until the amplifier terminals.

The next modification will be called, for lack of a better term, mirror imaging the crossover. This means having matched pairs of capacitors and resistors at similar locations in the left and right speakers. First, I measured all the resistors to find out how close to correct value they were and, most importantly, how close they were to their counterpart in the other speaker. Through the local parts store and the Dahlquist Company, I was able to obtain enough resistors to place matched pairs in all locations (within .1 ohm).

I then applied the same rationale to the capacitors. Again, with the aid of the Dahlquist parts department and some parallel wired low value high quality metalized capacitors, I achieved good right-to-left matching. (Do not get carried away looking for exact *production* values at each location. You will need a truckload of capacitors to do this and the results would not be worthwhile.)

The final modification involves stiffening the mid-woofer baffle board. A frequency sweep within the range of the mid-woofer will show significant vibrations of the baffle board, even at a modest one-watt level. I made a new baffle board from ⅝" thick clear acrylic (plexiglass). (See *Fig. 3.*) In addition, I placed additional metal brackets on the new mid-woofer board and on the existing midrange board.

The following cautions and comments apply:

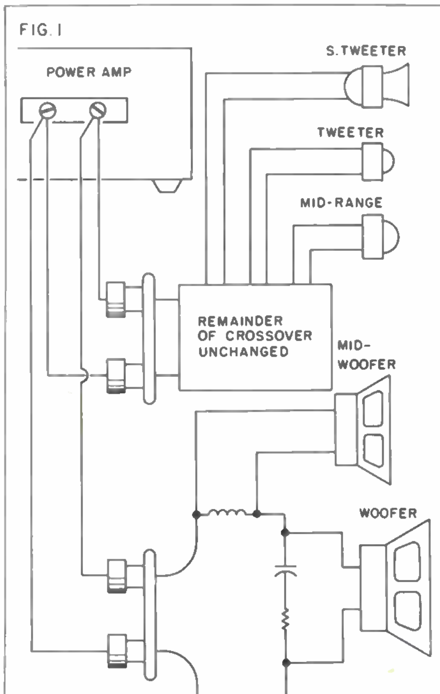

Fig. 1. Bi-wire procedure for modifying the DQ-10.

A. Cut, drill and rout out the plexiglass with care to avoid cracking. If self-tapping screws are used for the mid-woofer, drill the pilot holes only *slightly* smaller than the screw. (Experiment with a scrap.)

B. The mounting brackets for the new board must be moved back by the same distance as its additional thickness in order to keep the driver voice coils in the same relationship to each other.

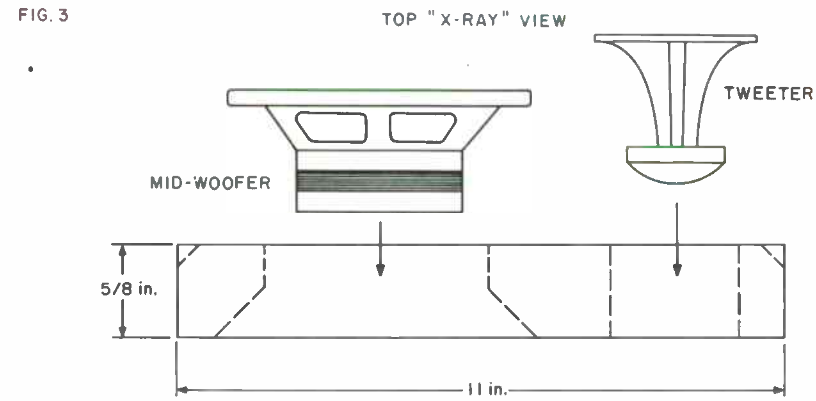

Fig. 3. Cutting details for the acrylic panel.

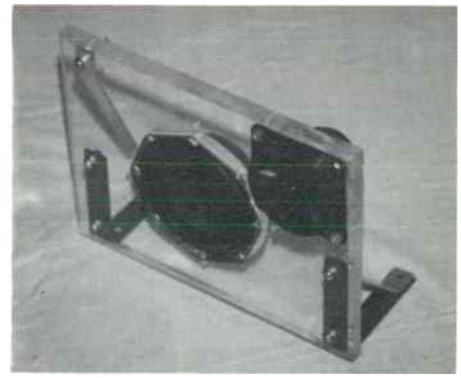

Fig. 4. Front view of the acrylic mid-woofer board.

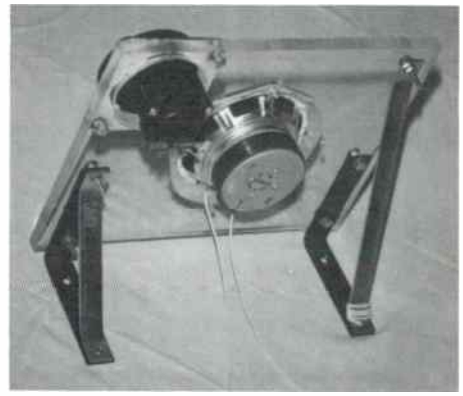

Fig. 5. Rear view of the new mount.

C. Fill in the old screw holes with white glue and wood match-stick stems and trim off flush.

D. Chamfer the *back* edge of the mid-woofer opening at a 45-degree angle down to within ¼" of the front edge.

E. Apply silicone bathtub caulk to the mating surfaces of the drivers prior to screwing or bolting them in place.

F. ⅝" plexiglass is expensive ($15-$20 per panel), but it has a very dense and dead quality that makes it ideal for this application.

G. No wisecracks about it giving a more "transparent" sound, please.

H. *Figures* 4 and 5 show mid-woofer board installation and assembly.

Most readers would probably want some idea of the sonic effect of these modifications. Without going into great detail, the modified speaker sounds smoother and cleaner throughout its entire range. It seems to suffer less from the effects of being a multi-way speaker. If twelve gauge or heavier wire is used for bi-wired leads, the bass will be tighter with greater detail. In short, I would not want to undo any of these modifications.

Jack Philpot
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FALCON FORUM

ON RECEIPT OF *SB* 4/81 I quickly turned to David Davenport's article on building the Falcon LS3/5A Mini. About two years ago I built a similar pair using the Falcon crossover kit and recently wrote an article for the Audio Society of Minnesota "Monitor" about my experiences. Feeling that your readers might like some additional perspectives on this excellent and inexpensive design, I pass along some comments on it and Davenport's article. Readers may want to dig it out of their bookcases as in the interests of brevity. I shall refer to some sections by number. Here goes.

1. #10 It really would be advisable in the interests of maximum reduction of reso nances and greatest construction quality to fill in all screw holes and gaps with, say, Durhams Water Putty prior to veneer application.

2. #28 I have used silicone sealer to mount the front baffle but found it generally unsatisfactory because it's so messy. A much better solution is adhesive-backed foam. It's cheaper (check your local surplus store) and is much more effective in decoupling the baffle from the rest of the box.

3. #33 Many adhesives will work for attaching the felt panels to the inner walls, e.g., roofing cement. Most hardware and building supply stores have a selection of usable products in caulking tube configuration. Petroleum-based substances are recommended as they are compatible with the bituminous compound impregnated in the felt. However, if you use such a substance it is recommended that you let the box stand open for a week or so before final assembly. This is because the esters given off by the adhesive can eventually break down the rubber surround of the B-110 if not allowed to work off.

4. It's OK to use the foam rings supplied with the T-27 and B-110. They will give an air tight seal on relatively smooth and gap-free surfaces.

5. It's also OK to use the bolts supplied with the B-110. I also recommend surface mounting this unit. As you'll see later, I've heard it both ways and don't think it makes any difference. I suspect the factory version is rear mounted to reduce production costs.

6. For the T-27 surround I used an inexpensive felt stripping used for insulating door jambs. This is available in ⅜ widths and can be laminated as Davenport describes. Try your local hardware store.

7. I did not use birch ply as the specs require as it was not available to me locally (or so I thought. I have now located a supply). However, I recommend that those looking to build these units find some. Don't ask for birch plywood because what you'll probably get will be birch veneer over pine. Ask for Baltic, or Russian Baltic plywood. This is all birch, has no voids, and can be recognized by its thin laminations. Half-inch Baltic plywood has nine layers of laminate rather than the five or seven of pine. It is, of course, more expensive but not outrageously so.

Some changes I made in the original design which one might like to try:

1. The decoupling of the B-110 [from the cabinet] requires more than the use of rubber grommets. In addition to these I used a ¼" high density foam gasket made from the foam padding commonly used under typewriters. This gasket can be cut using the template supplied with the B-110. Along with the adhesive-backed foam used to mount the front baffle, this has a pronounced effect on reducing cabinet vibrations. This same foam, by the way, can be used under the speaker boxes to help decouple them from whatever they are mounted on.

2. I have added another layer of felt around the T-27 inside the original barrier. This had a very subtle effect on treble clarity and imaging—it's just a little cleaner sounding.

3. I have recently bypassed all the caps in the crossovers with .01 polystyrenes. Of all the modifications, this one has had the most noticeable effect on sound quality, although the folks at Falcon may not approve. Overtones, especially those for higher frequencies, seem more apparent and there is considerably more depth to the sound stage. This was a cheap mod, about $1.00 per speaker, and I recommend readers to give it a try.

Prior to these most recent modifications, I had listened to my speakers, under varied conditions, against the Rogers LS3/5A, the KEF 101, and two versions of the home made Falcon design, one with the standard sized cabinet and one with a 9" deep cabinet. The most critical listening was done against the Rogers. Here I was assisted by Mark Balkowitch, owner of Audio Perfection here in Minneapolis, and a man possessed of an acute, and well trained Golden Ear. His impressions, briefly stated, were that the Falcon had a slight "ooh" quality in the midrange, and that the upper frequencies were slightly "confused" compared to the Rogers. In my opinion, the Rogers had a more spacious quality but that overall the differences were really quite minor. The "ooh" quality, by the way, may be attributable to the wood I used for my cabinets which was birch veneer lumber core.

The KEF 101s by comparison were surprisingly less musical than the Falcon. They had a distinct recessed quality in the midrange and sounded dead and dry. The two home made systems were virtually indistinguishable from mine with the exception of the 9" model which had a somewhat more pronounced but wooly bass.

After I built my speakers I had the opportunity to have frequency response curves run by Don Kleiwer of Soundmates/Janszen and Mike Shields of DLK Acoustics here in the Twin Cities. Originally my speakers had a very pronounced hollowness in the midrange, probably greater than the recessed quality Sabransky mentions in his listening test. On the curves this was shown to be a very deep trough between 1 and 4k, about 8dB down at 1200Hz. In consultation with another ASM member, Don Neal, the value of one of the resistors on the B-110 side of the crossover was dropped from 33Ω to 20Ω. This corrected the problem as later curves showed.

In my article for the ASM Monitor I discussed this anomaly in a bit more detail and provided the before and after response curves so that builders can get an idea of the change. Also included are some interesting polar response curves. The "after" curves and polars were done using a B&K gated sine wave set up while the "before" curves were done with a normal sine wave method. Copies of the Monitor containing this article can be obtained for $1.00 by writing the Audio Society of Minnesota, Box 3341, Traffic Station, Minneapolis, MN 55403.

I agree with Davenport that this is an excellent speaker, especially since it's so inexpensive. Being small and simple it also lends itself to experimentation. The crossover is quite complex and although Falcon might disagree, it can be tinkered with too. In fact, as in my case, it may need to be. I hope other *Speaker Builder* readers will

build similar units and share their experiences with us. As for me, I'm about half way through building the Linkwitz design using the Sanders' transmission line for the bass. When they're done I'd be happy to share my conclusions with the readers, if I have any energy left!
Charles Lyle
Minneapolis, MN 55417

MONITORS DELIGHT

David Davenport's article on the Falcon Monitor Kit [4/81] was significant to me because I built this same kit recently, but got the parts from Badger Sound Services, who advertise in these pages. My kit does not have the modified tweeter section, and the crossover parts must be assembled on a perforated board.

My pair sounds really marvelous, and a friend who has the original Rogers version says he cannot distinguish the sound between his and mine.

Having built the Webb, the Daline, and the "Pirate LS3/5a," as well as other speakers, I can say that the real attraction of this compact speaker is its image. Many people are willing to live with the real limitations of this design: very limited bass dynamics, lack of real bass (the same woofer in the Daline enclosure is astounding), and a very occasional tubby sound.

The Webb and the LS3/5a have a similar image which can be equally satisfying. So, on the basis of living with both systems for some time, I would say that the Webb speaker is decidedly preferable on an absolute basis, whereas the LS3/5a is preferable *only* in small rooms. The Daline's true attraction is its *very* wide range response made possible by the enclosure design and by its outstanding super-tweeter, the Coles 4001 G. But the Daline image is consistently up-front, with very little depth. This, in itself, does not bother many listeners who love the Daline sound.
Carlos Bauza
San Juan, PR 00936

MATH WRATH

I am renewing my subscription for the last time unless a basic change is made in your magazine.

You must realize that I as well as hundreds of other subscribers are rank beginners in speaker construction and subscribed to your magazine to learn *how*. I (we) also don't know advanced math. As currently edited, your magazine cannot be understood.

I would like to see plans for advanced speaker systems laid out in simple step by step instructions with the math relevant to proper bass alignment and crossover networks worked out (or provide us with the instruction to work out) in general math terms—not algebraic symbols.
Russell Novak
Brooklyn, NY 11217

We will do our best to simplify where we can. I suggest that a moderate sized calculator will do any math which has appeared thus far in SB.—Ed.

LOUDSPEAKER LIGHTUP

I truly enjoy *Speaker Builder*. The four part series by R. M. Bullock, III was lucid and probably the best tutorial I've read on "Thiele-Small" loudspeaker design. This series of articles plus the lively dialogue found in *Letters* (e.g. the exchange between Wagner and Sanders, *SB* 4/1980) has strongly ignited my interest in speaker design.

I appreciate the high technical level of many of your articles. Apparently you respect and recognize the ability of your readers.

I do see one serious problem to 'Design and Construct Your Own Speaker System'; there really is no reasonable way, myself or any home designer can objectively evaluate his work. Perhaps, *SB* could, in future issues, address this issue.

PHILLIP TROSKO
Troy, MI 48099

We will attempt to find and publish articles on computer aided tests, which is the most promising avenue to significant speaker evaluation.—ED.

HELPS AND TIPS

AS A REGISTERED ARCHITECT, and a long time audio equipment builder, I thought I should share some info not obvious to some of your readers. I find a recent book very useful in learning quantitative test techniques *How to Design, Build, & Test Complete Speaker Systems* by David Weems, Tab Books, No. 1064 (Old Colony T-4). This little gem has much info for the novice. I've bound just the test chapter for ease of access.

Two suggestions from my experiences; 1. no one should miss reading Thiele, Small and other important contributors to the *Journal* of the Audio Engineering Society. These journals are usually available through interlibrary loan programs. In Peoria I order from Western Reserve in Macomb. My own reference library is focused upon crossover design and works by the men mentioned above. Most of the articles date from 1969* on.

Continued on page 42

TABLE SAW BASICS

Continued from page 29

Woodworking Magazine[6] is an excellent source of ideas, although some of its articles may seem too exotic for the average hobbyist. I have learned more about woodworking techniques from reading this magazine for three years than from 20 years of reading the popular press type of shop article.

SUMMARY

I hope this article will help many speaker builders set up their table saws. In particular I urge you to try the *Fig. 2* "flip test" to true a saw: it will save you much grief over the long run. I recently sold the 10" motorized saw which appears in these illustrations and bought a "previously owned" larger saw, so now I have to go through the trueing up procedures all over again. But now I know what to do. I arrived at all the methods described in this article only after much head scratching, asking many questions of friends, and searching out many books and articles.

ACKNOWLEDGEMENTS

I thank Jim Finale and Joe Owens for their generosity in lending me many wood-working books and magazines. I'm also grateful to Fred Buechler for the photographs.

THE AUTHOR

Dr. Bruce C. Edgar is a space scientist for the Aerospace Corporation and an avid woodworker-speaker builder.

REFERENCES

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Tools, Tips & Techniques

Continued from page 34

which helps to keep down the cost of quality passive crossovers.

The final board on the bottom right of *Fig. 1* is a true photo-etched board that will pack a variety of midrange and tweeter crossovers. Why photo-etch a crossover board? Because they are free. I make all my photo-etched circuit boards on 3 x 6" presensitized stock. If the board layouts don't use up all the board area I add some useful little board to use up the free area. Boards to mount single op-amp stages, 555 timer stages, LEDs and dummy load or crossover boards are always handy candidates.

Let's get back to the "knife-cut" boards. As the name implies, they are made by cutting and peeling board scraps. I have used all three major board types, paper based phenolic, glass mat polyester and glass epoxy with equal ease, but glass epoxy is tough on your knife's edge! Each side of the copper strip to be peeled is cut and recut a couple of times with the knife, then the copper is lifted at a corner and peeled. You will find 2 oz. copper is easier to peel as it is less likely to break or tear.

Once the unwanted copper is peeled leaving the desired copper pattern, I drill holes and mount the parts normally. [Lightly center-punched dimples at hole locations will make drilling easier and avoid broken drills—Ed.] This includes cleaning up all the copper before trying to solder in the parts with fine steel wool. I tin the entire copper area with my iron as the parts are installed to give an environmentally protected surface that will allow future parts replacement or modification. I have had no board bowing problem or lead attachment failure with these large tinned areas.

With some practice reasonably complex circuits can be done with this technique. It makes a quick and convenient way to mount crossovers inside cabinets, rattle free and with secure soldered connections.

G. R. Koonce
Liverpool, NY 13088

Mailbox

Continued from page 40

2. Whenever I design a speaker system for someone, I usually make a data or spec sheet for their reference in making repairs or to aid in the resale value. Most of the systems I have designed are distributed throughout the US, and many have gone from friend to friend. (Speakers make a splendid wedding present, and a kit of tested parts with full instructions saves weight over long distances.)

I encourage you to continue the excellent publication. I hunger for more info, especially in application of testing techniques and interpretations of recent developments in the more technical engineering works.

Those readers in my area may write with questions about my library and/or designs. We have one store marketing speaker components here in Peoria (exclusively parts) but not much discussion takes place. We all grow when we share our knowledge.

LAR DAVIS
735 Knoxville
Peoria, IL 61606

*A review of a new *Loudspeaker Anthology* from the Journal which includes the Thiele and Small articles begins on p. 34, of 3/81.—ED.

KEF USAGE

I HAVE A FEW comments that you might pass on to Mr. Weil (*SB* Mailbox, 3/81). First, although the KEF B110 has been used very successfully in the Rogers LS3/5a and KEF 101, I have not been overly excited about its sonic characteristics when purchased separately and used with a home-built crossover. I don't doubt that the more elaborate crossover that KEF uses in their 101 offers better sound than the crossover they sell separately; it certainly contains more parts. The LS3/5a crossover is also more complex. I also understand that there are several different versions of the B110 and that possibly the version used in the 101 is inherently less colored than the one sold separately to the public.

I do know that when I used the KEF B110 (borrowed from a JR 149) as a midrange (500Hz-3500Hz with 6dB/octave crossovers), I detected a slightly hard, edgy sound from the midrange. Linkwitz points out that the B110 has a cone resonance at 5kHz, and one should use steep crossover slopes to avoid this, which of course, the first-order filters I used did not. Perhaps this resonance is still apparent, even with Mr. Weil's third-order filters, and the only solution is to get a different driver—or perhaps a notch filter could be carefully designed.

Second, the KEF T-27 tweeter has a large, undamped resonance at 1-1.4kHz (each tweeter seems a little different). This is very audible with first-order filters and may still be audible with third-order filters. This resonance can be cancelled electrically in the crossover with a tuned RCL circuit! Since each tweeter has a different resonance, each requires a slightly different resonance cancellation circuit. Perhaps KEF can do something of the sort when matching parts for their 101's. The home builder must measure his tweeters individually and design his crossovers accordingly.

Third, the one experience I have had with the KEF DN13 SP1017 crossover was that it uses the bare minimum of cheap parts. I believe the speaker builder is much better off designing his own crossover rather than using KEF's. Using an inductance compensation circuit on the B110 and inductance compensation and resonance cancellation circuits on the T27 produces nice, flat impedance curves for the drivers and makes it possible to use textbook first—or third-order filters with good results? One should also use polypropylene and polystyrene capacitors as much as possible.

In conclusion, I believe that improvements can be made for the loudspeaker, but the system will probably never be totally uncolored. I hope that future issues of *Speaker Builder* will provide help in loudspeaker crossover design. I, and perhaps other amateur speaker designers, know little beyond the basic filter designs.

Max Knittel
Bellingham, WA 98225

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1. A.N. Thiele, "Optimum Passive Loudspeaker Dividing Networks," Proceedings of the IREE (Australia), July 1975, pp. 220-224.
2. A.N. Thiele, "Another Look At Crossover Networks," *Audio*, August 1978, pp. 38-45.

DOUBLE CHAMBER FUN

I BUILT A PAIR of speakers with the "Double Chamber Speaker Enclosure" design (*SB* 1/80, p. 7) using 2 Rockwell 8's, a Peerless 2" dome, and a 1" SEAS. The performance was very good, particularly in the mid-bass. I did have a noticeable dip at 75Hz which may be due to small changes in proportion made for a vertical design.

A scaled down version using, 6½" units did well down to 50Hz. The double-chamber design is much superior to the passive radiator designs I have been playing with. Also I am convinced that two small woofers are better than one large one, easier crossover also.

I am really pleased with *Speaker Builder*. Since starting on this madness about two years ago, I have built about 10 pairs of speakers, trying different designs from acoustic suspension, to labyrinth, to horn. Your magazine certainly covers a wide range of skills and interests.

I am most interested in passive crossover networks. Those I have seen published by manufacturers are quite over-simplified and it is hard to believe that these are actually used. Veil of secrecy?

I am looking forward to future issues.

Frank N. Nichter
Sebring, FL 33870

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Recently we have had letters, quite unsolicited, from several readers suggesting that if we wished to make their names available to those vendors whom we consider might be of some interest to them, they would have no objection to rental of our list for such purposes.

We have decided to change our policy about mailing list rental and will consider such proposals in the future. We will restrict rentals to reputable firms whose products we consider to be of interest to you. We also exercise strict control on any unauthorized use of our lists by secondary sales of the information to other users.

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ST. LOUIS, MISSOURI 63135

Issue #5 is now available. It contains reviews of the ACM Linn platter assembly, the CART-A-LIGN alignment protractor, the JMAS moving-coil cartridge, LAST record treatment, the ACM, LEVINSON "Silver", and MENDOTA interconnecting cables, the MAGNEPAN Unitrac I pickup arm, the MARCOF PPA-2 headamp, the ORSONIC DS-250 disc stabilizer, the SUMO "Nine" power amp, and the WIN LABS SDC-10 turntable. Issue #5 also features a survey of 9 turntable mats, and another survey of 19 speaker cables.

Subscription rates to AUDIO HORIZONS for four (4) issues are: U.S.A.- $20 (FIRST CLASS MAIL); Canada and Mexico- $22 (FIRST CLASS MAIL); and outside North America- $26 (AIR MAIL). PLEASE REMIT IN U.S. FUNDS ONLY. Sample copies of all issues are available for $6.00 each (U.S.A., Canada, and Mexico), and $7.50 each (outside North America).

Classified

PRIVATE FOR SALE

Pair of KEF B-139's, never used, $130. pr; KEF B-110's, one used, one not, $55. pr; Pair of EV SP12C 12″ woofers, both good condition. Pair EV T-35 (Arnico) H.F. horns, $65. w/separate 10′ transmission line enclosures (Sanders TL) never used $250. pr. (designed for 10″ woofers). JVC ribbon tweeters, never used, $30 pr. Dan Hildreth, (602) 968-0027 or 894-2376.

Pair ¾″ liquid cooled tweeters for AR-11, $50/pr; tweeters for AR-3A, 2AX $45/pr; 1½″ midrange for AR-3A or 11, $60. each. Postpaid. George, 1069 Riverview Dr., Macedonia, OH 44056.

Magnaplanar Tympani III T/M with *TAA* X-over, $575; Marantz 15 60x2 amp, $165; Harmon Kardon Citation 12 60x2 amp, $140; Hafler DH-200 100x2 watt amps (2), brand new kits, $250 each. KEF B-139 drivers, $90 pr. Will consider offers. Rich Davidson, 501 Paige Loop, Los Alamos, NM 87544. (505) 672-1094.

Audio Pro B2-50 subwoofer, mint, walnut, $525; Yamaha M4 amplifier, C4 preamplifier, brand new, sealed boxes $650 the pair. Yamaha MC-1S cartridge, new sealed, $110. Bill Gallagher, 723 Higganum Rd., Durham, CT 06422. (203) 349-1560.

Transcendental Audio pair of unboxes w/8″ GAS drivers, pr. KTS 150 ACS crossovers; pair Jordan modules and unbox enclosures. Pair JVC ribbon tweeters, 2 pair 5″ Dalesford drivers, pair of heavy enclosures for push-pull alignment with 5″ Dalesfords, Rowland board for Win Labs or Panasonic strain gauge cartridge. Everything half price. Robert Kealhofer, 2416 Via Amador, Palos Verdes, CA 90274, (213) 541-2968.

Altec 604-E duplex speakers w/custom made 1500Hz crossovers, $550. pair. JBL 136A 15″ woofers w/foam surrounds and new cones, $270. pair. E-V T350 tweeters, $65. each. ESS-Heil air motion tweeters, $80. each. Will trade for old speakers and mic's. T. Young, 171 Moreland Ave., Waterbury, CT 06705.

Philips 212 electronic turntable, EC, $65; Heathkit Stereo FM generator, EC, $75; Octalizer frequency equalizer, slide pots, w/o power supply and chassis, $45; Eico 35 watt tube amplifier, $35. R. Beem, Rt. 2, Box 277, Commerce, GA 30529.

Kenwood KD-500 turntable, Grace 707/II tonearm, Sonus Silver P cartridge, with soft plastic dust cover for $225. (list $480). DBX model 21 disc decoder $75. (list $119). Harman Kardon 2000 cassette deck, 2 years olds, recently realigned and recalibrated, $200. (list $480). All units in A-1 shape. Ambrose Sims, 51 E. Springfield, Champaign, IL 61820. (217) 398-6455.

Speaker drivers—prices include shipping. SEAS 33FWKA, 13″, $85; SEAS 21FWBX-DD 8″, $35; SEAS H107 dome tweeters, $13; SEAS 13FGMB 5¼″ midrange, $18; Peerless KJ20DMR dome midrange, $20; Peerless 5¼″ polypropylene cone, $16; Pyle W69C290F 6x9 woofer, $27; Becker 908A278 8″, $18; Metal grilles for Peerless 5¼″ woofers, $5; Polydax HD17HR37 6½″ open-back midranges, $40. Also Koss ESP 9 headphones, factory overhaul, $65; Dynaco Mark VI, new tubes $600 pr. (no shipping); Signet TK7E, needs new stylus $50. All drivers new; some have solder marks made during test. Steve Fritz, (805) 969-1977 between 2-7 PST.

Hafler DH-500K, $500; DH-110K, $245; SAE 30pre, 31Bamp $225; Biamp Systems TC-60 amp, SAE 30pre, blk rack, $325; Sony PS-X600 Biotracer, $285; FX-6C Doly C cassette, $290; Phase III alum. box mini w/car brkts, $70. pr. Marantz 140 power amp, meters and vol. cont., mint, $225; Dyna ST-80A, very good, $100; Sony TCK-55 cassette, excellent, $150; TEAC 450 cassette, excellent, $200; Falcon mini in vinyl box, $140 pr.; Chronosonic 100 Quartz LCD Domino alarm clock, car and desk brkts., $17; Heath 5½″ 'scope w/complete set test gear, ideal for speakers, etc., $160. Audio Control:C-50A spectrum analyzer, $285; C-22 equalizer, $185; Concord CMC-300 hi-output M/C cartridge w/line contact styli, no head amp needed, new, $80. W. Gabriele, 1334 Chapel St., New Haven, CT 06511.

WANTED

Horn design info. Will buy or trade for magazines, tech. pub. or Xeroxes. Send list and prices to T. Young, 171 Moreland Ave., Waterbury, CT 07605.

Plans for building the eight inch (speaker size) Karlson speaker enclosure. These enclosures formerly were sold in kit form. Robert Desmarais, 8507 Corbin Dr., Anchorage, AK 99507.

Janszen 130 Electro-Static 8 ohm power supply or transformer. Speaker would be ok but grids are not required. W. Stanley, 963 E. End Ave., Pittsburgh, PA 15221. (412) 242-7914.

Dukane Inovac tweeters, model DUK-5 with external power supply box. In any condition. Jack Boyle, 107 Buckingham Dr., Vincentown, NJ 08088. (609) 859-3849.

Tweeter modification info. I am interested in hearing from anyone who has successfully modified sealed back dome tweeters to open transmission line style i.e. KEF 50mm dome. M. Campbell, 175 Woodvale Bay SW, Calgary, Alberta Canada.

1960s British speakers: Tannoy (8 ohms only), and Altobass Ltd. 12″, 10″ dual concentrics. Goodmans twin cone axioms, triaxioms 12″, 10″. Stentorian 15″ duplex coaxial. Lorenz 12″ coaxial LP 312-2. Racon 15″ triaxial #15 HTX. Trusonic (Stephens) 12″, 8″ coaxials. Calrad 12″ triaxial #12 TX-1, 12″ coaxials, 8″ coaxial #CR-8X. Stromberg-Carlson 12″ coaxials. RCA 12″ biaxial SL-123, 15″ # LC-1A. JBL #077 tweeters, crossovers. GE 12″ coaxial #1A-401. Singles ok. No cabinets. Write friends. Kalish, Box 52, Redlands, CA 92373. Call collect (714) 792-0220.

ADVERTISING INDEX

Old Colony KITS

Box 243
Peterborough NH 03458

POLICY: OLD COLONY SOUND LAB is a service agency for readers of *The Audio Amateur and Speaker Builder* magazines. It attempts to provide circuit boards and the basic, or hard to find, parts for construction projects which have appeared in the magazine. **Old Colony assumes that the constructor will use the *Audio Amateur* or *Speaker Builder* magazine article as the guide for building his unit.** Kits, with noted exceptions, are not priced to include article reprints or construction instructions. Old Colony kits, with stated exceptions, do not provide metal work, cabinets, line cords and the like. We suggest that before purchase amateurs secure and evaluate the articles, which give details on each unit. Kits vary widely in complexity and required construction skills. A very few can be assembled by the beginner. If you are just starting in audio, get some experience building Heath or Dyna kits before tackling an Old Colony kit, or locate an experienced friend to help in case of difficulties.

CROSSOVERS

ELECTRONIC

For both electronic crossovers: crossover points and R_1, R_2, C_1, C_2 MUST be taken from Fig. 3, p. 11, Issue 2, 1972, TAA. No other values can be supplied.

KC-4A: ELECTRONIC CROSSOVER, KIT A. [2:72] Single channel, *two-way*. Values of R_1, R_2, C_1, C_2 must be specified with order. All parts and C-4 circuit board. Includes new LF351 ICs. Each **$8.00**

KC-4B: ELECTRONIC CROSSOVER, KIT B. [2:72] Single channel, three-way. Values of R_1, R_2, C_1, C_2, must be specified with order. All parts and C-4 circuit board. Includes new LF351 ICs. Each **$11.00**

KK-6L: WALDRON TUBE CROSSOVER: Low pass. Single channel, 18dB/octave, Butterworth, [3:79] includes Bourns 3-gang plastic pot, level control, Mullard tubes, board, and three frequency range determining capacitors. *Specify ONE frequency range per kit please.* (Hz.): 19-210; 43-465; 88-960; 190-2100; 430-4650; 880-9600; 1900-21,000. Single channel. Each **$43.00**

KK-6-H: WALDRON TUBE CROSSOVER: High pass. Single channel, 18dB/octave, Butterworth, [3:79] includes Bourns 3-gang plastic pot, level control, Mullard tubes and 3 frequency determining capacitors. Please specify **one** of the frequencies above. No other can be supplied. Each **$45.00**

KK-6-S SWITCH OPTION. 6-pole, 5-pos. rotary switch, shorting, for up to five frequency choices per single channel. Each **$8.00**
When ordered with two kits above, Each **$7.00**

KK-7: WALDRON TUBE CROSSOVER POWER SUPPLY. [3:79] All parts, including board, transformer, fuse, semiconductors, line cord, capacitors. Will power four tube x-over boards (8 tubes), one stereo bi-amped circuit. Each **$88.00**

SBK-A1: LINKWITZ CROSSOVER/FILTER. *Speaker Builder's* [4:80] first kit, including all parts and board for one channel of the three-way crossover/filter/delay. 24dB/octave at 100Hz and 1.5kHz and 12dB/octave below 30Hz, with delayed woofer turn-on. Board is 5½ x 8½. Requires ±15V supply, not supplied. Use the Sulzer supply KL-4A with KL-4B or KL-4C. Per channel **$64.00**
Two channels **$120.00**
SBK Board only Each **$14.00**

PASSIVE

KF-7: CROSSOVER FOR WEBB TLS. [1:75] Passive four-way crossover, in pairs, assembled. Components are included for both STC and Celestion tweeters. Made by Falcon of England. Pair **$87.50**

FILTERS & SPEAKER SAVER

KF-6: 30Hz RUMBLE FILTER. [4:75] Two channel universal filter card supplied with WJ-3 (F-6) circuit board and all basic parts, 1% metal film resistors and 5% MKM capacitors for operation as an 18dB/octave 30Hz rumble filter. 30Hz, 0dB gain only. Kit may be adapted as two- or three-way single channel crossover with added capacitors and resistors. Each **$19.75**

KH-2A: SPEAKER SAVER. [3:77] This basic two-channel kit includes board and all board-mounted components for control circuitry and power supply. It features turn-on and off protection and fast opto-coupler circuitry that prevents transients from damaging your system. 4PDT relay and socket included. Each **$35.00**

KH-2B: OUTPUT FAULT OPTION. Additional board mounted components for speaker protection in case of amplifier failure. Each **$6.75**

KH-2C: COMPLETE SPEAKER SAVER WITH OUTPUT FAULT OPTION. Each **$40.00**

KK-8: COMPEX C. Two channel board with all parts to compress signal, including 1% polycarbonate capacitors and large tantalums. [3:79] Each **$45.00**

KK-9: COMPEX E. Two channel expansion board with all parts including precision Rs & Cs, [3:79] Each **$35.00**

KL-5 WILLIAMSON BANDPASS FILTER. [2:80] Two channel, plug-in board and all parts for a 24dB/octave 20Hz-15kHz with precision cap/resistor pairs. TL075 IC's. Each **$31.00**

SYSTEM ACCESSORIES

KH-8: MORREY SUPER BUFFER. [4:77] All parts & board for two channel output buffer to isolate tape outputs in your preamp from distortion originating in a turned-off tape recorder. Many uses for this versatile matchmaker. Each **$14.00**

KH-9: TONE ARM MOUNT BOARD. For the Thorens TD-124 turntable. Exact fit, unpainted fine grade hardwood. Three countersunk holes drilled to fit frame. Each **$3.25**

KF-1: BILATERAL CLIPPING INDICATOR. [3:75] Single channel, all parts and board for any power amp up to 250W per channel. (Does not work well with Leach Amp). Powered by amp's single or dual polarity power supply. Each **$5.50**
Two kits, as above **$8.25**

KJ-3: TV SOUND TAKEOFF. For extracting the TV set's sound to feed your audio system [2:78] Circuit board, vol. control, coils, IC, co-ax cable (1 ft.) and all parts including power transformer. Each **$21.50**

KJ-4: AUDIO ACTIVATED POWER SWITCH. Turn your power amps on and off with the sound feed from your preamp.[3/78] Includes all parts except box and input/output jacks. Each **$50.00**

KK-14A: MacARTHUR LED POWER METER. [4:79] Two channel, two sided board and all parts except switches, knobs, and Mtg. clips for LEDs. LEDs *are* included. No chassis or panel. Each **$110.00**

KK-14B: MacARTHUR LED POWER METER. [4:79] As above but complete with all parts except chassis or panel. Each **$137.50**

KL-2: WHITE DYNAMIC RANGE & CLIPPING INDICATOR. [1:80] One channel, including board, with 12 indicators for preamp or crossover output indicators. Requires ±15V power supply @ 63 mils. Single channel. Each **$49.00**
Two channels. **$95.00**
Four channels. **$180.00**

BENCH AIDS & TEST EQUIPMENT

KH-7: GLOECKLER PRECISION 101dB ATTENUATOR. [4:77] As basic to measuring as a good meter, and more accurate than most. All parts except chassis and input/output jacks to build author's prototype including all switches and loads. Resistors are MF 1% and 2% types. Each **$50.00**

KB-8: INVERSE RIAA KIT. Six precision components to shape your audio signal generator's output to the response curve of a recorded disc. Checks phono preamp inputs. Each **$5.75**

KL-3C: INVERSE RIAA NETWORK. [1:80] Two channels, 1% polystyrene capacitors and metal film resistors, gold jacks, cast aluminum box, solder lugs and alternate 600 ohm or 900 ohm r_2'/C_2' components. Each **$35.00**

KL-3R: INVERSE RIAA. [1:80] Resistor/capacitor package complete. Stereo R_2'/C_2' alternates. Each **25.00**

KL-3H: INVERSE RIAA. [1:80] Box, terminals, gold jacks, and all hardware, (No resistors or caps) in KL-3C. Each **$13.50**

KF-4: MORREY'S MOD KIT FOR HEATH IG-18 (IG 5818) SINE-SQUARE AUDIO GENERATOR. [4:75] Includes two boards and all added parts needed to modify the Heath unit to distortion levels of parts per million range. Replacement sine-wave attenuator resistors not included. Each **$35.00**

KG-2: WHITE NOISE/PINK FILTER [3:76] All parts, circuit board, IC sockets, 1% resistors, ±5% capacitors. No batteries, power supply or filter switch. Each **$22.00**

KJ-7: VTVM BATTERY REPLACEMENT KIT. [4:78] All parts to replace your VTVM's battery with a regulated supply. Each **$7.50**

KJ-6: CAPACITOR CHECKER. [4:78] All parts to build an accurate meter for measuring capacitance, leakage, and insulation. Check phono & speaker lead capacitance effects. Includes all parts with 4½" D'Arsonval meter. Each **$68.00**

KK-3: THE WARBLER OSCILLATOR. [1:79] For checking room response and speaker performance without anechoic chamber. All parts and board. Each **$56.00**

KL-6 MASTEL TIMERLESS TONE BURST GENERATOR. [2:80] All parts with circuit board. No power supply. Each **$19.00**

KM-1: CARLSTROM-MULLER SORCERER'S APPRENTICE [2:81] All parts except knobs, chassis. Includes four circuit boards. For construction of the first half of A Swept Function Generator, with power supply. Each **$145.00**

KM-2: CARLSTROM-MULLER PAUL BUNYAN. [3:81] All parts except knobs, chassis, output connectors and wire. Includes two circuit boards and power supply. Each **$85.00**

KM-3: CARLSTROM-MULLER SORCERER'S APPRENTICE/PAUL BUNYAN [2:81, 3:81] All parts in KM-1 and KM-2. Each **$225.00**

ORDERING INFORMATION

Prices, except as noted, are prepaid in the USA and insured. We prefer to ship via UPS, which requires a street address. If you cannot receive UPS delivery, please include an extra $2 for insured service via Parcel Post. We cannot accept responsibility for safety or delivery of uninsured Parcel Post shipments. PLEASE ADD $1 service charge for all orders under $10. PRICES SUBJECT TO CHANGE WITHOUT NOTICE.

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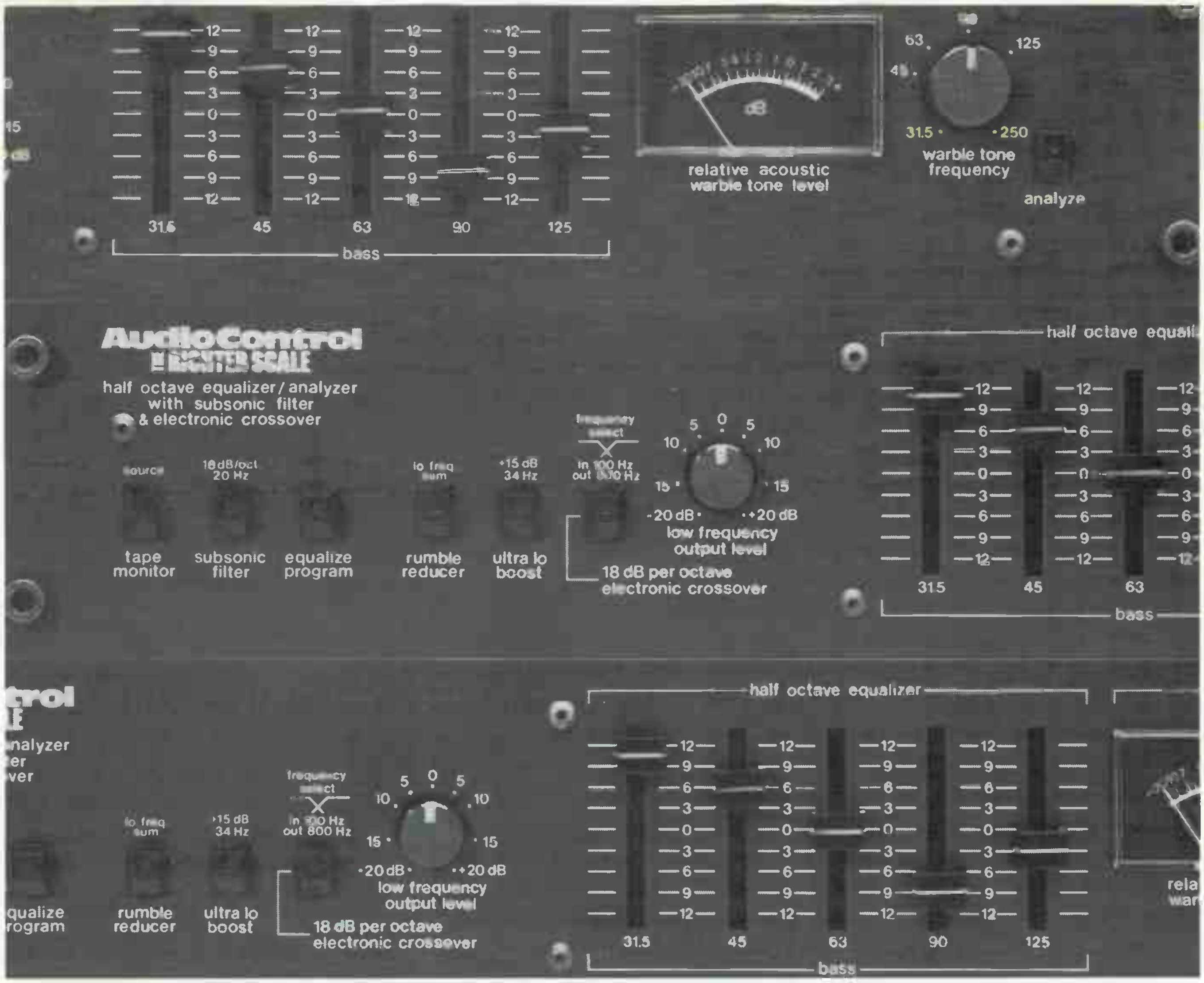

NEW HOPE FOR UNDERSIZED BOTTOM ENDS.


±1dB 20Hz-20,000Hz.

The Richter Scale™ is the world's first half-octave bass equalizer with built-in electronic crossover, Rumble Reduction Circuit, 18dB/octave Subsonic Filter, Ultra-Low Bass Boost circuit, sweepable Warble Tone Generator and Measurement Microphone. All in a unit just 14" x 2.5" x 6."

For precise equalization the Richter Scale employs a half-octave Warble Tone, the same type of test source used by B&K for calibration of its precision microphones under 150Hz. The stereo output tone is read with an Audio Control phantom-powered condenser Measurement microphone and a special damped ballistics dB meter.

The Richter Scale's Rumble Reduction circuit mono's bass under 200Hz to cancel vertical record components and tonearm resonances.

The 18dB Tchebechev subsonic filter is down 24dB at 10Hz.

An Ultra-Low Bass Boost circuit adds +15dB at 36Hz, seemingly an overabundance of EQ, but in reality barely compensation for the cumulative loss from microphones, analog tape, and mastering, not to mention wimpy woofers.

The electronic crossover is a special asymmetrical design with 18dB/octave roll-off of bass and 6dB/octave roll-off of treble. In addition to 100Hz subwoofer and 800Hz 3-way crossover points, the unit is dealer modifiable to any other custom crossover point. A recent Stereo Review evaluation observed less than ±.25dB deviation from flatness across the whole audio spectrum.

Overall distortion was found to be .003% compared to our modest .015% published spec.

How much?

$249.

For either a half-octave equalizer/analyzer or electronic crossover alone, a stunning price.

Write us for more information.

And then enlarge someone's bottom end soon.


shown: D-11 octave/analyzer, R/S, D-10 octave

AudioControl

6520 212th SW Lynnwood, WA 98106