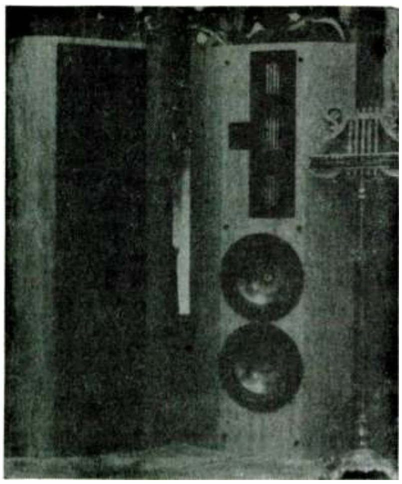
3/83 US $3.00

SPEAKER BUILDER

KEF's Cooke

Good News



If you are searching for sophisticated loudspeaker design, **INFINITY SYSTEMS** has a speaker just for you. The Reference Standard (RS) IIA accurately reproduces complex and demanding musical passages with three EMIT® tweeters, three newly developed EMIM® midrange drivers and two 10-inch polypropylene woofers.

The EMIT (Electromagnetic Induction Tweeter) is an ultra-thin, ultra-low-mass planar diaphragm driven by magnets of rare-earth samarium cobalt, several times more powerful than ferrite. This driver will reproduce up to 32kHz with transparent and exact detailing.

The EMIM (Electromagnetic Induction Midrange driver) is constructed of a highly damped low-mass diaphragm that is suspended in an enormous magnetic force-field. It delivers midrange frequencies with clarity, precise definition and accurate transient response.

The RSIIA's bass response, reaching down to 25Hz, is clean and crisp, utilizing acoustically inert polypropylene 10-inch woofer cones. The system includes an electronic control module for optimizing bass frequencies and phase response. Retail price is $2,800 a pair.

Write to Infinity Systems, Dept. S33, 7930 Deering Ave., Canoga Park, CA 91304.

MONSTER CABLE has begun shipping its Interlink high-resolution "bandwidth-balanced" cable for audio component systems. Introduced at last winter's CES, the cable is designed to increase clarity, dynamic range and imaging, while lowering distortion in the musical reproduction chain.

This new technology features a balanced line configuration of two identical litz wires inside a densely braided copper shield. The litz wire conductors incorporate a unique multiple-gauge construction that fine tunes audio signals for accurate response throughout the audible range. Since both sides of the waveform see the same impedance, variations in frequency response, phase disturbances and transient blur are virtually eliminated.

Price is $50 per meter pair. The cable is also available in custom lengths. Contact Monster Cable at Dept. S33, 101 Townsend Street, San Francisco, CA 94107.

The PS-30 is a new three-piece loudspeaker system from **DESIGN ACOUSTICS.** Similar in concept to the company's DA-30, this system includes many improvements. Its higher efficiency (90dB SPL per 1W at 1 meter) allows you to play it at room-filling SPLs with only 15W, while its nominal 8-ohm impedance allows it to work well with inexpensive low-powered amps.

To provide a more accurate image of the soundstage, the new system offers mirror-image asymmetrical driver placement. An improved mid-woofer/tweeter combination in the PS-5 satellites offers smoother output and better power-handling capacity, and its variable tweeter adjustment makes it adaptable to room acoustics. An Optimized Decade Crossover System is effective at 140Hz and 2.2kHz. Complete system price is $695.

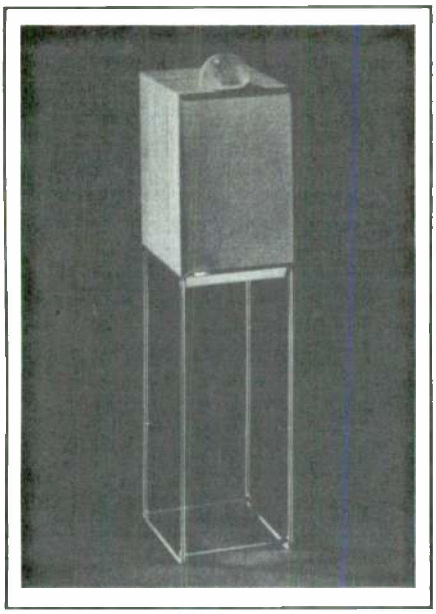
Design Acoustics is a division of Audio Technica, Dept. S33, 1221 Commerce Drive, Stow, OH 44224.

ACOUSTIC RESEARCH is ready to hit the road with two new car speaker systems. The AR1CS is a two-way, 5¼-inch, surface-mount system housed in a high-temperature, glass-fibre-impregnated, plastic mounting plate. A black steel grille "hood" also rides atop AR's ¾-inch, magnetic, fluid-injected dome tweeter. The driver features a 12dB/octave crossover slope, a 100W power rating and a 5¼-inch fully waterproofed woofer. It costs $129.99.

The single-driver AR3CS is a 4-inch, dual-cone, full-range, surface-mount system. Like the AR1CS, it offers a high-temperature housing and includes rear water shields. Suggested retail price is $64.99.

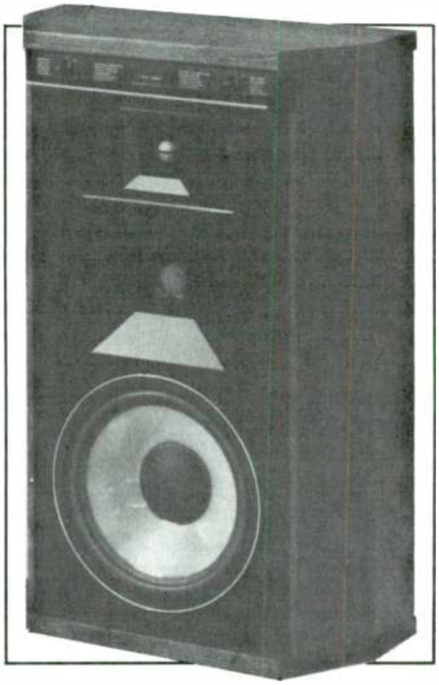
For more information, write to Teledyne Acoustic Research, Dept. S33, 10 American Drive, Norwood, MA 02062.

B&W's DM17 Limited compact speaker joins the company's two new digital monitors as the most recent additions to its products on the American market. The DM17 Limited is made for small listening rooms. Its two-driver system is arranged with the top-mounted treble unit time-aligned in relation to the bass/midrange driver. This combination complements the fourth-order crossover network to produce coherent, symmetrical sound. Performance is improved by a resonance-free cabinet and an automatic protection circuit. The DM17 Limited costs $395 per speaker.



The DM110 and DM220 digital monitors feature high sensitivity (not less than 90dB, 1W at 1 meter); a broad, extended and linear frequency response; and a dramatic production cost reduction. The DM110 is a two-way system that lists for $149 each, while the DM220 offers three-way sound for $249 each.

For information on B&W products in the Americas, contact Anglo American Audio, Dept. S33, 1200 Markham Rd., No. 506, Scarborough, Ontario, Canada M1H 3C3.



The CD Series speaker systems represent **ELECTRO-VOICE'S** new entry into the high-fidelity market. The three-way, time-coherent systems feature flat frequency response from 40Hz to 30kHz and a unique design called Controlled Directionality. This design evenly distributes the critical portion of the audio spectrum over a 100 percent area, horizontally and vertically. The speakers deliver 92dB from 1W, measured at 1 meter, and can handle up to 400W. Nominal impedance is 6 ohms, while crossovers are at 1.5 and 8kHz.

Two models are available. The type 35i has a removable grille; a tilt-down, brushed-brass time panel; adjustments for presence and brilliance; and the Automatic Power Sentinel, which warns of impending overloads. It costs $750 per speaker. The type 35 is a more basic model, with a permanently affixed grille and no speaker adjustments or Power Sentinel circuitry. It costs $550 per speaker.

For more information, contact Electro-Voice Inc., Dept. S33, 600 Cecil Street, Buchanan, MI 49107.

SPEAKER BUILDER
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About This Issue

When Contributing Editor **Bruce Edgar** goes globe-trotting, he carries his notepad and cassette recorder with him. His interview with KEF's **Raymond Cooke**, beginning on page 6, is one of the more informative we have had the pleasure of publishing. It is also encouraging to observe that a man of Cooke's candor, energy and intelligence is currently president of the Audio Engineering Society.

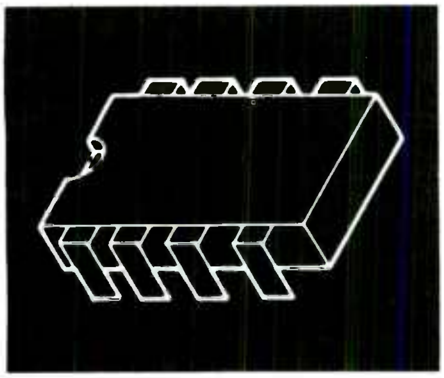
A major series by Contributing Editor **G. R. Koonce** begins in this issue (p. 12). For all those speaker builders who want to move more deeply into electronic construction as a means to build speaker systems based on more precise design data, Editor Koonce offers a whole series of devices that should fill the bill elegantly and inexpensively. If you have wanted a quick way to evaluate a set of drivers and estimate what size and shape of box you will need to house them, **Thomas L. Clarke's** handy nomograms (p. 26) might be just what you are looking for. **Robert Carlberg's** Odyssey is missing from this issue, but will return next time.

Andrew Keller's account of his update for a pair of venerable Advents and **Tom Nousaine's** pointer on dustless varnishing are our *Tools, Tips & Techniques* features this time. Note our "Thin Bin" call for more submissions to that department. A kit review of Acoustical Physics Laboratories' first product, a two-way, closed-box device with many interesting features, begins on page 34.

SPEAKER BUILDER

VOLUME 4 NUMBER 3 OCTOBER 1983

FEATURES



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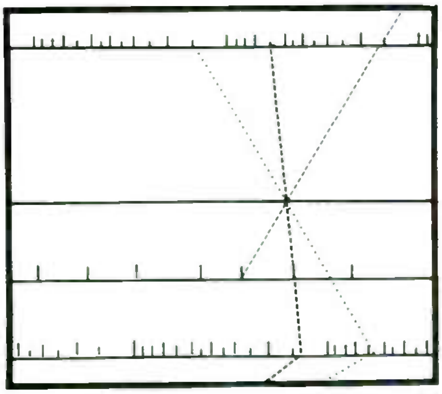

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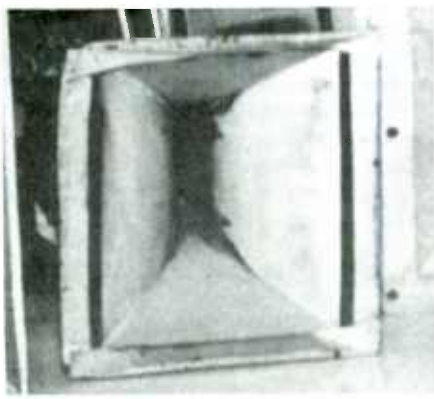

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DEPARTMENTS

Editorial

Face to Face

The development and growth of any human endeavor depends on interaction of minds and hearts. Publishing is one means of interchange. But that method is slow and lacks the immediacy, spontaneity and quick cumulative gains that are possible when we can plan, research and execute a project face to face.

My first editorial in *Audio Amateur* suggested audio clubs as a means to intensify, accelerate and enrich the pursuit of high-quality sound reproduction. Clubs have been slow in developing but are apparently now beginning to take hold and are forming at a faster rate than ever before.

The contributions of several clubs that have actively pursued important projects and published the results of those projects is invaluable. The work of the Boston Audio Society and the Southeastern Michigan Woofer and Tweeter Marching Society come to mind immediately. Such undertakings require exceptional skills and investments of large amounts of time, usually by a few dedicated group leaders. Large clubs are hard work.

The smaller groups that dot the country, however, provide an excellent forum, usually monthly, for the interchange of knowledge and production of modest newsletters to spread club news—to members and to other clubs. Clubs offer members opportunities to share instrumentation that might be too expensive for most members to afford individually. Clubs are usually able to borrow such equipment from local manufacturers for a weekend clinic that tests members' audio gear. Manufacturers are apparently finding it worth their while to travel the distances necessary to appear on club programs to discuss their particular approach to audio reproduction. Clubs are able to test and evaluate a wide variety of equipment, thus giving members more experience with a range of gear than they might have as individuals.

Since the founding of *Speaker Builder*, I have been continually amazed and delighted to discover that speaker builders are a special and unique breed of audiophile. They have turned up as authors from all points of the compass, each with a favorite way of turning those electronic impulses back into alternate compressions and rarefactions of air in a real room. The intensity of the speaker builder's interest is, I believe, a strong argument for local, intensive and regular face-to-face interchanges between speaker enthusiasts. Such meetings could provide interchanges of information, insight, skills and enthusiasm.

The "club" as a formal undertaking might, in the case of speaker builders, be more than is necessary. Small groups meeting informally could pursue a project or a group of projects that might be executed more easily by a group than by individuals working alone.

Six projects dropped into a pot could be cooperatively undertaken at one member's woodworking shop, at another's for finishing cabinets and at yet another's electronic workbench for crossovers and wire fabrication. One member might offer a series of seminars on electrostatic panel construction, then loan his jigs to other members who could build their own.

I can imagine a club making the necessary jigs and circuit board patterns to construct clones of the Quad 63 system. I also wonder why a group could not make the requisite patterns to replicate the Magneplanar speakers. Ken Rauen's excellent series on the Heil air motion transformers coupled to horns (*SB* 3/82, 4/82) would be far less work for a group of audiophiles who could produce a number of finished units together in less time than one amateur working alone.

Group action tends to spread skills. Neophytes learn from the experienced—and nothing is better than hands-on knowledge. The group can and usually does function as an evangelizing force. It can spread confidence to the uncertain and enlarge the hobby. And the size of the hobby has a clear relationship to how varied our choices of materials and our sources of supply become.

Groups with enough size and common interest might well use the club's group purchasing power to enjoy significant savings. Many audio clubs are taking advantage of that power in a number of ingenious ways.

Our classified ad columns have been open to audio clubs since this magazine's inception. Those of you who might feel the urge to meet with others in your area are invited to use the club classifieds. We will be happy to cooperate with established groups to put them in touch with all subscribers of this magazine in their region.

Audio club members might want to gather formal or informal subsections of the club for special-interest meetings on loudspeakers in general or some particular type of speaker. For example, our club classifieds currently list a club dedicated entirely to the Quad electrostatics.

Interchange enriches. Personal interchange among the like-minded enriches even more deeply. Perhaps speaker builders in your town are looking for you—or are just waiting to be found. □

AN INTERVIEW WITH RAYMOND COOKE

BY BRUCE EDGAR
Contributing Editor

Most speaker builders are familiar with the KEF driver line, but few people in the US know the story of why and how KEF started and has continued to flourish. In this time of change in the audio marketplace, KEF's maintenance of high-quality standards is a tribute to the leadership of its managing director, Raymond Cooke.

I recently spent a day visiting Cooke and his staff at the KEF factory in the village of Tovil (England), about 40 miles south of London. I came away from the visit with a new-found appreciation of KEF's success in integrating enclosures, drivers and crossovers and of Cooke's influence on this process.

Speaker Builder* (SB): *How did you become interested in audio?

Raymond Cooke (RC): At age 8, I took up the violin, joined an orchestra and started to learn music. But I did it purely mechanically. Three or four years later, through my father's record collection and his big horn gramophone, I suddenly became aware of orchestral color. I think the first trigger was a recording of the "Waltz of the Flowers" from the Nutcracker Suite made by Stokowski and the Philadelphia Orchestra in the early '30s. With that recording and a number of other things, I became interested in music and gramophones and began to collect second-hand records.

Then a young chum of mine started to mess about with electrical reproduction. I found an old pickup at home and hooked it up to a radio. With the improved reproduction, I became interested in loudspeakers and the whole business of designing amplifiers.

***SB:** What was your first job?*

RC: I first went to work at 15 as an analytical chemist for the London Northeastern Railroad. From there I went into the Navy. They had no use for chemists in the Navy, so they put me through a radio and radar course, and I became a technician. I rode out World War II in the Mediterranean Fleet and subsequently in the Indian Ocean Fleet as a radar technician. I was attached to a US-built aircraft carrier in the Royal Navy.

During the long waits between battles at sea, I did a lot of reading in the ship's library, which had been stocked in the US, and came in contact with American music and culture. I also began to design and build amplifiers using bits of circuitry out of these books. During that time I built a direct-coupled amplifier, doing away with the capacitor coupling between stages. When I came home, I had all this experience in music, amplifiers and loudspeakers. I started to take quite an intelligent interest in it.

***SB:** What did you do after the Navy?*

RD: After the war I went back to my old employer, the London Northeastern, as a scientist and worked on chemistry and metallurgy. But electronics still appealed to me because I could develop and build a circuit—and it would work. Also, I could look at a circuit and predict current flow and voltages. I really think that I was persuaded by Kirchoff's law. Chemistry always remained obscure to me. So I applied for a government grant to go to the University at the age of 21 or 22.

***SB:** What course of study did you take at the University?*

RC: I really wanted to pursue electronics and radio, but the nearest to it was electrical engineering. I had to study rotating machinery, but I managed to work in a few light current subjects. In my free afternoons, I used the telecommunications laboratory, where they had wave analyzers and signal generators, to experiment on pickups, amplifiers and the like.

I needed a good loudspeaker, so I used part of my war gratuity (bonus money) to buy one from Sound Sales in Surrey, a small company that made amplifiers, transformers and loudspeakers. It was in a reflex box and had a dual suspension, a spider for the outer rim of the cone and a spider on the inside of the cone. The voice coil was wound in the Voigt manner, with one layer on the inside and one on the outside of the former. It was crudely built, but it had real bass—something few loudspeakers had at that time.

***SB:** Is this when you really got serious about loudspeaker research?*

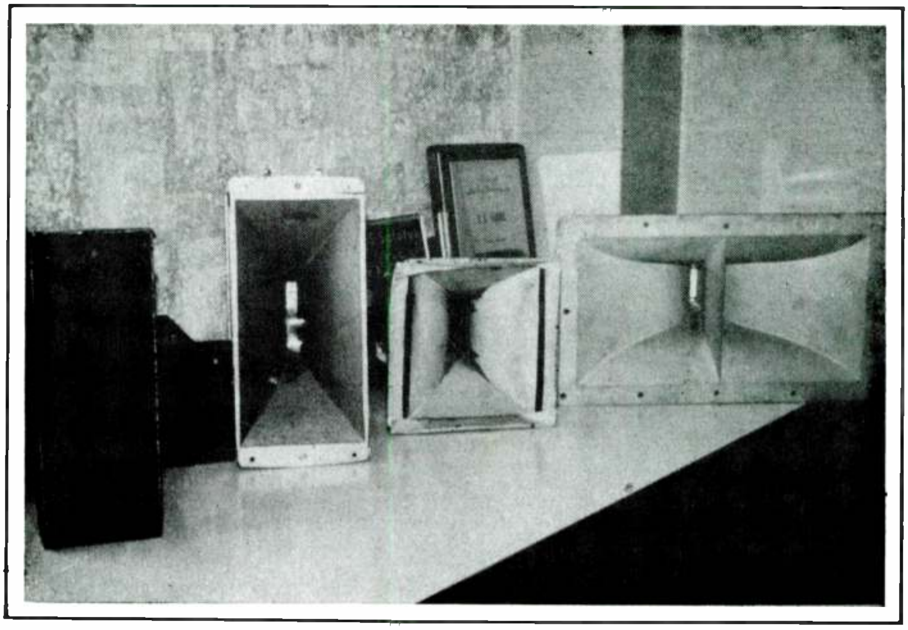

FIGURE 1: Cooke's collection of English ribbon horn tweeters includes, from left to right, the Quad Corner Ribbon, EMI ribbon, Kelly ribbon and Decca ribbon.

RC: Yes. I wanted to find out how this speaker worked—why the reflex action was beneficial. Hardly anything was published on it, and most of that was in magazines of doubtful repute. *Electronics* had published one article from the US on reflex boxes.[1] As it turned out, that magazine was quite a mine of information and gave me my first ideas about impulse testing.

In those days it was quite radical to think that you could test an acoustical transducer in a live room. Eventually, a friend and I used an FM probe to measure the acceleration and velocity of the moving surface. By painting some graphite on the diaphragm, we were able to get direct readings of the cone velocity and displacement.

At that time Briggs had just published a book on loudspeakers.[2] As I was reading his chapter on vented enclosures and looking at the FM probe results, I thought that he had correctly observed what happens in a reflex box, but that he had made a wrong assumption about the cause. He had attributed all the aspects to resonances in the air, and he hadn't understood that the diaphragm had a life of its own, doing things that were characteristic of moving systems.

In those days we had a society in England called the British Sound Recording Association (BSRA). I remember going to a lecture on loudspeakers by Peter Walker where he demonstrated his corner ribbon loudspeaker. (See *Fig. 1*.) The BSRA conceived what must have been the first exhibition and convention on audio subjects. From 1947 on, they held an annual weekend meeting at a London hotel. In a continuous series of demonstrations, each manufacturer had 20 minutes to move his equipment into position, give a little talk and demonstrate his products.

SB: Is this where you met Briggs?

RC: Yes, Wharfedale was exhibiting a small display at one of these meetings. Briggs was giving one of his delightful demonstrations, and afterward I buttonholed him. "I have been reading your book on loudspeakers, but I think you have made some mistakes in the conclusions on how reflex enclosures work," I said. "Oh, we better have a cup of tea," he replied.

So we went up to the terrace for a cup of tea, and I showed him my work. He made it pretty clear that he did not understand the point right away, but that he was in consultation on a weekly basis with a Mr. Price at the technical college in Bradford. He begged me to borrow the papers to show Mr. Price. Returning them the next week, he said that he'd found the work quite illuminating and helpful.

A few weeks later he wrote and said that his publishers had told him that the stocks of his book were nearly exhausted and that they had decided to do a reprint. "In view of what you have said about vented enclosures, it is clear that parts of the book ought to be revised," he said. "Would you be willing to do a revision?"

Well, I was a poor student at the time, so I jumped at the chance, which was a challenge and a welcome source of income. From that time on I became a consultant to Wharfedale. Whenever matters of a technical nature arose, Gilbert Briggs sought my collaboration. He wrote three books[3,4,5] in the '50s on which he sought my cooperation either in revising some of the chapters or acting as a technical editor.

SB: Where did you go after graduation from the university?

RC: I eventually took a job with Mullards, a division of Philips, as a production engineer for CR tubes for TV. TV had been my other love since I was 10 or 11. I had read all the books on TV and had made TV sets. After about three years there, a friend gave me a newspaper cutting that showed a job opening at the BBC designs department. I applied for it and got it. This was my first contact with professional audio.

In Britain, we have what I call the "musicality brigade," which is populated by people who do not understand the scientific principles behind audio. They believe that it has some element of witchcraft that they hope will always be inexplicable. I was probably in the tweaky black magic stage, but going to the BBC made me grow up and get rid of all the black magic.

SB: What did you do at the BBC?

RC: I worked in the recording designs department and dealt with the design and manufacture of disk and tape recording equipment. I was quartered at Maida Vale, where the main music studios are. Next door was the BBC transcription service. They were running Voigt horns as monitoring loudspeakers at that time. (See *SB* 4/81, p. 14.)

SB: Was that your first acquaintance with Voigt horns?

RC: No, my first acquaintance with them was in the late '40s through a friend named George Wise, who did quite a bit of work for Voigt in the '30s and ran a Voigt horn in his house for many years. Later I was introduced to Voigt by Harold Leak, who at that time was making a copy of the Voigt pickup under license from Voigt.

SB: What did you think of Voigt's impact on audio in England?

RC: He was a good public relations man. It was quite evident in the '30s, apart from the slight abrasiveness that sometimes afflicted things at the edges, that he was able to attract and hold attention and to put his point over in an interesting way. When he toured the country to give equipment demonstrations, he must have been one of the first people to recognize the importance of getting people's interest at the grassroots level. These are lessons that people have had to relearn 30 to 40 years later.

SB: Back to your career, how did you join Briggs at Wharfedale in a permanent position?

RC: One day in 1955, Briggs invited me to visit the factory. During the visit, he said, "I think it would be good if you came to work here." He sketched out a proposal that took a long time to work through, but eventually I came to work at Wharfedale as technical manager.

SB: What were your achievements at Wharfedale?

RC: There were two tangible results. The first is that I could be credited with putting Wharfedale onto a scientific footing. Up to that time, nobody in the company had scientific training. Particularly on the production side, nobody knew how to analyze rejects and jig a product for production. Briggs was an intuitive scientist: he took to it from the music side. He started Wharfedale because he loved music, but he wasn't a trained scientist or engineer, although he was the best PR man in the world.

SB: With the exception of Voigt?

RC: Well, Voigt's PR was not as commercial as Briggs'. Briggs will always remain in the audio memory for that. Briggs followed Voigt's lead. Voigt was instrumental in grabbing hold of the public's imagination. Briggs went farther because he had this nice balance of commercial acumen and a wonderful personality. He attracted a much wider audience at a much more comfortable level than Voigt.

It was through Briggs that I received a good start in domestic audio, and I learned much from him. But nobody in the company could take the business much farther. Everything was done in a haphazard way because it was really a cottage industry that was growing up. I think I can be credited with having put down the basis of an engineering approach with everything jigged up and working in a scientific fashion.

SB: What was the second achievement?

RC: That was in regard to products. I straightened out all the enclosure principles. Instead of designing the enclosures haphazardly and evaluating them by aural methods, I was able to calculate beforehand the performance we were

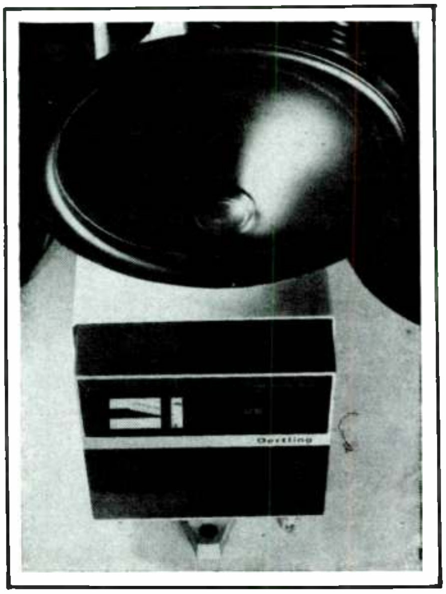

FIGURE 2: KEF can control the weight of this plastic diaphragm to within ±10 milligrams.

likely to get and what sort of performance we wanted. Then I would calculate the enclosure size that would give it at the low-frequency end. We had a whole series of models that were properly designed and damped to bring about the intended purpose.

I also invented the acoustic filter, which was a way of dividing the box into manageable sections to avoid standing waves, so you did not have to line the box with expensive material. I did much in profiling the fronts of the enclosures to minimize diffraction effects. We have continued this work at KEF.

I designed many new high-frequency units. Curiously enough, before I went to Wharfedale, I had a design for a 1½-inch-diameter dome tweeter. Nobody at Wharfedale took the slightest interest in it. They thought it would be too expensive to make. I actually designed it as a hobby while I was at the BBC. The design remained in the drawer from the early '50s until I came to KEF. When I started KEF, we began to make that unit, which is called the T-52. We are still making it, and it forms the high-frequency end of the Model 105.

SB: What does KEF stand for?

RC: It stands for Kent Engineering Foundry. A company here in the '20s made nonferrous metal parts for military tanks. It was called the Kent Foundry. Then a father of a friend of mine came down here in the early part of World War II and took over the company. After the war he made a spraying machine for orchards. The company thrived on that type of machinery for years, and the name was changed to Kent Engineering Foundry because they were doing more than foundry work.

I got to know these people, and we started KEF Electronics together in 1961. I rented a small hut on the grounds, and eventually the electronics and the loudspeaker side grew until it took over the whole site and plant. The engineering company was sold off in sections to people in the area.

SB: Why did you decide to leave Briggs and Wharfedale and start KEF?

RC: During the six years I spent at Wharfedale, Gilbert Briggs and I had an exceedingly happy and fruitful relationship, but he was not inclined to see the need for radical changes in the stagnant Wharfedale product line. When I became convinced that it was necessary to get away from paper diaphragms to make better and more consistent speakers, the only course open to me was to leave Wharfedale and start my own business.

No doubt my departure was a considerable shock to Briggs, but it was the right thing to do, especially after Rank bought out Wharfedale in 1959. I have no regrets, and in subsequent years Briggs and I became firm friends again. I believe he came to see why I had to move on and do new things.

SB: Why did you think that plastic diaphragms should replace paper diaphragms?

RC: Because plastic diaphragms are more controllable and predictable. I always like to work with things that I can control: I don't like any situation where God has too much say. The idea of chopping down trees, pulping them up, spreading them down on a mesh, drying it with a gas stove and hoping for the best never appealed to me much.

It might be interesting for you to know that you are sitting in the village of Tovil where the first felted loudspeaker cones were made. When Voigt started to make loudspeakers, the only way he could make a cone was to take a flat sheet of drawing paper, fold it into a cone and seam it. As we know from our researchers at KEF, that is absolutely the wrong way to make a cone because the essence of a diaphragm is that it must be absolutely symmetrical. It must be absolutely concentric in every regard. (See *Fig. 2.*)

SB: Why?

RC: As soon as you have any eccentricity, it predisposes the vibrational mode of the diaphragm at virtually all frequencies. It then makes the performance of the diaphragm—and hence the loudspeaker—completely unpredictable because the influence of the eccentricities is overriding. It is rather like trying to make a window that specifies proper thermal insulation and then through manufacture introduce an uncontrollable leak, which destroys the thermal properties.

It was actually a firm called Barchem Green, which was an expert in making filter paper for chemistry purposes, that suddenly hit upon the idea that it was just as easy to make a conical shell by the felting process as it was to make a flat sheet. They developed the scheme and the tools for it. For some years through the '30s they produced hundreds of thousands of cones in a factory just down the road from us.

SB: What was your first product for KEF?
RC: The first was the K1 slimline.[6] It had a strut in the back, which allowed the cabinet to stand upright or be tilted back to use what we now know as the listening window. It included a woofer with a diaphragm that was 18 by 14 inches. It was called the B1814 and was a polystyrene diaphragm, which was flock sprayed on the front to damp it and was suspended by a silicon rubber-impregnated textile roll surround. An elliptical midrange unit provided a better distribution pattern in the horizontal pattern in the horizontal plane. It had a foil-stressed diaphragm—i.e., a polystyrene shell with foil on each side—and a foam surround. The tweeter was the T-52 unit I mentioned before. It had a Mylar diaphragm with a copper voice coil cemented directly to it. That was the start. (See *Fig. 3.*)

SB: Was the K1 a closed or vented box?
RC: It was halfway in between. It used an acoustic filter and a concave plate of perforated steel covered with felt to reduce the flow resistance on the back. This was intended to have a cardioid distribution at low frequencies, working as does a line source loudspeaker with an acoustic filter open back.

SB: Was this acoustic filter running along the lines of the acoustic resistance unit (ARU) marketed by Goodmans?
RC: No, ours was somewhat different in concept. The ARU, invented by Ted Jordan, was a combination of a vent and a resistance in parallel with it. Ours was just a resistance.

SB: Do you consider that the K1 had a good response compared to today's standards?
RC: No. Since we first came out with the K1, we have learned a great deal about

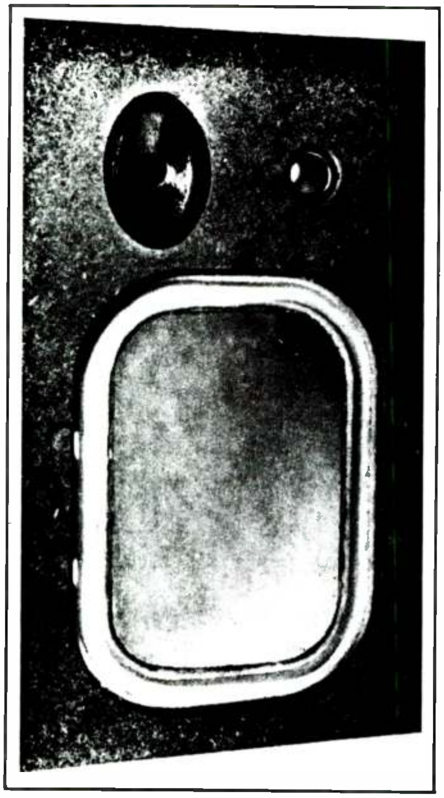

FIGURE 3: The KI Slimline was KEF's first loudspeaker product.

diaphragm behavior and, I think more importantly, about how loudspeakers behave in an array.

There are really two parts to the operation of a loudspeaker. One is how you design it, and the other is knowing the critical elements in the design so that you can control the response and the performance in manufacture. You want to maintain the standards for which you are aiming within close limits. This is important because too much of the loudspeaker business is like a Stradivarius violin. Reputations were built on a dozen samples, and the desirable features of those samples never got into the mainstream of production models, which the consumer actually buys.

SB: What is your design philosophy?
RC: I started the company making loudspeakers with particular materials. I think time has proved that this was the way to go because we have succeeded in maintaining our reputation over 20 years using essentially the same driver designs. Other manufacturers have come into the loudspeaker business using the same technology. For instance, the Japanese have just "reinvented" the flat-fronted speaker. Several years ago I remember going to an audio fair in Tokyo and seeing a display by a small Japanese company. Two or three loudspeakers were exact copies of the B1814 driver in the K1 slimline. There was nothing wrong with that, though, because the designs were not patented.

SB: Do you have patents on any of your products?
RC: We have patents on a number of features of our products, for instance the optical line-up device in the Model 105. But you can't patent the use of materials.

SB: What materials do you use in your diaphragms?
RC: We started to use Mylar in diaphragms in 1961, and a few years later we started to make diaphragms from Bextrene, a mixture of rigid polystyrene and rubber. Those technologies have since been taken up by other people. Many firms are now making conical loudspeakers with plastic diaphragms and dome tweeters using Mylar.

I'd like to go back to my first statement about consistency in materials. Although this was basically correct, what we *weren't* good at then was knowing how to design crossovers and what influence that had on phasing and the ultimate marriage of the inputs of separate drivers. □

Next time, Mr. Cooke will explain how his design philosophy changed to incorporate his discoveries about crossover design and its implications for sound reproduction.

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3. Overload Protection, *KEFTopics*, Vol. 4, No. 1.

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Model II Loudspeaker System Kits

The ACOUSTIC IMAGE™ Model II is a state of the art, two-way loudspeaker system which, although available as a factory assembled system, allows special savings to kit builders. The Model II Loudspeaker Kit is available either as a Basic Kit or as a Complete Kit. The Basic Model II Kit includes all woofers, tweeters, pre-wired crossover networks, enclosure damping materials, grill cloth, mounting hardware, casters, enclosure plans, and instructions. The Basic Model II Kit is recommended for those who, with the help of a local cabinet shop or with their own tools, are able to construct, from plans, their own loudspeaker cabinets. For those who do not want to get involved in cabinet construction, the Complete Model II Kit includes everything in the Basic Model II Kit plus finished walnut cabinetry and grills — only a screwdriver is needed for assembly. Both the Basic and Complete versions of the Model II Kit are pre-wired, pre-tested and are easy to assemble with no soldering required. A 30 day return policy and a 5 year limited warranty is in effect for both the kit versions of the Model II and the Factory Assembled Model II.

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The Model II obtains accurate high speed reproduction of bass and midrange acoustical information by incorporating low-mass polypropylene cone materials in a long excursion ten-inch driver. This low mass design allows the cone to respond to the input musical signals with extreme speed and accuracy. The result is clean, tight bass reproduction and a precise, ultra-smooth midrange response. Optimized electromagnetic damping, rubber damping of the cone suspension, and the use of a rigid cast driver frame effectively eliminates both transient distortion and tonal coloration from entering the reproduction process.

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Time domain accuracy is required for high resolution reproduction of the complex and intricate transient signal structures of which music is composed. Time domain accuracy is also critically relied upon by the hearing process to correctly position and dimensionalize spatial information contained in musical recordings. Acoustical Physics Laboratories, by analytically optimizing the system's acoustical-electro-mechanical parameters, has determined the parameter alignment which provides the most accurate time domain response in reproducing transient signals. This design approach not only insures that time arrival information between drivers is aligned, but also insures that the time domain response with each driver's range and the system as a whole is correct. Because the Fourier Transform mathematically relates time and frequency domains, optimizing the time domain accuracy of transient signals imposes accurate frequency and phase response on the system. The loudspeaker system, at this level of accuracy, presents the listener with an unperturbed acoustic analogue of the input musical waveform. The result is an unrestrained realism in resolving musical detail and an ability to precisely image a three dimensional musical soundstage.

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Impedance
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Amplifier Power Recommendations
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BUILD YOUR OWN VOLTMETER

PART I IN A SERIES ON MODULAR TEST INSTRUMENTS

BY G. R. KOONCE
Contributing Editor

The work of Thiele, Small, Keele and others allows speaker builders to delve deeply into the scientific design of speaker systems. To apply this work successfully, however, you need to measure driver parameters and evaluate the finished speaker. Like most hobbyists working with speakers, I owned basic test gear, such as an oscillocope, a frequency counter, an AC VTVM and an oscillator. But I wanted more convenience and, in some cases, more accuracy or extended capability than was possible with this equipment.

Since my occupation is circuit design, I decided to design and build test equipment that would facilitate speaker building, particularly Thiele/Small (T/S) alignments. For all the speaker craftsmen who feel uncomfortable with electronics and circuit building, this will be a fairly painless way to gain some practical knowledge, while building some useful test gear. This series of articles will show you how to build the following units:

• **Dual Wattmeter**—actually measures V^2/R directly, which is exactly what you want. R is selectable from 4 to 16Ω. Full-scale power ranges are 1W, 10W and 100W, with two different response-time constants provided.

• **Speaker Impedance Meter**—measures magnitude and phase angle of driver impedance for T/S parameters and crossover design.

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• **Two-Way Adjustable Crossover**—consists of active 12dB/octave

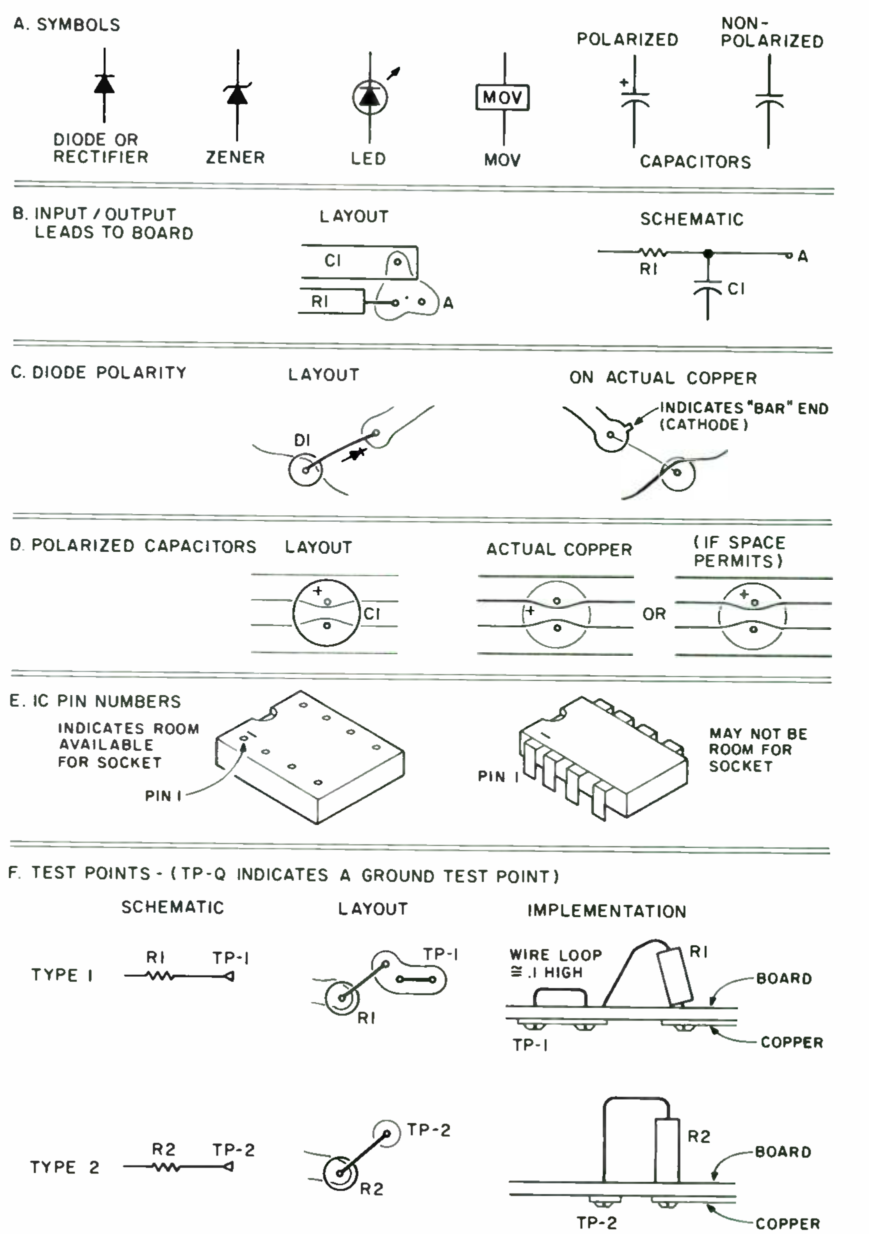


FIGURE 1-1: Symbols used on schematics and layouts.

Butterworth high and low-pass filters that can be tuned together over the 100Hz to 8kHz range. Each output has calibrated attenuation.

• **Warble Tone Modulator**—converts a function generator into a warble tone generator suitable for speaker testing. The function generator used determines the frequency range limits. The warble rate is adjustable, and the warble width is variable from unison to one octave.

More detailed specifications and optional features will appear in the construction sections. These are not intended for the electronics novice who requires step-by-step instructions such as those found in most kits. If you feel comfortable with projects described in *SB* and *TAA*, however, you should enjoy constructing these devices.

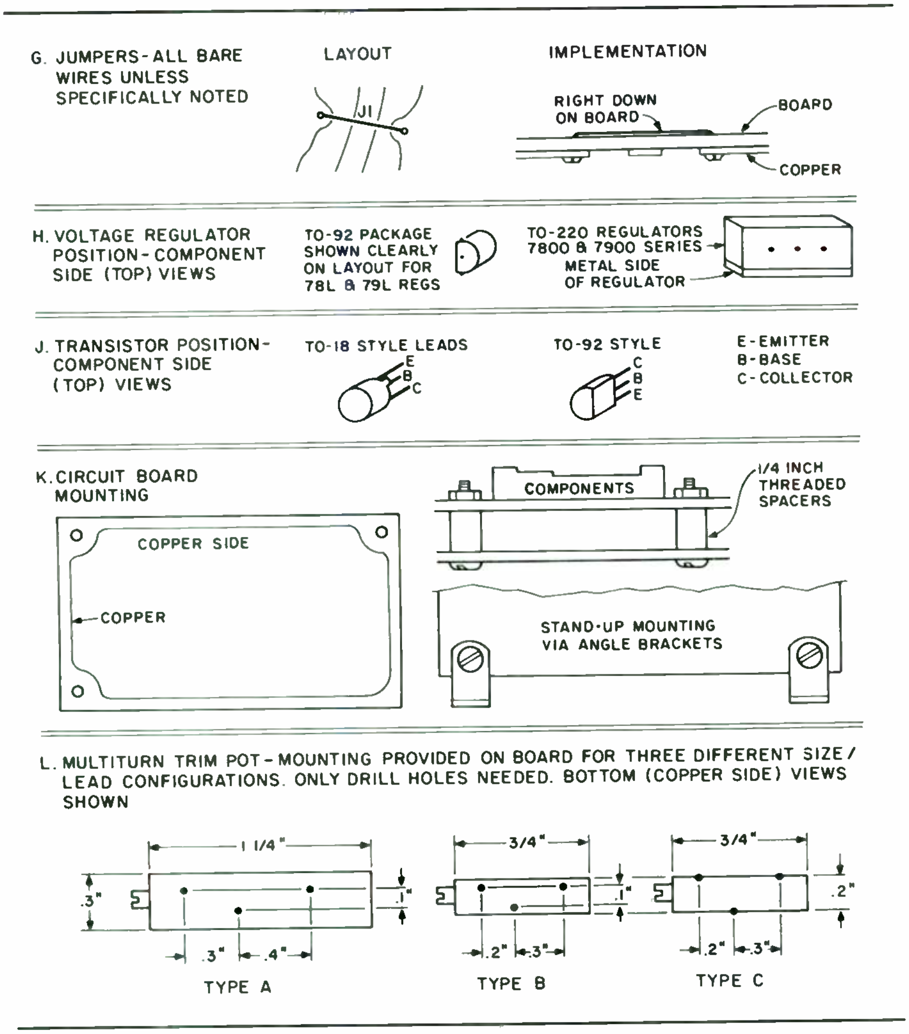
MODULAR BOARDS. The usual approach to circuit board layout is to arrange all the components as efficiently as possible in the space provided. My approach, however, is to separate the circuits into smaller modules that you can connect to form a functioning device. In this way, you can reassemble them to form various pieces of test gear.

I don't use all the standard schematic symbols because they aren't always clear enough. *Figure I-1* explains my variants on these symbols. Wherever possible, I try to show polarities and other essential information in the schematic, layout and even the actual copper. I built test points into the circuits, which are buffered with a 180Ω resistor to prevent test equipment from affecting circuit operation.

My labeling for board grounding needs some clarification. When I first started doing my boards, I used "G" to mark the ground copper. Soon I had pages of rub-on transfers with no "G's" left. So I started using other letters, such as "Q, N, and O" for ground. To avoid confusion, I always use the same letter on the schematic and stuffing guide.

My parts lists reflect my habit of building things from readily available parts. For standard parts such as carbon resistors, the lists show each component I actually used and, in parentheses, the true stress on the part, so you can substitute other values. For more unusual parts, I provide even more detailed information, especially regarding shapes and sizes that will fit on the board, as well as electrical values. See *Fig. I-2* to see how this might appear on a layout. In *Fig. I-2a*, C3, a stand-up mylar or axial-lead tubular capacitor, is mounted upright. In *Fig. I-2b*, C1 could be a stand-up electrolytic or mylar. *Table I-1* shows how these parts might appear in a parts list. This approach allows you to identify alternates that will fit the circuit board easily.

Full-size negatives for all the circuit boards will appear in this series. I normally use 1/16-inch-thick, one-ounce copper, paper-based phenolic boards, which are of sufficient quality. You could use glass mat polyester or glass epoxy. My boards might appear strange at first, but I try to use as much copper as possible. You pay for all the copper on the blank, and etching it away costs money, so why not use it? Putting more copper into the power and ground distributions allows you to drill new holes for components with lead spacings different from the specified parts.



VOLTMETER BOARD. The voltmeter (VM) full wave rectifies sinusoidal signals and averages them to provide a DC output voltage equal to the RMS AC input voltage. Since this is basically an average-reading function, any non-sinusoidal inputs must be corrected. A discussion of the full-wave rectifier-averager circuit shown in *Fig. I-3a* appears in National Semiconductor's literature.[1,2]

It operates as follows. The second stage, A2, is an inverting averager with two inputs via R3 and R4. With negative-going inputs, the first stage, A1, is clamped by diode D1 so that it does not contribute. Thus A2 averages the half-cycle contribution via R3, causing V_{out} to go positive. With positive-going inputs, A1 is a unity gain inverting amplifier, so A2 sees

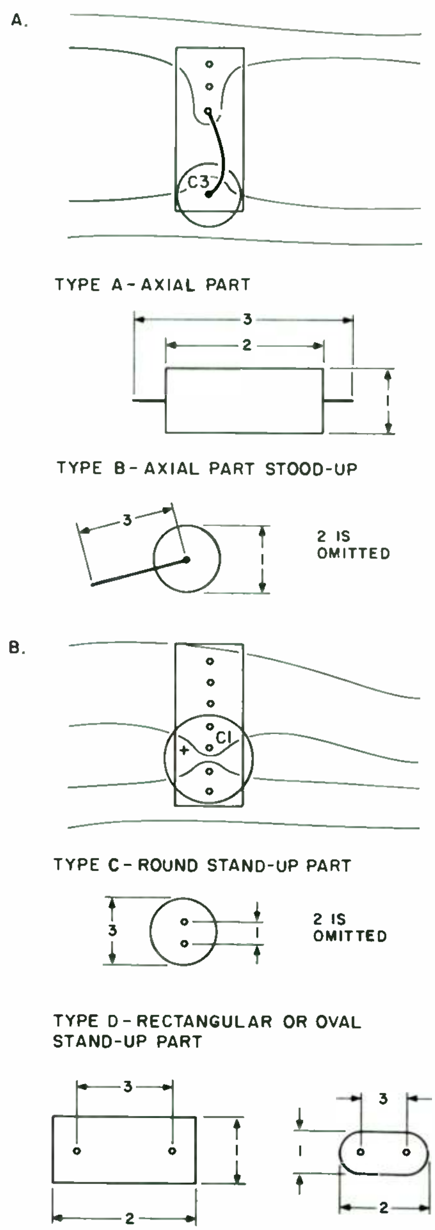


FIGURE 1-2: How parts might appear in a layout. In Fig. 1-2a, C3 represents a stand-up mylar or axial-lead tubular capacitor, mounted upright. Type A shows an axial part lying down, while Type B shows it standing up. Figure 1-2b shows C1, a stand-up electrolytic or mylar capacitor. Type C is a round stand-up part, whereas Type D is a rectangular or oval stand-up part.

TABLE 1-1

SAMPLE PARTS LIST

Component	Type	Dimensions (in inches) 1	2	3
C1	C	0.5	—	0.1 or 0.3
	or D	0.3	1.2	0.2-1.0
C3	B	0.3	—	0.4
	or D	0.3	1.0	0.4-0.8

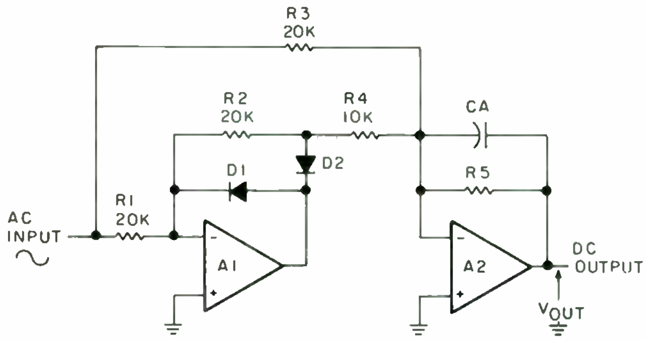


FIGURE 1-3a: Basic full-wave rectifier-averager circuit.

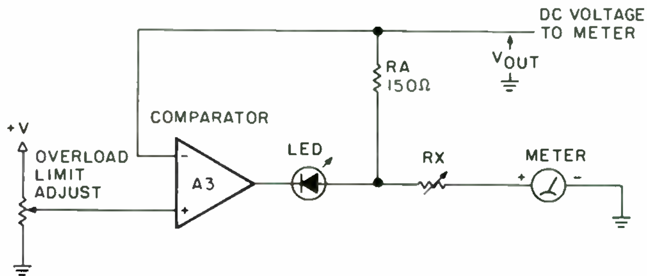


FIGURE 1-3b: Basic meter overload protection circuit.

the positive input via R3, but also a negative input current of double magnitude via R4, its value being half that of R3. Thus V_{out} continues moving toward positive and will go to the full-wave average of the input sinusoid. The A1 stage must slew quickly to prevent excess distortion as the input sinusoid goes through zero. This sets the frequency-response limit of this circuit.

Figure 1-3b shows how V_{out} drives a meter and how comparator stage A3 protects the meter from overload. I made Ra fairly small and set Rx to give full-scale meter deflection at full-scale V_{out}, which is 4V DC for the VM board. When the signal exceeds the preset V_{out}, the comparator A3 turns on, clamping the meter back on scale and lighting the LED to indicate overload.

CONSTRUCTION. Comparing the VM schematic in *Fig. 1-4* (see *Fig. 1-5* for the circuit board and *Fig. 1-6* for the stuffing guide) with National Semiconductor's published circuit reveals an important difference. Compensating capacitor C2 returns to the opposite end of D2 because, as I and several others have found out through experience, their schematic has an error. Use the hookup in *Fig. 1-4* to avoid oscillations at the input's center line crossings. I used two resistors to implement each 20kΩ resistor because while the absolute values are not critical, the ratios need to be accurate.

Various approaches are possible. You could buy a handful of 10k, 1 percent resistors (RN60 or smaller) and use them for R2, R3, R4, R5, R6, R7 and R11, omitting R10. Or you could buy 20k, 1 percent resistors, put them in R2, R4, R6, R10 and R11, and jumper out R3, R5 and R7. If you use a precision resistor for R10, it must be RN55 or smaller. For accurate operation, the following relationships must be true:

$$(R2+R3)=(R4+R5)=(R6+R7)=2[(R10\times R11)/(R10+R11)]$$

and

$$(R2+R3)\cong 20k\Omega.$$

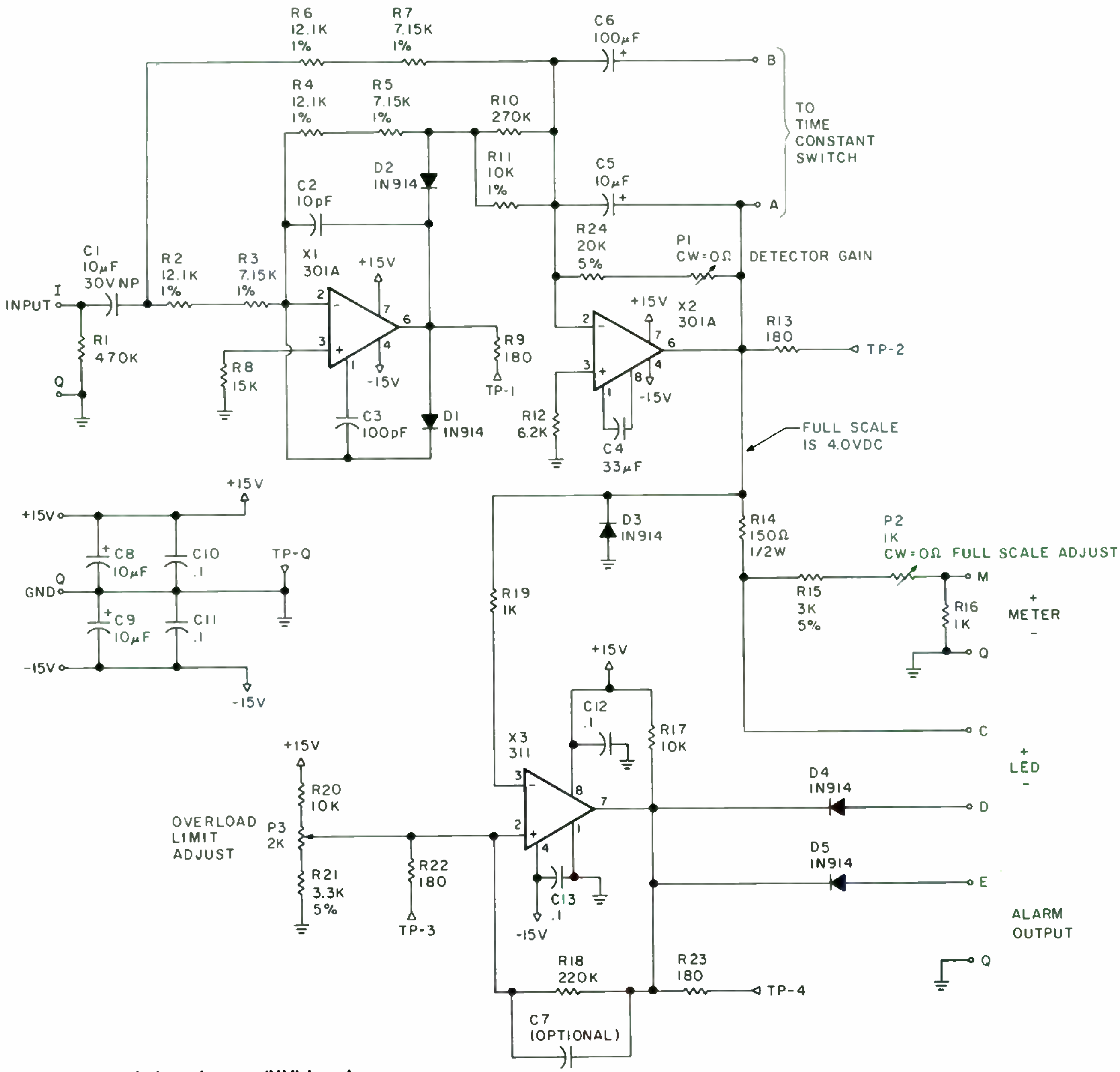


FIGURE 1-4: Schematic for voltmeter (VM) board.

This will prevent low-frequency loss due to input capacitor C1. The input impedance as seen by C1 is one-half of (R2 + R3), or about 10k (9.63k with my resistors). With C1 equal to 10μF, the −3dB point due to C1 is about 1.6Hz. At 20Hz the VM board response is down about 0.03dB. The voltage rating of C1 depends on what drives the VM board.

A resistor in each noninverting amplifier lead to ground (R8 and R12) maintains some control of DC offset. The R12 value varies somewhat with the application of the VM board, but this unit drives a meter so that high dynamic range is not required and a small DC offset can be maintained relative to the 4V DC.

The averager's time constant in the fast mode is the product of C5 and Ry, where Ry is the value of (R24 + P1) after P1 is adjusted correctly. For the slow mode, tie Point A to Point B. The time constant becomes Ry(C5 + C6). Tests show that the averager's time constant should be about 200ms for good VM response down to 20Hz. To get 4V DC output for a 4V RMS sinusoid input, Ry must be close in value to 0.707 (R2 + R3)/0.636. If (R2 + R3) is about 20k, Ry will be about 22.2k. Thus C5 should be 10μF minimum, a value that works out well when using the VM to set continuous wave (CW) levels.

A longer time constant is desirable when you are trying to monitor noise or program material and is provided by switching in C6. I have obtained good results with a time constant of about two seconds (C6 equals 80 to 100μF with Ry about 22.2k). Remember, this VM circuit is calibrated for sinusoid inputs, and you must make a correction for other shapes. For gaussian noise inputs, multiply the meter reading by 1.13 (or add 1dB) for true RMS value.

Both C5 and C6 may be polar types. They might see slight reverse volt-

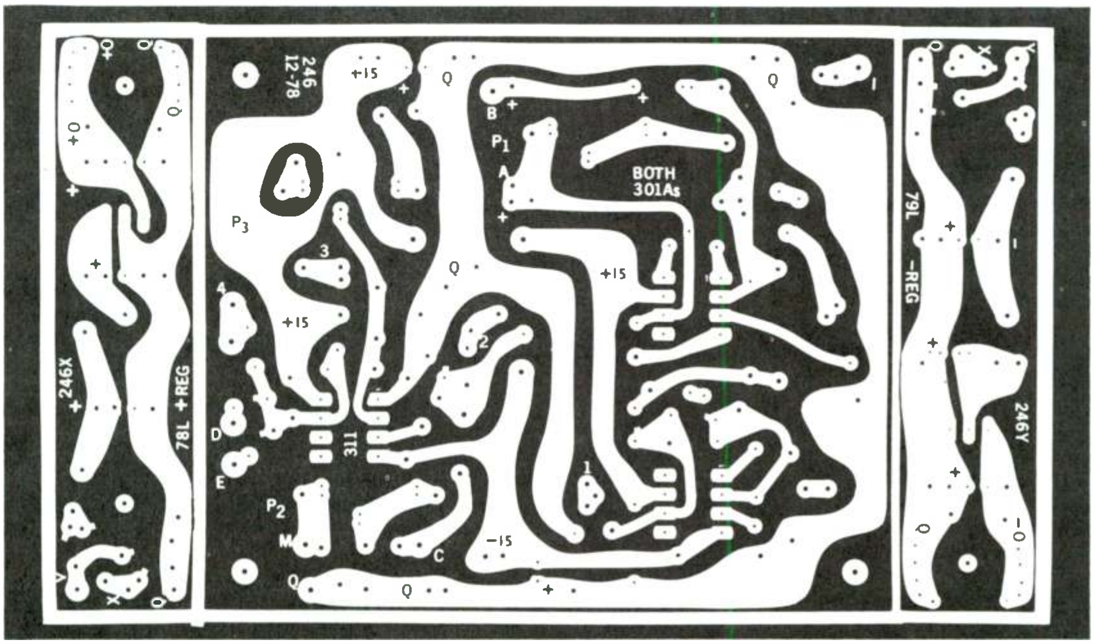


FIGURE I-5: Circuit board for voltmeter (VM) (No. 246). Also power supply boards 246X (positive) and 246Y (negative).

ages, but diode D3 limits this to one diode drop. The parts list in *Table I-2* indicates tantalums (which is what I had on hand) for C1, C5 and C6. Aluminum electrolytics should work just as well, although I haven't tested them myself. If you do use tantalums, be sure they are solid or foil types, as the wet anode types do not like even intermittent reverse voltages.

In the meter driving and protection circuit, D3 limits the meter reverse inputs to less than one-quarter scale during turn-on and off. R16 provides better damping on the meter for sudden signal changes. Some meters need a lowered source impedance to provide acceptable damping. You can trade off R16 against (R15 + P2) to get the best damping.

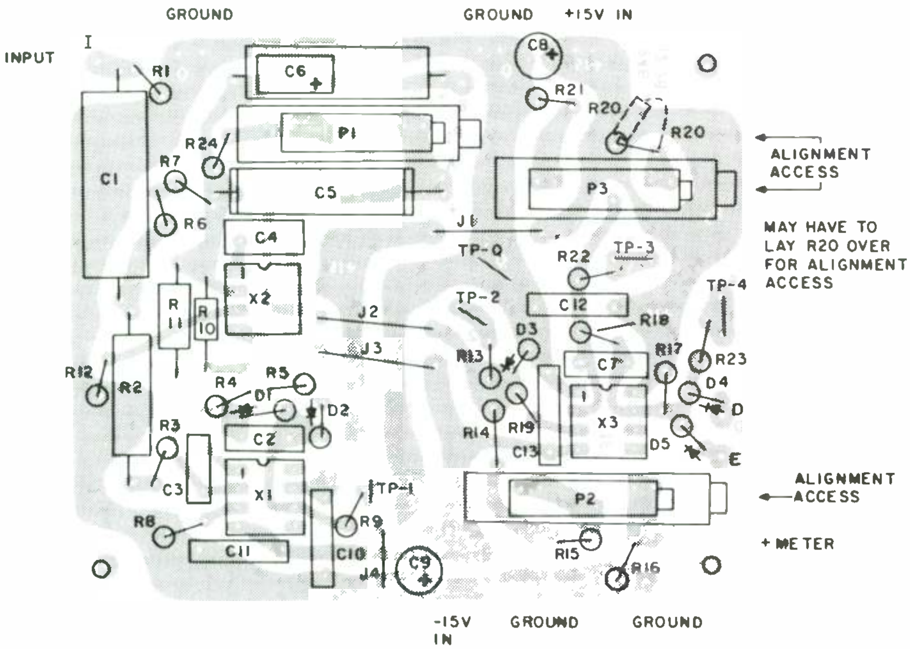


FIGURE I-6: Stuffing guide for voltmeter (VM) board (No. 246).

R17 and R18 (along with C7, which I have not needed to date) provide hysteresis to the comparator for clean switching. R17 tends to reverse-bias the overload LED (Point C to Point D), so D4 prevents this. D5 enables a remote alarm output. The board is in overload if Point E goes below 2V. Since Point E is designed to sink only 2.5mA, do not permit it to go above 12V when not in overload. Later in the series, I will describe a circuit that reads this alarm point.

The VM board has three trimpots: P1 to set averager gain, P2 to set meter gain, and P3 to set the overload limit. Clearly, you could use fixed resistors in place of P1 or P2, but I used variable types to retain flexibility. The board has no input protection because it will always be driven by a buffer with a ±15V maximum output. Both 301A op amps are driven through about 20kΩ, so they are well buffered. If you connect equipment that will cause the VM board to see very high input overloads, add the appropriate protection.

The VM board works with a wide range of meters. I used taut-band 1mA movements with internal resistance at about 33Ω. The board drives any meter that takes less than 5mA and has a terminal voltage of less than 3V at full scale. Initially, omit R16. When you know the full-scale

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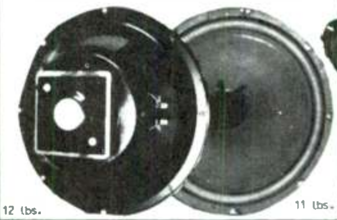

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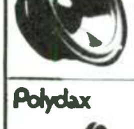

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current (I_{fs}) for your meter and its internal resistance (Rm), the following relationship holds:

$$4V = I_{fs}(150 + Rm + Rx)$$

where I_{fs} is in amperes and resistances are in ohms. Rx equals R15 plus the value of P2 at final full-scale setting. Once you have computed Rx, make P2 about 0.2(Rx + Rm) to allow about ±10 percent adjustment, and make R15 equal [Rx − ½(P2)]. You might get a negative R15 if Rm is high. In this case, just omit (short out) R15. If the meter strikes the pins when large inputs are applied or removed suddenly in the fast mode, try adding R16. If it starts to approach Rm, revise R15 or P2.

The meter scale depends on the intended use. For a typical AC VTVM application, the scale would look like *Fig. I-7*. The meters I used are no longer available and were nonlinear, so don't try to make your scales directly from *Fig. I-7*. The top scale on any meter is 1.0, so making this scale is easy (if the meter is linear). Each 10 percent deflection is 0.1V (2 percent is 0.02V, and so on). The bottom scale is "offset" 10dB, so full scale is really 3.162V and equals 100 percent deflection. On this scale 1V equals 31.6 percent deflection, 2V equals 63.25 percent, and 3V equals 94.87 percent, while each 0.1V mark is an added 3.16 percent deflection.

Once you find how many degrees of arc your meter swings from zero to full and that it is linear, multiply the degrees by these percentage values to find degrees of deflection for each scale. I make my meter scales with black rub-on lettering and heavy white paper. Then I reproduce them on a copy machine, which makes accurate copies on card stock, and glue the copies over the original meter scale.

The overload LED between Points

TABLE I-2

PARTS LIST FOR VOLTMETER BOARD (NO. 246)

R1	470k, ¼W (0.6mW)
R2, R4, R6	12.1k, 1% RN60 (9.4mW)**
R3, R5, R7	7.15k, 1% RN60 (5.6mW)**
R10	270k, ¼W (1.1mW)**
R11	10k, 1% RN60 (29mW)**
R8	15k, ¼W (≅0)
R9, R13, R22, R23	180Ω, ¼W**
R12	6.8k, ¼W (≅0)
R14	150Ω, ½W (140mW)
R15	3k, 5%, ¼W (function of meter)**
R16	1k, ¼W (function of meter)**
R17, 20	10k, ¼W (29mW)
R18	220k, ¼W (0.8mW)
R19	1k, ¼W (≅0)
R21	3.3k, 5%, ¼W (4.1mW)
R24	20k, 5%, ¼W (14mW)
P1	5k multiturn trimpot (2.3mW)***
P2	1k multiturn trimpot (function of meter)***
P3	2k multiturn trimpot (2.5mW)***
D1-D5	IN914 diodes (17V, 25mA)
C1*	10μF, 30V N.P. tantalum**
C2*	10pF NPO disk ceramic or dipped mica (17V)
C3*	100pF dipped mica (17V)
C4*	33pF dipped mica (17V)
C5*	10μF, 25V tantalum—foil (17V forward, 1V reverse)
C6*	100μF, 25V tantalum—dipped solid (17V forward, 1V reverse)
C7*	not used
C8,* C9*	10μF, 25V electrolytic (17V)
C10-C13*	0.1μF, 25V disk ceramic (17V)
X1, X2	LM-301A op amps, mini dip
X3	LM-311 comparitor, mini dip

*See Table I-3.
**See text.
***See text, Fig. I-1 (Part L) for sizes.

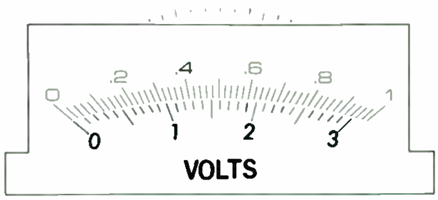


FIGURE I-7: Meter scale for voltmeter (VM).

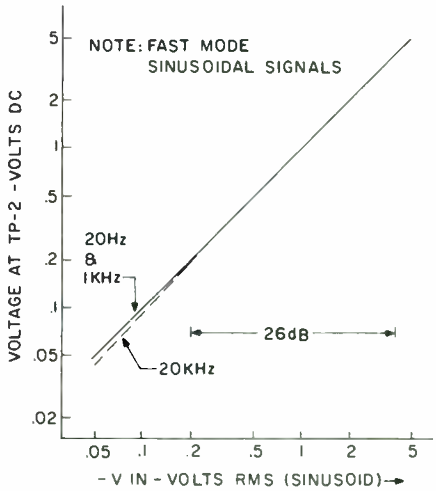


FIGURE I-8: The results of linearity tests of a voltmeter (VM) board.

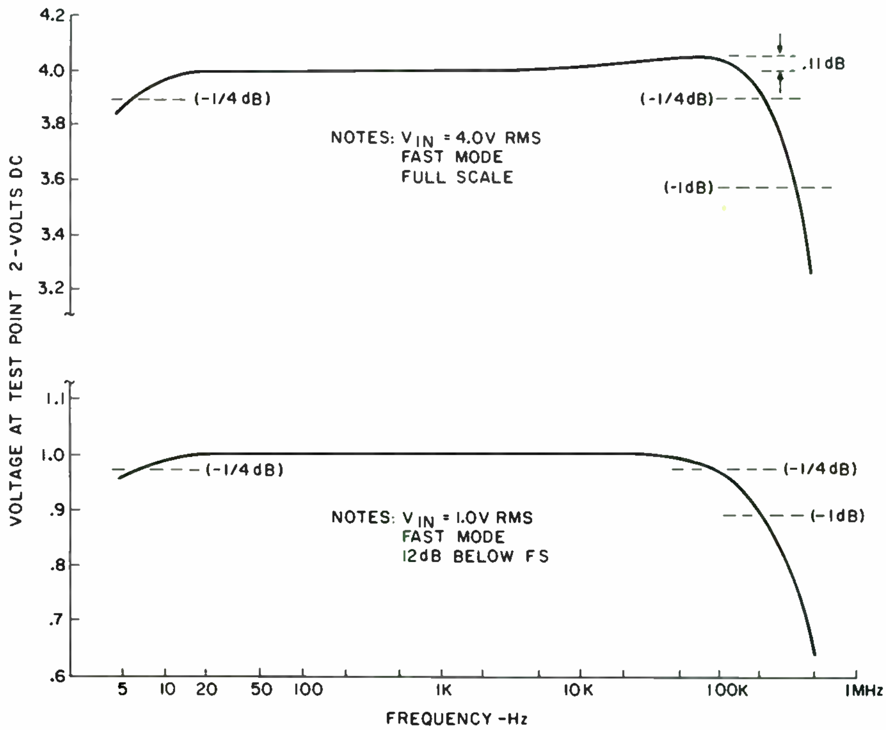
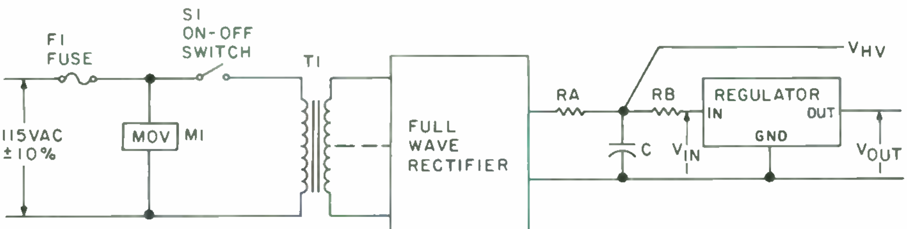


FIGURE I-9: Frequency response of voltmeter (VM) board.



F1 —1A fast fuse 3AG-1
M1—MOV General Electric V130LA10A
T1 —Transformer; 40V CT @ ¼A fully enclosed

FIGURE I-10: Block diagram of basic power supply approach.

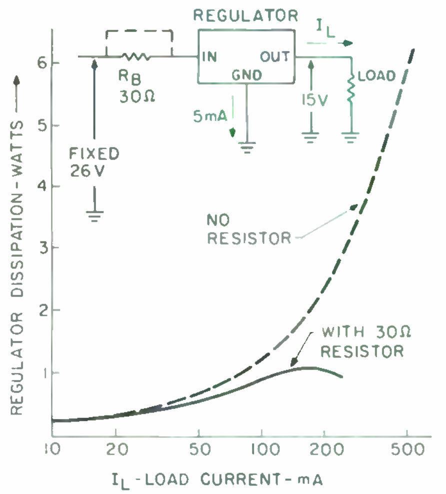


FIGURE I-11: Dissipation in voltage regulator, with V_{hv} fixed at 26V.

C and D also provides meter protection. If it fails, replace it immediately. Use red LEDs because they have the lowest voltage drop. Assuming a drop of 1.6V, the LED would see a current of about 10mA at slight overloads and 25mA at the maximum current set by the short circuit current limit of X2, the 301A averager. At 25mA and under worst case conditions, the output of X3, the 311 comparator, could rise to 0.5V with another worst case 1V across D4. This means that an LED drop exceeding 2V would allow the meter to go above full scale with the overload clamp on. This has never happened in practice.

TESTING AND CALIBRATION. Connect the VM board to the ±15V power supplies, but do not connect the meter and overload LED. Also leave Points A to B open for quick response. Set P2 to full resistance and apply power. The DC voltage at Test Point TP2 should be below ±50mV with no input signal and rise as a 1kHz sinusoid is applied. At 4V RMS, set P1 to give 4V DC at TP2. This assumes your DC voltmeter has a high resistance compared to the 180Ω resistor buffering the test point. Now touch the meter connections across Points M and Q (M is positive). The meter should move upscale, but not to full. If all is well, connect the meter, and with the 4V still at TP2, set P2 for full scale on the meter. Now go to TP3 and set the voltage to 4.1V with P3. The board must not be in overload when you make this adjustment.

Install the overload LED (Point C is positive). If the meter reading drops, reduce the AC input and bring it back

TABLE I-3

PARTS SIZES FOR VM BOARD (NO. 246)

Component	Type*	Dimensions* (in inches) 1	2	3
C1	A	0.3 max	1.0	1.2
C2	D	0.15	0.45	0.25
C3	D	0.15	0.45	0.25
C4	D	0.15	0.45	0.25
C5	A	0.3 max	1.0 max	1.0, 1.1, 1.2
C6	A	0.3 max	1.0 max	0.9, 1.1
	or D	0.3 max	0.5	0.25, 0.3
C7	A	0.15	0.45	0.25
C8, C9	C	0.25	—	0.1
C10-C13	D	0.1	0.5	0.42

*Refer to text and Fig. I-2.

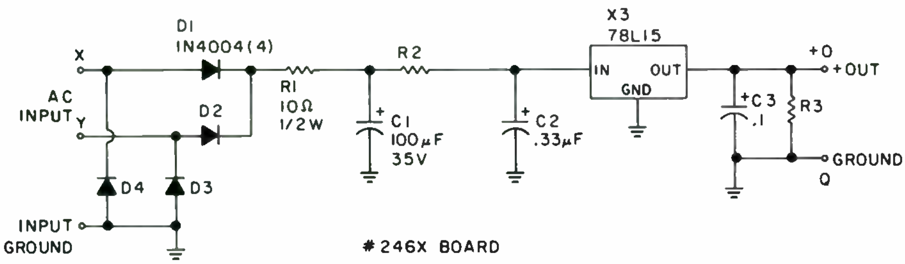


FIGURE I-12a: Schematic of 78L15 low-power positive regulator.

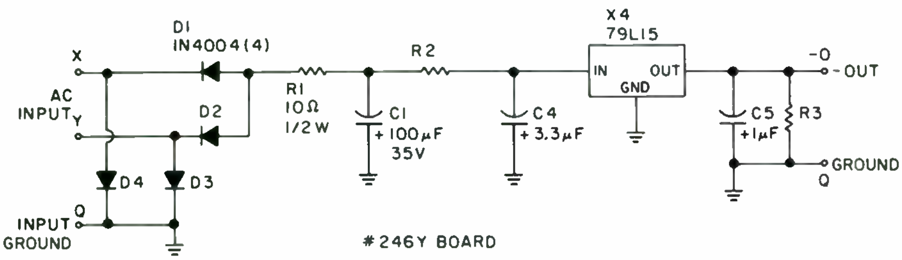


FIGURE I-12b: Schematic of 79L15 low-power negative regulator.

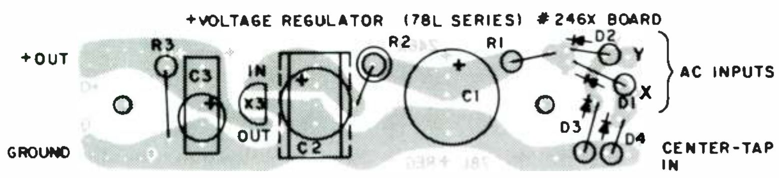


FIGURE I-13a: Stuffing guide for 78L series low-power positive regulator. See Fig. I-5 for board pattern (No. 246X).

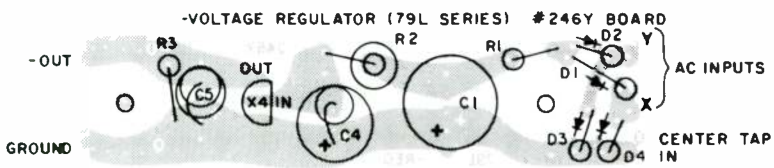


FIGURE I-13b: Stuffing guide for 79L series low-power negative regulator. See Fig. I-5 for board pattern (No. 246Y).

TABLE I-4

PARTS LIST FOR TO-92 REGULATOR SUPPLIES**

Standard Parts	
D1, D2	1N4004 (15mA, 65V)
R1	10Ω, ½W (do not change)
R2*	dissipation limit register (see text)
C1*	100μF, 35V electrolytic (32V)
C2*	0.33μF, 100V (0.33 μF minimum, 32V)
C3*	0.1μF, 100V (0.1 μF minimum, 17V)
C4*	3.3μF, 50V electrolytic (1μF minimum, 32V)
C5*	1μF, 50V electrolytic (1μF minimum, 17V)
X3	78L15 or 78L15A + regulator, TO-92 case
X4	79L15 or 79L15A − regulator, TO-92 case
Heatsink	clip-on sink, like thermalloy 6024
Optional Parts	
D3, D4	1N4004 (depends on application) for use with non-center-tapped transformers
R3	¼W resistor, minimum load if desired

*See Table I-5.
**78L15 +15V power supply (246X board)
79L15 −15V power supply (246Y board)

up. Slowly raise the input past 4V RMS. The overload comparator should trip at about 2.5 percent overload (4.1V input) and light the LED, then recover around 97 percent of full scale (3.9V) as you reduce the input. You can adjust the overload with P3.

TYPICAL PERFORMANCE. Using the parts values of *Table I-2*, one of two boards operating at ±15V with no input had a measured DC offset of −1.1mV. The other was +13.7mV. This offset is a function of the individual ICs, and my results are typical of what you should get. The DC current drain per board should be about as follows:

- **+15V**

No Input—7 to 8mA
Heavy Overload—25 to 35mA

- **−15V**

No Input—6 to 6.5mA
Heavy Overload—4.5 to 6mA.

Figure I-8 charts the results of linearity tests on a VM board at 20Hz, 1kHz and 20kHz. Over this frequency range, linearity is good, 26dB down from 4V RMS. Since meter driving requires only 10 to 12dB, the

TABLE I-5

PARTS SIZES FOR TO-92 REGULATOR SUPPLIES

Component	Type*	Dimensions* (in inches) 1	2	3
R2	B	0.25 max	—	0.25
C1	C	0.5 max	—	0.1, 0.2, 0.3
C2	C	0.3 max	—	0.1
	or D	0.3 max	0.5	0.1, 0.2, 0.3, 0.4
C3	C	0.25 max	—	0.1
	or D	0.25 max	0.5	0.1, 0.2 0.3, 0.4
C4	B	0.2 max	—	0.15, 0.2
	or C	0.4 max	—	0.1, 0.15, 0.2
C5	B	0.2 max	—	0.2
	or C	0.25 max	—	0.1, 0.2

*Refer to text and Fig. I-2.

TABLE I-6

PARTS LIST FOR TO-220 REGULATOR SUPPLIES**

Standard Parts	
D1, D2	IN4004 (70mA, 65V)
R4, R5	4.7Ω, ½W (do not change)
R6* or R6A*	dissipation limit resistor (see text)
C6* or C6A*	470μF, 35V electrolytic (32V)
C7*	0.33μF, 100V (0.33μF minimum, 32V)
C8*	0.1μF, 100V (0.1μF minimum, 17V)
C9*	3.3μF, 50V electrolytic (2.2μF minimum, 32V)
C10*	1μF, 50V electrolytic (1μF minimum, 17V)
X1	7815 + regulator, TO-220 case
X2	7915 − regulator, TO-220 case
Optional Parts	
D3, D4	IN4004 (depends on application) for use with non-center-tapped transformers
R3	¼W resistor, minimum load if desired
Heatsink	The following sinks have been used on the boards. I have listed them in ascending order of thermal resistance (best one first)—Thermalloy 6030,[1] 6025, 6045.

*See Table I-7.
**7815 + 15V power supply (249Y or 249Z board)
7915 − 15V power supply (249F or 249X board)

[1]Thermalloy catalogs show that they have moved the mounting tabs on the 6030 sink. The boards are marked for the early sinks, and you may have trouble drilling holes in the boards for the newer sinks. For information, contact Thermalloy Inc., 2021 West Valley View Lane, Dallas, Texas 75234.

indicated performance is fine. This is one of those unusual circuits that falters in the highs for low rather than high signal levels. It has a slew rate problem in the first stage: the signal must "jump" two diode drops quickly as the input goes through zero. The lower the signal, the larger the error produced by this slew rate limited portion. To improve the low-level dynamic range or frequency response, choose a faster op amp for the first stage.

The expanded scale linear plots of the averager output at TP2 in *Fig. I-9* show the frequency response at full scale and at 12dB down. The meter follows this voltage except at very low frequencies in the fast mode where the needle starts to wiggle. In the slow mode the averager prevents this. Although the curves in *Fig. I-9* were taken in the fast mode, the performance is nearly identical in the slow mode. The slight peaking in the full-scale response at high frequencies has occurred on all VM boards I have tested. Over the 12dB range required to drive the meter, response is flat from 7Hz to 90kHz ±0.25dB and is well within ±1dB for 5Hz to 100kHz. Performance in the audio range for sinusoidal signals is, therefore, quite good.

I offer no data for noise-like inputs because I do not have the necessary equipment. I would expect some nonlinearity at maximum input, however, with signals having a crest factor (peak-to-RMS ratio) of more than about 10dB. This is due to limiting in the VM board's first stage. In Part II, I will show a way to gain some improvement here.

POWER SUPPLIES. For large projects I provide the power supply output voltage with some form of overvoltage (OV) protection and a power supply monitor. In the event of a voltage regulator failure, the OV circuit protects the load, and the monitor alerts the operator to the problem. With small projects, the size and cost are prohibitive. I try to make the power supply as reliable as possible by:

1. Providing transient voltage protection on the input.
2. Derating diodes in voltage and current capability (both steady state and transient).

TABLE I-7

PARTS SIZES FOR TO-220 REGULATOR SUPPLIES

Component	Type*	Dimensions* (in inches) 1	2	3
R6 or R6A	A	0.4 max	1.9 max	1.0-2.0
C6	C	0.8 max	—	0.1, 0.2, 0.3
C6A	A	0.9 max	2.2 max	0.8-2.6
	or C	0.8 max	—	0.1, 0.2, 0.3
C7	D	0.2	0.5	0.2, 0.4
C7A	D	0.2	0.7	0.3-0.6
C8	C	0.25 max	—	0.1, 0.2
	or D	0.2	0.5	0.1-0.4
C9	C	0.25 max	—	0.1
	or D	0.2	0.5	0.2, 0.4
C10	B	0.25 max	—	0.2
	or C	0.3 max	—	0.1, 0.15, 0.2, 0.25

*Refer to text and Figure I-2.

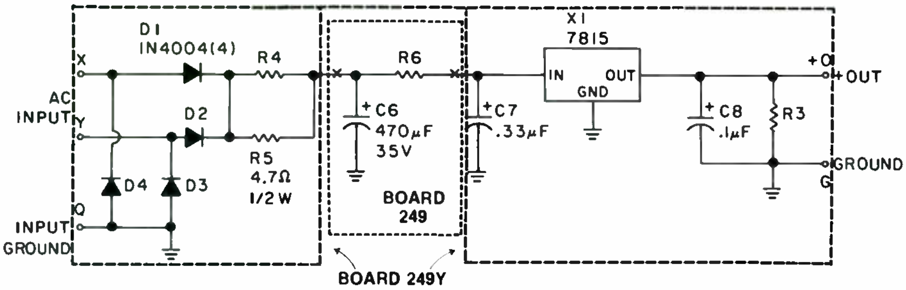


FIGURE I-14a: Schematic of 7815 positive regulator (both configurations).

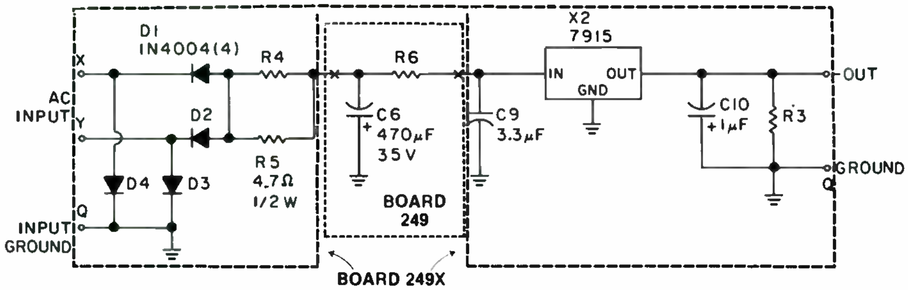


FIGURE I-14b: Schematic for 7915 negative regulator (both configurations).

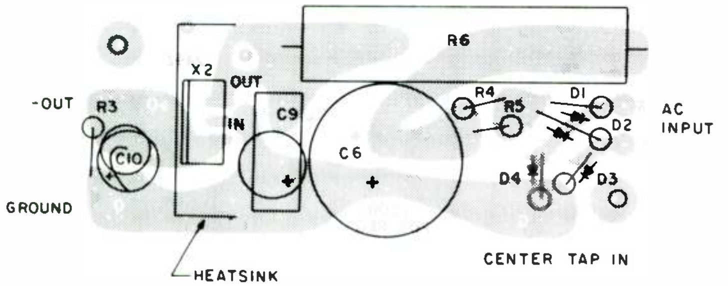


FIGURE I-15a: Stuffing guide for 7800 positive regulator. See Fig. 17 for board pattern (No. 249Z).

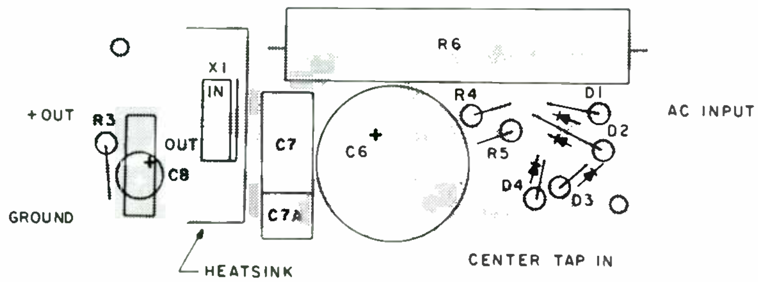


FIGURE I-15b: Stuffing guide for 7900 positive regulator. See Fig. 17 for board pattern (No. 249F).

3. Derating regulators for current and power dissipation (again steady state and transient—as when you accidentally short the output).

The basic circuit I used on all the test equipment in this series is in *Fig. I-10.* The input fuse is a 3AG 1A "fast" fuse and the MOV (GE's trade designation for its metal oxide varistor) is a GE V130LA10A. The transformer, T1, is a fully enclosed 40V, center-tapped at 250mA unit. Unfortunately, this transformer is no longer available. See the editor's note at the end of the article for possible substitutes.

T1 really drives two supplies, ±15V, but only one appears in *Fig. I-10* for clarity. It uses full-wave rectification, with Ra included to limit surge current at turn-on. Rb limits regulator dissipation, steady state and transient, and its size depends on the current the maximum load will draw. The voltage across capacitor C (V_{hv}) has to be reasonably high to allow for line-voltage variations and loss across Rb. *Figure I-11* illustrates the advantages of having Rb on a 200mA maximum load-regulated output in a hypothetical example where V_{hv} is considered "fixed" at 26V.

Even more impressive are the benefits that occur if the regulator output is shorted. While all the regulators used have internal current limiting and thermal shutdown, they will last longer if they do not have to dissipate large powers until their protection devices actuate.

No diode protects the regulator if V_{out} exceeds V_{in} by more than two diode drops. This can occur if the output decoupling capacity approaches 1,000µF. No unit in this series requires high decoupling capacity, but if you use the power supply boards in a project where this might happen, you should tack in a reverse-biased diode (IN4004, for example) from V_{in} to V_{out} across each regulator.

I will use four different fixed regulator families in this series. The 79LXX series negative and 78LXX series positive regulators (in TO92 cases) are rated at 100mA, but I use them only up to 25mA. For 25mA to 125mA loads, I use the 79XX negative regulator series and the 78XX positives (in T0220 cases), which are rated at 1 to 1.5A.

For the 78L15 (+15V) and 79L15 (−15V) supplies, see *Figs. I-12* and *I-13* and *Tables I-4* and *I-5.* With non-center-tapped transformers, four rectified diodes appear in each circuit. When using center-tapped transformers, as I did, omit D3 and D4. Remember that to run a positive and a negative power supply from the same winding, you must use the center-tapped type. Even though the TO92 regulators are highly derated, I use a clip-on heatsink.

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Based on a simple op amp design, the crossovers typically have a frequency response of ±0.2dB 30Hz-160kHz. Output impedance is 10Ω non-inverted, input impedance is 50kΩ. Power supply needed should provide ±15V DC @ 10mA per card.

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For less than the price differential between standard and fancy finishes on a pair of speakers, you can make a significant improvement in the *actual sound* of your system. This high definition Neglex cable is a coaxial configuration using Mogami OFHC wire and copolymer insulation. Termination kits provide two short lengths of OFHC wire, two spade lugs and an insulating sleeve (one kit required for each end of cable).

The cable has extremely low capacitance, impedance, inductance, and eddy current effects. In the audio frequency range, impedance is virtually flat (see Nelson Pass' article on speaker cables in *SB* 2/80 for a discussion of these effects). Small improvements in low bass, extreme highs, imaging, depth, distortion, and amplifier damping all add up to audibly better sound and greater listening enjoyment—just one more way to remove some of the haze which prevents your system from sounding as clear as it should.

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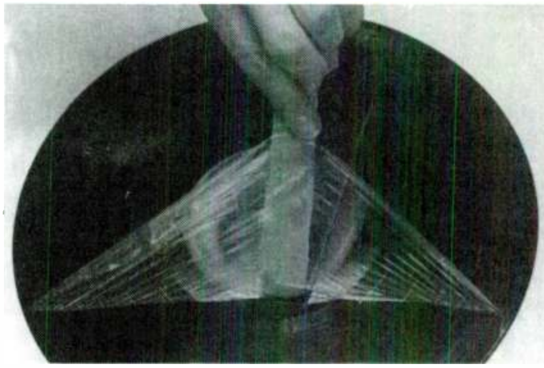
Actual size

If you have a personal stereo tape player or FM tuner, you will appreciate the sound quality and comfort of these earphones. So small and light they fit into the outer ear *without* a bulky headband, they sound considerably better than the headphones usually supplied with personal stereos. The bass is deep and strong, highs clear, and midrange smooth, with crisp, clean detail. Samarium cobalt magnets provide light weight—**just 18 grams**—and high efficiency. An extra pair of foam earpads is included. Because of their good sound and extreme comfort (they seem to melt away after a few seconds, leaving just the music), many people like to use them with their home systems as well (you'll need a mini to standard phone plug adaptor).

KM-9 WILLIAMSON RECORD CLEANING SYSTEM *Only $8.50!*



Developed by Reg Williamson, this two step system removes static charges from records virtually forever, and removes deep-down dirt thoroughly and safely. Static charges (as high as several *kilovolts)* lock dirt on the record and create annoying pops as the stylus traces over charged areas. The surfactant neutralizes those charges by supplying molecules with cationic ends to capture the negative ions.

The cleaning solution dissolves the dirt and holds it in a clear film when it dries. Simply peel the film away and the record is cleaner than when it left the pressing plant.

You supply distilled water, glycerin, isopropyl alcohol, an applicator and buffer pad. We supply ½ oz of de-static liquid (1000 treatments), and 4 oz of deep cleaner (80 disks). Regrettably, due to Postal Regulations, this cannot be shipped outside the US.

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______	Deep Cleaner Refill (4 oz) $4.00 each	______
	Total amount enclosed:	______

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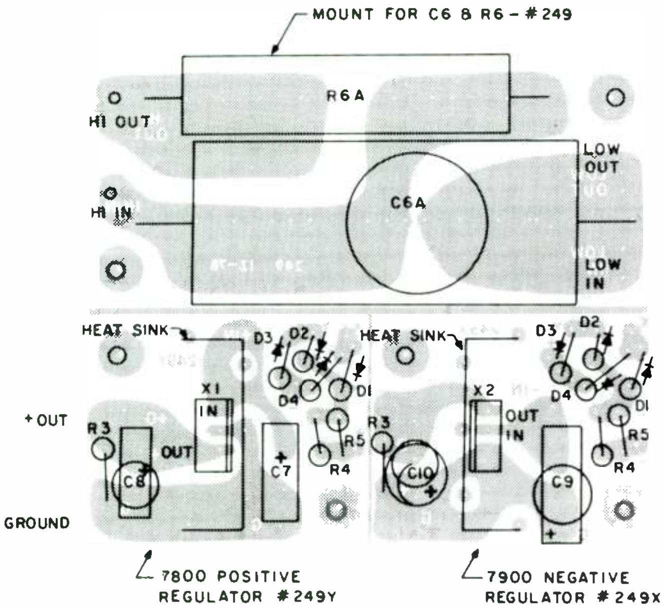


FIGURE I-16: Stuffing guides for power supply boards. See Fig. 17 for board patterns (Nos. 249, 249Y and 249X).

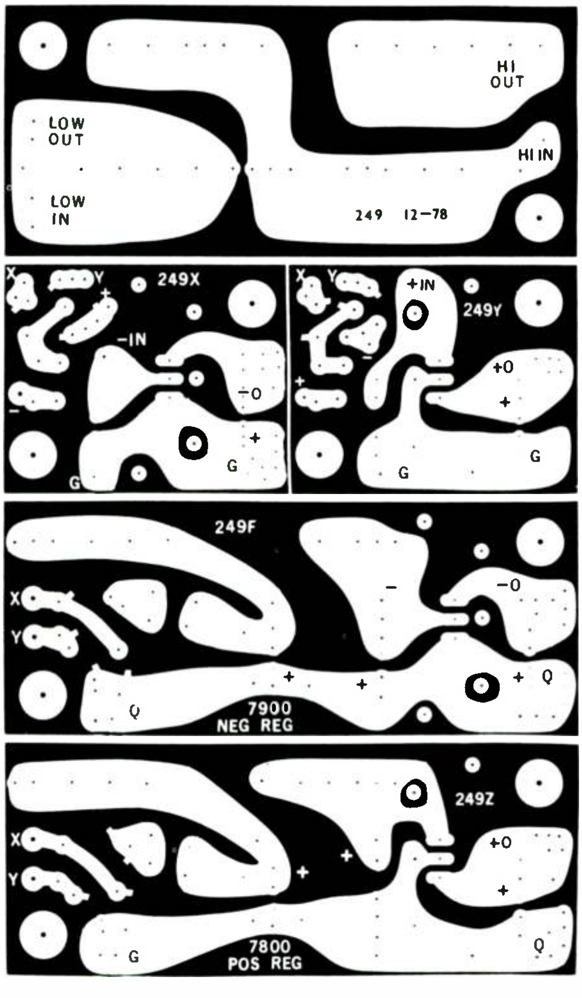


FIGURE I-17: Circuit boards for No. 249Z (Fig. 15a), No. 249F (Fig. 15b) and Nos. 249, 249Y and 249X (Fig. 16).

For the 7815 (+15V) and 7915 (−15V) power supplies, see *Figs. I-14* through *I-16* and *Tables I-6* and *I-7*. For all the units covered in this series, the 7815 regulator is built on the No. 249Z board (*Figs. I-14a* and *I-15a*), which mounts all the components. Also, the 7915 regulator is built entirely on the No. 249F board (*Figs. I-14b* and *I-15b*).

You might have other applications for these TO220 style regulators where filter capacitor C6 or limit resistor R6 might get too big or too hot to put with the voltage regulator. For these applications, put R6A and C6A on the No. 249 board and the remaining circuitry on the No. 249Y board for a positive regulator or on the No. 249X board for a negative regulator. The components division is indicated on the schematics (*Figs. I-14a* and *I-14b*) when this construction is used.

The calculation for the current limit resistor's value (R2 of *Fig. I-12*, R6 of *Fig. I-14*, and called Rb in general) is shown in *Fig. I-18*. This is based on tests of power supply circuits using the transformer in *Fig. I-10* and the same values for D1, D2, R1, R4, R5, C1 and C6 in *Tables I-4* and *I-6*, with a nominal line voltage of 115 to 117V. Any changes in parts will affect the equations shown for Vy. I sometimes take unregulated voltage off the power supply to light indicators or operate relays, and this is represented in the model as load Iz.

Figure I-18 shows a positive power supply, but all voltages and currents reverse on a negative power supply, so the same equations hold. The value of Rb is the maximum you should use so that at 10 percent low-line voltage and maximum load current, you still get at least 17.5V into the regulator. Note that 17.5V minimum is too low in a worst case with 78L15 and 79L15 regulators, which are specified to have a wide output voltage range. You should use a lower value of Rb and must correct even more if your normal line voltage is consistently below 115V. Then you can calculate the dissipation in Rb at maximum load current. If you short out the regulator, however, this dissipation can go way up. At least if this resistor fails, the power supply shuts down rather than going to full output.

Trying to find the maximum dissipation in the regulator with varying load current is a difficult calculation that I never bothered to solve. I have programmed the regulator on a calculator so that it lists the regulator's dissipation at various fractions of maximum load current. I simply scan this list to find regulator dissipation at any value of load current.

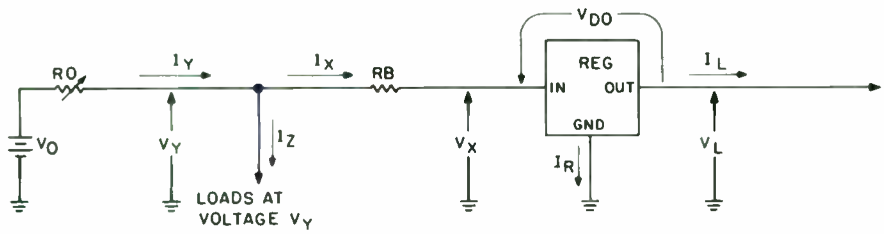
I offer no performance test data for the power supplies because the regulator manufacturers supply it on their data sheets, but remember that Rb will degrade the line and load regulation values somewhat. The 78L15 and 79L15 come in 10 and 5 percent versions. The 10 percent version could have values between 13.5 and 16.5V, while the 78L15A and 79L15A tighten this up to 14.25 to 15.75V. In my experience, the units are closer to 15V than the above seems to indicate. In any critical application, I test and select particular regulators for optimum performance.

I designed these power supplies for inputs of 115V AC ±10 percent. With low load currents (low drop across Rb), AC line inputs of more than 140V would exceed the regulator maximum input voltage. Such high voltage will also cause trouble with the 130V AC MOV across the input and take the main filter capacitor (C1 or C6) to its limit.

I did some thermal calculations on the regulator designs, based on 10 percent high-line voltage, 15V regulator outputs and with no heatsinks. The TO92s, designed for a maximum load current of 25mA, showed 345mW maximum dissipation and a 62°C rise from ambient to junction. The TO225s, designed for a maximum of 125mA, showed 1.2W maximum dissipation and a 76°C rise. Operation of these maximum power designs at ambients up to 45°C (113°F) results in junction temperatures of less than 125°C, a safe operating level ensuring long life. Heatsinks on the regulators, along with lower operating currents and line voltages, add an even greater margin of safety.

All four regulator series are avail-

Continued on page 42



- All voltages in volts, all currents in milliamps
- $Ix = Ir + IL$
- $Iy = Ix + Iz$
- For 7815 & 7915 regulators:

  $$Vy \cong Vo - \left(\frac{Iy}{19.5}\right)^{.77}$$

  $0 \le Iy \le 150mA$
- For 78L15 & 79L15 regulators:

  $$Vy \cong Vo - \left(\frac{Iy}{10}\right)^{.8}$$

  $0 \le Iy \le 30mA$
- For 115V AC line $Vo \cong 28.7V$; at 10% high line $Vo_H \cong 31.6V$; at 10% low line $Vo_L \cong 26.1V$

- At 10% low line and maintaining 17.5V minimum to regulator:

$$\text{maximum } Rb = \frac{Vy_L - 17.5(1000)}{(IL_H + Ir)}$$

Vy_L at Vo_L & maximum Iy
IL_H = maximum load current (mA)
Ir (regulator quiescent current) = 6mA for 78L & 79L
Ir = 8mA for 78 & 79

- Dissipation (PRb—in watts) in Rb computed above:
  $PRb = 1 \times 10^{-6}\, Rb\, (IL_H + Ir)^2$
  (Dissipation will rise if load is short circuited.)
- Dissipation (PR—in watts) in regulator (looking for maximum)

$$PR = \left[Vy_H - Rb\left(\frac{Ix}{1000}\right)\right]\left(\frac{Ix}{1000}\right) - VL\left(\frac{Iz}{1000}\right)$$

Vy_H = Vy at Vo_H and minimum value of Iz

FIGURE 1-18: Calculation of Rb (in ohms) for a positive power supply.

THIELE-SMALL NOMOGRAMS

HOW TO SIMPLIFY PARAMETER MEASUREMENT

BY THOMAS L. CLARKE

The theory of speaker design developed by Thiele[1] and Small[2] depends on knowledge of the three small-signal parameters for drivers—Q_T, f_s and V_{AS}. Knowledge of a driver's damping factor, resonance frequency, and equivalent acoustic volume are all you need to design a matching enclosure.

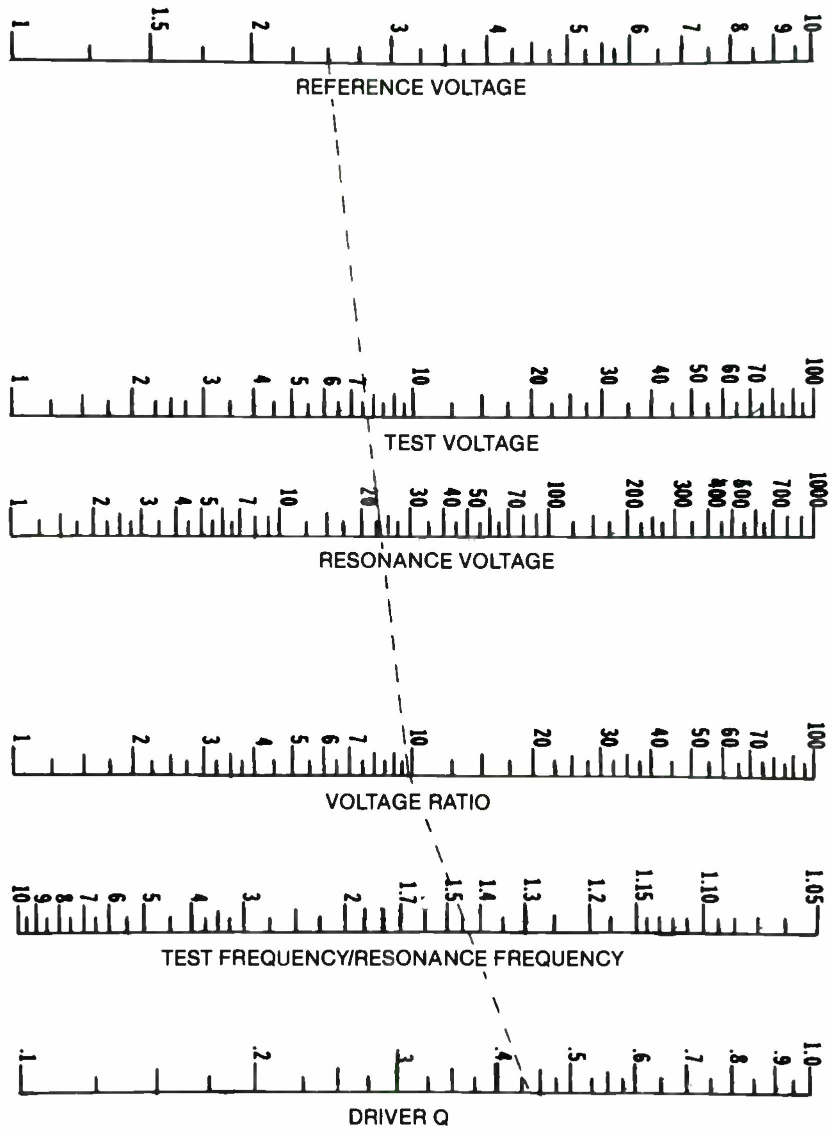
In his article, Small discussed the procedure for measuring these parameters using only a signal generator, a voltmeter, and a test volume. Bullock[3] and others have elaborated on this procedure.

Reducing the raw measurement to driver parameters, however, involves some fairly complicated algebra and can become tiresome when you are measuring a number of drivers. The nomograms presented here reduce this algebra to simple graphs and permit you to determine the driver parameters rapidly. An additional nomogram helps you to find the driver sensitivity, or efficiency, from the three small-signal parameters.

You do not usually calculate the driver sensitivity, but it is a useful guide when you are choosing a set of drivers to operate together in a multiple-way system. While you can pad down a tweeter to match a less sensitive woofer, it is difficult and wasteful of power to pad down a woofer to match a less sensitive tweeter.

I have also included design graphs and nomograms to help you design an enclosure for a given driver. For the highest accuracy, you should use Bullock's tables.[4] Nevertheless, the graphs presented here permit you to complete a design rapidly so that you can easily assess the feasibility of using a given driver in a particular enclosure. The design graphs are basically the same as those in theoretical design articles, but I have redrawn them to make them easier to use.

One of these nomograms relates driver parameters and enclosure type to maximum sound pressure level and electrical power input. The relationship is necessarily approx-



NOMOGRAM 1: Finding the Driver Q is simply a matter of plotting your measurements of driver impedance.

imate, as I have assumed a typical relationship between system cutoff frequency and driver displacement volume for each enclosure type. (Small explains the basis of these assumptions in his papers.) The power-handling capability that you can estimate from this nomogram, however, will be a useful guide to the capabilities of a given driver.

I have used an example driver to illustrate how you would use this set of nomograms to measure driver parameters and design an enclosure. As a matter of style, any quantity that you enter onto or read from a nomogram axis will appear in italics in the text, e.g., *Driver Q*. In addition, I have included a new type of loudspeaker enclosure, the augmented passive-radiator system, which I invented.[5] A theoretical analysis of this system appears in *JAES*.[6] For a description of how I constructed an augmented passive-radiator enclosure designed with these nomograms and the example driver, see my article in *CQ*.[7]

PARAMETER MEASUREMENT. This is the classic test setup. A voltmeter measures the voltage that a large resistor produces across the driver terminals in series with a variable frequency sine wave generator. You should, of course, mount the driver clear of obstructions unless you have deliberately mounted it in a test enclosure volume. For best results, use a precision voltmeter. Also, since the driver acts as a microphone, conduct the test in a quiet location.

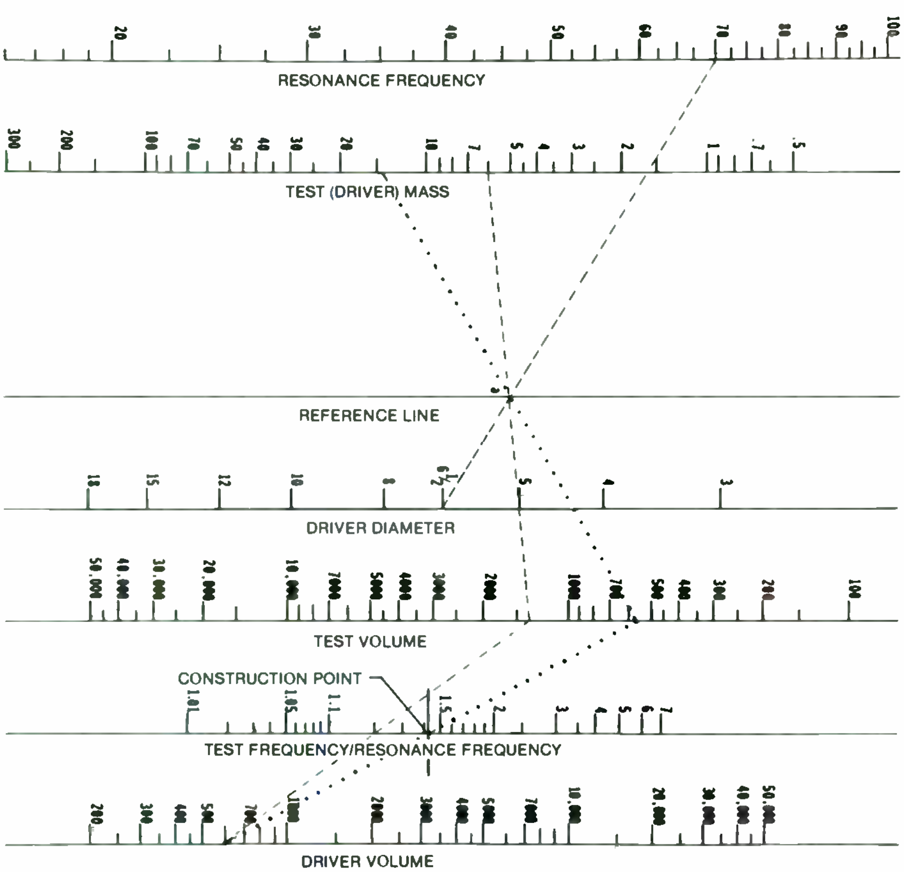
The series resistor must be as large as possible, but still be consistent with good voltage readings. Make low resistance connections to the driver, preferably with solder. For the highest degree of accuracy, use W. J. J. Hoge's method[8] for measuring Q. Unfortunately, reducing Hoge's method to a nomogram is not easy.

Begin by finding the *Resonance Frequency*, the frequency at which the voltage across the driver peaks at the *Resonance Voltage*. For the example driver, the values were 23 voltage units at 70Hz. (The type of voltage units does not matter, just be consistent.) Next, tune the oscillator away from resonance to find a minimum *Reference Voltage*. The sample driver read 2.5 voltage units. On Nomogram 1, join the values of the *Resonance Voltage* and *Reference Voltage* with a line to find a *Test Voltage* (7.7 voltage units) and extend the line to the *Voltage Ratio* scale (9.8 for the example).

Now tune the oscillator back toward resonance until you find the *Test Frequency* at which the voltage across the driver equals the *Test Voltage*. Divide the larger of the *Test Frequency* and the *Resonance Frequency* by the smaller, and draw a line from the *Voltage Ratio* through this ratio (1.44 in the example) on the *Test Frequency/Resonance Frequency* axis to the *Driver Q* axis. In the example, the *Driver Q* is 0.43. This value is Q_T, or total driver Q, and includes the effects of mechanical and electrical damping.

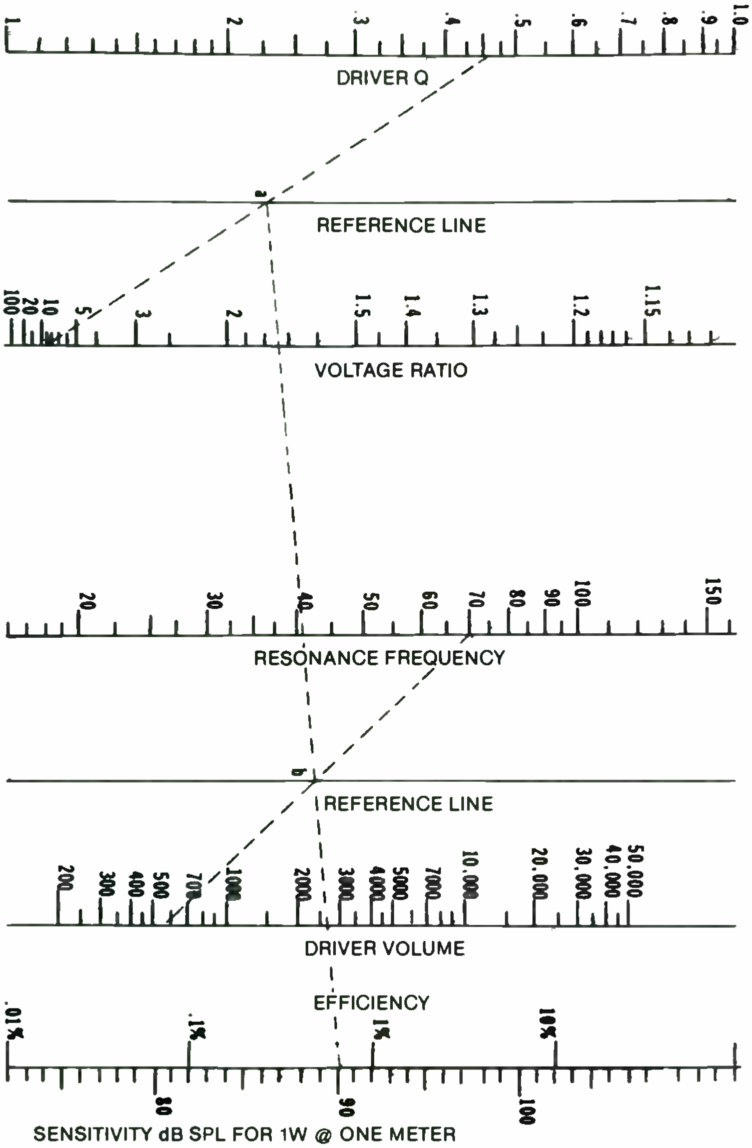
You can follow this measurement procedure by tuning either up or down from resonance to find the *Test Frequency*. The values in either case should be very close. If they are not, then the driver is unusual, and you cannot expect standard speaker theory to work well.

To find the remaining driver parameter, *Driver Volume*, you can use one of two methods. The more accurate method is to use a test volume, but if a test volume is not available, you can obtain fairly good results by using a test mass. You should construct the test volume carefully and use a gasket on the driver so that it has no air leaks.



NOMOGRAM 2: You can determine the Driver Volume and Driver Mass by using a test volume or weighing a test mass with the driver cone. Either method requires that you plot your measurements of frequency shift to determine these volumes.

NOMOGRAMS 2 AND 3. Both methods require that you connect the *Driver Diameter* (6½" in the example) to the *Resonance Frequency* in Nomogram 2, crossing the *Reference Line* at Point A. If you are using a test volume, mount the driver in the volume and note the ratio of the new resonance frequency to the free-air resonance frequency, which gives



NOMOGRAM 3: To evaluate Driver Sensitivity, or Efficiency, use the values for Driver Q and Driver Volume, along with these two other small-signal parameters.

you the *Test Frequency/Resonance Frequency.* Drawing a line from the *Test Volume* (1,400 cubic inches) through the value of the *Test Frequency/Resonance Frequency* (1.2 in the example) to the *Driver Volume* axis shows that the example driver has an equivalent acoustic volume of 600 cubic inches.

You can find the moving mass of the driver, i.e., the *Driver Mass,* by drawing a line from the *Driver Volume* through the *Construction Point* to the *Test Volume* axis (570 cubic inches). Continuing on through the *Reference Line* at Point A to the *Test (Driver) Mass* gives you 14 grams for the moving mass of the example driver. This value is useful in designing passive-radiator enclosures.

If no test volume is available, you can use a test mass. This is a small mass (two pennies, or six grams, in the example), which you temporarily attach to the cone with modeling clay to lower the resonance frequency. Starting at the value of the *Test (Driver) Mass,* continue through Point A on the *Reference Line* to the *Test Volume* (1,400 cubic inches). Continuing through the ratio of free-air resonance frequency to weighted resonance frequency (1.2) on the *Test Frequency/Resonance Frequency* axis, the *Driver Volume* is again 600 cubic inches. Find the driver moving mass as I described above.

You can use Nomogram 3 to evaluate the driver sensitivity, or efficiency. Join *Driver Q* and the *Voltage Ratio* from Nomogram 1 to find Point A on the *Reference Line.* Next, join the *Resonance Frequency* and the *Driver Volume* from Nomogram 2 to find Point B on the right *Reference Line.* Joining Points A and B gives you the value of 90dB SPL @ one meter for *Sensitivity.* Alternatively, the efficiency is about 0.6%.

This nomogram will work with the small-signal parameters given in the driver catalog by using the typical value of ten on the *Voltage Ratio* axis. Fortunately, the final value of *Sensitivity,* or *Efficiency,* does not depend much on the *Voltage Ratio.*

ENCLOSURE DESIGN. You can use *Figures 1 and 2* to estimate the enclosure size and performance. *Figure 1* plots the values of the *Cutoff Frequency* ratio versus *Driver Q* and the *Enclosure Resonance Frequency Ratio* versus *Driver Q* for several types of enclosure. These are the enclosure types: IB—infinite baffle, VB—vented box, PR—passive radiator, and AR —augmented passive radiator.

To find the system *Cutoff Frequency* and *Enclosure Resonance Frequency,* multiply the *Driver Resonance Frequency* by the corresponding values in *Fig. 1.* Similarly, use *Fig. 2* to obtain the *Enclosure Volume* by reading the *Enclosure Volume/Driver Volume* ratio from the graph and multiplying it by the *Driver Volume.*

For the example driver, a vented-box enclosure gives a *Cutoff Frequency* of 58Hz, an *Enclosure Resonance Frequency* of 60Hz, and an enclosure volume of 670 cubic inches. Note that no *Enclosure Resonance Frequency* is defined for the infinite baffle and that you can use only the infinite-baffle enclosure with drivers having Q_T's higher than 0.5.

Having chosen an enclosure type, you can estimate the *Maximum Power Input* and the *Maximum SPL* from Nomogram 4. Join the *Driver Diameter* to the *Cutoff Frequency* to intersect the *Reference Line.* Draw a line from the *Enclosure Type* through the reference line intersection to the *Maximum SPL* axis (109dB SPL @ one meter for the example driver in a vented box with a *Cutoff Frequency* of 58Hz). Connecting the *Sensitivity* axis with the *Maximum SPL* gives the

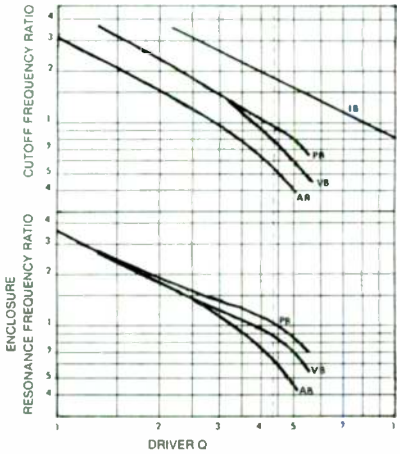


FIGURE 1: You can estimate your enclosure's performance—Cutoff Frequency and Enclosure Resonance Frequency—by using the values in this graph. The figure illustrates the Cutoff Frequency Ratio and the Enclosure Resonance Frequency Ratio versus the Driver Q for each type of enclosure.

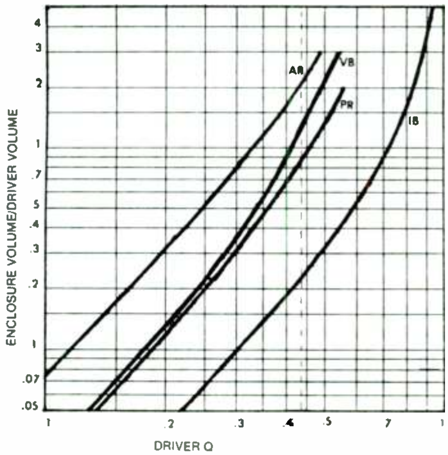
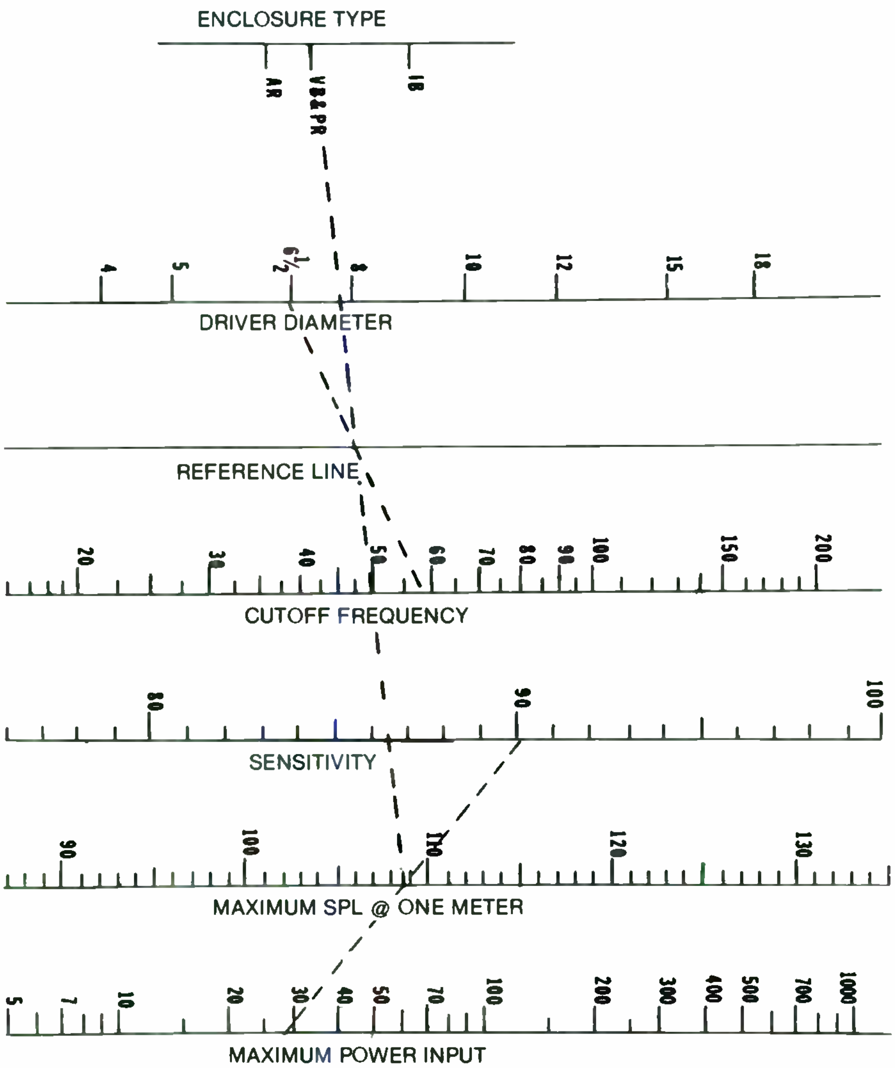
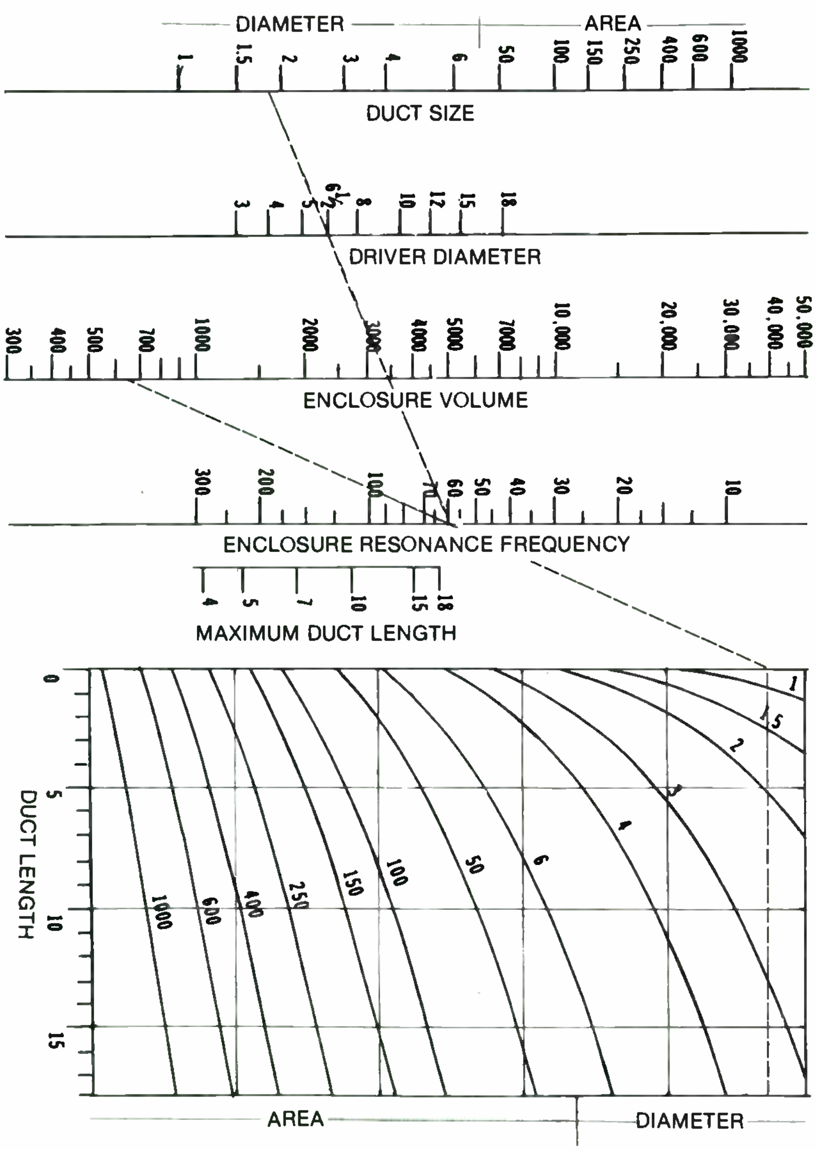


FIGURE 2: To determine the Enclosure Volume, multiply the Driver Volume by the appropriate value in this graph. The values represent Enclosure Volume/Driver Volume versus Driver Q.



NOMOGRAM 4: Estimating the Maximum SPL and the Power Input is a breeze once you have chosen the Enclosure Type and know the Cutoff Frequency and Driver Diameter.



NOMOGRAM 5: Tuning a vented-box enclosure requires careful planning of Duct Size. The values given for Duct Size are the minimum size recommended to avoid excessive wind noise. The Maximum Duct Length scale is an important reference point for avoiding organ-pipe effects. The rectangular graph defines possible combinations of Duct Length and Duct Diameter or Area.

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—Ed.

Maximum Power Input. For the example driver, a vented-box or passive-radiator enclosure gives a fairly good power-handling capability of 28W. When constructing this nomogram, I assumed a typical maximum driver excursion of 6 millimeters.

TUNING THE SYSTEM. The final two nomograms are useful in tuning the completed system. Nomogram 5 relates the *Enclosure Volume* and the *Enclosure Resonance Frequency* to the tuning duct size for vented-box enclosures. Joining the *Enclosure Resonance Frequency* to the *Driver Diameter* gives you the *Duct Size*, which is the minimum duct size recommended. Use of a duct smaller than the *Duct Size* is likely to result in excessive wind noise.

Also note the *Maximum Duct Length* scale next to the *Enclosure Resonance Frequency* axis. The duct should be shorter than the length opposite the *Enclosure Resonance Frequency* to avoid organ-pipe effects.

Join the *Enclosure Volume* to the *Enclosure Resonance Frequency* and continue the line to the left side of the rectangular graph. Continuing horizontally across the graph defines a line of possible combinations of *Duct Length* and *Duct Diameter* or *Duct Area*. If you choose a *Diameter* or *Area* for a potential duct, you can read off its length by continuing the intersection of the curved line with the horizontal line down to the *Duct Length* axis at the bottom of the graph. For the design example, a duct with an inside diameter of 2″ is larger than the minimum and gives a length of 5.3″, which is shorter than the 20-inch maximum.

The final nomogram relates the *Driver Mass* to the *Passive-Radiator Mass* for conventional and augmented passive-radiator enclosures. Fortunately, the ratio of the driver moving mass to the passive-radiator moving mass is nearly a constant, independent of driver Q_T, making this nomogram possible. Joining the *Driver Diameter* to the *Radiator Diameter* (6½ and 8″ in the example), gives an intersection at Point A on the *Reference Line*. You then determine the *Mass* by joining the *Driver Mass* to the *Radiator Mass* axis through Point A on the *Reference Line*. You will not know the moving mass of a commercial passive radiator, but the results of Nomogram 6 can still serve as a guide when you are adding mass to tune the system.

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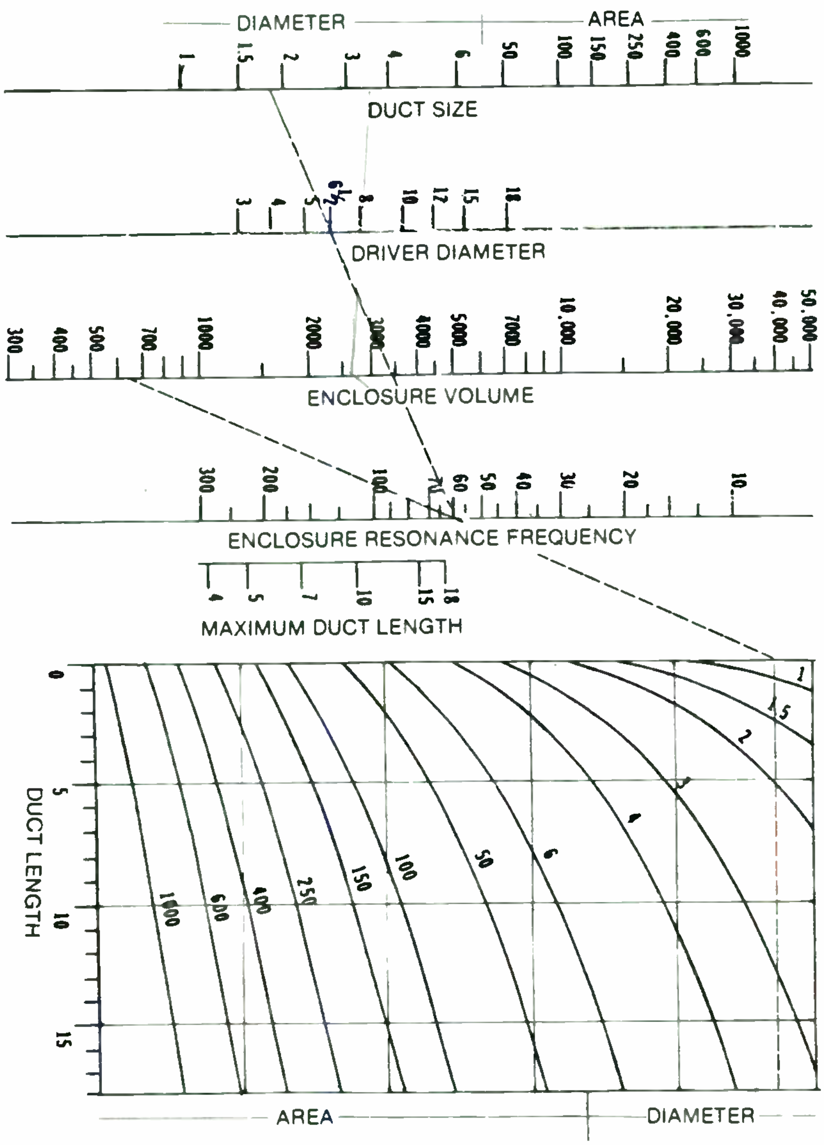

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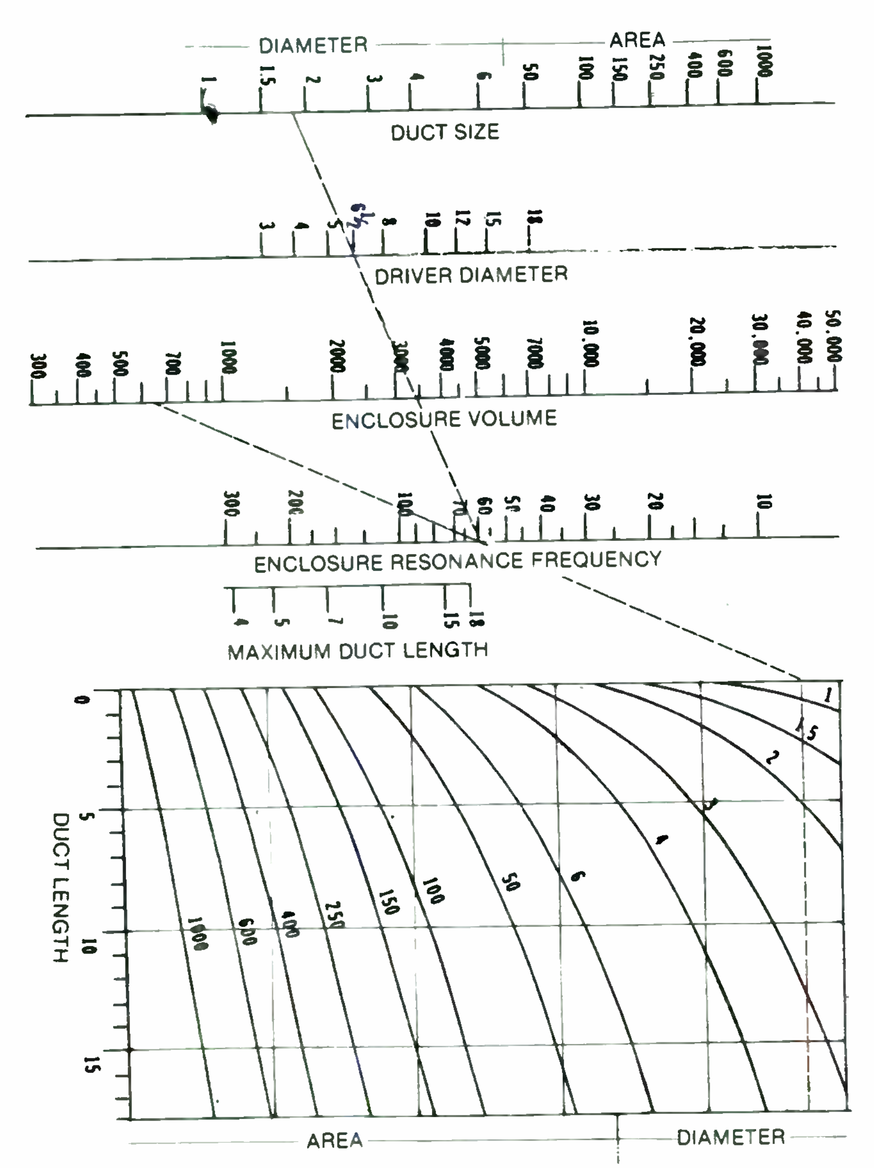

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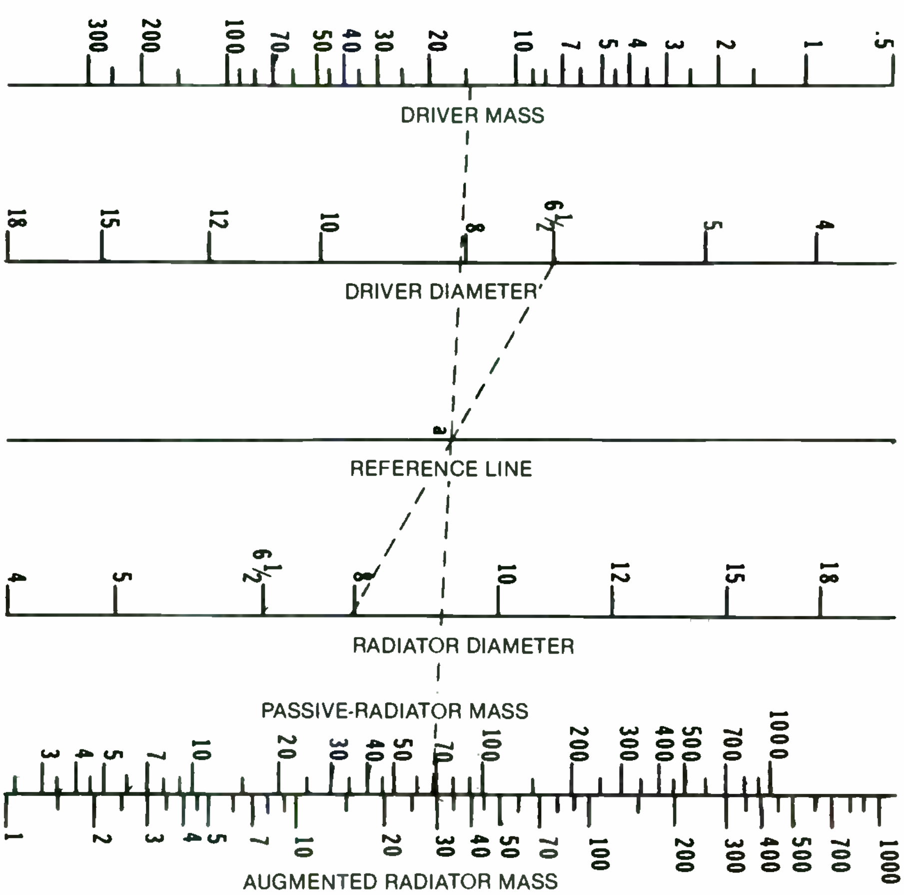

NOMOGRAM 6: To find the Radiator Mass for passive-radiator or augmented passive-radiator enclosures, use your values for Driver Mass, Driver Diameter, and Radiator Diameter.

enclosure, you can weigh the cones before mounting and determine the added mass necessary to tune the system by subtracting the weight from the nomogram value.

These procedures should permit you to determine driver parameters rapidly and to design the matching enclosures. So, clean out your junk box and measure all those old speakers. Then design enclosures for them or use the parameters published in your favorite speaker catalog to find the best driver for your next system. ☐

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Tools, Tips & Techniques

Geritol for Advents

I had long wanted to improve my old Large Advent speakers. I found the opportunity at a garage sale last summer in a pair of beat-up Advents. Now I could have the Double Advents that sounded so good at my dealer's several years ago. But like many older Advents, the tweeters were gone (in this case, not just with open voice coils, but gone).

Although Advent's sales literature does not specify the crossover point, I knew it was relatively low. I found it by measuring the voltage at each speaker as I drove the Advent with a constant voltage at a few frequencies in the octaves where the crossover point would likely be, eventually finding it at 1.3kHz. To do this I temporarily connected fine wires to the woofer and brought them out through the sealing compound around the rim of the woofer. I covered the hole for the tweeter and connected a temporary tweeter externally for a load. The crossover point does not change whether the tweeter level switch is set at "normal," "increase" or "decrease."

Not many tweeters go low enough to cross over at 1.3kHz. Replacement Advent tweeters cost about $39, so I looked for an economical substitute that would fit. I tried a Polydax 25mm dome tweeter, but it had insufficient midrange. The region between 1 and 2kHz (where the ear is most sensitive) is critical for music reproduction.

At my age my hearing in the last octave is not so good, so I decided to trade off high frequency response for better midrange output. Thus a midrange or midrange-tweeter seemed to be the best choice. I studied the spec sheets of several makes of speakers, including fine candidates by Polydax, SEAS and Philips. The Polydax HD-13D37 had about the right specs, but was a little too costly. About this time I saw a midrange soft dome speaker in a Radio Shack flyer. It has a voice coil diameter of about 41mm, and its other specs indicated that it should reproduce an adequate sound pressure level about one octave below the crossover point of the Advent. High-end response is 5dB down at 12kHz. I went to the local Radio Shack store and bought a Realistic 40-1281 midrange with the understanding that I could bring it back if it proved unsatisfactory.

I temporarily wired it in and found that it sounded quite nice compared to the original Advent tweeter. I have the two pairs of Advents wired together with a switch so I can compare them. When I use this Double Advent system, the bass improves considerably, and the RS drivers smooth out the midrange response, while the remaining Advent tweeters provide good highs.

The only disadvantage to using the RS speaker is that the original tweeter hole in the Advent's baffle board must be enlarged. An easy way to fit the Realistic speaker in the Advent's baffle is to make a circular cardboard template representing the clearance required for the speaker's magnet. Trace the two small crescents on the Advent's baffle board. Cover the woofer, lay the speaker on its back, and put a rag or some paper in the tweeter hole to catch sawdust. Cut out the crescents with a saber saw.

Place the speaker in the baffle and locate the mounting holes, which will be close to the cutout. (Note that I found the Advent's tweeter wired in reverse polarity—i.e., opposite of the color-coding standard.) Put closed-pore sealing foam or a sealant such as RTV silicone rubber on the back of the speaker flange. Secure the speaker with small screws (I recommend number 6 or 4 self-taping screws). Screw the speaker down gradually and evenly.

I have been living with this solution for several months, and it *sounds* like a good, cost-effective solution for Large Advent tweeter replacement.

Andrew D. Keller
Longmont, CO 80501

Thin Bin

Mother Hubbard's cupboard was no doubt in worse condition than our file folders for *SB's* "Tools, Tips & Techniques" feature, but we're about to get the "impending famine" warning light on our computer. Your handy tips, shortcuts and unique insights are all welcome, and *SB* pays $7.50 minimum for them. (It's a great way to pay for your subscription.) Photos of your handiwork and an account of how and why you built your beautiful gear are also welcome. Payment for illustrated tips is $20 and up, depending on length of copy and quality and number of photos.

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Fortunately, the cure is easy. Carefully sand each coat of finish with 600-grit wet or dry sandpaper. Gently wipe the surface —you want to polish out the dust, not remove the varnish. Sand the first coat when it is dry, then use water as a lubricant on subsequent coats. This technique is appropriate with varnish, polyurethane or tung oil finishes.

Some books recommend fine steel wool as an alternative to sandpaper, but I find that the wool strands are worse than the dust. Try my method—it really works and is easy to do.

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Kit Report
Acoustic Image Model II

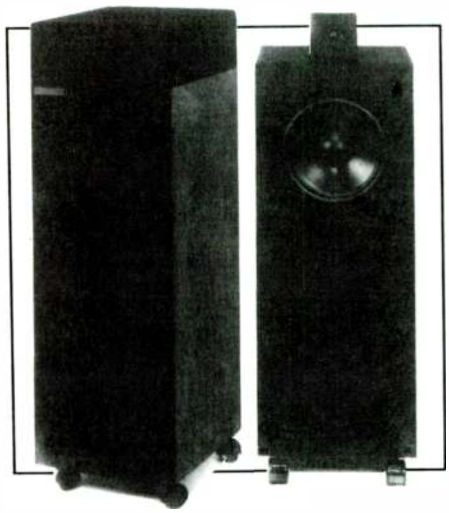

PHOTO 1: Acoustical Physics Laboratories' Acoustic Image Model II, with and without grille frames in place.

Acoustical Physics Laboratories (3877 Foxford Drive, Doraville, GA 30340) is offering a new two-way, floor-standing loudspeaker system, the Acoustic Image Model II, in three forms. All parts necessary to build the units, except the cabinets and grille frames, are supplied in the Basic Model II Kit at $225 per pair. The Complete Model II kit, at $400 per pair, includes everything needed to assemble the two units in about two hours. The factory-assembled Model II is priced at $600. Shipping in all cases is freight collect, except the basic kit can probably be shipped UPS by special arrangement with the manufacturer. Shipping charges for the complete kit pair from the Atlanta area to our office in New Hampshire were $43.

Each speaker cabinet comes packed in its own box, carefully braced against shock or puncture damage. The drivers, mounting screws, gasket material and casters are shipped in a separate box. The crossovers (*Fig. 1*) come pre-mounted in the cabinet on ¾-inch-thick chipboard panels. The standard five-way binding post terminals are nickel plate and will accept banana plugs or No. 18 wire comfortably. Larger wire sizes might be more difficult to insert in the cross-holes. I used No. 14 stranded wire with special spade lugs.

The terminals are recessed into a 3½-inch square hole in the back panel. The crossover components are connected directly to the input terminals as well as to tie lugs mounted next to them. Number 18 stranded wire with easy-connect Stak-on connectors is supplied, making connection to the drivers quite simple. The tweeter wires are fed through a small hole in the top of the bass cabinet, which is fully sealed with epoxy, making it airtight.

Pilot holes are pre-drilled for the tweeter mounting bracket, allowing you to locate the tweeter face exactly for proper time alignment with the woofer. The ½-inch adhesive foam gasket material supplied is easy to place under the tweeter bracket.

You must drill pilot holes 1/16-inch in diameter to mount the low-frequency driver. This is easily done by placing the driver in the opening and marking the locations. After removing the driver and drilling the holes, it is quite simple to peel the backing from the gasket foam and press it into place around the edge of the mounting hole. The foam has an "easy" tack, so you can apply, lift and relocate it with no difficulty. It is possible, by taking care, to put the material in place without stretching it. This is important if the seal of the driver is to be of equal thickness around its entire circumference. In this way, the seal is complete—quite important in closed-box systems. The mounting screws have a "fast" thread and are easy to drive and remove with either a phillips or standard blade screwdriver.

One detail that surprised me in the cabinet construction was the absence of a recess, which would have positioned the woofer-mounting ring flush with the cabinet's front panel. By now, we all know about the effects of diffraction. It would probably also have been a good idea to locate both drivers slightly to the left or right of the cabinet's center line to minimize the cabinet reflections' diffraction content.

The four handsome casters are easy to mount, and they raise the cabinet's bottom 2½ inches from the floor. Making the units easy to move is obviously convenient, but those of us who live in old houses (with sloping floors) would have liked two of each four to be locking types.

Handsome Grille Work

Physically, the two enclosures and their associated grilles are quite handsome. They stand 37½ inches high, which places the midpoint between the two drivers at ear level when the listener is seated. The front and back panels are painted matte black, while the top and sides are finished in a warm matte walnut veneer. The front and top grilles, which are covered in carefully stretched black cloth, are especially attractive. I could detect no difference in sound with the front grille removed or snapped into place on its four plastic snap-in mounts. The top grille is an elaborate frame and beautifully finished. All the outer edges of the grille frames (except the top and bottom of the bass grille) are rounded for a particularly attractive overall effect.

I comment here on the appearance of the grilles because of my earlier experience with a similar stretch grille material, which I mounted on plywood frames supplied in the SEAS 603-CK speaker kits (*SB* 3/80, p. 34). Stretching it evenly and with straight "grain" is no easy task. I commend Acoustical Physics Labs workers for their obvious care and skill.

The cabinets supplied for this report are solid, well made and have tight, well-glued corner joints without inner reinforcing corner cleats. Such construc-

Manufacturer's Specifications

Type: Closed-Box Woofer
Open-Back Tweeter
Frequency Range: 28Hz to 22kHz, ±2dB (Fast Fourier Transformer)
Recommended Amp Power: 40 to 150W/channel
Bass Enclosure: 2.18 cubic feet
Bass Driver: 10" polypropylene, SEAS P25REX H283
Treble: 1" soft dome, time corrected
Crossover: Passive, 3.5kHz, 6dB/octave
Impedance: 8Ω

tion techniques are easy with large woodworking machinery. Assembly was so easy I think the majority of neophytes could put it together successfully.

If you like the less-expensive, do-it-yourself Basic Kit at $225, you will receive everything you need to build the pair except the lumber—drivers, premounted crossovers, casters, screws, fiberglass, grille cloth and exceptionally complete instructions. Indeed, the instructions are unusually helpful, with many practical suggestions about construction methods and sources of tools and materials. The enclosure is a simple box that should be easy to duplicate. (See *Figs. 2* and *3*.) A single sheet of particle board should be plenty for two enclosures, and a local lumberyard could easily cut the parts. The woofer hole is the only complex cutting job, since all the box joints can be butted together, glued and screwed with added 1-inch cleats at each junction.

The manufacturer goes into great detail about building the boxes and even greater detail about making the grilles, even explaining how to stretch the cloth over the frames. The handy nylon fasteners for mounting the frames (male) and the cabinets (female) are supplied with the kit. The tweeter grille cover is a bit tricky to make, but not too daunting. It is made of ¾-inch plywood or dense particle board and is a box with four sides and a top (13 x 13¹³⁄₁₆ x 5 inches high), having large cutouts in the three sides and top (see *Fig. 3*).

Skilled builders will want to improve the cabinetry by recessing the woofer so it mounts flush, altering the tweeter mounting location accordingly to preserve the time alignment. They will also find ways to round or angle the inner edges of the grille frames to diminish the effects of diffraction. Purists will use the same size wire from the crossovers to the drivers as they use between their amplifiers and the speaker's terminals.

The crossover is, according to the manufacturer, constructed with "nonsaturating inductors and metal film capacitors." The capacitors are not electrolytics and appear to be either polyester or some better dielectric. The slope is a 6dB/octave type using a minimum of components. Bill Morrison, of Acoustical Physics, called me after the test pair of Model II kits had arrived to say that some of his listening panel had suggested that the crossover needed to be slightly altered in the midrange by approximately +2.5dB to help balance the bottom end of the response.

I added the optional 10Ω, 10W resistors across the 2.5mH iron-cored series inductors for the bass drivers, shown as dotted lines in *Fig. 1*. To evaluate the effect of the added resistor, I also drilled a small hole in the top of the cabinets and brought out a pair of wires to an SPST switch, since Morrison seemed unconvinced of the need for the change.

Listening Tests

I have listened to all sorts of program material on the speakers over a six-week

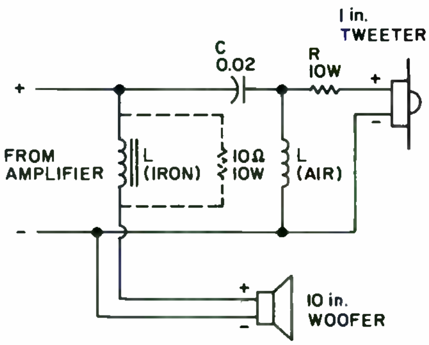

FIGURE 1: The crossover is specifically designed to account for the response, suspension and time alignment between the two drivers. You may parallel the optional 10Ω, 10W series resistor with the low-frequency, low-pass, iron-cored inductor to increase the relative level of the mid frequencies.

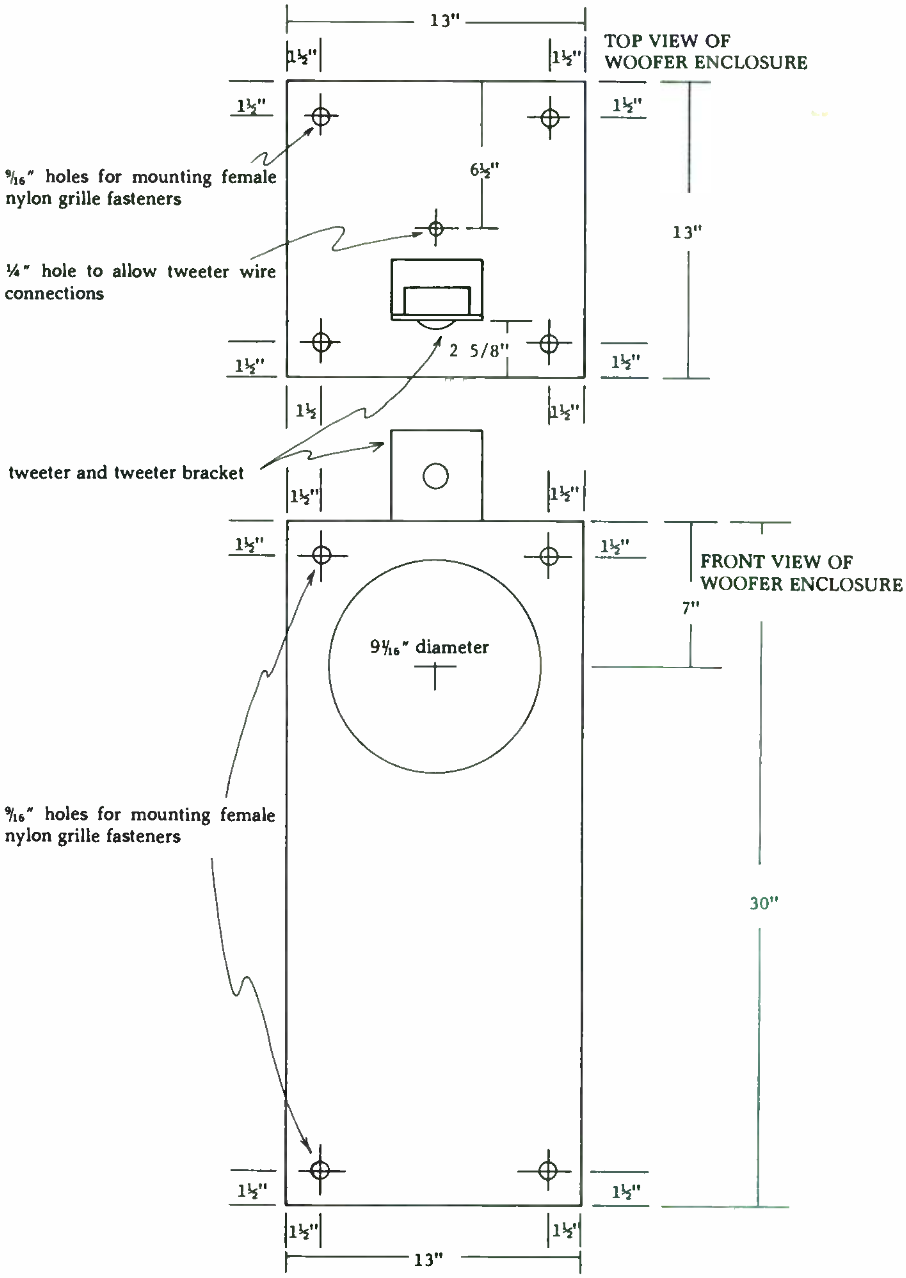

FIGURE 2: Front and top dimensions of the Acoustic Image Model II cabinet.

Kit Report

period and during some extended sessions listening to the effect of the added resistor. My test material included master tapes, FM live broadcasts and other sources. I used several preamps (all solid state) and several power amps ranging from 30 to 100W, class A and AB. The resistor change tends to brighten the midrange and gives the system what is, to my ears, a more natural sound, with a less "tubby" bass. Voices, particularly, sound more natural. On some material, however, the boost is too much, and the effect has a hard edge that is unpleasant.

I began to think that perhaps a 5Ω resistor might be a better answer than the 10Ω one suggested. It might be that end-users of the system will want to experiment with this proposed "balancing adjustment" by trying a variety of resistor values to match room conditions or associated equipment.

The Acoustic Image Model IIs are exceptionally clean and well imaged. Their depth definition is average to good, and left-to-right location of instruments is excellent and very stable. The bass surprised me. It is solid and below what I expected that size driver/box combination to produce. I detected no significant overhang on drums and other percussion. Strings are lifelike and not at all wire-like or edgy. I was able to listen for

Continued on page 42

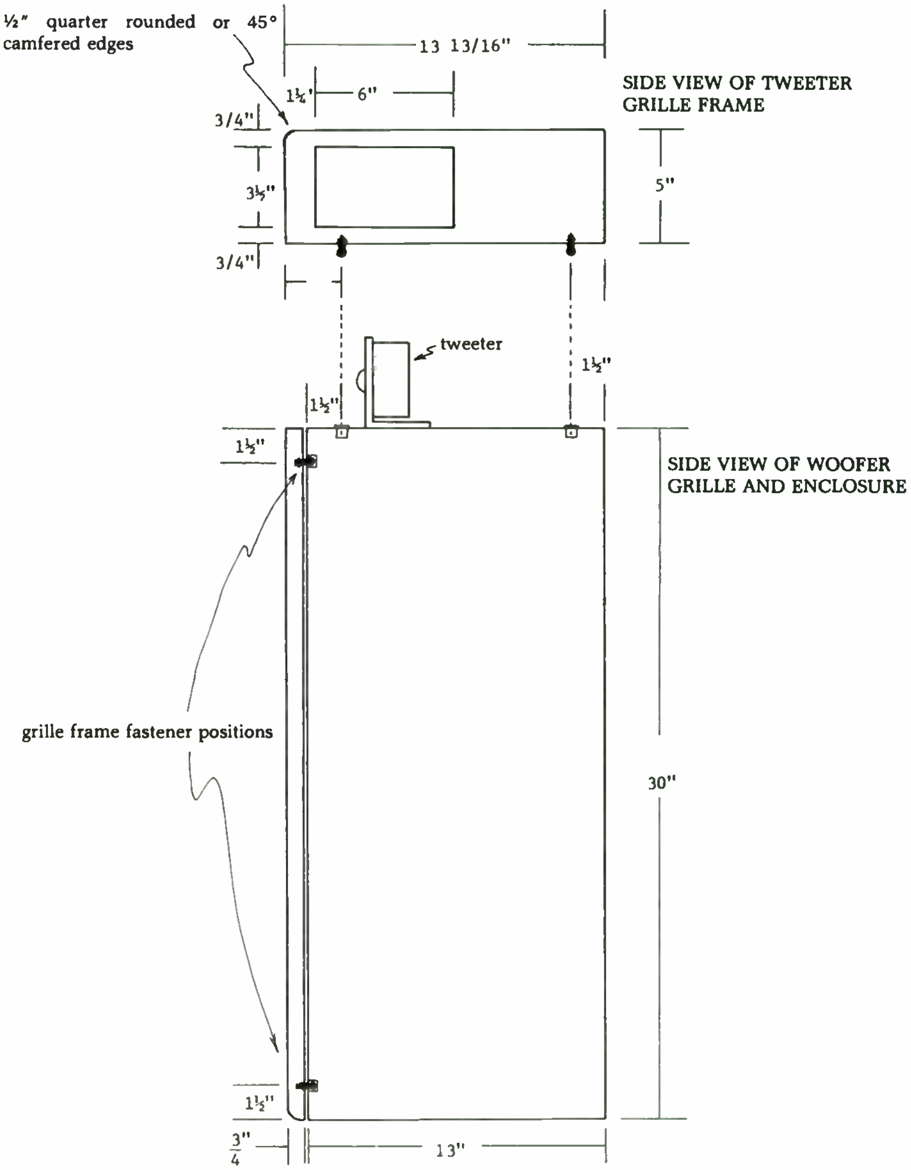

FIGURE 3: Side dimensions of the woofer cabinet and the top grille frame.

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The headphone output on most amps usually is a large resistor in series with the output to knock the level down to what is suitable for driving headphones. The resistor reduces the amp's damping ability, leaving your headphone drivers less tightly controlled. You will also suffer the distortions produced by the resistor's particular nonlinearities. To solve these problems, Jim Boak has designed a high performance amp specifically for headphones. Built around the powerful 540 op amp, it features a circuit modification,

derived from Walt Jung's work, which gives the op amp a highly linear transfer characteristic. The resulting distortion curve has that gentle rise associated with good tube amps, and a clean, wide open sound quality you will enjoy thoroughly every time you listen on headphones. To top it off, Boak gave it excellent power supply regulation. Each channel has independent power supplies using three-terminal regulators to deliver stable voltages across the entire audio range. The amp may be configured for driving either electrostatic or dynamic headphones, and parts for both are included.

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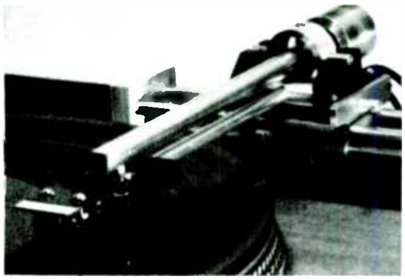

Here's your opportunity to own a tangential tracking tone arm—and have the fun of building it yourself. Rod Cooper's ingeniously simple design elegantly achieves the benefits long attributed to tangential arms. The kit has been sold in England for several years and has been praised for its high quality. The metal parts are precision-machined for a solid, tight-fitting assembly. Mount it on your choice of turntables, and you will have an outstanding piece of equipment which you can use and enjoy every day, for many years of listening enjoyment.

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CORRECTION: CARLBERG ODYSSEY

Three errors crept into Part IV of "A Speaker Builder's Odyssey" (*SB* 2/83, p. 24) during the editing process. In the first paragraph, the last sentence should read, "...JBL uses the 124A in the 4315 Studio Monitors, in a cabinet that is simply *terrible* for them." On page 25, in the second complete paragraph, the first sentence should read, "I was *not* surprised to find the Full-Range Panels...." Finally, on page 25, in the middle of the last paragraph, the sentence should read, "They turned out to be serviceable units, not nearly as good as the JBL's (*at* $100 more)...."

OUT OF THE CLOSET

This letter was inspired by your editorial in the 4/82 issue. Entitled "The Catalog Connection," it had the demeanor of a gentle lecture (appropriately so) and nudged me into examining the apathy behind at least one "invisible" hobbyist —myself.

In the days before *SB*, I consumed catalogs voraciously, looking for the odd bits of technical information that would comprise the parts of the huge, but ultimately solvable, puzzle known as speaker design. Without shame, I admit to having crucified my brain on the articles in JAES's *Loudspeakers: An Anthology* and having pored over Tremaine's *Audio Cyclopedia*, Boyce's *Hi-Fi Stereo Handbook*, and all the stuff put out by Howard W. Sams, Philips, Weems, Snyder and others. None of that material made me an audio engineer, but I did get a good, intermediate-level grasp of the elements of enclosure design.

In general, most of that material was theoretical, but *SB* exposed me to the *application* of theory as it relates to the real world. This information, unfortunately, cuts both ways. On the positive side, a hobbyist can gain the knowledge that enables him or her to translate the abstract formulas and procedures into a functioning sound system. On the negative side, *SB* often leaves many of its readers dangling in one extremely important area—test equipment.

You can divide the process of speaker building into three areas—theory; the mechanical, acoustical and electrical properties of the driver; and enclosure construction. In the three years I have been reading *SB*, one thing has become clear: the Thiele/Small parameters are critical for contemporary loudspeaker design. It is also clear that the manufacturer's specification sheets are not likely to reflect the true parameters of any given driver. Plainly, the builder must have some means of ascertaining accurate specifications, and I think *SB* overlooks this process.

A signal generator, frequency counter, oscilloscope, and VTVM or digital multimeter are as critical to this hobby as are a table saw, glue, clamps and screws. At one time I maintained a selection of current catalogs from about a dozen companies. I can't begin to count the times I have come across drivers with parameters that would have yielded a nice alignment in a box perfect for that little spot in the den. Then, while reaching for my checkbook, it occurs to me that the drivers will not meet the published specs. Being unable to determine the accurate values of F_s, V_{as}, Q_s and Q_{es}, I put the checkbook back into the desk.

Design theory and enclosure construction techniques abound in *SB*, but any discussion of driver parameters seems to assume that the reader owns test equipment and knows how to use it. Applying the spirit of *SB*'s article on table-saw basics (1/82, p. 25) to test equipment could be a real boon. Such an article would not only encourage uninitiated enthusiasts, but might also attract advertisers. That, in turn, might ultimately result in the surfacing of some more "invisible" hobbyists.

Who knows? I might get up to running an active inventory of a dozen catalogs once again.

Glenn B. Reynolds
York, ME 03909

Reader Reynolds will doubtless rejoice with us as we launch Contributing Editor Koonce's series of six instrumentation articles for speaker builders. See page 12.—Ed.

LETTER WRITERS AHOY . . .

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In questioning authors, please leave room in your letter for replies which should relate to the article, be framed clearly, and written legibly. Please do not ask for design advice or for equipment evaluations.

Letters to authors or other readers cannot be acknowledged, unfortunately. Any letter which does not comply with the requests above will not be answered.

ON THE HORN

A lot of "science" is undoubtedly involved in speaker building, but one must not risk following the formula and losing the music.

Robert Feeser's extensive replies to my comments on horns (*SB* 3/81, p. 41) and Bruce Edgar's article on his horn project

(*SB* 2/81, p. 9) indicate that both are strong proponents of this cabinet style. I find it fascinating to read the thoughts of those who have reached opposite conclusions to my own, if only to try to find the chinks in the armor of their arguments. I believe I have found a few.

By "following his formulas," Mr. Feeser's nose has led him to overlook some much larger considerations. For instance, he quotes distortion figures for the throats of some common horns, then goes on to say that direct radiators have inherently greater distortions. This may indeed be true, due to the smaller size and shorter excursions of horn-loaded diaphragms. But I believe that the horn itself, after the throat, instills its own colorations. With direct radiators, at least you are dealing with only one source of distortion, the accuracy with which the driver translates alternating current to alternating sound pressure levels (SPLs). With horns you have the additional distortion of the resonances in the horn itself, and the sum often seems to be greater.

It is ironic that Mr. Feeser's letters have run concurrently with the Paul Voigt interview, which devotes so much space to Voigt's attempts to remove the colorations in horns.

Second, Mr. Feeser attributes greater "transient response and dynamic range" to horns. This may appear to be the case from Mr. Feeser's experience, probably due to the admittedly higher SPLs from a given input. But I believe he will find that the horn's acoustic load (which he mentions later) can limit the transients and the dynamics (the two are closely related). Horns themselves can actually be overdriven, causing clipping, or severe transient limiting. Any perceived improvement in dynamic range probably comes from operating the amplifier at a lower level, with appropriately greater headroom. It has nothing to do, however, with anything inherent in the speaker design.

Third, I think that Mr. Feeser makes a serious error when he says "these factors (dynamic range, transient response and distortion) are related to the total loudspeaker size, and the best direct-radiator systems are now getting large enough that bass horns are becoming competitive in size." Any first-year engineering student can tell you that the relationship between driver size and these three parameters is *inverse*, not direct as Mr. Feeser implies. Larger drivers are certainly not cleaner, only louder. The flux of the magnet, the area of the voice coil and their relation to the size and weight of the cone determine the response. He makes the same argument himself when discussing the lower throat distortions of horns, so I can only attribute this error to a slip of attention.

Similarly, any horn capable of covering 40 octaves would be a phenomenon. Four was probably the intended figure.

Last, Mr. Feeser equates the requirements of a horn driver to those of an acoustic suspension driver, concluding that both require loose suspensions and long excursions. For precisely the reasons I have already mentioned (overdriving the horn itself) I think it is not a good idea. Particularly for the high SPL public address application for which it was designed, Bruce Edgar's choice of a guitar speaker is an intelligent one. Equating an acoustic suspension speaker, which has a totally sealed back loading, with a horn driver, which has a limited but not sealed front loading, seems a bit out of place. Most horn enthusiasts would prefer a bass-reflex woofer, which is designed for limited back loading.

Robert Carlberg
Seattle, WA 98116

Mr. Feeser replies:

Q1: *Have you followed the formula and lost the music?*

A1: *I am a musician, and I frequently attend live concerts. Since I have been designing loudspeaker systems as a hobby for a long time, I have done a lot of thoughtful comparative listening to both live and reproduced music.*

As for using formulas, once I have convinced myself that a mathematical expression is a useful approximation of what really happens in a loudspeaker, I use it. A formula often offers insight into why things happen and what to do to improve them.

Q2: *Doesn't a horn introduce coloration of its own?*

A2: *Horns can introduce several potential problems, including the following:*

- *Reflections between the horn's mouth and throat can cause large frequency response peaks and valleys.*

SB Mailbox

- *Various problems arise whenever a horn is bent or folded.*
- *The directional characteristics of bass horns are different (often narrower) from those for direct radiators. That is not necessarily better or worse, just different.*
- *The horn walls may vibrate, just as the sides of a direct radiator's enclosure do.*
- *The design of a good bass horn is much more complicated and much less well documented than the design of direct-radiator loudspeakers.*

Yes, a horn can introduce colorations of its own, if you aren't careful. You can, however, control all these sources of coloration.

My experience with bass horns is this: because the cone motion required to produce a given sound pressure level (SPL) at a low frequency is smaller, a bass horn produces less distortion. You must, however, consider many more factors when designing a bass horn. The trick is to solve all these problems. If you succeed, the reward is low distortion.

Q3a: *Aren't you confusing "dynamic range" with "higher SPLs from a given electrical input"?*

A3a: *The horn's improvement in dynamic range is unrelated to amplifier headroom or any other consideration having to do with the amplifiers. Instead, the cone of a direct radiator moves much farther than the cone of a horn driver to produce the same SPL at low frequencies. Thus, in the low bass area, which requires large driver motions, the horn can produce higher sound pressure levels before displacement-induced distortions become objectionable.*

Q3b: *Aren't horns themselves capable of being overdriven?*

A3b: *Any acoustic driver can be overdriven, but a horn will produce 10 to 20dB higher sound levels than a direct radiator will before it is overdriven.*

Q4: *Isn't it true that dynamic-range transient response and distortion are inversely related to driver size?*

A4: *No. Refer to the papers by Small, Thiele and others.*

Q5: *Aren't larger drivers only louder, not cleaner?*

A5: *For bass drivers operating at the low end of their frequency range, larger drivers are certainly not louder because their increased mass reduces their sensitivity. But they often are cleaner at the same sound level because less cone motion is required.*

Because they are cleaner, however, larger drivers can produce higher SPLs than smaller drivers at low frequencies. You can do this by turning up the level or volume control on the amplifier before it begins sounding bad, and that might make you think it is louder.

Q6: *Isn't frequency response determined by the magnet flux and voice-coil area in relation to the size and weight of the cone?*

A6: *I don't think the low-frequency response is related to the "area" of the voice coil. All the other factors mentioned are involved, but so are factors such as enclosure design, suspension stiffness, the suspension's mechanical damping, voice-coil resistance, the length of the wire in the voice coil and the moving mass of the diaphragm.*

Q7: *Didn't you mean to refer to a frequency range of four octaves instead of 40?*

A7: *Yes, four octaves is correct.*

Q8: *Why did you equate the requirements of a horn driver with those of an acoustic suspension driver?*

A8: *I didn't. You must consider several factors, including the following:*

- *You must specify a lot more in a driver than just its suspension stiffness and excursion capability.*
- *Large excursion capability is not required in a horn driver, although it is important in a direct radiator. Horn loading drastically reduces the cone motion required.*
- *The moving-mass requirements for acoustic-suspension and horn drivers are different. In an acoustic-suspension woofer a large moving mass is desirable because it lowers the low-frequency cutoff of the system. It also reduces the system's sensitivity, but that is usually acceptable. For a horn driver, however, I recommended that you "get the lowest moving mass possible...."*

Q9: *Don't most horn enthusiasts prefer a bass reflex woofer?*

A9: *Perhaps the point here is that in commercial loudspeakers you are more likely to see a horn tweeter than a horn midrange and least likely to come across a horn woofer. In one of its catalogs, Speakerlab sums up the prevalent feeling among "horn enthusiasts": well-designed horns sound better, but they are large and expensive. Because horn tweeters are reasonably small and inexpensive, you get the most improvement for your money if you use a horn tweeter with a direct-radiator woofer and midrange. If you can afford a somewhat larger enclosure and a substantial increase in cost, use a midrange horn, too. If size and expense are no object, however, and if you want great sound, then use a full-range horn system with a bass horn, a midrange horn and a horn tweeter.*

My opinion differs from Speakerlab's. Many direct-radiator midranges and tweet-

SB *Mailbox*

ers are now very good, but I think the bass horn improves the sound most. The best direct-radiator woofers I have heard don't even come close to a good bass horn. Their muddiness is immediately noticeable in comparison to a horn, even at moderate sound levels.

DYNAUDIO DESIGN

I have a few questions concerning Michael Boulais's Dynaudio two-way speaker system (*SB* 1/83, p. 7). First, did he use paper or polypropylene woofers? Second, do the two kinds of woofers produce any audible difference in a speaker system? Finally, where should I put the midrange if I decide to make this a three-way system?

Kenneth K. Choy
San Francisco, CA 94122

Mr. Boulais replies:

When I built the Dynaudio speakers, only the paper-plastiflex cone version was available. Dynaudio has since come out with a replacement, which is often called polypropylene, but is actually a polysulfate version designated the 21W54MPS. I have not yet tried the polysulfate units, but I am told that they are lower in distortion, almost to the vanishing point. I wouldn't hesitate to try them.

As to where you should place the D-52 midrange should you go three-way, I would move the 21W54 down to make room for the midrange, which would go directly below and as close as practical to the tweeter, with some overlapping of their flanges if possible. You must determine the forward-rearward speaker positioning (acoustical phasing) before *you can locate the optimum speaker placement on the cabinet face. The flanges cannot overlap if the speakers must lie in exactly the same plane.*

For proper phasing of tweeter-midrange or midrange-woofer, place a microphone connected to a preamp and voltmeter approximately 2 feet in front of and on a line that is central and perpendicular to the two drivers under test. Wire the drivers in parallel and in phase to your generator. With the generator set at the desired crossover frequency, vary the distance between one driver and the microphone until you get a peaking of the output where the signals are exactly in phase. This is the optimum spacing you should use for the forward or rearward positioning of your drivers. If possible, perform this test outside, free from extraneous noises and any nearby reflecting surfaces. □

Kit Report

Continued from page 36

long periods without fatigue. The high end is a pleasure and sweetly natural.

I am not generally impressed with piston high-end transducers, having most of my life listened to systems with electrostatic drivers in the top end. I will confess, however, to hearing a certain patina of richness here that I do not hear with my drier-sounding Janszens. It would be fun to try this system biamped with electronic crossovers. I would like to compare the two approaches just to satisfy my curiosity. Perhaps another day.

To sum up, the Acoustic Image Model II is an exceptionally well-conceived first product from a new company located near Atlanta and obviously benefiting from the influence of the speaker research work going on at Georgia Tech. The Model II is an excellent buy for the money. Indeed, it carries a five-year limited warranty and an unusual 30-day return policy.

Aesthetically, the units are a pleasure, both to look at and for listening. As a possible construction project, the builder will get the help he or she needs, and the result should be musically and fiscally satisfying.

Edward T. Dell
Editor/Publisher

TEST INSTRUMENTS

Continued from page 25

able in numerous output voltages other than ±15V. You can adapt the circuit boards and techniques presented here to power supply regulators for other projects.

Editor's Note

Author Koonce used a special transformer that was available for many years from a supplier, but is now no longer available. This transformer was rated at 40V CT at 250mA, totally shielded. An unshielded equivalent is Triad's F-91X at 300mA. This multipurpose unit, while unshielded, is very flexible and will produce voltages ranging from 7 to 30V not center-tapped and 14 to 40V center-tapped by appropriate connection of primary and secondary leads. This unit is available from Old Colony at $7.50 each. For those who want the best, the Avel-Lindberg toroidal unit is rated at 40V CT at 340mA. The toroid types have low hum fields, are easily mounted and are very efficient. They are, however, quite expensive.

By fabricating a steel shield plate and careful transformer orientation for lowest hum, any 40V CT transformer of reasonable quality will probably work in this series of devices. The voltage/current pair is very popular and should be easy to find.

Although the current ratings of the Triad and Avel-Lindberg units are higher than that used by Koonce, the regulators and associated circuitry should be able to handle the variables.—Ed.

Next time, Mr. Koonce will discuss using the voltmeter and power supply boards to build a dual channel wattmeter.

REFERENCES

1. National Semiconductors, *Application Note AN-20*, "An Application Guide for Operational Amplifiers," February 1969.
2. Dobkin, R. C., "Precision AC/DC Converters," National Semiconductors, LB-8, August 1969.

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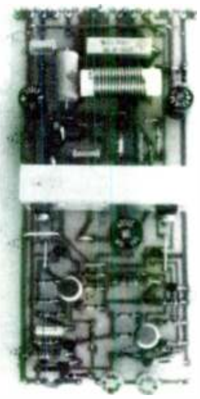

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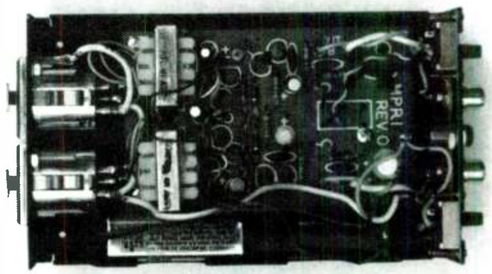

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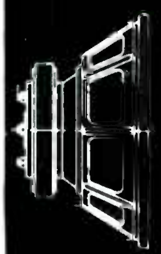

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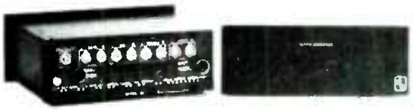

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THE VANCOUVER AUDIO SOCIETY publishes a monthly newsletter with technical articles, humor and news of interest to those who share our disease. We have 50 members and meet twice every month. Dues are $15/year which includes 12 newsletters ($15 US outside Canada). Call (604) 874-3225 or write Dave Mann, VAS, Box 4265, Vancouver, BC, Canada V6B 3Z7. We would like to be put on your mailing list.

THE AUDIO SOCIETY OF HONOLULU cordially invites you to attend one of our monthly meetings and meet others like yourself who are interested in the how's and why's of audio. Each meeting consists of a lively discussion topic and equipment demonstrations. For information on meeting dates and location contact Bob Keaulani at 1902 South King Street, Honolulu, HI 96826, (808) 941-1060.

SOUTHEASTERN MICHIGAN WOOFER AND TWEETER MARCHING SOCIETY (SMWTMS). Detroit area audio construction club. Meetings every two months featuring serious lectures, recording studio visits, design analyses, digital audio, AB listening tests, equipment clinics, annual picnic and audio fun. Club publication, *LC, The SMWTMS Network*, journals the club's activities and members' thoughts on audio. To join or subscribe call (313) 544-8453 or write SMWTMS, PO Box 1464, Berkley, MI 48072-0464.

THE COLORADO AUDIO SOCIETY is a group of audio enthusiasts dedicated to the pursuit of music and audiophile arts in the Rocky Mountain region. We offer a comprehensive quarterly journal plus participation in meetings and lectures. Membership fee is $10 per year. For more information, send SASE to: CAS, 4506 Osceola St., Denver, CO 80212.

THE NEW YORK AUDIO SOCIETY meets monthly with prominent guest speakers, discussions and demonstrations of the latest equipment. Its $20 annual membership dues include a subscription to S/N, the society's quarterly publication. For a free invitation to our next meeting, call (212) 544-1222, (212) 289-2788 or (201) 647-2788 or write us at PO Box 125, Whitestone, NY 11357.

QUAD OWNERS CLUB. We have joined together to share information, set up modifications and make the best speaker better. Special research projects and tests. For information write: Quad Owners Club, 33 No. Riverside Ave., Croton-on-Hudson, NY 10520.

SARASOTA AUDIOPHILES interested in forming a club—write: Mark Woodruff, 5700 N. Tamiami, Box 539, Sarasota, FL 33580.

MINNESOTA AUDIO SOCIETY. Monthly programs, newsletter, special events, yearly equipment sale. Write: PO Box 3341, Traffic Station, Minneapolis, MN 55402.

A CLUB FOR FM AND TV DXers, offering antenna, equipment and technique discussions, plus updates from FCC on new station data. Monthly publication "VHF—UHF Digest." Annual convention in August. For more info: Worldwide TV-FM DX Association, PO Box 97, Calumet City, IL 60409.

PACIFIC NORTHWEST AUDIO SOCIETY (PAS) consists of 50 audio enthusiasts meeting monthly, second Wednesdays, 7:30 to 9:30 PM at 4545 Island Crest Way, Mercer Island, WA. Be our guest, write Box 435 Mercer Island, WA 98040 or call Bob McDonald (206) 232-8130.

THE BOSTON AUDIO SOCIETY INVITES you to join and receive the monthly B.A.S. SPEAKER with reviews, debates, scientific analyses, summaries of lectures by major engineers. The BAS was the first to publish info on TIM, effects of capacitors, tonearm damping, tuner IM distortion, Holman's and Carver's designs, etc. Sample issue $1, subscription, $16/yr. P.O. Box 7, Boston, MA 02215.

SAN FRANCISCO BAY AREA AUDIOPHILES. Audio Constructors society for the active, serious music lover. We are dedicated, inventive and competent. Join us in sharing energy, interest, expertise and resources. Send self-addressed stamped envelope to S. Marovich, 300 E. O'Keefe St., Palo Alto, CA 94303 for newsletter.

AUDIOPHILES INTERESTED IN FORMING an audio club in the Washington, D.C. area please contact: Joseph Kmetz, 9861 Goodluck Rd., Apt. #10, Lanham, Maryland 20706 or call days (301) 794-7296, eves. (301) 585-3186.

PRIVATE FOR SALE

KEF 105.2 speakers, excellent condition, $1400/pair plus shipping. Heath AA 1640 power amp, 200W/channel, excellent condition, $325. Rick Bremer, 16 Ardmoor Dr., Hampton, VA 23666.

Infinity IRS style EMIT tweeters for use in QRS-1D reference system and other similar speakers, $17.50 each. Michael Marks, 3745 Grubb Lane, Richmond, VA 23234, (804) 743-0097.

Regulated ± 120V DC supplies, 20mA only, 13 cu. in. 1½" x 2½" x 3½", 5 terminals potted, use for pre-regulators, $20 each ppd. 0-500V DC meter included. Trade for Jordan mod, Japanese pressings, etc. V. Vogt, 6812 Rosemont Dr., Mclean, VA 22101.

PAS-3X, just acquired at garage sale for $20, will pass on at cost, has typical Dyna chassis rust and scratches on face plate top, runs. Fred Burgess, RR 3, Box 486-B, Gaylord, MI 49735, (517) 732-1684.

Genrad acoustic test system. 1521-B chart recorder, 1304-B audio oscillator, 1564-A sound analyzer. Includes chains, paper, pens, link units, manuals, etc., like new $1500. B&K 4134 microphone, 2619 FET preamp, 2801 power supply, like new $950. Roger Russell, 7 Normandy Court, Binghamton, NY 13903, (607) 723-1526 eves.

Panasonic leaf tweeters mod by New York Acoustics, new $120 pair, asking $80; 7Ω, excellent. Never used still in boxes, Audax HD-98D25A-1" dome, $15 pair; Audax HD 13D37-1½" dome, $25 pair; Audax HD 17B25J2C12 6" Bextrene, $25 pair. All 8Ω speakers: JVC ribbon HSW-1101-01A, $25 pair; Speakerlab 1N806P woofer-mid polypropylene 8" cone, $35 pair. Buyer pays shipping. David M. Landrie, 1309 E. 61st, Tacoma, WA 98404, (206) 472-9930.

Klipschorn, one woofer horn only, with Dayton-Wright 75Hz mixed-bass stereo electronic crossover and D-W subwoofer 50W amp, $875. Also, Beyer DT48SN (world's best???) headphone, normal stereo plug, 3 kinds of ear cups included, $85. Ben Barkow, 24 Pinewood Ave., Toronto, Ontario, Canada, M6C 2V1, (416) 653-9326.

New Jordan modules with manual, $140 pair; new Dalesford D30/110s with spec sheet (more lucid than KEF B110s), $60 pair; Powermate 6A, 12V DC highly regulated computer grade power supply with enclosure, $35. Call Wayne Robertson, (617) 593-5937 between 8 and 10PM EST.

Altec 800Hz crossovers, 4 @ $30 each. L. Cartwright, 2723 Darlington Rd., Beaver Falls, PA 15010.

Heath IM5248 intermodulation distortion analyzer, residual .006%, $100 or best offer. Heath 240W audio load, $20 or best offer. Fulton Gold 57" (2 guage silver plated) with banana plugs, $15. Mark, (503) 620-4783.

PRIVATE WANTED

Janszen (or similar RTR) 130 series (130 through 138 inclusive) top end array or the top end out of a full range box. Fred Burgess, RR 3, Box 486-B, Gaylord, MI 49735, (517) 732-1684.

Infinity RSII owners. I would like to communicate with you on your experience and modifications of these speakers. Please write to Robert Williams, Giesseu, MILCOM, CCC, GSN Germany, APO New York 09169.

Pre-recorded reel-to-reel tapes, classic or popular, 2 or 4 track made in the 50s and 60s. Also want early RCA stereo albums with numbers below 2800. Bill Watkins, 1019 E. Center St., Kingsport, TN 37660, (615) 246-3701 before 5:30PM EST.

Subwoofer enclosure parameters for Dynaudio 30W54 12" woofer wanted. Prefer TL or vented. Rick Bremer, 16 Ardmoor Dr., Hampton, VA 23666.

One 18" x 14" KEF woofer (model No. unknown) for ADC-18 or 16 loudspeaker system (produced in mid-1960s), or one complete ADC-18 or ADC-16. Thomas L. Larson, 52 Lafayette Mills Rd., Englishtown, NJ 07726, or (201) 834-3933 work; (201) 780-4597 home.

Service manual or good copy of same for TEAC A4010SL reel-to-reel tape recorder. Phil Addeo, 620 E. 3rd Ave., Roselle, NJ 07203, (201) 241-8259 after 6:00PM.

Advertising Index

TEST RECORDS

PERFORMANCE TESTS WITHOUT INSTRUMENTS

CBS LABORATORIES' STR PROFESSIONAL TEST RECORDS

OLD COLONY SOUND LAB · OLD COLONY SOUND LAB

For over ten years, the original series of these high-precision test records set a standard for the audio industry. The new series sets an even higher standard. It's been revised, recut and expanded.

The new series consists of eight records for professionals and one for non-professional audiophiles.

Each record contains a complete series of easy-to-use tests to help you rapidly and accurately evaluate components and systems. Even one of these records can eliminate the need for costly, additional equipment. Each will find productive use and save you hours in the laboratory, on the production line and in field testing.

TAKE A LOOK AT WHAT THIS ESSENTIAL TESTING SERIES CONTAINS:

STR 101 SEVEN STEPS TO BETTER LISTENING. For only $6.98, you can improve your system with CBS Laboratories' "Seven Steps to Better Listening." This high-precision test record enables you to make sure that your equipment functions properly . . . to tune your system to your ears and your room acoustics. Included is a detailed 16-page booklet by *Audio's* Edward Tatnall Canby explaining how to use the record to improve your system's performance. With the record you can perform the following "ears alone" tests: left-right identification, phasing, loudspeaker balance, tone control setting, alternate phasing, buzz and rattle elimination, lateral tracking, and vertical tracking.

STR 100 STEREOPHONIC FREQUENCY TEST RECORD. Designed for the evaluation of pickups and systems. Provides a constant amplitude characteristic below 500Hz and a constant velocity characteristic above 500Hz. Tests include: Sweep Frequency—with the sweep rate synchronized for use with a graphic level recorder; Spot Frequency—with voice announcements; Channel Separation; Wavelength Loss and Stylus Wear—to pinpoint oversize or worn-out styli, and excessive pickup tracking force; Compliance; Phasing; Vertical and Lateral Tracking: Tone Arm Resonance—to check system performance at low and subaudible frequencies and thus reveal undamped resonance which may cause equipment overloading.

STR 112 SQUARE WAVE, TRACKING AND INTERMODULATION TEST RECORD. Enables detailed study of tracking capabilities of stereophonic phonograph pickups. The square wave modulation allows a rapid appraisal of stylus-tip mass, damping, and tracking. Low frequency compliance and tracking are determined by means of 300Hz bands of progressively increasing amplitude. Intermodulation distortion measurements are made possible by graduated 200Hz intermodulation test bands. The STR 112 has been cut with vertical angle approximately 15° which is representative of current recording practice.

STR 120 WIDE RANGE PICKUP RESPONSE TEST RECORD. Makes possible the measurement of pickup response at frequencies far beyond the audible range, where elusive distortion elements can cause audible distortion. The low-frequency range includes glide-tones at twice normal level for the detection and elimination of arm resonance, loudspeaker cone and cabinet rattles. Other tests include: silent grooves for measuring rumble and surface noise characteristics; and standard level bands at 0dB for overall system S/N measurements. This record is suitable for use with a graphic level recorder to provide permanent, visible records for precise evaluation.

STR 130 RIAA FREQUENCY RESPONSE TEST RECORD. Provides RIAA frequency characteristics for the calibration of professional recording equipment and for testing the response of professional and consumer record reproduction equipment. This record is suitable for use with a graphic level recorder to provide permanent, visible records for precise evaluation. Spot frequency bands for use without automatic equipment are included.

STR 140 RIAA PINK NOISE ACOUSTICAL TEST RECORD. Designed for acoustical testing of systems and loudspeakers and for psychoacoustic tests on reproduction equipment. With the STR 140 it becomes possible to test loudspeakers in the room in which they will be used. Spot frequency tones with voice announcements facilitate the testing procedure. Continuous glide-tones in ⅓-octave bands cover the frequency range from 30 to 15,000Hz and are synchronized with a graphic level recorder.

STR 151 BROADCAST TEST RECORD. Developed especially to meet the needs of broadcast engineers, audiophiles, and other professionals seeking a convenient signal source for the testing and adjustment of all audio equipment. Tests include: phonograph pickup response and separation, speed accuracy at 33⅓ and 45 rpm, wow and flutter, rumble and hum detection, ballistic test of VU meters and many others.

STR 170 FREQUENCY RESPONSE 318 MICROSECOND TEST RECORD. Provides pickup designers and recording studios with a high-level, easily-equalized signal for frequency response and channel separation measurements. The STR 170 employs a 318 microsecond characteristic corresponding to the "test" or "flat" mode common to most disc recording equipment. Constant amplitude recording is employed in the region below 500Hz with constant velocity recording in the region above. The transition is smooth, in contrast with the STR 100 which employs a sharp breakpoint at 500Hz. The record is suitable for use with a graphic level recorder to provide permanent, visible records for precise evaluation.

SQT 1100 QUADRAPHONIC TEST RECORD. Designed for calibration, verification, and adjustment of SQ® decoding equipment. The record provides test bands for pickup measurements, for adjustment of decoder electronics and for channel identification and balance. Each band is described in terms of recorded characteristics and its intended use.

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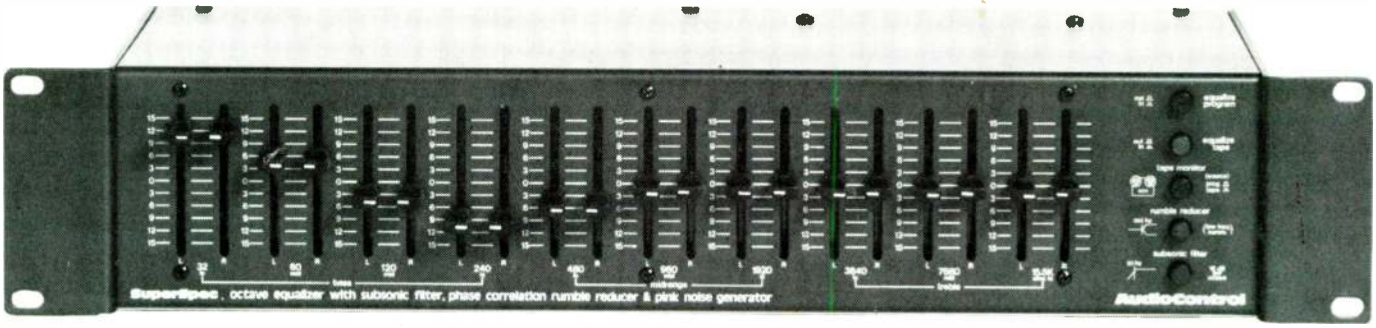
Quantities are limited. Be sure to order enough for many years of use.

Send me the following test records:

_______copies (STR 101) Seven Steps to Better Listening at $6.98 ea.
_______copies (STR 100) Stereophonic Frequency at $10. ea.
_______copies (STR 112) Sq. Wave, Tracking and Intermodulation $15. ea.
_______copies (STR 120) Wide Range Pickup Response at $15 ea.
_______copies (STR 130) RIAA Frequency Response at $15 ea.
_______copies (STR 140) RIAA Pink Noise Acoustical at $15 ea.
_______copies (STR 151) Broadcast Test at $15 ea.
_______copies (STR 170) 318 Microsecond Frequency Response $15 ea.
_______copies (SQT 1100) Quadraphonic Test at $15 ea.

WHY WE'RE OFFERING YOU A $299 EQUALIZER FOR $129.



Our neighbors here in Lynnwood make some of the finest equalizers and analyzers in the world: Audio Control Corporation.

But once in a while the engineering department gets the best of the marketing department and a product emerges that's too esoteric for the rank and file consumer.

THE SUPER-SPEC C-25 WITH PINK NOISE GENERATOR.

A few years ago, when Audio Control's C-22 Octave Equalizer was beginning to really take off, the engineering department said, "Why don't we make a version with even better specs and add a laboratory-grade pink noise generator for the experimenter?" Sounded ike a great idea: .009% THD, 102dB signal-to noise, pink noise generator ±.5dB 20-20kHz. So they did it.

C-25 Specifications:

DISTORTION (at 1 volt from 20Hz to 20kHz): less then .009%. **FREQUENCY RESPONSE:** From 3Hz to 100kHz, plus or minus 1dB. **HUM AND NOISE:** (10kHz band-width): minus 96dB re 1 volt, minus 102dB re 2 volts. **MAXIMUM INPUT:** 7 volts. **MAXIMUM OUTPUT:** 7 volts. **INPUT IMPEDANCE:** 100K ohms. **OUTPUT IMPEDANCE:** 680 ohms. **CONTROL CENTERS:** 32, 60, 120, 480, 960, 1920, 3840, 7680, 15.5kHz. **CONTROL BANDWITH:** "Q": 2.5 **CONTROL RANGE:** Plus or minus 15dB. **SUBSONIC FILTER:** 18dB per octave Tchebychev alignment. **SUBSONIC ROLLOFF:** Minus 1dB at 25Hz, minus 3dB at 20Hz, minus 21dB at 10Hz. **SIZE:** 19" (48.2cm) W, 3.5" (8.9cm) H, 6.5" (16.5cm) D. (standard EIA rack mount). **WEIGHT:** 6.75 pounds (3.2kg). **PINK NOISE GENERATORS:** ± 1dB 20-20kHz. **BACK ELECTRET MICROPHONE:** ±.1.5 dB 20-20kHz **WARRANTY:** 2 years.

Unfortunately, the vast majority of dealers just didn't understand the whole point and Audio Control ended up with a pile of superb equalizers. They languished until we noticed them on the back shelf and made Audio Control a deal they couldn't refuse.

THEIR LOSS IS YOUR GAIN.

We're not talking about a cheapo imported knock-off here. Audio Control lavished the best components and design into the C-25.

Fiberglass boards. Precision resistors and capacitors. Silky-smooth pots and superb specs. Frankly, there's probably $129 worth of materials in each C-25.

LAB-GRADE PINK NOISE GENERATOR.

Anybody who reads this publication knows how useful pink noise is in evaluating and adjusting speakers. Even if you don't have a measurement instrument, pink noise lets you do considerable adjustment by ear. In conjuction with a handheld spectrum analyzer it opens up a whole world of interactive EQ testing.

When we got the shipment of C-25's from Audio Control, Accessoterica benchtested it's pink noise generator against a B & K Model 1405 Noise Generator. The Audio Control C-25 was more accurate.

So even if you just use the C-25 as a pink noise generator, it's a great buy.

TWO SPECIAL CIRCUITS FOR HOME HI-FI.

Audio Control is a great believer in solving real-world audio problems. So they added an 18dB/octave Tchebychev subsonic filter circuit and a Rumble Reduction circuit to the C-25.

Subsonic filter is down 1dB at 25 Hz, down 3dB at 20 Hz and down 21dB at 10 Hz. If you bought or built vented or transmission line speakers, you know how important a circuit like this is, especially if you like a healthy 40Hz boost in your program material the way we do.

The Rumble Reduction circuit mono's bass below 200Hz to combat rumble, mechanical feedback, warped records and resonances. Vertical groove components are effectively cancelled without losing stereo spearation. I[f] you don't agree with this approach, the circuit comes out with the touch of a button.

THE $549 C-101 FOR $299!

We also grabbed up a few packaged C-101 Octave Equalizers with 101-LED Realtime Spectrum Analyzer, measurement microphone pink noise generator. All units are 100% guaranteed, electronically and cosmetically. They're not repairs, but demo units returned by dealers. Some manufacturer's would just sell them back as new, but Audio Control made a deal with Accessoterica to clear them out at cost. You couldn't do better if you bought a brand new C-101 at retail. Same features and specs as the C-25 with 10-band Spectrum Analyzer with 2 & 4dB range, slow and fast decay, SPL mode and microphone on 20-ft cord with ± .1.5dB 20-20K specs. A steal, while they last at $299. Full 2-year warranty from the factory.

PAIRED SLIDERS FOR EASY ADJUSTM

Audio Control is the only company that puts left and right channels next to each other. Doesn't seem like much until you start adjusting an equalizer frequently. As you probably know, a difference of as little as 3dB in the midrange bands can smear sound imaging. (A lot of bias against equalizers stems from this adjustment problem which is solved simply by putting left and right controls near each other so you don't have to build two curves.)

THE RIGHT STUFF.

Of course, the C-25 has an extra tape monitor loop, a program switch for comparison (especially useful in conjuction with the pink noise generator and your trusty ear for quick speakers EQ's), and an EQ-tape circuit which lets you equalize tapes without repatching C-25. It's packaged in a standard 19" rackmount chassis with RCA-type inputs and outputs on the back--including two for the pink noise generator. We even talked a pile of C-22 manuals out of Audio Control, although you're on your own concerning the pink noise generator. But then you wouldn't be reading this page if we didn't think you'll know what to do with pink noise.

VERY LIMITED SUPPLY.

Order your C-25 right now since we have a very finite supply. Order it toll-free with a bankcard and get it within seven days. Mail us a money order for two-week service or a personal check (which we have to let clear) for three to four week delivery. WE PAY FREIGHT via U.P.S. on all orders! Whether you need a pink noise generator, a great octave EQ or just a sharp subsonic filter, $129 is a superb deal on a great unit.

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