Project 463

THE MASTERPLAY Two-way Loudspeakers

These low-cost, two-way 'bookshelf' loudspeakers were designed to team with the ETI-442 Masterplay Stereo Record Player system. While they're simple to build and won't strain the bank account, the finished units look good and sound good.

Geoff Nicholls **Peter Ihnat**

THESE LOUDSPEAKERS were developed as a low-cost bookshelf system to team with the ETI-442 Masterplay Stereo Amplifier described last month. They can handle the maximum output from the '442. They utilise a 150 mm twin-cone driver with a 60 mm cone tweeter in a "two-way" system, housed in a 13-litre sealed enclosure. The two drivers cost less than $20 and a pair of ETI-463s should cost around $60 to make.

Development

The design of compact loudspeakers presents a challenge: to obtain a compromise between enclosure volume, bass-end response and overall efficiency. The '463s had an overriding parameter — the cost had to be kept in line with the '442 amplifier so driver choice was very restricted.

Consider the problems with the bass driver, or woofer as it is called, in multi-driver systems. At low frequencies the cone will move with the voice coil (which is the 'motor') as a single rigid unit and produce a fairly smooth frequency response.

This band of frequencies is called the "piston range" of the driver and can be roughly predicted from the diameter of the cone — when the sound wavelength approximates the radius of the cone the piston mode starts to falter.

As the frequency is increased above the piston range the cone can no longer follow the movement of the voice coil and vibration 'modes' or waves occur in the cone. This leads to various phase cancellation and reinforcement phenomena which manifest as peaks and troughs in the frequency response — this section of the response is usually called the "wave operating" region.

High quality loudspeaker system divide the frequency range up amongst several drivers so that each is operating in its piston region. This requires complicated (and expensive) 'crossover' networks to roll off each driver's response rapidly.

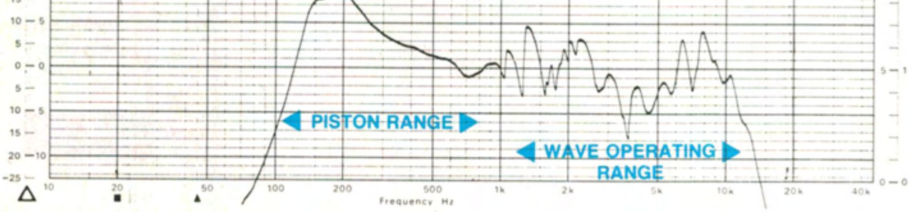
Twin-cone drivers partially overcome the limitations of a single, relatively large, cone by adding a small cone at the voice coil. As the larger cone enters the wave operating region and its response starts to fall off, the smaller cone takes over and extends the response. In practise, the phase cancelling still occurs in the larger cone as well as between the two cones — generally, twin-cone drivers having a single voice coil lean more toward low cost than high quality.

The limitations on the drivers' frequency ranges can be overcome by choosing compatible units (complementary frequency responses) and combining them with an electrical crossover network.

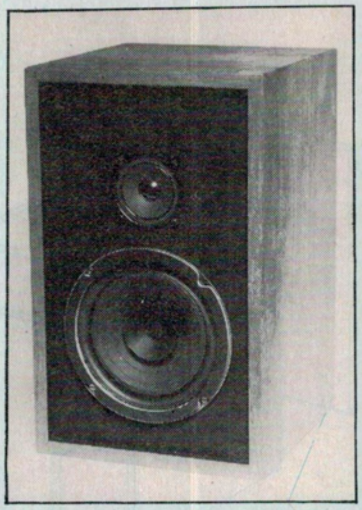
A more difficult problem arises from the nature of the design of the bass driver which causes a phenomena called resonance. This can be understood at a simple level by examining the construction of the driver.

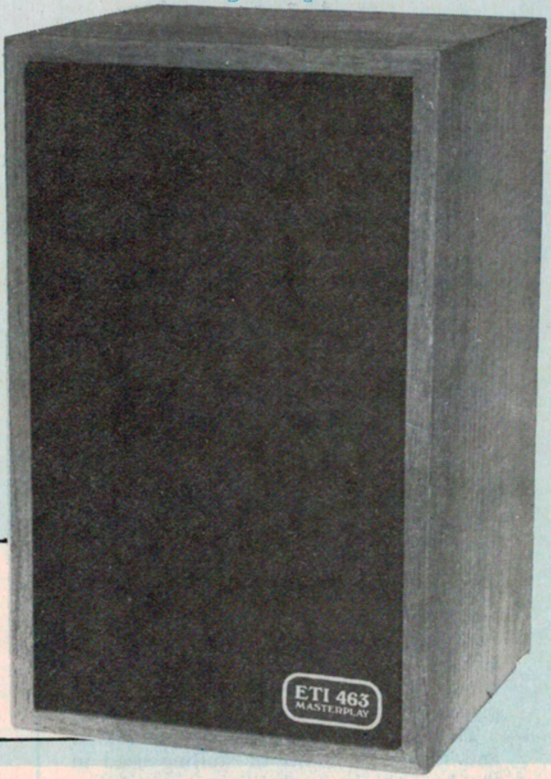
A coil of wire is suspended in a magnetic field in order to convert an electrical signal into an 'equivalent' acoustic signal. The voice coil is attached to the cone and system of supports arranged to make sure the voice coil does not touch the magnet. The moving parts of the speaker have a certain mass, and the suspension system inherently acts like a spring — and that leads to the problem of resonance.

As any physics student should know, a moving mass attached to a spring is the classic example of simple harmonic motion, and when a simple harmonic oscillator is driven by a force there exists a certain frequency where the amplitude of os-



Pistons and waves. Typical response of a low frequency drive unit, showing the piston operating region and the wave operating region.





NOMINAL SPECIFICATIONS ETI-463 2-WAY SPEAKERS

(measured on prototype)

Nominal impedance	8 ohms
Frequency response	60 Hz to 18 kHz (−6 dB), ±7 dB from median
Nominal power handling	10 watts
Box volume	13 litres

cillation is at a maximum. This is the resonant frequency. If the spring and mass was all that was involved, then the oscillation amplitude would increase to infinity. In practise there is always a frictional loss which extracts energy from the system and limits the maximum amplitude for a given input force.

In speaker parlance the 'springiness' is represented as an inverse quantity called *compliance*. The higher the compliance the easier it is to move the cone against the suspension. The resonant frequency is proportional to the (square root of the) inverse of the mass times compliance.

When a driver is mounted in an enclosure, the resonant frequency will be different from that obtained in free air. This is because the air enclosed has mass which must be moved and also has a springiness due to the pressure changing with the volume changes as the speaker cone moves in and out.

For sealed enclosures, the mass increase is small compared to the decrease in total compliance and this results in an increase in resonant frequency from the free air value. The smaller the enclosure the higher the frequency.

'Reflex' enclosures use a tuned port to add an extra resonant component to the system, a full treatment of the reflex theory is beyond this simplified discussion. Suffice to say that an optimum reflex enclosure can produce a flat response down to almost the free-air resonance of the bass driver, although below that frequency it falls off much more rapidly than for a sealed enclosure (18 dB per octave vs. 12 dB).

Unless the free-air resonance is low enough, this can lead to a sealed enclosure sounding subjectively better than a reflex system with the same driver, even though the reflex system has a lower resonant frequency. A good reflex driver needs to be designed for such usage and we were unable to locate a suitable low-cost unit that would work in a bookshelf system, so the sealed enclosure approach was adopted.

The free-air resonance of the bass driver will have an amplitude several times greater than the mid-band amplitude. When mounted in the enclosure such a response would produce 'one-note' bass and sound 'boomy'. The enclosure should be designed to dampen the resonance.

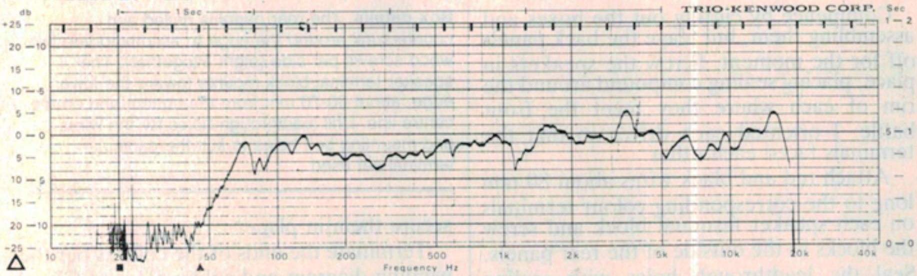
In sealed systems this is usually done by filling the box with an acoustically absorbent material that will convert some of the energy into heat. The amount of damping required is best determined experimentally. If too much loading is added then the response will roll off from too high a frequency and a loss of bass will result.

This section has presented a simplified description of loudspeaker design — many important points were omitted because of space limitations. For a more comprehensive treatment see David Tilbrook's "Principles and problems in loudspeaker design", originally printed in ETI January and February, 1980.

Speaker selection

With the foregoing in mind, and mindful of the price limitations imposed, we obtained several drivers to evaluate for the '463 project. We would have preferred to use a single wide-range driver, but the available units all fell away around 10 kHz at the top end so a two-way system evolved.

The low frequency driver needed to handle around 10 W RMS and have a resonance in the enclosure of about 100 Hz, which meant a free-air resonance ▶



Frequency response. The speakers have a reasonably smooth frequency response (measured on the tweeter axis) with few significant peaks and dips. The bass response will lift somewhat when they're mounted near the floor.

FINDING THE '+' TERMINAL

For correct operation, the speakers must be 'phased' correctly so that the output of each is in phase at the crossover region, otherwise, cancellation of the output from each driver will occur and you'll get a substantial drop in the level in the crossover region.

Generally, all speakers will have their '+' (positive) terminal marked in some way — usually with a red paint spot or somesuch. If you aren't sure which terminal is which, then there's a simple way to find out.

Take a *single* 1.5 V cell (any size) and briefly connect its terminals to the speaker's terminals. If the cone moves *out*, then then the battery's positive terminal is connected to the speaker's positive terminal. If it moves *in*, reverse the battery leads. Mark the speaker's positive terminal.

of around 60 Hz. The selected unit, a 150 mm (6″) twin-cone type made by Pioneer, was obtained from Jaycar (cat. no. CE-2315). This produced a resonance at 125 Hz in the enclosure we decided was about the largest that could be called a bookshelf speaker. This has a volume of 13 litres and is designed to be cut easily from readily available particle board pieces.

The low end response was measured and various amounts of stuffing used in the box to obtain the best compromise. The midrange and high end response was pretty lumpy at first, with a particularly big peak around 3.5 kHz the worst aspect.

After selecting a 60 mm cone tweeter (mainly for its low price), another Pioneer unit from Jaycar (cat. no. CT-2018), various crossover frequencies were tried until a reasonably good response was obtained.

The final crossover uses a 12 dB section for the low frequency driver (mainly to minimise the 3.5 kHz peak) and a 6 dB section with an attenuator for the tweeter. The crossover region is around 2.5 kHz.

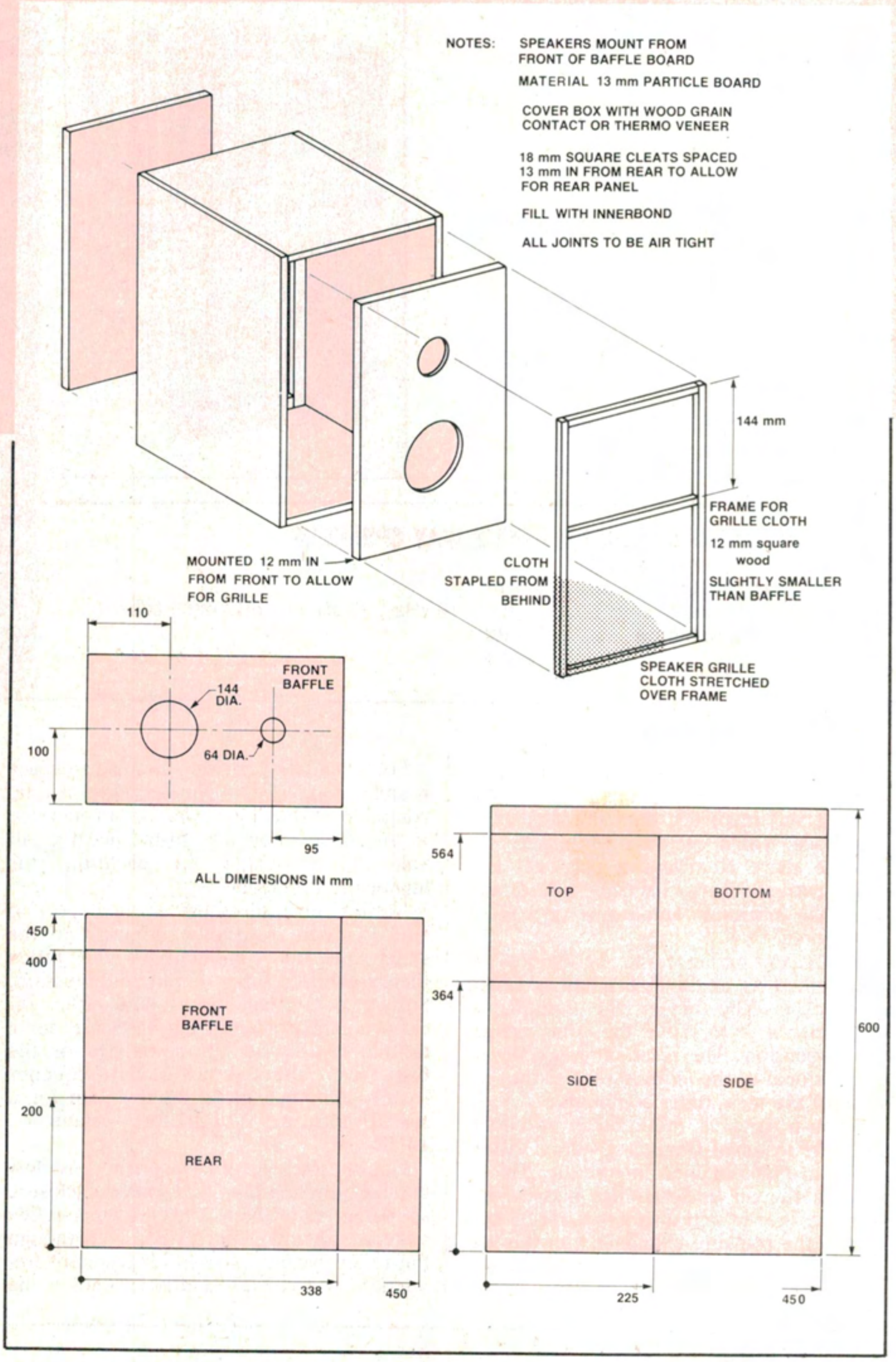
The second cone on the twin-cone driver does not contribute much to the top end, in fact the extra mass it adds to the suspended system probably does more for the bottom end by decreasing the free-air resonance!

Construction

All panels were cut from 13 mm particle-board. To make each enclosure you will need a 450 x 450 mm piece and a 600 x 450 mm piece. The baffle has holes cut for the two speakers. We used a jig saw to do this.

Since our woodworking skills stop at butt joints, we have dimensioned the box for butting the sides against the ends of the top and bottom panels — if you are up to mitred joints you will know how to adjust the dimensions anyway!

The front baffle mounts without cleats since it is glued in place with the speakers mounting from the front. The rear panel mounts against 18 mm cleats all round. It is sealed with a non-hardening sealing compound so that it may be removed to get at the crossover and acoustic stuffing. Such compounds can be obtained from most hardware stores.



Box details. The rear panel is drilled and countersunk around the edge to accommodate two wood screws per side (eight altogether). The speaker terminal block mounts toward the lower edge, about 60-70 mm from the bottom and on the centre line. Drill leadthrough holes for the wires and mounting bolt holes to suit the particular terminal set used.

Commence by cutting out the boxes and assembling them, but leave the back panels off for the moment. Screw the speakers in place, placing sealing compound around the rim of each where they meet the front baffle. I oriented each driver so that the terminals faced each other.

Attach red and black wires about 80 mm long to the corresponding colour terminals on each speaker terminal block and screw the blocks to the outside of the rear panels. Seal the leadthrough holes with sealing compound. Screw the two five-lug tagstrips in place (see the accompanying photograph). Now wind the two inductors and secure them in place.

Terminate the ends of the coils as per the winding diagram and solder R1 and C1 on each tagstrip. Make up a twisted-pair of red and black hookup wire (heavy duty, 24 x 0.2 mm) about 1.6 metres long. Cut it into

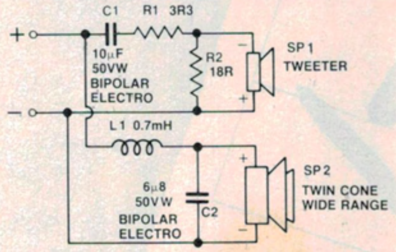
COIL WINDING DETAILS

If you cannot obtain a 0.7 mH inductor (and RFCs are RS in crossovers) then don't fret, wind it yourself! Here's how: Cut a 60 mm length of 50 mm (internal diameter) PVC pipe. Drill two 1.2 mm holes at each end, about 5 mm in from the ends.

Wind a layer of 1 mm enamelled copper wire (18 B&S, 20 swg), pushing the end through one pair of the holes to secure it. The turns should be close-wound, not jumbled. After 40 or so turns you will be near the other end. At this point, wind a layer of tape over the first 40 turns and start the second layer of wire, winding back towards the other end.

After three wire layers wound in this fashion you will have around 120 turns and can terminate the winding through the remaining holes in the other end of the pipe. Leave about 150 mm for leads and scrape the enamel off each end ready for soldering.

I mounted the coil on the inside of the back panel with three nails spaced so the pipe fitted snugly over them. A few blobs of epoxy glued the pipe in place.



Circuit. Simple, isn't it. Note that the tweeter is connected in the opposite phase to the twin-cone to ensure their outputs add in the crossover region.

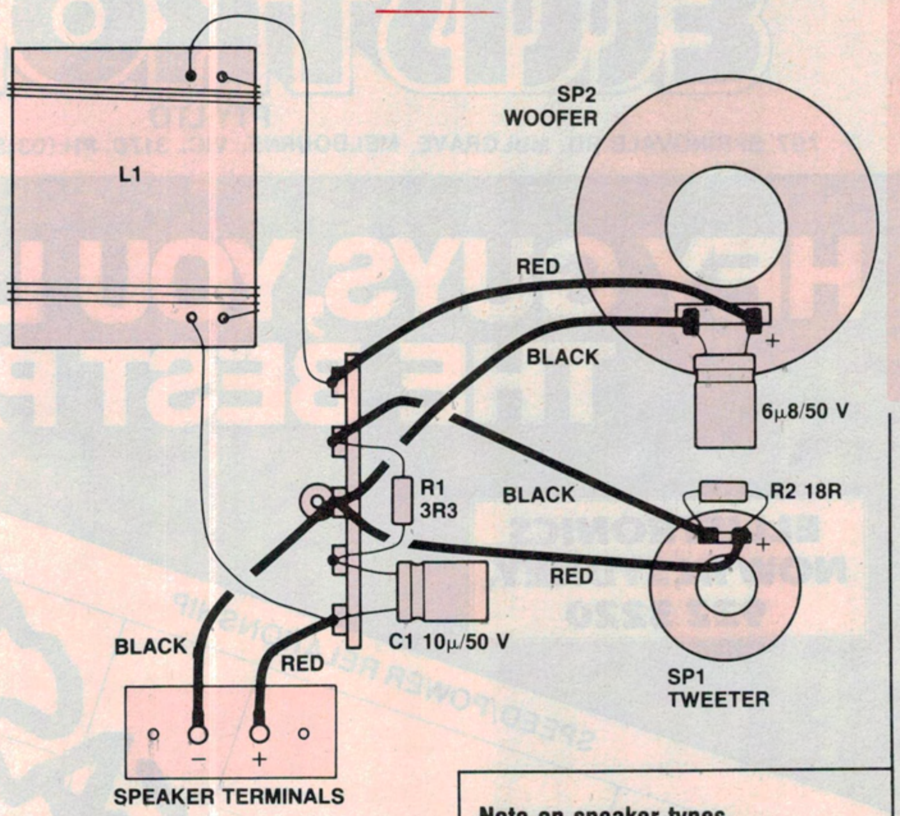
PARTS LIST — ETI-463

Speakers	
SP1	150 mm twin-cone speaker, 8 ohm 10 W RMS, Pioneer C16EC70-01FW or similar.
SP2	60 mm cone tweeter, 8 ohm Pioneer H66AP45-01F, or similar — see note below.
Capacitors	
C1	10µ/50 VW bipolar electrolytic
C2	6µ8/50 VW bipolar electrolytic
Resistors	
R1	3R3, 1/2 W
R2	18R 1/2 W resistor
Inductors	
L1	0.7 mH (see winding details)

Miscellaneous

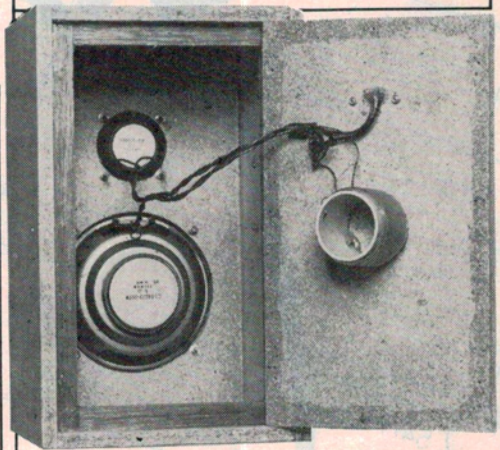
2-way spring terminal block; 1 x 0.5 m length acoustic damping material ("Innerbond"); 24 x 0.2 mm hookup wire; wood glue ("Aquadhere"); non-hardening sealant; 5-way tagstrip; one piece of 450 x 450 x 13 mm particleboard; one piece of 600 x 450 x 13 mm particleboard; 1.25 mm x 12 mm square wooden lath; 1.1 m x 18 mm square wooden lath; 250 x 390 mm of grill cloth; enough woodgrain veneer to cover box (optional); quantity of 30 mm panel pins; quantity of 25 mm woodscrews.

NOTE: Two of everything needed for stereo pair.



Note on speaker types

The speakers used in the prototype were from Jaycar in Sydney (at nos. CE-2315 and CT-2018). Other speakers may be used, but the crossover may require modification to produce a balanced response. The attenuator at the tweeter compensates for different sensitivities between the drivers. The amount of acoustic damping material used may also need adjusting to dampen the bass driver resonance.



On the inside. Showing the mounting of the crossover components. Note that the back panel is upside down in the picture.

Badge. Full-size artwork of the badge we made up from Scotchcal and stuck on the grille cloth.

four equal lengths and wire up the speakers to the tagstrips as per the wiring diagram. Take care with the phasing of the speakers! Solder the two C2s and R2s in place.

Give it all a thorough check. If, or when, all's well, stuff the acoustic wadding into each box and screw the rear panels in place, using sealing compound all around the cleats.

Connect them up and try them out. You should hear good clear sound at reasonable listening levels. Don't be tempted into winding the amplifier volume 'flat out'. This causes the amplifier's output to 'clip'. Under these conditions, the amplifier's output approaches dc and is capable of doing irreparable damage to the speakers. If, for safety's sake, you want to protect your speakers against such problems, or against amplifier faults applying dc to them, then you might like to construct the ETI-494 Signal-Powered Loudspeaker Protector, published in the October 1982 issue.

Happy listening! ●