Constructional Project

SIMPLE AUDIO CIRCUITS

Part 4 – Loudspeaker Enclosures, Tuning Oscillator and Resonance Detector

RAYMOND HAIGH

A selection of "pic-n-mix" low-cost audio circuits – from preamplifier to speaker!

ART and science collide in the design of loudspeaker enclosures and, transcending all the conflicting opinions, is the way a vibrating paper cone can reproduce sounds ranging from the human voice to a symphony orchestra with vivid realism.

Last month we discussed speakers and crossover networks. In this final instalment, enclosures and the simple test equipment needed to optimise performance are covered.

WHY AN ENCLOSURE?

Sound waves formed by the front of the speaker cone are out of phase with those at the back. If the pressure variations can leak around the cone there will be cancellation, particularly at low frequencies, and sound output will be reduced. The primary duty of the enclosure is, therefore, to prevent this leakage.

Speaker cones have a natural *resonant* frequency (just like a guitar string). The greater the mass of the cone, and the freer its suspension, then the lower the resonant frequency.

At resonance, very little energy is required to make the cone vibrate vigorously. This has electrical drawbacks, which were discussed last month. It is also undesirable from an acoustical point of view for speaker sensitivity to peak sharply at one frequency.

The second requirement of the enclosure is, therefore, to retain a volume of air which damps the cone and evens out the response of the system.

ENCLOSURE TYPES

Ignoring simple open baffles, there are four basic types of enclosure.

Infinite Baffles.

Infinite baffles are no more than sealed boxes filled with acoustic wadding to absorb the sound output from the rear of the speaker. Air trapped inside the box damps the cone, raising its resonant frequency by up to an octave (a doubling). Low frequency output falls off rapidly below resonance, and special speakers with high mass, high compliance (very low resonance) cones are sometimes used to offset the rise in resonant frequency.

Absorption of the energy delivered by the rear of the cone, together with the high cone mass, result in an acoustic efficiency as low as 1 per cent. Our Twin TDA2003 12·5W Amplifier (8·2W into 8 ohms: see Part One) requires a more efficient speaker than this if windows are to rattle.

Acoustic Labyrinth

Acoustic labyrinth enclosures are, in effect, a duct one quarter of a wavelength long at the speaker's resonant frequency (e.g., 7ft at 40Hz). Folding the fibreboard or plywood duct into a box shape produces a labyrinth, hence the name. Some designers fill the duct with acoustic wadding: others just line the interior surfaces.

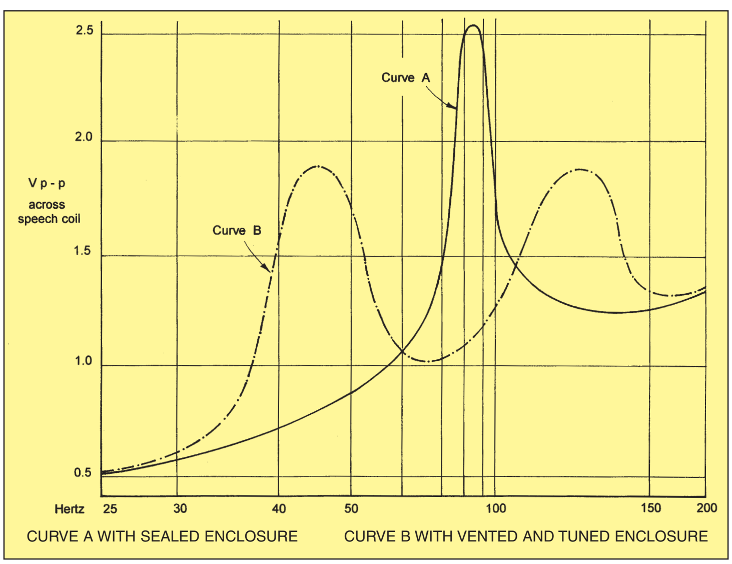


Fig.1. Speech coil impedance in region of resonance.

The quarter wavelength air column imposes the desired heavy damping on the cone at its resonant frequency. As frequency rises through an octave (i.e., towards 80Hz in our example) the air column approaches half a wavelength. The phase of the radiation from the rear of the cone is then inverted, and it emerges from the duct to reinforce that from the front, thereby increasing output.

Enclosures of this kind are not easy to construct or tune to suit different speakers. In our quest for good performance for a modest outlay of cash and effort, this highly regarded system has, therefore, to be rejected.

Horns

Loading the speaker cone with an expanding column of air in the shape of a horn results in very high efficiencies; of the order of 40 per cent to 50 per cent. The horn effects an impedance transfer: high at the throat and low at the mouth. The resulting heavy damping on the speaker cone, and the small cone excursions and low power input needed for a given sound output, greatly reduce distortion.

Many ingenious designs have been produced for folding large, low frequency horns into cabinets. However, cost, size, and complexity of design and construction remove this system from our consideration.

Bass Reflex

Bass reflex enclosures, also known as acoustic phase inverters, are based on the work of a German physicist, Herman Ludwig Ferdinand von Helmholtz (1821-1894).

Whilst exploring the nature of sound, he investigated the way air resonates inside vented chambers and close to the vent itself. The idea of mounting a loudspeaker in a Helmholtz resonator was patented, about half-a-century later, by A. L. Thuras.

Enclosures of this kind are simple and cheap to construct and tune. Efficiency is comparatively high: some authorities suggest 15 per cent to 20 per cent depending on the size of the loudspeaker (the bigger the better).

A reflex enclosure is, therefore, the natural choice when cost and effort are to be kept to a minimum and limited amplifier power demands good speaker efficiency.

HOW IT WORKS

A bass reflex enclosure is no more than a box with a small opening known as the "vent" or "port". The mass of air within the box is tuned, by the vent, to resonate at the same frequency as the speaker cone. This imposes heavy damping and results in two smaller resonances, one of lower and one of higher frequency than the unvented cone resonance.

Speaker output falls off rapidly below resonance, and the development of the lower frequency peak extends the speaker's bass response by almost an octave. Phase inversion takes place over most of the low frequency range, and output from the vent augments that from the front of the cone (the operation of the system is complex, and phase inversion does not occur at all frequencies).

Output falls off very rapidly below the lower peak but, in a well designed system, this will be in a region where there is little or no signal content.

The damping effect of the vented enclosure is displayed graphically in Fig.1. A plot of speech coil voltage against frequency, it represents variations in impedance which are intimately related to resonances in the system. The single resonant peak (curve A) developed when the vent is sealed contrasts with the two lower peaks (curve B) which form when the vent is opened. Correct tuning is indicated when the peaks are of equal magnitude (as is the case here).

DESIGN TECHNIQUES

Traditionally, designers matched enclosure resonance to the free-air resonance of the speaker cone on the basis of vent area being equal to effective cone area. This optimised low-frequency reinforcement by the vent but resulted in large enclosures.

Readers who like to build on a grand scale might find the formulae in Table 1 helpful. Much simplified, they relate speaker size and cone resonance to enclosure volume. The relevant speaker parameters are listed in Table 2.

Enclosures as large as this tune very broadly, and sizeable variations in vent area have only a modest effect on performance. As we shall see, enclosures can be too big, and it would be prudent to reduce the volume given by the formulae by, say, 25 per cent and tune to resonance by reducing the vent area or providing a duct.

Crossover/Audio Filter selection switch and amplifier input terminals.

When reflex enclosures are designed in this way, the ***frequency*** ratio between the two smaller resonances formed by tuning should be not less than 1·5:1 and not more than 2·4:1.

MODERN PRACTICE

During the 1960's, Australians, Neville Thiele and Richard Small, extended earlier loudspeaker research carried out by American, James Novak.

They were able to show that, for optimum performance, enclosure size is dependant upon the relationship between the damping effect of the enclosed air and the compliance of the cone suspension. If, when the enclosure vent is sealed, the frequency of the single resonant peak is 1·5 to 1·6 times the free-air resonant frequency of the cone, the relationship is correct.

Thiele and Small described an experimental method for determining suspension compliance, and produced formulae relating this, and other speaker properties, to enclosure size and vent area. Known as the Thiele-Small parameters, these speaker characteristics are now published by a number of manufacturers.

TABLE 1: TRADITIONAL ENCLOSURE DESIGN

Formulae relating enclosure volume to speaker cone size and resonant frequency

f res Hz	40	50	60	70	80	90	100	110
Vol cu ft	3R	2R	1·4R	1R	0·8R	0·6R	0·5R	0·4R

Notes:

(1) **F res** is the free air resonant frequency of the cone, in Hertz.
Vol is the internal volume of the enclosure in cubic feet.
R is the effective radius of the speaker cone in inches (see Table 2).

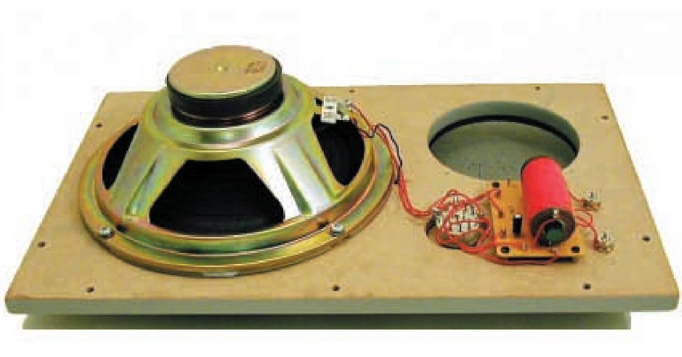
(2) These formulae are derived from traditional design procedures. Calculations in accordance with current practice, which relates cone compliance to enclosed air compliance, usually result in a smaller enclosure (see text).

(3) Although much simplified, the formulae will produce sufficiently accurate results (as size increases towards this maximum, tuning becomes less and less critical).

(4) Formulae are based on enclosure port area being equal to the effective cone area. See Table 2 for details of effective cone areas.

TABLE 2: LOUDSPEAKER DATA

Speaker Diameter (inches)	8	10	12	15	18
Effective cone radius R in.	3	3·75	4·75	6	7·5
Effective cone area sq. in.	28	44	71	113	177



D. B. Keel subsequently adapted the formulae for processing on a pocket calculator, but the procedure is still complicated. Readers with a mathematical turn of mind who want to optimise their enclosures in this way are urged to study the extensive literature on the subject.

BUILD AND TUNE

Theile-Small parameters are not usually available for the low cost, but often reasonable quality, speakers of Far Eastern origin (or for speakers in spares boxes). Even if they were, it is likely that many readers couldn't face the tedium of the calculations.

An alternative approach is to make an enclosure of manageable dimensions, having regard to the size of speaker, and then tune it to optimise performance.

Quite small enclosures can be tuned to frequencies in the 50Hz to 100Hz range. However, as volume is reduced vent area has to be reduced to secure resonance at a particular frequency.

Eventually, a point is reached when vent output is negligible and the enclosure is performing almost like a sealed box. Moreover, as size is reduced, the smaller, "stiffer" volume of air increases damping on the cone and its resonant frequency rises unacceptably.

The resonant frequency of a given vent and enclosure combination can be lowered by forming a duct or pipe behind the vent. The longer the duct the lower the resonant frequency. Although this involves more constructional effort, it does allow a reasonable vent area to be maintained when enclosure volume is small.

SIZE AND SHAPE

Speaker units were discussed last month, and it was clear that an extended and powerful low-frequency response becomes easier to achieve as speaker size is increased. It was suggested that speaker size ought not to be less than 8in, and this is especially true when an inexpensive unit is to be fitted.

Readers may wish to use even larger speakers for the advantages they offer: some highly regarded studio monitors comprise a 15in bass unit in a 5 cubic foot reflex enclosure.

Cabinet dimensions should not be exact multiples of one another, and some experts maintain that deep enclosures perform better than shallow ones. Greater depth also permits a longer duct.

Chamfers, formed around the enclosure front and reaching almost to the speaker aperture, are said to improve clarity at low frequencies, but this makes construction difficult. Keeping the front panel as narrow as possible is probably the best we can do to achieve this objective.

The vent can be any shape provided its smallest dimension is not less than one inch. Circular vents can be ducted with a length of cardboard tube, but some builders may find rectangular openings and box-form ducts easier to fabricate.

CABINET SIZES

The above requirements, together with the desirability of a reasonable vent area and the obvious influence of speaker diameter, tend to determine the smallest acceptable enclosure size. Suggested internal dimensions to suit standard speakers are listed in Table 3 and the general make-up of the enclosure is shown in Fig.2.

The enclosures for the 15in and 18in units are rather deep, and the speaker aperture and vent opening could be formed on the face with the larger dimension if desired (these cabinets are large enough for the cone to still be an adequate distance from what would then be the back).

Whilst the width of the front is determined by the speaker chassis and cannot be reduced much, the other dimensions can be changed to suit materials that are to hand or a particular space in a room. When making changes, try not to reduce the volume by more than 10 per cent or so (especially with the 8in. and 10in. units); and try to avoid dimension combinations that are exact multiples.

CONSTRUCTION

One of the best materials for cabinet construction, acoustically speaking, is medium density fibreboard (MDF). This material is reasonably heavy, easy to work, has a desirable "dead" quality and is inexpensive. Chipboard, blockboard and plywood are also perfectly acceptable.

Enclosures for the 8in., 10in. and 12in. speakers should be formed from 13mm (1/2in.) thick sheet with 19mm (3/4in.) square glued and screwed softwood corner fillets. The two larger enclosures require 19mm (3/4in.) material and 25mm (1in.) square fillets. One or two lengths of 25mm square softwood should be fixed across the larger enclosures, from side-to-side, near mid panel, to inhibit vibrations.

The construction must be air-tight. If any of the joints are less than perfect, apply liberal quantities of adhesive to fill the gaps. Use plastic foam draught excluder to seal the access panel.

MAKING DUCTS

Ducts need not be as rigid as the enclosures, and hardboard (Masonite in the USA) or very thick cardboard are suitable materials. Circular ducts can be formed by applying paste to a long strip of paper or thin card and winding it around a food or paint container until a thickness of 3mm (1/8in.) or so has been built up.

Slide the duct from the former and place it somewhere warm for the paste to dry. It is not too difficult to combine two pipes to form an adjustable, telescopic duct.

TWEETER MOUNTING

Tweeters can be mounted axially in front of the bass speaker to avoid the need for another hole in the cabinet. Small hooks and eyes and the kind of springy wire used for hanging net curtains are ideal for this purpose.

If the wires are cut short to provide a little tension the speaker will be held firmly in place. Strong rubber bands could be used, but these may perish over time.

Using cutdown curtain wire, hooks and eyes to suspend the treble speaker over the bass speaker.

Bass reflex cabinets are resonators and acoustic treatment should be applied sparingly. The rear and top of the enclosure should, however, be lined with about 50mm (2in.) of cellulose wadding to prevent the reflection of mid-frequency sounds which could otherwise escape through the speaker cone and impair clarity.

Cellulose wadding can be obtained from upholsterers and craft shops (it is used for stuffing soft toys).

TESTBENCH SPEAKER

The accompanying photographs show an enclosure for an 8in. speaker, constructed in accordance with the earlier guidelines, and incorporating the crossover and audio filter unit described last month. It is intended for workshop use, and this is reflected in the style and type of finish. Constructors wanting "hi-fi" speakers will have their own ideas for giving the units a more domestic appearance.

The surface mounted grille is of the type fitted to musician's speakers. The bezel around the vent opening is formed from

TABLE 3: RECOMMENDED MINIMUM ENCLOSURE DIMENSIONS

Speaker Diameter	8	10	12	15	18
Width A	9·5	11·5	13·5	17	20
Height B	15	18	21	27	33
Depth C	12	14·5	17	21	24
Speaker Aperture diameter D	7	9	11	13·75	16·5
Vent diameter E	4	5	6	7	8
Vent area sq. in.	12·5	19·5	28	38	50
Minimum distance F	3	4	5	7	8
Enclosure Volume (cu. in.)	1710	3002	4820	9639	15840
Enclosure Volume (cu. ft.)	1	1·75	2·75	5·5	9

Notes:
(1) All dimensions are in inches unless otherwise stated.
(2) Enclosure volumes expressed in cubic feet are approximate.
(3) Enclosures produced to these dimensions must be tuned for optimum performance (see text).

LOUDSPEAKER ENCLOSURE . . . *YOU WILL NEED*

Bass Speaker: 8in. diameter, 8 ohms impedance, preferably with a free-air resonance below 70Hz (most speakers with a rolled surround will meet this requirement).

Moving coil treble unit, 8ohms impedance (see text).

Sheet of MDF, 1200mm x 600mm x 13mm (4ft x 2ft x 1/2in.) thick; softwood corner fillets 4m × 19mm square (13ft of 3/4in. square); glue and screws.

Speaker and vent grilles; material for any duct (see text); draught excluding strip; springy curtain wire and small hooks for mounting tweeter unit; finishing materials etc.

The parts list for the crossover unit was included with Part 3, last month.

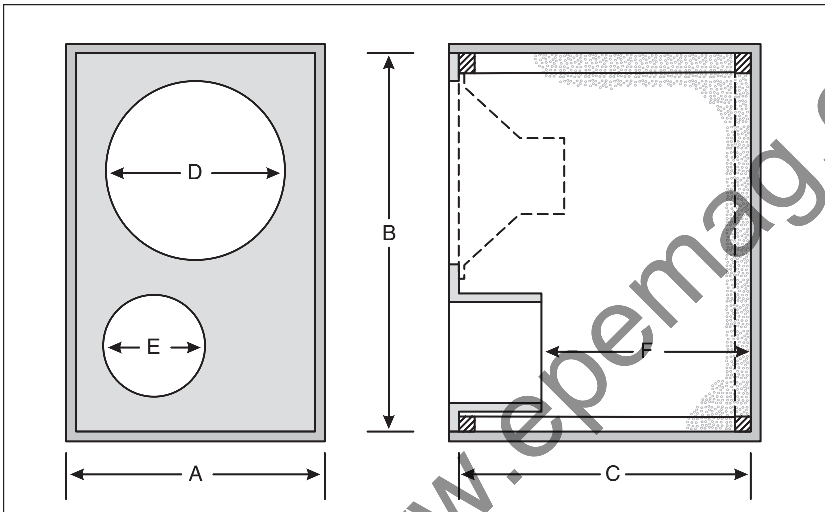


Fig.2. Front and side elevations showing the speaker and vent apertures. Recommended enclosure dimensions are listed in Table 3 above.

Main speaker and crossover filter (last month) mounted on the rear of the enclosure front panel.

Lining the rear of the cabinet with sound-absorbent wadding.

hardboard and nylon mesh is used as a screen. Bezel and mesh are spray finished matt black.

Photographs of the tweeter mounting were taken before the suspension wires were painted black to conceal them behind the grille. Car spray paints were used to decorate the cabinet, and the hard, smooth surface of the MDF makes it easy to obtain a good finish (spraying should be undertaken outdoors or where there is plenty of ventillation). Rub-down lettering, protected by varnish, is used for the panel annotations.

SPEAKERS

Manufactured in the Far East, the bass speaker used in the model is an inexpensive 8in. diameter unit with a rolled surround. Speakers of this kind are widely retailed and cost between £8 and £15 ($12 and $22).

A compliant suspension and robust cone give these units a free-air resonance in the region of 60Hz. Speakers with a free-air resonance much higher than 70Hz should be avoided if possible.

Suitable tweeters are readily available at a fairly reasonable cost. The paper-coned unit mounted in the prototype is a cheap surplus component.

It is sometimes desirable to adopt a cross-over frequency around 500Hz when large (15in. or 18in.) bass speakers are used. Suitable tweeters can be expensive, and experimentally minded readers may care to try one of the cheap Mylar cone speakers intended for alarm systems. The claimed frequency response extends up to 20kHz, and a 3in. or larger unit should cope with the lower cross-over frequency.

Chassis perforations should be covered with several layers of sticky tape to prevent interaction with the bass speaker. Alternatively, isolate the tweeter by mounting it inside a small box formed within the main enclosure. Fill the box with cellulose wadding. A 3in. diameter Mylar cone speaker performed better than the purpose-made tweeter mentioned above.

TUNING OSCILLATOR

In order to tune our enclosure we need some means of exciting and detecting resonances.

A simple Low Frequency Oscillator circuit diagram is shown in Fig.3, where IC1, a 741 op.amp, provides the necessary gain. A Wien bridge network, formed by C1, C2, R1, R2 and VR1a and VR1b, controls the phase of the positive feedback from IC1 output (pin 6) to the non-inverting input (pin 3). Potentiometer VR1 sets the frequency of oscillation.

Negative feedback, from the output to the inverting input (pin 2), determines the gain, thereby controlling the level of positive feedback. Gain should be as low as possible consistent with reliable oscillation over the full swing of Frequency control VR1. Negative feedback increases, and gain reduces, as the slider (moving contact) of preset potentiometer VR2 is rotated towards resistor R3.

The stabilising circuit usually incorporated into the negative feedback loop has been omitted in the interests of simplicity. Despite this, signal amplitude is constant over the frequency range and waveform is good when VR2 is correctly set.

OSCILLATOR CONSTRUCTION

Most of the oscillator components are assembled on a small single-sided printed circuit board (p.c.b.). This board is available from the *EPE PCB Service*, code 364.

The topside component layout, interwiring and full-size underside copper foil master pattern for the Low Frequency Oscillator board are shown in Fig.4. Solder pins, inserted at the lead-out points, simplify off-board wiring, and a holder for IC1 facilitates substitution checking.

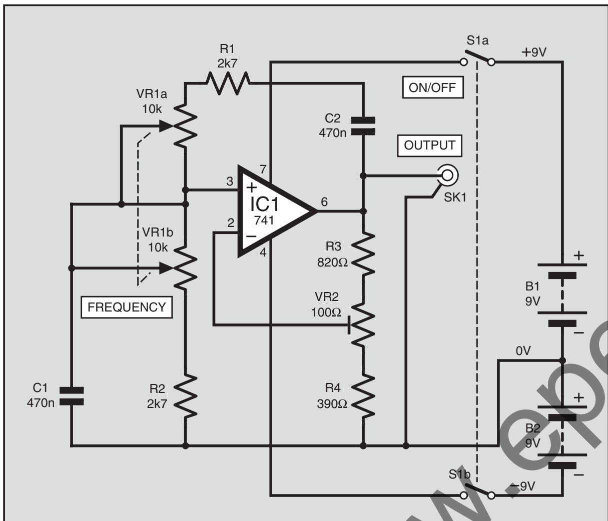
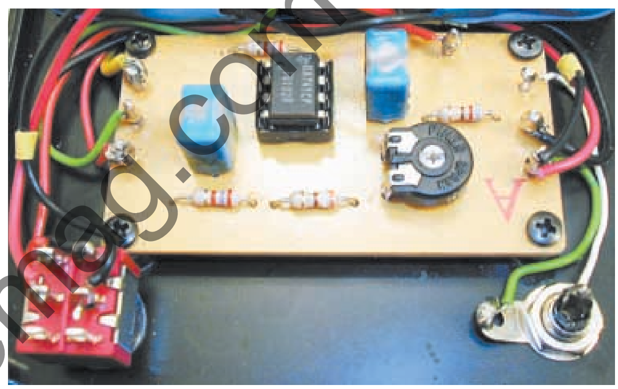


Fig.3. Circuit diagram for a simple Low Frequency Oscillator for loudspeaker resonance checking.



Component layout on the completed circuit board.

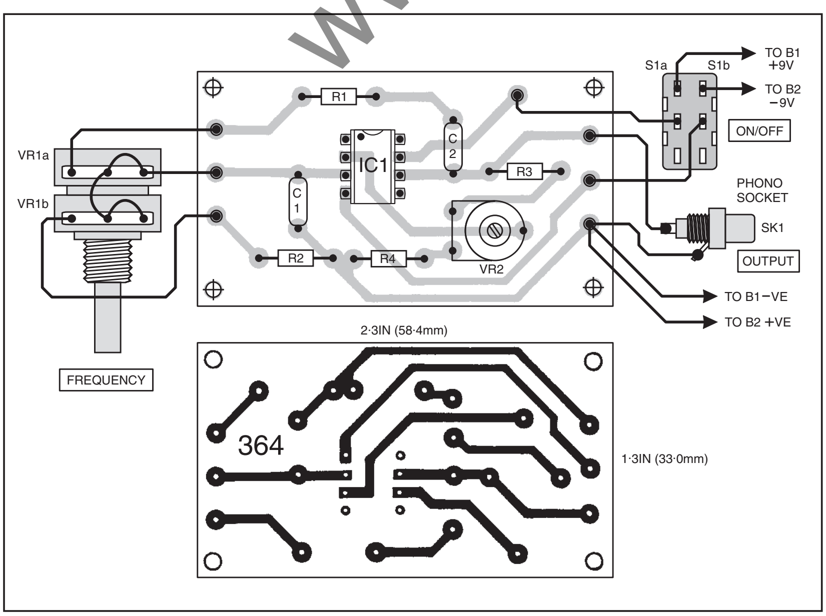


Fig.4. Low Frequency Oscillator printed circuit board component layout, interwiring to off-board components and full-size underside copper foil master pattern.

COMPONENTS

OSCILLATOR

Resistors

R1, R2	2k7 (2 off)
R3	820Ω
R4	390Ω

All 0·25W 5% carbon film

See SHOP TALK page

Potentiometers

VR1	10k dual-ganged rotary carbon, lin.
VR2	100Ω enclosed carbon preset

Capacitors

C1, C2	470n polyester layer, 5% tolerance desirable (2 off)

Semiconductors

IC1	741 gen. purpose op.amp

Miscellaneous

Printed circuit board available from the *EPE PCB Service,* code 364; small plastic case, size and type to choice; PP3 batteries and holders; pointed control knob; 8-pin i.c. holder; solder pins; multistrand connecting wire.

Approx. Cost Guidance Only **£9** *excluding batts.*

Packing the Low Frequency Oscillator components on the rear of the small plastic box lid.

Potentiometer VR1, On/Off switch S1, the p.c.b. and the batteries can be housed in a small plastic box. The compact internal layout inside the prototype unit is shown in the photographs.

It is not necessary to know the precise frequency to tune the enclosure, but an approximate idea is useful. Component tolerances will affect calibration, but the original dial should provide an approximate guide to the frequency control settings on other units. It is reproduced, full-size, in Fig.5.

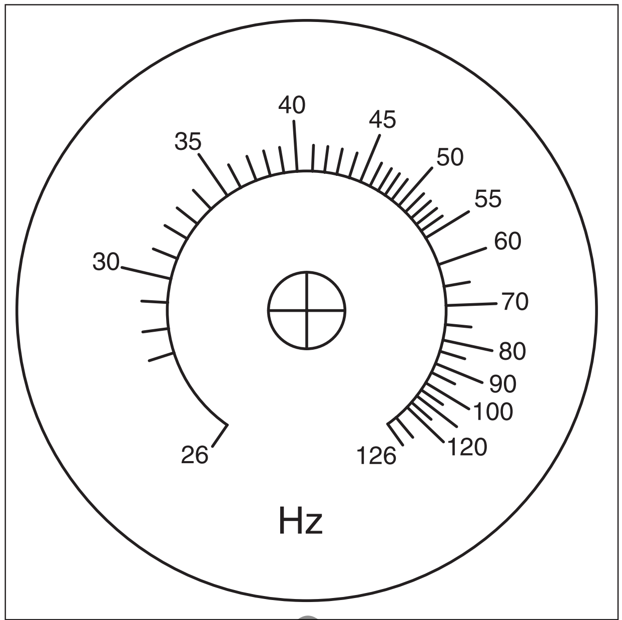


Fig.5. Full-size front panel dial as used in the prototype Low Frequency Oscillator.

RESONANCE DETECTOR

Some test meters, set to the lowest a.c. range, could be used to monitor the voltage developed across the speech coil. However, unless the meter is sensitive, the sound level from the speaker under test would be distressingly loud. Further, a resistor has to be wired in series with the speech coil to facilitate the test. This could make it difficult for the amplifier to deliver sufficient output to produce a reading on an insensitive meter.

Greater sensitivity can be achieved by rectifying the signal and measuring the resultant d.c. on the lowest testmeter range. A suitable loudspeaker Resonance Detector circuit is given in Fig.6, where diodes D1 and D2 are configured as a voltage doubler delivering almost the peak-to-peak value of the signal.

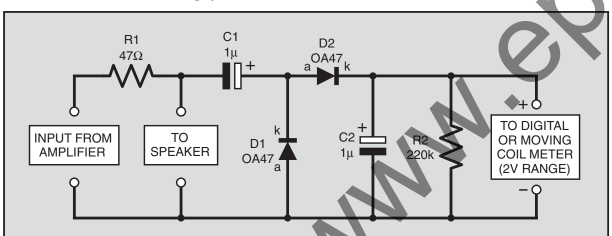


Fig.6. Circuit diagram for the loudspeaker Resonance Detector.

When the Resonance Detector unit is connected to a high impedance digital meter, reservoir capacitor C2 slows the response to voltage changes, and resistor R2 is included to reduce the delay.

Series resistor R1 increases the impedance of the signal source and magnifies the effect of changes in the impedance of the speech coil. The values of electrolytic capacitors C1 and C2 have been chosen to suit the frequencies involved.

DETECTOR CONSTRUCTION

All the components for the Resonance Detector are assembled on a small printed

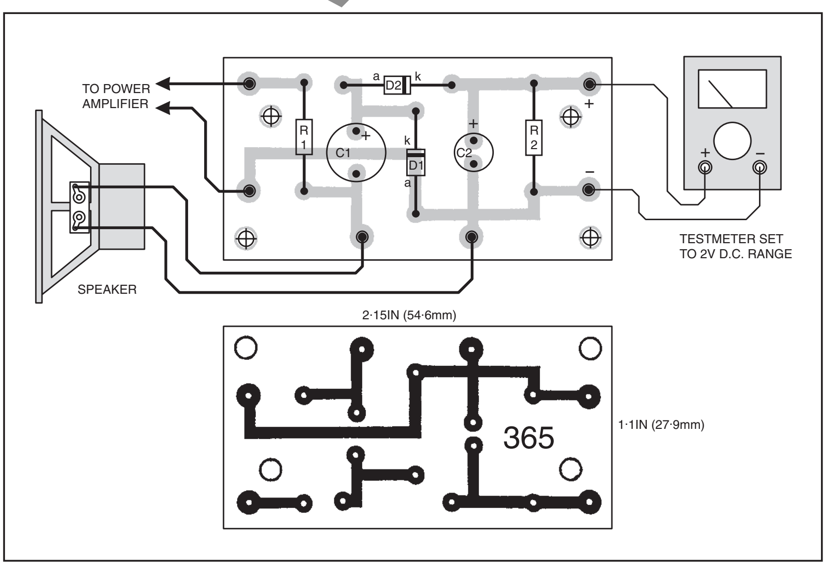


Fig.7. Printed circuit board component layout, interwiring details and full-size underside copper foil master for the loudspeaker Reasonance Detector.

COMPONENTS

RESONANCE DETECTOR

Resistors

R1 47Ω
R2 220k
All 0·25W 5% carbon film

See SHOP TALK page

Capacitors

C1, C2 1µ radial elect. 25V (2 off)

Semiconductors

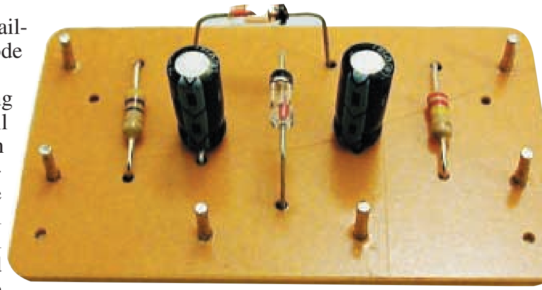
D1, D2 OA47 or OA90 germanium diode (1N914 silicon if lower sensitivity can be tolerated – see text) (2 off)

Miscellaneous

Printed circuit board available from the *EPE PCB Service,* code 365; multi-strand connecting wire; solder pins; solder, etc.

Approx. Cost Guidance Only **£6** *excluding speakers* circuit board (p.c.b.). This board is available from the *EPE PCB Service,* code 365.

The p.c.b. component layout, wiring and full-size underside copper foil master pattern details are illustrated in Fig.7. Construction is very straightforward and only the polarity of the capacitors and diodes needs special attention. Also, germanium signal diodes, D1 and D2, can be damaged by excessive heat and it is prudent to leave a good lead length and apply a heat shunt when soldering.



Completed circuit board for the Resonance Detector.

GENERAL SUMMARY

No difficulty should be encountered obtaining any of the materials and components needed for the construction of the loudspeaker enclosure and the setting up equipment. Details of the cross-over unit were given last month.

Silicon diodes (type 1N914) can be used in place of the germanium devices in the voltage doubling rectifier circuit of the Resonance Detector. The higher knee voltage (0·6V instead of around 0·2V) reduces sensitivity, but they will still reveal the resonance peaks when the sound from the speaker is not too loud, and this is the main requirement.

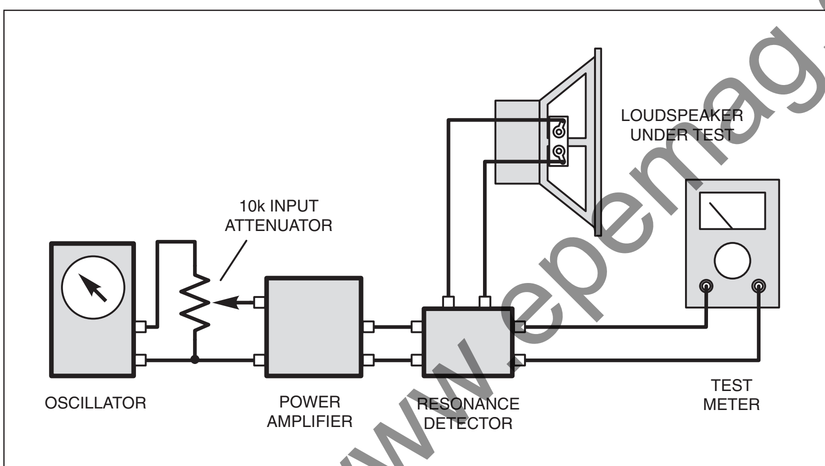


Fig.8. Block schematic diagram showing the interconnecting set-up for checking speaker resonances.

FREE-AIR RESONANCE

The free-air resonance of the bass speaker should be checked before embarking on the construction of the enclosure. To do this, wire up the test circuit shown in Fig.8. Details of the connections to the Resonance Detector are given in Fig.7. The Oscillator output is in the region of 4·5V r.m.s., and the 10 kilohm input attenuator potentiometer will have to be turned well down.

Hold the speaker, by the magnet, well away from other objects and sweep the Oscillator until the voltage across the speech coil peaks. The rise will be sudden and dramatic. Note the reading on the Oscillator dial. If an extended low frequency response is important, it ought not to be more than 70Hz.

ENCLOSURE TUNING

With the speaker now in the enclosure, connect it to the test circuit shown in Fig.7 (directly, ***not*** via the crossover). Seal the vent, sweep the oscillator and note the frequency and magnitude of the peak. It will now be at a higher frequency than the free-air resonance.

Open the vent and sweep the oscillator, again noting the frequency and magnitude of the peaks. If the tuning is correct (most unlikely), two peaks of equal magnitude will be revealed on either side of the original, vent-sealed peak.

If the higher frequency peak is of greater magnitude, the vent area is too small (or any duct attached to it too long). Enlarge the vent, or shorten the duct, and test again.

If the lower frequency peak is of greater magnitude (more likely with the design guidance given here), the vent area is too large or any duct is not long enough. Either reduce the vent area, add a duct, or increase the length of any duct already fitted, and test again.

Repeat the procedure until the two peaks are of equal magnitude. Some experts tune to a slightly higher frequency. This depresses the higher frequency peak and, it is claimed, results in a more uniform bass response. The impedance plot of the test bench speaker, after tuning, is given in Fig.1.

DUCTING

It is preferable to install a duct, rather than reduce vent area, in order to lower resonant frequency. Hold ducts in place with sticky tape during the setting up process.

If desired, a duct can be mounted externally and adjusted until its length is almost correct before fixing it behind the vent. Duct volume will then reduce cabinet volume, so err on the long side when adjusting its length in this way.

PERFORMANCE

The speaker unit has an extended bass response and, when driven by the 8W amplifier described in Part One (May '02), sound levels are more than sufficient for a domestic "hi-fi" installation.

Vent output makes a significant contribution at low frequencies (it will extinguish a candle held close to the aperture), and there are no audible resonances. The speaker is most certainly not a "boom box" with honking, one-note bass.

The middle range is clear but there is some colouration at high power levels with music that has a heavy bass content. Performance at the higher audio frequencies depends very much on the tweeter used: the enclosure is certainly worth something better than the cheap unit fitted in the prototype.

When the crossover network is switched to act as a "speech frequency bandpass filter", signals overlaid by noise are greatly clarified. Communications enthusiasts, or readers involved in surveillance, may find this circuit of interest. It certainly makes the unit more versatile as a bench speaker.

POWER CHECK

The Low Frequency Oscillator and Resonance Detector units can, of course, be used to investigate any speaker system. The rating of resistor R1 in the Resonance Detector is only sufficient for testing at comfortable listening levels. If speakers are to be checked at high power, fit a 5W component and use silicon instead of germanium rectifier diodes.

Although the test equipment will respond to very slight changes in venting, especially when the enclosure is small, only a refined ear could detect any audible difference, even when quite large adjustments are made. □