Vintage Radio

by PETER LANKSHEAR

A closer look at moving coil loudspeakers

One of the most familiar components found in a wide range of radio, video and audio equipment is the moving coil loudspeaker. Made in countless millions since Rice and Kellog produced the ancestral RCA 104 nearly 70 years ago (as described in this column for May 1989), the basic design has changed remarkably little.

The moving coil loudspeaker, has, in common with the conventional internal combustion engine, some fundamental weaknesses which will never be completely eliminated. But constant research, development and steady incremental improvements have so far held off any serious threats to the mass market from alternative types.

An old diagram shown here in Fig.1 shows the basic component sections: the frame or chassis, the magnet system, and the cone, with its voice coil and suspension. The basic operation is simple. A light coil of wire, attached to a conical diaphragm, is suspended with minimum clearances between the concentric pole pieces of a powerful magnet. The coil will move back and forth in response to audio currents flowing in its winding, and this motion is transferred to the cone which acts as a piston to move the surrounding air and generate sound waves.

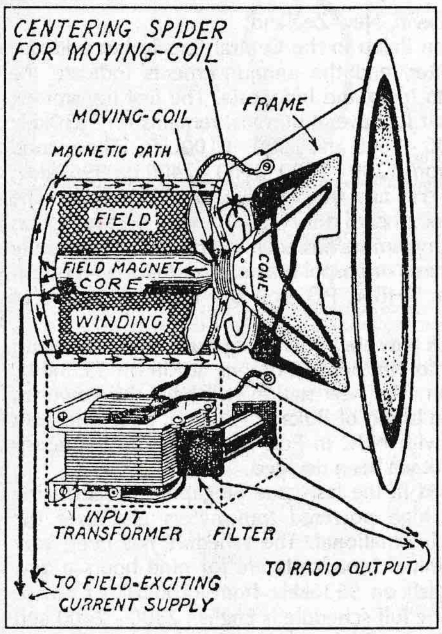


Fig.1: This 1930's drawing of a typical moving coil loudspeaker shows that the essentials have changed little in 60 years, other than the change to permanent magnet fields.

The chassis (sometimes called the 'basket') is usually made of pressed steel — although some, especially those for high quality speakers, have been made from diecast metal. Dimensional stability is most important, for if a chassis is distorted, the voice coil may rub on a pole piece, with unpleasant results.

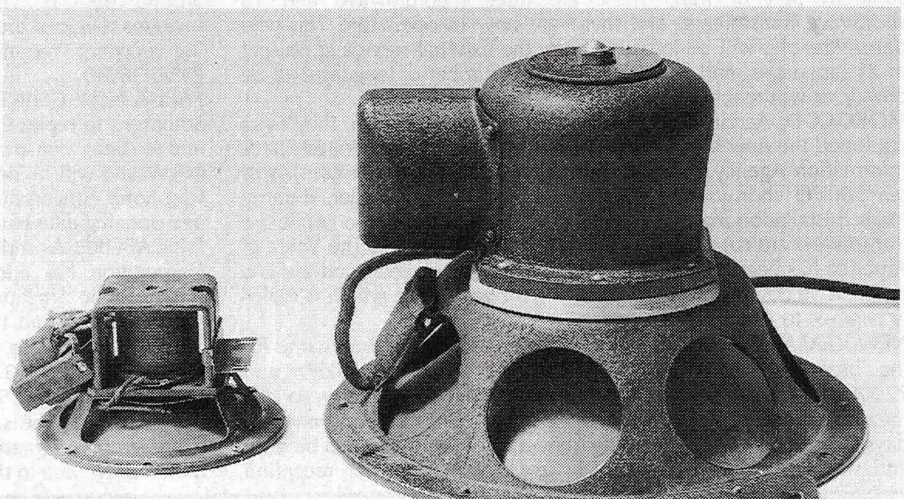
Attached to the chassis, generally at the rear, is the magnet assembly. This has a small circular air gap between the central core and and a matching concentric outer ring pole piece. (Some speakers have been made 'inside out', with the magnet at the front of the cone. Philips did this for space saving on some models.) No speaker can be better than its magnet, and much of the weight and cost of speakers comes from the magnet system.

Use of electromagnets

Permanent magnets were at first incapable of providing the strong fields necessary. More powerful alloys became available in the early 1930's, but were expensive and could still not match an electromagnet for field strength. Hence all of the early moving coil loudspeakers had electromagnetic (EM) fields, and were often called 'dynamic' speakers. Typical electromagnetic field windings were operated at between 750 and 2000 ampere-turns, requiring up to 30,000 turns or even more of fine wire.

In most domestic radios, the field winding was in series with the main HT supply. Some early receivers had a field winding with a resistance of 5000 ohms or more, shunted across the supply. A variation of this was to make the field

Fig.2: Moving coil loudspeakers are remarkable for their diversity of sizes, and this pair are by no means extremes. At the left is a 5" AWA unit made around 1935. The other is a 1930 Atwater Kent type N, about 11" in diameter.



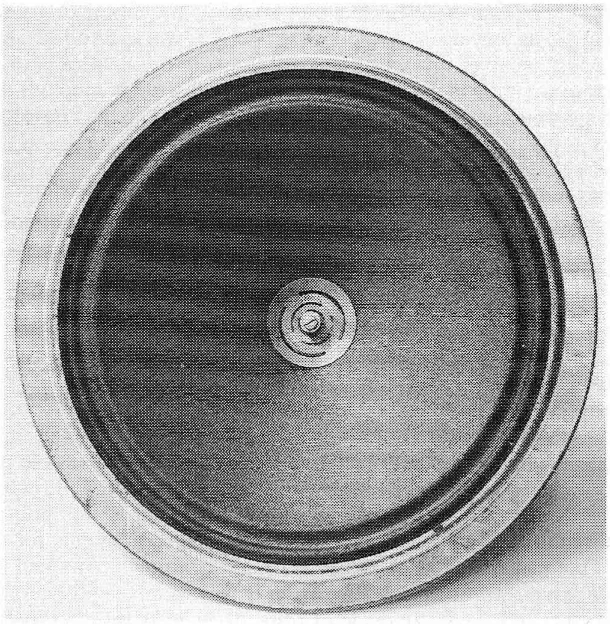


Fig.3: Philips was a pioneer in the use of permanent magnet speakers for mains operated receivers. This 1930's model has a front spider and a plain cone with corrugated surround.

part of the main voltage divider. This was the method used in the Majestic model 90 receiver described in the August 1992 column — the massive G3 speaker having a field winding with nearly 7km of wire, operating at 50mA!

The ultimate in field windings was probably the 3.5kg of wire in shunt and series windings used in an 18" Jensen speaker for McMurdo Silver's 1937 Masterpiece V receiver!

Sometimes, especially for cinema and PA systems, field windings were designed for low voltage, high current operation, and powered from a car battery — or in some cases, their own mains power supplies with gaseous or copper oxide rectifiers.

'Free filter choke'

It was soon realised that speaker field windings possessed considerable inductance and could, as a bonus, double as a high tension filter choke. A problem was that the current had a hum component, which created a ripple in the speaker's magnetic field, producing a noticeable hum.

Several methods were used to minimise this difficulty. One was to provide a degree of preliminary filtering by retaining a separate filter choke, or by using a heavy duty resistor following the rectifier. The choke meant extra cost and the resistor, although less expensive, created heat and needed additional HT input voltage.

A *shading ring* was another method of reducing hum. In effect a shorted turn, this was a heavy copper disc, sometimes sandwiched with iron, at one end of the field winding. This produced a measure of cancellation, with the eddy currents generated in the disc opposing the hum components in the magnetic field.

By 1932, the best solution of all had appeared: the hum bucking coil, which was thereafter to remain a standard fitting for EM speakers. This was a flat, single layer winding of a dozen or so turns of heavy wire, positioned similarly to the shading ring and connected in series with the voice coil. Hum cancellation came from the ripple component in the magnetic field inducing a voltage in the bucking winding, with the opposite polarity to that induced in the voice coil. Provided that the winding was suitably proportioned, virtually complete hum cancellation was possible.

Although information about current carrying ability, and number of turns might have been useful to designers, EM speaker fields were generally only rated by resistance.

It is clear from Fig.2 that there could be considerable physical variations in field windings of similar nominal specification. The field resistance of the small AWA speaker is 1500 ohms while that of the Atwater Kent is a comparable 1100 ohms. Obviously, the larger speaker has a winding with many more turns of heavier wire, which, with a given current, creates a considerably greater magnetic flux than in the midget. This was, by the way, one reason why larger loudspeakers were the most efficient.

With the advent of the hum bucking coil, the speaker field alone became sufficient for adequate filtering. Separate filter chokes were no longer necessary, and the high value 'shunt' type of field winding disappeared.

Field resistances for series operation came in several ranges. On the lower side there were many fields of 1000 - 1100 ohms. Middle values were around 1500 ohms, with a few at 2000 ohms.

More popular in Australasia than elsewhere were windings with a resistance of 2500 ohms. Although this type of field generated a very strong magnetic field, it also required very high transformer voltages, generally in the vicinity of 400 volts, and consequently caused more stress to components, especially during valve warmup, than was the situation with lower resistance fields.

Why not use permanent magnets?

Prior to 1932, the only permanent magnets available were the traditional carbon steel 'horseshoe' type, not very powerful and prone to self demagnetisation unless their length was considerably greater than their cross-sectional area. Some rather ungainly efforts were made to use this type, typically with four massive magnets arranged around the back of the speaker, but in no way could they compete with electromagnets.

In 1932 the first chromium alloy permanent magnets appeared, providing a significant improvement. 'Permag' or PM moving coil speakers were increasingly used in battery powered receivers, replacing the alternative moving-iron and inductor speakers.

Further progress in magnet development was dramatic, achieved through the use of cobalt steel, Alnico and Alcomax. This is demonstrated by the consequent reductions in weight and size. For a total flux of 27,600 lines, the 1932 magnet weighed 5lbs (2.25kg). The same strength of field, 12 years later, could be provided by only five ounces (141g) of Alcomax 1 — and by 1953, by using Alcomax III, the weight was down to 2.5 ounces (71g), only 1/32 of that of chrome steel.

Today, compact ring shaped ceramic ('ferrite') magnets are popular, providing inexpensive powerful and stable magnets in a minimum of space.

Electromagnetic speakers still continued to be used in mains powered receivers. Equivalent PM speakers were generally more expensive and there was the added cost of a filter choke.

One major manufacturer, Philips, did change to PM speakers for mains receivers in 1933, in both Holland and England. Later they overcame the filter choke problem by using resistor filtering in conjunction with high-value electrolytic filter capacitors, anticipating a technique that was widely adopted by other manufacturers 20 years later.

Meanwhile, until radio production ceased during World War II, the majority of receivers still used EM speakers. By the time post-war radio manufacture resumed, magnets were more powerful and significantly cheaper than field windings, and the EM speaker soon disappeared.

Cone materials

Although today practically all loudspeaker cones are made from paper, they have been made from a variety of materials, including varnished or metallised cloth, polystyrene, wood, and, in the case of one infamous British GEC model, Duralumin (an aluminium alloy)!

Cones are intended to function as pistons, but in practice the flexibility of paper makes operation very complex. There is continuing research and development in the speaker industry, and although there have been many refinements and the performance of modern high fidelity reproducers can be outstanding, moving coil speakers are unlikely ever to be perfected. Consequently the reproducer remains the weakest link in the audio chain.

Modern cones are carefully engineered, often with strategically placed corrugations and made of graded fibres to control resonances and spurious responses. But many vintage speakers used quite plain paper, cut and glued into a cone shape, very much on a 'try it and see' basis. The miracle is that they sound as good as they do.

Most receiver cones are general purpose, covering a reasonable frequency range, but some console receivers used two or more speakers — with a large heavy coned model, typically 12", as a bass unit or 'woofer', and a smaller lightweight treble speaker or 'tweeter'.

Two suspensions

The cone must be free as possible to move forward and back with minimal restriction, but at the same time must be firmly restrained against any lateral movement. There must be no possibility of the voice coil touching the pole pieces, in what is a very small gap. This calls for two suspension systems, working together to provide very accurate positioning and centring.

One part of the suspension is a flexible circular component called the 'spider' and generally made of fibre, although in some cases thin metal was used. This is fastened to the cone at the base of the voice coil, to accurately centre the voice coil in the magnetic gap. Why a 'spider'? The earliest form was mounted in front of the centre pole piece and voice coil, and fastened to the cone as in Fig.3. To increase its flexibility, the disc was cut away in a pattern which, in some instances was reminiscent of the legs of a spider.

The flexibility of the front-mounted spider was found to be insufficient to permit large voice coil excursions. Longer legs on a bigger disc were needed. There was much more room available at the rear of the cone and so the rear spider evolved, as shown in Fig.4. A more expensive, adjustable mounting ring and additional hardware were needed, but the results were worthwhile and the rear spider was widely adopted.

The next development was to simplify the construction of the rear spider. Fig.5 shows how it was replaced by an inexpensive moulded corrugated disc. No elaborate mounting ring is needed, the disc being simply glued in position. This is the method used in modern speakers, and has the advantage of keeping dust and dirt out of the voice coil gap.

The front surround

The other part of the suspension is at the outer edge of the cone, where some form of flexible mounting attaches it to the rim of the chassis. In positioning the cone at this point, there are conflicting requirements for this 'surround', as it is known. An ideal material would be infinitely rigid laterally, and yet have no resistance to fore-and-aft movement. At the same time it would completely absorb any vibrations reaching the edge of the cone. In most enclosures too, it must provide an airtight seal. No wonder the perfect moving coil loudspeaker has yet to be produced!

Two of the early surround materials were chamois leather and cloth. Both were superior to paper, but were succeeded by the cheaper to make and assemble one-piece moulded cone with corrugations at the rim. Cones of this basic type have been used for general purpose receiver applications for the past 60 years, and show no sign of being superseded.

Some manufacturers of high quality speakers found however, that cloth suspensions gave superior results and con-

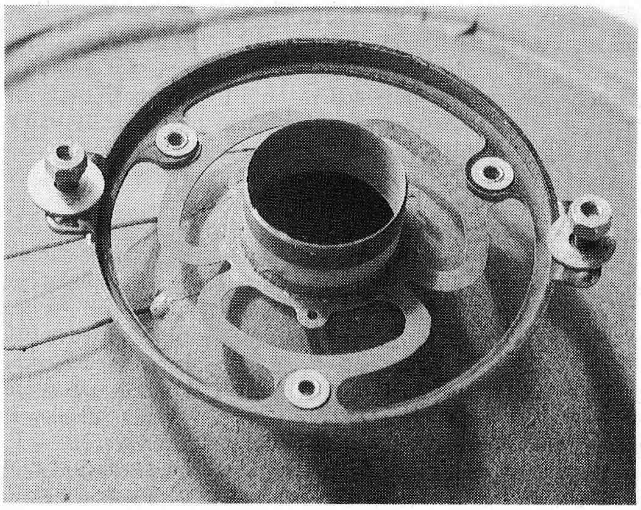


Fig.4: An advantage of the rear spider was that it could be made large enough to be very compliant. With its adjustable mount, this early type was also more complex.

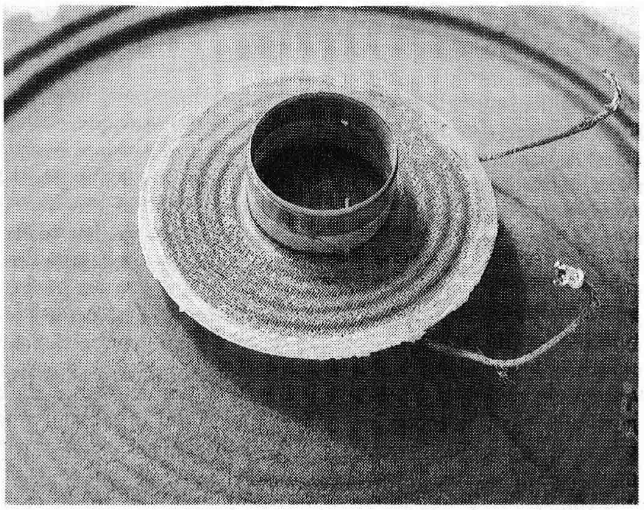


Fig.5: Inexpensively moulded from varnished or plasticised cloth, the modern spider is non adjustable. Simply glued to the chassis, it doubles as a dust seal for the voice coil.

tinued their use. The well known English firm of Wharfedale did run into trouble with alternative material. Around 1956 they experimented with a revolutionary new material — polyurethane foam sheet. Not only did it have superior absorption, but it was insect proof, and was claimed to be everlasting.

The results were so good that production was switched from cloth, but after a couple of years — disaster! Polyurethane was found to be not so everlasting, and in fact was disintegrating in speakers all round the world.

A common practice now is to mould a heavy corrugation into the rim of the cone, and soften it with a non-hardening plastic impregnation.

Voice coil sizes

Vintage voice coils come in only one shape, cylindrical; but there are many different sizes. Diameters vary from about 0.5" (12.5mm) for very small speakers, to 1.5" (38mm) or even bigger, in some of the large units.

A lightweight former, generally paper or fibre (although metal has been used), is wound with two or more layers of wire. In receiver speakers, this is almost always copper, but high fidelity types often use aluminium wire.

Finally, there is the question of voice coil impedances. Early speakers with large voice coils were often in the 10 to 15 ohm region, as were high fidelity and speakers for high powered operation. But for most of the valve era, small receiver speakers used 3.5 ohm voice coils and larger types had impedances in the region of 2.5 ohms.

The widespread use of semiconductors saw a practically universal standardisation of voice coils at eight ohms. It must be emphasised that voice coil impedances are very nominal and are specified in the region 400 - 1000Hz where they are lowest. At other parts of the spectrum, where even the method of mounting and enclosing a speaker can alter its characteristics, impedances are often considerably higher.

Much of this impedance is made up of the resistance of the voice coil wire. As a rough rule of thumb, the nominal voice coil impedance is only 30% to 50% higher than the DC resistance. For a speaker rated at eight ohms, this resistance is likely to be five or six ohms.

Maybe the existance of such a high proportion of unavoidable resistance in circuit should give a pause for thought to those hifi purists who consider that the only way to connect loudspeakers is by way of incredibly low resistance oxygen-free gold plated litz wire cables, heavy enough for a welder!

Loudspeakers are normally remarkably durable, and are considered by some experts to improve with age. Nevertheless they do have their problems, and next month we will look at some of these. We'll also provide some hints on their care, repair and feeding. ❖

NOTES AND ERRATA

Circuit and Design Ideas (March 1994): The schematic diagram for the Intelligent battery charger on page 41 is missing a number of connections and components on the right hand side. We've reproduced it here with all sections intact.

Playmaster Pro Series 3 Amplifier (March 1994): The PCB code in the parts list on page 60 should read 93ma12 — the same as the published PCB pattern.