Design of moving-coil head amplifiers

Douglas Self describes the problems of designing m.c. head amplifiers and illustrates them by means of a new design, originally intended for use with his precision preamplifier.

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In recent years, moving-coil cartridges have increased greatly in popularity. This is not the place to try and determine if their extra cost is justified by an audible improved performance; suffice it to say that a preamplifier now needs a capable moving-coil cartridge input if it is to be considered complete. The head-amplifier design presented here as an example was originally intended to be retrofitted to the precision preamplifier previously published in *Wireless World*[1], feeding the existing moving-magnet disc input. However it is adaptable to almost any preamplifier and cartridge as the gain range available is very wide; it should therefore be of interest to any engineer working in this field. Hereafter "moving coil" is abbreviated to m.c., and "moving-magnet" to m.m.

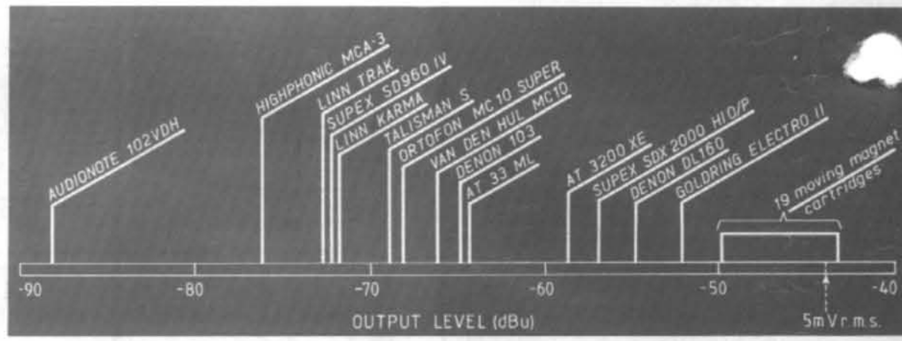

Fig. 1. Output levels of representative moving-coil cartridges plotted on a scale of decibels relative to 0.775V (1mW in 600 ohms), with the outputs of a number of moving-magnet cartridges as a comparison.

Traditionally, moving-coil cartridges were matched to moving-magnet inputs by special transformers, which give "free gain" – in a sense – and are capable of a good noise performance if the windings are carefully designed for very low series resistance. However, the inescapable problems of low-frequency distortion, high-frequency transient overshoots and the need for obsessive screening to avoid 50Hz mains pickup render them unattractive and expensive.

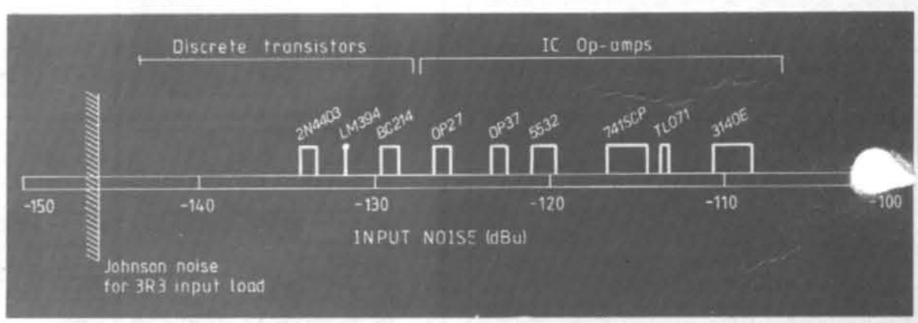

Fig. 2. Discrete transistors still, in the main, provide a better noise performance than op-amps at low source resistances, as shown here for five examples of each type.

The requirements for a high-quality m.c. head-amplifier are as follows. The overwhelming need is for a good noise performance, as the signals generated by m.c. cartridges are, in general, very low. However, this sensitivity is also much more variable than that of m.m. cartridges, where one can take a nominal output of 5mVr.m.s. for 5cm/s at 1kHz as being virtually standard. In contrast, a survey of the available m.c. cartridges gave a range from 2.35mV (Dynavector DV10X IV) to 0.03mV (Audionote 102vdH), though these are both exceptional and the great majority fell between 0.2mV and 0.4mV. Figure 1 shows the output levels of a number of current m.c. cartridges plotted on a scale of dBu (i.e. referred to 775mV) and m.m. cartridges are included on the right for comparison. It is notable how these bunch together in a range of less than 7dB,

A representative m.c. cartridge used both as a basis for design, and for testing, is the Ortofon MC10 Super, which has an output of 0.3mV for 5cm/s, and an internal resistance of 3 ohms. There is general agreement that this is a good-sounding component.

As detailed above, there is a need for easily variable gain over a wide range. This can be quite adequately provided in switched steps, avoiding the problems of uncertain stereo balance on dual potentiometers. From the above output figures, a gain range of 6dB to 46dB appears necessary to cater for all possible cartridges. It would seem, at the low-gain end, that the amplifier is virtually redundant, and so a minimum gain of 20dB was chosen.

Moving-coil cartridges are very tolerant of the loading they see at an amplifier's input, as a result of their own very low internal impedance. For example, Ortofon, who might be reckoned to know a thing or two about m.c. cartridges, simply state that the recommended load for most of their wide range of cartridges is "greater than 10 ohms". Nonetheless, since experimenting with cartridge loading is a harmless enough pastime, provision for changing the input loading resistor over a wide range has been made in this design.

The preamplifier should have the ability to drive a normal m.m. cartridge input at sufficient level to ensure that the head amplifier does not limit the disc headroom. Any figure here over about 300mVr.m.s. should be satisfactory. A less obvious point is that the input impedance, apart from the nominal 47k resistive component, usually includes a fair amount of capacitance, either to adjust cartridge frequency response or to exclude r.f. This can cause head-amplifier instability unless it is dealt with.

Finally, a head amplifier should meet the usual requirements for frequency response, crosstalk, and linearity. Capacitive crosstalk is usually not a problem, due to the very low impedances involved, but for the same reason, linearity can present problems despite the low signal levels.

DESIGN PROBLEMS

The theoretical noise characteristics of amplifiers have been dealt with very competently in other articles[2], and there is no need to repeat the various mathematical derivations here. The designer's options are usually limited to choosing a suitable input device, operating it at roughly the right current, (not usually critical due to the flat bottoms of the noise curves) and then making sure that the surrounding circuitry doesn't mess things up too much. M.c. head amplifiers are almost always built around discrete devices, with or without the addition of an accompanying op-amp (for an [illegible]tion see Ref. 3.). Figure 2 shows the reason why: when source resistances are low (say below 1k) even advanced op-amps are easily out-performed by discrete devices, due to the inevitable compromises in i.c. fabrication. The values of equivalent input noise (e.i.n.) in Fig.2 were taken from five samples of each device, using a source resistance of 3R3, and the general circuit configuration in Fig.3. The rather non-standard measurement bandwidth is due to the use of the internal filters on a Sound Technology measuring system; adding a third-order 20 kHz active filter at the ST input would be very difficult, as the levels of noise being measured are so low. To convert to 20 kHz upper bandwidth limit, subtract 1.5dB. One of the prerequisites for good performance in this role is a low value for R_b, and this has led to a fine miscellany of devices being applied to a job they were never intended for: medium power devices, print-hammer drivers (a lot of transistors seem to have been [illegible]ed as print-hammer drivers) and so on.

Apart from careful device selection, the other classical way of reducing noise with low source impedances is to use multiple devices. The assumption here is that m.c. amplifier noise will swamp the miniscule Johnson noise inherent in the source (this is usually all too true) and therefore, if two input devices have their outputs summed, the signals will simply add, giving a 6dB gain, while the two uncorrelated device noise contributions will partially cancel, giving only 3dB.

Thus, there is a theoretical gain of 3dB in noise performance every time the number of input devices is doubled. There are, of course, clear economic limits to the amount of doubling you can go in for; eight parallel devices is the most that I have seen. It also seems difficult in practice to get the full theoretical benefit.

M.c. head-amplifiers in use today can be roughly divided into three common topologies, as shown in Fig.4. That shown in 4(a) relies on a single device with low R_b, and the combination of limited open-loop gain and the heavy loading of the low-impedance of the feedback network on the final transistor means that both linearity and maximum output level tend to be uninspiring. Given the technical resources that electronics can deploy, there seems no need to ask the paying customers to put up with any measurable distortion at all. An amplifier of this type is analysed in Ref.4.

Figure 4(b) shows the classic multiple-parallel-transistor configuration; the amplifier block A is traditionally one or two discrete devices, that usually have difficulty in driving the low-impedance feedback network. Effort is usually expended in ensuring proper current-sharing between the input devices.

This can be done by adding small emitter resistors to swamp V_{be} variations, but these will effectively appear in series with the source resistance, and compromise the noise performance unless they are individually decoupled with a row of very large electrolytics. Alternatively, each transistor can be given its own d.c. feedback loop to set up its collector current, but this tends to be even more prodigal of components. Having said this, experiment proved that the problem of current-sharing was not as serious as conventional wisdom holds; this is explained below. For examples of circuitry see Ref.5.

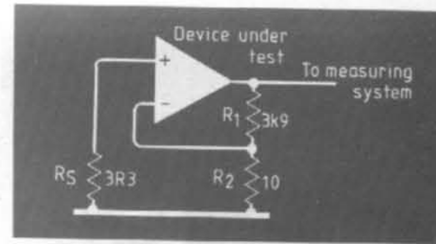

Fig. 3. Circuit used to obtain the measurements shown in Fig.2.

Figure 4(c) shows the series-pair scheme. This simple arrangement allows two input devices to give the normal 3dB noise improvement without current-sharing problems as substantially the same collector current goes through each device. The collector signal currents are summed in R_c, which must be reasonably low in value to absorb any current imbalance. This configuration has its adherents but it also has its difficulties, such as indifferent linearity.

It was therefore originally decided to base the design presented here on a single well-chosen device, with the spadework of providing open-loop gain and output drive capability left to an op-amp. This leads to the configuration in Fig.4(d), which gives excellent linearity, and less than 0.002% t.h.d. at

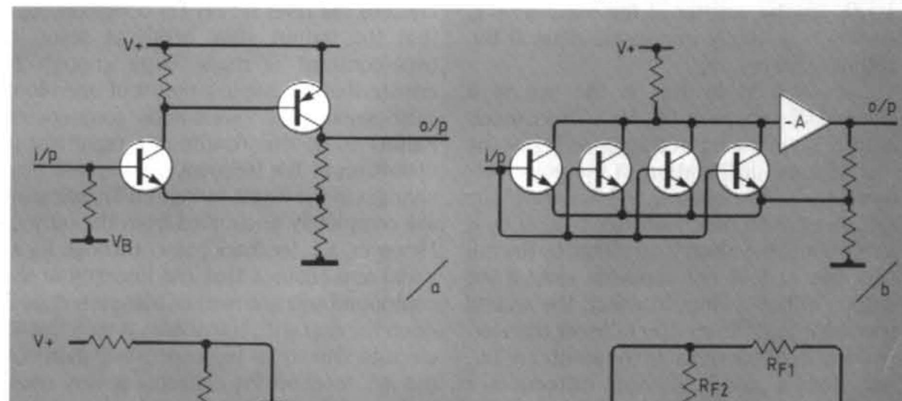

Fig. 4. Some head-amplifier configurations. A fairly low open-loop gain in the circuit at (a) results in poor linearity. At (b), the gain is provided by multiple transistors, which theoretically gives an improvement of 3dB in noise performance for twice the number of transistors, but can also present current-sharing problems. The arrangement at (c) provides the 3dB improvement without current sharing: linearity is not of the highest order. Circuit (d) uses one input device, the gain being provided by an ip-amp: the necessity for Cf presents problems, which are overcome in the (e) configuration at the expense of a lowered noise performance.