

Ceramic Pickup Equalization

1—Myths against maths and measurements

by B. J. C. Burrows, B.Sc.

Almost every human endeavour accumulates a fund of information, fundamental understanding, rule-of-thumb methods, folklore and mythology. Sound reproduction has its share of all these. In particular, items like pickups and loudspeakers have a somewhat higher proportion of mythology than others.

There is one aspect of pickup operation which has more than its share of myths, but which allows an objective analysis. This is the question of the influence of the pre-amplifier input loading on magnetic and, more especially, ceramic pickups. A thorough reading of published reports, papers, books and manufacturers' operating instructions reveals a wide range of opinion. Many sources assert that the electrical loading on the pickup caused by the pre-amplifier input impedance affects the mechanical operation of the pickup by damping mechanical resonances! Thus:

'It is advantageous in all cases to apply negative feedback* to the pickup, whether electromagnetic or crystal. This may be accomplished in any conventional manner and the feedback reduces non linear distortion and the effect of mechanical resonances!'

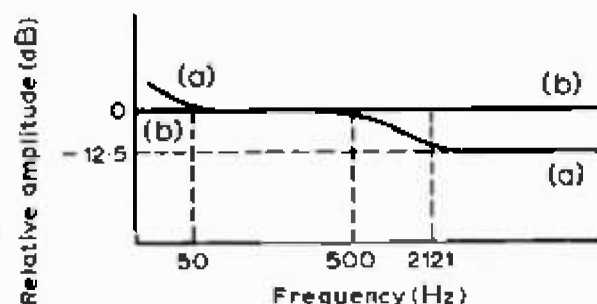


Fig. 1. Recording correction curves. (a) R.I.A.A. (b) constant amplitude.

'Now because of the (capacitive) nature of crystal and ceramic pickups it is only necessary to connect them into a sufficiently low electrical resistance for their inbuilt correction to be almost nullified!'

The inbuilt correction referred to is incorporated into most ceramic pickups

* The negative feedback referred to here has the effect of providing a low impedance load for the crystal of approximately $1.5k\Omega$ in series with $0.5\mu F$.

to compensate for the difference between the real R.I.A.A. recording characteristic, Fig. 1 (a), and a true constant amplitude characteristic (b). This is achieved by allowing a broad mechanical resonance to occur in the high frequencies. The degree of equalization achieved in practice is quite good. Fig. 2 shows the output from a Sonotone 9TAHC when playing an R.I.A.A. test record.

Certain other myths on pickup operation concern the use of ceramic pickups with fully R.I.A.A. corrected magnetic input sockets on pre-amplifiers. Information on the Leak Varislope II stereo pre-amplifier includes 'For optimum results no additional resistors are required. The input loading ($70-100k\Omega$) on the pre-amplifier forces this type of pickup to give approximately the same frequency characteristic as moving coil and variable reluctance pickups . . .'. Apart from one pickup only, the Connoisseur SCU1, this recommendation is totally wrong on two major factors! The Leak information, to compound its misdemeanour, goes on to say 'If more bass is desired you should insert a $100k\Omega$ resistor in series with each live pickup input lead'. If for more bass one substitutes *treble cut* starting at an even lower frequency than normally this would be more accurate!

More recently, fashion has veered away from low impedance loading, bringing forth a welter of designs of f.e.t. pre-amps and other high input impedance circuits and converters, presumably because of dissatisfaction with the results of following advice such as that quoted above. In fact, now there are signs of a return to the belief that ceramic pickups (stereo and mono) must be operated into a high impedance for best results. Indeed, two recently published pre-amp designs 4, 5 in *Wireless World* tend to perpetuate the idea by providing an input impedance of $2-5M\Omega$ for the ceramic pickup input (thus rigidly following the manufacturer's traditional recommendation).

Pickup design and operating recommendations remain almost unchanged from valve amplifier days when high input impedances were normally available. This has probably led to the belief that high impedance loading is necessary for best operation of the pickup because the manufacturers recommend it! Although

this myth, too, is widespread, there nonetheless appears to be no truth in it and I think, along with the others, it can be classified as an 'old wives' tale'.

I should hasten to add that I am not saying that loading a pickup with a high impedance is bad or wrong, but there are disadvantages with high impedance loading. References 4 and 5 are the best original transistor pre-amp circuits as yet published in *Wireless World* for ceramic pickups†, but see also reference 3 for modifications to the Dinsdale Mk. I and Mk. II pre-amplifiers.

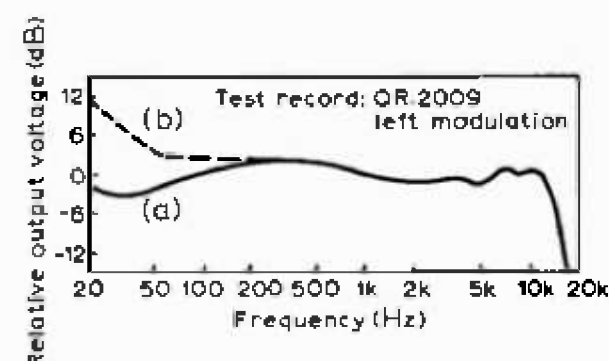


Fig. 2. Sonotone 9TAHC frequency response curve. (a) voltage across $2M\Omega$ load shunted by $100pF$. (b) internal pickup e.m.f. Curve (a) can be derived from (b) by calculating the bass cut due to the $2M\Omega$ load—which gives 3dB down at 88Hz.

It seems rather a pity to spoil the fun of the advocates of a host of 'bolt-on' goodies (f.e.t. pre-amps, impedance converters, etc., etc.) which claim to provide the necessary high-Z load for best performance but the 'old wives' tale' appears to have no foundation. This is demonstrably true by maths, measurement and listening tests. In the past it is probable that many designers have erred on the safe side in their design philosophy, preferring the devil they know ($R_{load} > 2M\Omega$) to the devil they don't know (equalization problems with $R_{load} \ll 2M\Omega$). Since conventional (and cheap) bipolar transistors are most conveniently used in low input impedance circuits this seems a good time to try to form an understanding

† The design of the rumble filter in both refs. 4 and 5 does not allow for the effect of the pickup capacitance, but see letter in June 1971 issue of *Wireless World* for suggested modifications.

of the effects of $R_{load} \approx 10k\Omega$ on ceramic pickups.

The existing mythology can be summarized in six main points. Low impedance loading is variously said to:

- (1) affect the mechanical damping and transient response of the pickup;
- (2) affect the built-in mechanical equalization which depends on broad mechanical resonances;
- (3) reduce the distortion;
- (4) affect the separation (i.e. crosstalk);
- (5) provide correct equalization into a magnetic pickup input with so-called 'velocity loading'; and
- (6) alter the needle tip mechanical impedance.

What is required then is an understanding of the interaction between the electrical and mechanical parts of the pickup.

A pickup is not a simple device mechanically⁶; whereas the equivalent circuit of the electrical part is simple—or is it? It is generally shown as in Fig. 3.

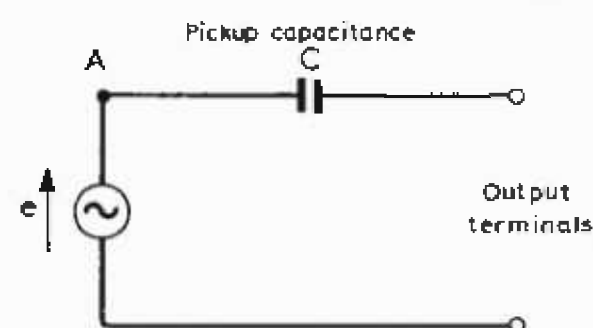


Fig. 3. Equivalent circuit of one channel of a stereo ceramic pickup.

This is an *equivalent* circuit. In the real thing C is the capacitance of the ceramic bimorph within which e , the pickup e.m.f., is generated. There is no physical access to point A in the actual pickup. The pickup capacitance, C , can be measured with a conventional a.c. bridge. Typical values of C and e for many stereo pickups are shown in Table 1.

The pickup e.m.f. is measured by connecting a very high input impedance voltmeter to the pickup terminals when tracking a known groove modulation. Fig. 2 shows the variation of e.m.f. against frequency for a mechanically compensated pickup (9TAHC).

So our simple equivalent circuit consists of just two elements: a voltage source and a series capacitance. But, e is produced by mechanical motion of the ceramic element, and is thus inextricably tied up with the mechanical constants—damping,

TABLE 1

Pickup type	Capacitance††	Output†
Acos GP94/1	900pF	100mV
BSR C1	—	110mV
Decca Daram	600pF	30mV
Garrard KS40A	600pF	200mV
Goldring CS90	900pF	50mV
Goldring CS91E	900pF	20mV
Sonotone 9TAHC	800pF	55mV
Connoisseur SCU1*	200pF	150mV

†at 1cm/sec at 1kHz, r.m.s. into $R_{load} > 1M$

*no mechanical compensation in this pickup.

††for each channel

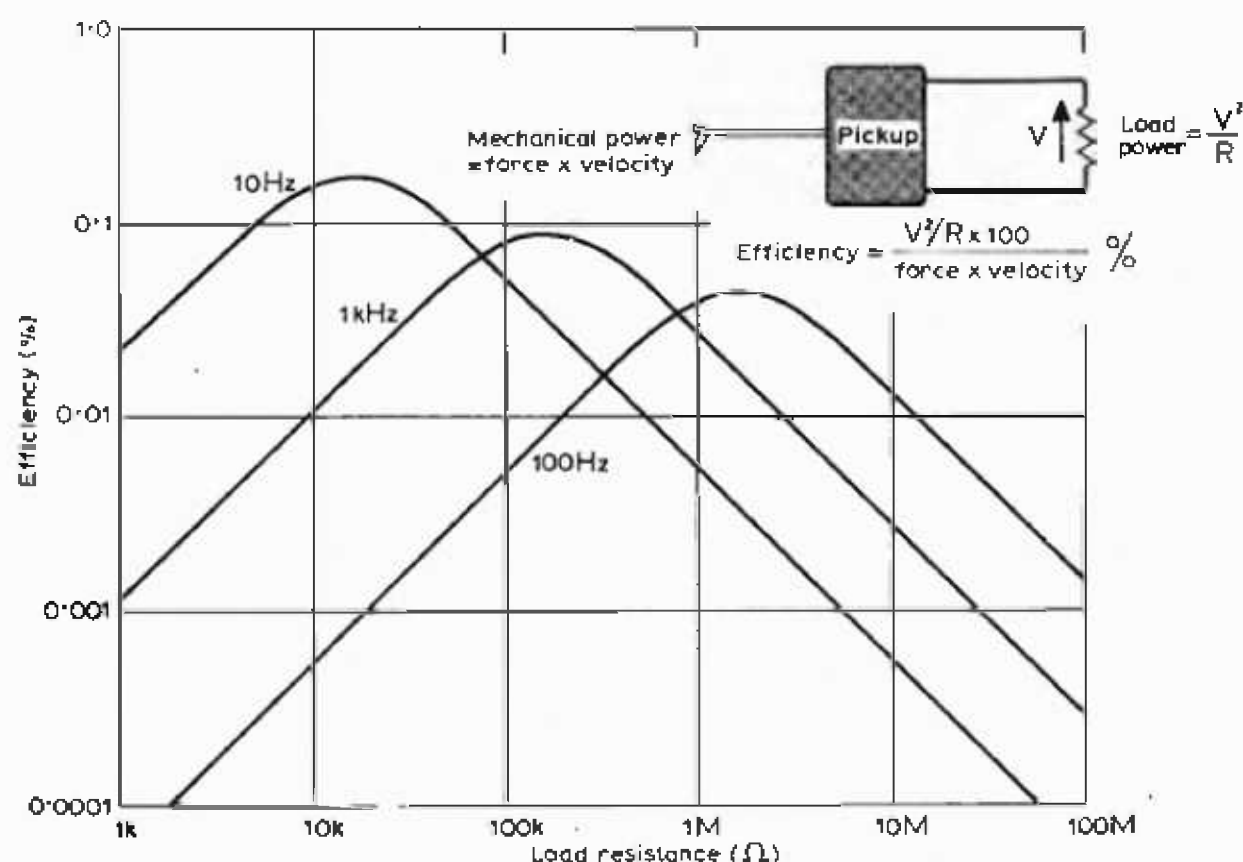


Fig. 4. Power conversion efficiency of a stereo ceramic pickup (9TAHC).

resonances, etc. To understand the six points mentioned above, what we need to discover is whether the electrical load across the output terminals in any way affects these mechanical constants, thus altering e . To be more specific.

- (a) are e and C independent of loading?
- (b) is the needle tip impedance independent of load?

Should e be affected by load this would imply that a much more complicated equivalent circuit is required involving both the mechanical and electrical equivalent circuits and the degree of coupling between them.

Pickup efficiency

Although it is plausible that the electrical load might affect mechanical resonances, it depends on the magnitude of the effect. A calculation of the efficiency would give a good clue to the likelihood of appreciable coupling within the pickup.

For a good ceramic stereo pickup*, at 1kHz with a fully modulated groove, 3g playing weight is needed.

Thus input power to pickup =

$$\frac{20 \times 3 \times 981}{10^7 \times \sqrt{2}} \text{ J/s} = 4.2 \text{ mW}$$

Its e.m.f. e is 1.1V r.m.s. in series with 800pF, and taking a load R of 160Ω, power into load

$$= \frac{e^2 R}{X_C^2 + R^2} = 3.8 \mu \text{ W}$$

Therefore transducer efficiency is 0.091%. That is, less than 1/1000 part of the input power appears in the load. Higher and lower values of R give an even lower efficiency than 0.091%. Fig. 4 plots the variation of efficiency for three frequencies over a wide range of load. Even at 10kHz with the optimum load the peak efficiency is merely 0.18%, i.e. less than 1/500 of the input power.

This is an important result since it shows

*Calculation based on 9TAHC.

that ceramic pickups are inefficient devices when looked at from the energy conversion point of view. So also are magnetic pickups†, most microphones and a host of other transducers. With such a low overall efficiency is it reasonable to think that the mechanical damping will be affected by different values of load resistor? Obviously not, since a 1/1000th part represents an insignificantly small proportion of the total absorbed power.

It follows that the voltage generator e in the equivalent circuit depends only on mechanical factors and these are unaffected by electrical loading.

Although e is independent of the load resistance R , the voltage developed across R will depend on the values of R and the pickup capacitance, C , since they form a simple high-pass filter. This effect is simple to calculate and very simple to correct in the pre-amplifier. We may now review the six 'myths' listed above.

- (1) The transient response is unchanged.
- (2) The mechanical equalization is unaffected.
- (3) Distortion is unchanged.
- (4) Separation is unaffected.
- (5) Velocity loading does work with certain special precautions³.
- (6) Needle tip mechanical impedance is unchanged.

To some this may come as a surprise and some readers may find mere calculations unconvincing, and, like the author, prefer a practical demonstration to show that the theoretical model upon which the deductions were based was a valid representation of the real thing.

Measurements were carried out with two different pickups—a Sonotone 9TAHC and a Garrard EV26. The important differences between these pickups are that the 9TAHC has a high capacitance and low

†The efficiency calculation, when performed for moving-magnet variable-reluctance and moving-coil pickups, reveals the same thing—efficiency about 0.01%.

output, but the EV26 has a low capacitance and a high output. The output from the pickup was fed to a microswitch so that it could be switched into an $R_{in} = 10M\Omega$ amplifier of gain -1 or straight into a resistor of $10k\Omega$ as in Fig. 5.

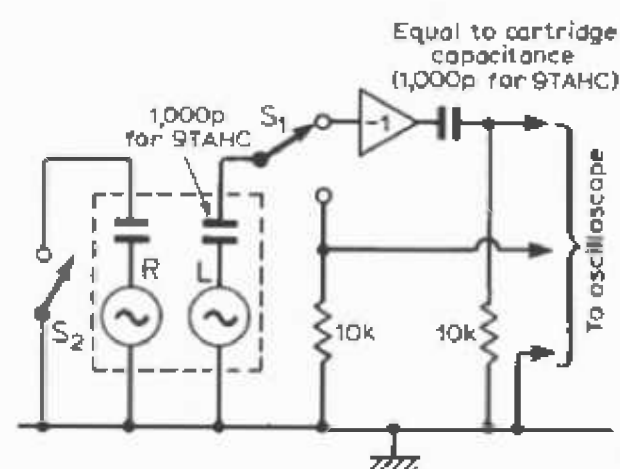


Fig. 5. Test circuit for high/low impedance loads.

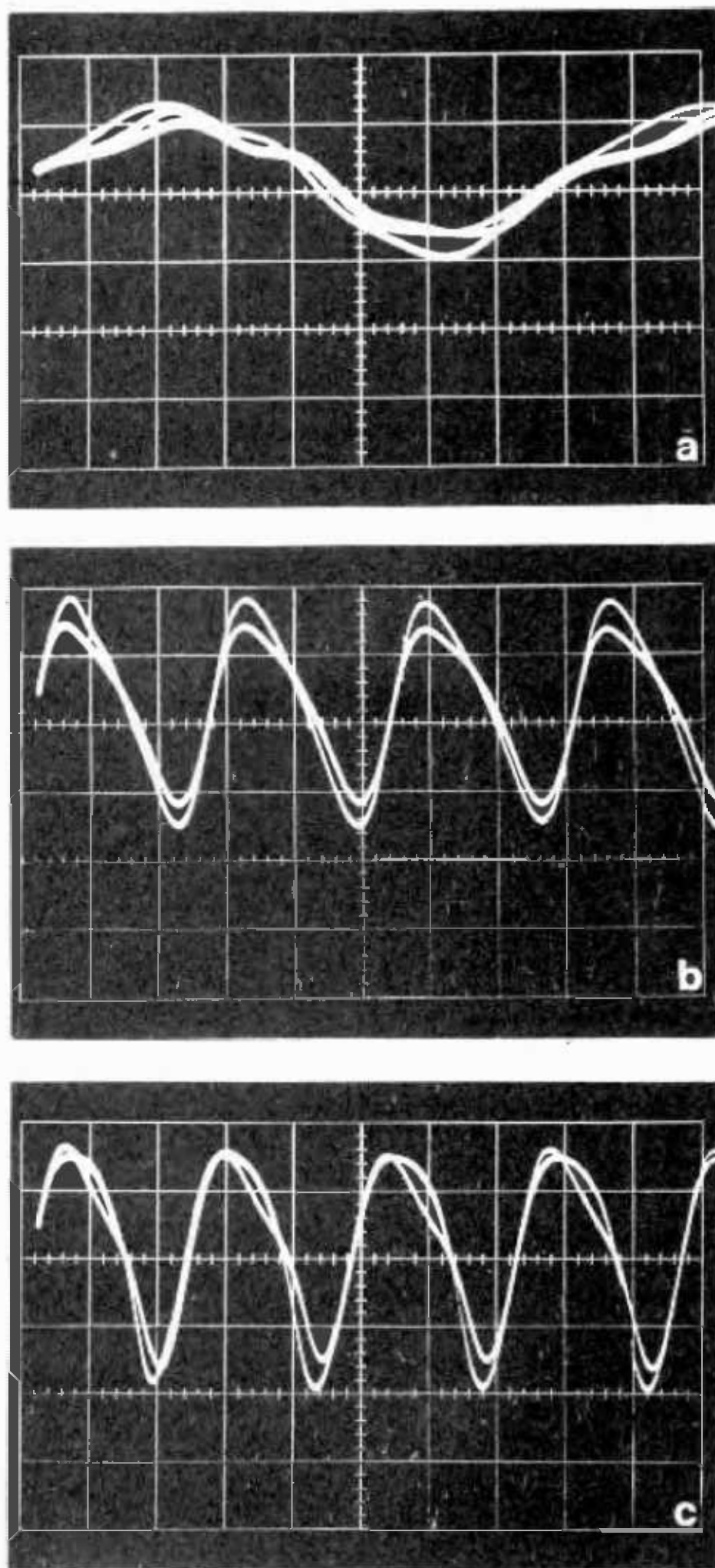
With switch S_1 up, the pickup 'sees' the $10M\Omega$ amplifier input resistance but the amplifier output is fed to the 'scope via a CR circuit of $1000pF$ and $10k\Omega$. With the switch down, the pickup is directly loaded by a $10k\Omega$ resistor. Therefore, in each case the output to the oscilloscope is taken from CR circuits of $f_0 = 16kHz$ but in the first case the transducer is loaded by $10M\Omega$ and the second by $10k\Omega$. This method of comparison eliminated rumble, and accentuated the distortion and resonances because of the $6dB/octave$ rising frequency response up to $16kHz$. An EMI test record TCS101 was used which consists of constant frequency bands of L only and R only at 20 spot frequencies from $30Hz$ to $20kHz$. During the comparison tests, differences were looked for in the output voltage amplitude and waveform throughout the whole range of the audio frequency spectrum down to $60Hz^*$ while S_1 was operated rapidly to change from high- to low-impedance loading.

The first clear fact to emerge from the comparison test was that mechanical equalization was completely unaffected when changing the load, and was also unaffected by making the other channel o.c. or s.c. The second clear fact was that the stylus mass/record compliance resonance dominated the distortion and it also was unaffected by the loading of either the test channel, or o.c. or s.c. on the other channel. Most ceramic pickups have a broad hump in the frequency response at about $8kHz$ caused by the piezoelectric element. On the face of it this resonance would be the most readily affected by electrical damping if electrical damping is significant since it is the actual ceramic element which is resonating thus giving the closest coupling to the output. But this too was unaffected. In fact no change in waveforms at all occurred on switching from high to low load.

This would have been a perfect experi-

*The reactance of the pickup capacitance can no longer be neglected in comparison with $10M\Omega$ at frequencies lower than $60Hz$.

Fig. 6. Superimposed waveforms at $6kHz$ (a), $18kHz$ (b) and $20kHz$ (c) taken at different points on the test record and using the arrangement of Fig. 5.



ment from which beautifully coincident oscillograms should have been produced, but for one thing. The distortion on any one test frequency varied continuously. Oscillograms would have shown this variation, and not the lack of it at the instant of load switching. Fig. 6(a), (b) and (c) show superimposed waveforms at 6, 18 and $20kHz$ respectively taken at different circumferential points on the record. Despite this difficulty, it was feasible by eye to check that no waveform change took place at the instant of load switching. Incidentally, the waveform fluctuations kept in step with the record rotation so they are probably caused by record pressing aberrations,

warps or changes in the hardness of the vinyl.

These measurements have confirmed the calculation. However, a listening test is always the final deciding test with audio problems since subjective assessment often reveals unexpected shortcomings. Comparisons made over a period of many months in day-to-day usage of a record player using alternate high- and low-impedance loading revealed that there is no detectable difference. The amplifier was frequency corrected as given in Fig. 8(b) of ref. 3 when the low-impedance load configuration was used, i.e. bass lift of $6dB/octave$ starting at $500Hz$ was applied

to compensate for the bass cut due to the 200k Ω input resistance.

Reasons for low efficiency

The calculations which produced Fig. 4 use the 'black box' approach, in which the 'innards' of the box (i.e. the pickup) are ignored, and only the input-output characteristics considered. The calculations show that whatever load is used the overall efficiency is very low. This fact allows many important deductions to be made without recourse to detailed knowledge of the contents of the box. For example, the needle tip impedance must be unaffected by electrical load and, with practically all magnetic pickups apart from sum and difference types, all the other factors mentioned earlier are unaffected. A plausible argument that might be raised at this point is that the low overall efficiency with ceramic pickups is caused by very weak coupling between the needle cantilever and the ceramic element, but the element might still be efficiently coupled to the electrical output terminals. But, the pickup series capacitive reactance precludes a high efficiency through limiting the current into the load, except at very high audio frequencies.

At these high frequencies, the ceramic element needs to be well damped to avoid pronounced resonances when the pickup is used with a high load resistance, and indeed the usual construction of ceramic pickups does include one or more damping blocks mounted directly on the bimorph, which makes it well damped, independent of any loading effects. It would be unworkable in any case to expect the electrical load to damp correctly the mechanical parts, such damping being inherently very frequency dependent. Thus, efficiency is low at high frequencies because of damping, and it is low at low frequencies due to the series reactance of the self capacitance. Tuning out the reactance at, say, 100Hz with a high- Q 2500H inductor might raise the efficiency to 4%, but give a very peaky frequency response!

The same type of argument can be used for magnetic pickups although different in detail. A magnetic pickup would be very inefficient at low frequencies owing to the very low e.m.f. and at high frequencies where the efficiency might be high, damping and the rising series reactance ($X_L \propto f$) once more work against this.

The requirement of aperiodic response from a vibrating system is in direct conflict with efficiency, and this is the main feature which automatically precludes high conversion efficiency from a gramophone transducer be it ceramic, moving-coil, variable reluctance or even strain gauge! Thus, interaction between electrical load and mechanical performance is to all intents and purposes negligible.

Choice of pickup operating conditions

Having established that the pickup loading has no influence on distortion, needle impedance, separation etc., the designer is free to choose the simplest and best operating circuit for the ceramic pickup.

High impedance circuits are very popular but there are many difficulties. All the pickups in Table 1 need at least 4M Ω to put the turnover frequency to 50Hz or below and the SCU1* needs 16M Ω ! High input impedance transistor pre-amplifiers are inconvenient, prone to noise and hum pick-up and need f.e.t.s or multi-transistor bootstrapped input stages. No conventional high-impedance circuit deals satisfactorily with the better quality ceramic pickups, particularly the Connoisseur SCU1, because the bass turnover frequency is too high. Also a "tone balance" type of tone control circuit is needed to provide the correct treble lift. Ceramic pickup input stage design will be more fully examined in Part 2 of this article.

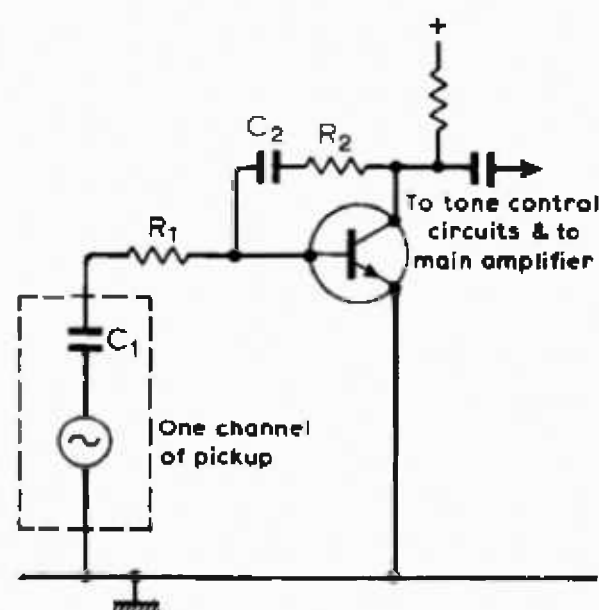


Fig. 7. Basic circuit for equalizing any ceramic pickup.

Low impedance loading suffers from none of these disadvantages. All equalization can be achieved around one transistor (see Fig. 7) and the circuit can be easily adapted for any of the pickups listed in Table 1. The pre-amplifier merely has to provide sufficient bass lift to counteract the bass cut due to the low input impedance, and the overall frequency response can be held flat to well below 50Hz; better than with a 1–2M Ω load in fact! Rumble filtering can be designed into the single stage as well to reduce the very low-frequency noise. Allowance can be made for the absence of mechanical compensation in the Connoisseur SCU1, since tone balance adjustment is a feature of the virtual earth feedback amplifier, and is achieved by varying one component— R_1 .

Conclusions

1. Pickup load impedance has no effect on the in-built mechanical compensation, transient performance, distortion, separation, etc.

2. Much published information on this subject, including amplifier manufacturers'

*Really intended for operation into a 100k Ω load (or less) fully R.I.A.A. magnetically corrected it then gives overall flat response ± 2 dB.

operating instructions, is often ill-informed to the point of absurdity.

3. High-impedance loading does not automatically cure all of the equalization problems particularly the low capacitance types and the SCU1.

4. Decompensation circuits as in ref. 3, (Figs. 12 and 13) are needed when operating most pickups (except SCU1) into magnetically corrected pre-amplifiers.

References

1. 'Radio Designers Handbook'. Ed. Langford-Smith, page 743. Ref. 220 quoted in this paragraph is E. O'Brien, 'Hi-Fidelity Response from Phonograph Records', *Electronics*, March 1949.
2. Walton J. 'Pickups, the key to Hi-Fi', Pitman. Chapter 5, page 56.
3. Burrows, B. J. C. 'Ceramic Pickups and Transistor Pre-amplifiers', *Wireless World*, February 1970.
4. Linsley-Hood J. L. 'Modular Pre-amplifier Design', *Wireless World*, July 1969.
5. Linsley-Hood J. L. 'Simple Audio Pre-amplifier', *Wireless World*, May 1970.
6. Kelly S., 'Stereo Gramophone Pickups', *Wireless World*, December 1969.

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Readers who missed earlier issues of this volume may like to know that copies of the January and March to June issues this year are still available price 27p each, including postage, from the Back Numbers Dept, Dorset House, Stamford Street, London S.E.1. The September and November 1970 issues are also still available.

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