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[1].

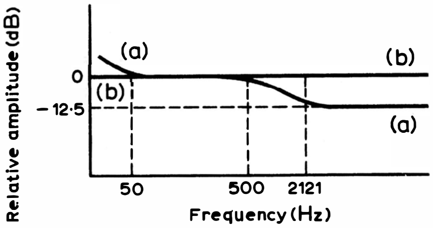


Fig. 1. Recording correction curves. (a) R.I.A.A. (b) constant amplitude.

'Now because of the (capacitative) 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'[2].

The inbuilt correction referred to is incorporated into most ceramic pickups 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 (70-100kΩ) 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 100kΩ 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 2-5MΩ 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.

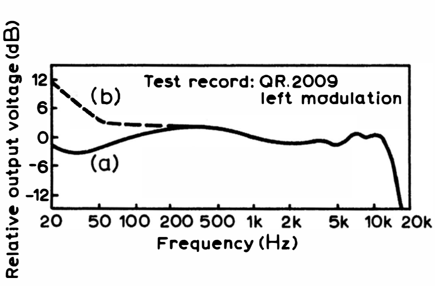


Fig. 2. Sonotone 9TAHC frequency response curve. (a) voltage across 2MΩ load shunted by 100pF. (b) internal pickup e.m.f. Curve (a) can be derived from (b) by calculating the bass cut due to the 2MΩ load—which gives 3dB down at 88Hz.

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 negative feedback referred to here has the effect of providing a low impedance load for the crystal of approximately 1.5kΩ in series with 0.5 μF.

† 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 $R_{load} \approx 10\text{k}\Omega$ 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 mechanically[6]; whereas the equivalent circuit of the electrical part is simple—or is it? It is generally shown as in Fig. 3.

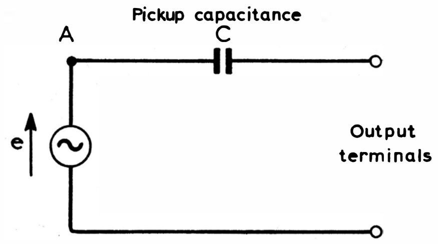


Fig. 3. Equivalent circuit of one channel of a stereo ceramic pickup.

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, 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.

TABLE 1

Pickup type	Capacitance††	Output†
Acos GP94/1	900pF	100mV
BSR C1	—	110mV
Decca Deram	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 $R_{load} > 1\text{M}$.
*no mechanical compensation in this pickup.
††for each channel.

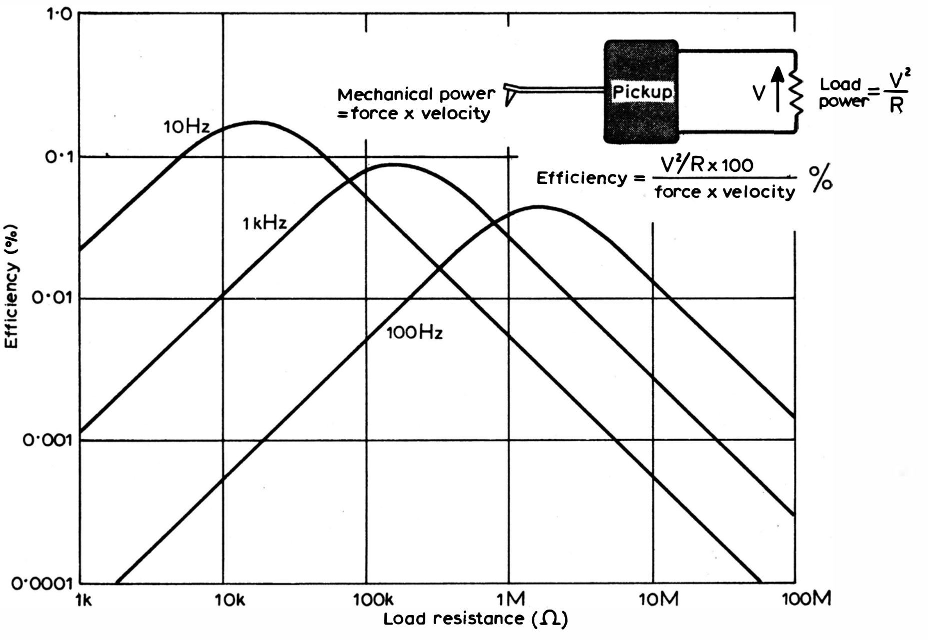


Fig. 4. Power conversion efficiency of a stereo ceramic pickup (9TAHC).

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 =

$$\frac{20\times3\times981}{10^7\times\sqrt{2}}\ \text{J/s}=4.2\text{mW}$$

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

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

Therefore tranducer 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 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 precautions[3].
(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

---

*Calculation based on 9TAHC.

†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 $R_{in} = 10\text{M}\Omega$ amplifier of gain -1 or straight into a resistor of 10kΩ as in Fig. 5.

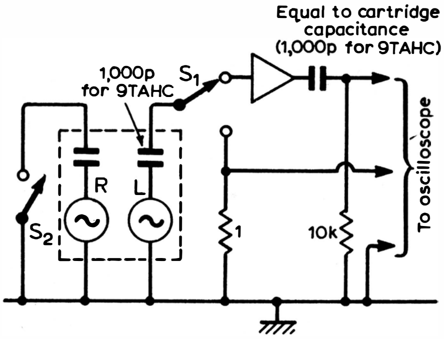


Fig. 5. Test circuit for high/low impedance loads.

With switch S_1 up, the pickup 'sees' the 10MΩ amplifier input resistance but the amplifier output is fed to the 'scope via a *CR* circuit of 1000pF and 10kΩ. With the switch down, the pickup is directly loaded by a 10kΩ resistor. Therefore, in each case the output to the oscilloscope is taken from *CR* circuits of $f_0 = 16$kHz but in the first case the transducer is loaded by 10MΩ and the second by 10kΩ. 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 experiment 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.

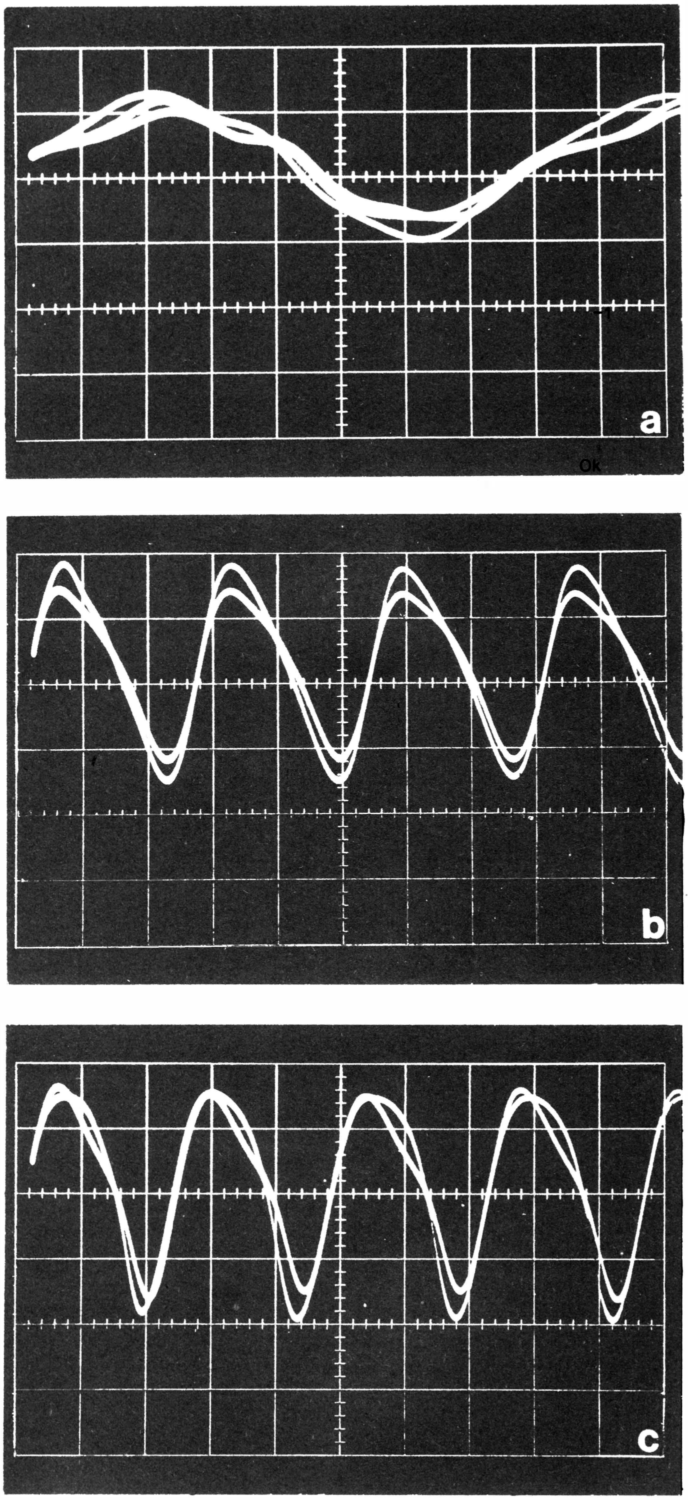


Fig. 6. Superimposed waveforms at 6kHz (a), 18kHz (b) and 20kHz (c) taken at different points on the test record and using the arrangement of Fig. 5.

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

---

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

to compensate for the bass cut due to the 200kΩ 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 4MΩ to put the turnover frequency to 50Hz or below and the SCU1* needs 16MΩ! High input impedance transistor pre-amplifiers are inconvenient, prone to noise and hum pick-up and need f.e.ts 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.

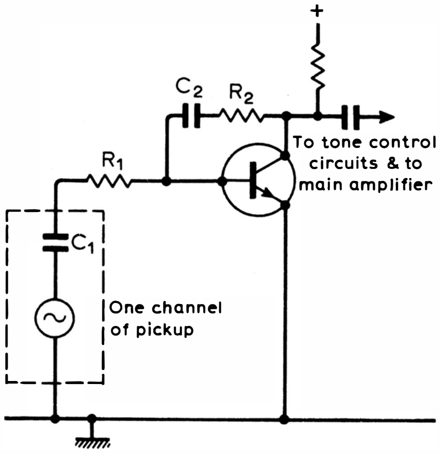


Fig. 7. Basic circuit for equalizing any ceramic pickup.

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 1–2MΩ 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' 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) arc 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. www.keith-snook.info
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.

Back Issues

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.

For the benefit of readers wishing to construct projects described in issues now out of print we can supply sets of pages of the following articles at 12½p each.

May 1970
Low-cost Horn Loudspeaker System *by "Toneburst"*
Simple Audio Pre-amplifier *by J. L. Linsley Hood*
June 1970
Transistor Tester *by D. E. O'N. Waddington*
Crystal Oven and Frequency Standard *by L. Nelson-Jones*
December 1970
High Quality Tape Recorder—2 *by J. R. Stuart*
Simple Class A Amplifier and Modular Pre-amp *by J. L. Linsley-Hood*
February 1971
New Approach to Class B Amplifier Design *by Peter Blomley*
Stereo Decoder using Sampling *by D. E. O'N. Waddington*

---

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

Ceramic Pickup Equalization

2—Practical low-impedance circuits

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

This article gives full circuit details of an economy and a high-performance pre-amplifier which use a new design principle to provide optimum performance from stereo and mono ceramic cartridges.

Many ceramic cartridges are capable of a very high standard of performance—but this is seldom realized in practice. This is because conventional pre-amplifiers cannot cope satisfactorily with the wide range of electrical parameters encountered in different makes of ceramic cartridge.

The two factors that cause the problems in pre-amplifiers for piezo-electric cartridges are (i), self capacitance, and (ii), the degree of built-in mechanical equalization. In conventionally designed circuits using high-value load resistances (1 – 2MΩ), the pickup self-capacitance has a profound effect on low-frequency performance and hence on the rumble performance. Fig. 1 shows curves of output voltage against frequency for two well known pickups when operated into a conventional pre-amplifier with 2MΩ input impedance. These show that the overall frequency response is far from flat.

Typical pickups vary in capacitance from 200pF to greater than 1500pF, and with manufacturing tolerances plus the uncertain nature of the lead capacitance an overall variation of 180pF to > 2000pF is possible. To obtain good l.f. performance with 180pF needs a loading resistance of 18MΩ (not 1 – MΩ as commonly provided). If 18MΩ were used with a pickup of 2000pF the bass turnover frequency would be 4.5Hz! This of course would result in very objectionable rumble and l.f. arm resonance† problems.

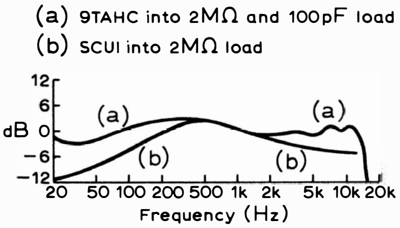


Fig. 1. Voltage/frequency curves of two well-known ceramic cartridges when used with a conventionally-designed pre-amp with R_{in}=2MΩ, and a flat frequency response.

Conventional pre-amplifier designs do not allow for built-in mechanical equalization which varies from one pickup to another, and unfortunately the usual type of tone controls are not suitable for providing the necessary correction.

We can draw up a list of performance characteristics which an ideal pre-amplifier should possess:

(1) l.f. performance independent of cartridge capacitance;

(2) accurate rumble filtering independent of cartridge capacitance;

(3) means of correcting for variability in mechanical equalization (i.e. some form of 'tone balance' control).

(4) ability to cope with pickups of widely differing output voltages.

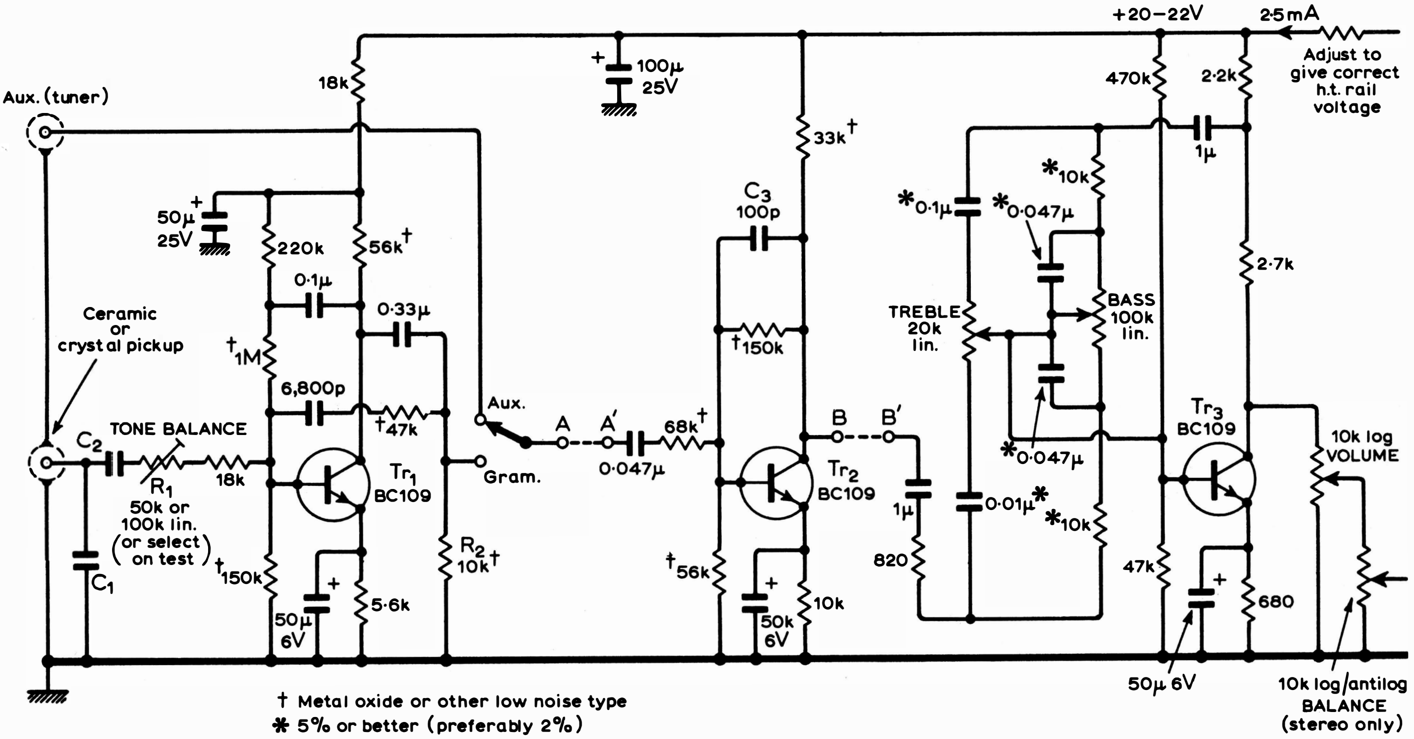
To these may be added: low noise, low distortion, good overload capability, built-in tone controls, etc.

Economy pre-amplifier

The complete circuit of the economy design is given in Fig. 2 for a positive h.t.

---

†See Appendix II.



† Metal oxide or other low noise type
✱ 5% or better (preferably 2%)

Table of values for C_1, C_2 & R_1 in economy circuit.

Cartridge type	C_1	C_2	R_1 (optimum value)	Comment
Decca Deram	3.3nF	0.1μF	18–27kΩ	low output
Goldring CS91E			56kΩ	
Goldring CS90	3.3nF	0.1μF	56kΩ	medium output
Sonotone 9TAHC			22kΩ	
Connoisseur SCU1	3.3nF	0.1μF	0	medium output
B.S.R. SC5M	10nF	6.8nF	22–56kΩ	high output
Acos GP94/1				
Garrard KS40A				

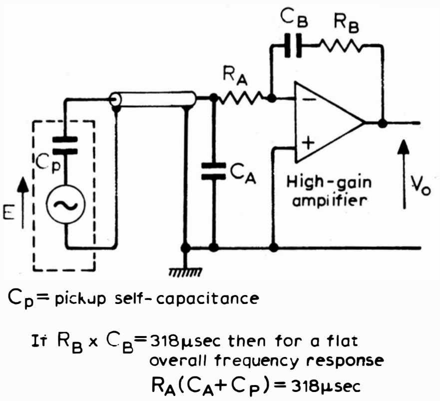


Fig. 3. First-stage design of equalization circuit.

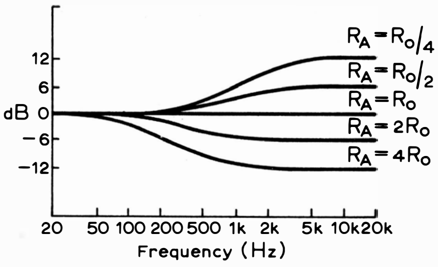
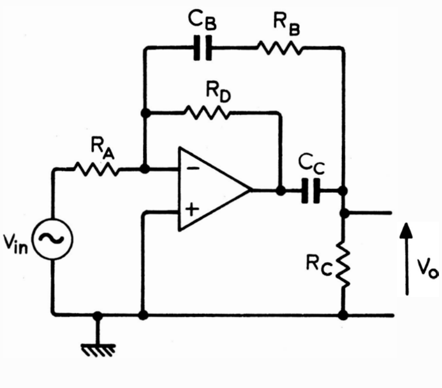


Fig. 4 Operation of tone-balance control, R_A in Fig. 3.



Design formulae for $Q=1$

(1) Choose R_C

(2) Make R_B several times R_C

(3) $C_B = \frac{1}{2\pi f_1 R_B}$

(4) $C_C = \frac{1}{2\pi R_C}\left(\frac{1}{f_0} - \frac{1}{f_1}\right)$

(5) $R_D = R_B\left(\frac{(C_C R_C + C_B R_B)^2}{C_C R_C C_B R_B} - 1\right)$

Fig. 5. Baxandall bass lift-and-cut circuit.

rail system. A negative h.t. rail version is given in Appendix I. For normal use connect *A* to *A′* and *B* to *B′* and use full circuit. For ultra-economy operation with any of the pickups except the Deram or CS91E, the second stage may be omitted by connecting *A* direct to *B′* and omitting the intervening circuitry associated with Tr_2. Thus a very good, yet simple, gramophone amplifier may be built by using only Tr_1 and Tr_3 directly connected into an amplifier with 100mV sensitivity for full output.

Design principles of equalization stage

Last month the merits of the shunt feedback (or virtual earth) amplifier were mentioned as being very suitable for ceramic pickup equalization. Further, it was shown that loading the pickup with a low impedance had no effect on its internal e.m.f. In the present design, then, the effects of the variability in capacitance have been eliminated by swamping the pickup in every case with a shunting capacitor of 3.3nF or more. An input resistor of 75kΩ then gives an input time constant of 318μs (equivalent to 500Hz); to match this, the feedback circuit has a time constant of 318μs also (see Fig. 3); the complete circuit has a *flat* frequency response:

$$\frac{V_O}{E} = \text{constant} = \frac{R_B}{R_A} = \frac{C_P + C_A}{C_B}$$

If any one of the components suffixed *A* or *B* is made variable, a 'tone balance' type of control is achieved in a much simpler manner than circuits described previously[1]. R_A is the best one to vary and provides performance variation as in Fig. 4. The value of R_A to give an overall flat frequency response is termed R_0. In practice only values of R_A between R_0 and $R_0/4$ are needed to fully correct all ceramic pickups for their lack of complete mechanical equalization, e.g. the Sonotone 9TAHC pickup needs $R_A = R_0/1.8$ and the Connoisseur SCUI needs $R_A = R_0/4$.

With an infinite gain amplier in Fig. 3, overall gain is flat down to d.c. theoretically. This is no use in audio work because of rumble and the l.f. arm resonance. Some form of rumble filtering is essential and may be built into the equalization stage by using the circuit due to P. J. Baxandall[2]. The essence of this circuit is in Fig. 5, and its performance in Fig. 6.

Economy pre-amplifier specification

rated output	500mV r.m.s.
distortion (1KHz)	0.1% at maximum recorded level
noise	below audibility at normal listening level
hum	depends on layout and h.t. decoupling
overload capacity	>6dB above maximum recorded level
sensitivity	full output for pickup with 50mVcm/sec
sensitivity is reduced by	raising C_1 and lowering C_2 to keep C_1 $C_2/(C_1=C_1) \approx$ 4000pF
input impedance	not applicable (68kΩ for aux input connected as shown)
disc equalization	in conjunction with the better ceramic pickups can be adjusted to flat ±1.5dB 30Hz—10KHz. Low-frequency performance independent of pick-up capacitance.
rumble filter	18dB/oct, f_0=50Hz independent of pick-up capacitance
low-pass filter	fixed, C_3=100pF gives f_{-3dB}=12KHz Scale C_3 up in proportion for low f_{3dB}
tone controls	h.f. about ±14dB l.f. about ±14dB.
current consumption	≈2.5mA,

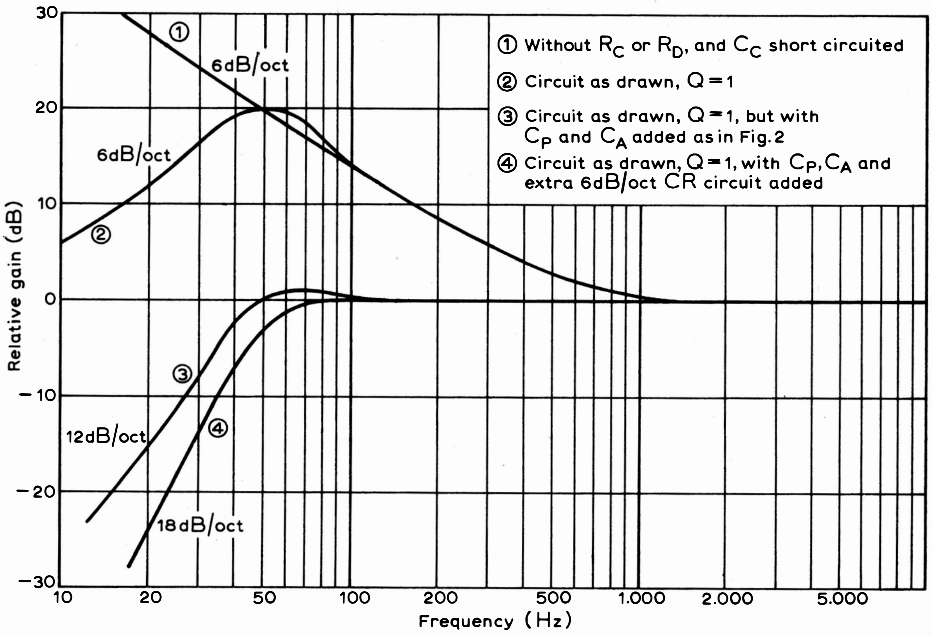


Fig. 6. Performance of circuit of Fig. 5 with f_0=50Hz and f_1=500Hz.

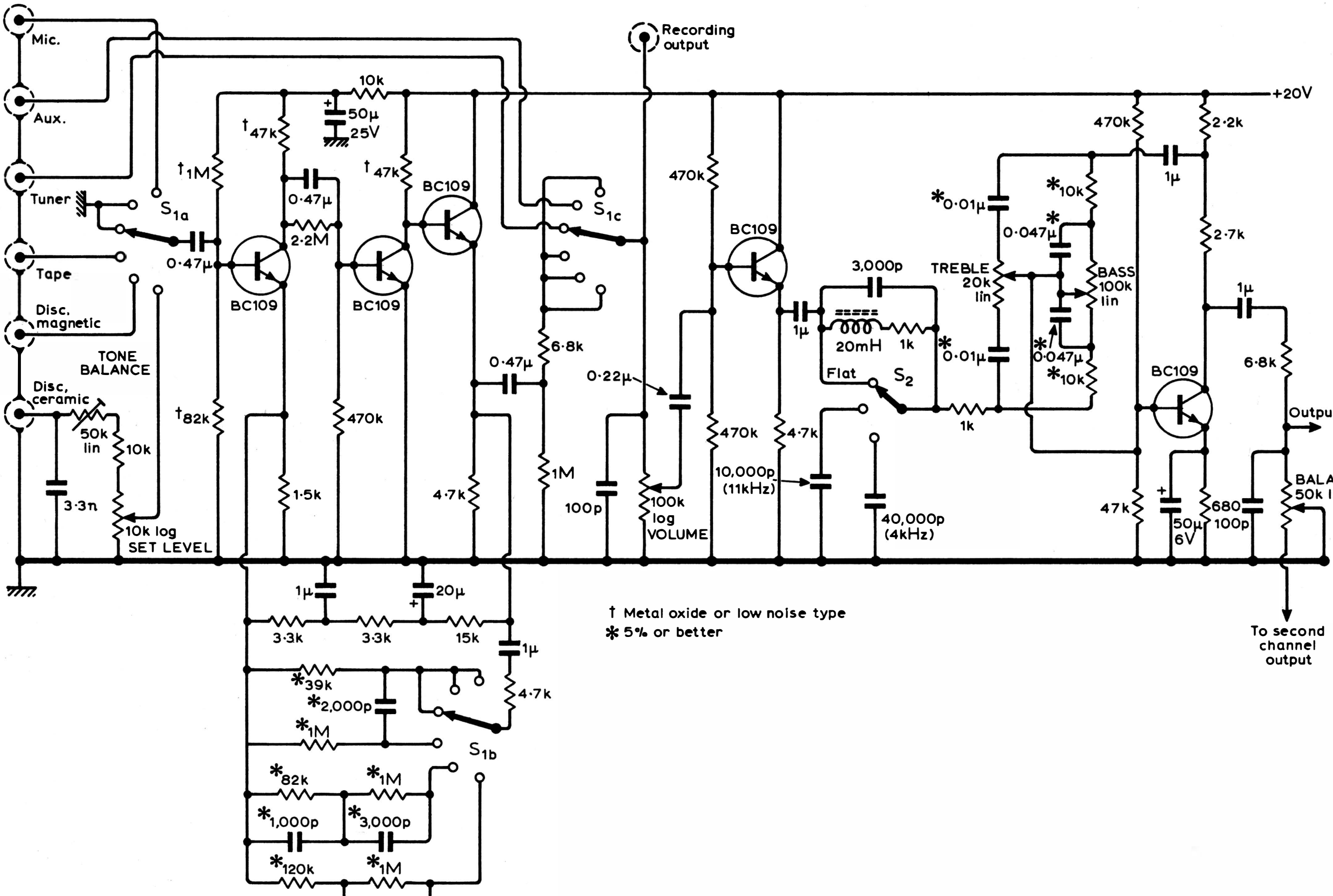


Fig. 7. Complete circuit of one channel of 'Bailey pre-amplifier'. No circuit changes are required for different ceramic pickup cartridges, only adjustment of 'tone balance' and 'set level'.

If a further high-pass RC filter is added,

$$f_0=\frac{1}{2\pi R_C}$$

where a flat response to nearly 50 Hz is achieved with a rapid turnover to a slope of 18dB/octave to attenuate rumble. Finally, with R_A adjustable, the tone balance facility is still retained as with the basic circuit of Fig. 3. It is common to design rumble filters with cut-off frequencies much lower than 50Hz; but, to achieve adequate attenuation at 25Hz—a common frequency of the l.f. arm resonance—a high value of f_0 is required. The actual circuit of Fig. 2 achieves −28dB at 15Hz and −15dB at 25Hz. In practice this is very satisfactory.

The economy-design pre-amplifier closely matches the theoretical performance of Figs. 4 and 6 and provides excellent bass, good balance and excellent freedom from rumble. As shown in the table relating to the main circuit, the only circuit changes needed to accommodate different pickups are for curbing those with a very high output voltage with a capacitive divider. In connection with the table of values given for the input capacitors it is very important to stress that the values given must be used as specified and that the manufacturers' recommendations regarding load impedance and equalization must be totally ignored. This circuit has been specifically designed to take care of all the loading, matching and equalization factors and *no further components are needed.*

High-performance pre-amplifier specification

rated output	500mV r.m.s.
harmonic distortion	0.02% at rated output
noise	−60dB all inputs −80dB for tuner and aux inputs
hum	negligible with good layout
overload capacity	23dB over whole audio range, infinite for tuner and aux
sensitivity	tuner 250mV aux 250mV disc magnetic 3mV disc ceramic 20mV tape 4mV mic 10mV
input impedance	tuner, aux 60-100KΩ disc magnetic 47KΩ disc ceramic frequency dependent tape, mic 47KΩ
disc equalization	magnetic—RIAA to within ± 1dB ceramic—can be adjusted to give flat response ± 1½dB l.f. response independent of cartridge capacitance
tape equalization	7½i.p.s. with R_{FB} = 39KΩ 15i.p.s. with R_{FB} = 18KΩ 3¾i.p.s. with R_{FB} = 82KΩ
rumble filter	modified design giving higher cut off frequency; response at 25Hz is −15dB
low-pass filter	switched, flat or cut off at any frequency from 4 to 11KHz (see Ref. 7)
tone controls	Baxandall type treble ±16dB at extreme bass ±20dB at extreme
current consumption	7mA

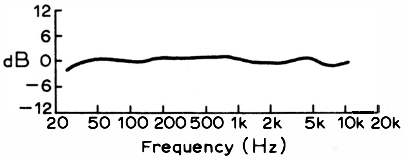
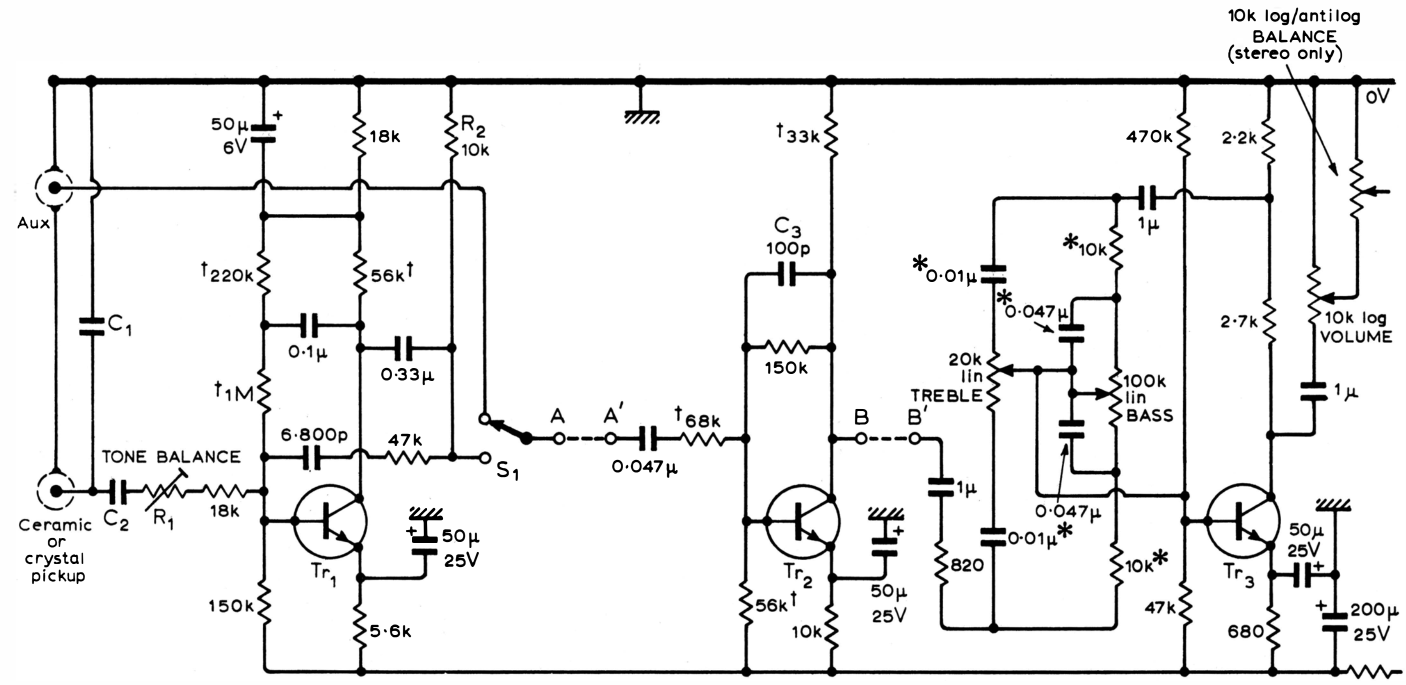


Fig. 8. Measured voltage/frequency curve for a 9TAHC operating into an 'economy design' circuit with $R_A=R_0/1.8$. The curve for the SCU1 would be just as flat, but with $R_4=R_0/4$.

The economy circuit as described fulfils all the design criteria enumerated earlier except for the slight inconvenience of changing two capacitors if pickups of widely differing output voltages are exchanged. The noise performance is very good with all the cartridges listed apart from two (the CS91E and Deram) with which it is satisfactory for everything but the most exacting requirements.

High performance pre-amplifier

This is based on the Bailey[3] design of 1966 but with all the subsequent modifications to improve the filter[4] and tone control[5] circuits, plus the addition of a complete ceramic-pickup equalizing circuit achieving the same performance with ceramic cartridges as the economy pre-amplifier. The complete circuit is given in Fig. 7, which also incorporates one further modification to raise the cut-off frequency of the rumble filter in accordance with the design philosophy discussed in Appendix II. Equalization for magnetic pickups has been retained and is selected by the input selector switch. The 'set level' control needs a mention. To avoid overloading the input stage, adjust the set level control with any particular



† Metal oxide or low noise type
*5% or better

Fig. 9. Economy circuit arranged for negative h.t. rail. For values of C_1, C_2, and R_1, see table earlier.

cartridge to give comfortable listening level with the main volume control at about half of its maximum rotation. This control need be only a preset with screwdriver slot adjustable from the back of the pre-amplifier. The tone balance could be the same, or it could be brought out as a front panel control, or as a skeleton pot mounted internally or even a 'select-on-test' fixed resistor.

On paper, the specification of the high performance pre-amplifier looks most impressive, but subjectively the economy version is very good indeed, and both represent a considerable improvement on conventional designs in that reproducible low-frequency performance, effective rumble filtering independent of pickup capacitance, and a simple means of correcting for partial mechanical equalization have been incorporated. Fig. 8 in conjunction with Fig. 1 gives a comparison of the performance of the Sonotone 9TAHC and Connoisseur SCU1 using conventional loading (2MΩ plus flat amplifier), compared with the measured results on the author's 9TAHC using the economy circuit.

The calculated performance of the Connoisseur SCU1 with $R_A = R_0/4$ is a straight line coincident with the 0dB line on Fig. 8, although in practice there would be a variation of up to ± 1dB about the 0dB line.

Modifications to provide a similar standard of performance with the Dinsdale Mark I and Mark II pre-amplifier circuits were incorporated in a previous article[6].

Appendix I

Alteration of economy circuit for negative h.t. rail operation, e.g. from a germanium-transistor amplifier like the Dinsdale Mark I or II, is basically to return all electrolytic capacitors to the positive potential rail, viz. the earth line (see Fig. 9). There are no modifications to circuit values apart from the voltage rating of the electrolytics.

Appendix II

Arm resonance (l.f.) is the tendency toward damped oscillation at a low frequency and is exhibited by most pickup arms. It has the effect of greatly increasing the cartridge output voltage at or near the resonant frequency. The frequency, f_{lf}, is normally in the range 10-25Hz, so its effect is to greatly increase rumble. The frequency of the oscillation is:

$$f_{lf}=\frac{1}{2\pi\sqrt{MC}}\text{Hz}$$

M is the mass of cartridge plus effective mass of arm measured at cartridge.
C is the compliance of stylus cantilever suspension. With M in grams, C is in cm/dyne.
With modern high compliance cartridges it is desirable to keep M very low—hence lightweight headshells—to make f_{lf} as high as possible. Generally speaking the lower the frequency of resonance the higher the Q, and vice versa. But a higher resonant frequency is more trouble electrically. A low-frequency high-Q resonance causes mechanical difficulties—the pickup tends to leave the record surface when excited. A resonance at 25Hz is acceptable mechanically if the Q is low enough and its electrical effects can be removed with a steep slope filter. Below this resonant frequency the cartridge output voltage falls off very sharply indeed (24dB/octave) thus providing the required severe attenuation of sub-audio frequencies.

With regard to pre-amplifier design, the point to note is that the highest amplitude rumble components will be at, or near, the l.f. arm resonance. A filter in the pre-amplifier should ideally provide 12dB or more of attenuation at 25Hz, yet not interfere with l.f. audio response. A cut off frequency of 50Hz with slope approaching 18dB/octave is a very good compromise since it causes very little error in the R.I.A.A. equalization, yet gives − 15dB at 25Hz and − 25dB at 15Hz.

References

1. Ambler R., 'Tone Balance Control', *Wireless World*, March 1970. pp. 124-6.
Hutchinson P.B., 'Tone Control Circuit', *Wireless World*, November 1970. pp. 538-40.
2. Baxandall P.J., 'Gramophone and Microphone Pre-amplifier', *Wireless World* January 1955. pp. 8-14.
3. Bailey A.R., 'High Performance Transistor Amplifier', *Wireless World*, December 1966. pp. 598-602. www.keith-snook.info
4. Bailey A.R. 'Modified Treble Filter for Bailey Pre-amplifier', *Wireless World*, June 1969. p. 275. www.keith-snook.info
5. Quilter P.M., Letter to the editor, *Wireless World*, April 1970. pp. 172/3.
6. Burrows B.J.C., 'Ceramic Pickups and Transistor Pre-amplifiers', *Wireless World*, February 1970. pp. 56-60.