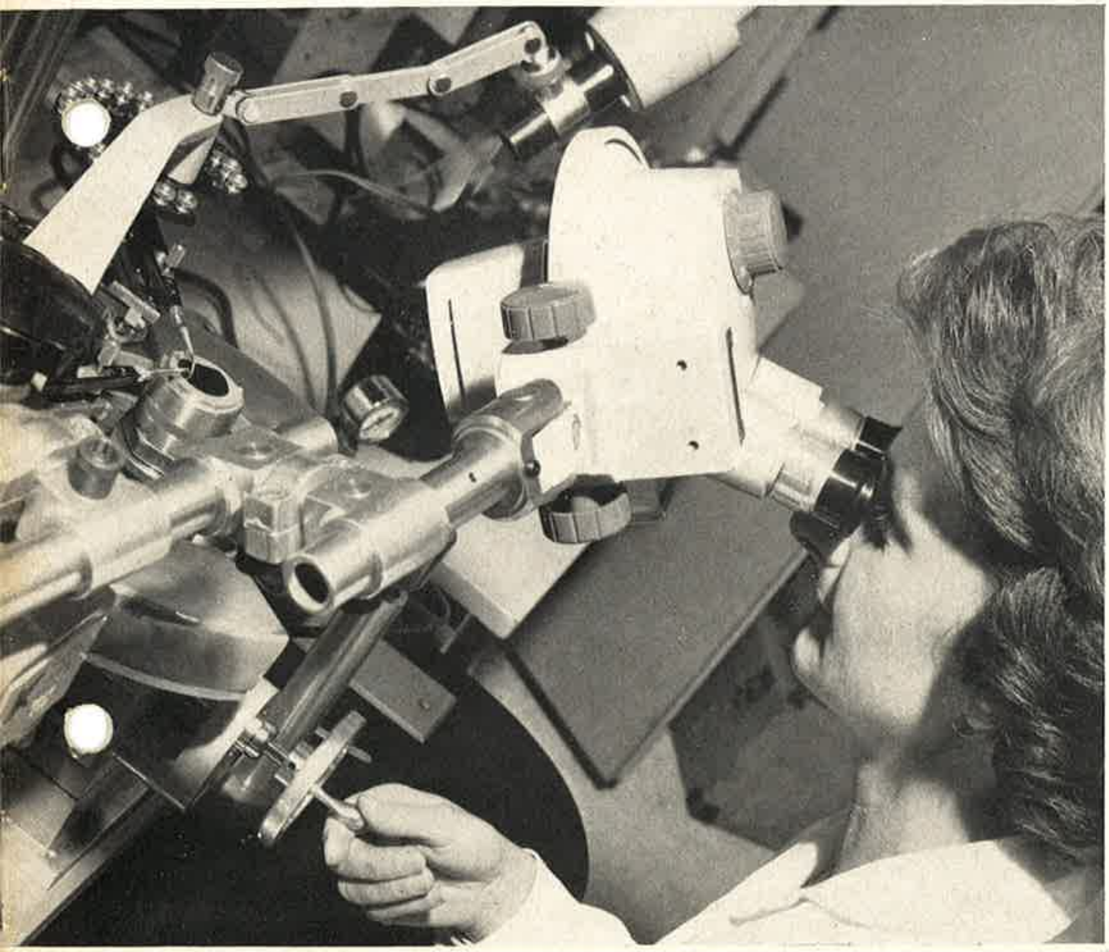
RADIOTRONICS



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COVER:

Precision bonding apparatus which handles wire one tenth the thickness of human hair in the manufacture of transistors at the Amalgamated Wireless Valve Company's plant at Rydalmere, N.S.W.

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Inside The Ceramic Cartridge

The ceramic cartridge is justly popular today, partly because it produces good results in relation to its cost. The inter-related factors of high signal output and the simpler amplifier arrangements necessary have in the past supported in a most adequate way the subject of low cost. Ceramic cartridges as a whole are more robust than electromagnetic types and are therefore less susceptible to damage caused by rough or accidental handling. Most if not all of them contain "built-in" equalization or require a less complex type of equalization involving lower losses. These are of course generalisations, to which valid objection can be made in specific circumstances.

It has been pointed out, for example, that as ceramic cartridges attain better performance figures, their output gets lower and lower. Some consideration had to be given initially to suitable amplifier input circuits using transistors, but this problem now appears to have been solved to the satisfaction of most, and without waiting for devices such as field effect transistors to become more plentiful.

However, the object of this article is not to deal with these matters, but with the cartridge itself, and particularly with considerations involved in the design of ceramic cartridges. The mechanical system of the ceramic cartridge is complex when compared with most magnetic cartridges, and will be discussed at some length as it forms the limiting factor in some aspects of performance.

General Considerations

The complexity of the ceramic cartridge has already been mentioned. Below a frequency f_p, which varies from one design to the other, the mechanical system of the cartridge can be represented by lumped parameters in a network comprising two loops, and the performance of the pickup can be predicted and explained qualitatively and partially quantitatively in terms of the network. At the frequency f_p, which typically occurs in the region 5 to 8 Kc, a parallel resonance occurs in the mechanical system, and the frequency response and the mechanical impedance become large.

Above frequency f_p, the comparatively simple explanation mentioned is not possible. Multiple reasonances can and do occur in the region above f_p, and in fact these resonances are often introduced or used to control the frequency response of the cartridge in the appropriate area. It will be recognised that the use of multiple resonances in this way, whilst it may assist in certain portions of the frequency response, will at the same time make it difficult or impossible to attain a smooth frequency response in the relevant area.

Further parallel resonances can occur above f_p, and at these frequencies the mechanical impedance of the cartridge can again become unduly high. For these reasons mis-tracking and distortion can occur on high frequency peaks even though the low frequency performance of the cartridge, below f_p, may be adequate. Because the channel separation in a stereo cartridge is closely related to mechanical impedance, the separation falls as the impedance rises. These matters are illustrated in the performance curves of the cartridges, as will be shown later in the article.

It is unfortunate that the outstanding advantages of high output voltage and built-in mechanical equalization which characterise the ceramic cartridge are obtained at the expense of other parameters such as the frequency response and the mechanical impedance. Because the ceramic cartridge, like all piezoelectric transducers, "looks" like a voltage generator in series with a small capacitor of perhaps 500 to 1,000 picofarads, depending on the type, it normally needs a very high impedance load to avoid a fall-off in low-frequency response. Alternatively, when working into a load impedance lower than that recommended, a simple form of equalization such as a shunt capacitor may be used, but this involves a loss of output. As a further and very satisfactory alternative that has been evolved for use in transistorized amplifiers, the input stage of the amplifier may be designed to "look" like a capacitor to the cartridge; whilst this also involves an effective loss of signal level, it is a highly satisfactory solution from the point of view of frequency response, and it has been shown ("Radiotronics", Vol. 28 No. 10, October, 1963, "Ceramic Pickup Cartridges", and "Radiotronics", Vol. 28 No. 11, November, 1963, "Crystal Pickup Cartridges") that where the circuit has been carefully designed around a cartridge, the overall response of the cartridge and input circuit can be better than that of the cartridge alone working into the recommended load.

Requirements

Before going further with the discussion, it may be profitable at this stage to remind ourselves of the most important features of the cartridge and the level of performance that may be expected of a ceramic cartridge today. To some extent we will be idealising here, so that the figures quoted must not necessarily be used as a yard-stick against units presently offered.

FREQUENCY RESPONSE. A smooth frequency response throughout the audio frequency range goes without saying. It is generally accepted in the present state of the art that a frequency response from 20 cps to 15 Kc ± 2 db will provide the best quality sound reproduction when the present performance of other units in the reproduction chain is considered.

SENSITIVITY. High sensitivity is undoubtedly desirable as a generalisation. However, except in relation to overall system cost, and provided always that a satisfactory signal level is available to overcome signal/noise problems in the amplifier, this would appear to be one of the less mandatory features.

TRANSFER COEFFICIENT. The cartridge is a transducer which converts mechanical energy imparted to it from the record into electrical energy. This mechanical/electrical energy transfer should be linear to avoid distortion of the signal, and must extend sufficiently far to accommodate the maximum energy input that can be expected from the record.

ELECTRICAL IMPEDANCE. Ideally the electrical impedance should be reasonably low in relation to the input impedances of amplifiers with which the cartridge will be used. There is a number of reasons for this. Because the ceramic cartridge is a capacitive source of voltage, cable and amplifier input capacitances cause a loss of signal level, but this loss is substantially equal at all frequencies of interest. High impedances also increase the problem of noise, and of noise and hum pickup. There is also the sheer difficulty of making amplifiers with input impedances which are very high, although as already indicated, other approaches to this problem are possible.

CROSSTALK. Crosstalk levels have been hotly debated in the past. The issue has been clouded by claims that from a subjective point of view channel separation of as low as 6 db can provide acceptable stereo results, and claims of a similar nature. Such claims probably always have an element of truth in them. In fact it has always been difficult to relate published separation figures with subjective results. This probably arises from the fact that separation is generally quoted at one frequency, which is likely to be 1 Kc or thereabouts. In other cases better information is provided by quoting a minimum separation figure which applies over a specified frequency range; this is of course the way it should be done. Because from a subjective point of view most of the stereo effect will be derived from frequencies above about 300 to 500 cps, and typically in the range up to frequency f_p at which the first parallel resonance occurs, there is little point in having a separation at 1 Kc of -20 db if it has fallen off to virtually nothing somewhere between, say, 5 Kc and 10 Kc. A separation of -20 db throughout the audio frequency

MECHANICAL IMPEDANCE. A low mechanical impedance at the stylus is desirable for all frequencies within the operating range, in order to avoid undue record wear and improper tracking of the stylus. Information on this property is generally conveyed to the user in terms of the cartridge compliances, which should be as high as possible.

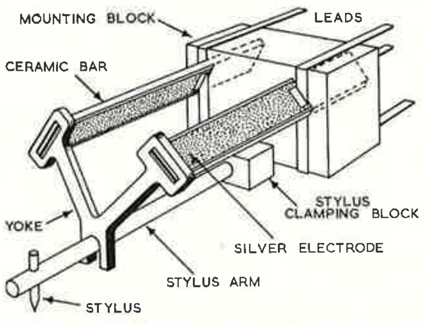


FIG. 1

In addition to the main properties listed above, it is clearly desirable that the cartridge have built-in mechanical equalization if this can be done without unduly compromising other aspects of performance, as this will simplify and cheapen the amplifier. If this is not possible, then it may be possible to provide a cartridge that requires a less complex equalization than the RIAA characteristic used with electromagnetic cartridges. It is clear that in the present state of the art it is not possible to provide a cartridge in which all the properties listed above are optimised, as some of them are mutually incompatible. A compromise has been made in all such cartridges offered today, so that the success and acceptance of the cartridge is largely determined by the way in which the compromise has been made.

Basic Arrangement

Whilst there are a few exceptions, most of the ceramic cartridges available at present have an interior arrangement similar to that shown in Fig. 1. This diagram shows a stereo cartridge having two active elements, each of which consists of a ceramic bar with silvered electrodes on each of two opposing faces. These two active elements are securely clamped at one end in the mounting block shown, which is in turn securely held in the casing of the cartridge when the assembly is complete. The outer end of each bar is left free to move. The bar clamped at one end therefore becomes a clamped-free cantilever beam which may be deflected by a force applied to the free end.

The two bars are set at an angle of 45° to the record surface so that they are mutually at a 90° angle. This is the standard stereo arrangement by which the cartridge extracts the right and left hand information from the grooves on the record. The free ends of the two bars are controlled by a yoke which has an included angle of 90° and forms a coupling between the bars and the stylus arm.

The stylus arm is held at one end in a manner similar to that of the two bars, with the exception that the arm is not necessarily held rigidly, but may be held in a rubber block, for reasons which will appear later. The arm is preferably of tubular aluminium or similar material in order to keep the inertia of the arm to a minimum. The stylus itself is mounted towards the outer end of the stylus arm in any convenient manner.

The yoke which couples the stylus arm to the active bars is a very important component, and a wide variety of materials have been used at one time and another for it. The arms of the yoke are so shaped that they will transmit longitudinal forces to the bars but not transverse forces, at least in theory. The extent to which this is in fact accomplished determines, among other things, the isolation between channels. The coupling to the stylus arm usually consists of a notch fitting over the stylus arm; this provides for easy replacement of the stylus and arm assembly when necessary.

When one of the ceramic bars is bent in a direction normal to the faces carrying the silvered electrodes, a voltage is generated across the electrodes, this voltage forming the output of the cartridge. If now the case is considered where the cartridge is traversing a stereo record and at the time under consideration there is a signal on one stereo channel and none on the other, the stylus will be driven at a 45° angle to the surface of the record. When this motion is translated by the stylus arm and the yoke to the ends of the two ceramic bars, the direction of motion will be such that the yoke applies longitudinal forces to one bar. This bar will then provide an output corresponding to the original modulation of the record groove.

If the design of the cartridge were perfect, and other factors were ideal, the yoke would not apply the same motion as a transverse force to the second bar, nor would there be any longitudinal component of force applied to the second bar, so that no output would be obtained from the bar. This does not happen in practice and it is necessary to compromise between lowest possible cross-talk and other desirable features. It is clear that when the cartridge is used on a stereo record with signal in both channels, each bar produces complex signals containing elements of both channels.

Mechanical Network

Having considered the general requirements and arrangement of the ceramic cartridge, it will now be necessary to consider the comparatively complex mechanical arrangement of the device to see how the idealised requirements can be met, or if they cannot fully be met, to find out why this is so. The electromagnetic cartridge has a simple mechanical system whose network usually consists only of a mass in series with the compliance of the stylus arm and its clamping block. The ceramic cartridge is very different.

In order to analyse the operation of the mechanical system of the ceramic cartridge, a number of assumptions will be made. It will be assumed first of all that only those elements comprising one channel are involved, as shown in Fig. 2A, where a further liberty has been taken by assuming all the elements to be assembled in the plane of the paper. It is further assumed that there is complete isolation between the two channels. In this manner an attempt will be made to analyse the dynamic behaviour of the device.

It will be seen in Fig. 2A that each of the mechanical elements has been labelled as possessing a mass M and a compliance C. The equivalent network of the mechanical system is shown in Fig. 2B. This analogue of the system shown in part A of the figure applies only in the frequency range over which the mechanical elements can be treated as lumped parameters, that is, below f_p, the frequency at which the first parallel resonance occurs. Only the reactive elements have been included in the analogue network shown, as these are the only elements necessary to consider the general aspects of frequency response and mechanical impedance. There will in practice be elements of mechanical resistance in the analogue network; the effect of these elements will be to add some damping and to shift the resonances to slightly lower frequencies.

Many readers will be familiar with analogue networks of the kind shown in Fig. 2B, particularly in connection with loudspeakers and their associated enclosures. For those who are not familiar with such networks it may be advisable to provide some further explanation before going further. Mass is represented in the electrical analogue by inductance and compliance by capacitance, whilst non-reactive components such as damping are represented by

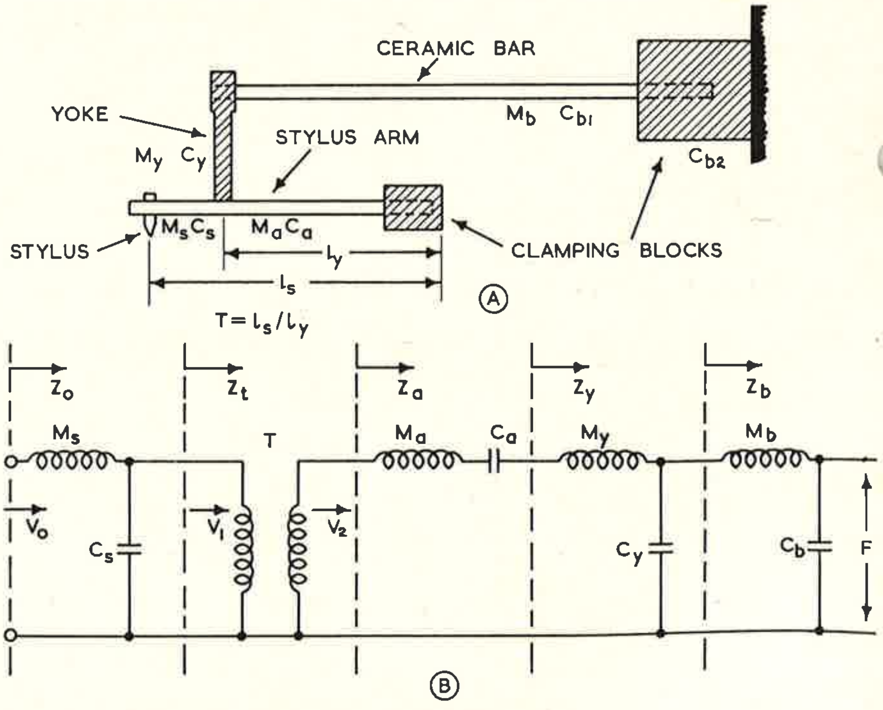


FIG. 2

resistance. Going quickly through the network therefore, stylus mass and compliance are represented by M_s and C_s and include that section of the stylus arm which is between the stylus and the yoke. The mass and compliance of the rest of the stylus arm is represented by M_a and C_a, the properties of the yoke by M_y and C_y, and those of the ceramic bar by M_b and C_b. The compliance C_b has two components C_{b1} and C_{b2}.

The mechanical impedance at the stylus, at the primary of the mechanical transformer T, of the rearward end of the stylus arm, at the driven end of the yoke and at the driven end of the ceramic bar are respectively represented by Z_o, Z_t, Z_a, Z_y and Z_b. The mechanical transformer T will be seen to consist of a second-order lever around the stylus arm, wherein the clamping block is the fulcrum and the yoke is the load. The transformation ratio is determined by the relationship between the total length of the arm and the length between the yoke and the clamped end.

If one assumes that the mechanical impedance of the record groove is infinite, then the stylus will be driven with a constant velocity V_o at all frequencies. The output of the pickup is proportional to the amount of bending, that is the deflection, of the ceramic bar, and this deflection is in turn proportional to the force F acting on the compliance C_{b1} of the bar. Calculation of the force F as a function of the driving velocity V_o at the stylus will produce the output voltage versus frequency response. It is also possible using the network of Fig. 2B to calculate the driving point impedance, i.e., at the stylus, as a function of frequency. For a simple mathematical treatment of the analogue circuit, see the Appendix.

The remarks made earlier regarding the relative complexity of the ceramic cartridge compared with the electromagnetic cartridge will be clear from the analogue network shown. Recalling the earlier statement that the analogue network of Fig. 2B is valid only up to the frequency f_p at which the first parallel resonance occurs, above this frequency the ceramic bars and other individual elements in the system resonate in modes higher than the first order, and can therefore no longer be represented by lumped parameters, but are more accurately represented by mechanical transmission lines.

Those resonances which are due to the higher modes of vibration are used in practice to extend the frequency response of ceramic cartridges. Further, the multiple resonances of this type of pickup are largely responsible for the comparatively high output by which it is characterised, and are used or modified to provide the built-in equalization characteristic so common to pickups of this type. Because of the difficulties presented by the multiple resonances to the accurate calculation prediction of the performance of the device at frequencies above f_p, a considerable amount of empirical knowledge is used in practice in the design of these cartridges. The resonant frequencies and the degree of damping are likely to be adjusted empirically and experimentally to provide a satisfactory frequency response, but often the mechanical driving point impedance is little considered except in relation to the provision of sufficient compliance at the stylus to allow it to stay in the record groove when tracking loud low-frequency passages. This will be reverted to later when dealing with the subject of driving point impedance.

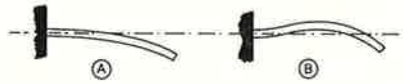


FIG. 3

Higher-order Resonances

Having mentioned the higher-order resonances which determine the performance of the cartridge above the frequency f_p, it will be instructive to see how the more important of these arise. Take for instance the ceramic bar, which is a cantilever loosely clamped at one end and free at the other, or substantially so. The time required for a wave at the fundamental resonant frequency of the bar to travel from one end to the other and back again is equal to one period or cycle of the sinusoidal driving force. The driving point impedance of the bar at this frequency is very low, and the deflection of the bar is monotonic, that is, no maxima or minima are exhibited, as shown in Fig. 3A. This is the first vibration mode of the bar. As the driving frequency is increased a point will be reached at which the two-way journey along the bar takes a time equal to 1.5 times the period of the driving frequency, and the reflected wave then arrives at the driving end 180° out of phase with the driving energy, so that the driving point impedance is very large. As the driving frequency is increased still further, the second mode of vibration of the bar is reached, depicted in Fig. 3B, where the travelling time of the wave down and back along the bar is equal to twice the period of the driving force. At this frequency the driving point impedance will again be very low. Further increases of frequency, then, excite still higher vibration modes in the bar, so that the driving point impedance varies with frequency between high and low values. Compare this action with that of a transmission line of fixed length with varying frequency applied.

The frequencies at which the various modes of vibration of bars occur can be calculated[1]. For a bar rigidly clamped at one end, where the first mode vibration occurs at frequency f_1, then the second mode vibration will occur at $6.27f_1$ and the third mode vibration at $17.56f_1$. For a bar which is not clamped but is provided with a simple support, the second mode vibration will occur at $4.4f_1$ and the third mode vibration at $14.2f_1$. Because the ceramic bar in the pickup is held in a rubber block, with a degree of clamping which varies from one maker to another, the case we have to consider lies somewhere between the two sets of conditions mentioned. For bars of typical size as used today in pickups, f_1 is likely to lie in the range 1.5 to 3.0 Kc. This means that the second mode vibration will fall within the audio frequency range of interest, but the third mode vibration will lie outside the range of interest.

If we look again at Fig. 3B, which depicts the second mode vibration, it will be seen that because of the nature of the deflection curve imposed on the bar at and near this mode, some parts of the bar are being deflected in one direction, which for convenience will be called positive, whilst other parts are being deflected in the opposite direction. Some degree of cancellation will therefore occur as the charges are collected at the electrodes disposed along the sides of the bar, and this will have a pronounced effect on the voltage output/frequency curve.

The second major component of the cartridge in which higher-order resonances will occur is the yoke. Each arm of the yoke is a substantially solid bar which transmits compressional waves from the stylus arm to the ceramic bar. In a bar driven at one end and free at the other, compressional resonances will occur at frequencies for which $l = n\lambda/2$, where l is the length of the bar, λ is the transmitted wavelength and n is the order of the mode. For a bar driven at one end and clamped at the other, the resonances occur at frequencies where $l = (2n-1)\lambda/4$. The condition at the undriven end of the yoke may lie anywhere between these two conditions, depending on the mechanical impedance of the ceramic bar, which will itself vary with frequency as already explained.

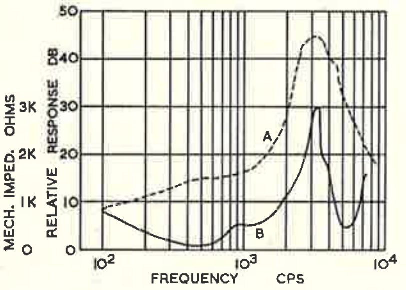


FIG. 4.—Response of an experimental cartridge plotted for constant displacement drive (curve A) and the mechanical impedance (curve B).

The mechanical impedance at the driven end of the yoke is therefore dependent in a complex way upon the interaction between the yoke itself and the ceramic bar. Further difficulties arise from the fact that the cross-section of the yoke arm will inevitably not be uniform over the entire length, and that the performance of a given yoke will depend also on the elastic constants of the material chosen for it. There is some reason to believe that the fundamental resonance of the yoke used in most pickups will lie within the audio frequency range of interest, and that in many cases the second order mode also occurs within that range.

Having dealt with the ceramic bar itself and the yoke, the remaining major component is of course the stylus arm. This arm is similar to that of the ceramic bar, in that it is driven at one end and clamped, at least to some degree, at the other, and the same considerations apply. The fundamental resonance of most stylus arms appears to occur in the mid-audio range of frequencies, that is, probably in the range 1.0 to 3.0 Kc. The low driving point impedance of the pickup at the arm resonance frequency has no appreciable effect on the frequency reponse, but at higher vibrational modes the driving point impedance becomes very large. In high quality pickups care has been taken to put this higher mode resonance above the frequency range of interest, but in poorer grade units this resonance has been observed to occur in the 8 to 15 Kc region, and is in fact often used to augment the response of the pickup in that range.

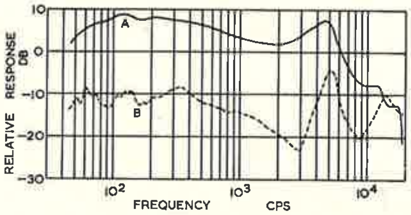


FIG. 5.—Single channel response (curve A) of a typical commercial ceramic cartridge, and the cross-talk response (curve B).

At frequencies slightly below that at which the second mode vibration occurs, the driving point impedance is large and is equivalent to a large mass. The equivalent mass resonates with the compliance of the record in the stylus contact area, and is the phenomenon known as stylus-groove resonance. Where this resonance occurs, and it will occur particularly in those cases mentioned above where there is a poorer unit and the resonance is used to augment the response, irrepairable damage will rapidly be done to the higher frequency components of modulation on the record.

Calculating Frequency Response and Impedance

Enough has been said to show how difficult if not virtually impossible it is to design a cartridge on paper, and so to support the empirical and experimental approach to the subject. Incidentally, although not often admitted, a similar approach is often used in the design of loudspeaker/enclosure assemblies. Further, the dynamic compliances of the various elements are likely to be between 2 and 3 times smaller than the static compliances which are studied on paper. The designer naturally knows the various single factors, say mass of the ceramic bar, and the general effect the variation of each of these factors may be expected to have on the final results.

The single-channel compliance at low frequencies is given by

$$C_1 = \frac{T^2 C_a (C_y + C_b)}{C_a + C_y + C_b}$$

The mechanical impedance of the cartridge becomes very small in the region of that frequency at which a series resonance is present between the compliance C_b of the ceramic arm (see Fig. 2B) and all the masses in series taking into account the transformer ratio. Conversely, in the absence of damping, the mechanical impedance becomes infinite at that frequency for which the yoke compliance C_y and the bar compliance C_b in series form a parallel resonance with the mass of the bar, M_b. The response also becomes

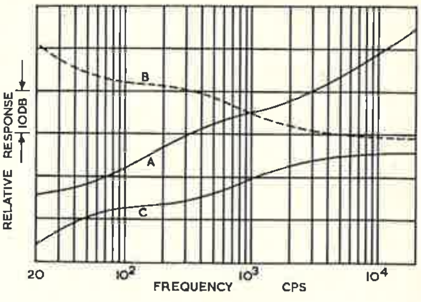


FIG. 6

very large at that frequency. Damping will of course reduce the magnitude of the impedance at this resonance to a finite value, and the mechanical impedance at the stylus may be further reduced at the expense of lower output by increasing the ratio of the mechanical transformer T.

A large mechanical impedance in the middle of the band can lead to improper tracking, increased record wear and increased distortion, and a satisfactory compromise must be found by the designer of the pickup in this area. To illustrate the inter-dependence of mechanical impedance and response, there is shown in Fig. 4 response and mechanical impedance curves for an experimental pickup, plotted on a constant displacement basis. The mechanical impedance of the pickup was a minimum at about 500 cps and reached a maximum at about 3.2 Kc, corresponding to a parallel resonance in the system. The maximum at 3.2 Kc is followed by a second minimum and then a rise again as the system approaches a higher-order resonance of the ceramic bar. As far as the frequency response is concerned, a peak occurred at the frequency of the first parallel resonance followed by a characteristic rapid fall off in response.

Driving Point Impedance

The tracking capability of the pickup depends on the mechanical impedance at the stylus, which is therefore a most important parameter. At low frequencies the driving point impedance is a compliance, and the force exerted in deflecting the stylus by the wall of the record groove must be at least balanced by the vertical tracking force if the stylus is to remain in the groove. This low frequency relationship of the mechanical impedance is well understood, and is adequately catered for in commercial units. The quoted vertical tracking force is likely to be determined largely by those factors involved in the low frequency relationship of the mechanical impedance.

It is possible at the high frequency end of the operating range for a higher order mode of vibration of the stylus arm to produce a high driving point impedance, leading to stylus-groove resonance and record damage as previously mentioned. Because this effect occurs at the stylus itself, it cannot be eliminated by adjusting the ratio of the mechanical transformer, i.e., by adjusting the position of the yoke on the stylus arm.

Improper tracking is a distinct possibility at any frequency at which the driving point impedance becomes large. For example, in the case of the experimental pickup previously mentioned and to which the curves of Fig. 4 apply, the main parallel resonance occurs at about 3.2 Kc, where the mechanical impedance is 3,000 mechanical ohms. With this impedance and with a 3.2 Kc signal recorded at a velocity of 10 cm/sec, a vertical tracking force of 30 grammes would be required to avoid distortion due to improper tracking. But this is an exaggerated example, due to the nature of the experimental unit. In commercial designs the parallel resonance will be more highly damped and the impedance at the stylus will be reduced by positioning the yoke closer to the clamped end of the stylus arm, i.e., increasing the ratio of the mechanical transformer T. However, it is still very difficult to reduce the vertical tracking weight below about 4 grammes for completely satisfactory results. The same remarks apply to resonances at higher frequencies caused by higher modes of vibration, but the damping will be more effective at the higher frequencies and the signals will of necessity be recorded at lower levels due to curvature-overloading considerations.

Because modern ceramic pickups are ideally required to have vertical tracking weights of the order of 2 grammes, the use of parallel mechanical resonances to control or influence the frequency response must be questioned unless means can be found to reduce considerably the driving point impedances, particularly at the higher frequencies so that the specified weight is still adequate to provide proper tracking.

Separation

So far a great deal of discussion has dealt with a single-channel cartridge so as to simplify matters. From a practical point of view, however, the stereo cartridge must now be considered. Vertical and horizontal displacements of the stylus and the forces involved are outlined in the Appendix.

In ceramic stereo cartridges the yoke is shaped to provide a high compliance with respect to transverse deflection of each leg of the yoke, i.e., of each of the two ceramic bars, but to provide a much lower compliance with respect to longitudinal deflections parallel to the axis of the leg. From a practical point of view it is inevitable that some interaction will take place between the two channels, through the yoke. Channel separation is an important feature of the performance of any stereo cartridge. Some cartridges can boast a very high separation of, say, 30 db or more over a limited frequency range, whilst others preserve a lower but reasonably consistent separation over a substantial portion of the operating frequency range. Cases are common in the lower grade units where high separation at comparatively low frequencies is followed by a rapid fall off in separation well within the operating frequency range and even in some cases, due to vagaries in the system, to a negative value of separation. That is, over a portion of the operating frequency range, the output from the "unwanted" channel is higher than that from the "wanted" channel.

Here again, in the matter of separation, the performance feature is very dependent on the mechanical impedance of the system, and is lower where the mechanical impedance is higher. This is illustrated in Fig. 5, which shows the single-channel and separation characteristics of a commercial pickup not on sale in Australia. The output voltage/frequency response of this unit shows the characteristic parallel resonance peak at about 5 Kc, followed by the usual fall-off of output. The separation curve is seen to show a maximum separation at about 3 Kc, where the mechanical impedance is low due to the first-order series resonance of the ceramic bar described earlier. The separation falls to a minimum at about 5 Kc where the parallel resonance causes the mechanical impedance to be high.

The separation has another minimum at about 14 Kc, where a higher order parallel resonance and stylus-groove resonance cause a high mechanical impedance. In this way the performance curves can be interpreted in terms of the design features of the cartridge and in general terms can serve to amplify the assessment of quality that would otherwise be derived from such curves.

The negative separation mentioned above is illustrated where the separation curve crosses the single-channel curve at about 14 Kc, in this case due to buckling in the yoke arm.

The fact that a higher output can under some conditions be obtained from the "unwanted" channel than from the "wanted" channel has led some researchers to examine the matter more thoroughly. For example, it has been shown[2] that the play back of single-channel high frequency signals with a high impedance pickup can lead to permanent wall deformation in the unused channel, the deformation being modulated at the frequency originally modulated in the used channel. This could, at least in theory, result in high frequency recorded sounds, say those of finger cymbals, changing position or apparent position during the life of a record!

Equalization

Recordings are made today using the RIAA recording characteristic shown in curve A of Fig. 6, wherein the vertical co-ordinate represents stylus velocity. If now the same curve were plotted in terms of stylus displacement, then the same equalization takes the form shown in curve B. When a record is played back, an inverse equalization characteristic must be included so as to provide a "flat" overall record/playback frequency response. Ceramic cartridges, like all piezoelectric devices, are responsive to displacement, so that the playback equalization required is the inverse of curve B and not of curve A (the inverse of curve A is of course the playback equalization required with electromagnetic devices), and is shown in curve C.

It is common practice, but by no means applicable in all cases, to design ceramic cartridges so as to provide an output voltage/frequency response at the terminals corresponding to curve C, providing the equalization in the mechanical rather than in the electrical circuit of the system by an adjustment of the frequencies and damping of the mechanical resonances already discussed. The extent to which this is successful is indicated in the response curve of the cartridge. For example, in the case of the commercial cartridge used to provide the curves of Fig. 5, the response curve was taken using a test record made according to the RIAA characteristic, so that the output of the right-hand channel should in theory have a "flat" response throughout the audio frequency range. In fact, ignoring the lower and middle range, which would provide acceptable listening from a subjective point of view, this particular cartridge is very deficient over about 7 to 8 Kc. At the same time it must be realised that the extent to which this deficiency in itself would have an effect on the overall performance of a system will be determined by the quality of the rest of the components in the system. Such a unit of comparatively low cost would probably be used with, say, speakers in a comparable price range, which themselves may not be capable of reproducing the higher registers, in which case the cartridge in question could be held to be acceptable.

Summary

The difficulties which present themselves in controlling the mechanical resonances and damping in such a comparatively complex mechanical device as the ceramic cartridge, will generally mean that the performance standards common in electromagnetic cartridges cannot be met in ceramic units. At the same time, some remarkable advances have been made in recent years which are a tribute to the tenacity of those workers who have produced them.

However, much of the improvement has been made at the expense of output voltage, coupled in some cases with increased recommended load impedances and/or the use of part mechanical and part electrical equalization, all of which are disadvantageous to the ceramic cartridge when compared with electromagnetic devices. Very few ceramic cartridges can track correctly over the complete audio frequency range (20 cps to 15 Kc) with tracking weights as low as 2 grammes, which is generally accepted as being the lowest tracking weight at which record wear can be kept very low.

One must also consider the fact that whilst all the recent improvements in ceramic cartridges have been going on, advances have also been made in the electromagnetic devices, not only in the exceptionally high grade units which do not have a place in this argument, but in lower cost units which have a very high standard of performance in relation to their cost. It is, for example, possible today to buy a magnetic cartridge at something around twice the price of a good ceramic unit where the magnetic unit still performs appreciably better than the ceramic unit, whilst at the same time the difference in amplifier costs between the two types of unit has in some cases vanished. An instance of this state of affairs is shown in a recently published set of preamplifier circuits ("Radiotronics", Vol. 30 No. 7, July, 1965) where the difference in cost between the preamplifier for ceramic cartridge and that for magnetic cartridge was negligible.

References

1 Acoustical Engineering", H. F. Olsen. D. Van Nostrand Co.
2 "Stylus Mass and Distortion", J. Walton, "Wireless World", April, 1963.

APPENDIX

Frequency Response and Driving Point Impedance

Referring to Fig. 2B, the bending compliance of that portion of the stylus arm which is between the stylus and the yoke contact point is designated C_s. This compliance is so small at the frequencies of interest as to be negligible. Calculation of frequency response then becomes simple since

$$V_0 = V_1 = T.V_2$$

where V_0 is the driving velocity at the stylus, V_1 is the velocity at the input to the mechanical transformer, and $T.V_2$ is the velocity at the transformer secondary transformed to the primary. The frequency response will now be given by

$$F = \frac{V_0}{wT[w^2C_bC_yM_b - (C_y + C_b)]}$$

The response has a maximum value when the denominator is zero. This happens at zero frequency and also at that frequency at which $C_y + C_b$ in series resonates with M_b.

The reactive mechanical impedance at the yoke is

$$Z_y = \frac{w^4C_bC_yM_bM_y - w^2M_y(C_b + C_y) - w^2C_bM_b + 1}{w(w^2C_bC_yM_b - C_b - C_y)}$$

to which must be added the impedance Z_2 due to M_a and C_a of the rearward portion of the stylus arm, so that

$$Z_2 = wM_a - \frac{1}{wC_a} + Z_y$$

This impedance Z_2 is referred to the stylus through the mechanical transformer T, in which the transformer ratio is l_s/l_y, and the reactive impedance referred to the primary of the transformer is $Z_t = Z_2/T^2$. In the significant frequency range the driving point reactance at the stylus is $Z_0 = wM_s + Z_t$. The driving point impedance is infinite at dc and has two resonances and one antiresonance.

Two-channel Case

In a stereo cartridge there is obviously some interaction between channels. In the vertical mode the stylus is made to move vertically with respect to the record groove, the vertical motion being transmitted through the stylus arm to the yoke, where the vertical displacement d is divided into two equal left and right components d_l and d_r along two axes at 45° to the vertical. These three displacements are related in the expression $d^2 = d_l^2 + d_r^2$, and the corresponding velocities are similarly related in the expression $g^2 = g_l^2 + g_r^2$. The forces and mechanical impedances in the two channels are related by $F_1 = g_l.Z_l$ and $F_2 = g_r.Z_r$, and it follows that the velocity

$$g = \sqrt{\frac{F_L^2}{Z_L^2} + \frac{F_r^2}{Z_r^2}}$$

If the two channels are identical, $F_l = F_r$ and $Z_l = Z_r$, so that

$$F_{vert} = \sqrt{F_L^2 + F_r^2} = \sqrt{2}F_L = \sqrt{2}F_r$$

and $Z_{vert} = Z_l = Z_r$. In general the two channels will not be identical, so that the resultant of F_l and F_r will not be truly vertical.

The same considerations apply in the lateral mode, where the stylus is subjected to a lateral displacement h with a velocity x, wherein

$$x = \sqrt{\frac{F_L^2}{Z_L^2} + \frac{F_r^2}{Z_r^2}}$$

and the vector sum of Z_l and Z_r will not in general be in the lateral direction. Differences between the vertical and lateral displacements and the resultant forces will not affect the performance of the cartridge, except that it may involve asymmetrical deformation of the groove wall under the stylus.

IMPLOSION PROTECTION FOR PICTURE TUBES MODERN DEVELOPMENTS

Since the advent of the laminated picture tube to minimize damage from a possible implosion, other systems have been devised to achieve the same result and at the same time give some cost saving to the set manufacturer, together with a lighter assembly and one more convenient to mount into the cabinet.

Broadly, there are two such systems, the first of which uses a high tensile steel strap around the bulb in the panel seal area pulled up to a predetermined tension. The second method uses a metal shell which is cemented to the edges of the tube.

The laminated tube has two variations. The most common approach in Australia is the glass cap cemented over the tube face as in type 23CP4. The other method uses a plain piece of glass, contoured to fit the tube face, cemented to the face as in type 25LP4. Both these approaches work very efficiently and no safety glass is needed. The only criticism compared to an unprotected tube is the added weight of the extra glass and the cementing resin.

Much work has been done on the actual mechanism of laboratory induced implosions and from these studies it has been found that the effects of an implosion can also be minimized if the area between the mould match line and the panel seal is kept under strong compression by an outside force or if this area of the tube is held securely in a metal container.

One way of putting the bulb into compression is to wrap a high tensile steel strap around the bulb with a predetermined residual tension. Such a tube can then be used in a set with the usual tube mountings, but the safety glass can be dispensed with.

A variation of this method is to first place two halfshells or rimbands, each complete with two cabinet mounting lugs or ears, around the tube. The steel strap is then pulled up to tension over these overlapping bands, securely locking them into their correct position. The bands are coated with epoxy resin before being applied to the tube and this resin is later cured after the tensioning has occurred. This tube can then be simply fixed to the cabinet by means of the four mounting lugs now securely fixed to the tube and again no safety glass is needed.

If the strap is tensioned and kept in that condition by means of a seal, which is crimped over both ends of the strap before the tensioning device is withdrawn, the assembly is known as KIMCODE. Another variation where the two ends of the strap are welded rather than crimped is known as PAN-O-PLY.

The other approach uses a complete close-fitting metal shell which covers the sides of the tube from the edge of the face-plate to the panel seal bulge. The shell is cemented to the tube with an epoxy resin and has a cabinet mounting hole in each corner for use by the set manufacturer. This system evolved simultaneously in both Europe and America and the latter version is known as SHELBOND.

All of the above implosion protection systems are currently being used where required by picture tube manufacturers in Australia.

Regulated Bias Supply

This short article is based on AWV Applications Laboratory Report No. VR104 entitled "Regulated Bias Supply", June, 1964, prepared by R. Walton, B.Sc.(Tech.) Grad. IREE, and is one of a number of such articles based on these reports which are being specially prepared for "Radiotronics".

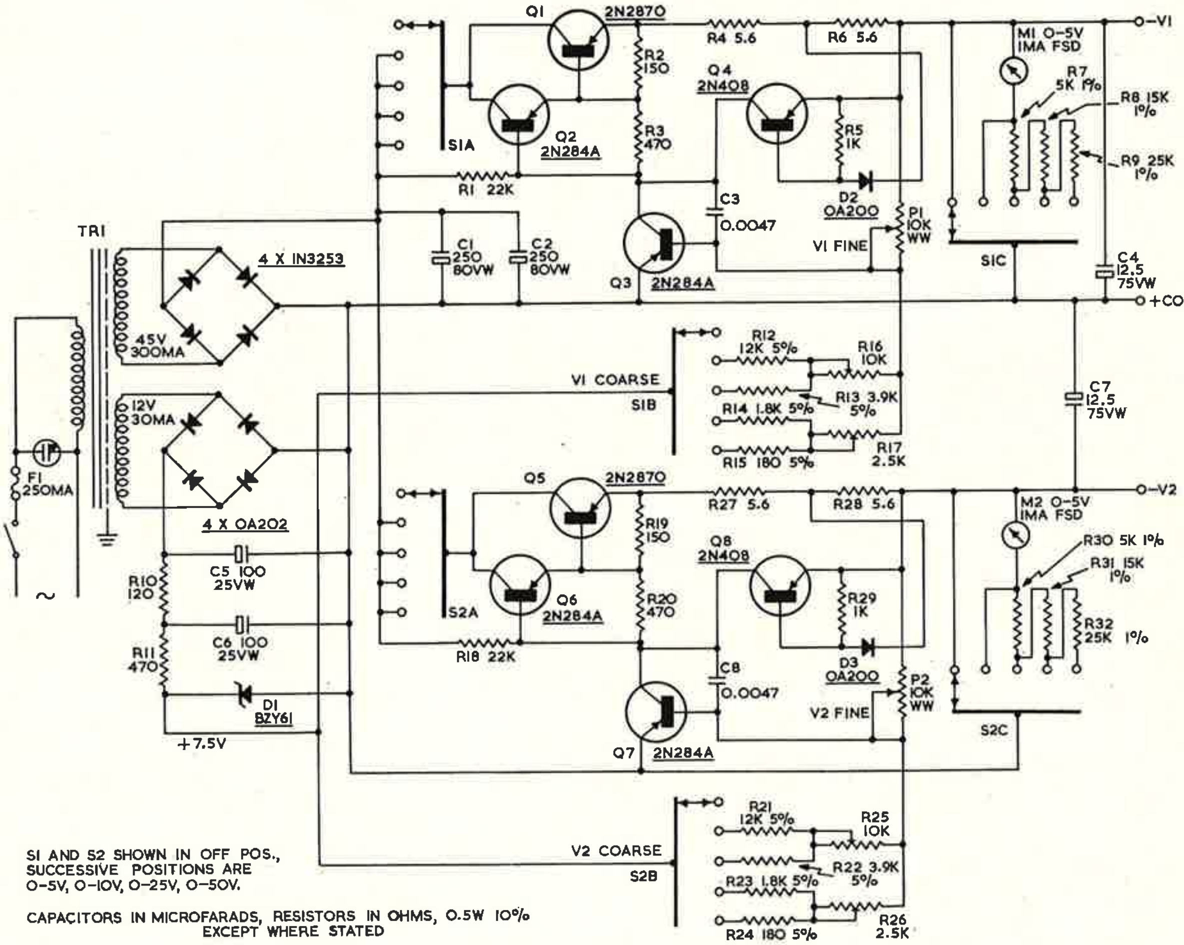
INTRODUCTION

In its original form the unit which forms the subject of this article was a regulated bias supply, which was intended primarily for use with TV receivers to supply external bias voltages to the video intermediate frequency and the tuner agc points. But it will be clear that several other applications are possible for such a unit within its capabilities. It will also be clear that the basic circuits used in the unit are adaptable to many different configurations and applications. For this reason it is expected that this article will have a field of interest far beyond the original scope of the unit as described in the report, and it will be referred to in this article as a regulated power supply.

In its original form the unit provides two regulated outputs, each of which is continuously variable in four ranges from zero to 50 volts. Each supply was provided with its own voltmeter. The two supplies have a common positive terminal but are otherwise completely independent, whilst all terminals are isolated from the chassis or mains earth. This provides the greatest flexibility in the use of the power supply.

In addition to the regulation feature of this power supply, overload current limiting is provided so that the power supply is substantially immune to short circuits or overloads on the outputs. Provision is made for an automatic reduction in the output voltage supplied to the relevant terminal when the output current rises above the permissible level, so that the output current is never allowed to rise above the prepredetermined maximum value, 100 ma.

CIRCUIT DIAGRAM OF THE REGULATED POWER SUPPLY.



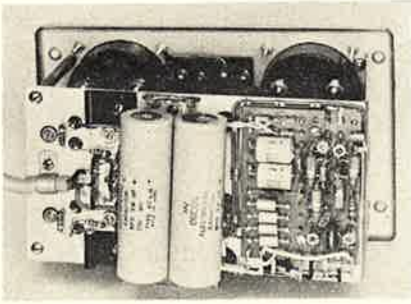
S1 AND S2 SHOWN IN OFF POS.,
SUCCESSIVE POSITIONS ARE
0–5V, 0–10V, 0–25V, 0–50V.

CAPACITORS IN MICROFARADS, RESISTORS IN OHMS, 0.5W 10%
EXCEPT WHERE STATED

Since putting this unit into service it has been found that improved operation is obtained by adding a 1μf *70 V.W. electrolytic capacitor across each potentiometer P1, P2.*

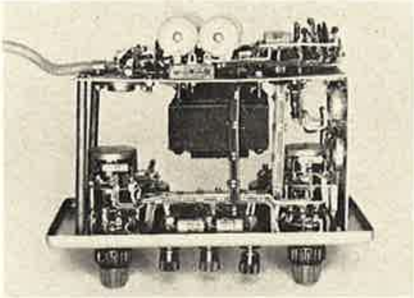
CIRCUIT OPERATION

The complete circuit of the power supply is shown in an accompanying diagram. Inspection will show that the power supply consists essentially of two identical voltage adjusting and regulating circuits, one for each output. These two identical circuits are fed from a common unregulated direct current supply circuit and from a common regulated reference-voltage supply circuit both of which common circuits use the same mains transformer and power input arrangements. For this reason, those parts of the complete circuit which are common to both outputs will first be described, followed by a description of one only of the identical voltage adjusting and regulating circuits.



INTERIOR OF THE POWER SUPPLY UNIT SHOWING THE GENERAL ARRANGEMENT.

The mains input is switched and fused, and provided with a neon indicator. One secondary winding on the mains input transformer provides 45 volts at 300 ma; this is applied to a bridge rectifier to produce approximately 65 volts rectified output, which is of course at this stage unregulated. A further secondary winding on the mains transformer provides 12 volts at 30 ma. Again a bridge rectifier is used, this time producing a rectified output of about 16 volts. This direct supply is filtered and then applied through appropriate series resistor to a zener diode to produce a regulated reference voltage. It will be seen that little filtering of the main direct output is required as the regulating action of the following circuits will also provide filtering. The regulated reference voltage produced by the zener diode provides a voltage against which the voltage-regulating circuits for the two outputs can be compared.



ANOTHER INTERIOR VIEW OF THE POWER SUPPLY UNIT.

Turning now to the two voltage adjusting and regulating circuits, that at the top of the diagram will be described, the other as already pointed out being identical in all respects. The active regulating element in the circuit is transistor Q1. This transistor, together with Q2, are connected in a Darlington pair configuration. This type of composite connection is often used to form what is in effect one transistor with a very high gain. In this case the two transistors so used have a minimum current gain of 2,500. Resistors R2 and R3 ensure that with no external base current the two transistors are cut off, whilst the value of resistor R1 is so chosen that under the worst conditions enough current is supplied to the base of Q2 to permit 100 ma of load current to flow. This corresponds to a base current of 40 μ. The worst case conditions already mentioned visualise transistors of minimum gain together with maximum output voltage from the unit, i.e., 50 volts.

Transistor Q3 controls the Darlington pair which form the actual regulating elements. Transistor Q3 compares the voltage at its emitter, which in this case is the voltage on the common positive output terminal, with the voltage at the junction of R16, R17 and P1, this last voltage being applied to the base of the transistor. If the voltage on the base of Q3 is negative with respect to that at the emitter, the transistor conducts, and in so doing reduces the bias on the Q1, Q2 pair. This in turn reduces the output voltage, i.e., on the terminal -V1, until the potential difference at the junction of R16, R17, and P1, and at the base of Q3 with respect to the common positive output terminal is almost zero.

It will now be clear that an adjustment of the output voltage of the unit can be achieved by a variation of the voltage at the base of Q3 with respect to the common output terminal. In this way the four ranges of output voltage are provided by the selection of appropriate resistors in the lead from the regulated reference voltage and the base of Q3, whilst precise adjustment of the required voltage within a selected range is made possible by the use of the potentiometer P1. Switch S1 functions therefore as a RANGE selector, whilst the potentiometer functions as a FINE voltage adjustment. The provision of the regulated reference voltage by means of the zener diode gives a point or reference which remains constant, and around which the adjustment and regulation of the output voltage of the circuit can be oriented.

THE ORIGINAL REGULATED BIAS SUPPLY WHICH FORMS THE BASIS OF THIS ARTICLE.

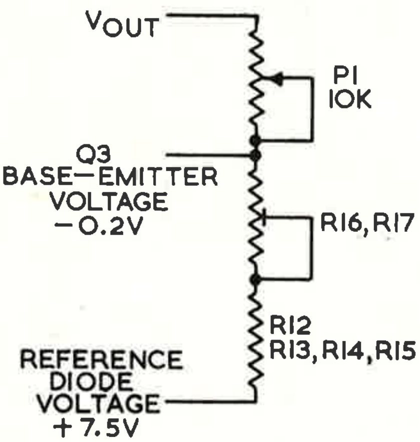
Having described the mechanism of adjusting and regulating the output voltage of the unit, it is now necessary to consider the overload protection. As already mentioned, this is provided in the form whereby the output voltage is reduced under conditions which would cause an overload current to flow so that the output current is always in fact held below a predetermined maximum figure. The transistor Q4 and its associated components form that part of the circuit which fills this function.

Two small resistors R4 and R6 are placed in series with the output terminal of the unit. As the load current through R6 approaches the operating maximum of 100 ma, the voltage across it, and across the diode D2, approaches the conduction value for the diode of approximately 0.6 volt for 0.1 ma. A further increase in the output current through R6 causes the diode D2 to conduct which in turn brings the transistor Q4 into conduction. The conduction in Q4 reduces the bias to Q1 and Q2 until the output current is limited to the predetermined value of 110 ma. The presence of resistor R4, across which a voltage drop similar to that across R6 appears, ensures that when Q4 conducts, it will pull the base of Q2 to a more positive potential than that appearing at the emitter of Q2.

The small capacitor C3 prevents oscillation at frequencies where the phase shift in the transistors causes positive feedback around the combination of Q1, Q2 and Q3. A capacitor C4 across the output of the supply reduces the ac impedance of the supply.

SELECTION OF RANGES

It was mentioned earlier that Q3 controls Q1 and Q2 until the voltage between the base and the emitter of Q3 is almost zero. In fact one would have to assume a small residual voltage here, and 0.2 volt is typical. Further, in the original unit, the zener diode was so chosen that the regulated reference voltage was +7.5 volts. It may be of interest to see how the resistors R12 through R17 and potentiometer P1 are chosen for the different ranges, and the selection of the values for the nominal 0 — 5 volt and 0 — 10 volt ranges (actually 0 — 5.2 volts and 0 — 10.5 volts) will be considered. A small diagram has been prepared and is presented here covering only the essential components in the circuit from the regulated reference voltage output to the base of Q3 and to the negative output terminal of the circuit. All voltages are specified with respect to the common output terminal.



EXPLANATORY DIAGRAM SHOWING ARRANGEMENT AND SELECTION OF RANGE-DETERMINING RESISTORS.

The diagram shows the reference voltage of +7.5 volts and the base-to-emitter voltage of Q3 at -0.2 volt. Also for convenience the value of the potentiometer P1 has been chosen at 10K ohms. Now

$$\frac{R16 + R12}{7.5 - (-0.2)} = \frac{P1}{V1 - (-0.2)}$$

Then for the 5.2 volts range, and with P1 = 10K ohms,

$$R16 + R12 = \frac{10,000 \times -7.7}{-5.2 + 0.2}$$

$$= 15.5K \text{ ohms.}$$

and for the 10.5 volts range,

$$R16 + R13 = \frac{10,000 \times 7.7}{-10.5 + 0.2}$$

$$= 7.5K \text{ ohms}$$

The R13 is chosen 3.9K ohms and R12 is chosen 12K ohms, the preset resistor R16 is set to 3.6K ohms.

PERFORMANCE

The performance of the unit may be summarised as follows:

Mains Variation. Variation in the regulated output voltage is not greater than ± 1% for a mains voltage variation of ± 10%.

Output Regulation. The output regulation is within ± 1% for load variation between zero and the full load current of 100 ma.

Output Impedance. The output impedance of the power supply is less than 20 ohms over the frequency range 50 cps to 300 cps, and is less than 10 ohms over the frequency range 1Kc to 200Kc.

Noise. Noise output is 50 μvolts rms, per volt dc output.

Power Consumption. No load, 5 watts, pf = 0.37, full load, 25 watts, pf = 0.93.

CONSTRUCTION

The accompanying photographs show the appearance and construction of the unit, which was incorporated into a standard Imhof type 1480A cabinet. However, in order to make the unit compact and fit it into this small cabinet, special controls were made in the AWV workshops consisting of a concentric arrangement of the switch and potentiometer forming the RANGE and FINE voltage controls. These are non-standard items and cannot be purchased, so that unless the intending constructor has the facilities for making these controls, a larger panel space will be required to accommodate separate controls.

The bridge rectifier for the reference supply may be replaced by a single halfwave rectifier IN3253 with a suitable increase in filtering capacitors.

Apart from the foregoing, no difficulty should be experienced in putting the unit together, layout being completely unimportant. Further, several variations of the original unit would be possible to meet circumstances. For example, it would be possible to build a power supply providing only one output or with more than two outputs. It would also be possible with appropriate rearrangements to construct a unit with positive outputs about a common negative terminal, or a mixture of both. Variations of the kind mentioned would require the provision of separate reference voltages for each output or separate unregulated direct supplies for each output, as the case may be. However, the number of variations possible are too numerous to discuss them all in detail in this short article.

BOOK REVIEWS

"CERAMIC ACOUSTIC DETECTORS", A. A. Anan'eva, Consultants Bureau, size 8½" x 10¾", 122 pages, soft covers.

This title is an authorised translation from the Russian of a text originally published by the Academy of Sciences Press in Moscow. Like many such translations becoming available today, this book displays high quality in the treatment of the subject matter, and is mainly of interest to those specialising in this field of endeavour. Piezoelectric properties in quartz were first discovered by the Curie brothers in 1880, whilst piezoelectric materials were first used in acoustic detection systems in 1917 by Langevin, who constructed the first quartz mosaic and used it for depth-sounding purposes.

Since then, many synthetic materials have been evolved with piezoelectric properties, out of which barium titanate ceramics have today achieved an important position. This book is chiefly concerned with work carried out by the author on the design of acoustic sound receivers (transducers) using barium titanate ceramic. Valuable introductory material reviewing the dielectric and piezoelectric properties of barium titanate ceramic and methods of determining transducer characteristics is followed by design and evaluation procedures on wide-band sound receivers employing non-directional cylindrical and spherical forms, and those which use plane diaphragms. Further chapters deal with natural frequencies of the various forms, and with the use of resonant transducers. Not the least useful feature of this book is the generous citation of pertinent literature, mostly of Russian origin.

"PRINCIPLES OF TELEVISION ENGINEERING", R. C. Whitehead, Iliffe Books Ltd., size 8½" x 5¼", in two volumes; Vol. 1, 178 pages; Vol. 2, 270 pages, soft covers.

This title is one of many excellent books that have come out of Britain over recent years as an inevitable product of the growth of technological training. To one who suffered with the stodgy old-fashioned type of text book in days gone by, the method of approach and clarity of some of these new books comes as a breath of fresh air, and they will not fail to make the students' lot a happier one. The author of this title spent nearly 20 years with the BBC and is now teaching at the Northern Polytechnic in London.

The first volume commences with an introduction to light and a comparison of sound and vision signals. The author then covers photo-electric circuits, picture analysis and synthesis, and brightness modulation, and then goes on to the problems of aspect ratio and scanning, and the spectre of video and RF signals. A gratifyingly thorough chapter on gamma is then followed by the treatment of blanking, scanning frequencies, synchronisation and porches. Extensive appendices deal with gamma control, blanking, gating, video switching, mixing, timing pulse and standard pulse systems.

The second volume deals first of all with the subjects of pulse types used in studios, programme mixing, telecine, telerecording, magnetic recording and standards conversion. This is followed by vestigial sideband operation, carrier modulation and detection. An interesting chapter deals with the transmission of television signals over various types of cable, and deals with the problems of attenuation, phase, differential and echo equalisers.

The author next deals with transmitters, including discussion of carrier frequencies, high-level and low-level modulation, combination of sound and vision signals, and aerials. A final chapter covers the subject of television amplifiers. Appendices deal with the characteristics of single CR combinations, production of 75-ohm sources, DC restoration and clamping, DC, HT and EHT stabilisation, transmitter modulator circuits and camera tubes.

As may be expected, the book is written with an accent towards practice in Britain and BBC methods, but this shows mainly in lesser detail and is readily recognisable.

"UNIFIED CIRCUIT THEORY IN ELECTRONICS AND ENGINEERING ANALYSIS", J. W. Head and C. G. Mayo, Iliffe Books Ltd., 174 pages, size 8¾" x 5½".

The purpose of this book is to show how the output, or response, of a linear system may be formulated, whatever the nature of the input may be. Steady-state conditions present no mathematical difficulties, but decidedly more advanced techniques are required when dealing with the non-steady state. There are alternative methods of solving problems of this kind, that involving the use of Laplace transforms being currently popular. The authors of this book prefer, and strongly advocate, the use of operational calculus, which they maintain has the outstanding advantage of directness and simplicity of working that makes it easy for practising engineers and students alike to appreciate the significance of each necessary process. Further, they justly claim that it does not require the memorising, or use, of tables of transforms or any special form of integration, only the standard integrals of elementary calculus.

Why with these advantages is operational calculus not more widely used? The answer lies in the fact that Heaviside, who invented it, was an engineer and more concerned with the practical results of his calculations than with explaining the theory underlying them to the mathematicians of his day, who considered them to be inspired guesswork incapable of rigorous proof. Operational calculus is closely associated with the generalisation of the Ohm's law known as the impedance "concept", and with the Fourier integral and identity. An infinitesimal variation of the Fourier integral, suggested by physical considerations, removes immediately all difficulties and ambiguities associated with the classical form of this integral.

The authors have a very easy style, and although the examples are expressed mainly in terms of electrical systems, the methods employed are equally applicable to a wide variety of other fields.

"QUANTUM ELECTRON THEORY OF AMORPHOUS CONDUCTORS",

A. Gubanov, Consultants Bureau Enterprises Inc., size 9" x 6", 277 pages, translated from the Russian by A. Tybulewicz.

The application of quantum mechanics to solids has resulted in a very satisfactory explanation of their electrical properties. The high electrical conductivity of metals and its dependence on temperature became understood, and then the differences between the electrical conductivities of metals, insulators and semiconductors were explained. The most outstanding achievements of the quantum-mechanical theory of solids was in the development of semiconductor physics. Electron and hole conduction, the great influence of minute amounts of impurities, the different effective masses of carriers, and many other phenomena which were inexplicable within the framework of the classical electron theory, were explained by quantum mechanics.

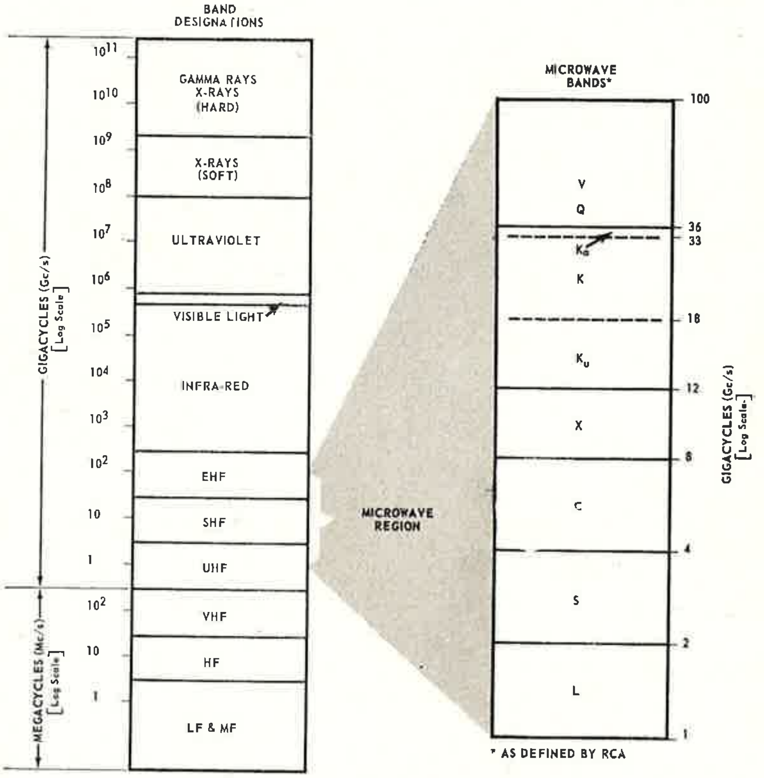
Most material so far published on the electron theory of solids is related to crystalline conductors, whereas a great deal of experiment and theoretical investigation has been made in the Soviet Union in the region of liquid and solid amorphous conductors. Although many papers have been published on this subject in various journals, this is claimed to be the first book in which an attempt has been made to present in a systematic fashion the quantum electron theory of amorphous conductors. The investigation of liquid and amorphous semiconductors is of great practical importance. In the first place, most solid semiconductors are prepared from the liquid phase and it is important to understand the electrical and other properties of this phase. Secondly, amorphous semiconductors are beginning to be used in industry (e.g., amorphous Sb_2S_3 *films in vidicons) where in many cases amorphous semiconductors have advantages over those possessing a crystalline formation.*

The preparation and referencing of this book must make it a valuable contribution to the fund of knowledge. Both the subject matter and the high level of writing and discussion make it a book for the specialist.

Electromagnetic Frequency Spectrum

Questions often arise as to the exact meaning of such terms as "SHF", "Gamma Rays", etc. in terms of frequency. Similar questions arise also regarding the meaning of the letter terminology used to designate particular frequency bands in the UHF, SHF and EHF regions, often referred to as the "microwave" region.

The diagram here is prepared on a logarithmic scale, and will help to answer these questions. It should be noted that the designations given to the microwave bands are those used by R.C.A. and in the U.S.A. generally; they may differ slightly from those used by British manufacturers.



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