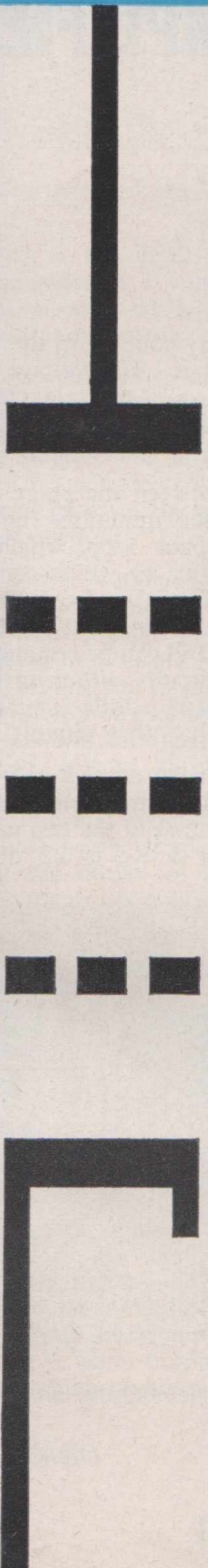
RADIOTRONICS



Vol. 29, No. 10 October, 1964

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A SIX-WATT MONOPHONIC AMPLIFIER 210

This unit is presented in response to several requests received lately for a mono unit.

PHOTOTUBES AND PHOTOCELLS. 5: PHOTOCELLS 214

Continuing our series of articles on photosensitive devices, we come this month to the solid-state side of the picture.

SOME TRANSISTORIZED PREAMPLIFIER CIRCUITS 220

An article describing a number of basic circuits or "building blocks", enabling the reader to assemble a wide variety of preamplifiers, according to his requirements.

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A SIX-WATT MONOPHONIC AMPLIFIER

Although stereo reproduction is so popular today, there are many people who still prefer monophonic reproduction. This could arise from a variety of reasons, but the most common reason seems to be a matter of personal preference, or the ownership of a large and treasured collection of mono records. A monophonic amplifier could also be required for monitoring purposes. We hope in this article to satisfy some of the requests that we get from time to time for such a unit.

The amplifier to be described here is largely derived from a stereo unit recently published in these pages, with a few small circuit changes, and the provision of a power supply of smaller size appropriate to the single channel being used. This unit has a high-impedance input, suitable for piezo-electric cartridges, and a sensitivity of approximately 50 mv for 6 watts output at 1 Kc. An add-on transistorized head amplifier can be used if provision for a magnetic cartridge is required.

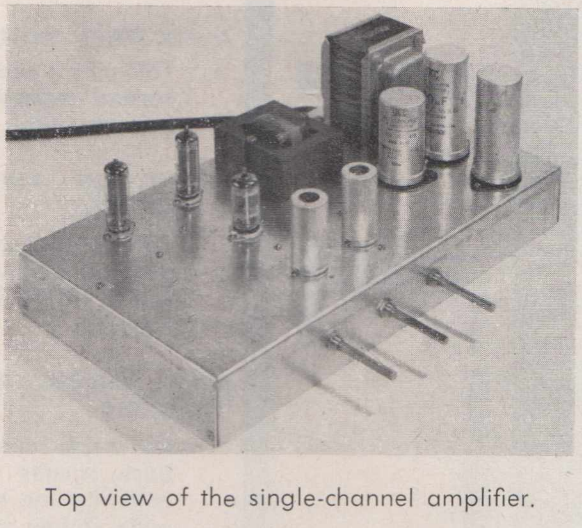
Circuit

An accompanying circuit shows the complete valve amplifier and power supply. The amplifier has been built in such a way as to be self-contained for all inputs requiring a flat frequency response, including piezo-electric cartridges, tuner inputs and the like. The input impedance is approaching 1 megohm, and the high sensitivity will generally allow "building-out" of the input impedance for some of the later cartridges which require a 2 megohm load. Full-range tone controls are provided.

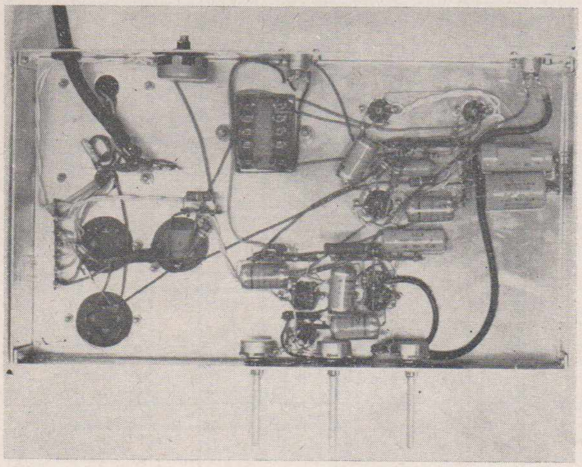
The output stage consists of two AWV 6AQ5s, operated in a conventional manner with cathode bias. The phase splitter used is the highly successful long-tailed pair circuit, using an AWV 12AU7A, which is directly coupled to the voltage amplifier which precedes it. The voltage amplifier is interesting, in that a cascode circuit is used, using both sections of a second 12AU7A valve.

The direct coupling between the phase splitter and the voltage amplifier minimises unwanted phase shifts in the feedback loop, which could otherwise lead to instability, or which conversely would limit the amount of negative feedback which could be applied. This arrangement has proved very successful overseas, and can be recommended against several popular circuits, although the gain that can be taken from it is a little lower than is the case with some of the other circuits.

Feedback is applied in the usual way from the voice coil winding of the output transformer to the cathode circuit of the first of the two cascoded stages. The feedback at 1 Kc is 22 db. The



Top view of the single-channel amplifier.



Underside view of the single-channel amplifier.

sensitivity at the input of the cascode amplifier is of the order of 1 volt for 6 watts output, just in case someone wishes to use this circuit with different tone controls and preamplifier section.

The preamplifier section uses only one 12AX7 valve in a resistance-capacitance coupled arrangement, with approximately 8 db of feedback over the two stages. The input circuit to these stages includes the gain control, whilst the tone controls are placed between the preamplifier and the main amplifier section.

The power supply for the amplifier is very simple. It uses one of the mains transformers specially developed by various makers, for use with silicon diodes in a voltage-doubling arrangement. The filtering of the B+ line is also simple, consisting only of a resistor and a capacitor. The heater winding on the mains transformer is returned to ground through a preset 100-ohm potentiometer and a preset potentiometer between the B+ line and ground. This allows the user to balance the heater supply for minimum hum and noise at the output of the amplifier, merely by adjusting the preset control.

A slightly cheaper alternative, but one which will give somewhat higher hum and noise levels, is merely to return the centre-tap on the heater winding to ground. This saves a potentiometer and two resistors, for a degradation in the signal/noise ratio. The ratio by which the signal/noise figure might be expected to change with the two alternative arrangements depends on the specific amplifier, but a ratio of 10 to 15 db might be a reasonable approximation.

Performance

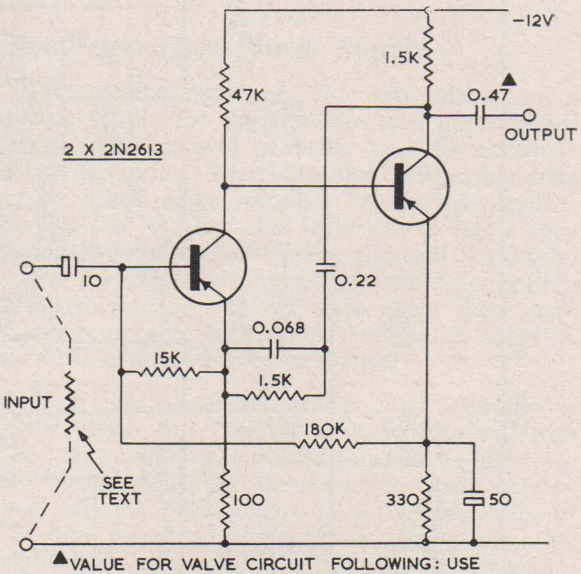
Sensitivity figures on both the main amplifier section and the complete unit have already been quoted. Total harmonic distortion measured at 1 Kc with 6 watts output is better than 0.35%, whilst the intermodulation distortion under the same conditions, but with equivalent power output is slightly over the 1%.

The signal/noise ratio, using the hum and noise balancing circuit shown in the circuit diagram, is —70 db below 6 watts. Turning to the tone controls, the bass control provides a variation of ±10 db, whilst a similar variation is provided by the treble control at 10 Kc. The overall frequency response of the complete unit, with the tone controls in the neutral positions, is ±1 db from 15 cps to 25 Kc at the 1 watt level, 3 db down at the 10 cps and 50 Kc points. At the 6 watt level, the frequency response overall is ±1.5 db from 25 cps to 40 Kc, 3 db down at the 20 cps and 40 Kc points.

Head Amplifier

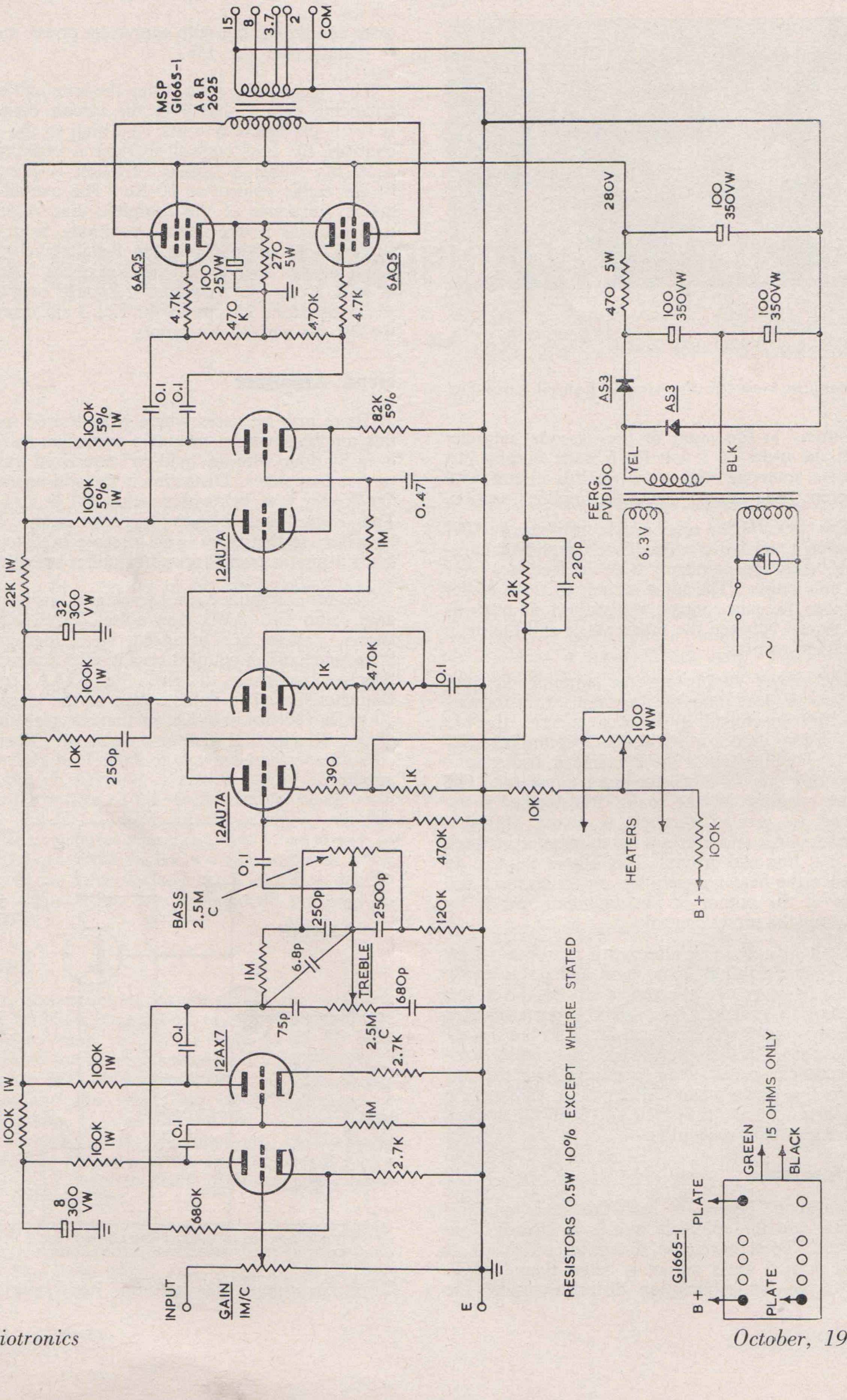
There may be cases where it is desired to use this amplifier with a magnetic cartridge, and this is easily done with an "add-on" equalized transistor head amplifier. Distortion in the add-on amplifier is very low, being well below 0.1% at 1 Kc. This is well below that measured in the valve amplifier, so that there is no increase in distortion when using the transistorized amplifier attachment.

The head amplifier is a two-stage transistorized unit using two AWV low-noise 2N2613 transistors. These are arranged in a high-input-impedance, direct-coupled circuit, with frequency-selective feedback to give the RIAA replay characteristic. The voltage gain of the circuit is 20 times (26 db) at 1 Kc, so that a typical input of 5 millivolts will give an output of 100 millivolts, more than enough to fully load the valve amplifier.

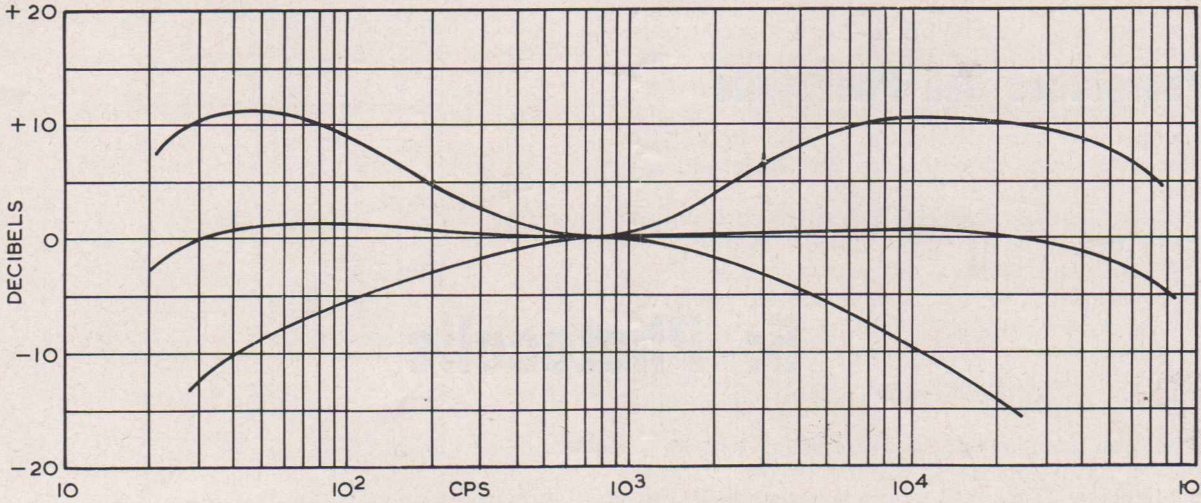


▲VALUE FOR VALVE CIRCUIT FOLLOWING: USE 10 TO 25 FOR TRANSISTOR CCT. FOLLOWING

Circuit diagram of the "add-on" head amplifier.



Circuit diagram of the single-channel amplifier, excluding the head amplifier.



Response curve of the amplifier at the 6-watt level, and effect of the tone controls.

Adequate dynamic range is provided in the head amplifier for any normal cartridge requiring a load impedance up to about 100,000 ohms. With the 12-volt supply as used here, the maximum input levels before clipping are 7 mv, 22 mv, 80 mv at frequencies of 30 cps, 100 cps, 1 Kc, respectively. The circuit is extremely stable, voltage variations of 25% up and down producing no appreciable change in performance characteristics. At lower supply voltages, however, the input level before clipping is reduced, falling to about one-third of the values quoted above when the supply voltage is lowered to 9 volts.

The measured input impedance on our models of this circuit is of the order of 120,000 ohms. This means that the circuit is suitable for any cartridge needing load impedances up to that value, 47,000 ohms being of course a fairly standard value; this is achieved by shunting the input with a 68,000-ohm resistor. Other values of load resistance can be obtained in a similar manner.

Construction

Construction of the main unit is very simple, following the photographs reproduced here. Whilst the unit is exceptionally stable, it would be wise to follow the layout used as carefully as possible to reduce noise. Layout should be used rather than screened leads in reducing noise pickup in the circuit, because due to the high impedances used in the preamplifier section, screened leads will lead to high-frequency roll off and a loss of highs.

Provision has been made in the original model for a gain control with mains switch, and the two tone controls. Other items, such as an input selector switch and pilot light, can be added, but these items are of course at the discretion of the builder. The chassis size used for the unit is 8″ x 14″, and this makes a nice compact unit. The head amplifier is probably best constructed on a small section of matrix board, and enclosed in a small tin or can of steel or tinplate. A small flat tin of the type used to pack throat pastilles would be very suitable. If required, the head amplifier may either be incorporated into the main unit, or used under the phonograph motor board.

Automatic switching of the supply for the head amplifier can easily be incorporated if required.

When the alternative type of output transformer, type A & R 2625, is used, it should be noted that this transformer has a multiple-tapped secondary. The feedback should always be connected to the 15-ohm winding irrespective of the tappings used for the loudspeaker. A sheet enclosed with this transformer details the connections.

Head Amplifier Power Supply

No specific provision has been made for a power supply for the transistorized head amplifier, as readers will probably wish to introduce a few variations. The choice lies between batteries and a mains power supply. The current drain is so low that the use of a battery is in fact a very acceptable method of driving the unit, especially when the other advantages of battery operation are remembered. If this were done, then extra contacts on the amplifier on/off switch could be used to control the battery also.

If a special mains driven power supply is constructed, this could also be controlled from the main amplifier, and could in fact be built into it. In this event, the power supply should be very well filtered, preferably with a dynamic filter of the type so often mentioned in these pages. We published a basic circuit of this kind in November,

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Phototubes and Photocells

5: Photocells

Photosensitive devices in which electron flow occurs in a solid photoconductive material are called **photocells.** In a photoconductive material, electrical conductivity is a function of the intensity of incident electromagnetic radiation. Although many materials are photoconductive to some degree, this section is limited to the three types which are most useful commercially: cadmium sulfide, germanium, and silicon.

Cadmium-Sulfide Photoconductive Cells

The basic elements of a cadmium-sulfide photoconductive cell include a ceramic substrate, a layer of photoconducting cadmium sulfide, metallic electrodes, and a protective enclosure. The photoconductive layer is prepared from cadmium sulfide which has been treated with various activating materials (such as a chloride and copper). The electrodes are formed by evaporation through a mask of a metal such as tin, indium, or gold. The finished cell is protected from moisture by a glass or glass-metal envelope of the type shown in Fig. 71.

In a circuit, a cadmium sulfide cell having ohmic contacts acts as an ohmic impedance. One of the important parameters of such a cell is its conductance as a function of illumination. Fig. 72 shows a characteristic of this type in which the slope of the curve is nearly constant around a given operating point. The conductance G may be expressed as follows:

$$G = G_1 L^{\gamma} \qquad (45)$$

where G_1 is the conductance for unit illumination, L is the illumination, and γ is the slope of the characteristic. The performance of the cell at a given operating point is described by specifying G_1 (expressed in terms of the current drawn through the cell at a given applied voltage) and γ. For a typical cell, the 7163, G_1 and γ are 53 micro-ohms and 1, respectively; the photocurrent measured at 1 foot-candle and 50 volts (ac) is approximately 2 milliamperes.

The capacitance of these cells does not respond instantaneously to changes in incident illumination because of the presence of electron traps

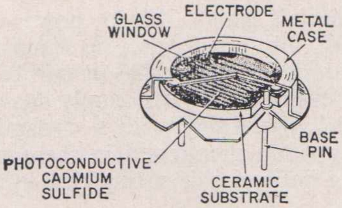

Fig. 71—Typical cadmium-sulfide photocell.

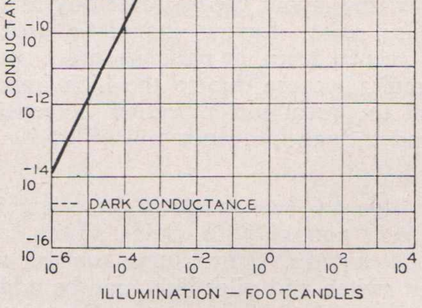

Fig. 72—Conductance as a function of illumination for a cadmium-sulfide photocell.

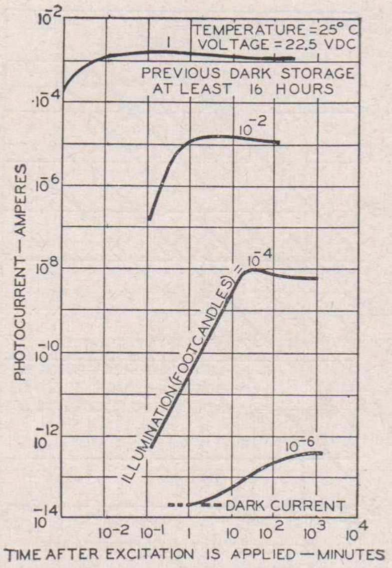

Fig. 73—Photocurrent rise characteristics for a cell selected for low dark current.

within the forbidden gap of the cadmium sulfide. Although the build-up and decay of conductance on the application or removal of illumination is only approximately exponential and depends on the magnitude of the illumination, the term **time constant** is frequently used to describe the time required for the conductance to rise to 63.2 per cent of the maximum value or to fall from the peak to 36.8 per cent of the maximum value. For example, if a cell has been in the dark for a long time and is then illuminated with 10 foot-candles, the time constant is approximately 70 milliseconds. In general, the cell responds more quickly at high light levels and the rise time is usually longer than the decay time. Typical photo-current rise curves are shown in Figs. 73 and 74.

In addition to the short-term time effects just described, other phenomena resulting from previous light exposure proceed more slowly. In general, long exposure to high levels of light makes the cell slightly less sensitive and somewhat faster in response. These changes are reversible; the cell reverts to its former condition during storage in the dark. Because of the long-term time effects, cells should be preconditioned to light before measurement of sensitivity. A commonly used production-testing preconditioning schedule provides for exposure of the cells to a 500-footcandle fluorescent light for 16 to 24 hours. Voltage is not applied to the cell during the preconditioning schedule.

Certain time effects are also related to the application of voltage, and as a result cells are often slightly less sensitive under ac than under dc operating conditions.

For most applications, the conductance of the photocell must be substantially lower in the dark than when the cell is illuminated. Cell performance under unilluminated conditions is described in terms of **dark current** and **decay current.** Dark current, the current passed under specified conditions of voltage and temperature when the cell has been in the dark a long time, is usually extremely low. Because of time effects it is more convenient to specify the decay current, which is observed at a given interval after removal of the light used for a sensitivity determination. For a typical photocell such as type 7163, the decay current is below 40 microamperes at a voltage of 50 volts, 10 seconds after removal of 1-foot-candle illumination. Typical photocurrent decay curves are shown in Figs. 75 and 76.

In the typical curve of photocurrent as a function of applied voltage at various levels of illumination shown in Fig. 77, linearity extends over six orders of magnitude of voltage. Peak-to-valley response as a function of frequency of square-wave light input is shown in Fig. 78. The curve shows that the frequency response improves as the level of illumination increases.

The sensitivity of a cadmium-sulfide cell tends to decrease as the ambient temperature rises. The typical curves shown in Fig. 79 indicate that the effect is marked at the lower level of illumination, but becomes negligible at 10 footcandles and higher.

The sensitivity of cadmium-sulfide photocells varies as a function of the wavelength of incident illumination, as shown in Fig. 80. The response curve is centred within the visible range, and has a peak of sensitivity near 5800 angstroms. Because the spectral response of cadmium sulfide closely matches that of the human eye, cadmium-sulfide cells can be used for control applications in which human vision is a factor, such as street-light control and automatic iris control for cameras.

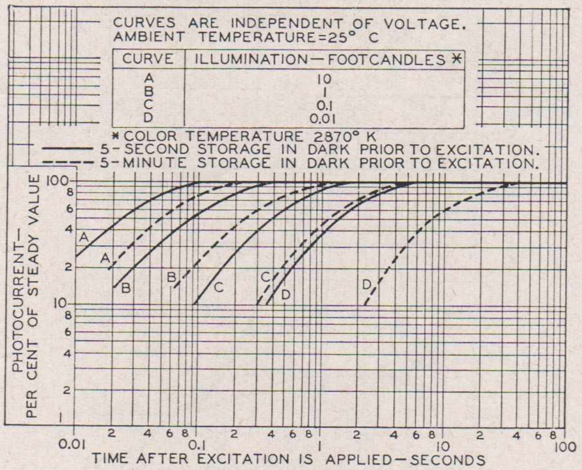

Fig. 74 — Typical rise characteristics of a cadmium-sulfide cell.

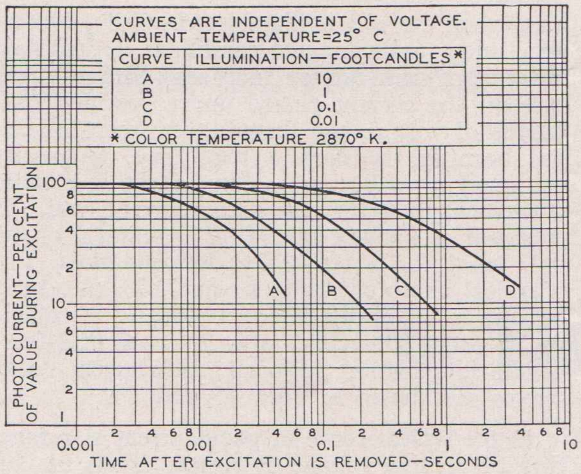

Fig. 75 — Typical decay characteristics of a cadmium-sulfide cell.

Junction Photocells

In some applications, photoconductive materials such as germanium and silicon are used in junction devices; a p-n junction formed of such material has a nonohmic characteristic, as shown in Fig. 81. The solid curve applies when the device is in the dark; when light is applied to the cell, the curve shifts downward as shown. The junction photocell is usually used as either a photoconductive or photovoltaic device. In photoconductive applications, the cell is biased in the reverse direction, and the output voltage is developed across a series load resistor. In photovoltaic applications, the cell is used to convert radiant power directly into electrical power.

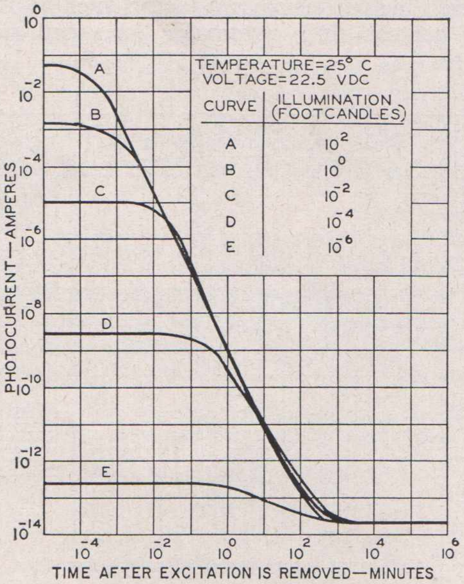

Fig. 76—Photocurrent decay characteristics for a cell selected for low dark currents.

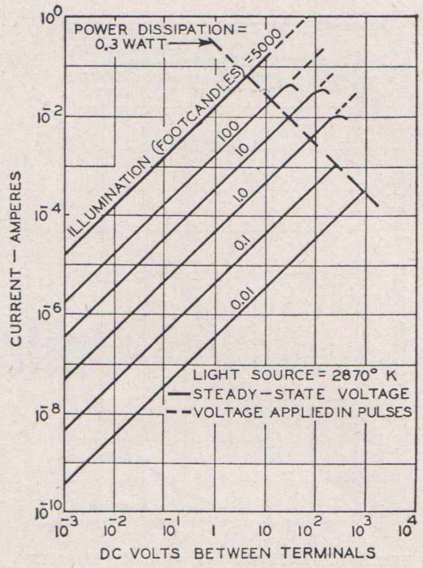

Fig. 77—Curve showing photocurrent as a function of applied voltage at various levels of illumination.

A photojunction device operated in the photoconductive mode has a characteristic similar to that of Fig. 81, but rotated 180 degrees, as shown in Fig. 82. The circuit analyzed by Fig. 82 is shown in Fig. 83; as the illumination on the cell is increased, a change in voltage is developed across the resistor.

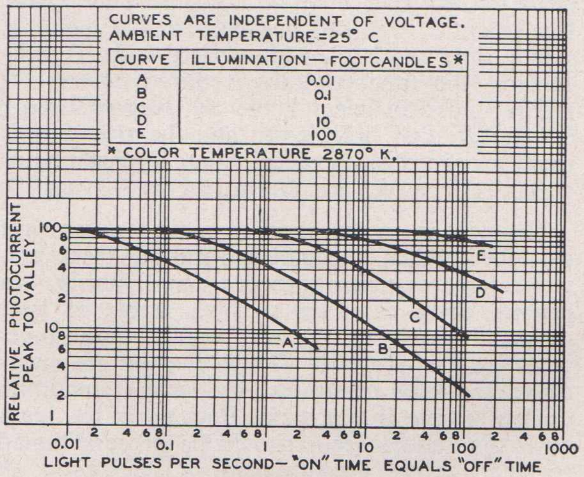

Fig. 78—Peak-to-valley response as a function of frequency of square-wave light input.

Germanium P-N Junction Photocells

A germanium photocell, such as the 4420, which has a quantum efficiency of approximately 0.45, is intermediate in sensitivity between a phototube and a typical cadmium-sulfide photoconductive cell. The 4420 has a dark current of less than 35 microamperes, and the current through the cell increases by about 0.7 micro-

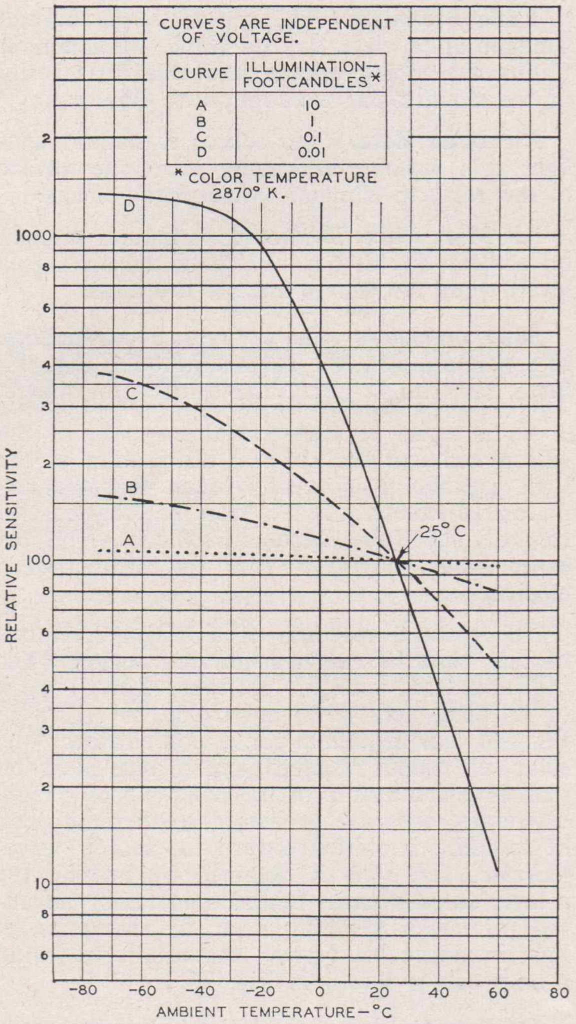

Fig. 79—Sensitivity as a function of temperature for a cadmium-sulfide cell.

ampere for each increase in illumination of 1 footcandle. The increase in photocurrent is linear with the increase of illumination.

The response of germanium junction photocells to sudden changes in illumination is fairly rapid. The 4420, for example, has a time constant (photocurrent-decay characteristic) of approximately 7 microseconds. Because of this relatively fast response, the germanium cell is useful for optical excitation frequencies well above the audio range.

The germanium junction devices contribute relatively little noise to a circuit. The noise is 1/f in character; a typical value of the equivalent noise input at 1000 cycles per second (1-cycle-per-second bandwidth) is 60 microfootcandles.

Silicon Photovoltaic Cells

Silicon solar cells, such as the SL2205 and the SL2206 are junction devices used to convert the radiant power of the sun to electrical power for space applications. The cell consists of a thin slice of single-crystal p-type silicon up to two centimeters square into which a layer (about 0.5 micron) of n-type material is diffused. The bottom contact of the cell is usually a continuous layer of solder, and the top contact consists of a series of grid lines (electrodes). A non-reflective coating of silicon monoxide is usually applied to the top surface to minimize reflection of usable radiant energy from the silicon surface.

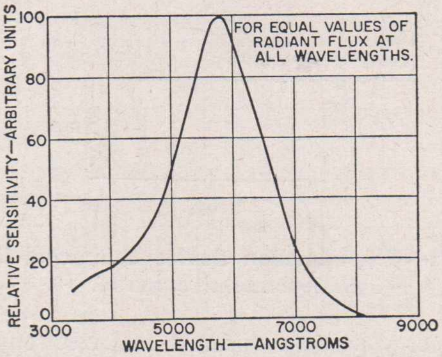

Fig. 80—Spectral response of a cadmium-sulfide cell as a function of the wavelength of incident illumination.

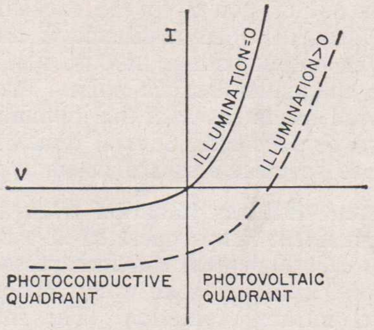

Fig. 81 — Current-voltage characteristic for a photojunction device.

N-on-p type cells are formed by diffusing phosphorous into a p-type base. The advantage of the n-on-p cell over the p-on-n cell is that it is far more resistant to degradation from the

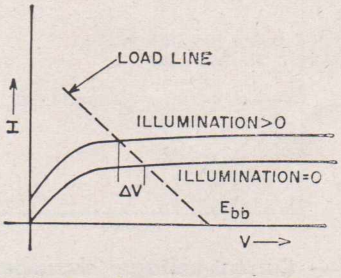

Fig. 82—Analysis of a photojunction device in the photoconductive mode of operation.

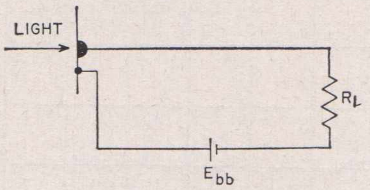

Fig. 83—Photojunction device connected in the photoconductive mode.

high-energy particles (protons and electrons) encountered in space applications.

When the electrical performance of a silicon solar cell is analyzed, the characteristic curve of Fig. 81 is inverted and appears as shown in Fig. 84. The analysis consists of drawing the load line consistent with the load resistor used in series with the cell. The power delivered to the lead is determined by the area of the rectangle constructed as shown in Fig. 84. The value of the load resistor may be adjusted to provide maximum power from the cell for a specific condition of input radiation.

The performance of a silicon solar cell is frequently described in terms of conversion efficiency, which is defined as the ratio of the electrical output power to the incident radiant power, when the load resistance is adjusted to provide an output voltage of 0.46 volt, which is near the maximum-transfer point. The spectral content and the intensity of the illumination used must also be specified. Several typical illumination-source specifications are listed below.

Tungsten efficiency radiation from a bank of tungsten-filament lamps operated at a color temperature of 2800 degrees Kelvin is passed through a filter of 3 centimeters of water, which absorbs unwanted infrared radiation. The intensity is adjusted to provide a calibrated photovoltaic cell with a short-circuit current equal to the current measured when the calibrated cell is illuminated by the sun at air-mass one at an intensity of 100 milliwatts per square centimeter (extrapolated). The load resistor is adjusted to provide 0.46 volt.

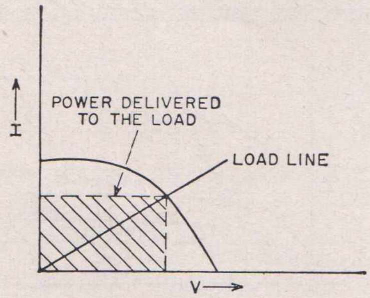

Fig. 84 — Current-voltage characteristic of a photojunction device connected in the photovoltaic mode.

Table Mountain. The source is the natural sunlight on a clear day on Table Mountain in California. (Table Mountain is the former site of the Smithsonian Astrophysical Observatory.)

Air Mass Zero. The source is natural sunlight at a distance sufficiently above the surface of the earth to eliminate atmospheric effects.

Air Mass One. The source is natural sunlight on a clear day at the surface of the earth (sea level) when the sun is directly overhead.

Solar simulators. The source is a combination of xenon and tungsten lamps adjusted to approximate the sunlight above the earth's atmosphere.

As a result of the spectral response of the silicon cell and the spectral distribution of the light sources, it is usually found that the air-mass-zero efficiency is less than the tungsten efficiency. The Table Mountain efficiency, on the other hand, is higher than the air-mass-zero efficiency.

The spectral response of a silicon solar cell has its peak in the near-infrared region. The radiation from sunlight, however, shows a peak of intensity near 4750 angstroms, as shown in Fig. 85. For maximum conversion efficiency, the solar cell should respond to more blue radiation than is characteristic of the band-gap of silicon. Therefore, cells are processed so that the peak of response is shifted toward the shorter wavelengths. The shift is obtained by making the n-layer (n-on-p cells) thinner and taking advantage of effects resulting from the absorption of light in silicon. A typical response curve for an n-on-p cell is shown in Fig. 86.

Other materials now in the developmental stage also show promise in the field of solar-energy power conversion. Gallium arsenide, for example, has a narrower band-gap than silicon. Consequently, because its peak spectral response is farther in the blue region of the spectrum, the potential conversion efficiency of the material exceeds that of silicon.

Data-Processing Cells

Data-processing (read-out) cells are multiple-unit silicon photovoltaic devices used for sensing light in such applications as reading punched cards, and in axial position indicators. A typical cell consists of a thin piece of silicon on which several n-on-p photovoltaic elements have been formed. Although these types have been designed for specific applications in data processing, the technique for preparing such devices is very flexible and permits wide variations in the location, size, and number of the sensing elements. Individual mechanical packages, of several cells per package, can be placed in various spatial arrays to form sensing strips over large areas.

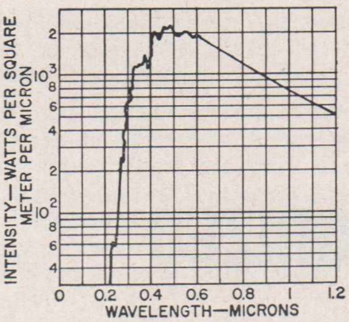

Fig. 85—Radiation from the sun (outside the earth's atmosphere); Johnson solar spectral irradiance curve.—Journal of Meteorology, 11, 431 (1954).

Germanium and Germanium/Silicon Infrared Detectors

The atmosphere is not uniformly transparent to electromagnetic radiation. It contains various "atmospheric windows" through which radiation of specific wavelengths can readily pass. As shown in Fig. 87, the **p-type gold-doped germanium cell** and the **zinc-** or **gold-doped germanium - silicon - alloy cells** have response ranges which take advantage of such windows.

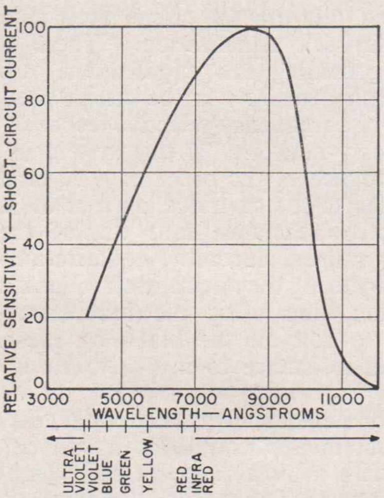

Fig. 86—Spectral response characteristic for a silicon solar cell.

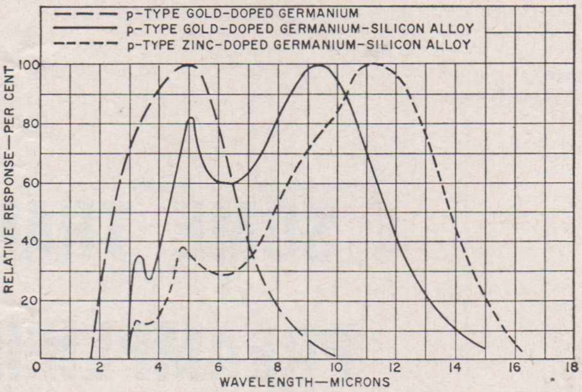

Fig. 87—Spectral response of infrared-sensitive detectors.

The sensitive material of the p-type gold-doped germanium cell is germanium activated with gold and compensated with arsenic or antimony. Incident radiation excites electrons from the filled band to a low-lying impurity level contributed by the gold. The spectral response extends to about 9 microns. Because the active gold level is relatively near the filled band, the cell must be cooled to suppress noise resulting from thermal excitation and recombination. Furthermore, because the radiation results in a relatively small change in the resistance of the germanium element, the input signal should be chopped, and the output amplified by a low-noise amplifier. A typical cell consists of the germanium element within an integrating chamber, a Dewar envelope containing liquid nitrogen for cooling, and a germanium window treated with an antireflection coating. The electrical circuit consists of the cell, a load resistor, a voltage source, and a low-noise amplifier.

Germanium-silicon alloy cells are similar to the p-type gold-doped germanium device. The alloy, however, makes it possible to use an activator level which is closer to the valence band. The spectral sensitivity of the alloy cell extends to 14 microns. As a result of this extended response, the device must be cooled to a lower temperature. Pumped liquid nitrogen at a reduced pressure (50 degrees Kelvin) is used as a coolant; liquid neon and liquid hydrogen are also sometimes useful.

SOME TRANSISTORIZED PREAMPLIFIER CIRCUITS

by B. J. Simpson

Introduction

A considerable amount of work has been done here over recent months on transistorized preamplifiers, directed towards the evolution of one or more basic circuits which would meet certain requirements. Some of the requirements were that each circuit or modular unit of a circuit should be reasonably cheap to put together, that it should be as independent as possible of circuit and transistor tolerances, and of reasonable voltage variations, and that the performance should be acceptable in terms of low distortion and high signal/noise ratio.

At the same time, the possibility was being borne in mind that it should be possible to evolve one basic circuit that could be used over and over again to do different jobs in a preamplifier. This would materially assist in simplifying construction and possibly reducing cost. Also whilst this work was going on, several published circuits were tried to evaluate them alongside the ones we had evolved. Many of them did not measure up to our requirements for a variety of reasons and were discarded. Some of them, whilst capable of extremely high-grade performance, were not considered suitable for home constructors because they needed laboratory adjustment before being put into service, or were too costly to make in relation to the benefits that would accrue. Some of these items might perhaps form the basis of a later article.

Some Decision Points

Before passing on to discuss some of the work in detail, it may be as well to pause here long enough to mention some of the points which were used as sign-posts. Whilst this could not possibly cover all the factors involved, it will perhaps cover some of them that are more familiar to readers.

Firstly, we assumed that in any high-quality equipment at the present stage of the art, a magnetic pickup would be used. This meant that a sensitivity of the order of 5mv or less would be required, and that the circuit must incorporate RIAA playback equalization. There are two ways of providing this equalization. Firstly, it can be applied entirely in the circuit itself, either by means of a frequency-selective feedback system, or in a lossy network. If this system is used, a high impedance of the order of 47K ohms or so is presented to the cartridge, so that the effect of the inductive reactance falls outside the audio frequency range. Secondly, equalization can be obtained by using the circuit itself to look after the bass region, and using the inductance of the cartridge to roll off the highs by presenting a lower load resistance to it.

It will be immediately clear that the first method is universal in application, as it will be able to be used with a large range of cartridges without major change. The second method, however, means that the design of the equalized stage is intimately bound up with the characteristics of the cartridge, and that unless a second cartridge with identical characteristics is found, then to change the cartridge for a different make or model may mean changes in the circuit also. Whilst possibly just a little dearer to make, the first method described was chosen, partly for the advantages mentioned, and also because in almost every case, it resulted in a smoother response curve for a given cartridge.

Further, the use of the high-impedance equalized stage makes it easier to adapt the circuit for use with tape input or microphone, merely by changing the equalization constants, and in some cases to adapt the circuit to the use of feedback-type tone controls.

Whilst on the subject of tone controls, many people today prefer the feedback-type as opposed to the lossy type. There are pros and cons for both, of course, and it is intended within this article to show both the feedback variety and the lossy variety. However, further arrangements are possible with the circuits to be discussed, as will be seen later.

The output level expected of preamplifiers used to be of the order of 1 or 2 volts, sufficient to drive most valve amplifiers. But with the increase in popularity of the semiconductor main amplifier, it often happens that much lower levels are required. In one case, which may form the subject of an article in the near future, the input level required for the main amplifier turned out to be as low as 40 millivolts. But this is probably an exception, and output levels of 250 millivolts to 1 volt appear to be common. The point is that with semiconductor amplifiers, there is a much wider range of specified input levels. To cater for this situation, arrangements will be described that cover a range of output levels from the preamplifier.

Many of the circuits published elsewhere which were tried in order to evaluate them alongside each other failed our requirements in respect of tone controls, not because of the range of control available, but because the range of control varied appreciably with the setting of the gain or balance controls. This is not acceptable, although it is a comparatively common thing to find. It very often, though by no means in every case, appears where the tone controls immediately follow other controls.

A Basic Module

Having paved the way in what has already been said, it now remains to get down to cases. It is proposed first of all to discuss a basic module, which, by small circuit variations, can be used in several ways. It can be used as an equalized stage, giving the RIAA, tape or other response required, it can be used as a "flat" amplifier stage, and can be used as the basis of a feedback tone-control circuit. The module is very stable, and can hold performance over a wide range of device, component and voltage variations.

Circuit

The circuit of the module is shown in Fig. 1, and the circuit shown is the RIAA equalized version for record playback. The circuit uses two AWV low-noise germanium alloy transistors type 2N2613 in a direct-coupled arrangement. The strapping of the first base to the emitter through the 15K resistor together with the un-bypassed emitter resistor gives a high input impedance of the order of 120,000 ohms. When using the circuit, it will in general be necessary to shunt the input with a resistor in order to bring the input impedance down to that required for the cartridge.

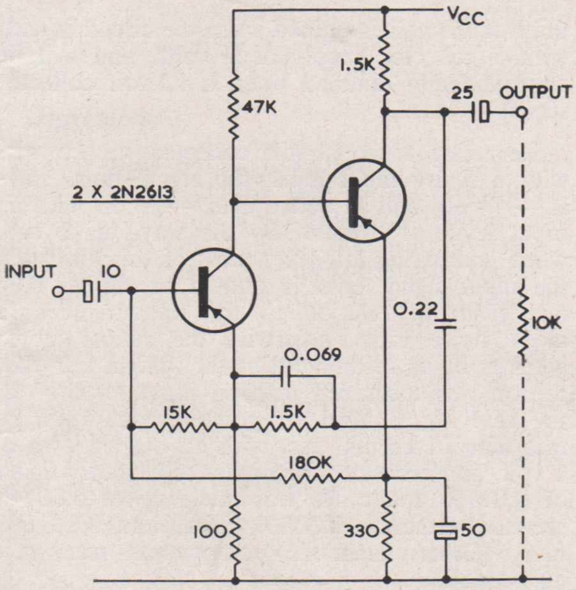

Fig. 1

Frequency-selective feedback is provided from the second collector to the first emitter through the 0.22 mfd capacitor, which controls the bass end of the response, and the 1.5K resistor and 0.069 mfd capacitor, which respectively set the level at the crossover point and control the high-frequency roll-off. The un-bypassed first emitter resistor and the dc feedback through the 180K resistor ensure very high stability.

The voltage gain of the equalized version of this circuit is 20 times (26 db) at 1 Kc, so that a typical input level of 5 millivolts will produce an output of 100 millivolts at that frequency. When the circuit is fed from a suitable magnetic cartridge, the same output level will of course obtain over the frequency range of the cartridge, depending only on the frequency response of the cartridge.

If an equalized stage of this kind is to find universal application, it must be capable of handling a reasonable dynamic range at the input terminal, because the outputs of magnetic cartridges will vary from one make and type to another. We have usually employed this circuit with a 12-volt collector supply, and under this condition, the input levels before clipping are 7 mv, 22 mv and 80 mv respectively at frequencies of 30 cps, 100 cps and 1 Kc. Again taking the 5 mv input as being typical, the maximum input level at 1 Kc is 16 times higher, a ratio of 24 db.

The maximum input levels quoted in the foregoing paragraph will be reduced to about one-third of the values quoted when the circuit is used with a collector supply of 9 volts, and will be approximately doubled when a 15-volt collector supply is used.

Reverting to a 12-volt collector supply, and with a 5 mv input level, the signal/noise ratio is —67 db, and is better than —70 db with an input level of 10 mv. By the way, make sure when comparing low-level units of this kind that the input signal level is quoted or similar data are given in relation to the measurement of signal/noise ratio, otherwise the ratios quoted will not be as meaningful as they might be. Distortion was measured with an input level of 50 mv at 1 Kc, a level far greater than would be met with in normal use, with an output level of 1 volt, and produced the highly satisfactory figure of 0.011% total; this was made up of 0.007% second harmonic, 0.009% third, and 0.0016% fifth. Other harmonic components were not measurable.

Tape Amplifier

This item can be disposed of quite quickly. It is obvious that the equalization can be adjusted for tape by substituting a suitable feedback circuit in place of the one shown. The characteristics would depend on the tape speed and the equalizing curve required. The performance of the circuit under these conditions would approximate very closely to that already described.

Flat Amplifier

By substituting a 1.5K resistor in series with a 25 mfd capacitor for the equalizing feedback circuit shown in Fig. 1, an amplifier with a flat frequency characteristic will result. This amplifier will have a performance similar to that which the equalized circuit has at 1 Kc. This has been measured and verified, so that we now have another version, flat, with a gain of 26 db.

Because of the high tolerance of this circuit to voltage variations, we can make the circuit available for higher input and output levels merely by providing a higher collector supply voltage. For example, using a collector supply of 15 volts, the maximum input level before clipping is about 130 mv, which gives us an output of 2.45 volts, more than enough to drive almost any main amplifier. Adjusting this circuit for an output level of 1 volt, which is a fairly standard preamplifier measurement level, total harmonic distortion measures at better than 0.05%.

If a higher output still is required, the collector supply may be raised to, say, 22 volts. Here we can get 3 volts output for 160 mv input with total harmonic distortion at 0.11%, 2.5 volts output at 0.09% total harmonic distortion.

Incidentally, in all these higher-level versions of the circuit the signal/noise ratio is better than —70 db, and in some cases much better, depending on the way the circuit is used.

Feedback Tone Control

The same basic circuit performs well in a feedback tone control circuit, and this is shown in Fig. 2. It will be seen that the basic module is modified by removing the internal frequency-selective feedback, and also the second emitter bypass capacitor. The second emitter is used as the take-off point for the feedback through the tone controls. A capacitor of suitable value may be used in the feedback line from the second emitter and/or in series with the output, if required to effect dc isolation.

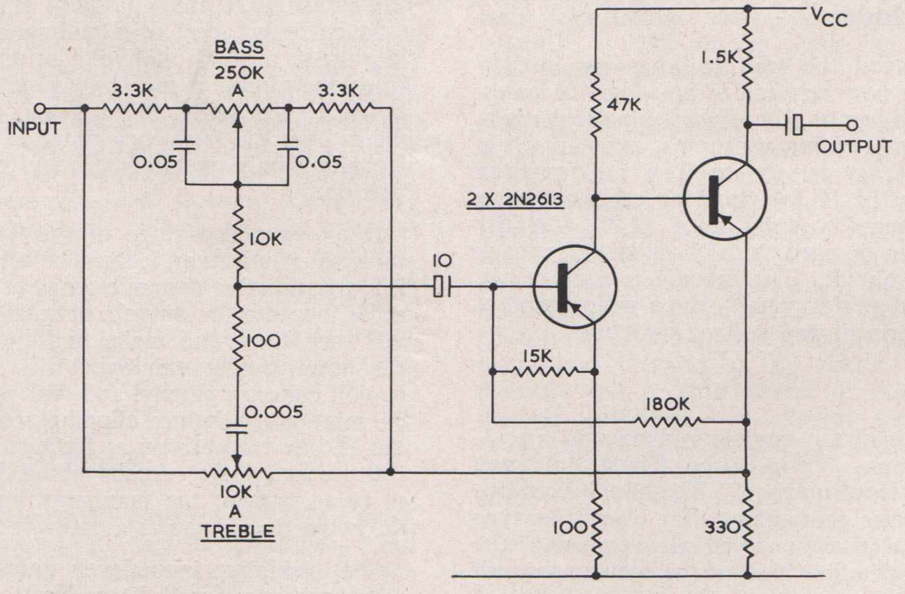

Fig. 2

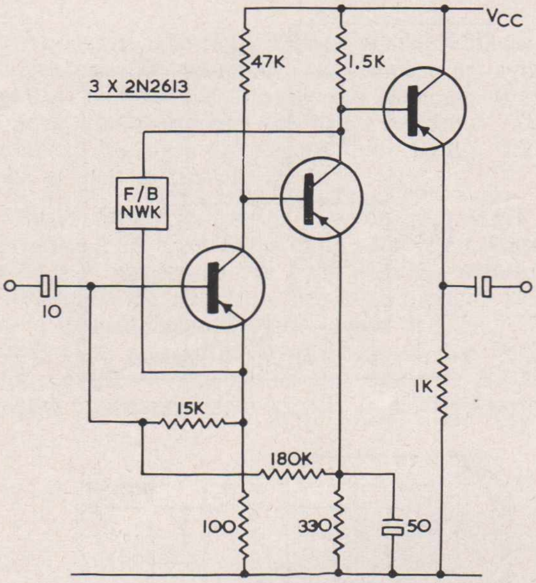

Fig. 3

The tone control configuration is a useful one, in that it avoids the use of a centre-tapped potentiometer for the treble control, a disadvantage of many feedback tone control circuits. The voltage gain of this circuit from input to output terminals is 4 times (12 db) with the controls in the central or neutral positions, and the heavy feedback ensures low-distortion performance. The degree of control available here is ±15 db at 100 cps and 10 Kc, when the circuit is fed from a low-impedance source; the range will be reduced as the source impedance is raised.

When using this circuit, and others like it, it is advisable to apply it at a point where the input signal level is as high as possible, that is, later in the preamplifier rather than earlier. The attenuation between the input terminal and the first base is high. A higher input level will help to ensure a good signal/noise ratio by getting the input signal at the first base as high as possible. Any collector supply voltage in the range already discussed will be suitable for the tone control, depending on the operating levels.

Low-Impedance Output

Some of the applications of this module may require the provision of a low-impedance output. This could happen, for example, with the last stage of the preamplifier, where a low-impedance output is required to feed the signal over some distance to the main amplifier or to reduce hum-pickup. Another example would be where the equalized stage is used as a remote amplifier under the turntable, and long screened leads are required to connect the output to the following amplifying equipment.

This is very easily done by converting the circuit into a three-transistor module, as shown in Fig. 3. It will be seen that the object is achieved simply by the addition of one transistor and one resistor. The rest of the circuit remains the same.

A Digression

Just to break the long discussion, it may be of interest to experimenters that it was thought at one time that a variation would be required to feed a low-impedance load, and also to incorporate a gain control. The three-transistor module lined up all right for what was wanted, but it seemed undesirable to use even a very low resistance potentiometer to control gain at the output of the circuit. Due to the extremely low output impedance of the common-collector stage, the potentiometer would have to be very low indeed not to introduce series resistance of appreciable magnitude in the intermediate positions.

Accordingly the circuit of Fig. 4 was evolved to cover the addition of the third transistor. It will be seen that the signal at the base of the common-collector stage is shunted away by the adjustment of the gain control, the series-connected capacitor being necessary to maintain dc conditions. The series 10K resistor ensures that the minimum load applied to the preceding stage will be of the order of 10K ohms, the recommended minimum load for that stage.

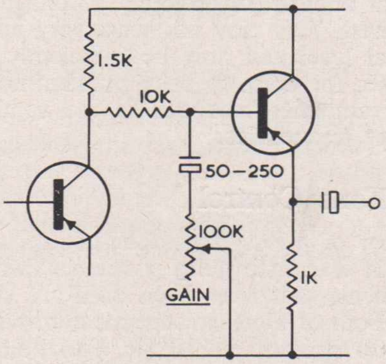

Fig. 4

The gain control works well, except that a large value of capacitor has to be used in series with the control in order to reduce gain to a very low level. However, if a value of capacitor is chosen so that its impedance is becoming significant at the lower frequencies, it may be possible to use this idea as a loudness control. The matter was no pursued further here, but the thought is put forward in case anyone would like to experiment.

Lossy Equalization

The virtues of the circuit of Fig. 1 or a similar circuit, when used to apply the RIAA replay characteristic, are largely those of cheapness and simplicity. It must be remembered, however, that in circuits of this kind, the degree of feedback varies with frequency, and that the feedback is falling to a minimum value in the deep bass region. At 20 cps, such a circuit may have only 2 or 3 db of feedback, or even less.

At the same time, the deep bass region is where it could be argued that reasonable feedback is still required. It is the area, for example, where the characteristic 1/f transistor noise may start to become a problem. One alternative is to amplify the input signal in a "flat" amplifier, and then apply it at a much higher level to an equalized stage; this could be done with the circuit variations described here.

Another alternative is to amplify the input signal in a "flat" amplifier, and then apply the signal through a lossy network with the RIAA replay characteristic. This method is fairly common in some of the more ambitious preamplifiers that have appeared from time to time. For those who may wish to try this idea, Fig. 5 shows a suitable network for use with the module described here.

The network shown, tested with our models, reproduced the RIAA replay curve within ±0.5 db. The loss at 1 Kc, as one would expect from the curve, is approximately 17 db. This means that the gain at 1 Kc using the "flat" module version and this network will be 26 db minus 17 db, or about 9 db, roughly a voltage gain of three times. This may not seem very much, but the signal level will now be sufficiently high in most cases for noise to be a problem no longer, and the amplifier feedback is the same at all significant frequencies.

Lossy Tone Control

The use of a lossy type tone control with this module is of course quite possible. Two typical arrangements that have been used are shown in Fig. 6. Both of these arrangements provide ±10 db at 100 cps and at 10 Kc, and both should be fed from a comparatively low impedance source. The range of tone control available will depend to some extent on the impedance presented to the output of the circuit also, so that in some cases, trimming of values may be necessary to get the results required.

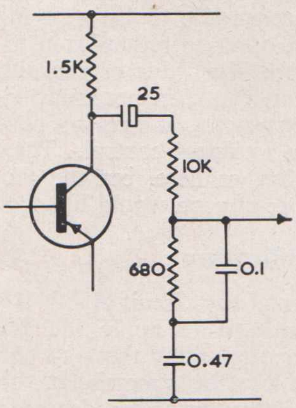

Fig. 5

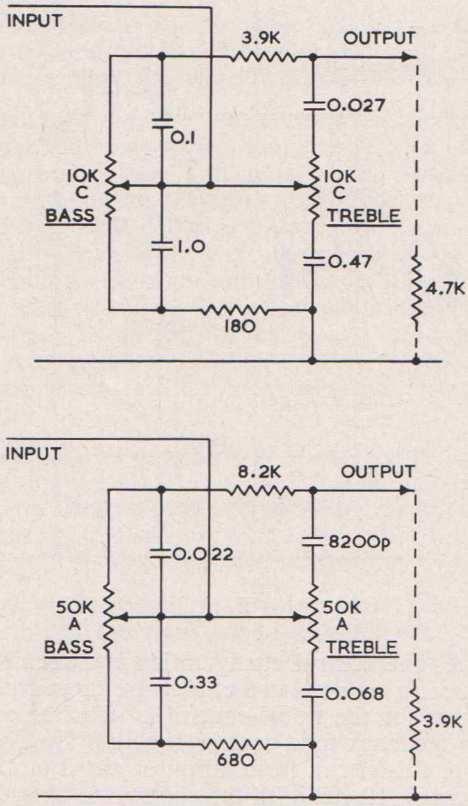

Fig. 6

The loss in a lossy type control with the system adjusted for "flat" response will normally approach the available range of boost. This means that a loss of 10 to 12 db may be expected in these controls between the input and output terminals.

Feedback Balance Control

No mention has been made so far of a balance control, which is an essential part of any stereo system. This control, and the gain control, have been omitted from the discussion because they are usually passive controls which can generally be inserted into the circuit at any convenient point.

It is possible that in many preamplifiers which could be put together using the basic circuits detailed here, there will be a "flat" module whose function is merely to lift the general signal level. In the original design, feedback in this module would be provided by a 1.5K resistor with a capacitor in series. It must be remembered, however, that a little more gain or a little less gain can be taken by varying the value of the feedback resistor. Whilst a large variation will affect the performance of the circuit, this does give some small margain available.

Whilst we have the feedback available, there is no reason why we should not employ an active balance control, substituting the elements of the control for the fixed feedback resistors. This seems to be quite an elegant thing to do. Let's take a look at how to do it.

First of all, so that it will be seen what is happening, the gain of the circuit has been plotted in Fig. 7 relative to the gain with the standard 1.5K feedback resistor. The first thought is to use a ganged balance control with "C" and "E" tracks (log. and antilog.) so arranged that at the centre position, the half of the element with the smaller resistance is in circuit in each channel.

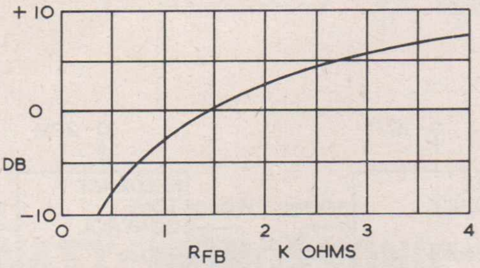

Fig. 7

To explain this, imagine a potentiometer viewed from the knob end of the shaft and with the tags pointing towards the ground. Then the tags are labelled 1 to 3 from left to right. In the case of the "C" track, makers' curves show about 10% of the total resistance between tags 1 and 2 with the shaft in the mechanical centre; in one channel, therefore, these connections would be used in lieu of the fixed resistor. In the case of the "E" track, the law of the XX element is reversed, and tags 2 and 3 would be used.

We will now have about 10% of the total value of each element in circuit, and rotation of the shaft from the mechanical centre will result in an increase of resistance and more gain in one channel, whilst at the same time a decrease of resistance value and less gain will be present in the other channel. In other words, we have a differential adjustment of gain, which is what a balance control should provide.

Being more specific, we know that about 1.5K ohms are needed normally in the circuit. If we look at the makers' data, we also learn that the "C" and "E" curves are not exact reciprocals one of the other, and equal resistance will be inserted in each channel with the shaft at about 53% of the total rotation, giving us about 12% of the total resistance in each channel.

If we take a 15K potentiometer unit, 12% of this is 1.8K, which is a little high. From the chart we read the gain at + 1.5 db. If now we rotate the control through 10% of its travel, the resistance in one channel falls to about 6%, 0.9K, corresponding to —3.8 db, a total of —5.3 db when the +1.5 db is added. At the same time, in the other channel, the resistance has risen to about 30%, 4.4K, corresponding to +8 db; when the +1.5 db is subtracted, this leaves us with a net increase of 6.5 db. The total variation between the channels, assuming them to have been equal at the start, will be 11.8 db.

If a 10K unit is used, 12% of that is about 1.2K, corresponding to —1.8 db on the chart. For a 10% rotation, the 6% and 30% values come out at 0.8K and 3K, —4.7 db and +5.3 db respectively; when corrected by the —1.8 db, this gives net results of —2.9 db and +7.1 db.

It could be said, why not use a ganged 3K linear pair of potentiometers? The answer is that this could be done too. With the mechanical centre giving 1.5K in each channel, 10% rotation gives 1.2K and 1.8K, —1.8 db and +1.5 db respectively, whilst with 20% rotation, we have 0.9K and 2.1K, giving —3.8 db and +2.7 db, a total differential of 6.5 db.

This has been followed through at some length, not because there is anything very highly original or technical about it, but to show to some of our experimenter friends how a problem can be approached in a systematic way.

Complete Preamplifiers

The only thing remaining to be done now is to indicate how the various units already discussed can be put together to make complete preamplifiers. So much has been said about them already that it is not proposed to produce a set of complete circuit diagrams, but some suggestions in block diagram form.

Some of the circuit possibilities are shown in Fig. 8. Fig. 8A shows the simplest use, which is a head amplifier intended to go under the motor board close to the pickup. It is equalized for use with a magnetic cartridge, and provides a gain of about 20 times at 1 Kc. If the three-transistor circuit is used, incorporating the common collector stage, the leads from this amplifier to the main amplifier may be of any reasonable length without attenuating the higher frequencies.

In Fig. 8B we see a further application which consists of a complete preamplifier to provide a low-level output. The first module gives us equalization and a gain of 20 times at 1 Kc, followed by the gain control. In all of these circuit, the gain control is assumed to be at the half-way position, thus giving us a 6 db margin in calculating levels. This results in a 50 mv input to the tone control module which follows, and an output of 200 mv from the preamplifier. With the gain control at maximum, the output level will of course be 400 mv. A balance control has

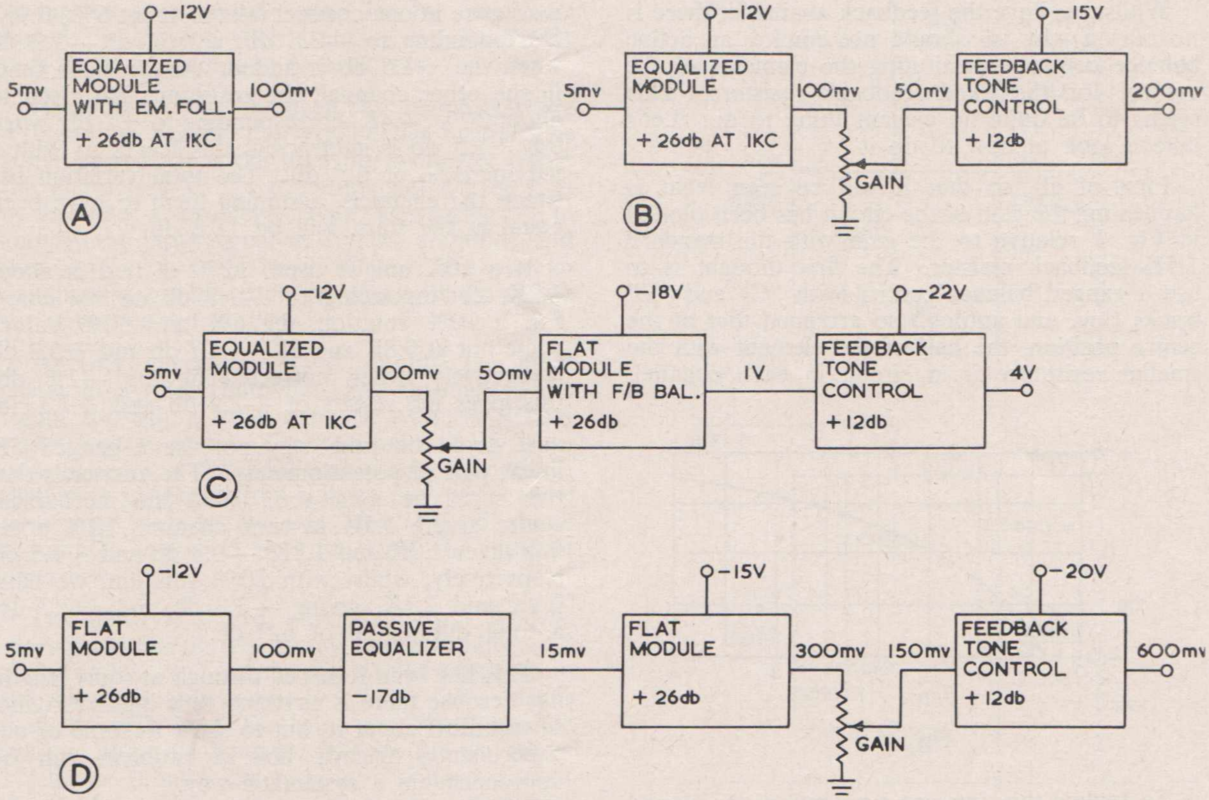

Fig. 8

not been included. It could be used either before or after the gain control, or at the output of the preamplifier.

Any type of balance control could be used, ranging from a simple linear potentiometer with the slider grounded to the system already discussed in these pages using ganged log, and antilog. controls. (See "Stereo Balance Controls," Vol. 28 No. 4, April, 1963.) Appropriate allowance must be made for losses in calculating levels through the preamplifier.

Fig. 8C shows a more complex preamplifier in which all three of the modules discussed are used. From what has gone before, a detailed discussion of this version is hardly necessary. The output level of 4 volts shown is likely to run the output stage into clipping and is therefore to be regarded as a theoretical level. It will be seen that this system has ample gain, so that measures which reduce the gain could be considered. One could, for example, use a lossy-type of balance control instead of the feedback type already explained. Alternatively, the amount of feedback applied in the "flat" stages could be increased to take care of some of the surplus gain.

Another variation of Fig. 8C could be used in which the "flat" module and the tone control module are interchanged. With all these circuits, if the signal from the preamplifier is to be fed through long screened leads to the main amplifier, then the final module in the circuit should incorporate the third or common collector stage to give a low-impedance output.

For those who would like to try passive equalization, Fig. 8D shows a typical system in which the passive network already described is used between two "flat" modules, followed by a gain control and the tone control circuit. For a 5 mv input, this gives us a 600 mv output, 1.2 volts with the gain control at the maximum position. As before, a balance control may be inserted at any convenient point. If more gain is required, a further module may be added, with excess gain taken up in extra feedback in the second "flat" module and in the added module.

Module Gains

The mid-frequency gain of the equalized module is largely fixed by the necessity of providing the right type of response curve, so that adjustment of this figure is not very practical. In the same way, the overall gain taken from the feedback tone control is largely determined by the necessity of providing the required range of control in an even manner without appreciable "drift" of the mid-frequency point with variation of the controls.

It is in the "flat" module, however, that we can make large adjustments in the gain we take from the stage. Whilst a very large increase of gain over the nominal 26 db that we have been discussing here may result in a degradation of performance, the reverse will be the case where increased feedback is used to reduce the gain taken from the stage. The ability to vary the gain of the "flat" module greatly increases the flexibility of the basic system described.

Summary

The development of a basic module of this kind is advantageous in that the same basic circuit can be used in a variety of positions. Many different preamplifiers can be made up using variations of the basic circuit. Some of the more obvious arrangements have been described here. Other possibilities, together with the ability to vary the gain taken from the "flat" module, make it possible to make up a preamplifier having almost any set of characteristics that may be required.

* * *

6-WATT MONOPHONIC AMPLIFIER

Continued from page 213

1962, which could be easily adapted for this purpose.

Except for readers who have had reasonable experience with amplifiers, it is not recommended at this stage that an attempt be made to take off dc power for the head amplifier from a point in the main unit. There is, for example, the possibility of constructing the head amplifier "upside down" for positive-active supply, and utilising the dc voltage developed across the cathode resistor of one of the output stages, with suitable dropping resistor and filter capacitor. Our own tests have shown that whilst this sort of thing can be done, it greatly increases the danger of instability in the system; it cannot therefore be recommended at this time.

* * *

ERRATUM

In the August issue this year, page 164, an equation for damping factor was reproduced as "E2(E1—E2)". It should of course read "E2/(E1—E2)". Our thanks are due to the reader who pointed out the error.

Editor .... **Bernard J. Simpson**

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