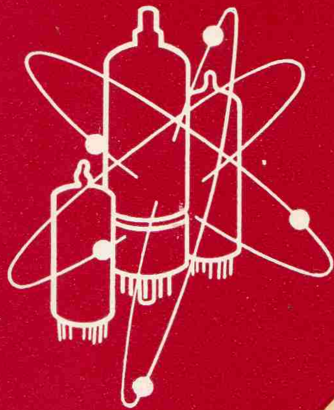

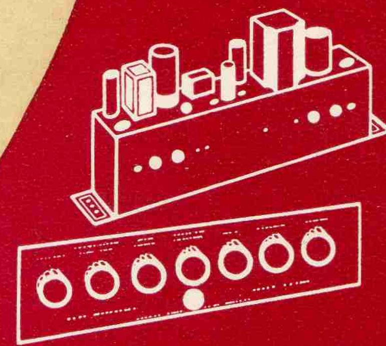

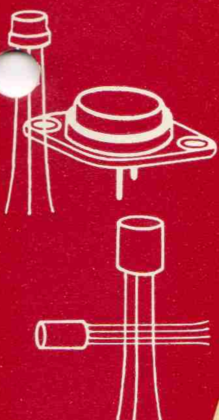

RADIOTRONICS

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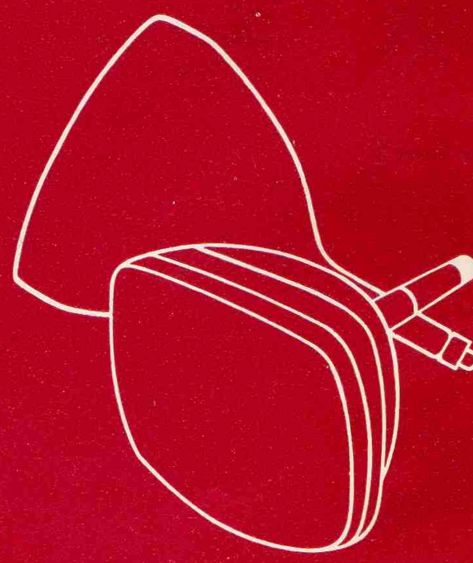

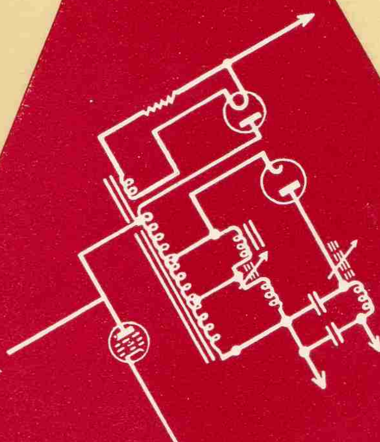

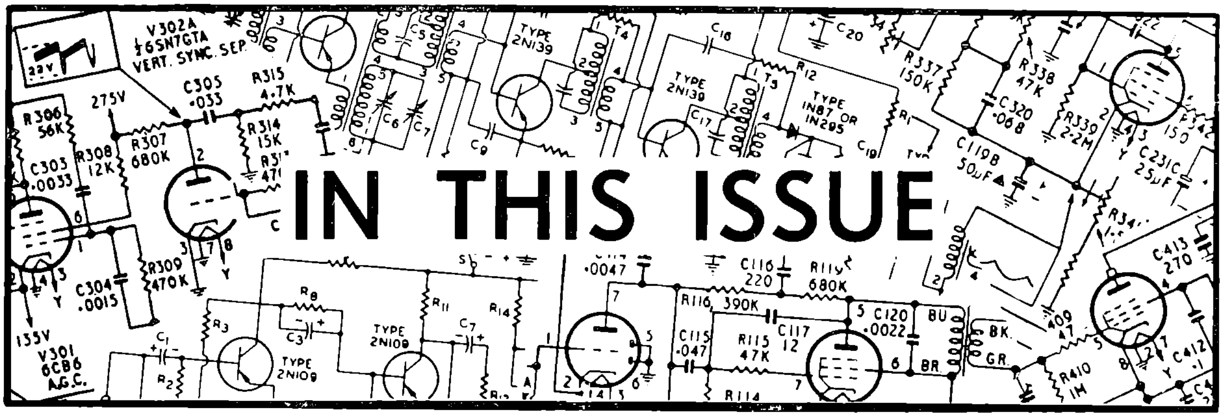

IN THIS ISSUE

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EDITOR .... BERNARD J. SIMPSON

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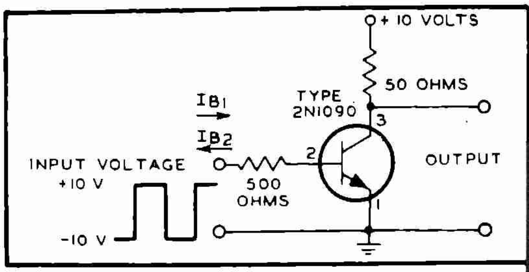
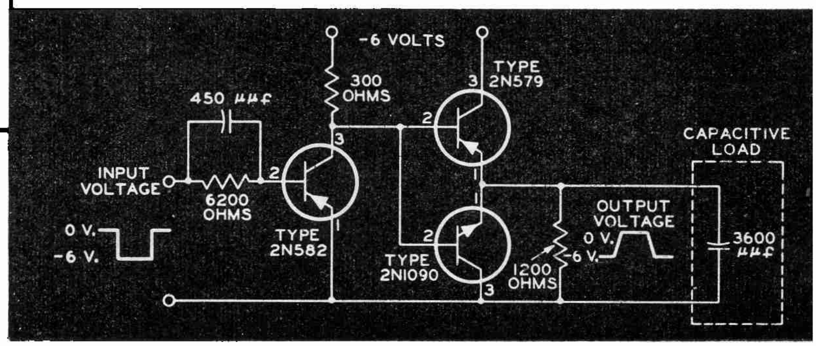
Transistor Dissipation Ratings



FOR PULSE AND SWITCHING SERVICE



The permissible dissipation of a transistor is determined by the maximum permissible temperature of its collector junction (usually given in published data as "Maximum Storage Temperature"). Published maximum dissipation ratings for RCA and AWV transistors are for class A or class B operation with signals having sinusoidal waveforms. These ratings do not apply for pulse or switching service.

When a transistor is used in pulse or switching service its instantaneous dissipation may greatly exceed its class A or class B dissipation rating, depending upon the pulse width and pulse-repetition rate employed. The resulting rise in collector-junction temperature depends upon the thermal time constant and thermal resistance of the transistor, and may easily be great enough to destroy the transistor unless the peak dissipation is limited to a safe value. Because it is impractical to give maximum-peak dissipation values for all possible combinations of pulse width and duty cycle in the published data for a transistor, the value for a specific pulse or switching application must be determined by the circuit designer.

Determination of Permissible Dissipation

To help circuit designers determine these peak-dissipation values, this article gives the maximum permissible collector-junction temperatures, typical thermal time constants, and maximum thermal resistances of 39 transistor types specially designed for or frequently used in pulse and switching service.

These thermal parameters are given in Table 1. Also given are two graphs which can be used to determine the permissible peak dissipation for any of the types listed in terms of pulse width, duty cycle, and either ambient temperature or case temperature.

Each graph consists of two sets of curves. One is a family of "Normalized Curves" giving the ratio of the permissible rise in junction temperature to the product of peak dissipation and thermal resistance [$\triangle T_j(max)/P(max)R_T$], as a function of thermal time constant (τ_1), pulse width (t_o), and duty cycle (d). The other is a "Multiplication/Division Chart" giving $P(max)R_T$ and $\triangle T_j(max)$ as functions either ambient temperature or case temperature. In Graph No. 1, R_T is the thermal resistance between the collector junction and free air, and $P(max)R_T$ and $\triangle T_j(max)$ are given in terms of ambient temperature. This graph is most useful for computer and other low-power applications. In Graph No. 2, R_T is the thermal resistance between the collector junction and the transistor case, and $P(max)R_T$ and $\triangle T_j(max)$ are given in terms of case temperature. This graph is most useful for higher-power switching applications.

Temperature Considerations

Separate graphs are provided for computer and industrial service because maximum-junction-temperature ratings for industrial-type transistors are usually higher than those for other types, and because the different methods of cooling employed in computer and industrial equipment make it necessary to use different thermal constants to determine permissible peak dissipation. Transistors used in computer equipment are generally cooled by radiation and convection, whereas those used in industrial switching equipment are generally provided with heat sinks and cooled by conduction as well as by radiation and convection. When a transistor is used in computer service, therefore, its significant thermal resistance is that between the collector junction and the surrounding air, and the significant temperature is the ambient temperature. When a transistor is used in industrial switching service, its significant thermal resistance is that between the collector junction and the transistor case, and the significant temperature is the temperature of the case.

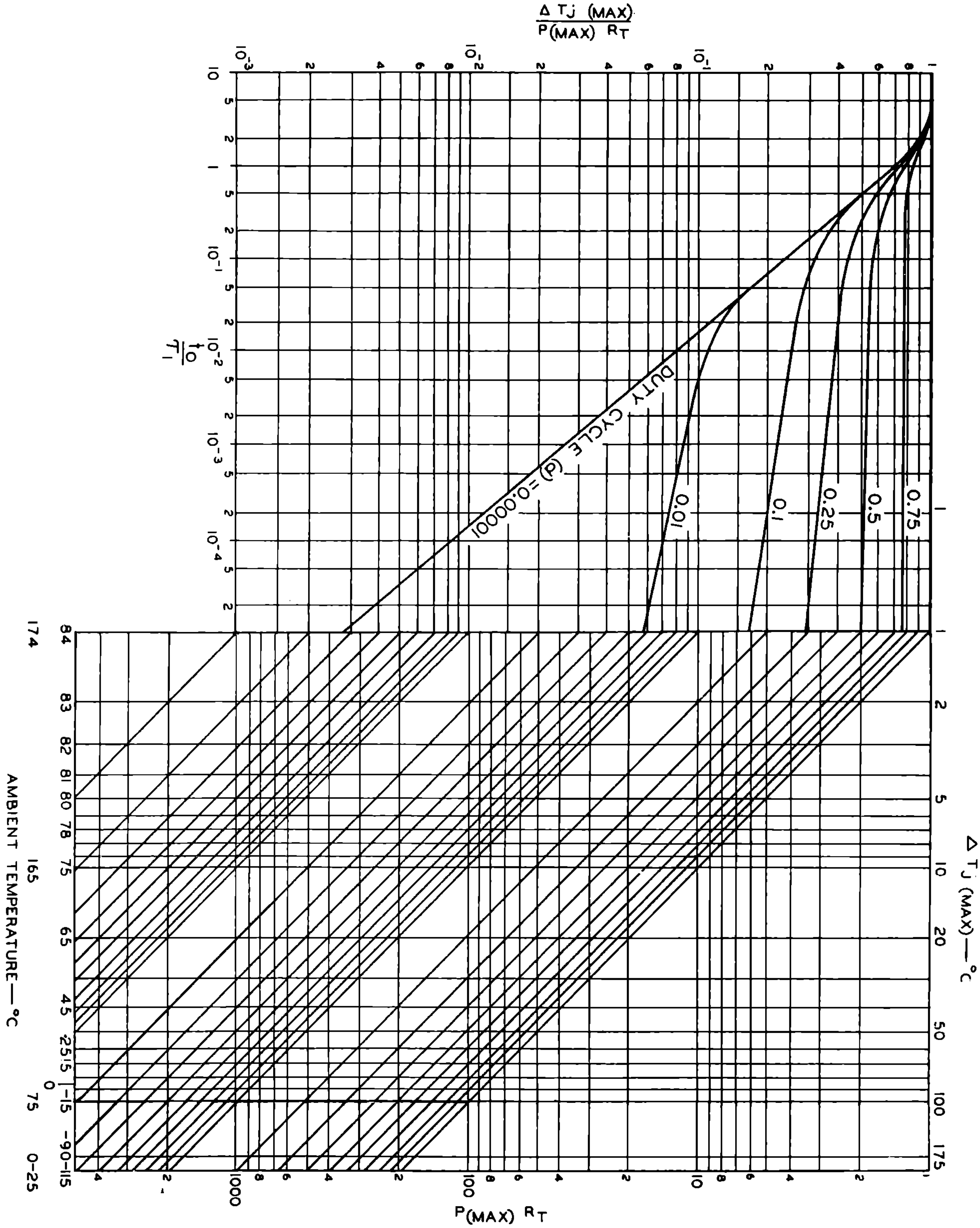
The mathematical derivations of the "Normalized Curves" are given in the Appendix.

Use of Graphs

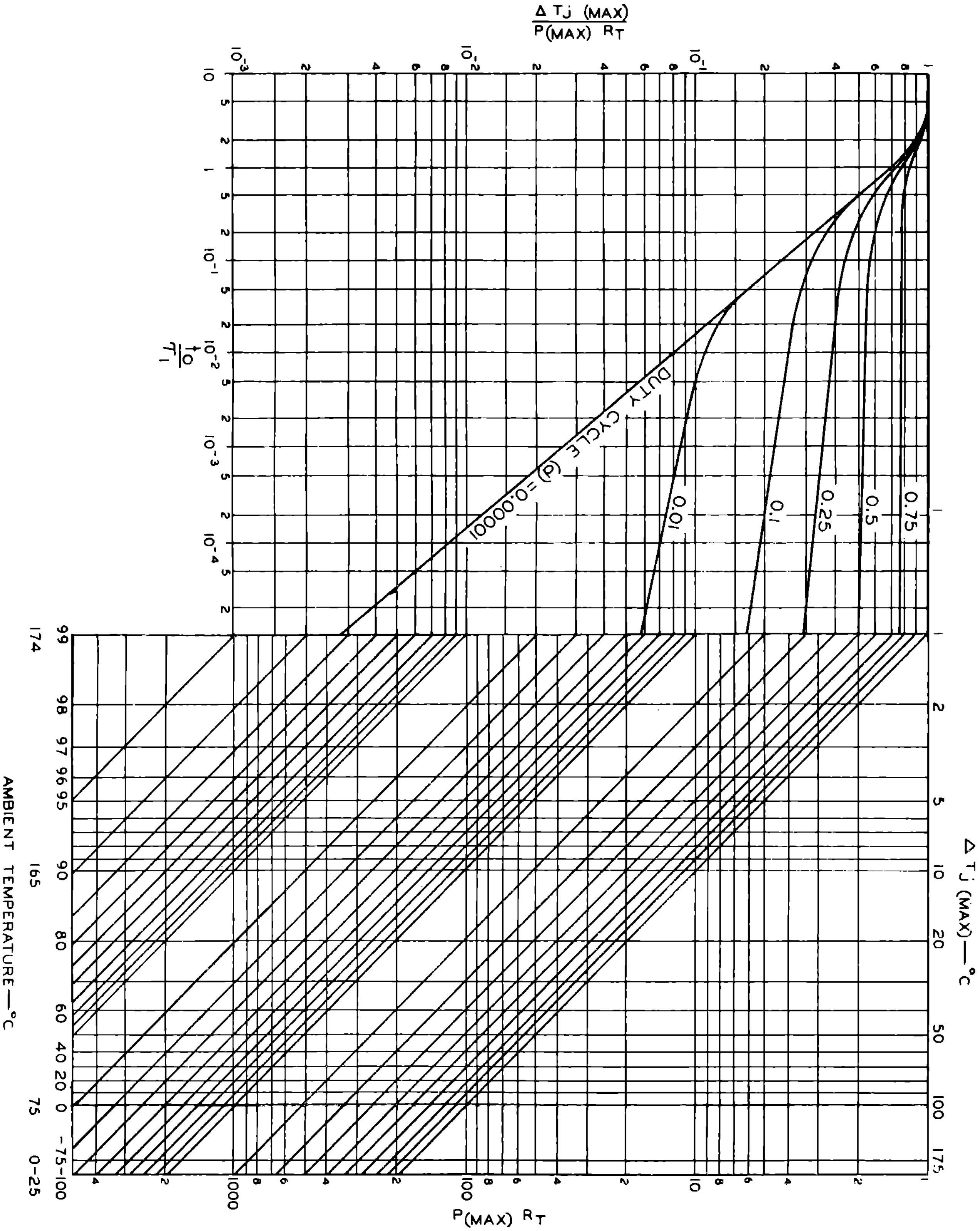
To determine permissible-peak-power dissipation for a specific transistor type in a pulse or switching application first determine the thermal time constant τ_1, and the appropriate thermal resistance R_T of the transistor from Table 1. Insert the value of τ_1 in the ratio t_o/τ_1 for the "Normalized Curves", and the value of R_T in the $P(max)R_T$ co-ordinates of the multiplication/division chart. Determine the value of $\triangle T_j(max)/P(max)R_T$ from the intersection of the appropriate duty-cycle curve with the coordinate for t_o/τ_1.

TABLE I

TRANSISTOR TYPE	MAXIMUM PERMISSIBLE COLLECTOR-JUNCTION TEMPERATURE $T_j(max)$ DEGREES C	TYPICAL THERMAL TIME CONSTANT τ_1 MILLISECONDS	MAXIMUM THERMAL RESISTANCE R_T DEGREES C/WATT COLLECTOR JUNCTION TO AIR (USE WITH GRAPH No. 1)	COLLECTOR JUNCTION TO CASE (USE WITH GRAPH No. 2)
2N109	85	12	400	
2N139	85	10	750	
2N140	85	10	750	
2N217	85	12	400	
2N218	85	10	750	
2N219	85	10	750	
2N247	85	12	750	
2N269	85	10	500	
2N270	85	12	240	
2N274	85	12	750	
2N356	85	15	600	
2N357	85	15	600	
2N358	85	15	600	
2N384	85	10	600	
2N398	85	12	750	
2N404	85	10	500	
2N456	100	8	-	1.4
2N457	100	8	-	1.4
2N561	100	8	-	1.5
2N578	85	15	500	
2N579	85	15	500	
2N580	85	15	500	
2N581	85	12	500	
2N582	85	12	500	
2N583	85	12	500	
2N584	85	12	500	
2N585	85	12	500	
2N586	85	12	240	
2N643	85	10	500	
2N644	85	10	500	
2N645	85	10	500	
2N1014	100	8	-	1.5
2N1067	175	8	100	30
2N1068	175	8	100	15
2N1069	175	10	-	3
2N1070	175	10	-	3
2N1090	85	12	500	-
2N1091	85	12	500	-
2N1092	175	8	225	5


Δ Tj (MAX) / P(MAX) RT
t0 / T1
DUTY CYCLE (P)=0.00001
0.01
0.1
0.25
0.5
0.75
Δ Tj (MAX)—°C
P(MAX) RT
AMBIENT TEMPERATURE—°C

Graph No. 1



Δ Tj (MAX) / P(MAX) RT
t0 / T1
DUTY CYCLE (d)=0.00001
0.01
0.1
0.25
0.5
0.75
AMBIENT TEMPERATURE—°C
Δ Tj (MAX)—°C
P(MAX) RT

Graph No. 2

Then read right along the coordinate for $\triangle T_j(max)/P(max)R_T$ to the corresponding diagonal on the multiplication/division chart. Determine the value of $P(max)R_T$ from the intersection of this diagonal with the coordinate for ambient temperature or case temperature, whichever is applicable. Solve for P(max).

Example:

Determine P(max) for transistor type 2N404 in a computer application using a pulse width of 10 microseconds and a duty cycle of 0.01, for an ambient temperature of 25 degrees C.

Solution:

t_o = 10 microseconds = 10^{-5} second
R_T = 500 degrees C per watt (from Table 1)
τ_1 = 10 milliseconds, or 10^{-2} second (from Table 1)

Therefore:

$$\frac{t_o}{\tau_1} = \frac{10^{-5}}{10^{-2}} = 10^{-3}$$

On the "Normalized Curves" of Graph No. 1, the value of $\triangle T_j(max)/P(max)R_T$ for $t_o/\tau_1 = 10^{-3}$ and $d = 0.01$ is 0.085. The diagonal for 0.085 on the multiplication/division chart of Graph No. 1 would be slightly more than halfway between the diagonals for 0.08 and 0.09, and would intersect the coordinate for $T_a = 25$ degrees C at $P(max)R_T = 710$.

Therefore:

$$P(max) = \frac{710}{R_T} = \frac{710}{500}$$
$$= 1.42 \text{ watts, or } 1420 \text{ milliwatts.}$$

APPENDIX

When a power pulse is applied to a transistor the resulting change in the temperature of the collector junction is determined by the pulse amplitude and width, and by the thermal time constant and thermal resistance of the transistor. The junction temperature is a maximum at the termination of the pulse and reaches its minimum value during the interval after the pulse has been removed. The junction temperature at any instant during the applied pulse is given by

$$T_{j1}(t) = PR_T\left(1 - \frac{8}{\pi^2}\sum_{n=1,3,5...}^{\infty}\frac{1}{n^2}\epsilon^{-\frac{t}{\frac{1}{n^2}\tau_1}}\right) + T_a$$

where (t) is the time after application of the pulse in seconds

P is the amplitude of the power step in watts

R_T is the thermal resistance of the transistor in degrees C per watt

τ_1 is the thermal time constant of the transistor in seconds

T_a is the ambient temperature in degrees C.

The temperature to which the junction cools after the pulse has been removed is given by

$$T_{j2}(t) = \left(\Delta T_j(max)\frac{8}{\pi^2}\sum_{n=1,3,5...}^{\infty}\frac{1}{n^2}\epsilon^{-\frac{t}{\frac{1}{n^2}\tau_1}}\right) + T_a$$

where (t) is the time after removal of the pulse in seconds

$\Delta T_j(max)$ is the difference between the maximum temperature reached by the junction during the pulse and the ambient temperature $[T_{j1}(t) - T_a]$

With repeated pulses the maximum temperature of the collector junction approaches the limit

$$T_j = P R_T \left(\frac{1-a}{1-ab}\right) + T_a$$

where $$a = \left(\frac{8}{\pi^2} \sum_{n=1,3,5\ldots}^{\infty} \frac{1}{n^2} \epsilon^{-\frac{t_o}{\frac{1}{n^2}\tau_1}}\right)$$

$$b = \left(\frac{8}{\pi^2} \sum_{n=1,3,5\ldots}^{\infty} \frac{1}{n^2} \epsilon^{-\frac{t_o}{\frac{1}{n^2}\tau_1}\left(\frac{1-d}{d}\right)}\right)$$

t_o is the pulse width in seconds

d is the duty cycle $\left(\frac{t_o}{\text{pulse repetition period}}\right)$

The maximum rise in junction temperature in normalized form is

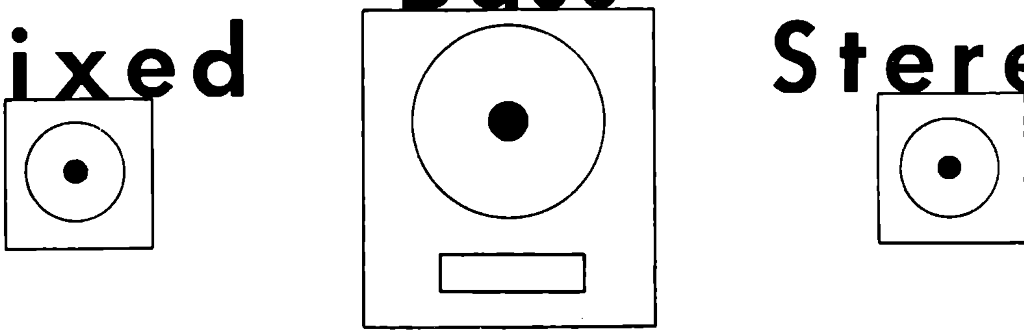
$$\frac{\Delta T_j(\max)}{P(\max) R_T} = \frac{1-a}{1-ab} = \frac{\left(1 - \frac{8}{\pi^2} \sum_{n=1,3,5\ldots}^{\infty} \frac{1}{n^2} \epsilon^{-\frac{t_o}{\frac{1}{n^2}\tau_1}}\right)}{1 - \left(\frac{8}{\pi^2} \sum_{n=1,3,5\ldots}^{\infty} \frac{1}{n^2} \epsilon^{-\frac{t_o}{\frac{1}{n^2}\tau_1}}\right)\left(\frac{8}{\pi^2} \sum_{n=1,3,5\ldots}^{\infty} \frac{1}{n^2} \epsilon^{-\frac{t_o}{\frac{1}{n^2}\tau_1}\left(\frac{1-d}{d}\right)}\right)}$$

where τ_1 and R_T are, respectively, the thermal time constant of the transistor and the thermal resistance between the collector junction and the transistor case.

The "Normalized Curves" in Graph No.1 and Graph No.2 are plots of $\Delta T_j(\max)/P(\max)R_T$ as a function of t_o/τ_1, with duty cycle as a parameter. The "Multiplication/Division" portions of these Graphs are provided to facilitate determination of P(max). In Graph No.1, the use of the thermal resistance between the collector junction and free air instead of separate values of R_T for the transistor and the case provides a safety factor and simplifies determination of P(max) for applications where heat sinks are not involved.

(With acknowledgements to RCA)

Mixed Bass Stereo



By B. J. SIMPSON

Stereo is not new. In fact, it is quite an old idea, as a search of the literature of the radio art will reveal. It has come upon us now, largely because improvements in technical facilities and "know-how" have made it a commercial proposition. Stereo records and the equipment with which to play them are now available in this country in ever-increasing quantity, and many of us are looking at the possibility of converting to stereo.

For those of us who must count the pennies, and that includes all but a fortunate few, stereo has raised many thoughts and problems. Many readers will of course already possess a single channel home music system, which has probably been built up over the years, with much trial and error, and which is dear to the owner. He has become attached to it. Frequently no specific data is at his fingertips to "prove" the quality of his set-up, and in some cases the fi is not as hi as it could be. This doesn't matter — he likes it and it gives him pleasure, which is surely why he listens to music. This of course eliminates the over - enthusiastic and unhappy few who play records to listen to the sounds rather than the music.

The point is that most listeners, even if they do convert to stereo, would also like to retain the character of their existing single channel for playing the stock of monophonic records they have collected over the years, and which they are certainly not going to discard.

Assuming then that there is a single - channel system already in the home, the first thing we learn is that a complete second channel is required. In other words, we are now faced with building up an almost complete duplicate set of the equipment already existing, plus the provision of a stereo pickup.

Much of this is inevitable of course if we want stereo, but there is at least one way in which we can produce acceptable stereo without complete duplication of the existing channel.

Let us look for a moment at the loudspeaker system in use. Most music systems will have either a single - unit wide - range speaker, almost certainly in an enclosure of large proportions, or they have a dual speaker system (woofer plus tweeter), probably also in a large box. The duplication of either of these two arrangements is costly, and is further complicated by the increased floor space required. This last point frequently causes distress to the distaff side of the family when the idea of a second unit is dangled in conversation, and is frequently vetoed without further discussion.

Granted then that a second amplifier channel and a stereo pickup or cartridge are required, what can we do about the loudspeakers? To answer this question, we must first take a look at the human hearing system, and the interesting phenomenon of binaural perception. At this stage we are fully aware of the mechanism of hearing, different lengths of sound path to the two ears, and how the brain, by detecting, measuring and interpreting signals generated by a different sound pattern at each ear, is able to tell us the direction from which the sound has come.

As with many things however, there is an imperfection, and this is going to save us space and money. The efficiency of our binaural perception is dependent on frequency, and it has been shown that this efficiency falls off very sharply for frequencies below about 350 cycles per second. In other words, frequencies below this figure play no part in producing the desired stereo effect.

With international standard pitch at 440 cycles per second for A, F is approximately 349 cycles per second. The fall-off frequency quoted therefore represents the usually - accepted top range limit for the bass tuba and a base singer. The range of the bass viol lies entirely below this figure, whilst substantial portions of the ranges of the cello, viola and wood-winds lie also below 350 cycles per second.

Before hundreds of letters are received from readers pointing out that they can locate the direction of a double-bass or the wood-winds in low register, this is quite so — we all can. But we derive this auditory perception, not from the fundamental frequencies being played, but from higher-frequency overtones and transients which occur at frequencies higher than 350 cycles per second.

Bearing these facts in mind it will be seen that acceptable and quite valid stereo can be reproduced if we separate the highs (above 350 cps) at the output of each channel, feeding the two sets of information to two high-register loudspeakers, whilst mixing the two bass outputs and feeding the combined bass to one low-register (woofer) loudspeaker. This conception is variously referred to as mixed-bass or blended-bass stereo, and is widely used at the moment overseas, particularly where "add-on" units are offered with the idea of converting to stereo. Some overseas manufacturers are offering special woofers for mixed-bass stereo, with two voice-coil windings, but so far as is known, no similar units are available locally. The arrangement produces a completely acceptable illusion of stereophony, giving directivity to instruments playing well below the cross-over frequency, by virtue of the harmonics and transients mentioned previously.

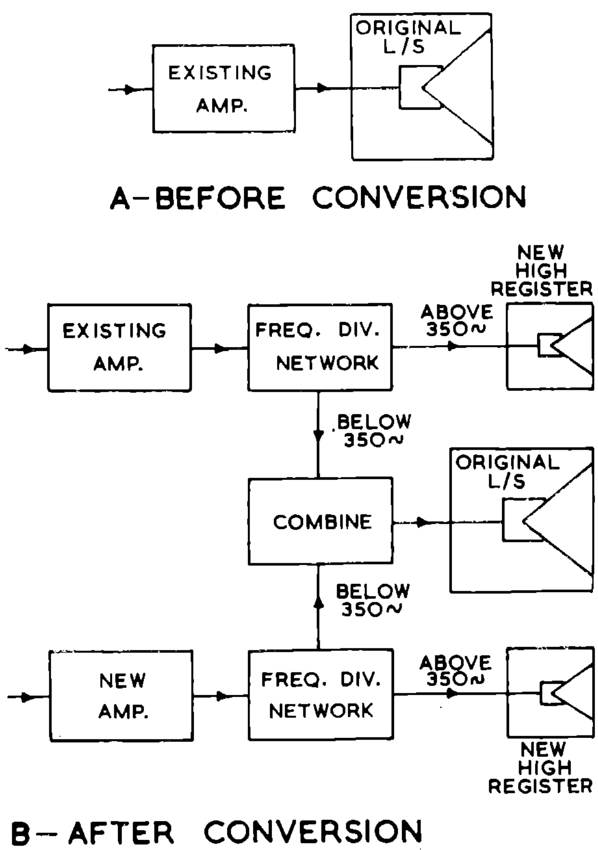


Fig. 1.—System Using Single Wide-range Loudspeaker Converted to Stereo using Mixed Bass.

CONVERSION TO MIXED BASS STEREO

It now remains to be seen how this idea can be adapted to existing home music systems, and then finally to review the advantages and disadvantages of mixed-bass stereo. Reverting to what was said before, the existing music system will probably have one of two popular speaker arrangements. One is a single, large, wide-range speaker, the other a dual arrangement consisting of woofer and mid-to-high-range unit.

Taking first of all the former case, wide-range speakers are expensive, and most enclosures for them are large. In this case, one solution which suggests itself is to provide an additional two mid-to-high register loudspeakers (say 8-inch units). These small units could be housed in quite small cabinets, as they are not required to operate below 350 cycles per second. These two units would then be given the customary stereo separation, and their size would present no trouble. Such units are often placed on bookcase shelves (the cabinet size can be arranged to suit individual room layouts), or are even fixed high on the wall of the room. This is a matter of individual taste and the characteristics of the room.

Meanwhile the original unit is used to reproduce bass when stereo reproduction is required, and is available as part of the original set-up when required for single-channel work. The location of the bass reproducer is relatively unimportant. It need not necessarily be located midway between the other two loudspeakers — in fact, frequently one of the newly-acquired smaller units is placed on top of the original unit.

The second case likely to be met, with two loudspeakers in one enclosure, is the simplest to deal with. All that is necessary is a second unit, preferably the same as the existing mid-to-high register loudspeaker, located n a small cabinet at an appropriate point.

One point to watch when making this type of conversion is that the two high-register loudspeakers are capable of good reproduction down to the rather low cross-over point of 350 cycles per second. The user will also need of course to provide suitable frequency-dividing networks in each channel to direct the different frequencies to the appropriate loudspeakers. In view of the rather low cross-over frequency, it is unlikely that any existing network will be of any use.

To illustrate the arrangement proposed, Fig. 1 shows a system using a single wide-range loudspeaker before and after conversion to stereo.

The conversion of a system using dual loudspeakers is shown in Fig. 2. With the arrangement shown in Fig. 1, advantage is taken of the wide-range speaker by letting it carry some highs as well as just acting as a woofer. This is done by mixing portions of the two high-register channels, and feeding the combined signal, with the mixed bass, into the wide-range speaker. In this set-up the speaker must be located between the

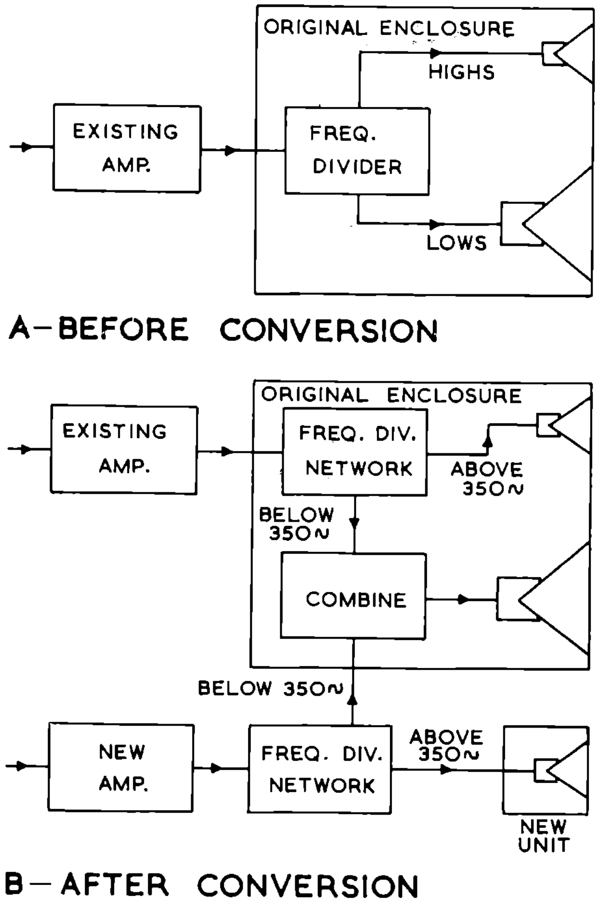


Fig. 2.—System Using High and Low-register Loudspeakers Converted to Stereo.

two small units. The amount of highs allowed to reach the centre speaker is controlled to give a simulated third or centre channel.

ADVANTAGES OF MIXED-BASS STEREO

Apart from the important considerations of cost and space, mixed - bass stereo offers a further major advantage. Probably the most important advantage is the comparative immunity it gives to the problem of excessive rumble in reproducing stereo records. In this regard a stereo system is much more sensitive to low quality in the turntable equipment, because the stereo cartridge is sensitive to vertical movement at low frequencies.

This is not the case with a monophonic cartridge, which is insensitive to vertical motion, and in which rumble in the reproduction is due to only lateral movement of the stylus. On single-channel reproduction, considerable vertical disturbance of the turntable can be tolerated without affecting the quality of reproduction. In stereo recording, remember that the vertical modulations in the record groove carry the difference intelligence between the two channels. In the stereo cartridge therefore, the system by its very nature requires good pickup sensitivity to vertical as well as lateral movement, and unless good quality turntable equipment is used, excessive rumble may result.

Now this rumble occurs of course only at quite low frequencies, and when the bass sections of the two channels are mixed, cancellation of most of the excessive rumble will take place without affecting the total bass in the required signals. Mixed-bass stereo therefore allows the use of cheaper turntables to produce an acceptable standard of reproduction. The prospect of having to change the turntable equipment is not always obvious when considering a changeover to full-range stereo.

DISADVANTAGES OF MIXED-BASS STEREO

It is obvious that a mixed-bass stereo system cannot duplicate exactly the performance of two identical full-range reproducing systems. It is a well-known fact that doubling the effective radiating area of a low-register loudspeaker by adding a second identical unit will increase the total bass output, and can moreover extend the effective bass range by up to one-half octave.

The full advantage of this effect is not realised in stereo systems employing two full-range loudspeaker systems due to the separation of the two reproducers, but some additional bass is realised. This is not so of course in a mixed-bass system. It is left for the reader to judge whether this is really a disadvantage, but let it be pointed out that in systems using two full-range loudspeaker systems, tweeter level controls are frequently incorporated to restore balance whilst retaining the additional bass range.

There is also the largely-unexplained tendency noticed when reproducing stereo through two-woofer systems towards a further extension of bass range. This further extension, peculiar to stereo, is over and above that mentioned above. This effect also is lost when using only one bass reproducer. The listener also loses the tendency for bass delivered from two separate loudspeakers to smooth out the "peaky" response which can result from standing waves in the listening room.

SUMMARY

Mixed-bass stereo, whilst losing some quality in reproduction, provides acceptable stereo at lower cost, not only in loudspeakers but possibly also in turntable equipment. The savings can be significant, not only in new systems, but in conversion of existing monophonic systems. The disadvantages claimed seem to be largely subjective, and are to some extent dependent on unpredictable factors, such as room acoustics, which affect all home music systems.

AV43

Demonstration Cathode-Ray Tube

DESCRIPTION

The AV43 is a demonstration cathode ray tube designed to illustrate electrostatic deflection and focusing, as well as magnetic deflection and focusing of a rectilinear electron beam. The tube consists of an electron gun, which forms a strip electron beam, and a display electrode. The essential electrode structure is sketched in Fig. 1.

The strip beam is produced by associating a long indirectly-heated oxide cathode, with two-dimensional beam-forming electrodes of the type proposed by Pierce (1940), designed to produce slight convergence so that the beam issues through a slot 1 mm wide in the anode. The display electrode, which is coated with willemite, is joined to the anode. The deflecting and focusing plates are mounted on separate insulated supports.

With the phosphor-coated conducting plate at anode potential held obliquely across the beam, potential conditions within the beam are unchanged, and a strip of phosphor will be excited which virtually gives visible sectioning of the beam. The strip beam may now be deflected and focused, and the trace on the display electrode will to all intents and purposes behave like a visible electron beam. Manipulation of the beam can be easily effected with externally-applied magnetic fields. The internal electrodes are designed to produce electrostatic deflection, and to illustrate the action of an electrostatic electron lens.

GENERAL DATA

Mechanical:

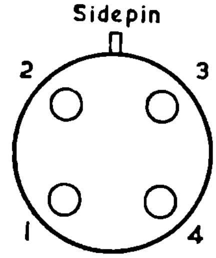
Mounting Position	Any
Maximum overall height	$8\frac{1}{4}''$
Maximum seated height	$8''$
Maximum diameter	$2\frac{1}{2}''$
Dimension, centre of defl. plates to end of screen	$3''$
Deflecting plate length	$\frac{1}{2}''$
Deflecting plate separation	$\frac{1}{2}''$
Bulb	T18
Base	Medium Metal Shell Jumbo 4-pin bayonet

Electrical:

Filament voltage	6.3 volts ac or dc
Filament current	1.25 amp
Fluorescent screen colour	green

Socket Connections:

(Bottom View)



Pin 1: R.H. Deflecting Plate
Pin 2: Heater
Pin 3: L.H. Deflecting Plate
Pin 4: Heater and Cathode
Top Cap: Accelerating Anode

Maximum Ratings:*

Accelerating voltage	500 volts
Focusing voltage	500 volts
Deflection voltage	200 volts

Typical Operation:*

Accelerating voltage	240 volts
Focusing voltage	0-240 volts
Deflecting voltage	0-100 volts
Accelerating anode current	10 ma
Deflection sensitivity	0.005"/volt

* Voltage and currents stated under "Maximum Ratings" and "Typical Operation" should be read as either "dc" or "ac rms" according to the mode of operation used.

OPERATION

When the deflecting plates are at anode potential, the beam is seen to spread under the action of thermal velocities and space charge (Fig. 2a). If the deflecting plates are tied together and their voltage with respect to the anode lowered, the electron lens system can focus the beam to a thin line (Fig. 2b), or to a definite crossover (Fig. 2c). Finally, a voltage difference between the deflecting plates will produce a deflected beam (Fig. 2d). The beam can also be deflected by an external magnetic field, using either a coil or a permanent magnet.

An anode accelerating voltage greater than 200 volts is recommended for viewing under normal conditions. The dc characteristic of plate current—accelerating voltage is given in Figure 3.

Circuits suitable for both ac and dc operation are shown in Figs. 4 and 5 respectively. In both cases a ganged potentiometer is used to prevent defocusing of the beam when it is deflected. By this means, even when the deflection voltage (voltage between the deflection plates) is altered, the voltage at a point mid-way between the plates would still remain at the focusing voltage.

The AV43, in conjunction with the AV25 (a demonstration triode described previously), is designed with educational uses in mind. It is natural, therefore, that the two valves be combined together in the one display unit. The circuit used for this two-valve display unit is shown in Fig. 6. For further data on the AV25 Demonstration Triode, see "Radiotronics", Vol. 24, No. 1, January 1959.

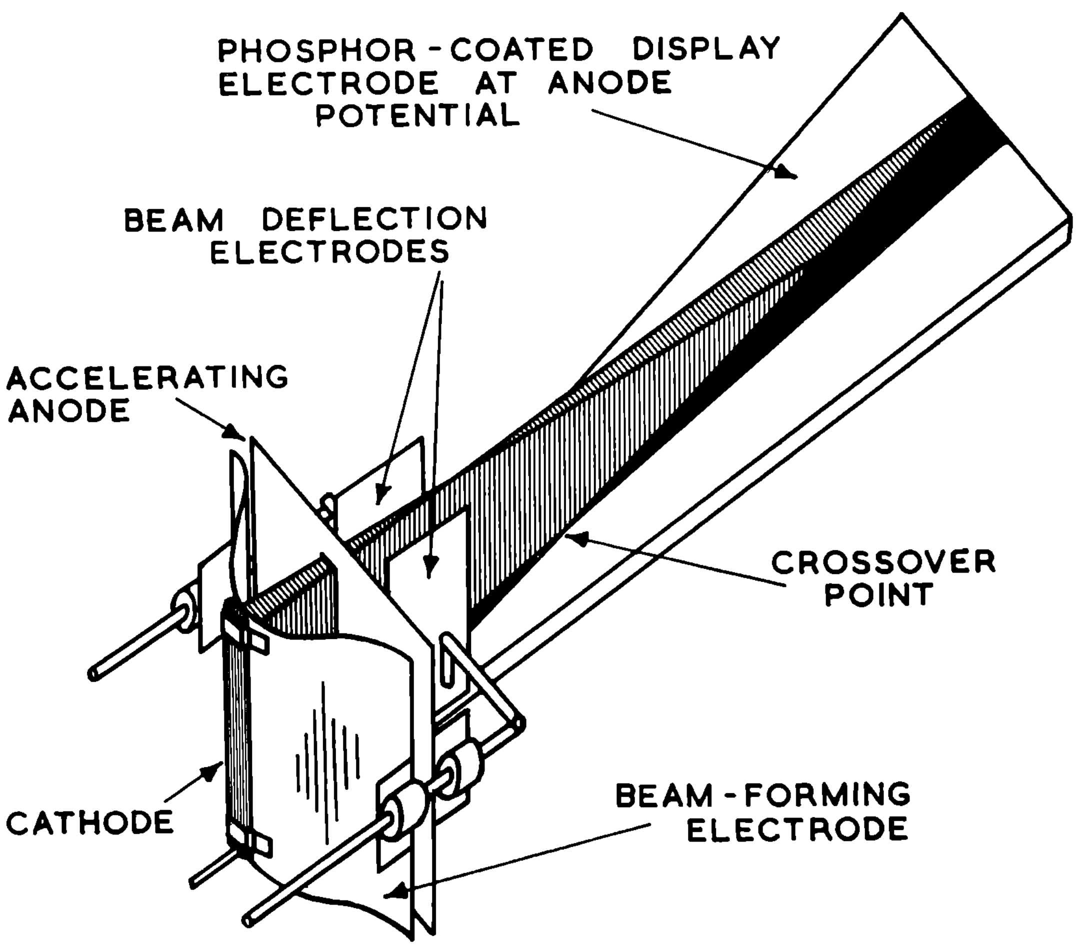


Fig. 1.—Electrode Structure of the AV43

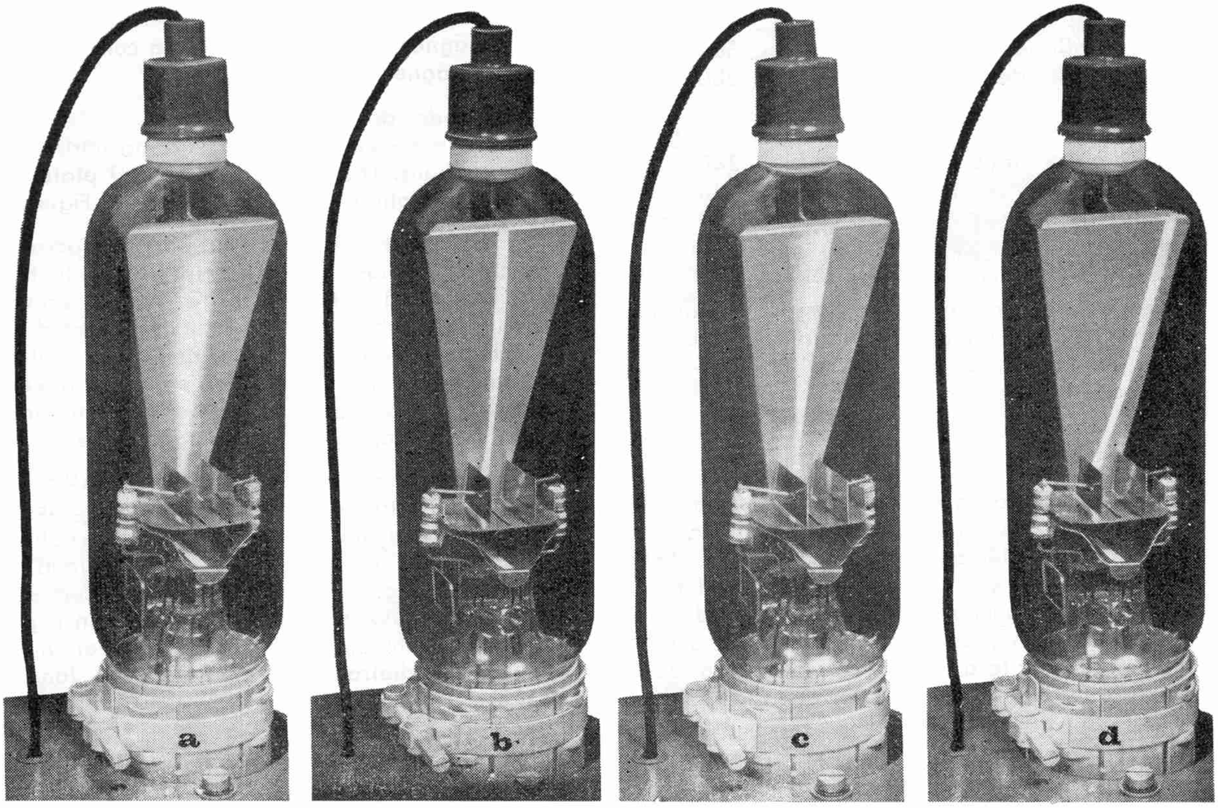


Fig. 2.—(Above) Photographs of the AV43;

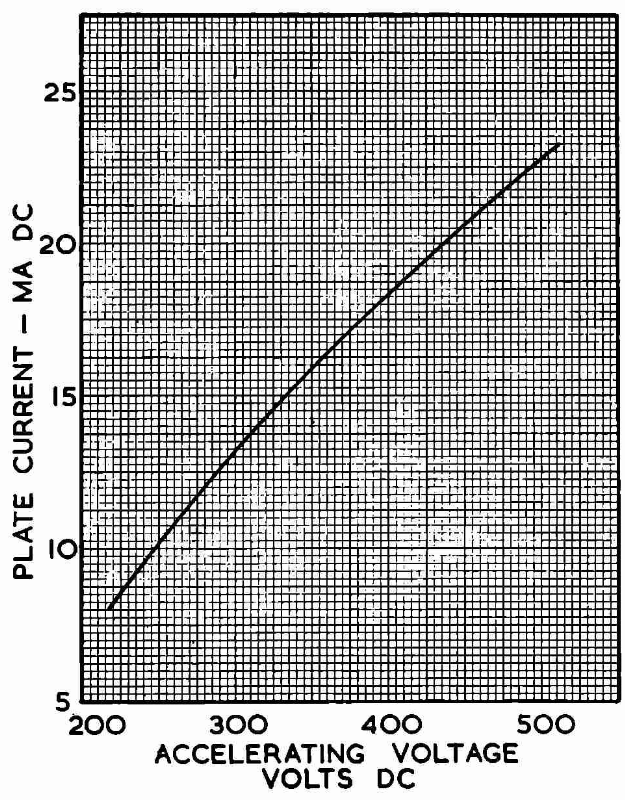
(a) With unfocused beam;

(b) With beam focused;

(c) With beam focused to crossover;

(d) Focused beam deflected.

Fig. 3.—(Right) DC Plate Current versus Accelerating Voltage Characteristic of the AV43.



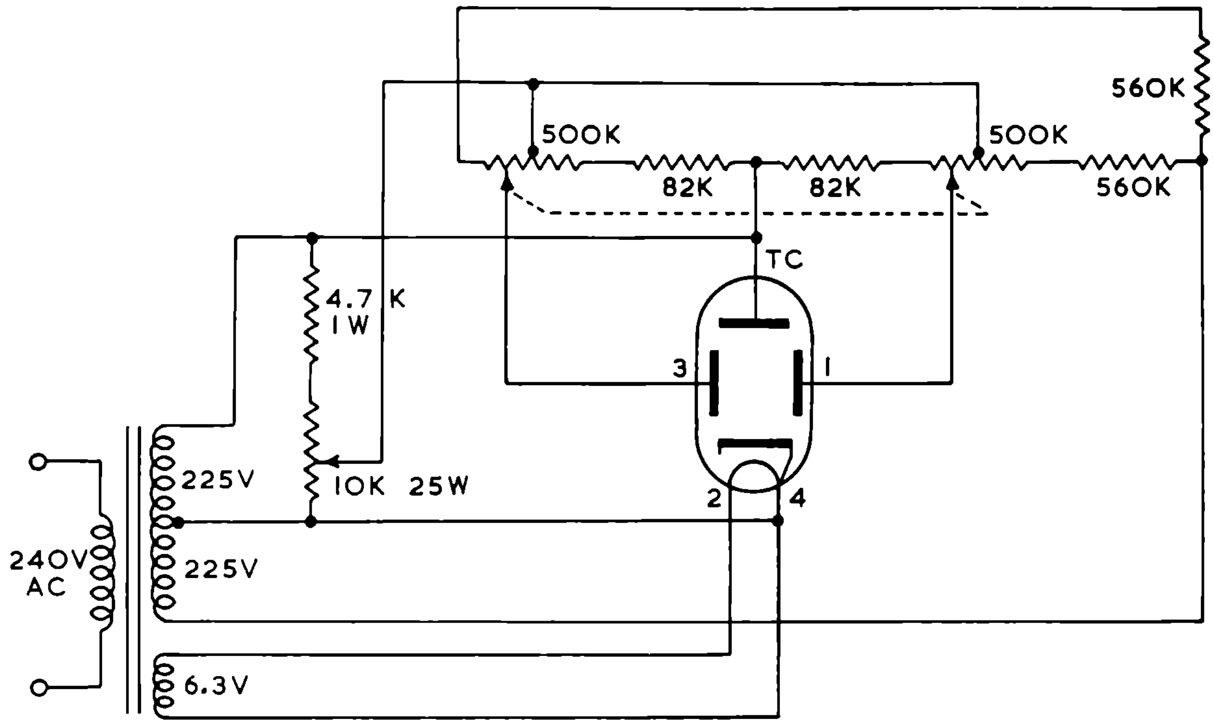


Fig. 4.—Circuit for AC Operation of the AV43.

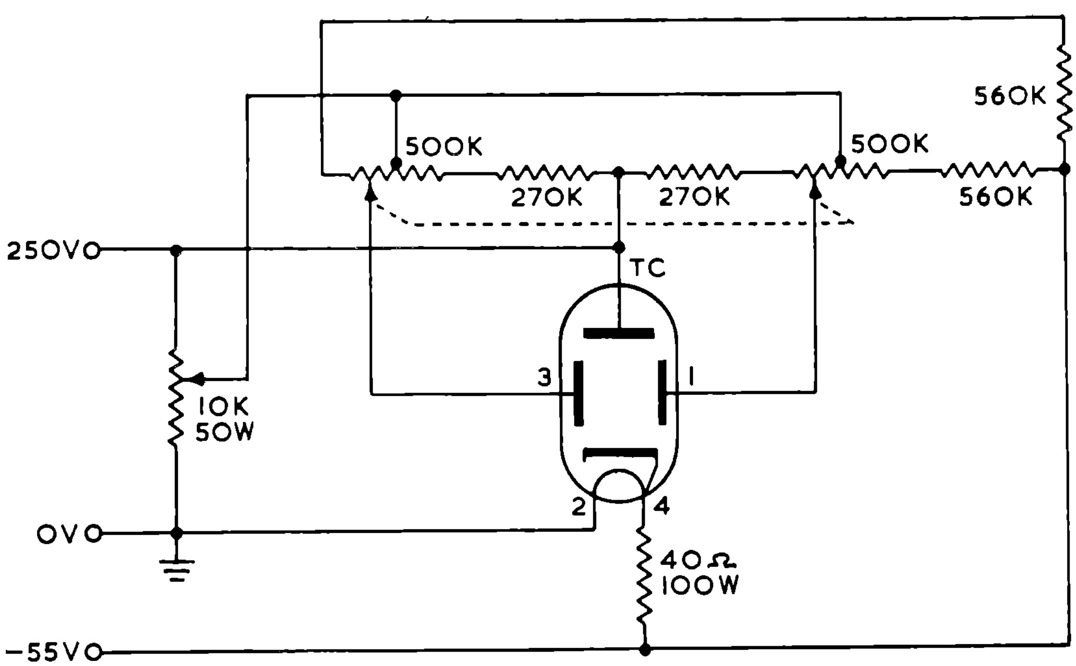


Fig. 5.—Circuit for DC Operation of the AV43.

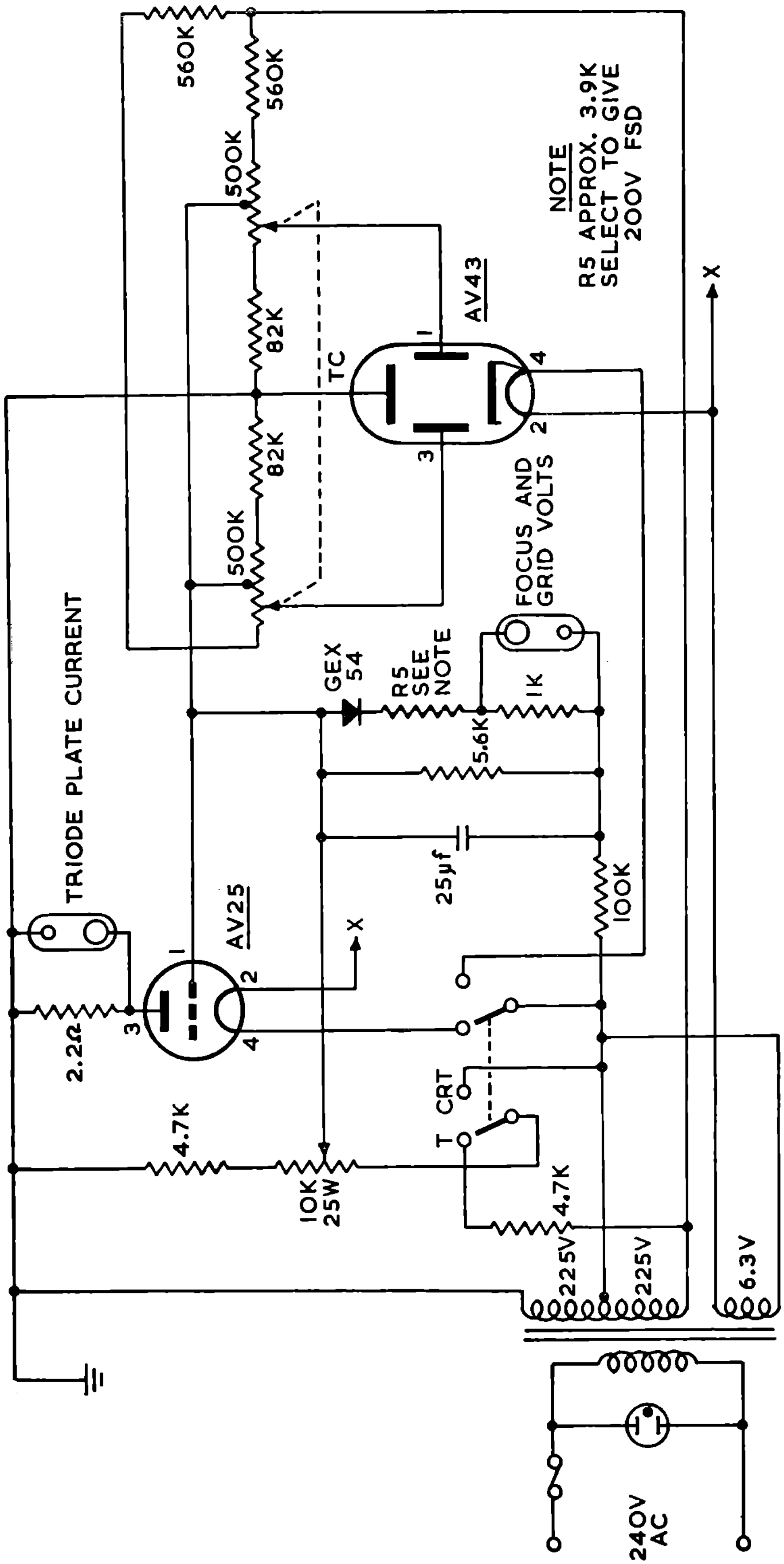


Fig. 6.—Circuit of Two-valve Display Unit using AV43 Demonstration Cathode Ray Tube and AV25 Demonstration Triode.

Off The Beaten Track

A SERIES DESCRIBING SOME OF THE MORE UNCOMMON VALVES AND VALVE DESIGNS

No. 4 — THE MAGNETRON

The magnetron, a highly efficient generator of rf energy in the microwave frequency range above 500 megacycles per second, is used in such diversified applications as radar, countermeasures, communications, relay service, telemetering, industrial heating, cooking, and diathermy. Magnetrons are useful as sources of both continuous-wave power and short pulses of high-intensity rf power. Although magnetrons can be designed for use as amplifiers, they are usually designed for operation as self-excited oscillators. Continuous-wave magnetrons may be frequency-modulated by means of an auxiliary electron beam and when so modulated are suitable for use in microwave communications systems. Amplitude modulation other than pulse modulation is usually not practical because frequency modulation occurs simultaneously.

Operation

The magnetron, which is a diode, generally consists of a cylindrical cathode surrounded by a cylindrical anode that may be divided into segments, and requires for its operation a magnetic field parallel to the cathode. The rf circuits are connected either between the cathode and anode or between the segments of the anode. The region between the cathode and the anode is called the "interaction space". In this region, the electrons interact with the rf field, and the energy gained from the dc field, applied between anode and cathode is converted into rf energy.

The most important type of magnetron is the "travelling-wave" type, which operates on the principle of approximate equality between the mean translational* velocity of the electron and the travelling-wave component of the rf field. The principal structural parts of this type of magnetron are illustrated in Fig. 1. The anode of this magnetron usually is made up of a number of rf resonators. In this type of magnetron, the product of the intensity of the magnetic field and the operating wavelength is inversely proportional to the number of resonators.

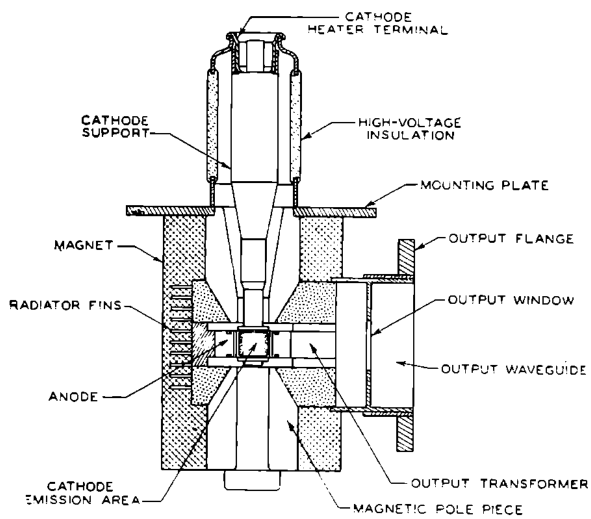


Fig. 1.—Structural Arrangement of the Essential Parts of the Magnetron.

In the analysis of the operating principles of a magnetron, it is desirable to consider first the case involving only dc operation (no rf voltage applied). An electron emitted from the cathode is acted upon by two radial forces, as shown in Fig. 2. The force, f_1, due to the dc electric field is directed toward the anode and is equal to eE, where e is the charge of the electron and E is the intensity of the electric field. The force, f_2, due to

* In transit between cathode and anode.

the magnetic field is directed toward the cathode and is equal to e (v X B), where (v X B) is the vector cross-product of electron velocity and magnetic-field density.

When the two forces, f_1 and f_2, are equal and opposite, the electron travels in a circular path around the cathode. In this "equilibrium" condition, therefore, a cloud of electrons circling the cathode extends to a certain radius. Beyond this radius, there is no electron space charge. If, however, the anode voltage is raised, the radius of the space-charge cloud increases, and electrons reach the anode.

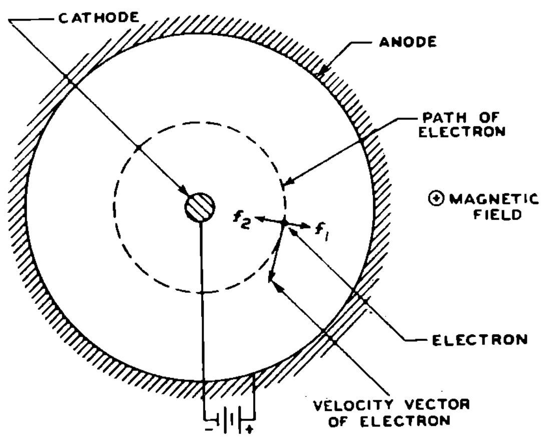


Fig. 2.—Electron Motion in a dc Magnetron (No rf Voltage Applied).

When a tangential rf field is present on the magnetron anode, the motion of the electron differs drastically from that described for dc operation. Fig. 3 shows an anode employing a multiplicity of vanes to divide the anode structure into a series of circumferentially disposed resonators. These resonators can be thought of as consisting of quarter-wavelength-long transmission lines shorted at their outermost ends, thereby producing an electric-field maximum at their innermost ends, i.e., at the vane tips, for optimum interaction with the electrons. A system of n coupled resonators can be shown to have n resonant frequencies, called "modes", each of which has a different electric-field distribution. The "π-mode", which gives the desired magnetron operation, is characterized by opposite rf potentials on alternate vanes, as shown in Fig. 3. Because a phenomenon called "mode selection" occurs at the start of magnetron operation, the magnetron designer generally uses a vane-type anode with strap rings, a hole-and-slot-type anode with strap rings, or a "rising-sun"-type anode to favour the desired π-mode. These types of anodes are shown in Fig. 4.

An electron located at point a in Fig. 3 and having velocity in the clock-wise direction experiences a force opposing its motion due to the tangential rf electric field. The electron, therefore, *loses energy to the rf field and is slowed down.* Because the decrease in electron velocity in effect reduces the force due to the magnetic field, the electron moves out toward the anode. If, during the time required for the electron to move from point a to a corresponding point, a′, between the next two vanes, the rf field reverses in polarity, the electron continues to lose energy as it circles the cathode, and moves further out until it is collected on the anode.

Because electrons which are out of phase with the rf electric field gain energy, the force on them due to the magnetic field increases, and they are pulled back toward the cathode. The alternating phase of the rf voltage, therefore, causes a series of spokes to form on the space-charge cloud extending out to the anode. The electrons in the spokes rotate about the cathode, staying in phase with the rf electric field and losing energy to it, until they strike the anode. Most of the energy gained by these electrons from the dc field between anode and cathode is lost to the rf fields existing across the vane tips. Electrons which are pulled back to the cathode give up this kinetic energy in the form of heat. When a magnetron starts oscillating, therefore, part of the cathode heating power is supplied by back-bombardment, and the heater input power must be reduced.

Magnetrons may be divided into pulsed, continuous-wave, and frequency-modulated types.

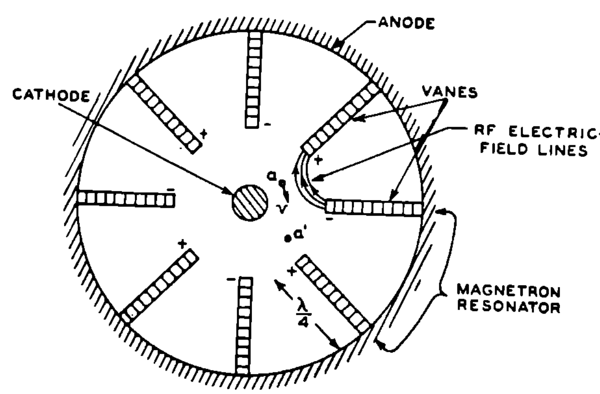


Fig. 3.—Field Distribution in an Oscillating Magnetron.

Pulsed Magnetrons

The pulsed magnetron, which is probably the best known type, is used extensively in radar applications. Both fixed-frequency and tunable types are anode-modulated by means of rectangular pulses which usually have a duration of 0.5 to 10 microseconds at a duty cycle of 0.0005 to

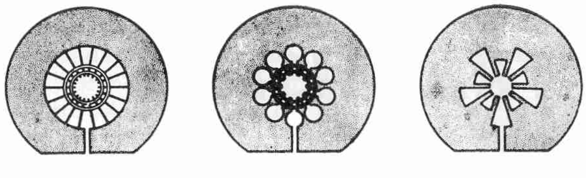


Fig. 4.—Three Main Types of Magnetron Anodes. l. to r.: Vane-type with strap rings, hole-and-slot type with strap rings, rising-sun type.

0.002. Present-day tunable types employ one of several tuning methods which provide mechanical tuning ranges of the order of 10 per cent.

Continuous-Wave Magnetrons

Continuous-wave magnetrons may be used in such applications as industrial heating, diathermy, "Doppler-effect" radar, and military jamming. These magnetrons may have a fixed frequency or may be tunable, depending on the application. Tuning methods used with these tubes are similar to those used for pulsed magnetrons.

Frequency-Modulated Magnetrons

Continuous-wave magnetrons can be converted to FM operation by means of an auxiliary electron beam provided by an electron gun. An electron beam controlled by a grid is introduced in a high-rf-field region in the tube. The electron beam follows a spiral path which increases in diameter as the electrons in the beam absorb energy from the rf field. After absorbing energy for a period of time, the electrons "fall out of" synchronism with the rf field and return energy to it. The electrons, therefore, alternately store and release energy. By proper adjustment of a dc magnetic field parallel to the electron beam, the effect of the beam can be made either inductive or capacitive, and the frequency can be changed. The magnitude of the frequency change is proportional to the number of electrons in the beam. Frequency modulation is accomplished, therefore, by the controlled variation of the electron beam produced by the application of a suitable signal to the grid of the electron gun. This type of modulation is known as "spiral-beam" modulation. FM magnetrons are useful in microwave communications systems such as relay links.

Magnetic Field

The strong magnetic field required by a magnetron may be provided either by a separate magnet meeting the required specification, or by a magnet built into the magnetron assembly; the latter arrangement is usually referred to as a "packaged" magnetron, and uses a permanent magnet. Where a separate magnet is used, either a permanent or an electro-magnet may be used. Care has to be taken to see that the strong field from the magnet does not adversely affect other parts of the installation, and to see that no degradation of the magnet is caused by rough handling and the proximity of magnetic materials.

A typical "packaged" magnetron is shown in Fig. 5. This shows the cathode and heater connector, top right hand, the large oval-shaped magnet, the rectangular waveguide output connector, and a series of cooling fins. This unit, like all high-power magnetrons, uses forced-air cooling. The type shown is six inches wide across the outside of the magnet; it produces a peak power output of 65 kilowatts, with a pulsed anode supply of 15 amperes at 16,000 volts.

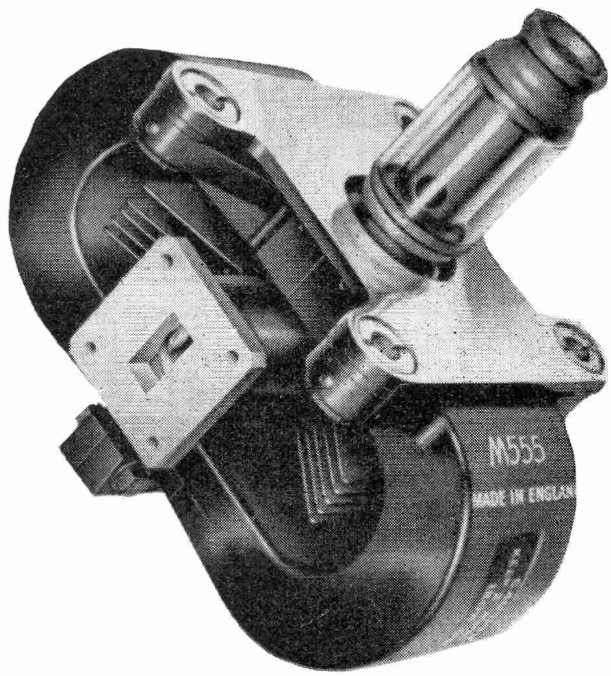


Fig. 5.—A Typical Packaged Magnetron, Wavelength 2 cm.

Output Arrangements

At the microwave frequencies at which magnetrons are used, waveguides are used in lieu of open or coaxial transmission lines, and the magnetron output arrangements are designed accordingly. The rf energy is picked up by means of a loop inserted in one of the anode cavities. This is satisfactory because all the cavities are mutually coupled. The energy is then led through a short coaxial line to an output probe.

The mounting arrangements for the magnetron are such that when it is in position, the probe enters the main waveguide, forming a transformation section. Very close mechanical tolerances are involved. Alternatively, as in the case of Fig. 5, a short length of waveguide, including the transformation section, is incorporated as an integral part of the valve; this is probably the more efficient arrangement of the two, permitting as it does a very short connection between anode block and waveguide, together with less possibility of faulty matching, rf leakage and other troubles.

NEUTRALIZING TRANSISTOR IF AMPLIFIERS

GENERAL

In the design of high gain if amplifiers using transistor types at present available, it is necessary to take into account the feedback inherent in the transistor itself. Stable operation generally requires that this feedback be neutralized. This condition may be obtained by applying external feedback in opposite phase to that through the transistor itself. The commonly used circuit shown in Fig. 1 lends itself to neutralization very simply. Here a capacitor C_n is connected from the end of the winding remote from the collector back to the base. By choosing a suitable value for C_n, the voltage at the base, fed via C_n, may be made to cancel that due to capacitive coupling back through the transistor. The feedback through the transistor will also include a resistive component, and for complete cancellation of the feedback, a resistance R_n must be added in series with C_n.

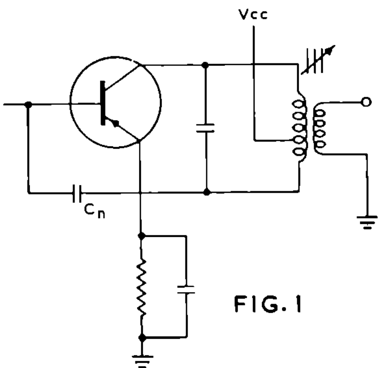


FIG. 1

The value of C_n required to neutralize feedback across the transistor itself should be relatively independent of frequency. Any large variation with frequency may be due to feedback through common impedances in power supplies, etc., or may be due to errors in the method of measurement.

It is desirable that the transistor be neutralized with as few changes in circuitry as possible, both for ease in carrying out the operation and accuracy of the result obtained.

SIMPLE DETERMINATION OF CORRECT NEUTRALIZATION

A typical if amplifier circuit is shown in Fig. 2A. An unmodulated 455 Kc signal is fed to point A, through a series resistor to prevent loading of the circuit. A detector is connected as shown at the point B, and C_n is adjusted for minimum detected signal.

A simplified circuit is shown in Fig. 3. C_f is the internal feedback capacitance of the transistor, and C_n is the neutralizing capacitor.

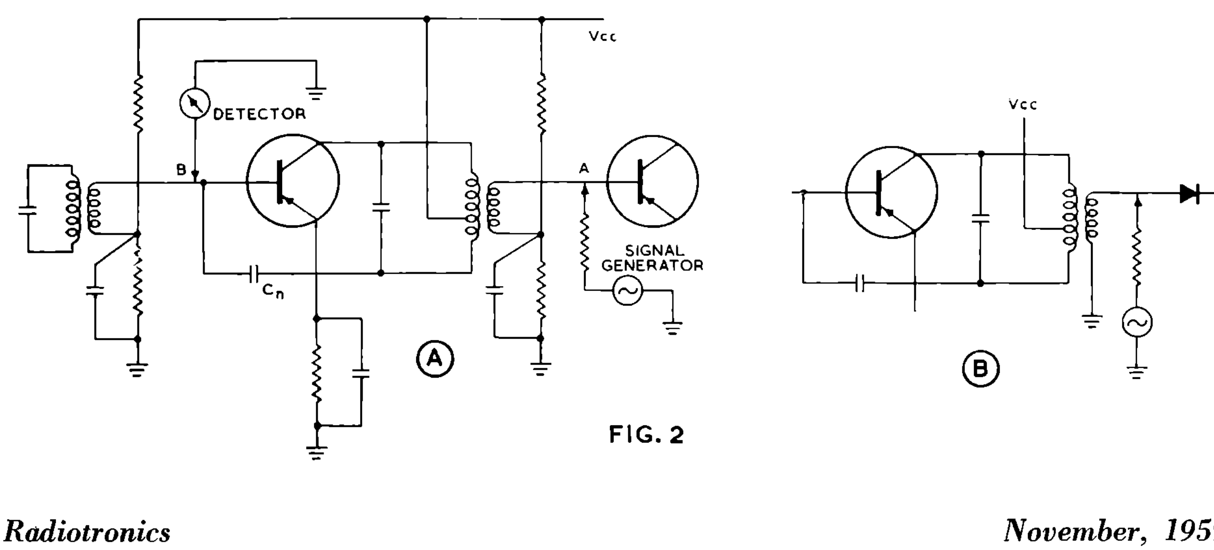


FIG. 2

If the value of C_n obtained is in fact the required neutralizing capacitance, it should be independent of frequency. This may be checked by readjustment of C_n with the signal generator tuned to say 455 Kc and 465 Kc. The variation in C_n should be only a fraction of 1 uuf. Variations greater than this may be due to external feedback effects, or errors in measurement due to incorrect use of equipment. This will be discussed in more detail later.

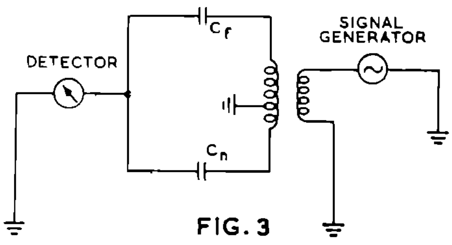


FIG. 3

PRACTICAL CONSIDERATIONS

Converter

The converter should be either removed from the circuit or prevented from oscillating. With the oscillator functioning it is practically impossible to obtain satisfactory neutralization.

AVC

When neutralizing the transistor to which avc is applied, it is desirable that neutralization be most effective when the gain is highest. (See Reference 5). The technique used to disable the avc will of course depend on the circuit. It may be sufficient to short-circuit the diode winding on the final if transformer, or a separate bias arrangement may be necessary where the avc is more elaborate. In most cases, if the if transistor following the controlled one is removed, the avc will be ineffective.

Signal Amplitude

Although the balance point is relatively independent of the amplitude of the applied signal, it is desirable that this amplitude be of the same order as that of the signal which is present at the point of injection during normal operation of the receiver. The signal level at the detector in the average receiver may be approximately 100 millivolts. A typical level at the base of the first if amplifier will then be approximately 2 millivolts. Difficulty will be experienced using a signal of this order since the out-of-balance component will be very small and will require a very sensitive detector. It will therefore be necessary in most cases considerably to increase the level. In one particular receiver an input of 50 millivolts was required to produce an out-of-balance component of 40 microvolts when C_n was correctly adjusted. Hence the sensitivity of the detector must be sufficient to indicate clearly a level of approximately 40 microvolts. The effect on the value of C_n of using very high input levels should be checked in individual cases.

Connection of Equipment

Although the detector is shown in the circuit with one side earthed, this arrangement is not always practicable. In particular, for the circuit shown in Fig. 2, the results obtained when attempting to neutralize in this manner will vary greatly with frequency. In this circuit the secondary of T1 which supplies the transistor to be neutralized, and the "cold" side of the collector load, i.e. the tap on the primary of T2 are bypassed to the emitter. An attempt to obtain a balance with this arrangement will be upset by a component of the signal which is derived from the tap on the if transformer, and which is applied between emitter and ground, and hence will contribute a signal between base and ground and between base and emitter. For purposes of neutralization, the emitter resistor in this case must be bypassed to ground.

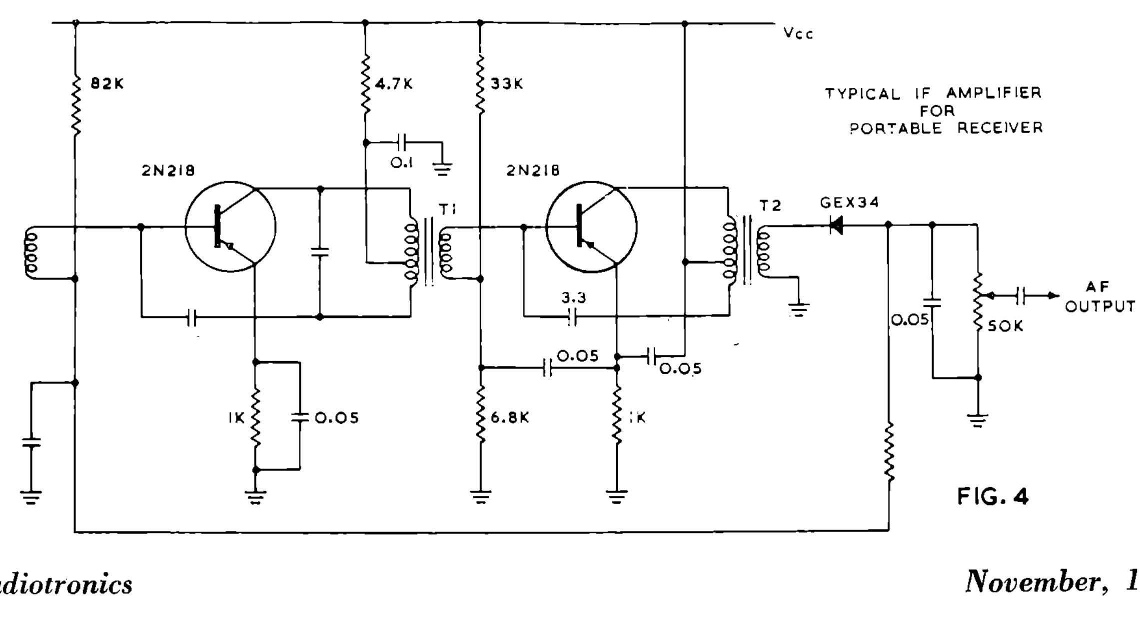


FIG. 4

A resistance should be used in series with the generator to prevent undue loading of the if transformer. A value of 1000 ohms is satisfactory.

Equipment

The equipment required consists of a signal generator having an unmodulated output of at least 100 millivolts, and a detector with a sensitivity of 40 microvolts or better. In the original work, the detector was an oscilloscope used in conjunction with a video amplifier.

A tuned amplifier having a bandwidth of 10-20 Kc could be used followed by an oscilloscope, electronic voltmeter or multimeter. The if section of a standard broadcast receiver could be used, but an investigation of the variation in neutralizing capacitance at different frequencies would be difficult due to the greatly reduced gain off resonance.

References

1. "Transistor I" (RCA Laboratories 1956) p. 323.
2. Shea — "Transistor Circuit Engineering" (Wiley 1957) p. 191.
3. Lo and others — "Transistor Electronics" (Prentice Hall 1955) p. 345.
4. Hunter — "Handbook of Semiconductor Electronics" (McGraw-Hill 1956) pp. 12-15.
5. Dewitt & Rossoff — "Transistor Electronics" (McGraw-Hill 1957) pp. 256, 262, 315.

NOTE

This article is a report based on work contributed by R. Frator whilst employed in the AWV Application Laboratory.

2N1300, 2N1301

The 2N1300 and 2N1301 are germanium p-n-p diffused-junction Mesa transistors specifically designed for high-speed switching applications in commercial and military data-processing equipment. In such equipment, these transistors are particularly useful in pulse amplifier, inverter, flip-flop, and logic gate circuits.

The 2N1300 and 2N1301 feature (1) a rugged Mesa structure with an extremely small base width to insure top performance at high frequencies, (2) high power dissipation, (3) high current gain, (4) high breakdown-voltage and punch-through-voltage ratings, (5) fast switching speeds because of high gain-bandwidth product and low total stored charge in saturation-type switching circuits, and (6) a typical gain-bandwidth product of 40 Mc and 60 Mc for the 2N1300 and 2N1301 respectively, which make these units especially useful in electronic computers operating at pulse repetition rates up to 10 Mc.

These features in addition to the use of stringent environmental and mechanical tests conforming with military specification MIL-T-19500 insure the dependable performance of the 2N1300 and 2N1301 in critical commercial and industrial data-processing equipment.

RADIOTRON 7214

The 7214 is a new, small, forced-air-cooled beam power valve designed for use in grid-pulsed and plate-and-screen-pulsed rf amplifier service in airborne, mobile, and fixed-station equipment. The 7214 can be used with full ratings at frequencies up through the Aeronautical Radio-Navigation Band of 960 to 1215 Mc. It has a maximum plate-dissipation rating of 1500 watts.

When used under CCS conditions as a plate-and-screen-pulsed rf amplifier in a cathode-drive circuit at 1215 Mc with a 10-microsecond pulse duration and a duty factor of 0.01, the 7214 is capable of delivering a useful peak power output of about 65 kilowatts with a driver power output of about 11 kilowatts at peak of pulse. Under similar conditions at 400 Mc, the 7214 can deliver about 100 kilowatts.

RADIOTRON 7270, 7271

The new transmitting types 7270 and 7271 are high-perveance beam power valves with high power gain. Alike except for heater ratings, these types are designed for use as vhf power amplifiers, and as af power amplifiers and modulators. The 7270 has a 6.3-volt, 3.1-ampere heater; the 7271, a 13.5-volt, 1.25-ampere heater. Each of these types has a maximum plate dissipation rating of 80 watts under ICAS conditions, and can be operated under these conditions with a cw input of 315 watts up to 60 Mc or with 235 watts cw input at 175 Mc.

As linear rf power amplifiers in single-sideband suppressed-carrier service, the 7270 and the 7271 under typical ICAS conditions can each provide a useful power output of about 135 watts. The 7271 is intended primarily for operation in mobile equipment having a nominal 12-volt power-supply system. In properly designed equipment, a 10 per cent reduction in electrode voltages caused by a 10 per cent reduction in the voltage of a 13.5-volt power supply will result in less than 3 db decrease in useful power output from any individual 7271.

RADIOTRON 7358

The new 7358 is a small beam power valve designed specifically for pulse modulator applications where dependable performance under severe shock and vibration is essential. It is electrically equivalent to type 6293.

The 7358 can deliver a peak plate current of 3 amperes during a pulse length of 30 microseconds under conditions with duty factor of 0.003 and plate-supply voltage of 2000 volts; or a peak plate current of 1.4 amperes during a pulse length of 200 microseconds under conditions with duty factor of 0.02 and plate-supply voltage of 3500 volts.

Small in size for its power-handling capability, the 7358 has a rugged button-stem construction with short internal leads, a T-12 bulb, triple base pin connections for grid No. 3 and cathode and an octal base with metal sleeve having its own base-pin terminal. The plate lead is brought to a top cap. The 7358 is designed to withstand special tests for shock, fatigue, low-frequency vibration and variable-frequency vibration.

RADIOTRON 7467

The 7467 is a small, photojunction cell of the side-on type employing a germanium p-n alloy junction. It is especially intended for sound-pickup-from-film and computer applications. The photocurrent of the 7467 has fast rise and decay characteristics. Signal output is approximately proportional to the intensity of the incident radiation. Other design features of the 7467 include an illumination sensitivity of 0.7 microampere per footcandle, and a power-dissipation capability of 30 milliwatts.

The special response of the 7467 covers the range from about 3500 to 19,000 angstroms. Maximum response occurs at about 15,000 angstroms. The 7467, therefore, has high sensitivity to red and infrared radiation as well as good response across the visible region of the spectrum.

RADIOTRON 7513

The 7513 is a television camera tube intended to provide high-quality performance in colour cameras utilizing the simultaneous method of pick-up, and in black-and-white cameras. The 7513 features precision construction which includes accurate alignment of each section of the tube with respect to the tube axis and maintenance of a high degree of uniformity for the location of all electrodes and interelectrode spacings. The resultant effect is excellent registration producing both a superior colour-television picture and a high-quality picture when viewed on a black-and-white TV receiver. In addition to its precision construction, the 7513 combines other design features to provide pictures of better photographic quality and realism in both colour and black-and-white TV.

AWV