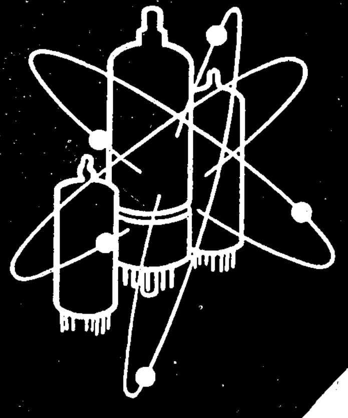
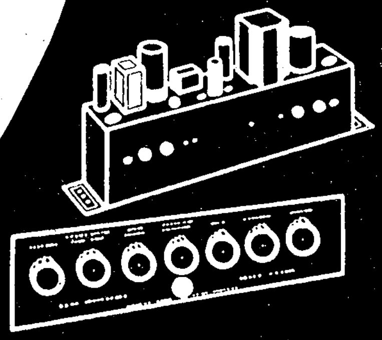
VOL. 23, No. 9 SEPTEMBER, 1958 ONE SHILLING

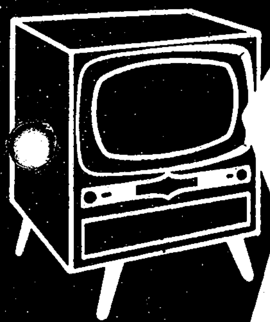
141.



ELECTRONIC VALVES

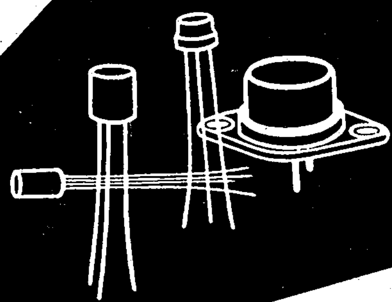
AUDIO





REGISTERED AT THE GENERAL POST OFFICE, SYDNEY, FOR TRANSMISSION BY POST AS A PERIODICAL

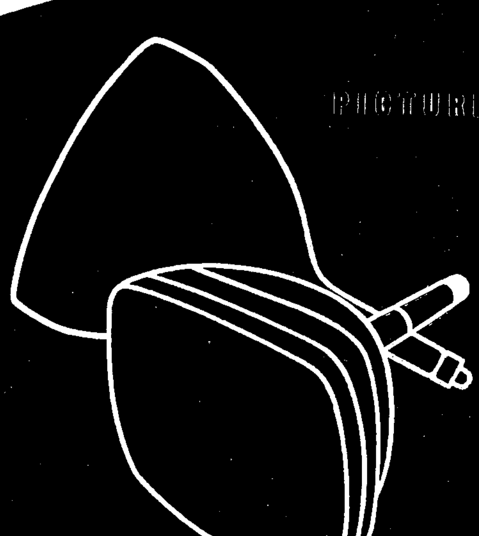
TELEVISION

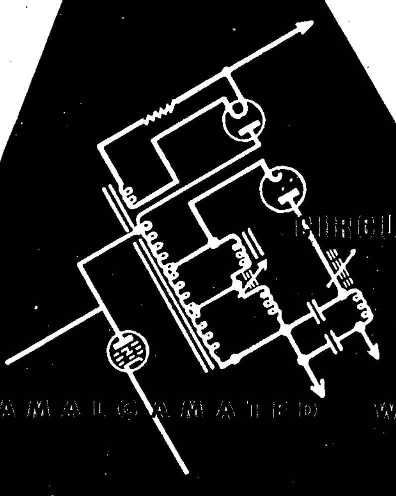


TRANSISTORS

RADIOTRONICS

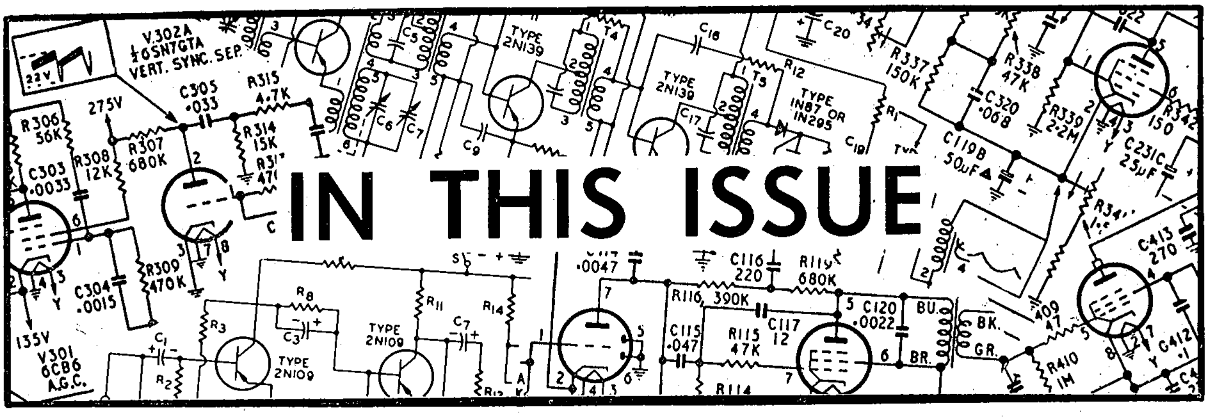
PICTURE TUBES

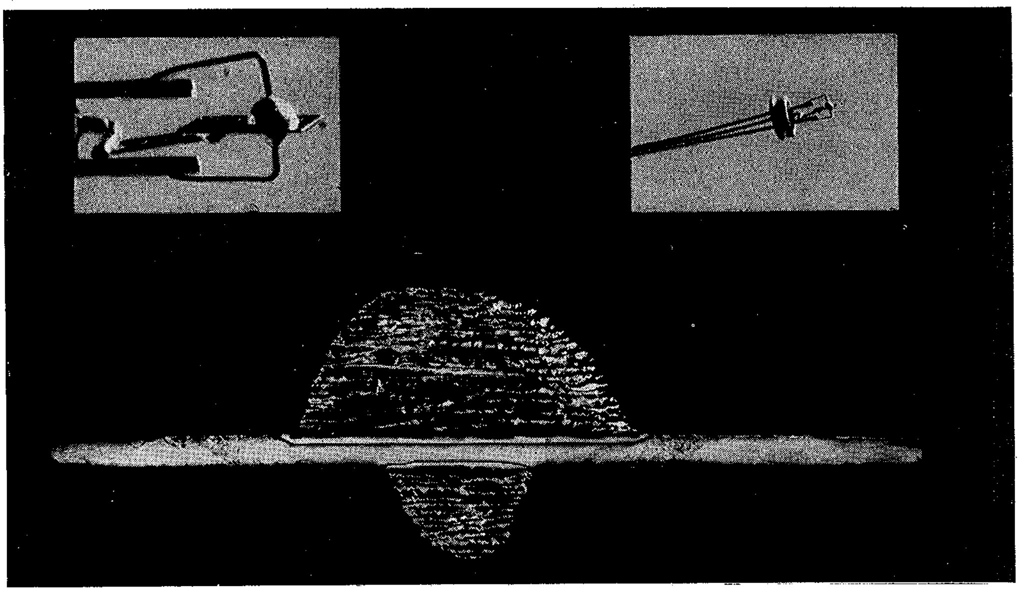




CIRCUITRY

AMALGAMATED WIRELESS VALVE COMPANY PTY. LTD.





The illustration consists of photographs of an AWV 2N408 transistor. The small inset photographs show the transistor (less outer case) actual size and magnified five times. In the X5 view the wafer of n-type germanium is clearly seen, together with the collector and emitter dots.

The rest of the illustration is a magnified (X50) cross-sectional view, where the cross-section has been lapped and etched to make visible the p-n junctions.

TRANSISTOR TRENDS AND DEVELOPMENTS

by H. S. BLANKS, M.E., B.Sc.

SUMMARY

Transistor production in the U.S.A. is expected to reach 60 million units this year, with 40% being used in the entertainment field. Present day transistors operate at up to 85 watts and 500 Mc, but new types such as the mesa and spacistor are expected to raise these limits.

In transistor production diffusion techniques are tending to replace alloying, but germanium remains as the most commonly used semi-conductor material with silicon reserved for applications subject to high ambient temperatures. PNP units make up the bulk of production with NPN types confined to switching and complementary symmetry type circuits.

INTRODUCTION

Whilst the growth of transistor sales and applications is evidence of the acceptance of the transistor as a major and permanent member of the electronic component family, transistor types and developments are still so much in a state of flux that the general reader of the technical literature finds it difficult to form a clear picture of the device's future. This article is therefore intended as a brief summary of trends and developments in this field.

Figure 1 shows the volume of transistor sales in the U.S.A. during the past years, together with the expected 1958 figure. Both in 1956 and 1957 the entertainment field used about 40% of units sold and this figure is expected to remain for 1958. The next important field has become that of package, or module, circuits, followed by communications and military applications.

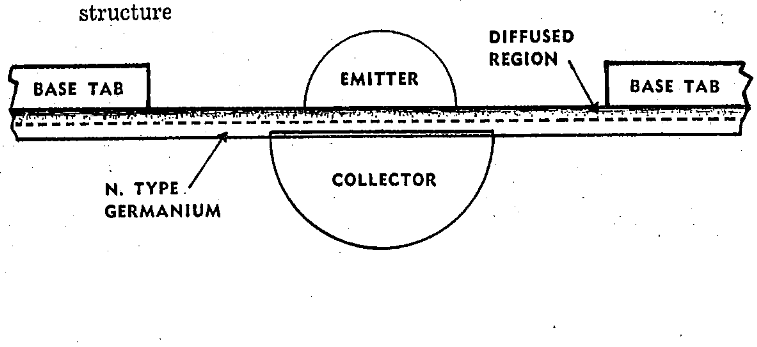
Whilst a completely transistorized TV receiver was recently demonstrated in the U.S.A., it is not considered that such receivers will appear on the market for a few years. The set shown had a 14" screen, had 31 transistors and weighed about 30 pounds including the 5 hours capacity 12v accumulator.

At the moment the main disadvantage of fully transistorized automobile radios is the economic one. This may be expected to diminish relatively soon. The tendency will be to make such radios in the form of plug-in units, with their own sub-accumulator, so that they can be removed for use outside the car.

Rating forecasts are difficult to make. The present established transistor types, i.e., the Drift, MADT† and Grown Diffused, are all considered to have an ultimate upper frequency limit, for amplification purposes, around 500 Mc. Power outputs of such units will probably be below

† Micro Alloy Diffused-base Transistor.

Cross-sectional view of the A.W.V. drift-transistor structure



20 mw, particularly with the grown type. Output from units designed for use below 100 Mc may be considerably higher and an experimental transistor providing 1 watt at 70 Mc in an amplifier circuit was announced at the 1958 I.R.E. Convention Show in New York. The above figures all relate to germanium transistors — due to the considerably lower carrier mobilities in silicon, smaller geometries have to be used for equivalent frequency response and the practical upper frequency limit should therefore prove to be somewhat lower than for germanium.

In the power field one cannot see an ultimate upper limit, particularly if alloying is replaced by diffusion so that large area planar junctions may be achieved. For any given semi-conductor material, however, power must be traded against frequency response. At the moment permissible dissipations at room temperature range up to the order of 50 w for germanium and 85 w for silicon. These figures should gradually be increased as existing techniques are perfected and then be significantly lifted by 1 to 2 orders of magnitude when the intermetallic semi-conductors, composed of elements from groups 3 and 5 of the periodic table, such as Ga-As and In-P, enter the field. That, however, will not be for quite some years.

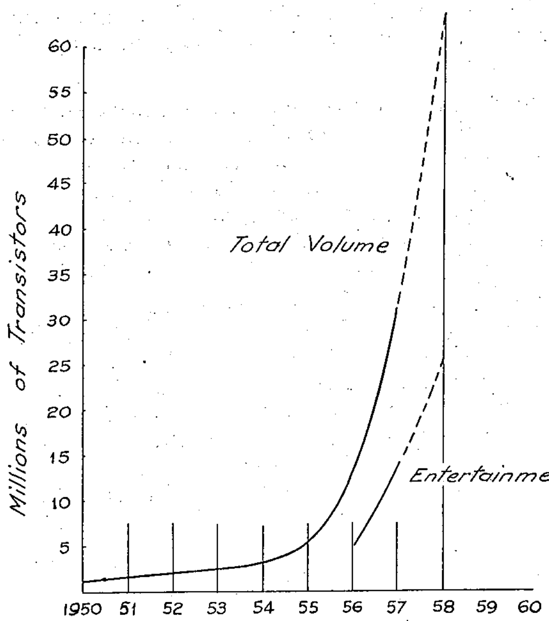


Figure 1.—Growth of transistor sales in the U.S.A.

Whilst the projected upper frequency limit of the presently established types is taken in the vicinity of 500 Mc, some new developmental types, mentioned below, make promise to go considerably higher, figures up to 10,000 Mc having been claimed as the ultimate limit for some types now being developed.

TYPE DEVELOPMENT

It is of interest to note that all three of the present high-frequency types, i.e., the Drift, MADT and Diffused Grown, are merely the transistor types with which the respective manufacturers had been associated plus one diffusion process. The reason for the importance of the diffusion process as a transistor manufacturing technique lies in the very fine penetration control possible, the non-destruction of the crystal-structure and the achievement of a graded impurity level so that, due to the gradient of fixed charge concentration, an electric field arises to accelerate carrier flow from emitter to collector. It is the latter factor which is most relevant to the high frequency types mentioned, whilst the first factor is most relevant to the large area power units. It is noteworthy that a very great number of pellets can be diffused simultaneously, with no jigging required.

The above is an example how a new technique added to existing, and quite different, types can bring to each an almost equal enhancement of performance. A further new technique, which may have almost equally dramatic results, is that of thermo-compressive bonding. This consists of applying a gold wire under pressure and at a temperature below the zero-pressure eutectic temperature to the semi-conductor surface. Although the temperature is quite low, fusion between wire and pellet occurs and a good ohmic contact results. This technique permits the very close and accurate positioning of the base connection relative to the emitter and is particularly applicable to the Mesa‡ structure described below.

Other directions possible for new developments are those of new geometries, new materials and new principles. Regarding this last field, much speculation has centred around the possibility of a sort of solid-state klystron, i.e., distributed amplification. Whilst not completely rejected, it is believed on theoretical grounds that this is not possible in a structure which imposes collisions on the energy carriers. A new departure in the field of applying known principles in a new way has been the introduction of a high accelerating field, by means of a reverse biassed p-n junction, into the carrier flow region of a unipolar transistor[1]. This is utilised in the "spacistor" mentioned below. Another new principle, utilised for a number of switching types, has been that of the avalanche. A new geometry plus the application of the surface-barrier principle have brought a spectacular boost to the old field-effect transistor. The new device, announced from France, is the "Tecnetron" (Figure 2) and is said to amplify up to 2,000 Mc.

‡So-called after a Mexican mountain formation having a similar profile.

1. Shockley, W., "A unipolar field effect transistor", Proc. I.R.E., 40, 1952, 1365-77.

For the ordinary (bi-polar) transistors the most radical geometrical innovation has been that of the Mesa transistor described below. This new geometry (see Figure 2) recognises the fact that the base current is the smallest of the three electrode currents and that the dissipation at the collector is the greatest. It has been suggested that a very thin emitter strip, surrounded by a rectangular base connection, would give better power performance of high frequency types than the present dot-and-ring configuration. The practical problem of making such an emitter, e.g., 0.010" x 0.0015", is however not solved, although the base configuration should lend itself to the thermo-compressive bonding technique. It the field of power units the comb-like emitter structure, projecting into a similar base connection, proposed some years ago, has made no headway.

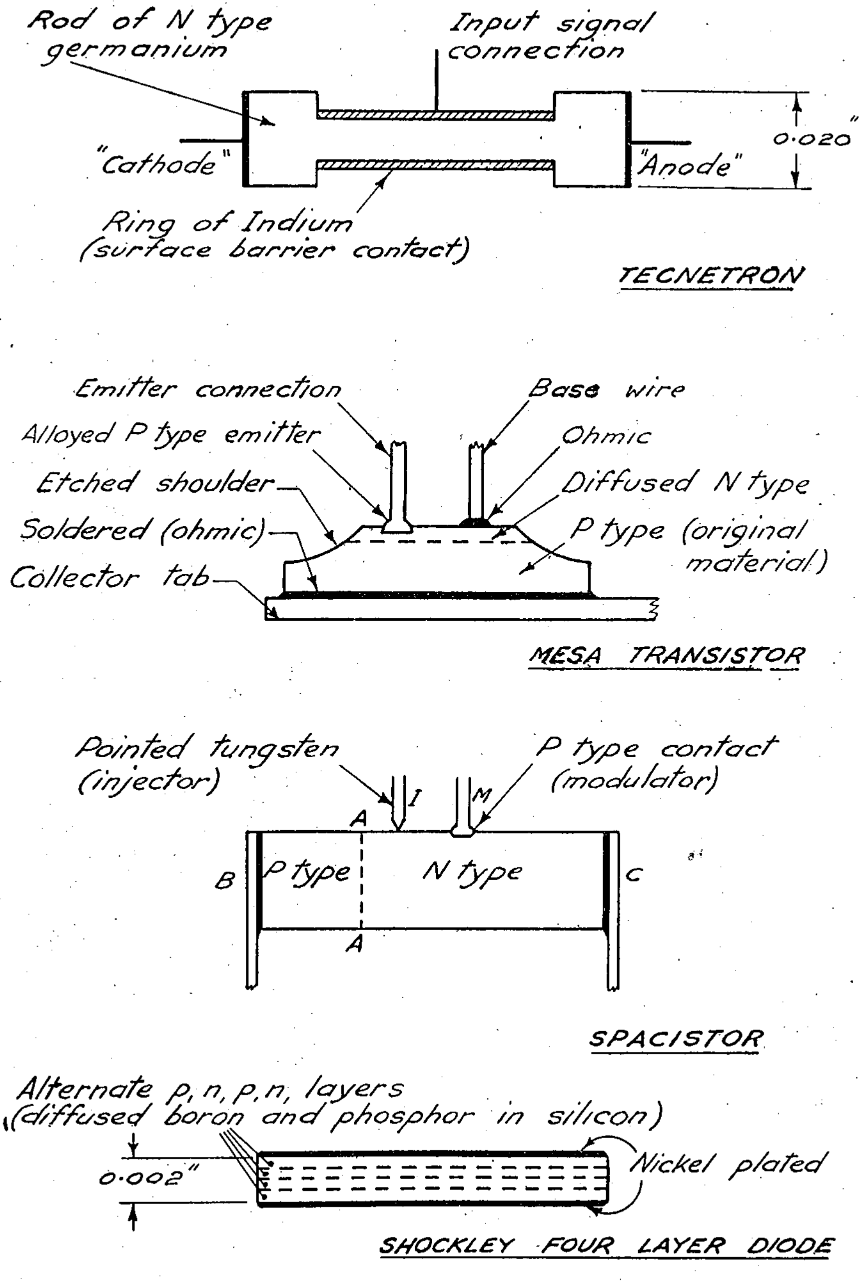


Figure 2.—Cross-sections of some recently developed semi-conductor devices.

NEW TYPES

MESA

The most promising of the new transistors presently being investigated is the Mesa, a schematic cross-section of which is given in Figure 2. It is made by diffusing an n-layer inward from one face of a high-conductivity p-type pellet. A p-type emitter is then alloyed into the n-type face and metallic connector is ohmically soldered to the opposite face of the pellet, forming the collector connection and also the mechanical support and heat path. The base connection is made by ohmically soldering or bonding a fine wire to the n-type face in very close proximity to the emitter. Finally, to reduce collector capacity and leakage, the unit is masked and etched to have the cross-section shown in the diagram.

This transistor, which is expected to have an ultimate frequency range of close to 10,000 Mc, incorporates some striking departures from existing types. Having no high-resistivity region between emitter and collector, it requires no starting voltage. Its geometry facilitates heat removal and base-emitter proximity. The only alloying operation, that of the emitter, is a shallow one and emitter-collector spacing becomes almost entirely a matter of diffusion control. The collector junction is diffused and graded so that reverse characteristics should be considerably improved.

Consideration of the dimensions of the device, namely say 0.020" square by a few thousandths of an inch thick, makes the imagination boggle at the difficulty of making such a unit. Apart from this question of size, this should however, be an easier transistor to make than any of the other high frequency types. Apart from the elimination of the collector alloying operation, there should be significance, from the viewpoint of automation, in the fact that after the diffusion process (which can be done in batches of tens of thousands) all operations on the pellet can be performed in sequence from the one side, i.e., the pellet side of the collector connector, without critical alignment reference to the other side.

SPACISTOR

The status of the recently announced spacistor schematically shown in Figure 2 is less clear. A reverse bias is applied to the p-n junction AA by means of a dc voltage connected across the pellet ends B, C. A high electric field then exists in the depletion layer, which extends on the n side of the junction, under the two electrodes I, M. The former is a pointed tungsten contact, dc biassed to inject a stream of electrons into the germanium beneath it; the latter is a p-n junction to which is applied the input signal superimposed on a reverse bias. This signal affects the potential immediately beneath I and thereby modulates the injected current which is also the load current. The expected good frequency performance arises from the high accelerating field existing in the depletion layer beneath I and M. The device is still in a very early stage of development and the nature and consistency of the injecting contact, as well as the maintenance of high input impedance at high frequency, are serious problems. It has been claimed that since current flow is by majority carriers, low minority carrier lifetime should not matter, making the device amenable to 3-5 intermetallics at a relatively early stage. This, however, ignores the lowering of input impedance consequent upon the use of such high recombination rate material.

SWITCHING DEVICES

A number of bistable switching devices have been under recent development. The simplest is the two-terminal Shockley four-layer diode, represented in Figure 2, which can exist in either an "open" or a "closed" state. It is switched "closed" if the voltage across it exceeds a certain value and "opens" if the current through it falls below a certain value. Another four-layer diode has the addition of a third connection, namely to the inside p layer to trigger the switching operation.

Of great interest is the "Thristor" high speed switch. This resembles the Mesa, but the collector connection is soldered with an alloy of lead, tin and indium, instead of being ohmic. The $\alpha > 1$ condition, necessary for the "closed" state, arises from the fact that this contact is found to inject electrons at high currents.

SEMI-CONDUCTOR MATERIALS

Whilst silicon, with an energy gap of 1.2 ev, permits much higher transistor temperatures than does germanium, with a gap of 0.72 ev, it suffers from having considerably lower carrier mobilities and hence, for the same dimensions, inferior frequency performance. Conversely, for equivalent frequency performance, the electrode spacings of a silicon transistor need to be very much smaller than those of a germanium one. This increases the manufacturing difficulty and heightens the heat removal problem in high frequency types to a major degree.

Quite apart from economic factors (due to the difficult metallurgical problems associated with the purification of silicon), there are thus reasons against the future replacement of germanium by silicon for transistor manufacture, particularly in high frequency types where the increased temperature rise due to the smaller active transistor region partly offsets the increased operating temperature permissible. It is therefore chiefly in the high ambient temperature applications that silicon will be advantageous. The main use of silicon transistors will be in military applications and, when prices fall to a competitive level, in automobile receivers. This latter may take from 2 to

5 years. It is thought that for the next 5 years 75% of transistors will still be made from germanium.

Germanium-silicon alloy has not fulfilled earlier expectations, the benefits from the increased energy gap being more than offset by the loss in mobilities which are much lower than is found even in silicon alone. No transistors are therefore being made from this material.

A very promising if distant field is that of the 3-5 intermetallics which in some cases combine high energy gaps with good mobilities. If the metallurgical problems can be solved, some of these materials, e.g., Ga-As, In-P and Ga-P, should ultimately oust silicon. Ga-As has an energy gap of 1.35 ev and is therefore useful up to about 400°C. Its theoretical mobilities are 8000 and 500 cm/sec/cm/v for electrons and holes respectively. Purification, which includes getting the exact balance between Ga and As, remains a tremendous problem. So far, resistivities obtained have been 1-2 orders below that desirable for transistor use, and minority carrier lifetimes have been low by about 3 orders. Some successful low p.i.v. diffused diodes have however been demonstrated. Similar problems remain for Indium-Phosphide (energy gap of 1.25 ev) and Gallium-Phosphide (2.2 ev).

P-N-P VERSUS N-P-N TRANSISTORS

Whilst the alpha cut-off frequency varies as the minority carrier mobility, the base resistance r_{bb}', for given collector characteristic, varies inversely with majority carrier mobility. In amplifier application the power gain varies with the quotient of cut-off frequency and base resistance, so that there is little practical difference in frequency performance between the n-p-n and p-n-p types, unless the mobilities ratio is so large that the importance of cut-off frequency predominates. In switching applications r_{bb}' generally is unimportant and here the faster transit time of the n-p-n is advantageous.

A further field for the n-p-n is in complementary symmetry audio circuits. Here progress has been slower than expected, partly due to difficulties in n-p-n alloy-type manufacture, partly to difficulties in matching the n-p-n, p-n-p pairs over their full current range. Both these problems are being solved, and increased activity in this type of circuit is to be expected.

The electron/hole mobilities ratio in intermetallics such as In-P, Ga-As and Ga-P being rather high, transistors made from these materials may be expected to be of n-p-n type. In germanium, however, except for switching and complementary symmetry circuits, the p-n-p type will continue to predominate.

CONCLUDING PREDICTIONS

The conventional, i.e., diffusionless, if and rf transistor types will gradually be replaced by the diffused types, thereby the cut-off frequencies in these ranges will no longer be straining near the upper limit achievable from the manufacturing technique used. As a result, transistor specifications will be more easily met with less critical manufacturing control and consequently at lower cost. Circuit design will also become easier and cheaper, e.g., the use of drift transistors in the if strip of a receiver will obviate the need for neutralization.

The bipolar types are holding their own against the unipolars and this, in view of the Mesa development, is expected to continue. One implication of this is that most transistors will continue to be low input impedance, high output impedance, devices and that the circuitry being developed now will not become obsolete. Valve circuitry would be applicable to the tecnetron.

Alloying will be increasingly replaced by diffusion and the growing-technique of making transistors may well lose popularity in the high

(Continued on page 135).

THE AUTHOR:

Henry S. Blanks graduated B.Sc. in 1948 and B.E., with First Class Honours in Electrical Engineering in 1950, both times from Sydney University. At the beginning of 1952 he went abroad, first working at the RCA David Sarnoff Research Centre in Princeton and then at the Marconi Baddow Research Centre in England where he was engaged on all phases of germanium semi-conductor work, particularly on the development of a high power rectifier. For this work he received the M.E. from Sydney University in April of this year.

Mr. Blanks returned to Australia in 1956 to work for Amalgamated Wireless (Australasia) Ltd. on transistor applications, and in 1957 transferred to the Amalgamated Wireless Valve Co. Pty. Ltd. on whose behalf he has just spent four months in America and England studying transistor manufacturing control and investigating application developments.

HIGH FIDELITY

PART 5

HIGH FIDELITY COMPONENTS

Crystal Pickups

In all record players one of the most important single items is the pickup. There are many kinds of pickups but these generally can be divided into two classifications, namely, high impedance and low impedance.

The most common of the high impedance pickups is the crystal-type shown in figure 35. It is probably the most popular of all pickups for several reasons. It is capable of good quality with minimum or no equalisation, and has reasonably high output. Its major drawback is the fact that it is very susceptible to change because of temperature and humidity. This makes it poor from the standpoint of a warm, damp climate. However, in general it is an excellent unit. The crystal itself is a Rochelle salt crystal, which has the characteristic of generating a voltage as the crystal is strained or twisted. The amount of this voltage is proportional to the record groove amplitude.

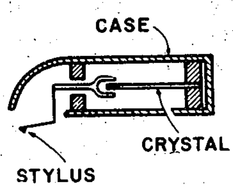


Fig. 35. Crystal Pickup.

The crystal pickup is, therefore, an amplitude sensitive pickup. Surface noise will be somewhat higher with a crystal pickup than with magnetic types, since any movement of the stylus will cause crystal strain and cause a voltage to be generated. That is, lateral movement of the stylus which is transmitted from the actual recording in the grooves will strain the crystal and generate the voltage which we desire. Also, the grain of the record and irregularity of the groove wall itself will tend to cause up and down motion of the stylus which will be transmitted to the amplifier equipment as noise. The noise created by the up and down motion of the stylus will be over and above that caused by the lateral movement, and lateral movement much greater than in the magnetic types.

A new kind of crystal commonly called the ceramic has been introduced during the last few years and operates the same as does the Rochelle salt crystal, the only difference being that this new crystal is made of barium titanate and is not susceptible to temperature and humidity changes.

A crystal pickup is reasonably flat without the use of compensation and also has sufficient output so that no pre-amplifier is required.

Another type of high impedance pickup is the capacitance pickup. It is a very excellent pickup but is not used widely because of circuit complications. Because of the small amount of usage of this unit it will not be discussed here.

Variable Reluctance Pickup

Most of the low impedance pickups fall in the magnetic classification to which the variable reluctance pickup belongs. The variable reluctance pickup makes use of a magnetic field between two poles between which is mounted an armature actuated by the playing stylus. This is shown in figure 36. The armature is free to move in the magnetic field. A coil is located on each pole piece. As the armature moves closer or further from the pole, the reluctance (magnetic resistance) of the magnetic circuit changes. Due to

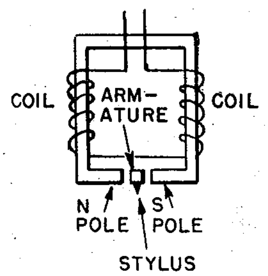


Fig. 36. Variable Reluctance Pickup.

the respective change in the flux which cut the coils, voltage is generated in each of the coils. As there are two coils, one on each pole, the action of the pickup becomes equivalent to a push-pull circuit. The generated voltage of this unit is proportional to the lateral velocity of the stylus in the groove, so it is definitely a velocity sensitive pickup. Vertical pickup is extremely low thus giving a minimum of surface noise.

As the output of a magnetic pickup is extremely low a pre-amplifier must be used to increase the audio signal to a level high enough to drive the regular amplifier equipment. Because of the velocity characteristic of the pickup, the pre-amplifier must be compensated in the opposite direction to the pickup in order to have maximum gain at the low frequencies and low gain at the high frequency end of the response range in order to provide flat output for the system.

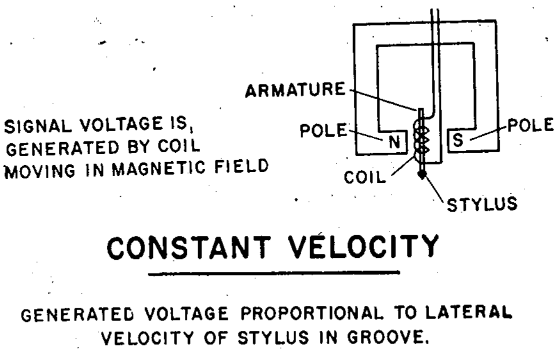


Fig. 37. Moving Coil Pickup.

Moving Coil Pickup

Here again the moving coil pickup is magnetic and low impedance. In fact, one pickup which is used in a current high fidelity instrument has an impedance of approximately $1\frac{1}{2}$ ohms — practically a short circuit for any vacuum valve grid circuit. In this type of unit a coil is placed between the two pole pieces and around an armature as shown in figure 37. The playing stylus can either turn the coil to correspond with the movement of the stylus, or the armature can be moved within the coil by the stylus. In either case the flux lines through the coil will be changed causing voltage to be generated in the coil. As in the case of the reluctance pickup, this unit is a velocity operated mechanism and the generated voltage will be proportional to the lateral velocity of the stylus in the record groove. Again, this type of pickup has a very low output and requires a pre-amplifier stage, and where the impedance is extremely low a matching transformer is required, which, unless special care is taken in the circuit design, can cause hum problems to be encountered. Also, when extremely low impedance is used, more than one stage of pre-amplification will be necessary which causes a fairly high valve noise content in the signal.

Recently the transistor has been developed to a point where it is a practical tool in sound equipment. A transistor is a very low impedance device and has the advantage of extremely high gain. By proper choice of voltages the relation between the input and the output impedances can be made almost any value. Therefore, a transistor is used in current high fidelity equipment with the moving coil pickup to great advantage. The very low impedance of the moving coil pickup can be fed directly into the transistor. By the use of proper voltages, the output of the transistor is such that it matches the pickup to the input of the main amplifier. Because of the high gain there is sufficient output from the single transistor to drive the input of the main amplifier to its full requirements. Also, because no filament voltages are necessary, the hum level from this source is nil; and as there is no cathode, emission noises, or secondary emission from other elements, the noise level is also reduced to a minimum. Because of these factors this pickup is capable of extremely high quality.

Because of the small size of the pickup, it is very lightweight, the armature is very small and light, so excellent high frequency response and generally good results are possible. Because vertical response is extremely low, the surface noise from the record source is reduced to a minimum.

The response of this pickup as well as the amplifier compensation required is approximately the same as for the variable reluctance pickup.

Stylii

Because the music recorded on a record usually is transmitted to the playing equipment through the very fine contact point of a stylus, this small item becomes extremely important in high fidelity quality considerations. Usually the stylus pressure on a record is thought of in terms of, let us say, seven grams, which is a common pickup arm weight. However, most pressures are calculated in pounds per square inch. It might be interesting to figure it on the basis of a seven-gram weight applied to a record through the average one mil point radius stylus. This figures out to be approximately 16,000 pounds per square inch. This may give a little different idea regarding the importance of the stylus as related to the record, even if for no other reason than wear.

Perhaps the most important consideration is that of correct size and shape. The shape should be perfectly rounded so that the stylus will slide along the groove as though it were a part of a ball. If the ball could roll, everything would be perfect, but it can be easily seen that there would be problems in trying to obtain a rolling contact this small. Figure 38 (a) shows that when a stylus is too small it will not follow the groove solidly and that distortion and noise will result because of this looseness in the groove. The signal-to-noise ratio will be high due to the small area of contact with the groove wall which contains the recorded information. (b) shows a stylus of correct size. It will be noted that it does not sit tight at the groove bottom, but rides the centre of the area of the side walls. This gives the minimum of contact for optimum pickup and the best possible signal-to-noise ratio. (c) shows that when the stylus is too large, the groove edge takes the wear and after only a few playings becomes badly worn and distorted.

A stylus point is measured by the radius of the point curvature. The correct stylus size for playing 78 r.p.m. records should be three one-thousandths of an inch (3 mils) point radius, and for 45 r.p.m. or 33 r.p.m. records, one mil point radius. It is clear from these pictures why one stylus cannot be used satisfactorily for the playing of all types of records but why the pickup must be changed or turned to the correct stylus position.

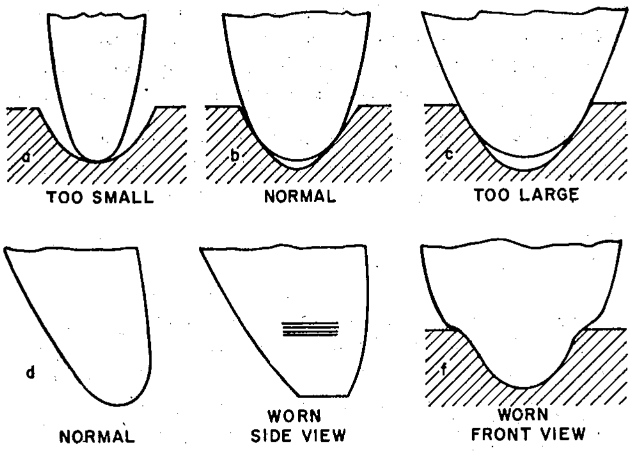


Fig. 38. Stylii-Wear.

Figure 38 (d) shows an unworn stylus. (e) shows that regardless of the material of which the stylus is made, as it wears, the point becomes flattened. This, then, will act like a chisel on the soft plastic material of the record and rapidly spoil it for further playing. The stylus should be inspected regularly through at least a thirty-power glass for any sign of wear, and changed as soon as any can be detected. Figure 38 (f) shows a worn stylus from the front. Note that it has worn down into the groove, a ridge being formed along the side walls. This will also cause terrific groove-edge wear. This is an extreme condition.

Regardless of the material of which the stylus is made, if it is good and of the correct size and shape, equal quality will result. The main difference will be the length of life; the softer the stylus material the shorter the stylus life will be. It is very important that a diamond stylus be closely checked for flaws, since a diamond is so hard that the flaws will not readily wear smooth, and much record damage can result. The same thing, of course, is true of softer stylii, but in proportionately reduced seriousness. A synthetic sapphire stylus should be checked carefully for fractures or chips, as synthetic sapphires are susceptible to this and a chip can seriously damage a record in one playing.

1. EARLY TYPES
   - A. STEEL
   - B. TUNGS-TONE
   - C. CACTUS
   - D. CHROMIUM
2. CURRENT
   - A. OSMIUM
   - B. SAPPHIRE (SYNTHETIC)
   - C. DIAMOND

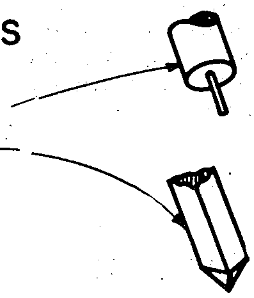


Fig. 39. Stylii-Types.

The length of life of a stylus is variable and no accurate number of plays can be assigned to the different materials. The safe thing is to regularly check the stylus for wear and to replace it when wear shows, or when a change in quality becomes noticeable. With high fidelity equipment, a loss of high frequencies can be detected by a critical listener after a fairly short period. This is the reason that records which have been used as demonstrators should never be purchased for high fidelity use, and why new records should always be used in high fidelity demonstrations.

It may be of interest to outline a number of different types of needles or stylii, both early types and current types, and discuss some of the advantages and drawbacks of these different playing points. In figure 39, it is noticed that the first one listed is the steel needle. A steel needle was used for only one play. In the early days of sound, steel seemed to be about the best point for all purpose usage. Steel was used with the old records because of the difficulty in obtaining satisfactory record materials to give high quality sound and yet have the physical strength to drive the needles and pickups against the heavy compliance of the old type diaphragm under the heavy weight of the pickup and the tone arm. In order to assist the record in rapidly grinding a needle point to fit the groove to the exact dimensions and so to get the maximum drive from it, an abrasive was included in the record material. Of course, this did not help the noise level any, but in those days the noise level was already so great that it added very little additional noise and with some type needle points that could not be ground to groove tolerance, the abrasive became a necessary method of fitting the needle to the groove. In addition, the steel needle could be made short and stubby so as to obtain fairly decent quality transmission between the groove and the sound box with good volume, or it could be made long and slender so that it would have a certain amount of bend and cause less motion of the sound box than generated by the groove itself and so play softly. This was called a soft tone needle and actually tended to reduce the high frequency response. Such needles as this were important in the very early days when horns were used, with no control of volume.

Under 1 (b), is listed the "Tungs-tone" needle. Here again, an abrasive was badly needed in order to grind the needle point to fit the record groove. This needle was made of a piece of steel wire in which had been embedded a small tip of tungsten wire. If a brand new needle were looked at under a microscope the point of this tungsten wire appeared rough and square, nowhere near the shape of the groove. Until the tungsten point was ground to fit the groove, of course, record damage would result. The abrasive in the record was depended upon to do this.

The cactus needle became very popular because of the soft muffled quality of the tone resulting from its use. However, the poor customer did not realise how much damage these needles caused to be inflicted upon his very expensive records. Records really were expensive in the days when these needles were used. The cactus needle was strictly a fibrous point. Unlike metal it gave extremely poor radiation of heat. Therefore, the friction at the point was so severe that extreme temperatures would be generated; in fact, such high temperatures that the record material at the point would become soft and small bits of fibre would stick in the soft area as the needle passed over, and, as soon as it was passed would again solidify leaving the fibre sealed in the record material. As a result, the surface noise of the records would rapidly rise because of the bits of fibre left in the record surface and because of the softening of the record surface as the needle passed over, there was extreme distortion of the surface, plus extreme wear. The point of the cactus needle was sharpened with a tool of one kind or another just to give it a point. No attempt could be made, because of tool tolerances, to fit the needle to the record groove shape. It also had to be worn by the abrasive.

The chromium needle was one of the best needles as record material and recorded quality was improved. Because of the hardness of the chromium plating on the point, the life was much longer than that of a steel needle, and many playings could be made before record wear resulted. These needles could, like the steel needles, be ground to the correct point shape, so did not have to depend on being worn-in by an abrasive in the record material.

Figure 39 (2) lists the more popular of the current types of needles. Of course, since the coming of plastic record material no abrasive is used or needed. Here we see osmium, which is a precious metal point, the synthetic sapphire, and the diamond. All three of these points can be machined to the correct point shape so that they fit the record grooves. Therefore, equal quality sound can be obtained with any of these points when they are new and if they are the proper size and the proper shape. The only difference between them is the length of life of the different points. Naturally, the diamond will last the longest because it is the hardest. The synthetic sapphire will be the next in length of life. However, the synthetic sapphire does have one drawback; it's susceptibility to fracturing. If the point of a synthetic sapphire fractures and it is not immediately discovered, very serious record wear can result within a very short period of time, as a chipped point, just like a worn point, will act the same as a chisel on the soft surface of the modern record. The osmium point being the softest material will give the shortest length of life. With the modern lightweight tone arms and pickups with very excellent compliance, any of these points will give satisfactory life compared to cost, and the length of life will depend roughly on what the customer pays for his stylus. The harder the stylus material, the higher the price and the longer the life.

Record Storage

Some care and thought must be given in order to maintain a record collection and to protect the records from damage over a long period of time. Shelves which have large enough dimensions so that the records will not hang over the edge of the shelf should be designed to hold the records. The shelves should be located in a cool, dry place, out of the sun, and away from any radiators which might be heated during the winter. Never leave records in an automobile parked in the sun. Temperatures above 120°F will cause serious record damage. Low temperatures will make a record brittle, but the record will again become normal when returned to room temperature. The records should be stored in their albums or in sleeves and should be filed on edge. They should be filed snugly so as to sit straight and not leaned over at an angle. "45" records may be stored either vertically or flat. Flat storage is satisfactory if each record is well supported over its entire surface. Do not intermix sizes. Never leave a record on the supports of a changing mechanism. They should not be jammed together so tightly that sleeves and records must be damaged in order to remove them. Of course, the room in which the records are stored should be kept reasonably clean and free of dust, and at a normal room temperature.

Record Wear

Even with the best of care, records eventually wear in usage. Record wear can result from a number of different causes. In many cases wear comes because of abuse, sometimes unknowingly, but just as damaging as though the owner were trying to ruin the record.

Probably the worst offenders towards record wear are stiff, non-compliant pickups and/or worn or chipped stlii. Either one of these defects is probably found in more instruments than almost any other defect. Of course, the only solution in either case is to replace the defective item. A stiff, non-compliant pickup usually becomes noticeable when records having a fairly high level of recording begin to skip grooves. When this occurs, the pickup should be checked in order to determine whether the stylus is still moving with as light a pressure as it did when new. If it is, the compliance is probably satisfactory and the skipping of grooves is being caused by a perhaps worn or chipped stylus. This can be checked by looking at the point from all angles with a magnifying glass of 20 or 30 power or greater. A worn or chipped stylus will generally manifest itself by a slight greying or whitening of the record surface. If this is noted — beware — and change the stylus immediately. Wear can also be caused by too heavy a pressure on the stylus or incorrect shape of the stylus. In either case, the record will show greying or whitening almost immediately.

The records will soon become noisy and scratched if handled with fingers containing some greasiness or grit, and gripped in the area of the groove surface. If a record is picked up in this way, scratches and grease will be deposited as a result. The scratches will cause the noise level to increase, and the greasy deposit will cause more dust to collect which will cause more scratches and still higher surface noise.

Many of the worst types of scratches are caused by the customer not knowing how to properly remove and install a record in its sleeve. The correct way to do this is to support one edge of the sleeve against your body, the opposite edge with the palm of the left hand, with the open edge towards the front. By slight pressure with the left hand, which is against the outer edge of the record sleeve, the sleeve can be caused to bulge slightly so that the right hand can reach into the centre of the sleeve and with the middle finger, the record can be hooked in the centre hole. This will allow the record to be pulled out to a point where it can be picked up between the thumb at the outside edge, and the finger, which is still hooked in the centre hole. As soon as it is clear of the sleeve the record can then be handled by opposite edges or by the centre. A record should be inserted in exactly the opposite way from that in which it was removed. Records should never be handled by the playing area.

Warpage is a problem which sometimes causes the owner of records some worry. Warpage which occurs after the record has been purchased is usually due to being left in too warm a place, on a surface which was not flat, or leaving the record tilted at an angle against some other object in a place that was too warm. Leaving a record stored flat without complete support is another cause of warpage. Leaving the records stacked on a motorboard or on the loading platform of the changer is a sure way to warp records. Warpage can be straightened if it is not too severe by leaving the record on a flat piece of plate glass in a room just warm enough to allow a slight amount of cold flow. This means a temperature a little bit warmer than room temperature. If necessary, another piece of plate glass can be laid on the top of the warped record to assist in flattening. Almost any attempt to remove warpage will result in some distortion of the record surface. It is usually much better to try to prevent warpage than to try to correct it after it has occurred.

Another damaging habit of the record customer is to place the pickup on the record manually, somewhere in the playing area. Oftentimes, the listener wants to play one little section over and over again. Each time the pickup is set down on the record it will make a little dig or a scratch. Each of these pits will then bring up the noise level so that in a very short time the record has become very noisy and no longer has high fidelity quality.

Another habit that causes damage is to play records which are dusty and dirty. Any grit on the surface of a record during its handling or playing will leave scratches and increase the noise level. The best way to clean records is to use a cloth, slightly dampened in a dilute solution (at room temperature) of a soapless detergent. Keep away from the label area. If a detergent solution is not readily available, use a soft cloth which has been dampened in plain cool water, and then immediately dry the record with another soft, dry cloth. Most of the so-called record cleaners are not to be recommended and, oftentimes, do more damage than good. Static charges cause excessive dust pickup by a record. Wiping with a damp cloth will relieve the static charge.

A record is a small disc from which an extremely large amount of pleasure can be obtained. The more and better the care of the record the more pleasure the listener can obtain from the record. It is foolish economy to have an expensive, high quality, high fidelity player, and to take such a small amount of care of one's records that they are in such poor condition that the maximum in quality cannot be obtained from them.

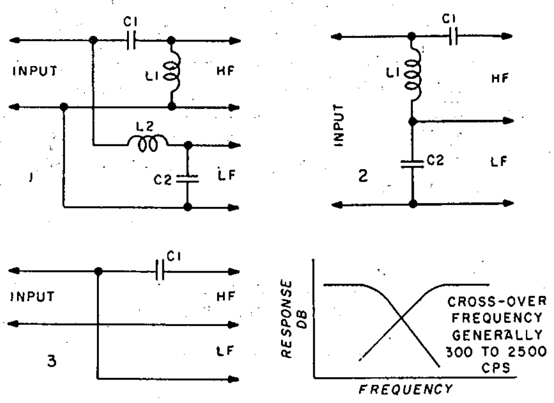


Fig. 40. Cross-Over Networks.

Speaker Systems

A high fidelity instrument is no better than any of its parts. This is particularly true of the speaker system, the matching transformers, and cross-over networks. All parts must have a so-called "flat response", or compensation must be made somewhere in the instrument to equalise for the nonlinearity of the part that is not flat. Compensation has already been discussed for several items (such as in the preamplifier) to compensate for the pickup characteristics. The speaker, which is the unit generating the pressure waves to which the ear listens, must be as perfect as possible.

A single cone speaker, in general, is not equally efficient over the full range of frequencies which it is wished to reproduce in a high-fidelity instrument. However, there are speakers which are capable of this wide frequency response with a single cone. In general, a large cone, with a very flexible mounting must be used for efficient low-frequency response. A speaker with a small cone is required for efficiency at the high frequencies. Some speakers combine these characteristics by building both the large and small cone units in one speaker. Since the average speaker has a ragged response outside it's designed range, it is important that a cross-over network be used in order to keep the high frequencies out of the low frequency speaker. Likewise, it is still more important to keep the lows out of the high-frequency cone, as power from the lows could easily burn out the high-frequency voice coil, yet would not transmit sound from the small cone. A cross-over network is designed to present a constant impedance to the amplifier output, and to deliver power to the individual units at the correct frequencies and at the correct voice-coil impedance for each speaker.

Cross-over Networks

When an instrument uses speakers which are efficient over the entire spectrum, a cross-over network is not required to keep the high frequencies out of that speaker. When multiple units are used, a simple cross-over network must, however, be used in order to keep the lows out of the high-frequency units. This type of network is shown in figure 40 (3) where a capacitor (C1) is used to prevent the low frequencies from reaching the high-frequency units, yet will allow the high frequencies to pass.

When speakers designed for narrower ranges are used, a more complicated network is necessary. Figure 40 (1) shows a system which allows highs to reach the high-frequency speaker through

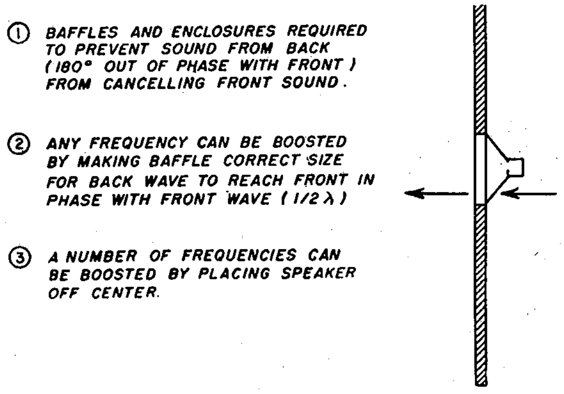


Fig. 41. Speaker Baffles.

a capacitor (C1), and also has a choke (L1) to bypass any lows which might get by. As this is a series-resonant circuit, fairly sharp cut-off will result. High frequencies are kept from the low-frequency unit by the series inductance (L2), and any highs that might get through are shorted through the shunt capacitor (C2). This also is a series-resonant circuit and results in sharp cut-off. Figure 40(2) shows a less expensive method of accomplishing this, as one of the inductances is not required. Cross-over frequencies generally range from approximately 300 c/s to 2500 c/s, depending on the speakers to be used.

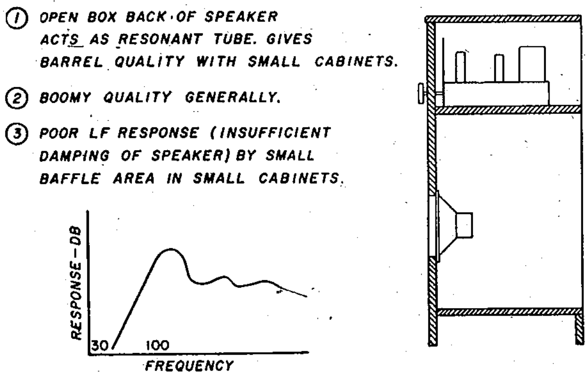


Fig. 42. Open-Back Cabinet.

Speaker Baffling

In order to obtain low-frequency efficiency from a speaker it is necessary to use a baffle or enclosure of one or more types. Such a baffle or enclosure is required as shown in figure 41, to prevent the sound from the back of the speaker, which is 180° out of phase with that from the front, from cancelling the sound from the front. By the choice of the baffle size, any frequency can be boosted. This is done by making the baffle such a size that the back sound will reach the front of the speaker in phase with the front sound and add to it. This occurs when the distance from the speaker to the edge of the baffle is one half-wave length for the frequency it is desired to boost. Actually, it is possible to boost a number of frequencies by placing the speaker off-centre, so that there are a number of different distances from speaker to edge involved. In order to obtain good low-frequency response from a flat baffle, it is necessary to have the baffle at least eight feet square. This is a popular system where a speaker can be placed at a permanent location in a wall, but is not recommended when a speaker must often be moved.

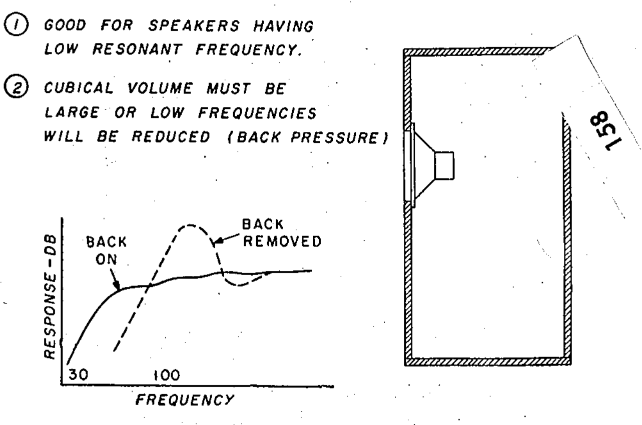


Fig. 43. Closed Back — Infinite Baffle.

The open-back type of cabinet is generally used in most radio and television instruments. Where the cabinet is large enough to give sufficient baffle area, reasonably good response is obtained. However, the quality has a tendency towards boominess due to the fact that a cavity of this sort acts as a resonant tube. In small cabinets of this kind this can be very noticeable. Also, in the smaller cabinets, low-frequency response is poor because of insufficient damping of the speaker by the small baffle area. A typical response curve is also shown at the bottom of figure 42.

The closed back or infinite baffle type of enclosure is excellent for speakers having a low resonant frequency. However, the cubical volume of the box must be large, or the low-frequency response will be reduced because of the back pressure reducing the cone movement. The effect of closing the back is the same as using an infinite baffle, so that the back sound never reaches the front. The response curve at the bottom of figure 43 shows what happens to the response when the back is removed.

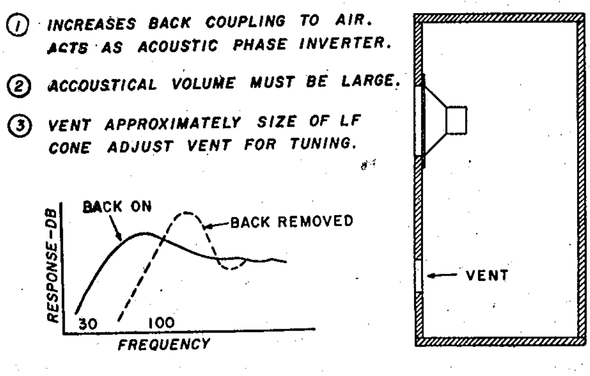


Fig. 44. Bass Reflex Enclosure.

The bass reflex enclosure, shown in figure 44, has become very popular as it is small enough to be used as a piece of furniture in a normal size listening room. It has excellent low-frequency characteristics as the response curve shows, and the low-frequency response is adjustable by using a variable slide on the vent. This type of enclosure acts as an acoustic phase inverter, as well as increasing the back coupling to the air, which was the one shortcoming of the closed back enclosure. The acoustical volume should be large, and the vent size should be approximately the area of the low-frequency cone.

A labyrinth enclosure is no more than a long, resonant tube with the loudspeaker in one end. The tube is made of absorbent material and the frequency at which the unit acts as a phase inverter is determined by the length. This long tube is folded into a box in order to put it in usable size and shape. The folding of a horn or tube at the low frequencies makes no difference in the response. A half-wave tube at the back of the speaker will, of course, add for that frequency. A quarter-wave tube will cancel.

The response curve in figure 45 shows what happens to the frequency response at the low end of the spectrum with this type of enclosure.

The folded horn can be designed to either fit into the corner of a room, or to be a square-shaped box. It is just exactly what the name implies, a folded horn. The folded horn type baffle is shown in figure 46. The high frequencies

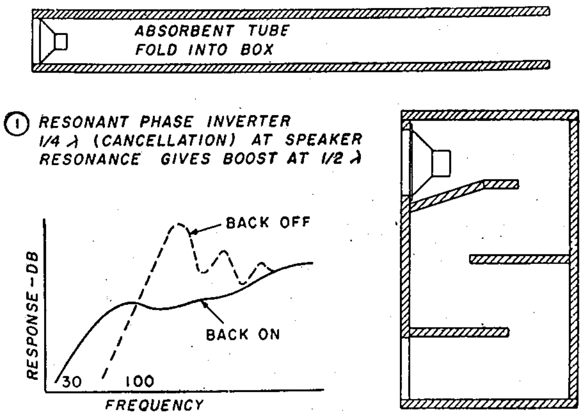


Fig. 45. Labyrinth.

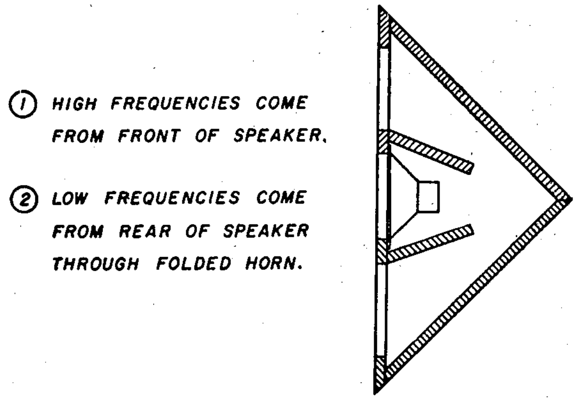


Fig. 46. Folded Horn.

come from the front of the speaker, and the lows from the rear, and reach the front through the horn. High frequencies do not bend around corners efficiently, though low frequencies do. Actually, the very low-frequency end of the spectrum is felt much more than heard.

General Note on Enclosures

In concluding the subject of enclosures, a few things of interest, and applicable with any type of enclosure, must be borne in mind.

The walls of the enclosure must always be constructed of heavy material. All joints must be well sealed. The interior should be well padded on at least two of the walls in order to prevent standing waves. The grille cloth used should be extremely light and porous in order to allow the high frequencies to pass with a minimum of loss. A special cloth should be used, such as radio grille cloth of the best grade, or organ grille cloth.

END

TRANSISTOR TRENDS AND DEVELOPMENTS

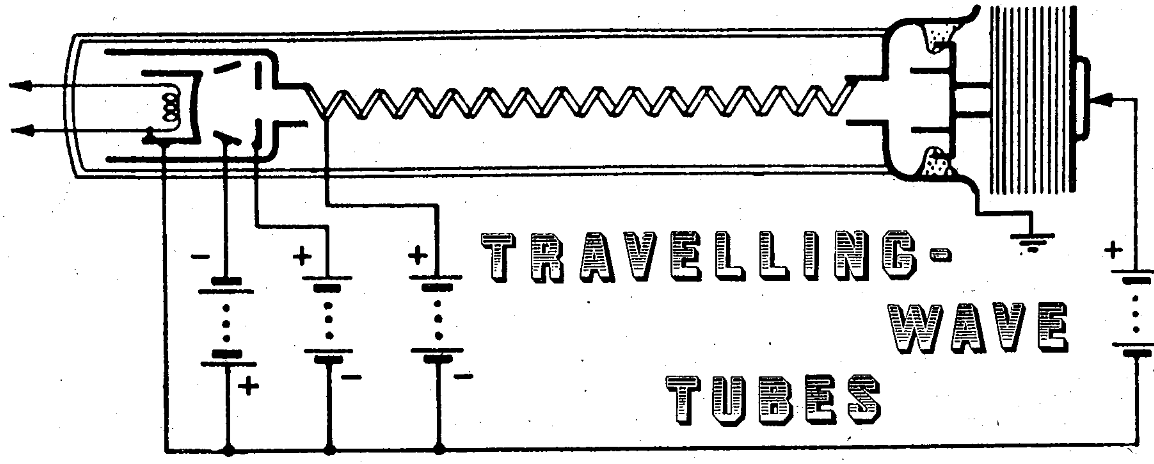
(Continued from page 127)

frequency field. Increased interest will be shown in glass encapsulated transistors for the sake of manufacturing economy. This may not apply to those types where heat dissipation is a major consideration. The unipolar "tecnetron" has already been mentioned above.

The ultimate future of transistors will depend on the solution of the metallurgical problems of purification and crystal perfection of the high energy gap, high mobilities intermetallics. Considering the vast range of semi-conductor compounds theoretically available, extending beyond the 3-5 group, one must conclude that the ultimate rating and performance limits are too high and too distant to be predictable. It is an intriguing thought.

ACKNOWLEDGEMENT

This article is reprinted from Proceedings of the Institution of Radio Engineers (Australia), by kind permission of the Institution.



PART 2

APPLICATIONS

Amplitude Modulation

Travelling-wave tubes can be amplitude- modulated simply by variation of the voltage applied to the electrode which controls the beam current. Gain in db is a one-third-power function of beam current at low level. Under saturated-power-output conditions, power output varies as the 4/3 power of beam current. A typical curve of power output as a function of grid voltage is shown in Fig. 8. High modulation ratios are generally possible.

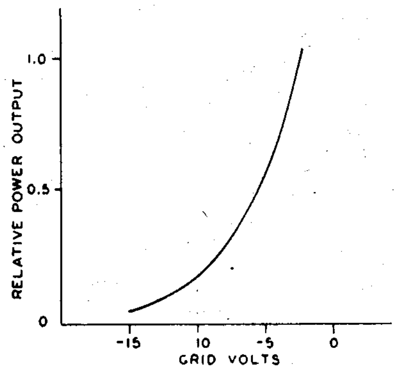


Fig. 8 Power Output of a T-W Tube as a Function of Grid Voltage.

Variation of the voltage on the beam-current-controlling electrode also causes phase modulation because the change in beam current affects the tube-gain parameter, C. This phase modulation, $\triangle\phi$, can be calculated from the following expression:

$$\triangle\phi \cong 90 \frac{\triangle V}{V} C(1 + QC) N \ldots (1)$$

where $\triangle\phi$ is expressed as change in phase angle in degrees,

V is the voltage on the beam-current-controlling electrode,

C and QC are tube constants, and

N is the number of wavelengths along the interaction circuit.

Typical values for C, QC and N are 0.01, 0.015, and 50, respectively, for a low-noise travelling-wave tube.

For small signals, therefore, expression (1) indicates that the phase varies essentially linearly with the voltage on the beam-current-controlling electrode.

Pulse Modulation

Pulse modulation is also accomplished by variation of the voltage on the beam-current-controlling electrode. The capacitance of this electrode with respect to the cathode is generally of the order of 5 to 12 micromicrofarads. It is also possible to pulse the cathode with respect to the remaining electrodes.

It is important to note that a CW travelling wave tube operates at the same helix voltage as the same tube under pulsed conditions. For a given tube type, therefore, the peak power output can be made larger than the CW power output only by an increase in beam current. In general, the beam current for a given tube type can be increased only to a limited extent.

Phase Modulation

Because a change in helix voltage produces the greatest change in phase angle, phase modulation can usually be applied most efficiently at the helix. For small-signal operation, the effect of helix-voltage variation on phase can be calculated from the following expressions:

$$\triangle\phi \cong -105 \frac{\triangle V_o}{V_o} N \ldots (2)$$

where $\Delta\phi$ is expressed as change in phase angle in degrees,

V_0 is the synchronous helix voltage, and

N is the number of wavelengths along the interaction circuit.

Expression (2) indicates that, for small signals, the phase variation as a function of helix voltage is essentially linear at synchronous low helix voltage. When the beam current is constant, the modulation of the helix voltage may produce some amplitude modulation along with the phase modulation, because power output and gain also vary with helix voltage, as shown previously in Fig. 5. In applications where amplitude modulation is objectionable and some phase-modulation linearity can be sacrificed, a compensating signal may be applied to the beam-current-controlling electrode of the tube to reduce the amplitude modulation.

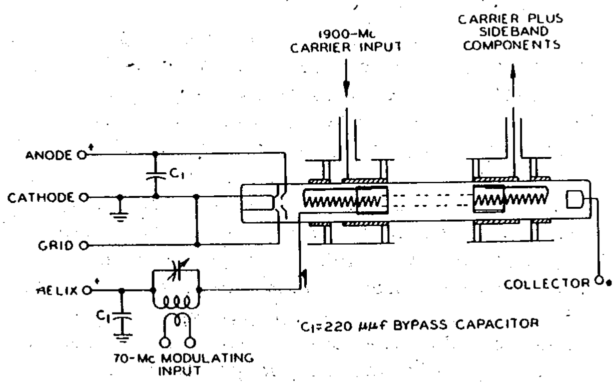


Fig. 9 Circuit for Phase-modulating a T-W Tube.

A circuit for phase-modulating the travelling-wave tube at the helix is shown in Fig. 9. Measured modulation components produced by this circuit are shown in Fig. 10. A complete theoretical discussion of phase modulation of travelling-wave tubes has been given by Bray, Proc. I.E.E., July 1st, 1952.

Frequency Shifting and Mixing

The method for synchrodyne (or frequency-shift) operation is the same as that discussed for phase modulation, although the useful end result is different. In synchrodyning, the desired (generally constant) frequency shift is introduced at the helix. With a frequency-shift voltage corresponding to a modulation index of 2.40, it is possible to reduce the carrier to a very low value (theoretically to zero) in accordance with Bessel functions for phase modulation. The maximum sideband output, however, occurs at a different value of drive from the required for the null carrier, as shown in Fig. 10. This result, in accordance with the appropriate Bessel function, indicates that maximum first-order-sideband output occurs for a modulation index of 1.84.

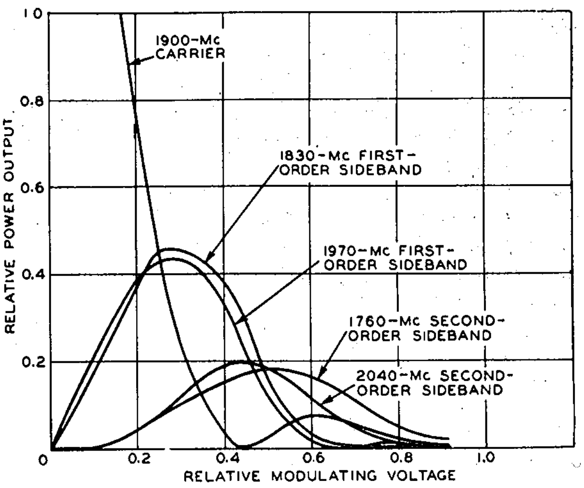


Fig. 10 Measured Modulation Components due to Phase Modulation of a T-W Tube.

The theoretical minimum conversion loss is then 4.7 db.

If the helix-to-cathode impedance is low at the desired shift frequency, and, therefore, a large amount of power is needed to obtain the required drive, it is possible to drive the cathode voltage and keep all other voltages fixed. The modulation characteristics are then more complex, however, because it is necessary to consider not only the phase change produced by the helix-voltage variation, but also all the changes produced by variation of the beam current.

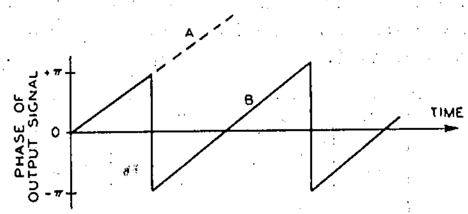


Fig. 11 Sawtooth Phase Modulation which may be used to Simulate a Continuous Phase Shift.

Sawtooth Phase Modulation

A continuous advance of the phase of a signal can be simulated by the use of a travelling-wave tube which is phase-modulated by the application of a saw-tooth voltage to the helix. A saw-tooth voltage of proper amplitude causes the phase of the microwave signal at the output of the travelling-wave tube to take the form shown in Fig. 11. Curve A represents a continuous advance in rf phase which is equivalent to an increase in rf frequency. For a sawtooth voltage having a frequency f and an amplitude which causes a total phase excursion of 2π, the shift of the travelling wave tube output-signal frequency with respect to the rf input signal frequency is equal to f. It can be seen that curve B is equivalent to curve A in this figure except for the finite time interval for the flyback. This method is analogous to single-sideband modulation. It is useful in amplifier chains in which frequency must be shifted, and can also be used to simulate the "Doppler" shifts which occur in certain types of radar equipment.

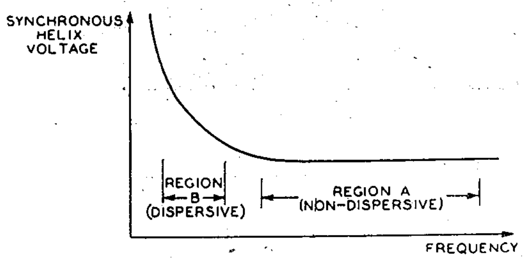


Fig. 12 Dispersion Curve for Helix Slow-wave Structure.

Tunable Amplifier

The variation of synchronous voltage with frequency for a helix is illustrated in Fig. 12. Broadband travelling-wave tubes are designed for operation in region A, the so-called non-dispersive region. If the tube is designed for operation in region B, the dispersive region, it is possible to obtain gain over a more restricted frequency band for a fixed helix voltage. The travelling-wave tube can then be tuned electronically by variation of the helix voltage.

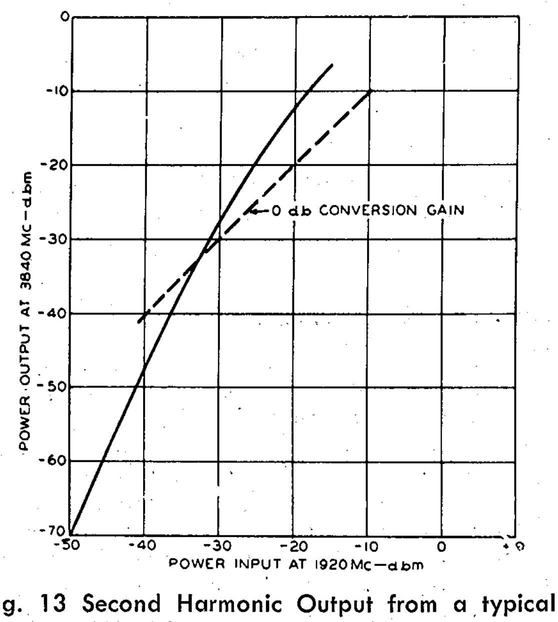


Fig. 13 Second Harmonic Output from a typical T-W Tube.

Because such a dispersive-type travelling-wave tube has a relatively narrow frequency band, it is easier to prevent oscillations, and therefore, higher gains can be obtained.

Frequency Multiplier

Measurements indicate that a travelling-wave tube generates harmonic output, particularly as tube saturation is approached. When the travelling-wave tube is used as a frequency doubler, conversion gains of 10 db can be realised. Fig. 13 shows the second-harmonic output of a low-noise travelling-wave tube operating into a matched load. Increased conversion gain may be obtained by operation into a mismatched load, or by design of the tube for specific use as a frequency multiplier.

Microwave Limiter and AGC

The saturation characteristic, shown previously in Fig. 3, can be used to keep the power output of travelling-wave tubes essentially constant with variations in input power. When two travelling-wave tubes operating in the saturation region are used in cascade, the power-input range over which limiting action is obtained can be quite substantial. Limiting action can be obtained in any travelling-wave tube. A modification of standard travelling-wave tubes, however, produces useful limiting over a power-input range of about 20 db. The use of two such tubes in cascade permits the output power to be held constant to within 0.5 db over an input range of approximately 50 db and a frequency range of 25%.

Automatic gain control can also be obtained by means of a feedback voltage applied to the beam-current-controlling electrode of the travelling-wave tube.

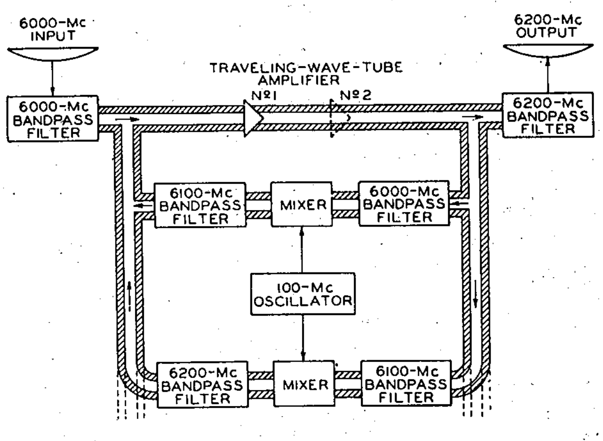


Fig. 14 Re-entrant T-W Tube System for obtaining Increased Gain.

Multiplied-Gain Re-Entrant System

Substantially increased gain can be obtained from a travelling-wave tube by taking advantage of the large bandwidth of such tubes and passing the signal through them more than once, as shown in Fig. 14. In this system, the signal is amplified by the travelling-wave tube, and is then heterodyned to a second frequency and reapplied to the travelling-wave tube. For a system using two travelling-wave tubes with a gain of 30 db each in cascade and having a conversion loss in mixer and filters of 10 db, a net overall gain of 110 db is obtained when the signal is reapplied once.

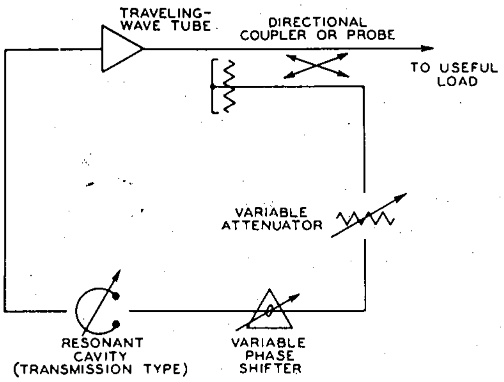


Fig. 15 T-W Tube Oscillator Circuit.

Oscillator

The travelling-wave tube may be used as an oscillator in the simple regenerative circuit shown in Fig. 15. The variable attenuator and phase shifter shown in the circuit are used to adjust the feedback to a suitable level and phase. The transmission cavity serves as the main frequency-determining element.

Calculations show that such a circuit has excellent frequency stability. For example, when a cavity having an internal Q of 20000 and a broadband travelling-wave tube having a noise figure of the order of 20 db and a small-signal gain of 30 db are used, a calculated noise bandwidth of 0.01 cycles per second is obtained at a frequency of 3000 Mc/s. Without extra care to reduce power-supply ripple, the measured frequency modulation of the output is 15 c/s.

Tunable Oscillator

The circuit shown in Fig. 15 can be tuned mechanically merely by tuning of the resonant cavity. Electronic tuning can be obtained by variation of the helix voltage, which effectively varies the electron velocity inside the helix and, therefore, the phase velocity of the wave. Electronic tuning ranges of 4% to 8% appear possible.

Input Tubes for Radar Receivers

Low-noise travelling-wave tubes are especially suitable for use as input tubes for radar receivers because of three factors: (a) low initial noise figure, (b) low noise figure with life, and (c) protection of the crystal mixer following the travelling-wave tube against burnout.

Although reasonable noise figures can be obtained from crystals, under carefully controlled conditions, there is evidence that such figures are seldom obtained in actual field use. In a radar system, a gas tube known as the TR (transmit-receive) switch tube effectively short-circuits the receiver input during the transmitted high-power pulse. The greatest problem encountered with crystals is burnout or deterioration as a result of TR tube leakage, called "spike", which gradually increases during the life of the TR tubes so that the crystal is subjected to increasing energy peaks. A second possible source of crystal deterioration is radiation from nearby radar equipment.

A low-noise travelling-wave tube may be used in radar receivers to protect the crystal by isolating it from the high-power portions of the radar system. The travelling-wave tube accomplishes this isolation by means of its saturation characteristic, i.e., within reasonable limits, any amount of power fed to the low-noise travelling- wave tube produces a maximum power output of the order of only 1 milliwatt, which is far below the burnout point of crystals.

When the travelling-wave tube is used, therefore, the "spike" leakage limit can be made less stringent. A first step in using a low-noise travelling-wave tube in a radar receiver is to eliminate the "keep-alive" voltage from the TR tube, thus also improving recovery time and TR tube life. In addition, because the maximum peak power input to a low-noise travelling-wave tube may be as high as 500 watts or more, the attenuation requirement on the TR tube can be reduced.

The effective noise figure of the radar receiver is reduced, therefore, not only by the use of the low-noise travelling-wave tube, but also by the reduction of the effective insertion loss of the circuitry preceding the travelling-wave tube by as much as 0.5 db compared to that of a standard crystal-input receiver. The insertion loss is reduced by design of the system specifically for lowest insertion loss without compromises due to requirements for low "spike" leakage or large high-level attenuation. The travelling-wave tube also substantially reduces local-oscillator radiation.

The broadband characteristics of the low-noise travelling-wave tube is important to designers of tunable radar systems. The ability of low-noise travelling-wave tubes to operate at high ambient temperature is sometimes also important.

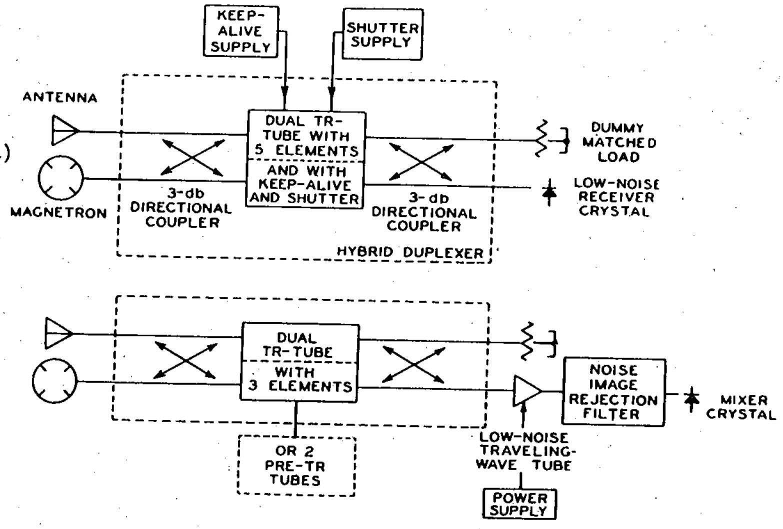


Fig. 16 Comparison of Radar Systems using low noise T-W Tube and Conventional Crystal input. (a) Conventional system using crystal. Operation of Hybrid Duplexer places a premium on mechanical and electrical symmetry of Directional Couplers and TR tubes. (b) System using T-W Tube. Simplified TR tube has reduced insertion loss, resulting in further improvement in system noise figure. Symmetry requirements on Directional Couplers and TR tubes are less stringent.

Fig. 16 shows a radar duplexer circuit and its modification using a low-noise travelling-wave tube.

Millimicrosecond Pulses and Wideband Video Signals

The frequency spectrum of a rectangular pulse has a $[(\sin x)/x]^2$ distribution. As the pulse width is decreased, the frequency band occupied by the pulse spectrum is increased. The central lobe of the spectrum has a width equal to twice the pulse duration. A 0.01-microsecond pulse, therefore, has a spectrum whose central lobe is 200 Mc/s wide. It is evident that the amplification of such pulses requires circuitry of wide bandwidth. The travelling-wave tube appears to be particularly well suited for this application.

For example, in a short-pulse radar system using 0.02-microsecond pulses, a travelling-wave tube may be used as an intermediate-frequency amplifier operating at 3000 Mc/s. For such usage, one travelling-wave tube compares favourably in terms of cost, engineering work required, and reliability to the alternative of several dozen conventional valves plus associated circuitry.

Generation of Millimicrosecond Pulses

A travelling-wave tube may also be used as the active element in a self-excited oscillator circuit which generates micro-wave pulses of the order of 0.002 microsecond and direct-current pulses as short as 0.005 microsecond. The major components of the circuit include a loop containing an expander, a travelling-wave tube, a band-pass filter, a time delay, and a means of automatic gain control.

Radiotronics is published twelve times a year by The Wireless Press for Amalgamated Wireless Valve Company Pty. Ltd. The annual subscription rate in Australasia is 10/-; in U.S.A. and dollar countries $1.50, and in all other countries 12/6. Price of a single copy is 1/-.

Subscribers should promptly notify Amalgamated Wireless Valve Company Pty. Ltd., 47 York Street, Sydney, and also the local Post Office of any change in address, allowing one month for the change to become effective

EDITOR .... BERNARD J. SIMPSON

PRINTED BY THE CLOISTER PRESS, 45-49 GEORGE STREET, REDFERN