RADIOTRONICS

Vol. 28, No. 4 April, 1963

IN THIS ISSUE

4

AN AWV PUBLICATION

REGISTERED IN AUSTRALIA FOR TRANSMISSION BY POST AS A PERIODICAL.

STEREO BALANCE CONTROLS

By B. J. Simpson

Introduction

Several readers have written to us, asking for data on stereo balance controls, and this article has been prepared to meet their requests. This may be a good time to remind readers that we are always happy to receive suggestions for articles for "Radiotronics", and all suggestions are carefully considered. There may of course be many reasons why certain ideas cannot be used, so that no promises can be made. All the same, letters and ideas are always welcome.

The BALANCE control in a stereo system is one of the new controls brought to us by stereo techniques. The basic function of the control is very simple, but there are so many ways of achieving the desired object that one may be pardoned for being a little confused. I cannot even try in this article to cover all the methods used to adjust balance, as I have no doubt that there are some that I have not yet seen. I will however try to show what the control does, and some of the more common ways in which it is incorporated into a stereo system.

Why Balance?

In the ideal form, a stereo system consists of two identical reproducing systems, each of which amplifies and reproduces different but interconnected sets of information. Each of the two systems is in essence the single amplifying and reproducing channel which we had before stereo became a practical reality. Both the single "pre-stereo" channel, and the two channels of the stereo system, can be as simple or as complex as desired; the details of each channel are of no importance in this article.

Whilst we know what is wanted from the ideal point of view, we also must recognise that in man-made things, the ideal is rarely if ever achieved. We are faced therefore with the fact that the two sections of a stereo cartridge may not have exactly the same sensitivity, the two amplifier chains may not have exactly the same gain, the two loudspeakers may not have exactly the same efficiency; in fact we have to admit that it will be virtually impossible for any two parts of the system to be identical.

Further, there are considerations outside the equipment itself which must be examined. It is possible that there may be small degrees of imbalance in the two channels recorded on tape or disc, arising in the recording process from imperfections similar to those already mentioned. More important, perhaps, from the practical point of view is the wide variety of rooms in which reproduction may be required. Every room will vary in geography, in the reverberation time and amount of reverberation, or in the absorption of sound. In addition, other variable factors are the placement of the loudspeakers in the room, and the relative placement of the listeners.

When all the variable factors, both inside and outside the actual reproducing chain, are put together in all their combinations and permutations, we are faced with virtually an infinite number of conditions. The result of all this is

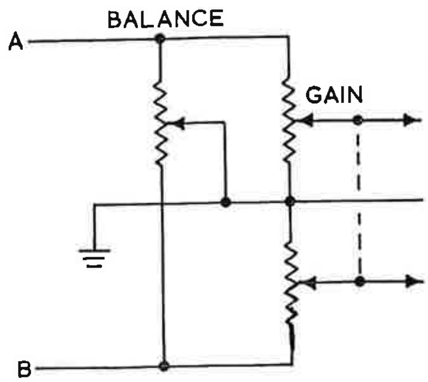


Fig. 1

that in case the system is unbalanced, and it always is, some way of restoring balance must be included.

It is important to remember that the balance correction is used to correct the complete system, right from the recorded medium until the sound reaches the listener's ear; that is, the recorded medium, the pickup, amplifiers, loudspeakers and the listener's environment are all taken into consideration. This is essential if satisfactory reproduction is to be obtained. The method of obtaining this balance is quite simple in concept, because all that is needed is some differential adjustment of gain in the two stereo amplifier channels. The practical methods used are many.

Some Solutions

Possibly the simplest and cheapest way to provide a balance control is to provide separate gain controls for the two channels and then adjust them for the best balance at the same time as for the required average listening level. This system allows the gain in either channel to be reduced to zero. Like all simple and cheap ideas, this one is not necessarily the best. It has the disadvantage of being difficult to use in practice, particularly by those not versed in the electronic art. Often concentric controls are provided, with the idea that once balance is obtained, overall gain may be adjusted as required by turning the two knobs simultaneously. I have even seen provision for locking them. Unfortunately this does not work in practice, a variation of system gain invariably requiring an adjustment of balance.

The next solution is a better one, and requires one more potentiometer. It is shown in Fig. 1. In effect, this arrangement differentially adjusts parallel resistance connected across the two gain controls, and therefore the available signal levels in the two channels. It is assumed here that the customary ganged gain controls are used. A linear balance control must of course be used, and this system usually exhibits a lack of sensitivity over a fairly wide central portion of its travel.

Where the arrangement of Fig. 1 is used to reduce the gain of one channel severely, it imposes additional loading on the foregoing stage. The extreme case occurs when the gain of one channel is reduced to zero. This may be countered by the insertion of additional resistors, either in series with the inputs at A and B, or better still, in series with the ends of the balance control. In the case of the latter, however, it is then no longer possible to silence one channel, and the control is rendered even less sensitive.

A further variation of the same idea is shown in Fig. 2, which is similar to the arrangement just discussed, except that the position of the balance control has been changed. This arrangement avoids the loading problem, except when the gain controls are at or near the maximum gain positions, but the poor sensitivity is still with us.

Whilst the two systems just shown are depicted in conjunction with the gain control, this does not have to be the case. Often the two halves of the balance control form the grid resistors in RC-coupled stages, and there are numerous similar ways in which the same basic idea could be used. For example, one rather more elaborate method used by RCA is shown in Fig. 3. Here we see two triode stages, which are the counterpart of each other in the two stereo channels. They are RC-coupled to the following stages. In shunt across the plate loads are half the balance control and a small fixed resistor. It will be seen that as the balance control is turned, the effective load resistor of one stage will increase, whilst

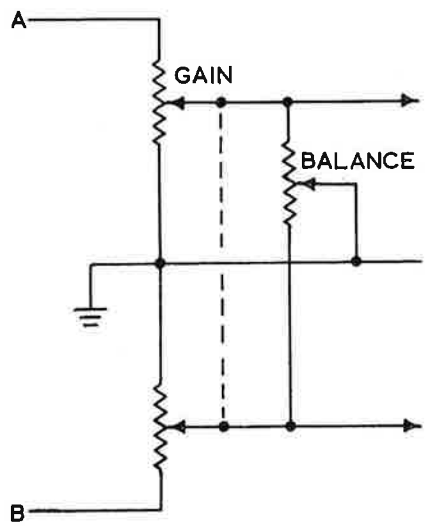


Fig. 2

that of the other stage will decrease. The capacitor in series with the slider is for dc isolation, and should have a value which presents a low impedance at the frequencies of interest.

So far in this discussion, mention has been made of differential adjustment of gain to achieve balance. This method has the advantage that the mean level in the listening room should remain fairly constant for small changes of balance setting. When the system using separate gain controls was described, however, differential gain control was not in fact being used, as it is most likely in practice that only one gain control would be adjusted at a time. That system, however, shows that balance can be achieved by adjustment of the gain in one channel only.

If we go back to the usual ganged gain controls, we can still operate on one channel only by using a system similar to that shown in Fig. 4. Here are shown parts of two RC-coupled stages, one in each channel. It will be seen that the signal in channel A passes through a fixed potentiometer, and suffers a 6 db loss in so doing. The balance control must be a linear control, and at the nominal balance point also introduces a 6 db loss. Here again, of course, we are not providing a differential adjustment of gain, and are therefore making no effort to maintain a mean listening level in the room.

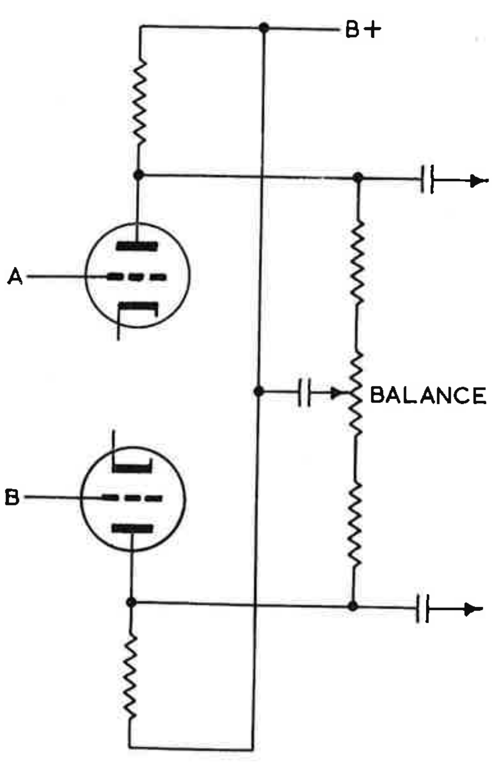


Fig. 3

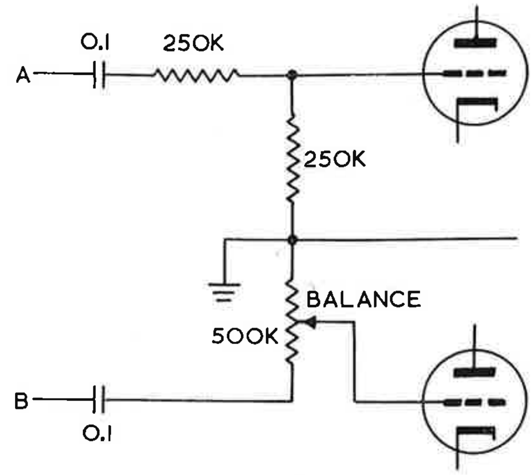


Fig. 4

Some Better Solutions

We are now coming to some of the more common good solutions of the problem of providing balance. The methods to be discussed now are generally used with matched ganged gain or volume controls (or level or loudness controls), but are not necessarily adjacent to these controls in the circuit. They will be shown in association with the gain controls in the examples only as a matter of convenience.

The balance controls now to be described use a ganged potentiometer, one section of which is placed in each channel. One obvious form of this type of control is seen in Fig. 5. In this and similar applications, it is important to establish the direction of rotation of the two pairs of ganged controls. Inspection will show that for correct operation, the two sliders of the gain control (as shown in the diagram) must move in opposite directions, whilst the two sliders of the balance control must move in the same direction. A pictorial diagram is shown in Fig. 6 to clarify this point, and to corelate the electrical and mechanical arrangements.

This system permits the gain of one channel to be reduced to zero without undesirable loading effects. If linear elements are used in the balance control, then at the nominal balance point, the control will introduce a loss of about 6 db. The available variation in gain for each channel will then be plus 6 db minus infinity. Linear controls are more sensitive in this arrangement than in some of the simpler systems described earlier.

A variation of the arrangement shown in Fig. 5 uses ganged logarithmic elements instead of linear elements for the balance control. With this idea, one of the tracks is logarithmic, curve C, whilst the other track is antilog, curve E. As readers will be aware, at the mechanical centre of a

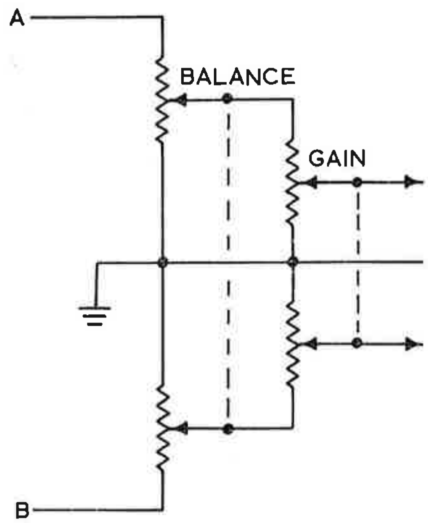


Fig. 5

logarithmic track, there is about 15% of the available resistance at one side of the slider and about 85% at the other side.

Assuming such a ganged control, with the C curve track nearest to the shaft and the E track at the rear, which is the normal arrangement, let the control be connected into circuit as shown in Figs. 5 and 6. Now on the channel A side, there will be about 15% of the total resistance between A and the slider of the balance control. Because the element in the B channel has an antilog track, a similar situation will obtain in that channel also.

It may be asked what is the advantage of this variation, which after all requires a special control. (These controls can be made and supplied by Australian makers, but they are not stock items; some delay may therefore be encountered in obtaining them). Well, the advantage here is twofold.

In the first place, this arrangement inserts a loss of only about 1.5 db per channel at the nominal balance point. Secondly, because the change of resistance in a logarithmic (or antilog) control becomes very fast once the approximate centre of the track has been passed, this arrangement provides a control which appears more positive in operation than some others. With the connections of Fig. 5, there is available a variation of gain in each channel of plus 1.5 db minus infinity.

Both of the two arrangements just described using dual ganged controls may also be used as shown in Fig. 7. Neither of these two new arrangements allow the gain in either channel to be reduced to zero, and both have a limited variation of gain per channel. The variation of gain per channel, and the insertion loss at the nominal balance point, will depend on the types of elements used, their values, and the values of the gain controls or other associated components.

We can readily arrive at the variation in gain available with such a simple series system by a comparison of the values of the elements of the gain and balance controls. For example, if both the controls have 500K ohm tracks, then irrespective of the laws of the tracks, the maximum attenuation in each channel will be 6 db. The ratio between the values of the elements in the gain and balance controls will require to be about 1:4 to provide a maximum attenuation of 12 db, and this may make the use of this system rather unwieldy where a large range of adjustment is required.

Going back to the 6 db example quoted, we will by simple calculation find that at the nominal balance point the loss in each channel will be about 2.5 db. This means that each channel has an adjustment range of plus 2.5 db minus 3.5 db. If the logarithmic and antilog elements are used, with the same element values, the maximum attenuation will remain the same, the attenuation at the nominal balance point will be about 1.25 db, and the adjustment range will be plus 1.25 db minus 4.75 db, taking idealised figures.

Required Range

Sufficient has been said already to allow us to digress a little. A few of the more common balance arrangements have been described, with the more salient features. A hint has been given that with some of them, the available range of adjustment is likely to be limited. It is difficult to find anyone who is prepared to state just what range of adjustment should be provided. I feel that an absolute minimum range of 6 db will be required in a high quality system, with a wider range as the general quality of the system is lowered.

It is significant that apart from some of the very cheap solutions, one of the most popular appears to be that of Fig. 5, using logarithmic and antilog elements. This arrangement gives low loss at the nominal balance point, and because the gain of one channel can if necessary be taken right down to zero, there is no question of insufficient range of adjustment being available.

Other Methods

There are many ways of providing a balance control other than those mentioned here, as any arrangement which provides the necessary change in gain could be considered. In practice, it is

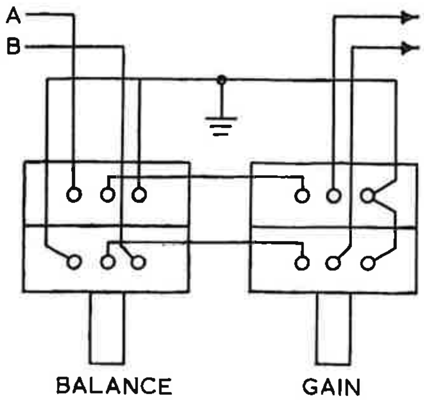


Fig. 6

likely to be difficult to find a better and at the same time a cheaper solution than that already mentioned as a preferred method.

Checks and Adjustments

Having established just what the balance control is and what it does, the next question is that of how to use it. Attempts are often made to set the control whilst playing a stereo record, but this method is unlikely to succeed if only because the two channels on the record must naturally be different.

Suggestions have also been made that a mono disc be played for the purpose of setting up balance. This is a possibility, though falling short of receiving a 100% endorsement. Remember that some of the high quality stereo cartridges available are not compatible with mono records, and may suffer damage if this were done.

It is sometimes recommended that a tone be injected into both channels of the system and the control set by ear for apparent equal output from both sides. This is alright as far as it goes, but does not take into account possible variations between the two halves of the pickup cartridge.

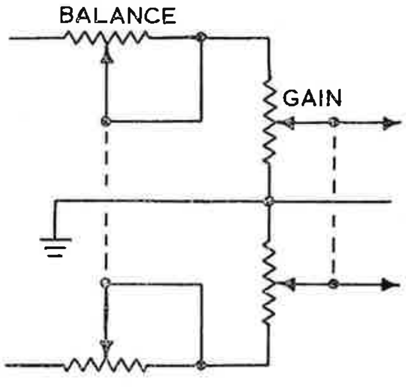


Fig. 7

In the same way, some amplifiers are fitted with balance meters which measure the voltages developed across the voice coil terminals or some similar point in the circuit. These fail rather badly, as they cannot take into account variations in the loudspeakers and connecting leads, or the environmental effects of room placement and similar matters.

It appears that a truly acceptable method must start with the record, which should carry a tone, with the same amplitude on both left and right channels. This requires the use of one of the special stereo tone-band discs used in audio work, or the use of one of the many stereo test and demonstration discs which have a track specifically provided for balancing purposes.

It is recognised that these discs may not be available, and that many people will seek a compromise. Those with good musical experience may be very successful in setting the control according to their taste, their experience leading them to what the item should sound like rather than to the perhaps synonymous idea of balance. Others may get reasonable results by playing a stereo disc in which there is little spatial consideration, that is, perhaps a solo performer.

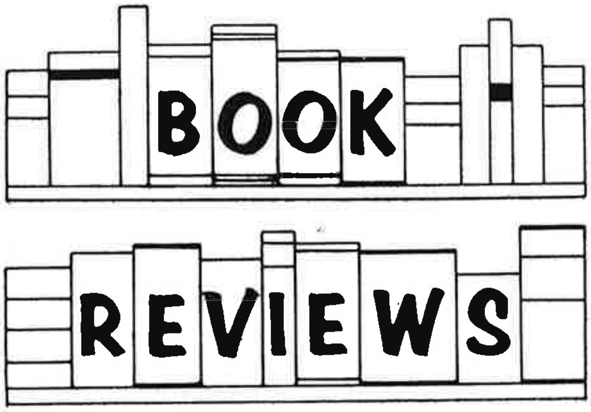
In theory, balance will hold good only over the comparatively restricted ideal listening area, but in practice, readers should not allow themselves to be too much dismayed by this thought. Where the listeners are seated to one side of the listening area, perhaps because the chairs there are more comfortable, the balance control will allow the theoretical centre of the reproduction to be so turned as to give good stereo results at the desired spot.

In connection with this, and for general ease of operation, it is very desirable that the balance control be so installed that counterclockwise rotation lifts the left-hand level, and vice versa. This will enable the user more readily to get the feel of the system. A simple changeover of connections will give you this sense if you do not already have it. Note however, that in order to preserve this sense, the balance control must appear in the circuit later than any stereo reversing switches that may be fitted.

Conclusion

The whole idea of a balance control is seen to be a very simple one when analysed, and it is perhaps only the variety of methods used which is confusing. The added cost is very small, and I can remember only one stereo system which did not have a balance control; this was a very simple and cheap portable record player, where quality of reproduction was obviously not a prime consideration. Incidentally, it was not made in

Australia. One last word concerns gain measurements on the system; these should be made with the balance control in the nominal balance position, and not in the position giving maximum gain for the channel under test.



When we first pick up a new book, there is always a first impression, and that isn't meant to be a pun either. The first impression of "Transistor Laboratory Manual", by Milton S. Kiver and Bernard Van Emden (McGraw-Hill Book Co. Inc.) was the format. This book is intended for use in electronic training on an introductory level. The work consists of eighteen experiments, full details of which are given, together with tabulated forms where the experimenter can write in the results of the experiment and the conclusions drawn. There is no doubt that a good grounding and familiarisation would be gained from the experiments. This is one of the interesting volumes produced specifically for educational purposes over recent years.

It was coincidental that two books on TV repair arrived together, both paper-covered and published by the same company. (Howard W. Sams Inc.) The 160 page octavo-sized "Photofact (R) Guide to TV Troubles", D. Herrington and C. Oliphant, is one of those useful books designed to exploit the possibility of diagnosing TV troubles by observation of the effect on the picture. One cannot pay too much attention to this phase of trouble detection. A careful study of the dozens of photographs, with faults explained in relation to typical circuits, yields a surprising amount of information, not only about TV troubles, but also about circuit operation.

The second TV book is the 96 page octavo-sized "TV Diagnosis and Repair", by the "P.F. Reporter" Editorial Staff. This book essays a general approach to the problem, instead of the specialised approach of the previous title. Although physically small, and admittedly not an exhaustive work on the subject, this volume holds a wealth of useful information. The accent on correct diagnostic approach before attempting repair is very pleasing, and very important if efficient servicing is desired.

A complete change of accent is introduced by John Carroll's "Design Manual for Transistor Circuits" (McGraw-Hill Book Co. Inc.) This is a 381-page quarto-size hard-bound volume edited by Mr. Carroll, and is a reprint in useful, collated and indexed form, of tested transistor circuits and the articles describing them, as they appeared in "Electronics", of which Mr. Carroll is the Managing Editor. The twenty-one chapters of this large volume contain no less than 128 circuits and their descriptions, making this title an extremely useful and versatile reference and "ideas" book.

Passing further along the list of new arrivals, the next title is from Iliffe Books Ltd., and is "Servicing Transistor Radios and Printed Circuits", from the pen of Leonard Lane. This is the English edition of an American Title "How to Fix Transistor Radios and Printed Circuits", and apart from some editing by Mr. E. A. W. Spreadbury, would be the same book. This duplication of books under two titles seems to be getting more frequent. This book is octavo size, with 264 pages, well illustrated, and satisfyingly thorough in coverage, ranging from physical fundamentals through all aspects of servicing, including the techniques necessary for transistor and printed circuit work.

Just to emphasise the variety of fields now available within the general framework of electronics, let us look at a book on and entitled "Industrial Electronics". This is by Alan Lytel, published by McGraw-Hill Book Co., and is written at the technical college level. The subject is treated with special emphasis on control techniques, as they do in fact cover a large proportion of the ways by which electronics is pushing into industry. Solid state devices are well covered as well as thermionic valves, and although the book is intended to follow basic courses on active devices, any interested tradesman or technician could also gain benefit.

Some of the books we receive are unusual, specialised, or notable in some similar way. Into this category could perhaps fall "Electronic Measuring Instruments", McGraw-Hill Book Co., by Harold Soisson. This title is an introduction to the science of electronic measurements as used in industry and research, and is written at the technical college and university junior years level. Whilst perhaps a specialised book, it is a fact that the whole art of electronics rests on measurements, so that the more we know of measurements, and the methods of making them, the better we can work. The 352 pages of this book would be useful reading for any technician or undergraduate.

Also published by McGraw-Hill Book Co. is John Markus' "Television and Radio Repairing", here reviewed in the second edition. This 568-page work is an extensive and sincere effort to turn a reader with no previous radio or TV experience into at least a journeyman radio tradesman, and perhaps into the operator of a servicing business. It is perhaps fair comment to point out that this mode of entry into the servicing business is hardly likely to be successful, here in Australia, where great value is placed on formal trade and technical training. This is partially recognised in the preface to this book, which concludes with a suggestion of further studies for greater proficiency. With these remarks in mind, the title could be a useful one for those just embarking on a radio trades course.

LASER CRYSTALS

Widened quests to fully explore the characteristics and applications of semiconductor and solid-state materials are daily yielding new data to serve as the basis for an ever-increasing flow of new products.

Now comes word of RCA participation in an amazing industry development that challenges the imagination and moves the pages of science fiction into the realm of everyday reality. Known as "light amplification through the stimulated emission of radiation" or, more simply, "laser," this latest advancement presages an era in the not-too-distant future when super-powerful light beams will be used to perform the most delicate surgery, weld and machine the most difficult refractory metals, vaporize hostile ballistic missiles in flight, guide space vehicles, detect enemy submarines lurking in the ocean deeps, and communicate between planets.

Already, RCA scientists are in the process of evolving a laser communications system that in theory may use a beam of light to carry all the radio, TV, and telephone broadcasts now being transmitted throughout the world. Other current RCA research involves development of a laser computer that operates at amazingly high speed.

How did this remarkable "breakthrough" come about? What are the principles on which it operates?

Investigation of higher spectra as a means for transmitting intelligence was initiated primarily for two reasons: the growing concern of Government and private industry over increased crowding of communications channels; and the limitations of existing communications methods which became evident during recent orbital space flights.

Research into the higher frequency bands, which include infrared radiation and visible light, seemed to offer the logical answer, but many drawbacks were present. Ordinary light, for example, is composed of varied colours in the visible spectrum and radiation in the near-visible regions, each of which represents a separate frequency. A light beam for communications, on the other hand, would have to consist of a single frequency. Furthermore, this light beam would have to be capable of amplification and be "coherent"; that is, among other characteristics, it should have the capacity to travel over enormous distances without appreciable "spreading".

Working independently, RCA found the answer to all these formidable problems in a device built around a new type of laser crystal of superior optical quality.

In the new device, the desired amplification is achieved by shining ordinary light, consisting of many different frequencies, upon a crystal, some of whose electrons are thereby stimulated to emit light at only one of those frequencies. By silvering both ends of the crystal—one partially and the other completely—most of the emitted light is reflected back and forth, inducing still other electrons to emit. The effect is cumulative until the highly directional beam of coherent energy radiating from the partially silvered end is more intense than light at the surface of the sun.

Because laser beams concentrate tremendous amounts of energy into tiny diameters of amazing coherence, power loss due to spreading is relatively slight over great distances.

RCA's new laser crystal is distinguished from other reported materials in that it reduces by 10 times the amount of energy required by other types to generate powerful beams of infrared light. Moreover, such emission is triggered by a very broad band of light energies stretching across the entire visible spectrum. In a relatively short time scientists expect this device to operate continuously, activated only by a 100-watt bulb. By contrast, most solid-state lasers currently give only pulsed output and require the intense power of a xenon flash lamp to operate.

Two laser crystals are already available from RCA, with others in the immediate offing. Designated developmental types XLC100 and XLC101, both are cylindrical, single crystals uniformly doped in controlled valence states, only one inch long and one-quarter inch in diameter. They feature low laser threshold; strain and light scattering at undetectable level; exceptionally high doping uniformity; wide selection of doping elements; and excellent control of valence state. Typical threshold energy for XLC100 (actual threshold supplied with each crystal) is 10 Joules at an output wavelength of 7,080 angstroms. With a wavelength of 25,100 angstroms, the XLC101 features typical threshold energy of 15 Joules.

REVOLUTIONARY SOLID-STATE ELEMENT

New RCA development combines the best properties of transistors and electron valves

The development of a revolutionary solid-state element, combining the best properties of transistors and electron valves was reported in February by the Radio Corporation of America.

Called a metal-oxide-semiconductor transistor, the new device can be fabricated in large interconnected arrays. It may be regarded as a "new fundamental building block" of integrated, microelectronic circuits for a broad range of future electronic systems.

Among future products that should become both possible and economically practical with such circuits are portable, battery-operated, high-speed computers; lightweight, high-performance communications systems; and a new generation of tactical and industrial equipment operating over wider temperature ranges and with greater resistance to nuclear radiation.

Electronic valves and transistors co-exist throughout electronics today because each offers its own particular advantages. Electronic valves have greater flexibility and simpler circuitry, while transistors offer low operating power, small size, and longer life.

With development of this new device there is, for the first time, a circuit element that combines the best features of both and, at the same time, offers certain unique features of its own.

The new unit is an insulated-gate, field-effect transistor: it is a semiconductor device made from silicon and capable of amplifying electric voltages.

By varying the input voltage on the insulated gate, the device as a whole can be made to switch, amplify, or otherwise regulate its output of electric current in a manner analogous to a pentode electron valve. In conventional transistors, similar results are achieved by making changes in the magnitude of the input current.

Circuits using these new elements are made by producing conducting paths in a slice of high-resistivity silicon, leaving gaps wherever an active element is desired. An insulator is produced by simply oxidizing the silicon over the gap. A metal electrode or "gate" is deposited on top of the insulator and connected into the circuit. By applying proper voltage on the insulated gate, the gap becomes conducting and the circuit is closed.

Both "n" (negative) and "p" (positive) type devices have been made. The nature of their electrical characteristics is such that complete digital (computer) circuits can be constructed from them without the need of other components.

While voltage-controlled transistors are not new in principle, their great promise has gone largely unrealized due to high production costs, technological difficulties and the commanding role assumed early by current-controlled transistors.

Arrays of up to 850 of the new components have been produced in an area the size of a shilling. Experimental microcircuits being built from these arrays include electronic switches and counters for computers, amplifiers for military and commercial communications systems, and control networks for a variety of industrial and military applications.

The new solid-state element is the result of a two-year research effort sponsored jointly by the U.S. Air Force Cambridge Research Laboratories, Bedford, Mass., and Radio Corporation of America.

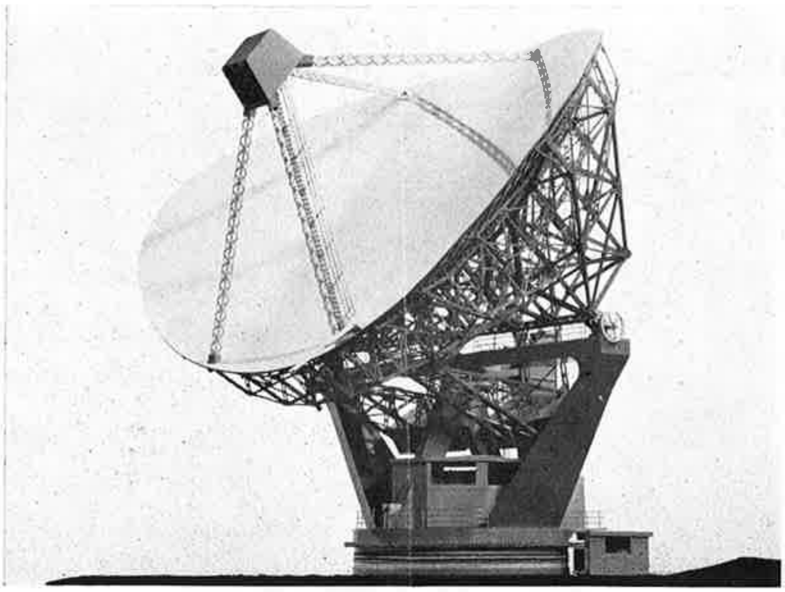
Typical capability of the new device is expressed in some of the technical data now becoming available. The new element has an operating temperature range of −80 to +190°C, with switching speeds of the order of 10 to 20 nanoseconds. Preliminary tests indicate that this revolutionary device has less sensitivity to nuclear radiation than conventional transistors, by a factor of about ten times.

JODRELL BANK'S SECOND RADIO TELESCOPE

Work has started on the construction of a 125 ft radio telescope (Mark 2) to be used by Sir Bernard Lovell, Professor of Radio Astronomy at Manchester University. The new telescope will be near the famous 250 ft instrument at Jodrell Bank which has become overloaded with work. The new telescope is required to extend the present work of the observatory and to open new lines of research. In particular it will be used to map radio emissions from interstellar space, for work on radio stars in conjunction with the existing instrument, and is to operate on very high frequencies for which the other telescope is not designed. The cost of the new instrument—about £300,000—will be met by a grant to Manchester University from the Department of Scientific and Industrial Research.

Husband and Company, Consulting Engineers for the original Mark 1 telescope, have also designed the new instrument. It will be erected under the supervision of the Ministry of Public Building and Works, and it is expected that construction will take about 17 months.

The instrument will consist of receiving equipment mounted in front of a paraboloidal reflecting bowl with a focal length of 40 ft. Four legs springing from the edge of the bowl will support



the receiver at the focus. The bowl will be 125 ft in its longer axis and 83 ft 4 in. in the shorter. The bowl mounting will be altazimuth, with 420° in azimuth and 0° to 90° in elevation; with its bracing and counterweights the bowl will tilt on horizontal bearings supported by a prestressed reinforced concrete structure. This whole superstructure, weighing 850 tons, will revolve on rollers on a circular track 42 ft in diameter. The instrument will be 112 ft high.

The new telescope will supplement the 250 ft instrument. The more accurately formed bowl and the precise control system will enable it to work in the centimetre band. During the last few years radio astronomical observations in the region of wavelengths between 3 and 10 cm have become of particular importance because of the possibility of using the new types of low noise parametric and maser receivers. Mark 2 is expected to provide a major facility in this waveband which does not exist elsewhere in the country. Although the Mark 1 telescope is still the largest instrument in the world capable of work on the important hydrogen-line wavelength of 21 cm, this is near the limit of its performance.

The possibility of carrying out some of the current hydrogen-line studies on the Mark 2 instrument will help to release the Mark 1 for new programmes of work at lower frequencies. In another important programme the Mark 1 and Mark 2 telescopes will be used simultaneously, for the measurement of the positions of radio stars by the lunar occultation technique developed at this observatory.

A new Ferranti Argus 100 computer is to be used on-line for the guidance and control of the new telescope. This is thought to be the first time that a digital control computer will be directly connected to a radio telescope to exercise continuous control over its movements. Another of the computer's functions will be to log astronomical data obtained with the telescope, which will then be passed by data link to the giant Atlas computer at Manchester University for interpretation.

Guidance instructions will be given to the computer either in galactic co-ordinates, which have an equator based on the Milky Way, or in terrestrial co-ordinates based on the earth's equator. The computer must convert this information into control signals for the drive motors allowing for the relative motions of the earth and the rest of the universe.

The reverse calculations must also be performed to display or print galactic or terrestrial co-ordinates from information derived from digital shaft encoders fitted to the telescope for azimuth and elevation. The design accuracy for display and data-logging is to be 16 bits, which corresponds to about 1 part in 64,000 or 20 seconds of arc.

NOTICE RE SUBSCRIPTIONS

Readers and intending subscribers are reminded that the subscription rate for this magazine is now £1 (£1-5s. foreign) for 12 issues, and that subscriptions are accepted for multiples of 12 issues if required. Delivery commences with the first issue after receipt of order. Back copies for the current year are no longer sent automatically, but may be ordered separately if required; the rate for back copies is 2/6d per copy, post free.

Simple binders intended to hold 12 copies are available at 2/6d each post free, whilst existing stocks last.

Changes of address require one month to become effective, and normally operate on the first issue mailed after receipt of advice. Subscribers are particularly reminded that requests for changes of address should include both the old and the new address; this ensures speedy handling, and protects other subscribers of the same name.

New address stencils now coming into use will carry information regarding the duration of the subscription, allowing readers to check for themselves when their subscriptions are due to terminate. These stencils will be used progressively as renewals are made. The stencil carries a code consisting of two numerals and a letter. The two numerals are the last two figures of the expiry year, whilst the letter shows the last monthly issue due. The letters commence with "a" for January, and go through, omitting "i" and "l", to "n" for December. Thus for example, code 64j indicates the last copy due to be that for September, 1964. At this date, only a small number of readers have these coded stencils, but within 12 months it is expected that all will have them.

THE CONTINUING REVOLUTION IN SEMICONDUCTORS

By Dr. R. B. Janes*

Several times in the past few years the revolution in semiconductors seemed to slow down. Each time, however, a new development arose to keep the pot boiling. A continuation of this rapid pace now and in the near future appears certain. This article reviews the present state of the semiconductor art and attempts to look forward to the immediate and the distant future.

Although the pace of technological change in semiconductors has been rapid, some of the earliest devices have held on tenaciously. Typical is the technically obsolete point-contact transistor presently doing an excellent job in certain equipments. The cost of re-engineering such equipments to accommodate newer types cannot be justified. Of course, the point-contact transistor is not being used in modern designs.

The same pattern of long application life is true, to a greater degree, for the grown-junction transistor. Following the point-contact method, the grown-junction technique was developed next for the manufacture of transistors. The early germanium grown-junction types used primarily in the consumer market have nearly disappeared today.

The first practical silicon transistor was the grown-junction type. The higher operating-temperature capabilities of the silicon types prompted designers to use them in many military equipments; as long as these equipments are produced, a continuing market will exist for the technically obsolete silicon grown-junction types. Certain characteristics of grown-junction types are difficult to reproduce in the modern mesa or planar structures thus often preventing a direct substitution. The silicon grown-junction transistor is used sparingly for new designs.

*Manager, Advanced Development Applications, Semiconductor and Materials Division, Radio Corporation of America.

Another situation exists in the historical third class of transistor structures—the alloy transistor (Fig. 1). Over the years, the germanium alloy transistor has reached a peak of refinement in its characteristics and reliability (Fig. 2). User prices have fallen to an extremely attractive level because of the very large volumes produced for the computer and consumer markets. For many years to come, the germanium alloy device will be attractive to many areas; moderate-speed computers, the audio portion of consumer equipment, and a wide variety of industrial uses involving frequency ranges less than 1 Mc. In low- and medium-speed computers, the greater speeds of the more modern transistors can actually cause difficulty. Industrial applications of germanium alloy transistors will continue to grow at a slower rate, and prices will stabilize near their present levels.

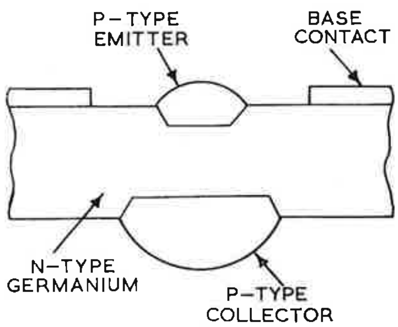


Fig. 1—Cross-section of a p-n-p alloy junction transistor.

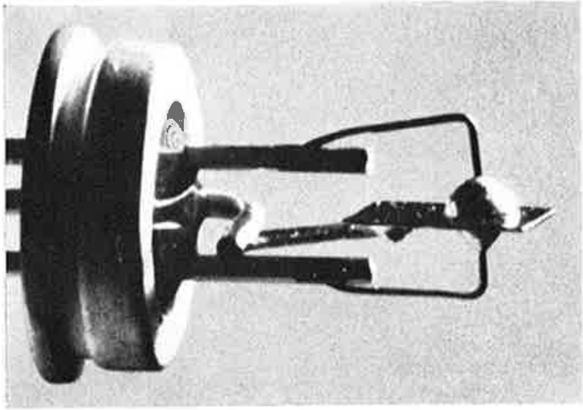


Fig. 2—Germanium alloy transistor structure.

The outlook for silicon alloy transistors is quite different. Except for a few specialized applications, there appears to be little future for silicon alloy transistors, since their characteristics are relatively poor; they are not expected to be used in volume applications.

LOW-POWER TRANSISTORS

In low-power transistors having a frequency response above that of germanium alloy types (greater than about 10 to 20 Mc) there have been many changes. The first attempt to provide a low-power, high-frequency device was the micro-alloy type; in this approach, the base width was closely controlled by automatic means to obtain a narrow base width W and, consequently, a high-frequency response. The micro-alloy type was the only high-frequency transistor available for a considerable period.

Alloy-Drift Types

Development of the alloy-drift transistor (Fig. 3) was next. This approach used a graded region in the base just below the emitter plus an intrinsic region near the collector. For use in an amplifier when low output capacitance and low base resistance are needed, the resultant characteristics were nearly ideal: high-resistivity base region near the collector, a low base resistance because of a low-resistivity base region at the emitter; and an improved high-frequency response caused by the graded base. The alloy-drift technique resulted in regular alloyed structures like the 2N247 and 2N384. Both types have found great usefulness in consumer and industrial equipment for frequencies up to 100 Mc and in computers using nonsaturating logic circuits. In all of these applications, the alloy drift-field type is now facing strong competition from both germanium and silicon mesa and planar units.

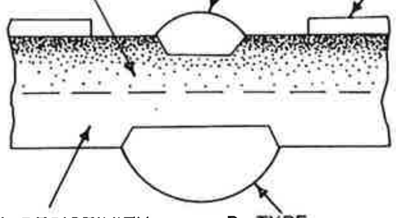


Fig. 3—Cross-section of an alloy drift-field transistor.

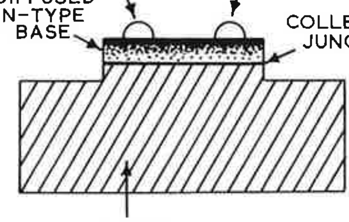


Fig. 4—Cross-section of a dot alloy mesa transistor.

Madt Types

The drift-field and micro-alloy approaches have also been combined to produce the micro-alloy diffused transistor (Madt). Until recently, these were used extensively in very-high-frequency amplifiers and in very fast low-power switches. Because the intrinsic region thickness of the Madt can be carefully controlled, it works well in saturation. Madt types, like the regular alloy types, have been refined and improved continuously. However, the low power capability of the Madt (which makes it susceptible to burn-out) and its poor mechanical reliability have been disadvantages. Moreover, epitaxial germanium and silicon mesa and planar transistors are now able to compete technically and cost-wise with the Madt in all respects. Therefore, these advanced types appear to be the transistors of the future.

Mesa Transistors

Mesa transistors differ from alloy and alloy-drift transistors in that the starting material is the collector rather than the base. The base of the mesa is diffused into the collector, and the emitter is either diffused or alloyed into the base. A mesa is then etched to reduce the collector area at the base-collector region (Fig. 4).

The mesa structure has several important advantages:

The base width can be very closely controlled, especially when shallow emitter alloying or emitter diffusion is used. With this narrow base width, there is no loss of mechanical strength or power dissipation as in the Madt. The diffused base-collector junction allows a higher voltage breakdown with a given collector resistance. This feature has made the mesa technique invaluable in producing high-voltage transistors.

There are, however, some drawbacks:

Because of need for a base contact, the collector capacitance is larger than that of an Madt having the same emitter size. Also the collector thickness required for mechanical handling purposes produces a voltage drop across the collector and increases the stored charge in saturation. However, developments in the past few years have made the mesa transistor competitive with the Madt in every way and have placed it in a power and reliability class by itself.

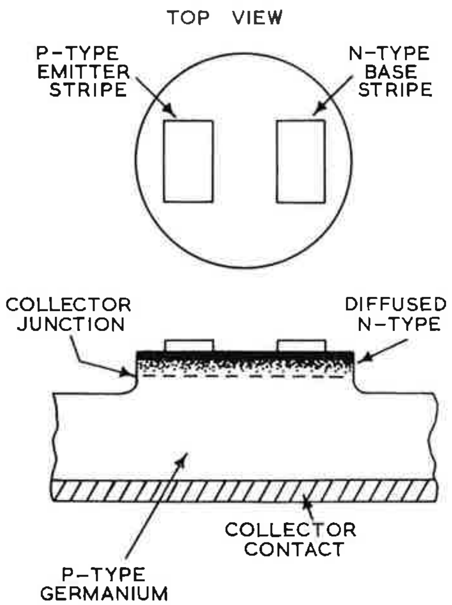


Fig. 5—Cross-section of a p-n-p germanium evaporated-stripe transistor.

Geometry Control of Mesas

Some of the geometry control that permits the collector area and capacitance to be reduced has been accomplished by brute force. As shown in Fig. 4, the alloyed dots have been made smaller for mesas that use alloyed emitters and base contacts. Since the mesa has no line-up problem between the emitter and collector dot, as in the usual alloyed transistor, dot sizes are limited only by the need for making contacts to them; present limits for dot diameters are three or four mils. The mesas are etched right to the edge of these dots to keep the collector capacitance to a minimum. Mesa types with gains up to 20 db at 200

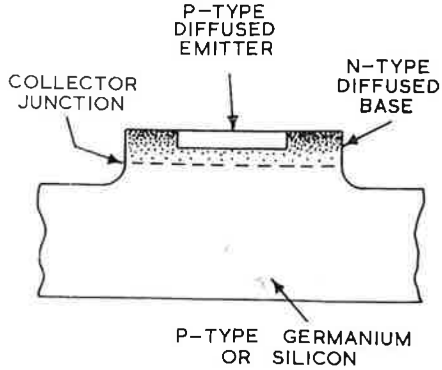


Fig. 6—Cross-section of a p-n-p germanium or silicon double-diffused mesa transistor.

Mc have been made for amplifier applications. Further advances are being actively pursued by the possible use of smaller dots.

Mesas using evaporated emitters and base contacts are shown in Fig. 5; such transistors are limited in area only by the lead attachment problem. Emitters as small as 1 by 2 mils are possible when $\frac{1}{2}$ mil connector wires are used; these mesas provide gains approaching 20 db at 200 Mc. Laboratory units with very small areas have demonstrated appreciable gain in the gigacycle region. Such typical new germanium mesa types as the 2N705 for switching and the 2N700 for amplifiers have become most popular and are rapidly supplanting the Madt for new applications.

Double Diffusion

A more elegant method of controlling base and emitter areas is by masking and double diffusion; a typical p-n-p device is shown in Fig. 6 and an n-p-n in Fig. 7. To date, this method has been carried further with silicon than germanium. The oxide deposit formed by heating silicon to a high temperature masks the transistor against either an n- or a p-type impurity. The oxide can be removed by the usual photoetching techniques in areas where diffusion is required in a base or an emitter. The photoetching techniques have been refined to such an extent that lines 0.1 mil wide can be etched in the oxide, thus permitting emitters and base contact areas as small as the wires that can be attached to them. Amplifier transistors with 1-mil-diameter emitter and base areas of about 2 mils in diameter appear possible. Gains of 20 db at 200 Mc appear easily possible.

The Planar Approach

Other new techniques such as the planar approach open up even greater possibilities; in this method, base diffusion as well as emitter

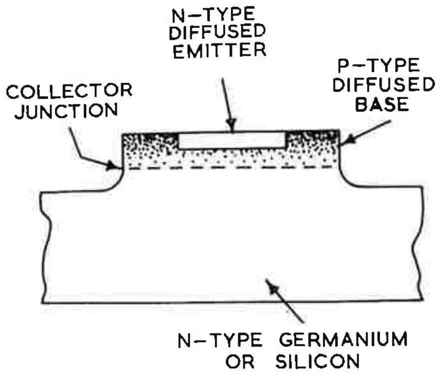


Fig. 7—Cross-section of an n-p-n germanium or silicon double-diffused mesa transistor.

diffusion is from a limited-area source (Fig. 8). The principal advantages of this are greater stability during life, a more constant beta with current, and a very low collector-to-base leakage current. Planar transistors have been found to have a very low noise at very low frequencies (1/f noise) consistent with the low collector leakage current. These features are probably inherent because of the oxide coating of all junctions—something not possible in mesa types. Another advantage of the planar construction is that the metallic coating from the emitter or base contact area can be extended onto the oxide where connections can be made. This approach permits very small active areas with larger areas for the wire contact, a very useful feature for integrated devices.

The planar device, however, has two drawbacks: First, for a given collector area, capacitance is somewhat larger; this disadvantage can be compensated with a slightly reduced geometry. Second, although the low-voltage collector-to-base leakage current is an order of magnitude or more lower with the planar structure, voltage breakdown figures have not been as good as those obtained with mesas having the same crystal resistivity. Processing refinements should dispel this problem.

Silicon vs. Germanium

The use of masking and photoetching has been carried further with silicon than germanium; however, a great deal of work is being done to apply the same approaches to germanium. The planar approach appears to be applicable to both p-n-p and n-p-n germanium structures. Because of the greater carrier mobility in germanium, it is generally thought that germanium would be used for the very highest frequencies. In very-high-frequency structures however, the input and output capacitances are as important as the mobilities. This fact, along with the better temperature capability of silicon, may make it the logical choice.

Gains of 20 db at 200 Mc are achieved with both silicon and germanium. The noise figure at 200 Mc for germanium is as low as 5 or 6 db; for silicon, it has so far been higher.

Germanium has been pushed faster than silicon into the gigacycle ranges, but silicon may overtake germanium. In the next few years, transistors with gains of 20 db at 1 Gc appear feasible in both germanium and silicon. The noise levels obtained may be the determining factor as to which material is used for very high-frequency low-level amplifiers. For switching, this is not a consideration.

Epitaxial Layers

The second development which has improved the mesa (or planar) approach is the use of epitaxial material. This idea is an old one, but its use in semiconductors is recent. Epitaxial construction permits the growth of a very thin layer of semiconductor material of the desired resistivity. The epitaxial layer need only be thick enough for the needed design parameters of the transistor. The epitaxial approach to a planar transistor is shown in Fig. 8 and to a mesa transistor in Fig. 9. The layers are usually in the range of 0.1 to 0.5 mil. The carrier material, which serves only as a holder, is of such low resistivity that the voltage drop across it and the charge storage in it are negligible. Improvement in the performance of mesa or planar transistors with the epitaxial approach make them completely competitive with the Madt.

Triple Diffusion

Another approach is to use triple diffusion instead of the epitaxial method. Triple diffusion applied to a planar structure is shown in Fig. 10; the collector side of the wafer is diffused to provide a very low resistivity. The triple-diffused method has one drawback; in diffusing the transistor base, it is more difficult to control the top layer thickness of original resistivity. However, triple diffusion has the advantage of producing

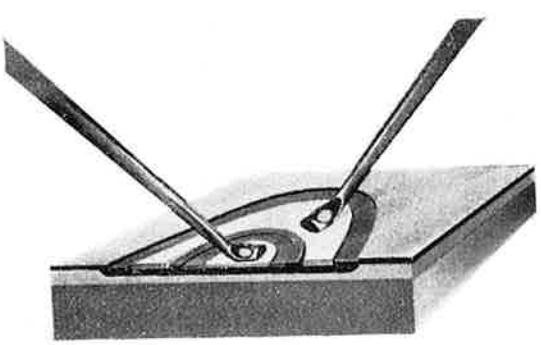


Fig. 8—Planar type n-p-n silicon transistor with epitaxial layer.

a top layer with any desired value of resistivity; the epitaxial approach is at present limited to a few ohm-centimeters. The triple-diffused structure, therefore, is applicable for high-voltage transistors, especially for nonsaturated use.

HIGH-POWER TRANSISTORS

As mentioned above, it is not clear whether silicon or germanium will dominate the small-signal and low-power switching fields. However, in most areas of the high-power transistor field, silicon is rapidly becoming the preferred material. Audio-output-amplifier and power-supply-regulator transistors are an exception because of the very low cost of germanium audio power transistors. The initial problem with silicon power transistors was the poor saturation voltage, which made the usual mesa approach unattractive. This problem was solved by transistor designs like the 2N1492, in which the collector and emitter are simultaneously diffused from opposite sides and part of the emitter is etched off to obtain a base contact.

Triple-Diffusion and Epitaxial

The single-diffused approach described above has provided excellent silicon power transistors with low saturation resistances and good reliability. Because of the very low saturation resistance, this approach will be used for a long time. Diffusion from both sides, however, like alloying from both sides in an alloy type, makes control of the base width difficult. The frequency response, therefore, is limited in the single-diffused device. With the advent of triple-diffusion and epitaxial layers, it is now possible to make power devices using the mesa or planar approach, and obtain fairly low saturation resistance and much higher frequency response. Transistors with power outputs of nearly 100 watts at 50 Mc

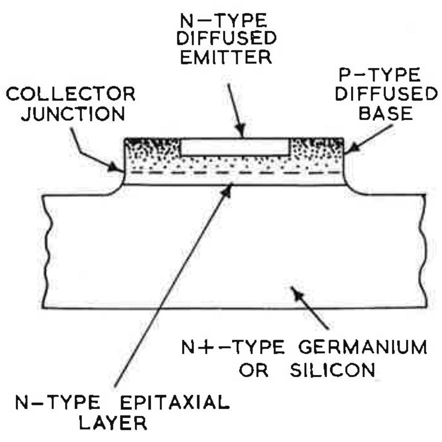


Fig. 9—Cross-section of an n-p-n transistor with epitaxial layer.

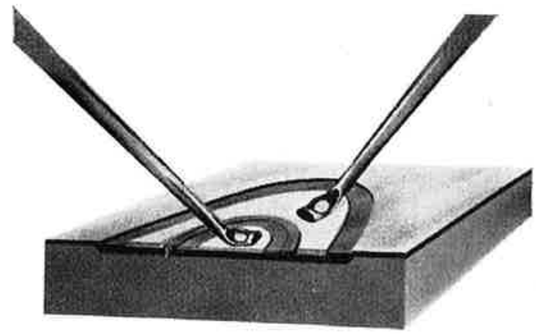


Fig. 10—Planar type n-p-n silicon transistor with diffused collector.

have been designed using triple diffusion. There will be a place both for these and the older single-diffused designs.

Geometry Considerations

Another important factor in the design of high-frequency, high-power devices is the tendency for the emitter to emit only at its edges at high currents, especially in silicon types. Optimum high-frequency results are obtained with the largest emitter perimeter for the smallest emitter area. The shape of the base with respect to the emitter also must be considered, in order to keep the base area and, consequently, the base collector capacitance small, and at the same time keep extrinsic base resistance low. Good results can be obtained with a variety of geometries, including a ring emitter, a star emitter, and interdigitated emitters and base contacts.

The Future

The field of high-power, high-frequency devices is only beginning to open up. Today, devices are available that will provide 3 watts at 200 Mc, 10 watts at 100 Mc, 50 to 100 watts at 50 Mc, and several hundred watts at 5 Mc. In the next few years, devices capable of several watts at a gigacycle, 50 to 100 watts at 100 to 200 Mc, and several kilowatts at a few megacycles appear to be possible. This area is one of the most exciting in transistor design.

GALLIUM ARSENIDE DEVICES

Other materials such as gallium arsenide, are also being investigated. From the point of view of temperature capability and carrier mobility, GaAs is the ultimate material; however, in high-frequency transistors it must compete with the refined geometry-control techniques already developed for silicon and germanium. These techniques have not yet been developed for GaAs, but the promise is there. The temperature capability is especially important in the future for microcircuits in which packaging density is very high.

GaAs has found a very substantial place in other areas: In solar cells, its high efficiency together with greater resistance to space radiations make GaAs very suitable. In very-high-frequency parametric diodes, GaAs is an ideal material to achieve the highest frequency performance. Other areas include GaAs power varactor diodes and GaAs tunnel diodes. In tunnel diodes, life performance has been a problem; however, it appears that this problem limits the use of GaAs in only a few applications.

DIODES AND RECTIFIERS

Although this article has considered mostly one semiconductor device, the transistor, improvements are also being made in other devices. In power rectifiers, the changes over the last few years have been less revolutionary. The line has broadened, and the reliability has been greatly improved. By stacking junctions, rectifiers can be built to carry several hundred amperes at a few hundred volts, or a few amperes at hundreds of thousands of volts. To date, planar techniques have not been widely used because of the greater difficulty in obtaining high reverse-breakdown voltages. This difficulty will probably be overcome in the near future. Epitaxial layers cannot yet be made of high enough resistivity, but they too offer hope for the future.

However, planar and epitaxial techniques are now being used for silicon signal diodes with great success. The use of planar techniques with signal diodes makes new forms of packaging for these devices possible; junctions are so stable that the usual hermetic package may not be needed. Silicone resins, plastics, and even no encapsulation are being tried. A very attractive approach is the direct sealing of a borasilicate glass directly to the junction. This approach provides both a very small package and a hermetic seal. The planar, passivated surface is needed to withstand the required sealing temperature.

In contrast to the minor changes in the power-rectifier and silicon-diode fields, the semiconductor controlled rectifier is moving very rapidly. Types are available to control currents from a few microamperes to hundreds of amperes. The techniques for controlled rectifiers have tended to follow those of transistors. For the future, all-diffused types (compared to partly alloyed, partly diffused types) will be the most common. The controlled rectifier is rapidly taking over from the vacuum-tube thyratron; with lower prices it will begin to compete against the mechanical switch, and with faster turn-on and turn-off speeds it may compete with the hydrogen thyratron in radar applications.

THE TUNNEL DIODE

Tunnel diodes have not received the widespread use that was predicted for them early in their development. Today, it does not appear that the tunnel diode will ever approach the popularity of the transistor; however, in several applications the tunnel diode is establishing a foothold. As an oscillator or an amplifier at microwave frequencies, for example, the tunnel diode is considerably easier to use than a parametric amplifier which requires a driver; noise level is close to that obtained with a parametric amplifier. For use at higher frequencies and higher power levels, the tunnel-diode package must be redesigned to fit into a microwave circuit and have very-low-inductance leads. Several watts at a few gigacycles may be possible if these changes are incorporated.

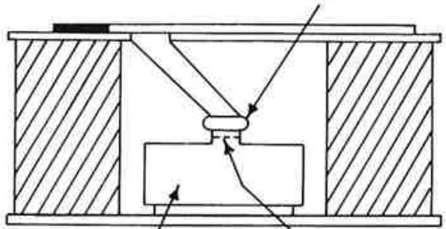


Fig. 11—Cross-section of a tunnel diode.

Tunnel diodes are also being used for sampling waveforms in very-high-speed oscilloscopes, as level detectors, as pulse discriminators, and for many other special applications. Successful results for diode logic depend upon holding very close tolerances on such tunnel-diode characteristics as the peak current and the peak and forward voltages. Tunnel-diode logic circuits offer shorter delays, several times less than those of transistor circuits. Recent results indicate that logic stage delays of less than 1 μsec are possible; if accent is put on power consumption, a logic stage with a dissipation of about 50 microwatts can be obtained. Figs. 11 and 12 show the tunnel diode in cross section and in the final package. For computor memories, the tunnel diode offers speeds several times greater than any other semiconductor on the horizon, but higher cost will probably limit use of the tunnel diode to small systems. Very small size and low power consumption of tunnel diodes also make them attractive for integrated electronics.

INTEGRATED DEVICES

Device integration and microcircuitry are the newest and loudest revolutions in the semiconductor field. Already there has been a great deal of talk and many preliminary starts.

The first approach to integrated circuits has been to put two or more semiconductor devices into one package. For example, a package could include the several diodes and one transistor needed for a nor logic gate. The advantages are smaller size (reducing the length of interconnections), lower cost, and greater reliability because of the fewer packages. A variety of devices in a single package are now available, and the list is increasing daily.

The next step is to put the passive devices into the same package. In the past, the circuit designer has generally chosen to keep the active devices at a minimum and use more passive devices because of their low cost. When building microcircuits in one package, however, the semiconductor manufacturer tends to increase the number of active devices (it costs him little to add one with the planar design) and keep the passive components to a minimum. The circuits chosen by the semiconductor manufacturer are often a compromise because of this approach. A long period will elapse before he and the circuit designer get together completely. The microcircuit offers a complete package to the customer; it puts the burden of circuit design and "prove-out" entirely in the supplier's hands. This approach may turn out to be very attractive to small companies that do want to keep their engineering costs at a minimum; it is, however, restrictive in designing an entire computer, where a myriad of small circuit changes may give a better over-all design.

The approaches discussed thus far, although valuable, do not solve the real problem of computer design—interconnections. It appears possible that interconnections can be shortened by use of integrated devices or microcircuits. Many microcircuits can be put into one package to permit the logic to be carried out inside a single package. Reliability must be of a very high order, because failure of one element will cause the entire package to be thrown away. Logically, the only real solution to the interconnection problem appears to be the microcircuit approach, where all the functions of a computer are included in two or three packages. Such an elegant solution calls for solving the reliability problem, the problem of removing heat, and others. Many approaches will have to be explored before a satisfactory solution can be obtained.

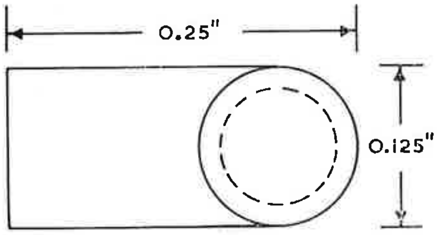


Fig. 12—Tunnel diode package.

STANDARDIZATION AHEAD

The rapid pace of device development has made industry-wide standardization of electrical characteristics very difficult. Each manufacturer has attempted to write specifications which emphasize his own technical advantages. This situation has led to a "specification" contest which is very confusing to the customer. This problem will probably continue to exist until the technical revolution slows down.

There has been great progress in one area, however—that of standardization of the mechanical packages or outlines of semiconductor products. Five years ago, there were no accepted industry standards. Today, the bulk of semiconductors are in industry-recognized packages. Outline standardization becomes even more important as we face the challenge of the integrated devices and microcircuits.

(With acknowledgements to RCA)

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

Radiotronics is published twelve times a year by the Wireless Press for Amalgamated Wireless Valve Co. Pty. Ltd. The annual subscription rate in Australasia is £1, in the U.S.A. and other dollar countries \$3.00, and in all other countries 25/-.

Subscribers should promptly notify Radiotronics, P.O. Box 63, Rydalmere, N.S.W., and also the local Post Office of any change of address, allowing one month for the change to become effective.

Printed by CLOISTER PRESS (W. Short), REDFERN, N.S.W.

AWV