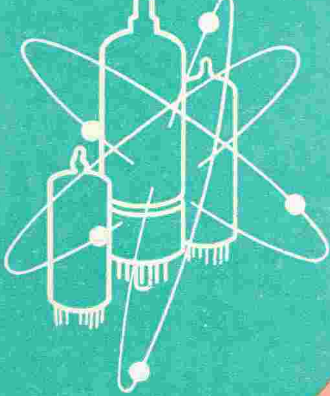

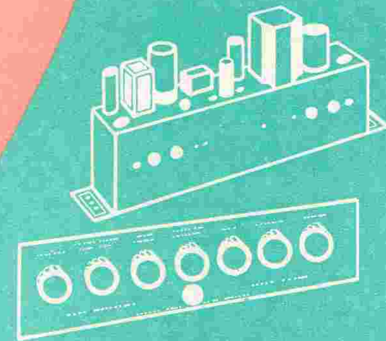

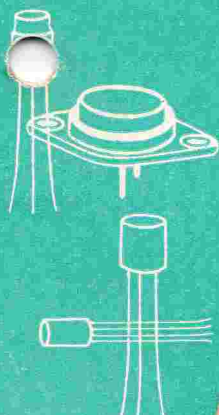

RADIOTRONICS

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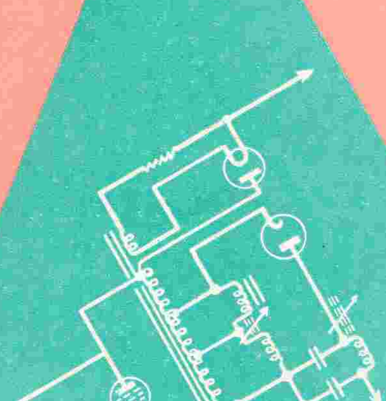

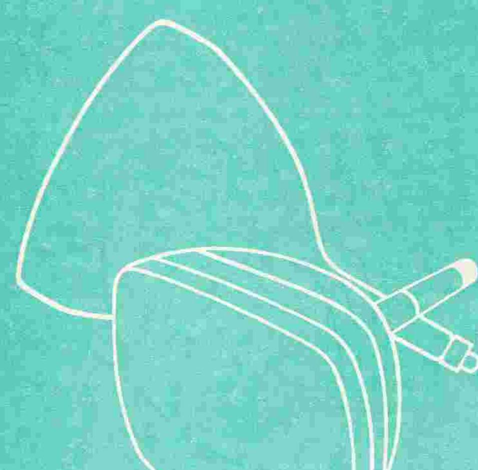

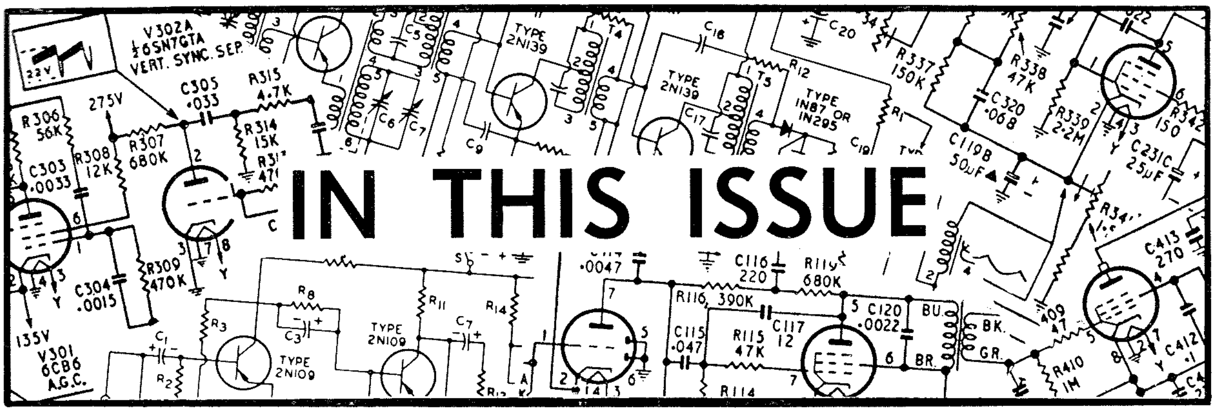

IN THIS ISSUE

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Music and Stereophony

By ERNEST ANSERMET

We rarely publish in "Radiotronics" a non-technical article, but we were so impressed by the philosophy behind this article that we felt no music-lover and hi-fi enthusiast would want to miss reading it. It is not every day that a distinguished conductor, mathematician and musical philosopher gives us such an insight into aspects of perception and imagination in the realm of music and its reproduction.

The appearance on the market of the so-called "stereophonic" records has thrown a crude, not to say cruel, light on our general ignorance of the nature of music and the impossibility of explaining musical phenomena by purely physical argument. In fact, practically all that has been said about them serves to show that they bring us a more "realistic" reproduction of sound than the old methods of registering did, although this realism does not so much involve the phenomenon of sound itself as the **mental image** that we create from it. It would seem as if the inventors of the new procedure, while realizing to perfection what they were aiming at, did not understand fully what their object consisted of.

To hear in the case of music is in fact something entirely different from hearing in everyday life. In casual hearing we notice a street cry, or the passing of a car, or the wireless in the neighbour's flat. The sound is captured by the ear and reaches the brain as a nervous impulse, where it gives rise to conscious activity by means of which we leave the sound for what it is and apprehend "the presence of something sounding" which at the same time we locate in space — far or near, right or left, moving or stable. What we "hear" when listening to music is the sound of an instrument tracing a rising or falling line in "space." It is evident that this latter space is in no way the space in which we find ourselves but a purely subjective one, or rather the projection outwards of an imaginery space born from a supposed movement of sound.

In reality there is no such movement, but a succession of tones of different pitch, which we place linked with Time as moving in space. This creates a horizontal line, while the pitch is being projected on a vertical line: depth is provided by differences in intensity and timbre of the simultaneously sounding voices. As all these data are of a **subjective** nature, our mental image is in no way a **realistic** representation of the **sound phenomenon.** If we are listening to a choir of which the sopranos are on the left and the basses on the right, the melodic line of the sopranos does not lie to the left but above that of the basses. If our auditory perception simply reflected physical events, our image of the Fifth Symphony would change according to the placing of the players; but nothing of the kind occurs. The first concern of a conductor is to dispose the instruments precisely and to regulate their playing in such a way that the mental image the playing creates takes form without any trouble.

Now, if our perception of musical sounds takes this spatial character, it must be attributed to the fact of our possessing two ears; but mind! hearing by one ear is spatial already. The high place in our mental image of high notes is due to their having been captured by the higher parts of the cochlea of the internal ear, the lower ones by the lower. It is this difference in level that is being reproduced in our mental image.

In order better to understand the function of the two ears in conjunction, we must not think of listening to a single note, but to a complex heard simultaneously. Only then do the three spatial dimensions shows themselves clearly. The phenomenon is analogous to that of binocular vision. An ordinary photograph shows us by its lights and shadows that perspective is there, but **projected on a plane.** To disengage the objects of the picture, so that the interstices come to view and appear in relief, the photograph (black-and-white or coloured) must be taken with two lenses these being the corollaries of our two eyes. We then obtain twin images taken from slightly different angles and therefore of different lighting; this gives a blend in which objects show their three dimensions. We see their volume.

In a similar way one ear renders the sound perspective in a geometrically flat image, a projection on a plane. Our two ears working together, on the contrary, give us two distinct and different impressions of the sound perceived; the differences being both in "phase" and in strength (luminosity). Sounds coming from the left will reach the left ear a trifle sooner than they do the right one, and vice versa. But there will also be a marked difference in strength, similar to that which occurs in visual perception. The mental image composed from these data will be a sound perspective with depth based on the mixing of these two; the melodic lines will seem to us unfolding freely in space, each on its own plane with the consistence and colour belonging to it. Such is roughly the condition of direct audition of music; and this is the condition we must try to arrive at in registering music for the gramophone.

It stands to reason that the registering of sound by a single microphone could reproduce only monaural audition. The techniques by which sounds can be captured by a group of three microphones disposed in a suitable manner permits us at last to reproduce binaural conditions of hearing; this creates the full-perspective mental image which we were seeking to obtain. This is evidently not only the last step of technique, but also the last possible in that direction. After the "high fidelity" which was but an illusion we have finally the true and simple fidelity. I now hear in front of the revolving record (if it is a good reproduction of the magnetic tape) what I hear from my podium.

It is therefore "stereo**scopic**" rather than stereophonic that this technique should be called, because it enables us to procure a true mental **vision** of sound structures.

This being so, it must be admitted that the way in which stereophonic recording has been introduced commercially and commented upon must have served to confuse the public. Inasmuch as the new method gives us a binaural effect, it is clear that it must be particularly fitted to make us hear the movement of a source of sound, allowing us to notice how we locate such a source to the left, the right, or in front of us. But this is neither its purpose nor its importance. Its purpose, as I have insisted upon above, is to let us recover in the sound image, provided through the record, the plasticity, the sound-body of direct audition, as it presents itself in the **mental musical image.** To attain this end, the method of registering has to have recourse to the double musical rendering, **but on condition that the two elements are completely blended**; the listener should not have to divide his attention between the two separate sources of sound.

With piano music the two perspectives do not seem to differ much one from the other, and still the mental image has the same quality of body as when we deal with an orchestral piece of music. The miracle of binaural audition is also just as striking, or even more so, in my opinion, in the case of a simple form of music — a solo instrument or an accompanied melody — as it is in a more complicated work. This proves clearly that the real task of stereophonic reproduction is not to let us hear what exactly is going on in the surrounding space, but to give us to the full the subjective musical image. It is useless, therefore, to add to the reproduction noises of running trains or to enliven an opera recording by making us conscious of the movements of the source of music on the stage; besides, everybody knows that a singer hardly moves when singing, and the perspective of our musical image is not brought about on imaginary space of which we become aware within our mind.

In this short analysis of stereophonic audition I have tried to stress the subjective character of our musical perception. I found its explication not in the sonorous instrument that gives off the music, but in the perceiving listener himself, as subjective human being, not seen as individual. If this applies to sound perception in general, how much more must it apply to music. For music should as little be confused with sound as **elements of speech** with the **sound** of speech. This is why the science of physics cannot throw any light here for a physicist. We know what is a third, a fifth, etc., but no one has yet been able to tell us which meaning they have for the human soul, in the musical language.

As long as such elementary notions remain a mystery, all our ideas about music lack a sound foundation, and speculative theories dealing with music should remain subject to caution.

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Off The Beaten Track

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

No. 1 — THE MULTIPLIER PHOTO TUBE

The multiplier phototube evolved out of the need for a phototube of higher sensitivity than that available from a single-unit vacuum tube. It consists basically of an elaboration of the original cell, by the addition of a multi-stage electron multiplier to provide high amplification.

Multiplier phototubes are many and various, but the basic principle of utilizing the phenomenon of secondary emission to amplify signals composed of electron streams is used in all of them. They vary according to the mechanical design and arrangement, the type of photosensitive material used in the cathode, and hence the spectral response characteristic, and in the number of electron multiplier stages used, and hence the sensitivity.

To illustrate this note and to serve as an example of this type of tube, the 7046 has been chosen. This is a 14-stage head-on type of high sensitivity, and is primarily intended for use in scintillation counters for the detection and measurement of nuclear radiation, and in applications involving the measurement of low-level light sources. The 7046, illustrated in Fig. 1., has several interesting features, including the large photocathode with a diameter of about $4\frac{1}{2}$ inches. This and other interesting features of the tube mentioned in this note do not, of course, apply to all photomultipliers, but are quoted to indicate some of the design features of this class of tube.

The spectral response curve of the 7046, as shown in Fig. 2, covers the approximate range 2500—6500 angstroms, with a peak at about 4200 angstroms. The tube has, therefore, high sensitivity to blue-rich light and very low sensitivity to red radiation. In order to assist the sensitivity to blue light, the faceplate of the tube, on the inside of which is deposited the photo emissive material, is of special glass which transmits ultra-violet light well.

A schematic arrangement of the 7046 is shown in Fig. 3, and the arrangement is typical of this class of tube. The electrons emitted from the illuminated curved photocathode are directed by fixed electrostatic fields provided by grids No. 1 and No. 2 to the first dynode or secondary emitter. The curved surface of the photocathode assures very good collection of electrons from all parts of the useful cathode area by dynode No. 1 and helps provide minimum spread in electron-transit time.

The electrons impinging on the dynode surface produce many other electrons, the number depending on the energy of the original electrons. The secondary electrons are then directed by fixed electrostatic fields along curved paths to the second dynode, where they produce more new electrons. This multiplying process is repeated in each successive stage, with an ever-increasing stream of electrons, until those emitted from the last dynode

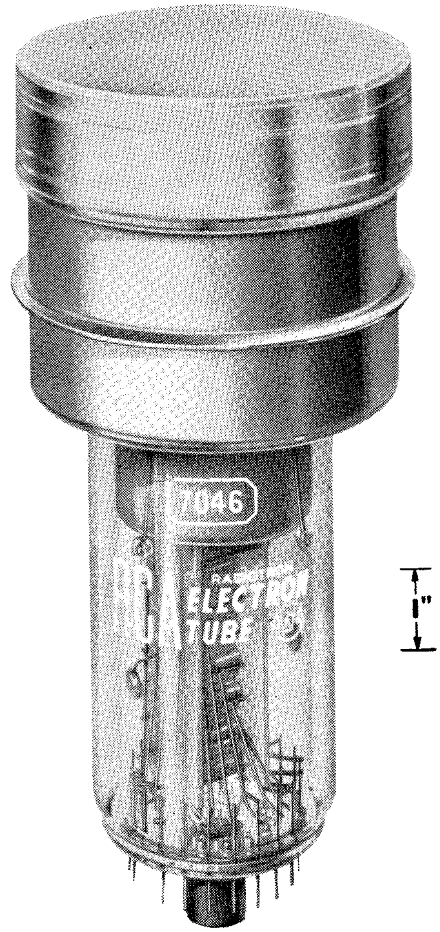


Fig. 1 — A Multiplier Phototube.

(No. 14) are collected by the anode, and constitute the current utilized in the output circuit.

The anode consists of a grating which allows the electrons from dynode No. 13 to pass through it to dynode No. 14. The spacing between dynode No. 14 and the anode creates a collecting field, such that all the electrons emitted by dynode No. 14 are collected by the anode. The output current is, therefore, substantially independent of the instantaneous positive anode potential over a wider range, and the tube may as a result be coupled to any practical load impedance.

The shield which is adjacent to dynode No. 1 shields dynode No. 1 and the cathode, and prevents ion feedback. If positive ions produced in the high-current region near the anode were allowed to reach the cathode or the initial dynode stages, they would cause the emission of spurious electrons, which, after multiplication, would produce undesirable and often-uncontrollable regeneration.

The metallic coating on the inner side wall of the faceplate end of the envelope is connected both to the photocathode and the metal portion of the envelope. This arrangement, in addition to providing a connection to the photocathode, serves to direct the electrons emitted from the cathode towards dynode No. 1. Grids No. 1 and No. 2 are focusing electrodes, which shape the fields which direct photoelectrons emitted from the photocathode to dynode No. 1, and, therefore, act in concert with the metallic coating and metal portion of the envelope. The potentials applied to grids No. 1 and No. 2 may be adjusted to optimize the magnitude, uniformity, or speed of the tube response in critical applications.

The accelerating electrode or grid No. 3 serves to minimize the effect of space charge in the region of dynode No. 12. The potential on this electrode may be adjusted within stated limits to obtain either maximum gain or maximum peak output current.

This particular tube is capable of multiplying a feeble photoelectric current produced at the cathode by a median value of 3 million times when operated at a supply voltage of 2400 volts, and by a median value of 20 million times when operated at the maximum rated supply

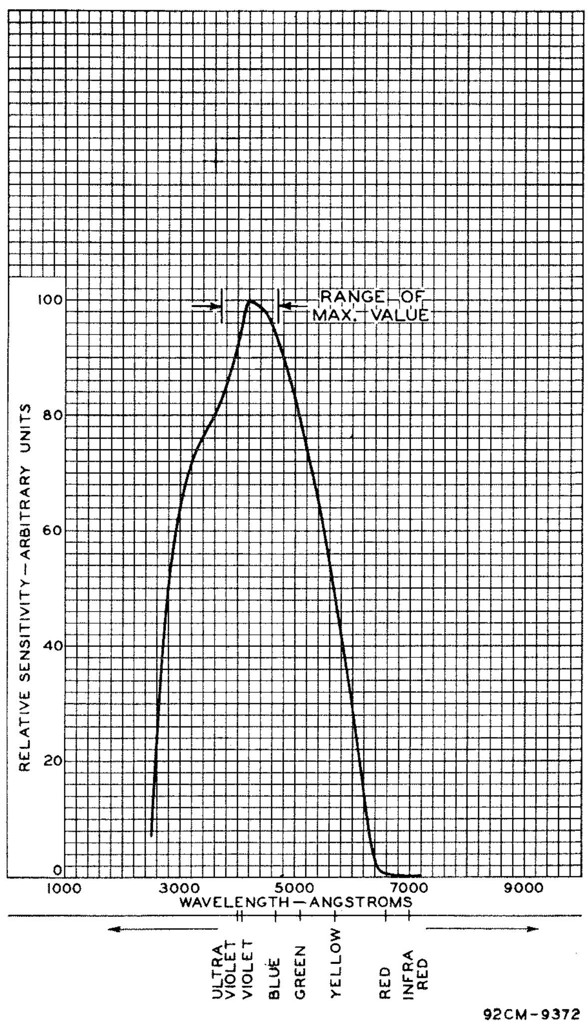


Fig. 2 — Spectral Sensitivity Characteristics of Type 7046 Multiplier Phototube.

voltage of 3400 volts. The output current of the tube is a linear function of the exciting illumination under normal conditions.

In order to make use of the secondary emission phenomenon, each dynode must have a successively higher potential applied to it, and the tube is, therefore, connected across a voltage divider as shown in Fig. 4. The voltage distribution is arranged according to the manufacturer's data to provide the highest current amplification consistant with the optimum collection of electrons.

Phototubes of all types, including multipliers, exhibit a phenomenon called "dark current". This current is observed when voltage is applied to

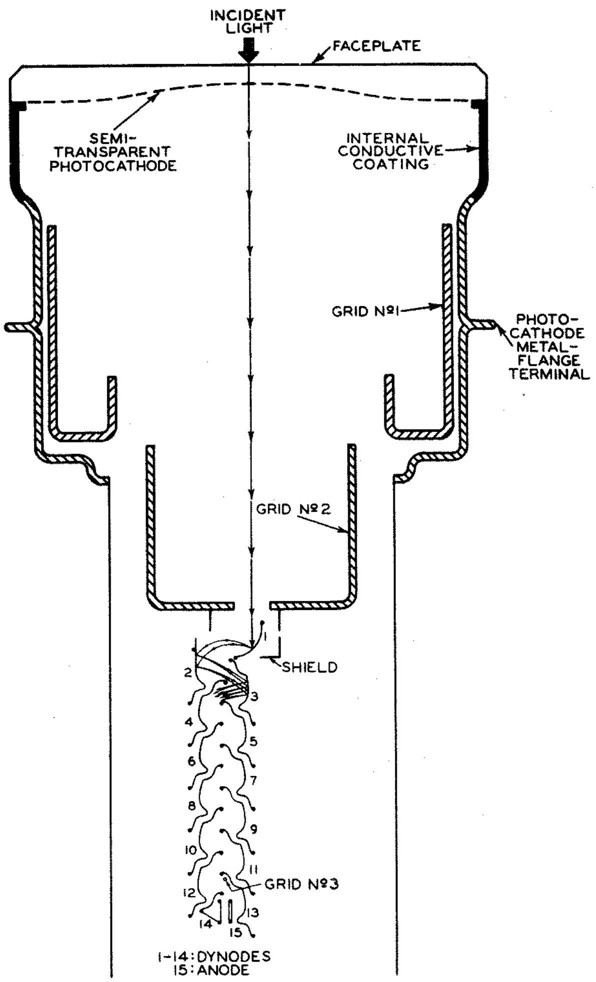


Fig. 3 — Schematic Arrangement of Type 7046 Multiplier Phototube.

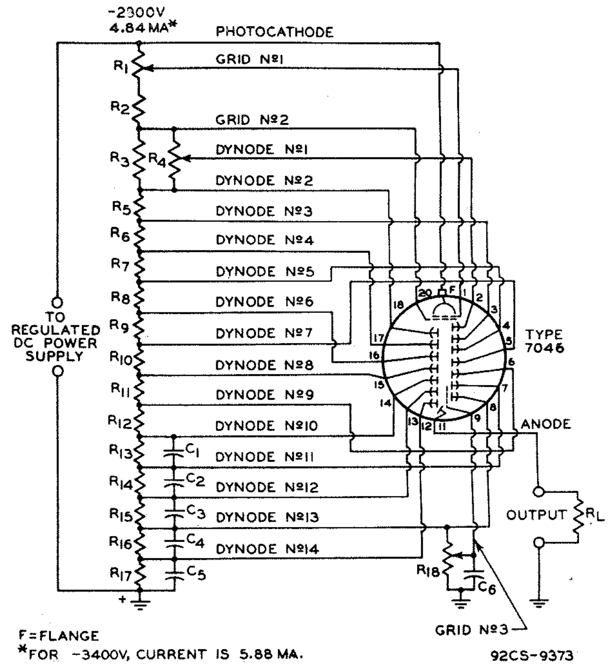


Fig. 4 — Voltage Divider Arrangement for Multiplier Phototube.

the tube in total darkness. The dark current has two components. One is caused by leakage. The other consists of pulses produced by electrons thermionically released from the photocathode, by secondary electrons released from the cathode or dynodes by ionic bombardment, or by cold emission from the electrodes. The magnitude of the dark current establishes, of course, a limit below which exciting radiation on the cathode cannot be detected; dark current is, therefore, analogous to noise in a valve. Refrigeration is sometimes used where maximum gain with very low dark current is required.

The sensitivity of the 7046 and similar tubes is such that the response can be noticeably affected by the Earth's magnetic field. Magnetic shielding or optimum orientation of the tube (magnetic field parallel with tube axis) or both can be used to minimize this effect. In the same way magnetization of the metal portion of the envelope will effect performance, requiring degaussing.

This series has been specially prepared by the "Radiotronics" staff. Illustrations are by courtesy of RCA.

Special-Quality Valves

By J. ZIEGLER, B.Sc.

The radio valve, considering its nature as a complex of many chemical and physical processes all taking place during its life, and in view of its varied use, is a remarkably reliable device. An equipment such as a television set, using two dozen or so valves, is dependent on the correct functioning of each valve and component: yet the modern TV set is of the same order of dependability as the modern motor car. It is not always appreciated what a high degree of freedom from faults this demands of the ordinary receiving valve. This sort of quality has been achieved, partly, by the constant improvements in both major and detailed design, and largely in production control measures due to opportunities offered by high production rates. A responsible manufacturer of valves avails himself of every opportunity to achieve as trouble-free a product as he can, since his reputation stands or falls as a result of his efforts.

Reliability, therefore, is relative, as valves performing well in a domestic receiver may not be satisfactory in an anti-aircraft missile, or in a submarine cable amplifier under the Atlantic. The reliability of a valve is to be judged against the overall requirements of the equipment or complete system of which it is a part — complete with the physical and electrical environment it is expected to encounter.

From the user's point of view the indication of reliability needs is an economic question, taking into account the safety of life and property or other costs dependent upon them, and the maintenance or replacement costs involved. The ultimate result is an economic balance between cost and reliability suited to the particular type of equipment.

The functional features of a valve design fix its circuit behaviour — mixer, rf amplifier, etc. — and the electrical performance level it gives in this basic task. Now it frequently happens that circuit requirements in industrial and other non-receiving equipments are best satisfied by valves having the functional features of commercial receiving types. However, their various special requirements entail that such valves have special features, which are not called for in ordinary receiving types.

These special features are of two kinds, viz.:

Environmental features, which enable the valve to continue to function and to maintain its inherent reliability in various special environments such as limited space, conditions of shock and vibration, frequent switching, etc.

Reliability features, which increase the probability of batches of valves operating satisfactorily and uniformly. Reliability features include low rate of failure due to mechanical faults, uniformity of characteristics between different valves of the same type, and maintenance of characteristics of the same valve over long periods of service.

It is the inclusion of environmental or reliability features, or both, which distinguishes "special quality" valves, many of which are based on commercial prototypes having essentially the same functional characteristics.

Environmental features (and functional feattures) are achieved mainly by valve **design.** That is, the average valve is made to fit specific conditions.

There are certain basic incompatibilities in valve designing which lead to choice of some features at the expense of others. For example, subminiature valves are inherently more rugged, but are not, in general, capable of dissipating much power.

Reliability features are achieved mainly by **manufacturing control and conditions.** That is, the individual valve is made to conform closely to the average valve, both functionally and environmentally. It is the taking of pains in this department which leads to the distinguishing marks of the production of special quality valves. Here again, however, the question of design incompatibility arises. For example, high performance valves, such as valves using close cathode-grid spacing to realize high transconductance, tend to have reduced mechanical reliability due to inherent greater possibility of short circuits.

Accordingly, it will be profitable to consider the various requirements calling for special quality valves, the steps which can be taken to meet them, and the types of test which can be applied to assure compliance.

ENVIRONMENTAL REQUIREMENTS

Environmental requirements fall into several categories which are discussed in detail below. They may be briefly summed up in the headings under which they are dealt with, as follows:

(a) Limited space.
(b) Electrical output under shock and vibration. (Microphony).
(c) Shock and vibration survival.
(d) Heater switching.
(e) On-off cutoff conditions.
(f) Physical environment conditions.

LIMITED SPACE

This is usually the first requirement for aircraft, missiles, or for very portable equipment. It is met by miniaturization or subminiaturization, of which a desirable by-product is usually ruggedness. Alternatively it is met by using high-performance valves in order to reduce their number. Whilst from some points of view, the loss of individual valve reliability which tends to occur with high-performance valves is undesirable, it is likely that electronic equipments carrying out complex functions could not be operated without small high-performance reliable valves.

ELECTRICAL OUTPUT UNDER SHOCK AND VIBRATION (MICROPHONY)

Both ballistic microphony and vibrational output arise because of displacement of grids and cathode, as a result of impact and periodic accelerations. In aircraft and land vehicles, and also industrial situations where equipments must be operated whilst subject to vibration and shock, the noise output produced by these external forces becomes important, particularly in low level stages.

These forces are normally low-frequency vibrations not exceeding 100 cycles per second. The noise output which results is the combined output due to movement of the whole assembly, cathodes, grids, grid turns, etc.

The resulting deflections and hence noise output are reduced by keeping the natural resonant frequencies of the valve structure as high as possible commensurate with electrical characteristics. These natural frequencies range from 500 to 5,000 cycles per second in typical valves, but are considerably reduced where there is any loose fitting of electrodes.

Where shocks (as distinct from sustained vibrations) occur, they are normally of higher equivalent frequency, and tend to excite valve components of the same or lower - frequency resonances at their own frequency. The resultant noise is the more simple "ringing".

Design action is aimed at limiting the deflections of critical parts under given accelerations, since it is the amount of this deflection which determines the amplitude of the resultant change in plate current. It is directed towards improvement in the methods of fitting vital components (cathodes and grids), including both special attachment devices and the selection of components, and by raising as high as possible the initial resonant frequency of components.

Care in construction, often involving selective assembly, and similar measures, which incidentally do not conduce to copious operator output, also go far to reduce microphonic effects. Testing for these features is performed by reading the changes in plate current resulting from impact and vibrational accelerations, these changes having suitable maximum limits.

In bad cases of "ringing" due to shock, a limit is reached in the valve, and action should be taken to limit the transmitted shock by suitable mounting in the equipment.

SHOCK AND VIBRATION SURVIVAL

Apart from the immediate effect of noise output arising from shock and vibration, mechanical damage, which may be accompanied by deterioration of performance, can occur.

The points at issue are (a) inelastic **deformation** of cathode and grids — which would lead to permanent changes in electrical characteristics — and (b) **fatigue** fracture of welds and other parts of the structure. High shock or vibrational accelerations may also liberate sorbed gas from micas as a result of fatigue damage to them, causing degradation of cathode emission, or may enlarge holes in micas, allowing grids free movement under subsequent small forces (resulting in microphony).

Action taken to control noise output during vibration, such as better fitting of parts and increase of natural frequencies by shorter structures, also reduces chances of damage or deformation during shock and vibration.

Stronger grid side-rod materials can be used to resist permanent set following impact. This may well be at the cost of reduced heat conductivity (for the same size side rod), entailing danger of electron emission from the hotter grid resulting; this in turn may have to be countered by reducing valve ratings.

Holes in micas intended to carry electrode supports may be reduced in size slightly to give tighter fits, reducing danger of their being enlarged as a result of sustained vibration: but this leads to assembly difficulties, and the danger of electrode distortion with attendant characteristics changes, in turn requiring great care in assembly.

Further, additional hardware such as extra micas or strengthening struts can be introduced — all, incidentally, requiring outgassing properly during valve processing. In addition, secondary components such as shields and getters may be treated by providing additional support welds.

Testing valves to meet these requirements takes the form of prolonged vibrational testing at suitable frequencies and accelerations, and impact loading by hammer blows or dropping, resulting in known accelerations. No appreciable changes in electrical characteristics may be allowed as a result of these tests, and suitable microphony tests must be passed.

Fig. 1 — Making Miniature Valve Stems.

HEATER SWITCHING

The heater wire in a heater-cathode valve operates at a considerably higher temperature than the cathode sleeve which it heats. The expansions and contractions of the heater wire may cause stresses in it which are beyond its elastic limit (and its elastic constants while hot differ greatly from those while cold), causing permanent deformation or breakage. A large number of on-off cycles during the normal life of the valve will greatly increase the probability of development of such faults, unless precautions are taken to counter them.

Such precautions, as in the commercial prototypes, centre on geometrical design and control over the insertion of the heater wire, and choice of insulation coating and wire materials. For example, if proper attention is given first to achieving suitable metallographic grain structure, pure tungsten wire has good properties for use in heater wires. The grains — crystals — of metals tend to grow to larger sizes when the metal is heated, causing changes in mechanical properties and even in shape. Suitable choice of initial grain shape and size minimises the effect of this, control lying in wire drawing and heat treatment. From the design point of view, low-temperature heater designs are used wherever possible, achieved by longer and thicker heater wires within the limits of the available space.

Thermal expansion and contraction resulting from on-off switching may also fatigue the cathode and its connections. Precautions are taken with the shape of cathode connections to avoid intense fatigue strain at points where crystallization is likely to be high.

Testing involves applying a large number of on - off cycles at elevated heater voltage, with a suitably large heater-cathode voltage applied, to statistical samples from the production batch which is to be approved. In addition, surge testing of heaters is applied where this is critical, by switching on from cold up to very much more than rated voltage.

ON-OFF CUTOFF CONDITIONS

An oxide cathode is manufactured by first applying to the cathode support sleeve a mixture of the carbonates of the "alkaline earth" metals barium, strontium, and frequently calcium. This mixture is then reduced to a mixture of the oxides of these metals by heating under vacuum during valve processing. However, this mixture of oxides will not yet emit significant amounts of electrons, this requiring the presence in the mixture of a small amount of free metallic barium. This excess barium is provided by further reduction of some of the barium oxide, and this takes place by two mechanisms, viz.:

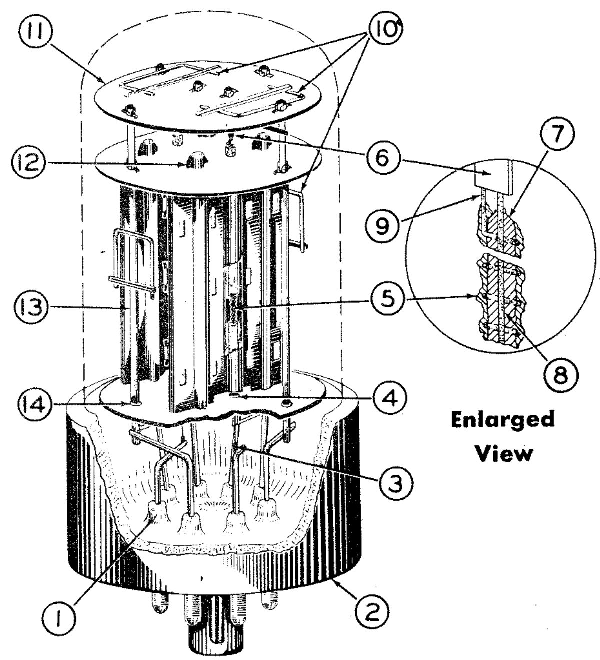
Chemical reduction in the presence of a chemical reducing agent. Of the various ways of achieving this, the only really practicable method is to provide slight amounts of solid reducing elements alloyed into the cathode sleeve material. Since nickel is commonly used in cathodes, these reducing elements conveniently take the form of impurities such as silicon and manganese normally present in nickel, the refining being continued to the point where suitable quantities of these substances remain.

Electrolytic reduction due to the passage of the cathode current through the cathode oxide coating. This process continues so long as cathode current is being drawn.

Of these two mechanisms, chemical reduction has the main effect in establishing emissivity at first, due to the high cathode temperatures reached during processing. Barium has, however, rather high vapour pressure for a metal, and with the cathode operating as it does in the vicinity of 800°C, barium is constantly being lost by evaporation and requires constant replacement during the service life of the valve. Barium is also lost by combination with the residual gas in the valve, the loss in this fashion being known as "poisoning".

Fortunately, this barium can be provided by the largely self-regulating process of electrolytic reduction. (At normal operating temperatures, chemical reduction is not of major significance.) But this process is of much less avail in providing the initial reduction needed during manufacture to establish emission, and it is very difficult to achieve this reduction by electrolytic means alone; that is, if the cathode nickel is free of silicon and the like, with the result that little chemical reduction takes place. Chemical reduction, does, however, entail the formation of some compound of the reducing agent, and in the case of silicon this happens to be barium orthosilicate, which is formed as a thin layer between the cathode sleeve and the oxide coating.

Now under certain conditions this interface layer of barium orthosilicate can develop an appreciable electrical resistance. The effect of this is as if a resistor were inserted between the cathode connection of the valve and earth, with an associated parallel capacitor. The capacitance arises because, even though the **area** of the interface is not large, the **separation** of the sleeve and coating is very small. The RC product of this combination can reach values such as would be used to separate high from low audio frequencies. In effect, a valve exhibiting appreciable interface RC product would behave normally at radio frequencies, but would show a loss of performance at the lower audio frequencies and under direct current conditions.



1—Low-leakage button stem.
2—Non-hygroscopic base with barriers between pins.
3—Reinforcing sleeves on legs of each heater insure good mechanical and electrical bond between heater and heater leads.
4—Each cathode sleeve locked to mica insulator.
5—Pure-tungsten heater in each unit for high mechanical strength. See enlarged view.
6—Reinforcing sleeve for top heater connection. See enlarged view.
7—Insulation.
8—Tungsten core rod.
9—Coiled heater.
10—Four getters.
11—Extra mica insulator provides getter shield.
12—Plate of each unit held rigid by plate ears wedged into mica insulators.
13—Mount secured by supporting rods.
14—Reinforcing eyelets provide a firm bond between mica insulators and supporting rods.

Fig. 2 — Cut-away View of a Special Quality Full Wave Rectifier.

The conditions under which the RC product of the interface can become appreciable are now well known empirically, but imperfectly understood theoretically. The explanation to be given now is one of several theories that have been proposed, but seems to have the advantage of explaining all the known facts consistently.

Barium orthosilicate is a semiconductor, and like most semiconductors, has a reasonably high resistivity when quite pure, but a low resistivity when it contains a very small amount of a suitable "impurity" distributed throughout its crystal structure. In this case the "impurity" is some of the very excess barium metal it has helped to provide. So long as cathode current is being drawn, the electric field thus set up causes a certain amount of this barium to tend to flow towards the cathode sleeve, into and through the interface layer, keeping the interface resistance low. When the cathode is hot and cathode current is biassed off, this electrolytic action ceases, and the barium diffuses gradually out of the interface layer, whose resistance consequently rises.

The position regarding interface may be summed up thus:

It is unlikely to cause trouble if either (a) Cathode current is always drawn when the cathode is hot, or (b) The valve is used in a high-frequency circuit.

It may cause trouble if the valve is used in a low-frequency or dc circuit, being operated for prolonged periods with cathode current cutoff (such as is not uncommon in computers).

It may be eliminated by using a cathode whose nickel is free of silicon, etc., but such a valve is not only difficult to provide with a reasonable level of emission during manufacture, but a very-low-silicon nickel is used in such valves only at the expense of a less copious emission.

Testing for interface takes the obvious form of life testing under cutoff conditions, with suitable tests to detect and measure the values of the equivalent resistance and capacitance.

PHYSICAL ENVIRONMENT CONDITIONS

Physical environment requirements of special kinds, such as high - altitude or marine usage, require consideration in the design of external connectors. At high altitudes there is greatly increased probability of air ionisation causing arc-over between neighbouring points at high potential difference. In marine usage salt spray can cause corrosion.

Increased altitudes also increase the bulb-operating temperature, and in some cases may make necessary a reduced dissipation rating. Where altitude rating is specified, life tests at increased temperature are carried out. Suitable tests for these factors consist in duplication of these environments.

RELIABILITY REQUIREMENTS

The requirements for reliability may be divided into **mechanical reliability** and **electrical uniformity.** Mechanical reliability may be further subdivided into four main factors, as follows:—

(a) Lint control and cleanliness.
(b) Welding control.
(c) Dimensional control of parts.
(d) Glass quality.

Electrical uniformity is considered under three categories. They are valve-to-valve uniformity of characteristics, stability of characteristics, and long life with electrical uniformity.

MECHANICAL RELIABILITY

By this is meant the probability that the individual valve will not develop a mechanical fault rendering it inoperative when it is used in a normal environment for which it is designed, including even undisturbed situations. These faults cause sudden rather than gradual failure. They are more prone to occur when there has been a departure from optimum standards of workmanship, either in individual valves, or in particular batches of valves — by an operator, a machine or process, or in raw materials.

They usually account for most of the early failures in a given batch of commercial valves. That is, such faults tend to show up fairly early

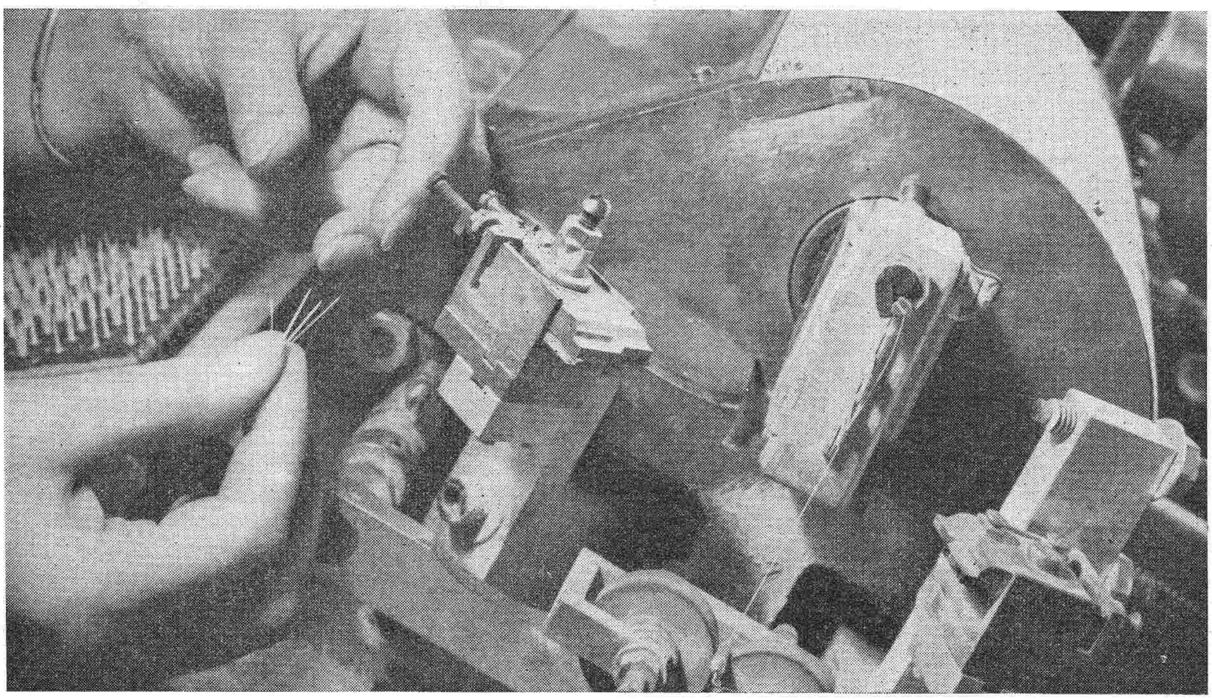


Fig. 3 — Heater Fabrication.

during life, and the survivors of a short life test will have a very low incidence of them. Although the incidence of these faults in ordinary receiving valves is already low, applications using very large quantities of valves in a single equipment, such as computers, require that the sudden failure rate be very low indeed. This is emphasised when it is realised that the sudden failure of a valve, unlike its gradual loss of performance, cannot be predicted by readings taken during regular maintenance checks.

One way of achieving low failure rate due to mechanical faults of this sort, is to fill all sockets with standard commercial valves, and simply replace these failures as they occur. After an initial period, the failure rate reaches a low value. This method may often prove to be the economical one in computers and the like.

On the other hand, valves with lower probability of sudden failure than commercial valves may be produced if steps are taken to eradicate the various causes of sudden failure. Several aspects are important:

Lint Control and Cleanliness

Two noticeable features of the assembly area of a special-quality valve production unit are the tight precautions taken against the presence of airborne lint — air filtration and the use of special clothing, etc. — and the deliberate working pace of the operators.

An anti-lint campaign is a big part of reliable valve production. Lint from the atmosphere or from operators' clothing can, if undetected, lead to intermittent leakage in a final valve or even a short circuit. Any lint particles which may adhere to valve parts before processing become carbonised during the high temperatures attained in sealing and exhaust, and capable of sufficient electrical conduction effectively to short out any pair of electrodes they may happen to bridge.

Assembly is carried out in an air-conditioned room, the air to which is carefully filtered. Operators wear overalls, work at covered benches, and are made "lint conscious". Individual parts and sub-assemblies are blown with an air jet just prior to insertion. Grids are inspected for lint, using an optical system which shows up the smallest traces.

Welding Control

Great care taken by operators with each individual weld in the structure helps guard against possible faults, such as embrittlement due to overheating, and unnecessary stressing, both of which may lead later to weld failure. Of great importance also are such details as the careful shaping of a cathode tail to guard against fatigue failure resulting from heating and cooling cycles during service.

Dimensional Control of Parts

Tight statistical control right from the acceptance of piece parts to completion of the reliable valve is necessary to ensure a high degree of conformity. In many cases, 100 per cent inspection of important dimensions would be called for.

Glass Quality

The control of stresses in the glass envelope must also be carefully carried out if glass failure is to be avoided. Glass is a strong structural material when in compression, but weak in tension, especially if the tension appears at a surface exposed to atmosphere. In the latter case, failure may not take place immediately if the tension is not great, but may occur many months later. The reason for this is bound up with the physical nature of the glassy state, the chemical bond strength of glasses, and the interesting effect on this of atmospheric moisture.

Tension (or compression) in a glass specimen can arise in three ways: from temperature differences between different parts of the same body of glass ("Thermal Stress"): from mechanical stress from some outside cause: and from strains frozen into the glass whilst cooling from the molten state, causing the stresses known as "permanent" stresses.

Thermal stress is the reason for the tension that causes fracture of a cold glass article which is differentially heated. Examples are a cold bottle suddenly filled with hot water (thermal shock), or failure of the glass window of an oven (steady thermal stress) due to its being maintained hot on one side and cool on the other. These effects are not of much concern in field service of valves, because the thermal shocks or steady thermal stresses likely to arise are well within the capabilities of the glass envelope.

Mechanical stress does arise, notably in the case of miniature valves whose contact pins can transmit considerable mechanical forces to the glass button base if the valve is forced by wriggling into a tight socket. In addition, many socket designs impose forces which remain as long as the valve is in the socket, these likewise being transmitted to the glass button base. As said above, tensions in the glass arising in this latter way could cause glass failure after a protracted period.

Permanent stress, the third cause of tension in glass, is always likely to arise if care is not taken to cool a glass article at a suitable rate after performing glassworking operations upon it. Such precautions are, however, taken during normal manufacture of commercial valves. Moreover, in order to counter the hard usage encountered from tight or poorly-designed sockets, it is necessary **deliberately** to introduce permanent stresses into the glass button base. These are introduced so that only compressive stresses appear at the surface, by giving the glass base of miniature valves a suitable differential cooling treatment in manu-

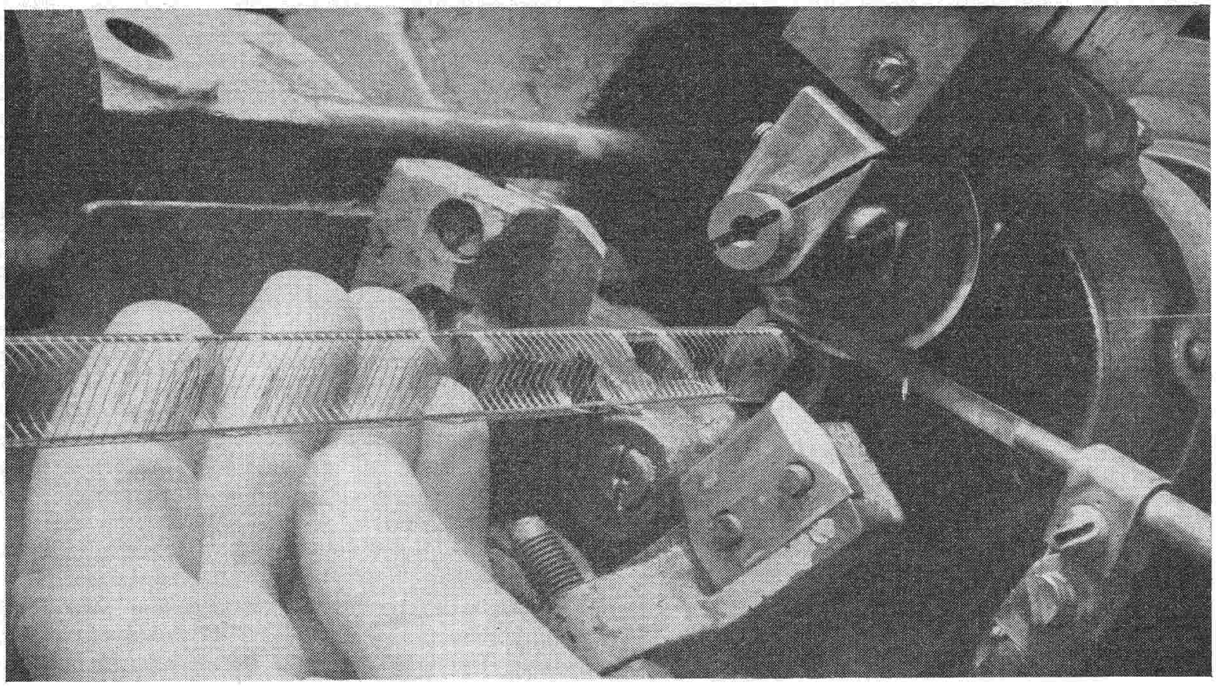


Fig. 4 — Grid Winding.

facture to produce **permanent compressive forces to oppose any tensile ones** arising in service. However, if too little of this prestressing is done, the valve has not sufficient protection, and if too much, danger exists of other kinds of glass failure.

Thus, it is necessary to ensure (a) that unwanted tensions do not exist on any outside glass surface, and (b) that the correct amount of prestress is given to the button base of a miniature valve. Control of these factors is achieved through attention to glassworking temperatures and cooling rates. Testing is done, both by applying appropriate stresses by thermal means in such a way as to add to any possible tensile stresses present, and by the application of suitable simulated "tight socket" tests for long periods. These tests as performed on special quality valves are similar in nature to those applied to ordinary valves, since the design objectives are the same, but differ in stringency to ensure even closer adherence to those objectives. For a rather more detailed account of the factors involved, the reader is referred to "Glass Technology in Valve Manufacture", by J. Ziegler, Radiotronics, Vol. 21, No. 11, November, 1956.

It thus appears that control and test methods for faults of this nature are of necessity statistical, being aimed at lowering the **probability** of failure. That is, the criterion of quality would be expressed in some such fashion as "Type X has an average failure rate, due to inoperatives, of better than so many failures per thousand valves."

ELECTRICAL UNIFORMITY

Valve to Valve Uniformity

Valves are of such a nature that it is difficult to control precisely the spread of characteristics between valves of the same type during manufacture. Hence, the achievement of close tolerances usually means not only testing to narrow limits, which often involves high rejection rates, but also tight and expensive production control to keep these rejection rates within reason. The latter involves the maintenance of tight tolerances on the characteristics of each particular group of valves constituting a production batch, and allowing only small variations between the averages of different groups.

On the other hand, rather large variations between the averages of different groups may arise in ordinary receiving valve manufacture. The effect of tighter control is that an individual valve will have an increased probability of having its characteristics near those of the average valve.

With proper statistical distribution of characteristics about the central average, the spread of equipment performance around its design centre is minimised when the valve is placed in circuit with its auxiliary components also having controlled distributions.

The difficulties involved in achieving close tolerances in valve manufacture appear when it is realised that characteristics such as plate current and transconductance, for example, or cutoff bias, are only to some extent dependent upon one another. Two valves of the same type having nearly the same plate current may well not have transconductances or cutoff biases alike. Mere selection from ordinary production, therefore, although it could achieve the same result, would probably prove uneconomic without suitable production controls.

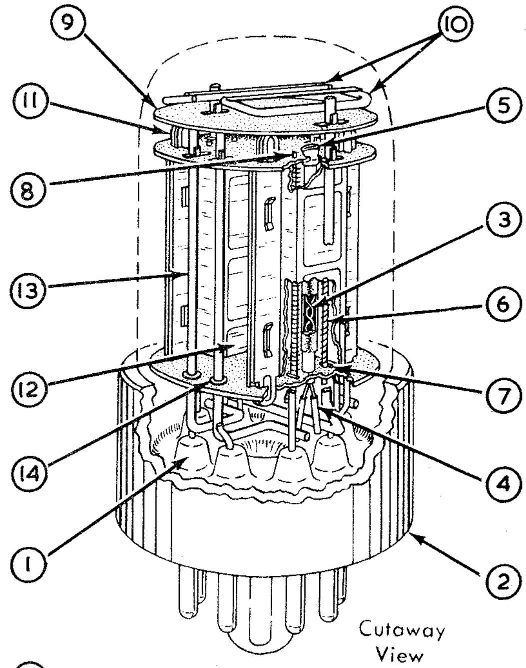
Statistical control of electrical characteristics is dependent on control of dimensions of the operating electrodes, control of the chemical and vacuum processes which influence the chemistry of the emissive coatings and getter deposits, and the removal and ultimate residue of gas distributed throughout the valve components. Control of dimensions of the operating electrodes follows the pattern described for parts generally under "Mechanical Reliability". Control of the vital exhaust processes supplemented by uniformly - controlled conditions in cathode spraying, washing and firing of parts, time delay in use of clean parts, and the conditions of aging, contribute their effect to the ultimate uniformity of these less-measureable factors of residual gas and chemical conditions.

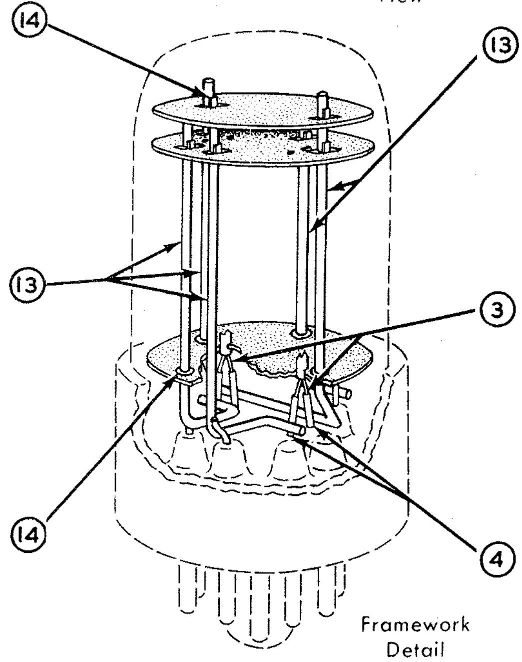
Stability

This term indicates freedom from drift in characteristics during the few tens of hours following initial switch on. Certain key processes, all continuing during the life of a valve, determine or at least affect its electrical properties. The final equilibrium reached between these processes, whilst it fixes the final values of the characteristics, takes time to establish; it is, moreover, itself affected by the valve's conditions of operation.

Typical of these processes are (a) the reduction of barium oxide to barium in the cathode coating by the passage of cathode current through it: (b) the loss of free barium from the cathode, both by evaporation and by chemical combination with gas within the valve: (c) the evolution of gas from valve parts: (d) the deposition by evaporation of conducting films on insulating surfaces (and the "cleanup" of these by the same gas within the valve): and (e) the deposition of primary and secondary electron-emitting surfaces — and likewise their cleanup — on various electrodes. It will, incidentally, be apparent that a small and controlled amount of gas evolution from valve parts usually is actually beneficial.

Certain design measures can, in a limited way, improve stability. For example, the effect of changes in the work functions of grids due to deposition of evaporated materials can be minimised by first coating the grids with substances having inhibitory effects on electron emission. That is, substances having high work functions; gold and platinum are typical.





1—Low-leakage button stem.
2—Non-hygroscopic base.
3—Pure-tungsten heater for high mechanical strength.
4—Sleeves on heater legs insure good mechanical and electrical bond between heater and heater leads.
5—Cathode sleeves locked to mica insulator.
6—Grid plated to minimize variation in contact potential.
7—"Stops" prevent vertical movement of grid rods.
8—Grid rods fit tightly into mica insulators.
9—Extra mica insulator provides getter shield.
10—Two getters.
11—Plates held rigid by plate ears wedged into mica insulators.
12—Plates are designed to minimize electron coupling between units.
13—Mount secured by five supporting rods.
14—Twelve reinforcing eyelets provide a firm bond between mica insulators and five supporting rods.

Fig. 5 — Cut-away view of a Special Quality Twin Triode.

However, the most effective way to avoid early drift in characteristics is to establish equilibrium, by operation under intended circuit conditions, before the valve leaves the hands of the manufacturer. The normal aging given every oxide-cathode valve approximately achieves this result, but if a more exact approach to precise stability is required, a run under as nearly as possible the user's desired final conditions, for some tens of hours, is the best answer.

Long Life

This term is largely synonymous with long term stability, but considered from the point of view of changes in characteristics proceeding to a point where the valve ceases to operate satisfactorily. It is to be borne in mind that, after a long life, a valve may still be quite operable, but its characteristics, such as transconductance, or capacitances, may have changed enough to cause an intolerable change in performance in a particular circuit. This would be the end of the useful life of that valve used in that circuit. A circuit placing unreasonable demands on the invariance of a valve's characteristics will necessarily be less reliable than one in which due allowance is made, even if proper attention is given to operation of the valve within its ratings and in spite of the use of valves having special long life and stability features.

The consideration of long life is an economic one from the point of view of the user, and reaches its extreme in valves designed for use in submerged amplifiers in submarine cables. Since the cost of fishing up the cable to replace a valve is very great, it is economic to expend a large amount of effort to ensure that maintenance is rarely needed. Many industrial equipments also, for economic reasons, demand valves with lives longer than can ordinarily be expected.

In practice, the theoretical upper limit to the life of an oxide-coated cathode valve, the loss by evaporation of all the barium from the emitting surface, is scarcely achieved. As explained earlier, this barium is constantly being supplied during life by reduction from barium oxide on the cathode. More than 100,000 hours' operation time could be expected in theory if the only factor determining ultimate failure were loss of barium. But the effects of many other of the actions within the valve tend to culminate in significant changes in performance. For example, the gradual deposition of very thin films of conducting materials on insulating surfaces — if this takes place faster than the slowly evolved gas within the valve can deal with it — can lead to intolerable changes in the various impedances, capacitative or resistive, of the valve.

Again, the lowering of the work function of a grid surface by condensation of evaporated barium — likewise if faster than can be dealt with by the gas — may lead to grid emission, the consumption of significant current by the grid even when biased well negative, lowering the grid circuit impedance, and thus to loss of gain. Further, if gas is evolved too fast due to insufficient outgassing in manufacture, it can combine with the free barium on the cathode faster than this is produced, thereby weakening the barium concentration and reducing the emission reserve even to the extent of materially lowering the transconductance.

It will be appreciated that too slow a rate of gas evolution can lead to valve failure just as surely as too fast a rate. The degree of outgassing in manufacture of every part must be adjusted to a nicety to attain the desired optimum which permits long life.

There are other examples of processes whose end result is degradation of valve performance, which are not so intimately bound together as the foregoing ones. The glass envelope, in its capacity of insulating, vacuum tight support for the external connectors, conducts minute current, as do all "insulators". Part of this current is carried by ions within the glass, resulting in slow transport of these ions. The effect of this is gradual decomposition of the glass, which can lead ultimately to loss of vacuum. This effect proceeds faster with higher voltage gradients, and faster still at rather elevated temperatures. This is why many rectifiers, particularly those employing pinch-stem construction, use special glasses featuring very high resistance to ionic conduction — the same glasses, unfortunately, being rather difficult to work.

Steps to combat all of these deleterious effects are taken as a matter of course in ordinary valve manufacture, but almost complete elimination of them is extremely difficult. The very delicacy of balance between many of the effects necessitates minute care in manufacture if increased life expectation is to be had. It is this special degree of care, with its concomitant strict life testing to extended limits, which characterizes the production of valves having special long life features

SUMMARY

Receiving valves have found their way into all kinds of applications, having special requirements not encountered in entertainment equipment. To meet these requirements, special quality versions of many commercial valves, both octal based and miniature, are now available.

COMPLEMENTARY SYMMETRY

An Explanatory Note

This term is used to describe a circuit arrangement involving a direct coupling between two transistors, one a p-n-p type and the other an n-p-n type. The arrangement takes advantage of the fact that the polarity of the signal necessary to increase current in one type is the opposite of that necessary to increase current in the other.

The diagram in Fig. 1 shows a typical arrangement, using 2N217 and 2N647 transistors. The 2N217 is forward-biased in the conventional manner, and the base is negative with respect to the emitter. The component valves have been chosen so that the collector voltage of the 2N217 is more positive than the emitter voltage of the 2N647. Since the base of the 2N647 is directly connected to the collector of the 2N217, the condition for forward bias of the 2N647 is satisfied (base negative with respect to emitter).

When the input is positive-going, collector current in the 2N217 decreases, producing a negative-going signal at the collector. This signal decreases the forward bias on the 2N647, causing a decrease in collector current and a positive-going signal at the output. Note that the input and output signals of this arrangement are in phase.

"Complementary Symmetry" can be used in connection with class B output stages, a typical arrangement being shown in Fig. 2. It will be

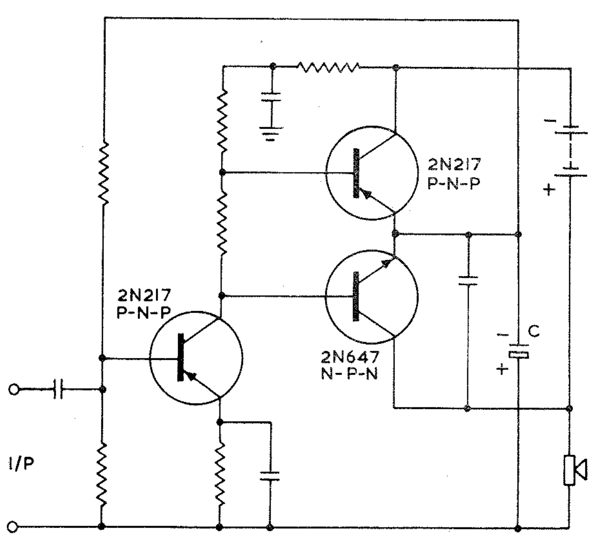


Fig. 1 — Direct-coupled Amplifier using P-N-P and N-P-N Transistors in Complementary Symmetry.

noted that this circuit is very economic, as it dispenses with a coupling transformer between the driver and output stages. An output transformer is omitted by using a 45-ohm loudspeaker connected directly into the circuit.

In the circuit shown in Fig. 2, 2N217 and 2N647 transistors are used in a complementary symmetry class B output stage, driven by a directly-coupled 2N217. A positive-going input signal to the driver results in a decrease in collector current, and the application of a negative-going signal to the bases of the output transistors. Remembering that the transistors for class B operation are biased near cutoff, this means that the forward bias on the 2N647 is decreased still further, and in effect the 2N647 will be cut off, whilst the increase in forward bias of the 2N217 will bring that transistor into heavy conduction. With a change in input signal polarity the converse will apply.

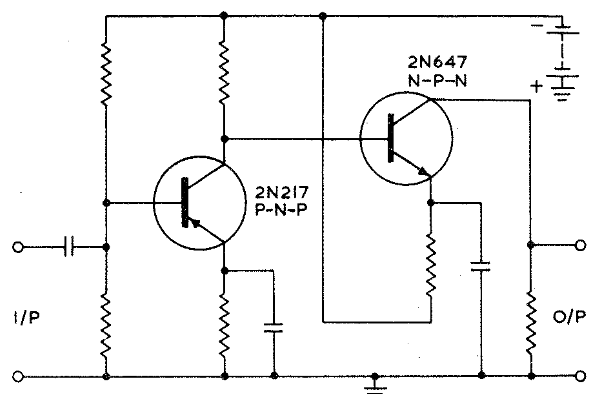
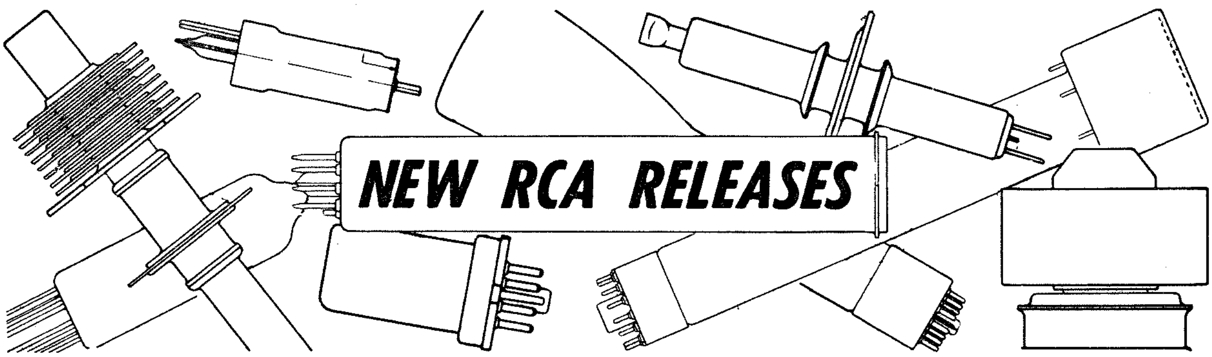


Fig. 2 — Direct-coupled P-N-P and N-P-N Transistors in Class B Complementary Symmetry.

Other interesting points about the circuit shown in Fig. 2 are the method of providing bias for the output stage, and also the coupling to the loudspeaker. The capacitor C is a large value component, usually about 50 microfarads, and is charged in the quiescent state to approximately half the battery voltage. The stored energy in C is then used by the 2N647 when it is driven into conduction. When the 2N217 is conducting, the speaker is in series with the battery, transistor and capacitor C, and restores the energy to C depleted by the 2N647. In practice the high capacitance of C means that the potential across it may for practical purposes be regarded as a steady supply voltage.



2N456 and 2N457

The 2N456 and 2N457 are germanium p-n-p alloy junction transistors, intended for use in power-switching voltage-regulator, multivibrator, dc-to-dc converter, and power-supply circuits, and as relay-actuating devices in industrial and military equipment. These transistors may also be used in large-signal class A or class B push-pull audio-frequency amplifier service, and in low-frequency oscillator service.

The 2N456 and 2N457 have a maximum collector current rating of -5 amperes, a maximum collector-to-base voltage rating of -40 and -60 volts, respectively, and a maximum transistor dissipation (at a mounting-flange temperature of 25°C or below) of 50 watts. The 2N457 is like the 2N456 but has the higher maximum peak collector-to-base voltage rating (-60 volts) for use in those industrial applications requiring such voltages.

2N640, 2N641, 2N642

Three new drift transistors of the germanium p-n-p type are announced. These transistors are designed specifically for AM Broadcast Band applications in automobile receivers — the 2N640 for rf amplifier service, the 2N641 for 262.5— Kc or 455 — Kc if amplifier service, and the 2N642 for converter service. These transistors provide the equipment designer with a transistor complement for receivers utilizing an audio driver stage and a single-ended output stage, and featuring high signal-to-noise ratios, high gain per stage and good agc characteristics.

The 2N640 in an unneutralized circuit is capable of providing a power gain of 28 db at 1.5 Mc: the 2N641, in a neutralized circuit, power gains of 41 db at 262.5 Kc, and 40 db at 455 Kc; and the 2N642, a useful conversion power gain of 40 db at 1 Mc.

These drift transistors have excellent uniformity of characteristics, exceptional stability, and low feedback capacitance made possible by their unique design. Furthermore, close manufacturing controls for the small-signal parameters insure optimum performance in auto receivers operating over the frequency range of 535 Kc to 1640 Kc.

2N643, 2N644, 2N645

Three new drift transistors of the germanium p-n-p alloy type are announced. These transistors are specifically designed for use in high-speed (millimicrosecond duration) non-saturating switching circuits of electronic computers such as inverters, flip-flops, and logic gates where high gain-bandwidth product and pulse repetition rates up to 10 Mc are primary design requirements.

The 2N643, 2N644, and 2N645 feature a minimum gain-bandwidth product of 20, 40, and 60 Mc, respectively. This figure of merit makes possible the design of switching circuits having rise, fall, and propogation times in the order of 20 millimicroseconds. Furthermore, their excellent high-frequency performance, together with their excellent stability and uniformity of characteristics, contributes to the dependable performance of the 2N643, 2N644, and 2N645 drift transistors in electronic computers and other "on-off" control applications.

2N649

The 2N649 is a new alloy-junction transistor of the germanium n-p-n type. It is designed for use along with its p-n-p counterpart, the 2N408, in class B Complementary-Symmetry power output stages of compact, transformerless battery-operated portable radio receivers, phonographs, and audio amplifiers operating at battery-supply voltages up to 9 volts. In such equipment, the 2N649 insures good frequency response and relatively high power output at low cost. This transistor may also be used in conventional class B push-pull and in class A audio amplifier circuits.

In a typical class B complementary-symmetry circuit, a 2N649 (n-p-n type) and a 2N408 (p-n-p type) used together in the output stage and driven by a 2N408 as a class A driver are capable of providing a power output of approximately 100 milliwatts at a power gain of 54 db.

In a typical push-pull circuit, two 2N649's used in the output stage and driven by another 2N649 as a class A driver are capable of providing a power output of approximately 100 milliwatts at a power gain of 66 db.

The 2N649 has a dc current gain which is essentially constant over the operating current range to insure circuit linearity, a collector cutoff current of only 14 microamperes to insure stable performance under varying ambient temperature, and excellent uniformity of characteristics to provide unit-to-unit interchangeability.

2N1090 and 2N1091

The 2N1090 and 2N1091 are two new germanium alloy-junction transistors of the n-p-n type designed for use in medium-speed, high-current switching circuits of industrial and military electronic data processing equipment. In such equipment, the 2N1090 can provide a switching time of 0.3 μsec; the 2N1091, 0.25 μsec, both at collector current levels of 200 milliamperes.

The 2N1090 has a minimum gain of 30 (at a collector current of 20 milliamperes) and 20 (at a collector current of 200 milliamperes), a minimum alpha-cutoff frequency of 5 Mc, and a maximum stored base charge of 1600 micromicrocoulombs.

The 2N1091 has a minimum dc current gain of 40 and 30, respectively, at the collector currents indicated above, a minimum alpha-cutoff frequency of 10 Mc, and a maximum stored base charge of 1000 micromicrocoulombs.

In a typical switching circuit, a 2N1090 and its p-n-p counterpart 2N579 used in a complementary-symmetry emitter-follower stage and driven by an inverter stage using a 2N582 (p-n-p type), are capable of providing a "turn-on" time of 0.21 μsec. and a "turn-off" time of 0.34 μsec., for a capacitive load of 3600 μμf. In the same switching circuit, a 2N1091 with its p-n-p counterpart 2N580, is capable of providing a "turn-on" time of 0.18 μsec. and "turn-off" time of 0.28 μsec. for a capacitive load of 3600 μμf.

RADIOTRON 4009, 4010

New packaged, light-weight travelling wave tube types 4009 and 4010 are particularly suitable for use in the design of air borne electronic equipment. They operate over a frequency range from 2000 to 4000 Mc and can be used with full ratings at altitudes up to 50,000 feet without pressurization.

The design of these types utilizes integral periodic - permanent - magnet focusing and the structure is capable of withstanding shocks up to 30 g for 11 milliseconds and vibrational accelerations of 5 g up to 500 cps.

The 4009 is intended primarily for use in driving an intermediate - power travelling wave tube such as the 4010. It can also be used, when low noise figure is not essential, in the first stage of microwave receivers and repeaters, as well as in grid-No. 1-pulsed applications having negligible driving-power requirements. In typical cw amplifier service, the 4009 can provide a small-signal gain of 38 db and a saturated power output of 28 milliwatts.

The 4010 is intended for use as a driver for a high-power travelling wave tube or in an output stage when a power output of only 1.5 watts is desired. In typical cw amplifier service the 4010 can provide a small-signal gain of 35 db and a saturated power ouput of 1.8 watts.

RADIOTRON 7044

The Radiotron 7044 is a medium-mu twin triode of the 9-pin miniature type. It is designed for use in pulse-amplifier, inverter, frequency-divider, cathode-foller, and multivibrator circuits of electronic computers particularly of the high-speed digital type, and in other equipment utilizing such circuits.

In such equipment, the 7044 maintains its emission capabilities even after long periods of operation under cutoff conditions, and, therefore, maintains consistent values of plate current during its "on" periods. Production controls correlated with typical electronic computer operating conditions together with rigorous tests for cathode interface, interelectrode leakage, high resistance and intermittent shorts, and conduction and standby life performance insure long and dependable service from the 7044.

The 7044 has separate terminals for each cathode to facilitate flexibility of circuit arrangement, and a mid-tapped heater to permit operation from a 6.3-volt or a 12.6-volt supply.

RADIOTRON 7264

A new head-on type multiplier phototube, the Radiotron 7264, is intended for use in scintillation counters for the detection and measurement of nuclear radiation and in applications involving the measurement of low-level light sources. The 7264 has fast response, high current gain, high peak-current capability, extremely small spread in electron-transit time, and a pulse-height resolution of about 8 per cent.

Other design features of the 7264 include a semitransparent photocathode on the inner surface of the spherical faceplate of the tube; a minimum photocathode diameter of 1.68"; 14 electrostatically focused multiplying (dynode) stages; and a focusing electrode with external connection.

The spectral response of the 7264 covers the range from about 3,000 to 6,500 angstroms. Maximum response occurs in the blue region at approximately 4,400 angstroms. When operated at a supply voltage of 2,000 volts, the 7264 has a median luminous sensitivity of 875 amperes per lumen and a current amplification of 12,500,000.

Continued on page 223.

nuvistor

The New Look In Electron Valves

INTRODUCTION

For many years, the objective of improving the receiving valve has been vigorously pursued by the electron valve industry. The goal, a dynamic one, is improved performance, higher quality, increased reliability, uniformity and reasonable cost.

It is a goal that the Electron Tube Division of RCA has subjected to determined assaults on two fronts. On the one front, refinements and improvements are constantly being made in conventional receiving valves. On the other, entirely new designs, materials, and techniques are being investigated. The first approach is the steady pace into the future. The second can result in the daring leap that places the industry one step beyond the threshold of the future.

Nuvistor, the new look in electron valves, is that daring leap into the future. Although the devices themselves are still in the development stages, their principles are already well established. The results achieved to date give us the confidence and assurance to proceed with the design of commercial products.

In the course of the Nuvistor development, planar structures, cylindrical structures, ceramic-spaced stacked structures, metal-to-glass seals, metal-to-ceramic seals, and many other areas were carefully explored. Planar valve elements, because of the apparent ease of assembly, were one of the areas in which substantial investigations were made. Critical appraisal, however, revealed that any advantage in assembly technique offered by the planar structure was more than offset by disadvantages in electrical and thermal characteristics.

The concept of cylindrical symmetry in receiving structures, however, gained increasing favour as it passed one test after another. It offered a stable and efficient design both electrically and thermally. In addition, it was found that a valve of cylindrical structure, utilizing properly selected materials, could be easy and economical to manufacture and would permit rigorous processing even when scaled down radically.

As a result of these investigations, a new basic design has been achieved. This new design, employing concentric cylinders supported in an open-ended cantilever construction, together with an ingenious combination of new materials, processes, and fabrication techniques, promises a major breakthrough for size, performance, power drain, quality, and reliability.

RCA expects that this new design concept will open up a broad new vista for equipment designers and will keep the receiving valve industry in the vanguard of electronics progress.

The confident optimism for this new valve's future is reflected in its name — Nuvistor, the new look in electron valves.

ELECTRICAL AND THERMAL DESIGN CONSIDERATIONS

From the standpoint of electronic theory the current miniature valve and even the Nuvistor, is much larger than it need be. A set of valve elements — cathode, grid and plate — need hardly be larger than a grain of wheat to provide the electronic performance called for in perhaps 90 per cent of all small-valve applications. Present technology, however, does not permit downward-size scaling to this degree. Nevertheless, it can now be approached more closely than ever before.

When a valve structure is proportionally scaled down in size, some characteristics remain constant, others improve, and still others become less favourable. For example, cathode efficiency and high-frequency performance both improve. General operating characteristics such as mutual conductance and plate resistance remain substantially the same. Cathode current density, however, increases, and the grid and plate operate at much higher temperatures. These latter effects tend to act adversely on valve life and reliability. Both these effects can be offset if the electrode spacings are scaled down by a greater amount than the other dimensions and if more efficient thermal paths are provided for removal of excess heat. This differential scaling makes possbile the use of much lower electrode voltages thereby

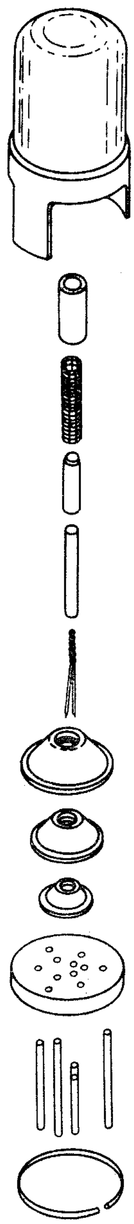


Fig. 1 — Assembly of a Nuvistor Triode.

providing several advantages in addition to the corresponding reduction in power input. One of the major advantages of voltage reduction is a substantial improvement in cathode life, because less energy is imparted to any residual gases which might damage the cathode through ion bombardment. Another advantage is the reduced high-voltage insulation required in the valve, its socket, and in associated circuit elements, such as capacitors.

The thermal paths in valves are very significant. In the case of the cathode and its supporting structure, heat conservation is the major consideration. For maximum cathode efficiency, low thermal conductivity and low thermal emissivity are required. In the case of the grids and plate, however, paths of high thermal conductivity are required to enable the grids to stay cool enough to avoid grid emission, and to enable the plate to operate at low enough temperature so that gas evolution is minimized.

Practical solutions to the problems of thermal conductivity have been found in the Nuvistor through the use of unique structures, unique assembly techniques, and the careful selection of materials.

These same structures, techniques, and materials have also provided the means for accomplishing the dimensional scaling down required for improved performance.

STRUCTURAL DESIGN FEATURES

In arriving at this new design, RCA has drawn on its wealth of experience acquired over many years in electron valve manufacturing to develop a valve, readily assembled and processed with inherent ruggedness and reliability.

For ruggedness, a strong ceramic base-wafer is used as a platform on which is erected an array of electrodes, each solidly held in place by a tripod-like structure.

The electrodes themselves are thus strongly supported in an open-ended cantilever construction. They are small, light cylinders, which because of their form and low mass are able to withstand a high degree of shock or vibration.

There are no micas to fray under vibration or to interfere with high-temperature exhaust processing of the valve. There is no glass to limit the processing temperature or to shatter under mechanical or thermal shock.

All of the joints in the complete valve are brazed together in a simple operation at high temperature. The parts are thus joined in a strain-free assembly. Because the elements are accurately secured in their original strain-free position, the possibility of shorts developing in the valve during operation is remote.

Eliminating the use of spot-welding has eliminated (1) a potential source of failure, (2) a source of residual strains in assembly, and (3) an operation requiring a high degree of manual skill.

The ingenuity of the design and the cylindrical symmetry permit a high degree of mechanization in the assembly of the valves. This structure permits the assembly of valves in which the accuracy and uniformity of assembly is inherent because of the accuracy with which both the simple parts and the jigs can be made, and without the individual matching of parts which may be required in close-spaced planar designs. The high degree of control obtained permits close spacing of the valve elements and at the same time provides increased protection against interelectrode shorting. This accurate control results in improved uniformity of electrical characteristics.

The materials chosen to form the basic framework of the valve structure are ceramics and strong metals such as steel, molybdenum, and tungsten.

These materials are processed at high temperatures in the brazing furnace and in the vacuum exhaust furnace. These high-temperature processes can be expected to eliminate many of the gases and impurities that cannot be eliminated when valves of conventional design are processed at temperatures limited by glass and mica. Because residual gases eventually impair valve performance, the new processing techniques contribute materially to more reliable performance and life.

Because the valves have been outgassed at high temperatures, they can operate at temperatures in excess of those permitted conventional types. At normal operating temperatures, reliable operation over long periods of time can be anticipated.

Although the more immediate objective of the Nuvistor development was conventional receiving-valve applications, several types of tests have been applied which indicate much promise for military applications. For example, Nuvistor triodes have been subjected to half sine-wave shocks at 67.5 g's with a duration of 11 milliseconds. Other valves were subjected to an impact of 500 g's for 0.75 millisecond perpendicular to the long axis of the valve. No shorts were indicated, either permanent or temporary. Several valves were also subjected to a sweep-frequency vibration test from 50-10,000 cps; the valve performance was encouraging. More complete testing is required to evaluate performance under unusual environmental conditions.

The combination of strong structural assembly, brazed joints, all ceramic-metal construction, and high-temperature processing has resulted in a valve design in a small envelope that can operate well under difficult environmental conditions, such as thermal or mechanical shocks, continuous vibration, or high temperature.

Another important and novel feature of the Nuvistor is its indexing lugs. These lugs serve as two small shields which not only protect the leads during insertion of the valve into a socket but also permit safe, easy, rapid insertion.

FUTURE

The Nuvistor provides the basis for the design of a complete line of small, highly versatile, receiving valves. For example, valves patterned after the two small-signal types described in this article, the triode and the tetrode, are capable of performing 80 per cent of the electron-device functions in a modern television receiver.

The future of the Nuvistor is indeed promising. It is especially promising when the inherent advantages of electron valves, and specifically the Nuvistor, are compared with competitive devices. Some of the more significant advantages are:

A. In a valve the electrode spacing can be 50 times larger than the electrode spacing in a transistor intended for comparable performance. Consequently, valve spacings and the associated tolerances can be more easily controlled in manufacturing operations.

B. The valve is economical in initial cost, has high impedance and gain, and generally requires less expensive associated circuit components.

C. At high frequencies, the noise factor and the gain of a valve are superior.

D. The valve has high uniformity of initial characteristics and does not require a costly selection process.

E. The valve is capable of handling momentary overloads.

F. The valve is inherently less susceptible to radiation damage.

G. Valves, and particularly the Nuvistor design, maintain their characteristics over a wide range of ambient temperatures.

Additionally, it can be shown that in many typical amplifier circuits, the power required for a Nuvistor scaled down to only about one-half its

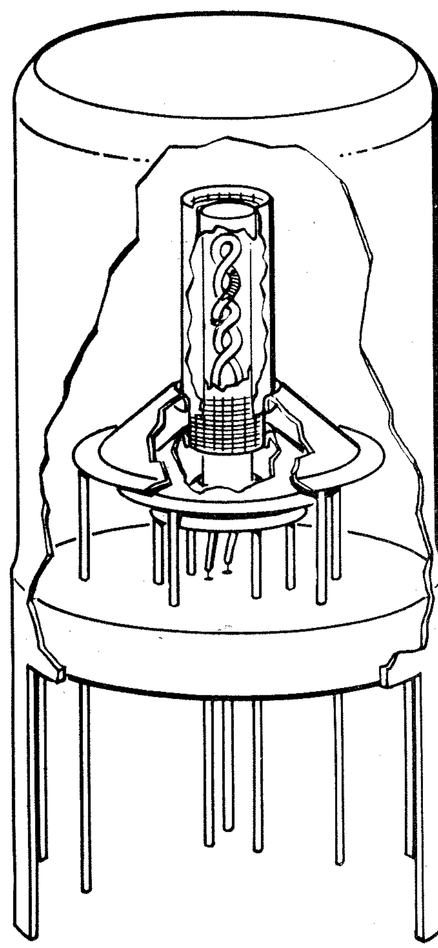


Fig. 2 — Cut-away Diagram of a Nuvistor Triode Assembly.

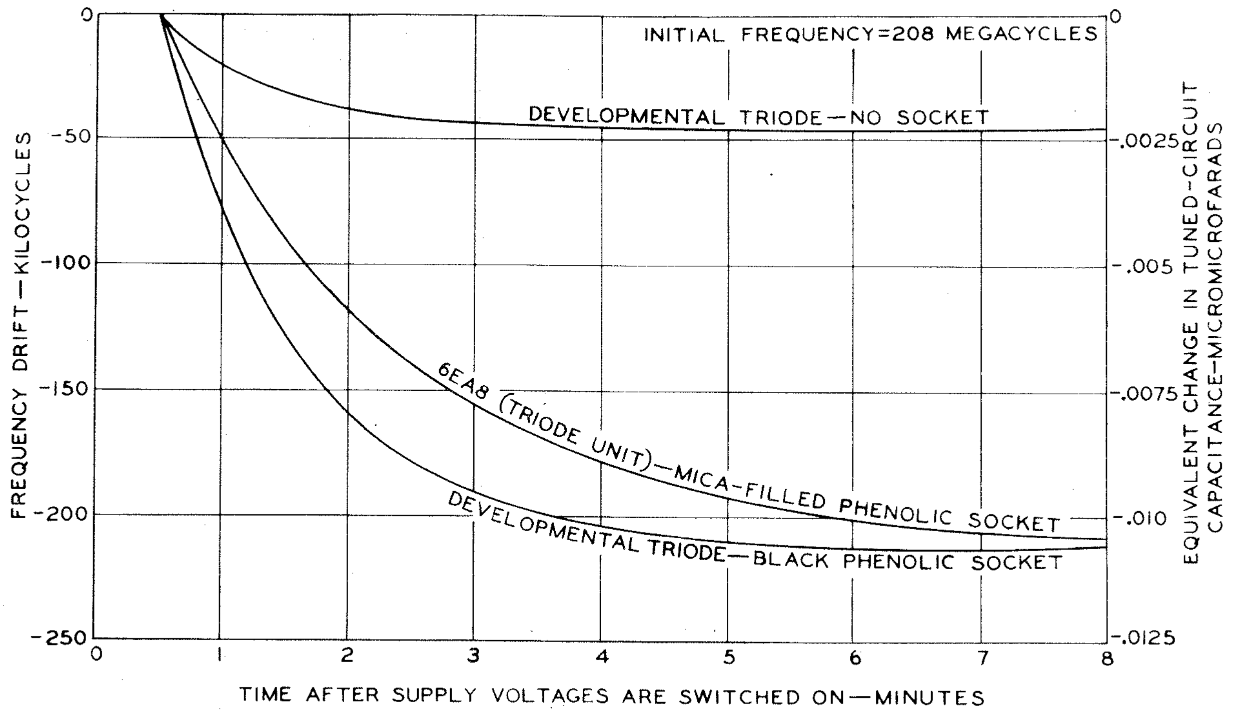


Fig. 3 — Oscillator Frequency Stability Curve, Developmental Small-signal Triode and 6EA8.

present size can be reduced to five per cent of that required by conventional miniature valves.

Such a valve, the Nuvistor, can not only fill its circuit functions in a fashion superior to that of a transistor but can also compare favourably in size and efficiency, two areas that no longer need be conceded to the semiconductor device. The advent of the Nuvistor forecasts many new contributions to the electronics field by the receiving valve industry.

DEVELOPMENTAL SMALL - SIGNAL TRIODE

The material which follows gives characteristics and performance data on an RCA developmental general-purpose small-signal triode. It is suitable for use in applications such as radio-frequency amplifiers and local oscillators in tuners of television receivers.

ELECTRICAL:

Heater, for Unipotential Cathode:		
Voltage (AC or DC)	6.3	volts
Current	0.14	amp

DIRECT INTERELECTRODE CAPACITANCES (APPROX.):

Grid to Plate	2.4	$\mu\mu$f
Grid to Cathode, Heater and Shell	5	$\mu\mu$f
Plate to Cathode, Heater and Shell	2.2	$\mu\mu$f
Plate to Cathode	0.5	$\mu\mu$f
Heater to Cathode	1.8	$\mu\mu$f

CHARACTERISTICS, CLASS A, AMPLIFIER:

Plate Voltage	40	75	volt
Grid Resistor	1	—	megohm
Cathode Resistor	—	150	ohms
Amplification Factor	32	32	
Transconductance	10700	10500	μmhos
Plate Current	7	9	ma
Grid Voltage (approx.) for plate current of 10μa	—	−6	volts

MAXIMUM RATINGS:

PLATE VOLTAGE	100	max.	volts
GRID VOLTAGE	−50	max.	volts
PEAK POSITIVE GRID VOLTAGE	2	max.	volts
PLATE DISSIPATION	1	max.	watt
PEAK HEATER-CATHODE VOLTAGE:			
Heater negative with respect to cathode	100	max.	volts
Heater positive with respect to cathode	100	max.	volts

HF PERFORMANCE

Although the short-circuit input admittance of a triode has little significance by itself in circuit design, it is often used as an indicator of high-frequency performance. Some preliminary measurements have been made on this developmental triode and typical values of input conductance with a transconductance of 10,000 micromhos are 200 micromhos at 100 megacycles and 2500 micromhos at 250 megacycles. These values are approximately the same as obtained for conventional type 6BN4 using the same test methods.

A grounded-cathode, neutralized triode rf amplifier has been used to compare noise figure and gain of the developmental triode with type 6BN4-A at television channel 13 (210-216 megacycles). The developmental valve has given superior performance — about 3 db more gain and from one-half to one db better noise figure. This performance places this valve in the same category as available television tuner valves using frame grids. Other experimental triodes having 0.5-mil grid wire are about one-half db better for noise. In this test, the Nuvistor triode was operated with 40 volts on the plate and 7.5 milliamperes of plate current, about one-third the voltage and one-half the current required for the 6BN4-A.

REMOTE CUTOFF, CROSS MODULATION, AGC

The signal-handling capability, rf distortion, and the cross-modulation characteristics of the developmental triode, especially as gain is varied with grid bias, are recognised to be of vital importance in many systems. It must be realised at the outset that increased ratio of transconductance to plate current intrinsically implies reduced signal-handling capability. From another viewpoint, reduction of plate power input necessarily means reduction of power-output capabilities. Consequently, the equipment designer applying a new device may find it advantageous to take a new look at the system design from the standpoint of signal levels in circuits intermediate to the terminal devices. To date, all of the valves have been made with uniform-pitch grids, although some experiments have suggested feasible methods of fabricating grids having extended cutoff characteristics. There are circuit techniques for reducing rf distortion, however, the most common being operation of the plate of the triode (or grid No. 2 of a tetrode) from a relatively high supply voltage and using a series dropping resistor so that the cutoff is extended. The unusually small electrode voltage required by these valves is especially instrumental in making this circuit technique practical in system design. Experiments have demonstrated substantial improvements resulting from this technique, and it has the advantage over remote-cutoff valves that no compromise is made on performance under maximum-gain conditions.

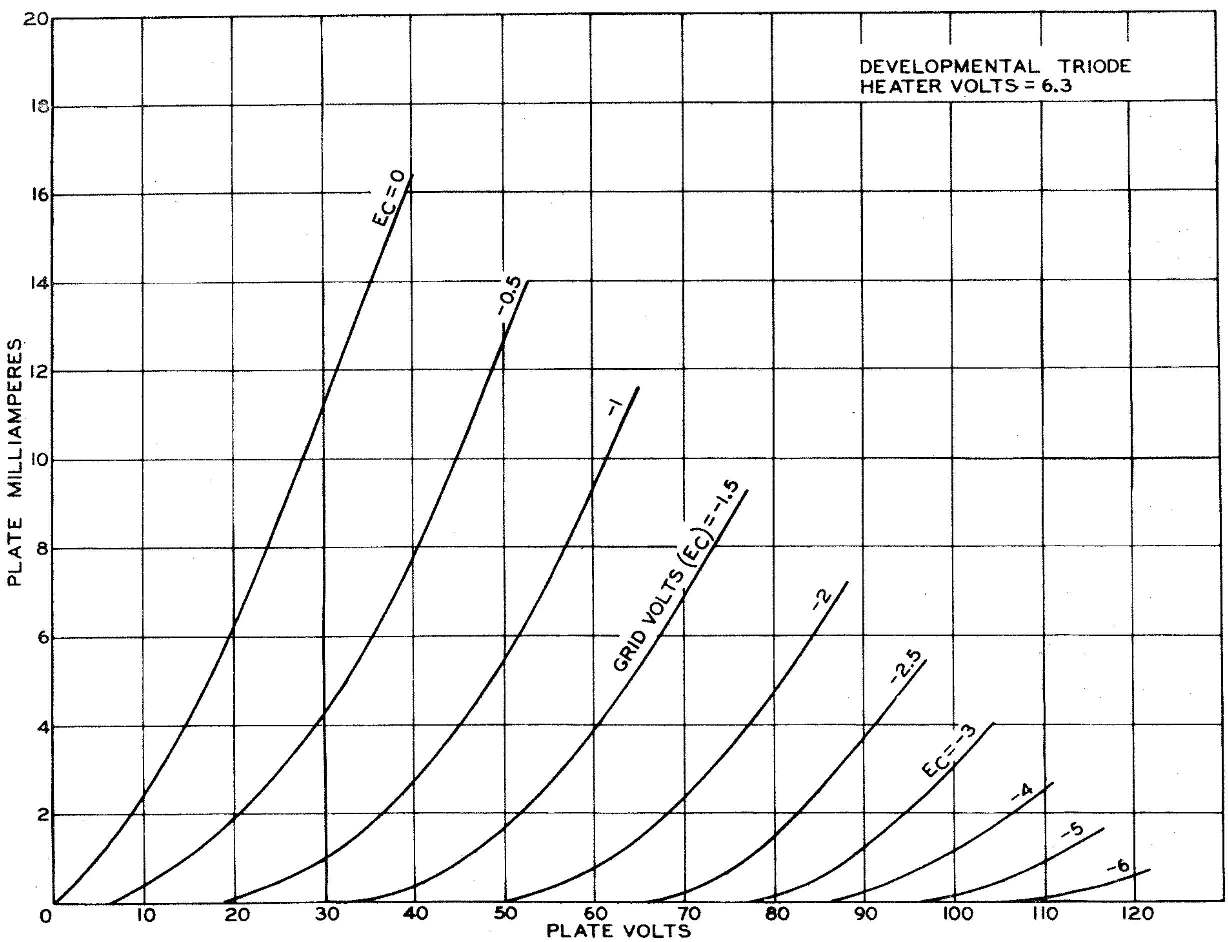


Fig. 4 — Typical Plate Characteristics for Developmental Small-Signal Triode.

OSCILLATOR PERFORMANCE

Developmental Nuvistor triode valves have been tested for maximum frequency of oscillation in breadboard circuits. Normal oscillator efficiency is observed up to about 450 megacycles. With the valve in an experimental black phenolic socket, oscillation is still strong at about 800 Mc, and is just detectable by a wavemeter at 900 Mc with a plate power input of over 0.5 watt. When the valve is connected directly to the circuit with no socket, the maximum frequencies are about 300 megacycles higher.

The valve efficiency may be illustrated by oscillator performance with low plate voltages. Tests of a 435-megacycle oscillator showed that oscillation started with 7 volts at the plate. With 15 volts supply the plate current was 1.6 milliamperes and a grid bias of —0.55 volt was developed across a 3300-ohm grid resistor. A lower-mu version of the valve (mu=20) starts oscillation at 2.5 volts and gives similar performance with 5 volts at the plate.

Tests of oscillator frequency stability were made in an oscillator circuit typical of vhf television tuners. All sources of circuit drift were reduced to an inconsequential amount in the test oscillator. The accompanying graph (Fig. 3) shows the valve drift during the warm-up period as compared to that of a typical good vhf tuner valve in the same oscillator circuit. The only available sockets for the developmental triode in these tests used wood-flour-filled phenolic dielectric, known to have a poor temperature coefficient. Nevertheless, the new valve stabilizes more rapidly with about the same total drift as the triode unit of the 6EA8. The use of mica-filled or other socket of good dielectric material should reduce the drift to little more than that observed with no socket.

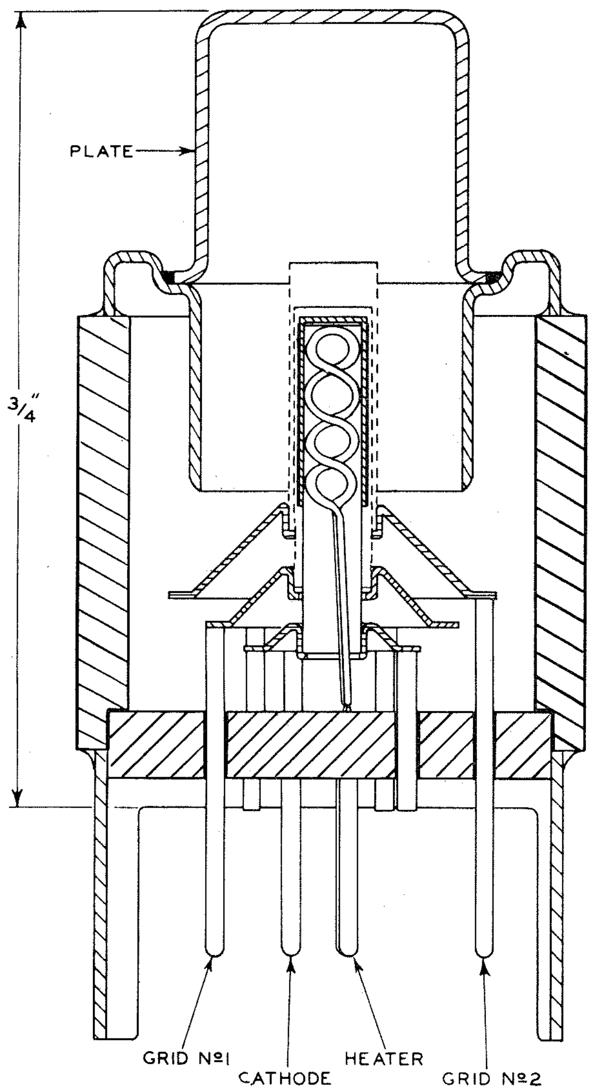


Fig. 5 — Arrangement of Developmental Small-signal Tetrode.

DEVELOPMENTAL SMALL - SIGNAL TETRODE

The material which follows gives characteristics and performance data on an RCA developmental general-purpose small-signal tetrode. It is suitable for use in applications such as intermediate-frequency amplifiers and radio-frequency amplifiers of television receivers.

ELECTRICAL:

Heater, for Unipotential Cathode:		
Voltage (AC or DC)	6.3	volts
Current	0.14	amp

DIRECT INTERELECTRODE CAPACITANCES (APPROX.):

Grid-No. 1 to plate	0.01	μμf
Grid-No. 1 to cathode, metal shell and internal shield, grid No. 2, and heater	7	μμf
Plate to cathode, metal shell and internal shield, grid No. 2 and heater	1.5	μμf
Heater to cathode	1.8	μμf

CHARACTERISTICS, CLASS A, AMPLIFIER:

Plate Voltage	75	volts
Grid-No. 2 (Screen-Grid) Voltage	30	volts
Grid-No. 1 (Control-Grid) Resistor	1	megohm
Plate Resistance (Approx.)	0.25	megohm
Transconductance	9000	μmhos
Plate Current	5	ma
Grid-No. 2 Current	1.7	ma
Grid-No. 1 Voltage (approx.) for plate current of 10μa	−3.5	volts

MAXIMUM RATINGS:

PLATE VOLTAGE	250 max.	volts
GRID-No. 2 VOLTAGE	100 max.	volts
GRID-No. 1 VOLTAGE	−50 max.	volts
PEAK POSITIVE GRID-No. 1 VOLTAGE	2 max.	volts
GRID-No. 2 INPUT	0.3 max.	watt
PLATE DISSIPATION	3 max.	watts
PEAK HEATER-CATHODE VOLTAGE:		
Heater negative with respect to cathode	100 max.	volts
Heater positive with respect to cathode	100 max.	volts

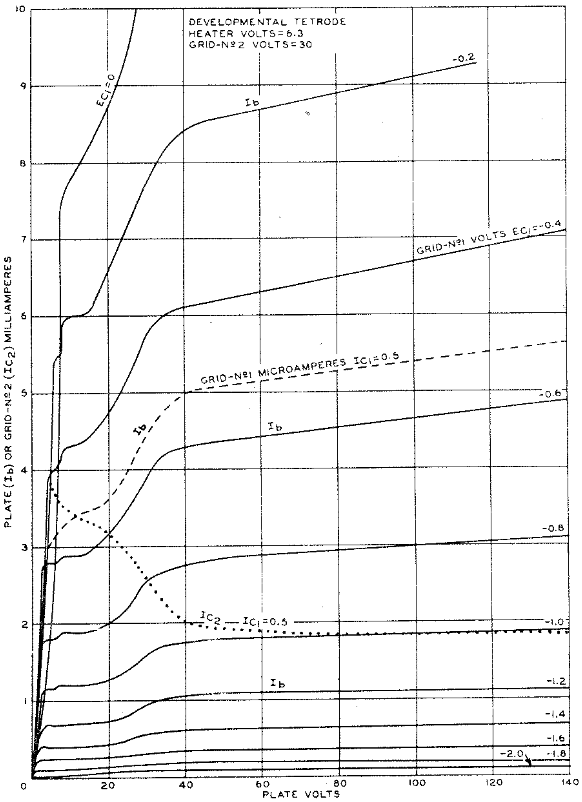


Fig. 6 — Typical Characteristics for Developmental Small-signal Tetrode.

BEAM POWER VALVE POTENTIALITIES

As the techniques were developed and the design concepts were crystallized for the small valves, consideration was given to the potentialities of larger-scale versions. Calculations showed very interesting prospects for a beam power valve in a small size. Peak current capabilities would be high with low grid-No. 2 and plate voltages and with exceptional power sensitivity, and insulation could be provided for high pulse plate voltages. In this small size, electrode areas are too small for adequate radiation of heat, but very good conduction paths can be provided to a heat sink. This method permits low electrode temperatures for reliable valve operation, and dissipation capabilities are dependent upon the thermal connections to the chassis. It appears quite feasible to handle thirty watts plate dissipation for horizontal scanning in colour receivers with a valve only one inch in diameter and one and one-half inches high. The valve would have obvious application to other power amplifiers. For example, a Hi-Fi amplifier could be built to supply considerable power with a B supply of the order of 150 volts or less. Calculations indicate very efficient performance to about 400 megacycles, and a single class C amplifier could handle about 100 watts (or more with special heat-sink connections). The design of a beam power valve is now in the early stages of advance development.

OBJECTIVE DATA ON DEVELOPMENTAL BEAM POWER VALVE

ELECTRICAL:

Heater, for Unipotential Cathode:		
Voltage (AC or DC)	6.3	volts
Current	0.8	amp

DIRECT INTERELECTRODE CAPACITANCES (APPROX.):

Grid No. 1 to cathode, shell, grid No. 2, and heater	30	$\mu\mu$f
Plate to cathode, shell, grid No. 2, and heater	4.5	$\mu\mu$f

CHARACTERISTICS, CLASS A AMPLIFIER

Plate Voltage	65	65	volts
Grid-No. 2 (Screen-Grid) Voltage	65	65	volts
Grid-No. 1 (Control-Grid) Voltage	0	−10	volts
Plate Current	600	200	ma
Grid-No. 2 Current	60	12	ma
Grid-No. 1 Voltage (approx.) for plate current of 1 ma.	—	−20	volts

MAXIMUM CIRCUIT VALUES:

Grid-No. 1 Circuit Resistance	1 max	megohm

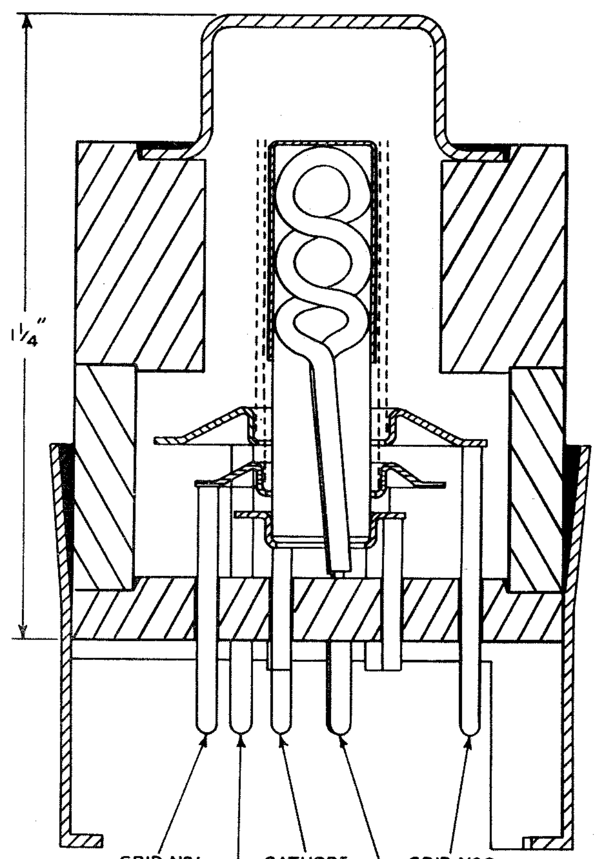


Fig. 7 — Arrangement of Developmental Beam Power Nuvistor.

MAXIMUM RATINGS:

PEAK POSITIVE-PULSE PLATE VOLTAGE	5000 max.	volts
GRID-No. 2 VOLTAGE	100 max.	volts
PEAK POSITIVE GRID-No. 1 VOLTAGE	5 max.	volts
GRID-No. 1 VOLTAGE	−200 max.	volts
DC CATHODE CURRENT	250 max.	ma
GRID-No. 2 INPUT	2.5 max.	watts
PLATE DISSIPATION	30 max.	watts

CONCLUSION

Limited commercial production of the Nuvistor is expected to start in 1960. Samples have already been demonstrated to the industry in the U.S.A.

In the demonstrations, RCA showed a completely "nuvistorized" tuner unit of a television set in operation. The tuner required only a fraction of the plate voltage required by conventional tuners. This experimental tuner, believed to be among the smallest ever designed for TV receivers, reduces the overall volume of conventional valve TV tuner units by approximately one third.

The ruggedness of the Nuvistor design was displayed in several torture and endurance tests. The tiny valve continued to function normally in an electronic circuit when placed alternately in the heating coils of a special furnace (660 degrees Fahrenheit) and in liquid nitrogen (320 degrees below zero F.). In another demonstration, the new valves were shown operating continuously in both the special furnace and in liquid nitrogen. Operation of the Nuvistors was not disturbed by a guillotine-type device which repeatedly subjected them to severe mechanical blows.

These experiments, as well as other rigourously-controlled laboratory tests, illustrate the high-temperature capabilities of Nuvistors as well as their reliable performance under conditions of severe shock and continuous vibration. These features, plus the valve's compactness and high efficiency, will make the Nuvistor design ideal for many types of military and airborne electronic systems. Modern jets, guided missiles, and military vehicles all require sturdy, rugged and compact electronic components capable of reliable, efficient performance. Preliminary tests indicate that Nuvistors should better meet the very critical military reliability and environmental objectives than larger, traditional - design valves. The materials used will maintain the excellent resistance of the electron valve to damage from nuclear radiation.

Development of the Nuvistor concept leads the way to further reductions in size and power requirements and to improved reliability and performance characteristics of electron valves. Because of the many new techniques already uncovered, a complete line of valves is assured. The now-look design clearly confirms that the electron valve has not yet approached its theoretical limitations.

(With acknowledgements to RCA)

New RCA Releases

(Continued from page 215)

RADIOTRON 7265

A new head-on multiplier phototube, the 7265 features a new and improved photocathode characterized by broad response range, high sensitivity, low thermionic dark current, and high conductivity even at low temperatures. This 14-stage, high-current-amplification type is especially useful in scintillation counters for the detection and measurement of nuclear radiation and in applications, such as flying-spot scanning and low-light-level photometry, which require low dark current as well as high sensitivity over the entire visible spectrum.

The spectral response of the 7265 covers the range from about 3000 to 7500 angstroms, with maximum response at approximately 4200 angstroms. The response of the 7265, therefore, extends beyond the visible region of the spectrum into the blue region of the one end and well into the red region on the other end.

Other design features of the 7265 include electrostatically focused dynode stages utilizing dynodes having stable high-current capability, a puse-height resolution of about 8 per cent., and focusing and accelerating electrodes having external connections.

RADIOTRON 7326

The Radiotron 7326 is a new 10-stage, head-on type of multiplier phototube having a new and improved photocathode. This new photocathode is characterized by broad response range, high sensitivity, low thermionic dark current and high conductivity even at low temperatures. Well suited for use in applications such as flying-spot scanning and photometry, which require low dark current as well as high sensitivity over the entire visible spectrum, the 7326 is also useful in scintillation counters.

The spectral response of the 7326 covers the range from about 3000 to 7500 angstroms, with maximum response at approximately 4200 angstroms. The response, therefore, extends beyond the visible region of the spectrum into the blue region on the one end and well into the red region on the other end. Other design features of the 7326 include an in-line dynode-stage structure; a flat faceplate; and a focusing electrode having an external connection. The 7326 has a minimum photocathode diameter of 1.68" and a maximum length of 6.78".

AWV