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AMALGAMATED WIRELESS VALVE COMPANY PTY. LTD.

EDITORIAL

CONTENTS

This month we are pleased to make the announcement of the range of Radiotron valves, picture tubes and special components for television.

We are also pleased to publish the first article by one of our own engineers on T.V. It deals with the measurement of the power dissipated by the plate of a 6BQ6GTB/6CU6 horizontal-deflection output valve. This is one of several directions in which T.V. requires techniques differing markedly from conventional radio engineering.

In this issue we also publish an article on the subject of high speed electronic fault protection for power tubes and their circuitry.

In the next issue we hope to include data on the Radiotron TV range, including the 5AS4 and the picture tube.

Arthur J. Gabb.

Editor .. .. A. J. Gabb, B.Sc.
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Measurement of the Power Dissipated by the Plate of the Radiotron 6BQ6GTB/6CU6 Horizontal-Deflection Output Valve

*by H. Wilshire, A.S.T.C., A.M.I.E. (Aust.), S.M.I.R.E. (Aust.)**

In the design of television horizontal deflection circuits a knowledge of the power dissipated by the plate of the horizontal output valve enables the designer to make sure that the circuit efficiency is high and that the maximum ratings for the valve are not exceeded. The latter is always a requirement when fixing the operating conditions since it ensures longer life and a smaller variation in performance as the valve ages.

Due to the non-sinusoidal waveforms of current and voltage in these circuits, calculation or measurement of the power dissipated by the plate of the output valve is difficult. Two methods exist whereby this factor can be determined. The first† involves the adjustment of the horizontal output circuit so that the swing in output voltage in the plate circuit takes the operating point close to the knee of the characteristic curve. The measurement of four factors—(1) the r.m.s. current in the horizontal deflection windings, (2) the total resistance of these windings, (3) the r.m.s. current in the damper diode circuit and (4) the average plate current of the horizontal output valve then enables the plate dissipation to be calculated. While this method is reasonably quick it involves the adjustment of the circuit to bring the operating point to the knee of the plate characteristic, some assumptions being made regarding the operating conditions of the circuit and the evaluation of two quantities—the r.m.s. values of the deflection coil and damper diode current, the measurement of which may present some problems. The second or bulb temperature method is in many ways simpler, is applicable to all circuits and operating conditions and, depending on the precautions taken with each method, may be more accurate. Its main disadvantage is that it is relatively slow since it depends on the temperature rise of the glass envelope of the valve and sufficient time must be allowed for this to stabilise.

The measurement is carried out by first using a suitable indicator, as described below, to obtain a reading proportional to the temperature of the bulb of the 6BQ6GTB/6CU6 when operating under dynamic conditions in the circuit and at the same time noting the power dissipated by the screen of the valve. The drive to the grid of the valve is then disconnected and the static operating conditions adjusted, generally by means of bias or screen voltage, until the same temperature and screen dissipation is obtained. A simple measurement of the direct voltage applied to the plate and the current flowing in the plate circuit enables the power dissipated at the plate of the valve to be calculated. Since the temperature rise is the same for both cases this measured static plate dissipation is the same as that existing for the valve operating under dynamic conditions in the circuit.

Bulb temperature is most conveniently measured or indicated using a millivoltmeter and a small thermocouple which is fastened by means of putty (glazing variety) to the glass bulb at a point opposite the heat radiating fin of the plate. The thermocouple junction must be small in physical size and must be mounted in intimate contact with the glass and insulated from ambient temperature changes by means of a good covering of putty. A suitable thermocouple can be made quite simply by welding together one end of a 0.010″ diam. chromel and one end of a 0.010″ diam. alumel wire. The cold ends of these wires are then connected with the proper polarity to a moving coil meter of 50 ohm resistance and 8 mV. full scale deflection. (Chromel to +ve, alumel to —ve.) This arrangement will produce a mid-scale reading for a rise of approximately 200°C in the temperature of the hot junction.

The following precautions are necessary to ensure good accuracy:—

(1) The weld between the two wires which form the thermocouple must be small in size and the couple must be maintained in close contact with the glass bulb.

(2) The covering of putty must be sufficient to thermally insulate the couple from the surrounding air.

(3) The cold ends of the chromel and alumel wires should be at least 12″ from the hot junction and for best accuracy should be maintained at ambient temperature.

(4) The equipment, which should be protected from air draughts while the test is being carried out, should not be mounted in an enclosed space such as a receiver cabinet. This is desirable to avoid a change in the ambient temperature in the region of the 6BQ6GTB/6CU6 during the time elapsing between taking the dynamic and static test readings.

(5) After setting up both the dynamic and the equivalent static operating conditions for which the plate dissipation is required, sufficient time must elapse for the temperature of the bulb to stabilise. The time required for this to occur may vary from 15 to 30 minutes.

(6) The static operating conditions should be arranged so that the proper temperature rise is obtained for a similar screen dissipation to that measured with the valve operating under dynamic conditions. This is most conveniently carried out by adjusting bias and/or screen voltage.

The test can be speeded up somewhat by first plotting a curve of static plate dissipation versus

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* Applications Laboratory, Valve Works Ashfield.

† This method is based on an analysis of horizontal deflection circuits by O. H. Schade—"Characteristics of High Efficiency Deflection and High Voltage Supply Systems for Kinescopes"—RCA Review, March 1950.

millivoltmeter deflection. Reference to this graph then enables a quick check to be made on plate dissipation as the dynamic test proceeds. This determination of plate dissipation by comparison with the thermocouple calibration is subject to some errors and therefore should be used only as a guide when adjusting the dynamic operating conditions. When circuit adjustments are complete the final plate dissipation should be obtained by carrying out the static check immediately following the dynamic test.

For the purpose of checking whether or not the operating conditions for a particular circuit are within the maximum ratings for the 6BQ6GTB/6CU6 valve, the test should be carried out using a valve which has characteristics close to those of a "bogie" valve, i.e., one with the same characteristics as those published for this type. Ideally, a "bogie" valve should also be used for the damper diode (6AX4-GT) and the e.h.t. rectifier (1B3-GT) positions in the circuit.

Before finally determining the operating conditions for these circuits, the effect of changes in the operating controls on the power dissipated by the output valve plate should be checked. The linearity control, for example, when varied within the limits of its range, will be found to have a profound effect on the plate dissipation.

For further information concerning suitable thermocouples or the measurement generally, reference should be made to the Application Laboratory, Amalgamated Wireless Valve Co. Pty. Ltd., 552 Parramatta Road, Ashfield, N.S.W.

Equivalent Characteristics of Cascode Amplifiers

By F. LANGFORD-SMITH

An error on page 534 of the Radiotron Designer's Handbook has been found by Dr. L. B. Hedge, of Washington, D.C. Although eqn. (4) is numerically correct, it was in the wrong form to apply for determining the equivalent μ, g_m and r_p of the whole Cascode amplifier, and hence led to incorrect values in eqns. (5), (6) and (7).

We give below the full treatment commencing on top of page 534.

A cascode amplifier may be considered as a single valve having the characteristics μ', g_m', r_p'. The load which V_2 works is given by

$$\frac{r_p + R_L}{\mu + 1}$$

where μ, g_m and r_p are the characteristics of both V_1 and V_2.

The amplification of V_2 is therefore given by

$$A' = \frac{\mu R_L}{r_p + (r_p + R_L)/(\mu + 1)} \quad \ldots \quad (3)$$

$$A' = \frac{1}{\dfrac{r_p}{\mu R_L} + \dfrac{r_p + R_L}{R_L} \cdot \dfrac{1}{\mu(\mu + 1)}}$$

$$A' = \frac{1}{\dfrac{r_p}{\mu R_L} \cdot \dfrac{\mu + 1}{\mu + 1} \quad \dfrac{r_p + R_L}{\mu(\mu + 1) R_L}}$$

$$A' = \frac{1}{\dfrac{\mu r_p + r_p + r_p + R_L}{\mu(\mu + 1) R_L}}$$

$$A' = \frac{1}{\dfrac{r_p(\mu + 2)}{\mu(\mu + 1) R_L} + \dfrac{1}{\mu(\mu + 1}}$$

$$A' = \frac{1}{\dfrac{\mu + 2}{g_m(\mu + 1) R_L} + \dfrac{1}{\mu(\mu + 1)}} \quad \ldots \quad (4)$$

Eqn. (4) may be compared with the ordinary form for expressing amplification, namely:

$$A \; \frac{1}{\dfrac{1}{g_m R_L} + \dfrac{1}{\mu}}$$

and it will be seen therefore that from equation (4)

$$u' = \mu(\mu + 1) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

$$g_m = g_m(\mu + 1)/(\mu + 2) \quad \ldots\ldots\ldots\ldots \quad (6)$$

and therefore

$$r_p' = \mu'/g_m' = (\mu + 2)\, r_p \quad \ldots\ldots\ldots \quad (7)$$

It is possible to check this value of μ' by making R_L in equation (4) infinite. This gives $\mu' = A' = \mu\ (\mu + 1)$, which agrees with eqn. (5) above and confirms the whole procedure.

RADIOTRON VALVES, PICTURE TUBE AND SPECIAL COMPONENTS FOR TELEVISION

Current trends overseas are towards aluminizing all picture tubes and towards a progressively increasing usage of electrostatic focusing. The combined advantages of these features over previous techniques are immediately obvious to the user of a television receiver and both are incorporated in the Radiotron 17HP4B, a 17 inch, 70 degree, aluminized, electrostatic-focus, magnetic-deflection, all-glass, rectangular picture tube with spherical filter-glass face plate.

We have pleasure in announcing our range of valves, picture tube and special components for television receivers.

The valve types selected are those which have demonstrated their superiority over competitive types in America and which receive wide—in some cases almost exclusive—usage in the seven million television receivers manufactured annually in that country.

Individual valve types, picture tube information and the range of associated deflection components are detailed below:

Receiving type valves

1B3-GT: Half-wave high-voltage rectifier. Important features of the 1B3-GT are its low-wattage filament (1.25 volts at 0.2 amp) and its low plate-to-filament capacitance.

5AS4: Directly heated full wave vacuum rectifier. The high rectified current-rating of this valve, e.g., 300 mA DC with 300 volts per plate, make it a suitable single rectifier for the majority of T.V. receivers.

6AL5: Miniature twin diode. A high-perveance type especially suited to F-M and video detection.

6AQ5: Low-microphony beam power amplifier for audio power output and vertical deflection circuits.

6AU6: High gain pentode for use as a sound I.F. amplifier. It may also be used in gated A.G.C. circuits.

6AV6: Duplex-diode-triode a-f amplifier. The diodes may be used as an A.G.C. clamp in delayed A.G.C. Circuits.

6AX4-GT: Half-wave damper diode. A high-current quick-heating diode of adequate size to dissipate the heat generated in damper-diode service in TV receivers.

6BQ7A: Medium-mu twin triode. A high-transconductance type especially designed for cascode operation with low input capacitance, low input loading and low plate-to-cathode capacitance.

6CB6: Video i-f amplifier pentode. Low capacitance values combined with high mutual conductance give the 6CB6 a high wide-band factor.

6BQ6GTB/6CU6: Horizontal-output beam power valve. A structure which guards against emission from both grids and provides for maximum dissipation of heat from the plate, in conjunction with a design giving a high ratio of operating plate to screen current, enables the 6BQ6GTB/6CU6 to deflect picture tubes having deflection angles up to ninety degrees. A.

6SN7GT~~B~~: Twin triode. Especially designed to give stable, reliable operation throughout life in vertical and horizontal oscillator circuits. The 6SN7GT~~B~~A may also be used in multivibrator, phase inverter and other T.V. circuits.

6U8: Triode-pentode converter. Oscillator-mixer valve with separate triode and pentode sections, having particularly high triode transconductance. The individual sections of the valve may be used for independent functions, e.g., pentode as sound i-f amplifier, triode as sound a-f amplifier.

12AU7: Medium-mu triode. A miniature type for use in circuits in which the stability of the 6SN7GT~~B~~ ~~is required~~.–A is not required.

12BH7: Medium-mu twin triode. A miniature combined vertical oscillator and output valve of adequate size for picture tubes up to ninety degree deflection angle, when operated from the boost supply voltage.

12BY7: Pentode video amplifier. Very high mutual conductance at low plate current, together with low capacitances, give the 12BY7 a remarkably high figure-of-merit as a video amplifier.

Picture tube — Type 17HP4B

This is a 17 inch, 70 degree, electrostatic-focus, aluminized tube with filter-glass face plate, designed for EHT voltages up to 16 KV.

An electrostatic-focus tube was chosen so that full advantage can be taken of the Australian 625 line system, practical experience having shown that electrostatic focusing makes best use of the available definition over the whole face of the screen. Not only does electrostatic focusing provide the best picture, but it also dispenses with the need for an expensive and weighty focus magnet assembly. This is replaced by a simple centring magnet.

Further important considerations are—simplified receiver adjustment on the production line, the maintenance of accurate focus adjustment during shipment of completed television receivers and automatic focus compensation for supply voltage variations.

Aluminizing was adopted because of its obvious advantages. The mirror action of the aluminium film behind the phosphor minimizes diffusion of light from high-lights in the picture to darker parts and thus provides better contrast.

While adequate brightness may be available without aluminizing, the additional brightness provided by aluminizing at high E.H.T. voltages makes it possible to use a filter safety-glass in addition to the filter-glass face plate on the tube and thus to obtain blacker "blacks" in the TV picture and also to minimize a "washed out" appearance in conditions of high ambient lighting.

Special components

To ensure that complete satisfaction will be obtained from our range of valves and picture tubes, we are also making available a range of components for use in the deflection circuits of a TV receiver. These components are those necessary to produce a raster on the screen of the picture tube and are:—

	Code No.
Horizontal Sine Wave Coil	CHS1
Horizontal Width Coil	CHW1
Horizontal Blocking Oscillator Transformer	~~TVB1~~ THB1
Horizontal Output Transformer ...	TH01
Horizontal Linearity Coil	CHL1
Deflection Yoke	Y70D1
Ion Trap Magnet Assembly	MIT1
Centring Magnet Assembly	MCA1
Vertical Blocking Oscillator Transformer	TVB1
Vertical Output Transformer	TV01

Corrections :- 6SN7GTB is identical with the "A" version, except that it has controlled heating time — an unnecessary feature for Australian usage.
— from P.50.

TUBE ENVELOPE TEMPERATURE

By *WALTER R. JONES*

Panel on Electron Tubes, 346 Broadway, 8th Floor, New York 13, N.Y.

Operating temperature of tube envelopes becomes increasingly important as the size of electronic equipment is reduced. If the same amount of power is to be dissipated within two enclosures one of which is much smaller than the other, the temperature of the smaller enclosure will rise to much higher values than that of the larger. This fact is borne out in Table I, which indicates both areas and maximum dissipations for the bantam or T9 tube, the miniature or T5½ tube and subminiature or T3 tube. It will be noted that as the sizes decrease, the value of watts per square inch is increased and the maximum bulb temperature is increased correspondingly. The life of a vacuum tube is materially affected by the operating temperature of its bulb, as well as its other parts.

TABLE I — Bulb Temperature at Sea Level

There are some absolute limits on the permissible glass temperature, one being the softening point of the glass and another the point at which appreciable conductivity occurs — called electrolysis. Below these limits there is an indefinite region in which varying kinds and degrees of trouble are encountered, especially owing to evolution of gas from the bulb, itself the getter and other tube parts. The temperature of concern is that at the hottest spot on the envelope, which usually occurs midway between the top and bottom micas. The location can be readily found by the use of temperature sensitive lacquers marketed by Tempil Corporation, 11 West 25th Street, New York City.

TABLE I—Bulb Temperature at Sea Level

	T9	T5½ 6C4	T3
Bulb Area (Sq In.)	10.5	4.1	1.7
Max. Watts Dissipation	18.7	16.8	7.8
Watts per Square Inch	1.78	4.1	4.6
Max. Bulb Temp deg C Ambient 23C	160	255	280

During manufacture, while the vacuum tube is on the production pumping set-up, the envelope and the metal parts within the tube structure are heated to much higher temperatures than those to which they would normally be subjected during operation in order that all of the absorbed and adsorbed gases may be removed. If, however, during operation, the operating temperature of the envelope or the parts themselves exceeds the temperatures reached while the tubes were being pumped during production, it is likely that varying amounts of gases will adversely affect tube life.

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Normally, the function of the getter that produces the silver-like deposit or the black deposit on some of the newer tubes is to provide a means for removing any gases that may subsequently be set free during the operation of the tube. There is a limited amount of gas that this getter material can safely pick up. Amounts beyond this will result in the tube's gas content being materially increased. In addition, if the glass bulb should be heated sufficiently the getter patch may be caused to migrate or leave the bulb.

TABLE II — Bulb Temperatures 23° C Ambient at Sea Level

It may redeposit itself on some cooler part of the tube so that a considerable amount of gas trapped by the getter will now be released and may not recombine when the getter condenses on the cooler portions of the tube. In this instance, then, the gas content would also be materially increased. Should the getter condense on the mica supports of the tube there is a possibility that leakage between elements supported in the mica may be increased. This leakage may affect performance materially.

As seen from Table I, a tendency to decrease the size of electronic gear aggravates the bulb-temperature condition. Tube life, in general, can be extended by maintaining low temperatures for the glass envelope. This is especially important in high-power output tubes because of their higher plate and cathode dissipations. The temperature rise in the envelope may be limited by: reduction of total tube dissipation; provision for improved ventilation; maintenance of low ambient temperatures.

TABLE II—Bulb Temperatures 23° C Ambient at Sea Level

		Percent Maximum Plate Dissipation				
Type	Bulb	20	40	60	80	100
12AU7	T6½	77C	100C	118C	133C	146C
6C4	T5½	64	82	98	113	125
6AH6	T5½	88	103	116	126	132
5U4G	ST16	105	116	127	138	149
5687	T6½	123	140	155	155	183

(Continued next month.) on P. 56.

HIGH-SPEED ELECTRONIC FAULT PROTECTION FOR POWER TUBES AND THEIR CIRCUITRY

By W. N. PARKER and M. V. HOOVER

Tube Division, Radio Corporation of America, Lancaster, Pennsylvania

Summary.

High-speed electronic circuits capable of microsecond response have been developed to minimize the possibility of power tubes being damaged as a consequence of the "flash-arc" or "Rocky Point Effect". These circuits detect the development of fault conditions in a power tube (and/or its circuitry) and trigger a gaseous conduction device connected in shunt with a dc power supply. Because fault currents from the tube are rapidly bypassed by means of the gaseous conduction device, the "flash-arc" in the protected power tube is extinguished before serious damage results. The gaseous conduction device by-passes the rectifier output and filter-circuit energy until the rectifier is de-energized. In the vernacular, this protection system is known as the "electronic crowbar".

The need for Fault-Protection Circuits.

Most power tubes are subject at sometime during their lives to a phenomenon known as the "Rocky Point Effect", which derived its name from experience with power tubes in communications transmitters at Rocky Point, Long Island. The "Rocky Point Effect" manifests itself as an internal flash-arc developing with little warning in power tubes which apparently are of good design and are operated in a conservative manner. Triggering of the flash-arc has been attributed to a wide variety of mechanisms ranging from cosmic rays to line-voltage transients, parasitic oscillations, spurious renegade primary and secondary electrons, material "whiskers", photoelectrons, and the like. The cause of this effect is not thoroughly understood despite studies of the problems dating back to the days when the first power tubes were built. Internal flash-arcing may be described as a rapid failure of the excellent insulation normally provided by the high vacuum between the electrodes of a power tube. Until a remedy for the flash-arc is found, attention must be given to techniques by which power tubes may be protected against the "Rocky Point Effect".

The gradual increase in the power handling capacity of tubes has necessitated a concomitant increase in rectifier capacity, thus adding to the possibility of power tubes (and/or their circuitry) being damaged in event of faults, whether due to flash-arc or other causes. In UHF electronic systems, where power tubes are being operated at increasingly higher power concentrations, adequate fault protection becomes even more important. Many installations employ several power tubes in multiple connection and utilize a common rectifier supply having low internal impedance and characterized by possible fault currents of thousands of amperes. Television and other services have utilized increasing numbers of linear amplifiers in which the dc filter capacitor must be of low impedance for the lowest modulating frequencies. It is not uncommon to find circuits such as the one shown in Fig. 1, in which reservoir filter capacitors (C_r) as large as 150 microfarads and charged to potentials as high as 10 to 20 kilovolts may damage a faulting power tube. These factors, together with other circuit problems, combine to make adequate fault protection a matter of prime importance.

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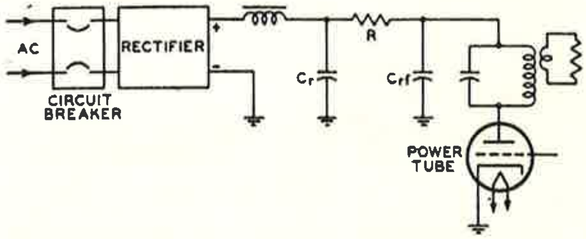

Fig. 1
Simple RF Power Amplifier System Utilizing Series Limiting Resistance to Minimize Flash-Arc Damage.

Conventional Fault Protection.

Circuit breakers are a means of primary circuit protection. Although improvements have been made regularly in the performance of circuit breakers, they are not completely effective in protecting power tubes under all circumstances. Even the fastest primary circuit breakers require about 50,000 microseconds to perform an interruption, and their average operating time is probably closer to 150,000 microseconds. Damage to faulting power tubes and/or their circuits is contingent upon the speed with which circuit breakers can be opened during faults. Additionally, damage is a function of the magnitude of fault currents which in turn depend upon the available stored energy and the impedance of the power supply system.

The advent of all-electronic, grid-controlled rectifiers has contributed greatly to the protection of power tubes. A rectification interruption time in the order of 8,000 microseconds can be achieved by means of grid-controlled rectifiers. Their success has been limited to a certain extent by a lack of proper circuits for the expeditious detection of faults. Furthermore, the grid-controlled rectifier does not solve the coulomb storage problem in large reservoir capacitors. High cost has been a deterrent to the widespread adoption of the grid-controlled rectifiers as a replacement for diode rectifiers. Experience has taught that consideration must also be given to the possibility that even the most carefully designed grid-controlled rectifiers may fail to block for one reason or another, causing possible damage to the faulting power tube. Nevertheless, the contribution of grid-controlled rectifiers to smooth, expeditious, and satisfactory operation of power tubes cannot be overemphasized, particularly when these rectifiers are supplemented by the use of modern, high-speed, fault-protection systems.

In the past, the chief technique available for minimizing the effects of "flash-arc" damage in power tubes has been the addition of resistance in series with the dc supply to limit surge currents during faults. Fig. 1 shows a circuit of this type in which the resistor (R) is the series limiting resistance. In high-power installations this type of circuit dissipates an objectionable amount of power in the series limiting resistance if even marginal protection is to be afforded. After studying this expedient system of protection, Dailey[1] has challenged its effectiveness.

High-Speed Electronic Shunting of Fault Currents.

In 1948, Dailey[1] wrote rather prophetically that "surge currents and limiting thereof is of particular interest, for with the gradual increase in tube size, satisfactory current limiting, if necessary, could easily become one of the most difficult factors". When these words were written, the development of the first 500-kilowatt, super-power tube was introducing many fault-protection problems. L. P. Garner[2] had suggested that an "electronic crowbar" be built and "electronically slammed" across the high-voltage-supply bus in the event of a fault as a means of shunting the fault currents of a 2000-kilowatt rectifier from the faulting tube. This protection device places a virtual "short-circuit" across the rectifier output, similar to that placed on the rectifier by the "flash-arc", but transfers the "short-circuit" to a device which is not damaged by the momentary "short-circuit" condition.

A schematic diagram of a simple "electronic crowbar" circuit is shown in Fig. 2. A fault in the protected power tube results in a sudden increase in current through the cathode resistor, R_k, thereby producing a positive voltage pulse which is coupled by capacitor C_c to the grid of the "Electronic Crowbar" tube. This impulse ionizes the "crowbar" tube and effectively "short-circuits" the rectifier output currents by shunting fault currents away from the faulting tube. The currents through the "crowbar" tube energize the coil of the overload relay, causing its normally closed contacts to open and thus de-energizing the primary source of ac power to the rectifier. In the sequence of these operations, plate voltage across the faulting tube is quickly reduced to a value of 15 to 20 volts, which is the voltage drop across the ionized gaseous-conduction "crowbar" device. This low voltage "starves" and extinguishes the "flash-arc" in the protected tube before serious damage can result. As a precautionary measure, a small series resistor, R, provides for adequate voltage across the "crowbar" tube to ensure its conduction despite severe low-impedance "flash-arcs" in the protected tube. In a typical large-power-tube installation, the value of the series resistor is only about five ohms.

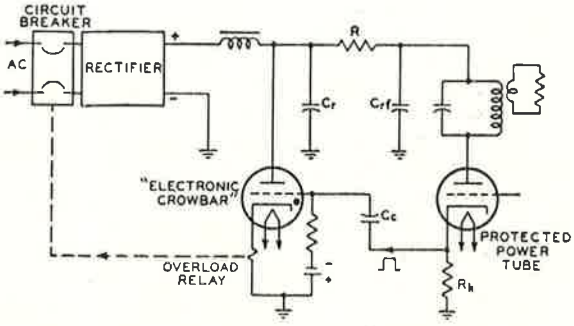

Fig. 2
Simple "Electronic Crowbar" Fault Protection Circuit.

Effectiveness of High-Speed Electronic Fault-Protection Systems.

Measurements have revealed that the "Electronic Crowbar" tube is capable of beginning its protective function within one to five microseconds after the fault has been detected. When vigorously triggered, hydrogen-thyratron "crowbar" tubes begin to conduct within approximately one microsecond, and mercury-vapor devices within about five microseconds.

A simplified schematic diagram of a "crowbar" protection circuit currently in commercial use is shown in Fig. 3. This circuit is employed in the RCA TTU-12, a 12.5-kilowatt uhf television transmitter.[3] In the arrangement shown in Fig. 3, the series resistance corresponding to resistor R of Fig. 2 consists of three series resistors, R1, R2, and R3. Resistor R2 also serves as a "sensing resistor" which, in the event of a sudden overcurrent in the load circuit as a result of a fault, transmits a steep-wavefront positive pulse through the transformer to the grid of the thyratron "crowbar" tube, which is normally biased off by the bias source. This pulse causes almost immediate ionization of the thyratron, which then conducts and forms an effective "short-circuit" parallel to the load. Energy stored in the reservoir capacitor, C_r, and that which is subsequently furnished from the power supply, is dissipated in resistors R1 and R2. Because R3 has a large value compared to the resistance of the ionized thyratron, very little current flows to the faulting load. The series resistance of R1 and R2 in combination with the impedance of the power supply limits the fault current to a value not exceeding the peak-current rating of the thyratron. Conduction of the thyratron operates the overload relay, which ultimately interrupts the primary source of ac power by means of the circuit breaker.

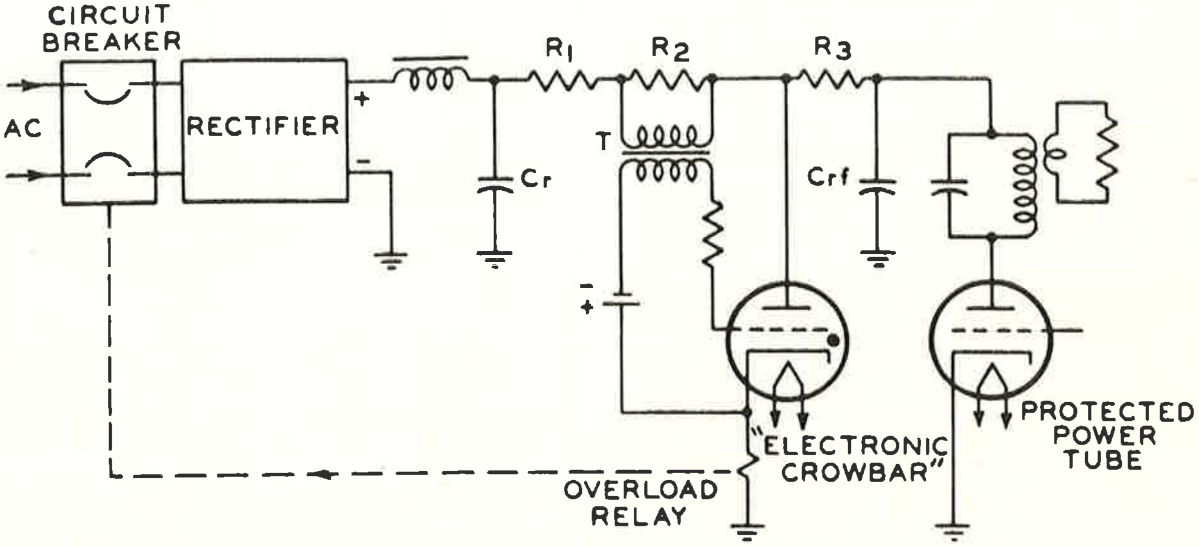

Fig. 3
High-Speed Electronic Protective System Used in RCA TTU-12 UHF Television Transmitter.

The effectiveness of this circuit can be demonstrated by the use of a wire having a diameter of 0.003 inch. When such a wire is placed directly across the energized 7000-volt plate lead of the circuit shown in Fig. 3, the resulting arc is so slight that it produces only a small pit in the wire. However, a tremendous cone of fire results if the plate potential is "short-circuited" with the protective system disabled. In another test of effectiveness, the positive power supply lead is touched to a small (approximately 2 inches x 2 inches) sheet of thin metal foil at ground potential. The thin metal foil used in cigarette packages is quite satisfactory. If the protective circuit is operating properly, the foil will show no melting, pitting or burn marks. However, the foil will disappear in a cloud of vapor if the test is performed with the electronic protective circuits disabled. Further information on appropriate circuitry of this type is given in the Technical Bulletin for the RCA-6448 UHF Beam Power Tube.[4]

The effectiveness of the "electronic crowbar" was demonstrated in 1948 by the application of ignitron "crowbar" tubes to the fault protection of super-power tubes. This "crowbar" system of fault protection has been utilized in the development of a wide variety of power tubes, including klystrons and magnetrons. A number of these developmental tubes contained mechanical structures which were relatively delicate in comparison with the 2000- and 5000-kilowatt rectifiers used to supply the power. The insignificant fault damage experienced during this work clearly illustrates the advantage of microsecond fault protection. An "electronic crowbar" system of protection has been employed in conjunction with a 1700-kilowatt breaker-protected rectifier utilizing hot-cathode diode rectifiers[5,6] in a part of the Navy's Jim Creek Million-Watt Transmitter. More recently, super-power transmitters for the Voice of America have used the "electronic crowbar".[7] In these super-power installations, it is not uncommon to find rectifiers having fault-current capabilities in the order of 2000 amperes.

The effectiveness of fault-protection circuits in these large systems may be demonstrated by a deliberate "short-circuiting" of the high-voltage bus (or tube terminals) by means of a movable horn-gap in which one of the electrodes is a piece of conventional (0.060-inch-diameter) rosin-core solder. A slight melting and pitting of the solder will result when the "electronic crowbar" is in operation. When conventional breaker-protected rectifiers are used, however, the horn gaps will disappear in a frightening display of aural and visual fireworks. Although the use of grid-controlled rectifiers reduces tube damage significantly, experience has demonstrated that such rectifiers are also capable of damaging tubes and circuits.

Another advantage of rapid fault protection is that full power can be restored almost immediately when the damage due to the flash-arc is minimized. Operators of high-power transmitters are familiar with the lengthy aging process demanded by power tubes after a severe flash-arc. These periods of operation at lower power level may require many hours or days. Furthermore, tubes which have suffered from severe flash-arc damage are often somewhat gassy and may produce a final and fatal flash-arc unless they are adequately protected during reaging. Actual tests of "electronic crowbar" circuits in super-power transmitters have demonstrated that full-power operation can safely be restored almost

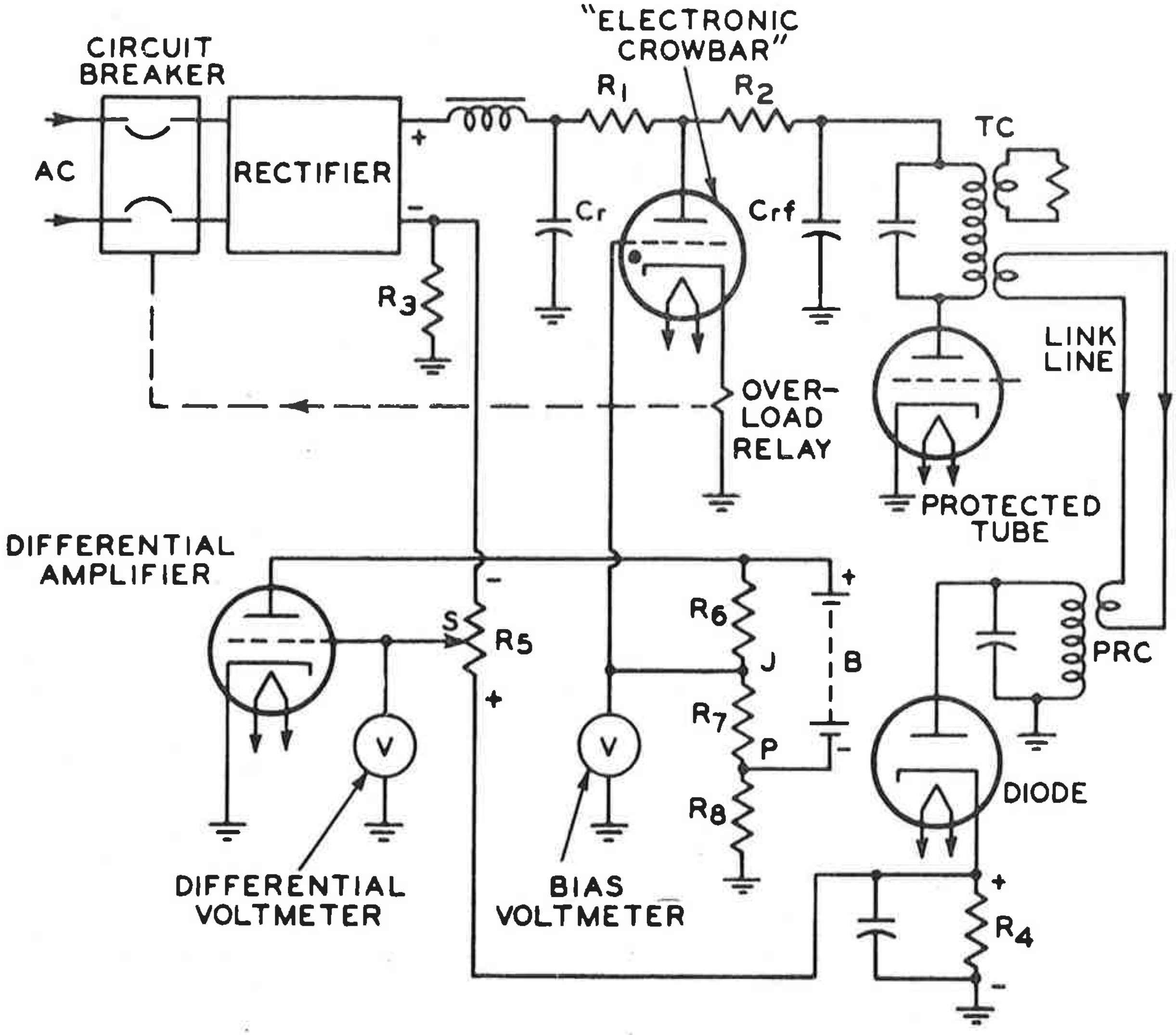

Fig. 4
"Differential" Fault Detector in High Speed Electronic Protection System.

immediately after a flash-arc. When these protective circuits are operated in conjunction with grid-controlled rectifiers, the total "down" time due to a flash-arc is of the order of 50,000 microseconds, a period almost unobserved in most communications services. The "down" time is, of course, directly proportional to the severity of flash-arc damage.

The effectiveness of high-speed fault protection is not limited to power tubes, but is equally applicable to circuitry associated with the tubes. Capacitors, inductors, insulation, and the like can also be damaged by fault currents. If a potential circuit flash can be interrupted in the stage of a corona or bush discharge, the possibilities of damage can be eliminated or, at least, minimized. The early detection and application of "crowbar" protection greatly enhances the possibility of survival of circuit components and of early restoration of full-power operation. Circuit damage from untamed flashing is far more difficult to repair than the slight blemishes observed in adequately protected systems.

Although the "electronic crowbar" circuit was developed for use in difficult and unusual tube-circuit applications, the life and performance of most high-power tubes and their circuits can be greatly increased by the use of electronic fault-protection systems. In many cases, long-lived tubes have finally failed only as a consequence of a severe flash-arc.

Detection of Power-Tube and Circuit Faults.

The effectiveness of high-speed fault-protection circuits is contingent upon the early detection of a fault in the tube or circuitry. In the simplest fault-detection systems, such as that shown in Fig. 2, a sudden increase in the cathode current of the protected tube produces a positive voltage pulse across the cathode resistor, R_k, thereby providing a trigger pulse to actuate the fault-protection system.

Although this method of fault detection protects the power tube against faults, it is incapable of sensing fault conditions in the circuitry associated with the protected tube. This disadvantage may be obviated by the use of a fault-detection system such as that shown in Fig. 3. In this system, any dc fault in the tube or circuit on the load side of resistor R2 triggers the protection system into action.

Several other fault-detection systems are available.[8] A "differential" system of fault protection suggested by H. C. Vance[9] has also proven very successful. The operation of the differential fault detector is predicted on the fact that a fault which develops in a vacuum tube operating as an oscillator or an amplifier causes the radio-frequency output to decrease sharply and the dc input to increase. In the differential fault-detector circuit shown in Fig. 4, rectifier load currents manifest themselves as a negative voltage across resistor R3 in the negative return of the rectifier. A sample of the rf power output from the protected tube is coupled by means of a link line from the tank circuit to a parallel resonant circuit (PRC). Rectification by a diode develops a possitive voltage across resistor R4 having a magnitude directly proportional to the rf amplifier output. The slider of resistor R5 may then be adjusted until the differential voltmeter reads zero voltage with respect to ground, indicating balance between the sample of rectified rf power output and the sample of dc input from the negative return of the high-voltage rectifier. Because the rf power output is approximately proportional to the dc input, this null balance from point "S" to ground should be approximately maintained at all signal levels, despite a 100-per-cent modulation of the protected tube. It should be noted that the voltage from point "S" to ground is zero when the high-voltage rectifier and protected tube are idle. Consequently, under all *normal* circumstances the differential voltage is zero, resulting in zero-bias operation of the differential amplifier. This amplifier normally draws plate current through resistor R8 to produce a negative voltage at point "P" with respect to ground. When all the circuit parameters are designed properly, the negative voltage across resistor R7 produced by the battery B (point "J" is positive with respect to point "P"). A resultant negative voltage is produced from point "J" to ground which serves to bias off the thyratron, as indicated by the bias voltmeter.

The operation of the differential circuit under tube or circuit fault conditions is as follows: In the event of a fault, the rectified rf voltage sample (indicated by a positive voltage across resistor R4) decreases very rapidly toward zero, while the dc sample voltage across resistor R3 in the negative return of the high-voltage rectifier suddenly becomes increasingly negative. Either or both of these sample voltages produce a resultant voltage which is increasingly negative at point "S" as fault conditions develop. A negative voltage is thus produced from point "S" with respect to ground, and the differential amplifier is biased off, reducing the negative voltage across resistor R8 to zero. Point "J", which is positive with respect to ground because of the voltage-divider ratio of R6 and R7 across the battery B, then vigorously triggers the thyratron "electronic crowbar". In addition to its protective function, the thyratron also interrupts ac power to the rectifier by means of the overload relay and the circuit breaker.

Tubes for "Electronic Crowbar" Service

The tubes employed in "electronic crowbar" service must be reliable and rugged. They must also be able to conduct very heavy surge currents for a short period of time after having been idle for a long period of time.

In high-power installations, the type 5563-A mercury-vapor thyratron has demonstrated its effectiveness in commercial equipment[3] with circuits similar to that shown in Fig. 3. Hydrogen thyratrons are also reported to have been used effectively in connection with "crowbar" applications in super-power transmitters[7].

From the standpoint of long life, dependability, and ruggedness, the ignitron appears to be an ideal choice for "crowbar" service. The absence of a hot cathode in this tube is an attractive feature. Ignitrons appear to be almost indestructible in "crowbar" service. One tube has been in almost daily use in the protective circuits of super-power-tube test equipment at the RCA plant in Lancaster, Pennsylvania, for the past seven years. In the course of this activity, the ignitron "crowbar" has been operated in conjunction with a 5000-kilowatt grid-controlled rectifier in which fault currents may approach several thousand amperes at output voltages of 27 kilovolts. Because many flash-arcs are experienced during the early operation and aging of large power tubes, this particular ignitron has been subjected to an unusually rugged life. Since the "electronic crowbar" has been used, not a single protected tube has been seriously damaged by flash-arcs during testing in the Lancaster plant. Ignitrons are employed as the "crowbar" in the Megawatt Jim Creek Navy transmitter.[5,6]

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