August/September/1960

INTERNATIONAL RECTIFIER CORPORATION

A WORLD OF DIFFERENCE THROUGH RESEARCH

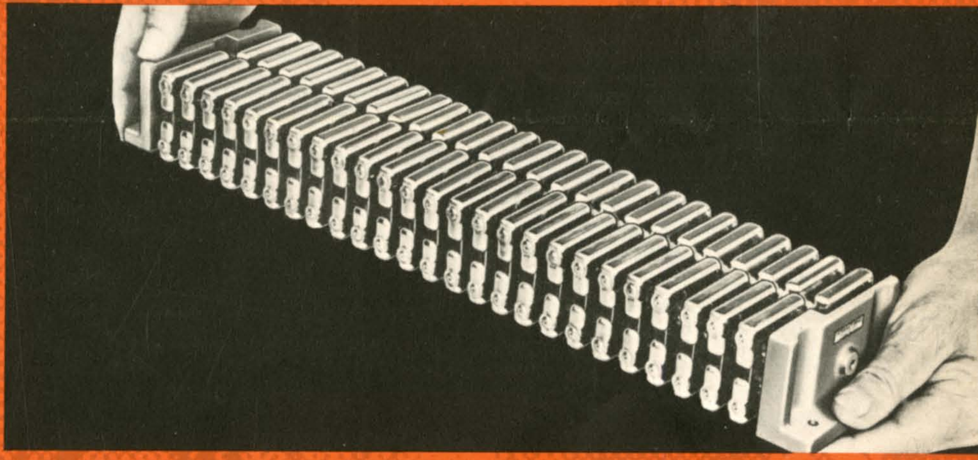
SYMBOL OF QUALITY IN SEMICONDUCTORS

RECTIFIER NEWS

PUBLISHED BY INTERNATIONAL RECTIFIER CORPORATION • EL SEGUNDO • CALIFORNIA

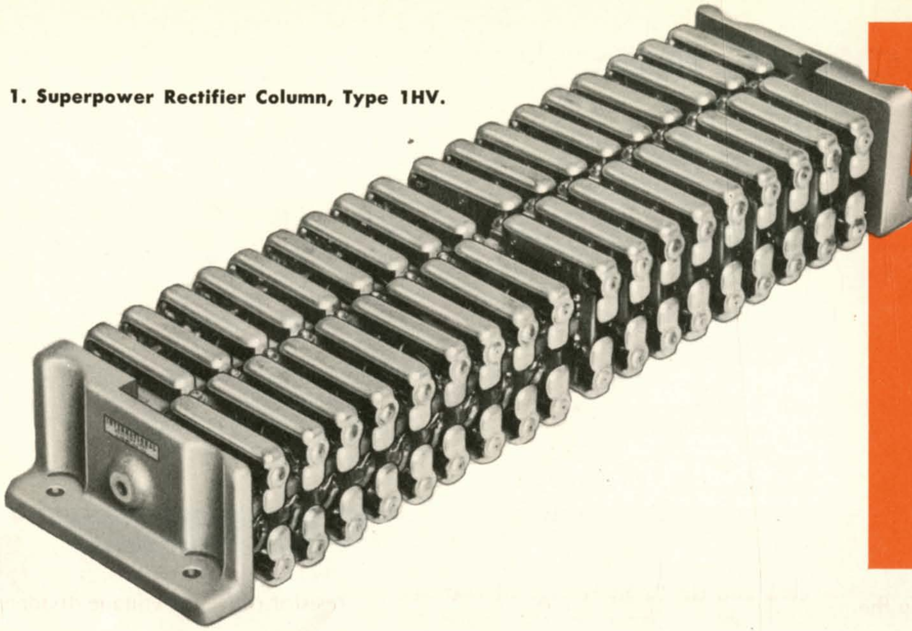
Introducing a significant advance in the design of power supplies for super-power electronic tubes...

SUPERPOWER HIGH-VOLTAGE RECTIFIERS



...for long-range radar, long-range television and communication transmitters

Figure 1. Superpower Rectifier Column, Type 1HV.



THE MOST ADVANCED ENGINEERING DESIGN OF ITS TYPE IN THE INDUSTRY

VOLTAGES UP TO 120 KV
CURRENT UP TO 50 AMPERES
POWER UP TO 1200 KW

POWER DENSITY UP TO 1 KW PER CUBIC INCH!

A High Reliability Design for High-Voltage High-Power Rectification...

Superpower High Voltage Rectifier Columns

With the development of superpower electronic tubes, a demand has been created for high voltage, high power rectifiers for their power supplies. This new field is expected to bring significant advances in long range radar, long range television and communication transmitters. Other applications are for particle accelerators, induction heating and pulse modulators. The superpower rectifiers, themselves, can be used as high voltage clippers, for pulse forming and for supplying the extremely high power required in plasma research.

General Properties

Superpower rectifiers are now available from International Rectifier in voltages ranging from 10,000 to more than 100,000 volts, and in current capacity ranging from 1 - 50 amperes.

If special circuits are used, such as multiplier, cascade, or series circuits, these values may be greatly increased. The standard rectifier circuits are single-phase and three-phase bridge. With these simple circuits, the maximum power capacities of superpower rectifiers are above 1,000 kw.

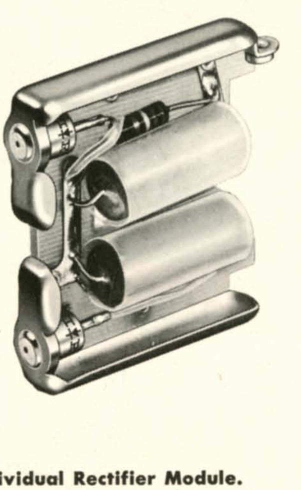
Compared to other means of high voltage, high power rectification, the superpower semiconductor rectifier has the following advantages:

Having no need for a filament power supply, the equipment is cheaper, more flexible and less space consuming.

The greater flexibility removes some of the limitations, notably in development time, procurement cycle and space, which are inherent to other means of rectification.

Superpower semiconductor rectifiers have the property that the reliability of the complete system is higher than the reliability of the individual devices. Accordingly, by adopting an appropriate application policy, the balance of cost versus reliability can be dictated by the application.

Superpower rectifiers are basically developed for industrial frequency power input. They can be used for higher frequency repetition rates, but require special consideration for the semiconductor devices and capacitors. Without exception they are designed for trouble free performance under fast rising voltages and high frequency, non-repetitive oscillations.



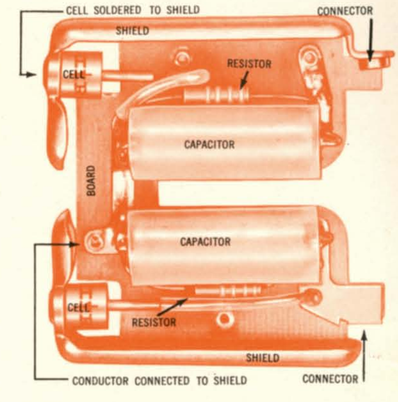
Individual Rectifier Module.

Construction

Superpower rectifiers consist of one or several high voltage rectifier columns. A number of high voltage columns in series forms usually a rectifier element (i.e., the equivalent of a single rectifier device).

High voltage rectifier columns consist of a central beam, supporting a large number of identical modules. Each module contains rectifier cells, voltage dividing circuitry, connectors and shields. Rectifier columns are terminated by end shields.

International Rectifier high voltage columns have the form of a straight bar with rectangular cross-section. The bar



has rounded corners and terminates into mounting pads. Fig. 1 shows an example of such a rectifier column. The column is made up of identical modules, each module bearing two cells, each cell with its own shield. The cell shields, together, form an external skin of the column which provides a unified surface for electrical shielding. The individual cell shields are matched to end shields which give the column its unified appearance and unified performance as a single-electrode electric device.

Each column is supported by a strong central beam. This beam is made from polyester-fiberglass and has a cross shaped section. This central beam provides fastening and insulation. This beam, however, is not subjected to the strong electric fields occurring externally to the rectifier column. These strong electric fields must be supported by the ambient insulation of the column, e. g. air, compressed gas or oil. Thus the insulating performance of the supporting structure is not jeopardized by external fields. It is only subjected to the internal fields of the column which are closely controlled by the voltage dividing networks within the modules attached to the beam. Fig. 2 shows a view of a beam, with one board attached to it. Each module is fastened to one polyester glass board, $\frac{1}{16}''$ thick. This board fits into notches of the beam. The board itself is cut to fit the beam. In reality, the notches in the beam and in the board are so tight that the board fits tightly on the beam and has no play to cause misalignment. As seen in Fig. 1, the modules along the beam are fastened alternately from the right and the left, progressing in a "split level" fashion along the beam to form the entire column.

Connection between modules is achieved by the connectors which are also shown in the figure and which provide positive interconnection by a bolted joint. Thus, the flow of current along the rectifier column occurs entirely through solid copper plates, except when flowing through the rectifier cells and their leads.

Each module can be removed from the rectifier column by removing its two interconnecting screws and sliding it from the notches in the beam. Each rectifier cell potential level is accessible on the rectifier column by the potential of the shield. Testing of modules for the aggregate of rectifier cell, resistor and capacitor, can be done by connecting test probes to two adjacent shields.

Table I shows the designation of the standard type columns with the types of cells and the rated voltage of both the cells and the columns. It is not complete because each column can be made with other types of cells, either in voltages, current ratings, temperature ratings or military specifications. The table is mainly useful to demonstrate the wide range of rectifier cell sizes and voltages which are available in these columnar designs. Additional information pertaining to each type of column is also given.

ELECTRICAL PRINCIPLE

Each rectifier column is essentially a string of rectifier cells connected in series. In accordance with the theory each cell is shunted by a resistor and a capacitor. Thus each rectifier cell of the series string has a definite low frequency and high frequency reverse impedance. Furthermore, by connecting all the metallic parts of the rectifier column to the proper step within the string, every part of the column operates at a definite potential. The potential changes gradually, by equal steps, from one terminal to the other terminal of a column. This voltage division is held for the entire reverse voltage cycle, at any voltage, from zero to operating voltage and beyond to the rated voltage of the column, to the test limit, until it is finally limited by the destruction of the rectifier cells in the column. It is maintained for direct voltages, low frequency components, high frequency oscillations and sudden transient voltages.

Reliability

The electrical principle of the International Rectifier columns has been selected to achieve utmost reliability. Semiconductor rectifier cells, as they are applied in the rectifier columns have a very low failure rate. Whenever a rectifier cell within the column fails, the resistor-capacitor voltage divider allows its reverse voltage to collapse, without upsetting the voltage division of the other cells. This collapse of reverse voltage prevents the flow of excessive reverse current through the failed cell. Thus a failed cell is not completely destroyed and mechanically separated; instead it remains a conductor which keeps the current flowing through the string. If a sufficient number of identical rectifier cells is used, the failure of any one cell does not affect the performance of the column. Accordingly, the reliability of the entire column is greater than the reliability of its parts.

The capacitors and resistors shunting the rectifier cells are also selected to have very low failure rates. Should a capacitor fail, the string behaves similarly as in the case of a cell failure, the voltage across the failed capacitor disappears, without further power dissipation in the capacitor.

Circle No. 1 on Information Request Card for a 16-page Design Engineering Manual describing High Voltage Rectifier Columns.

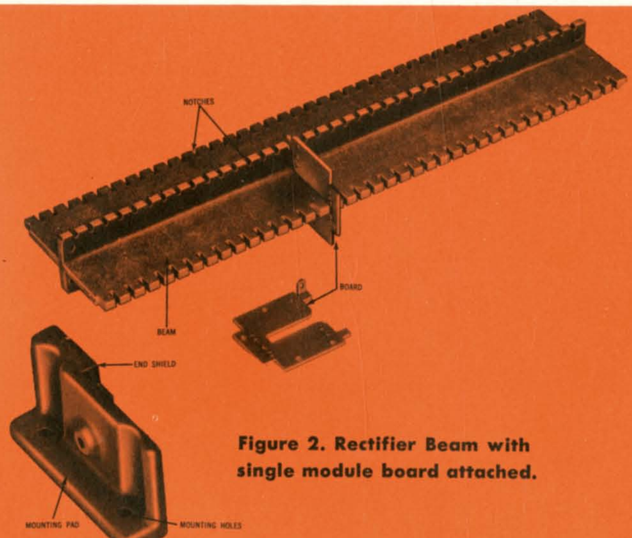


Figure 2. Rectifier Beam with single module board attached.

TABLE I DESIGNATION OF RECTIFIER COLUMNS

Example of Code

Increment. Length. **1HV6E** Cell Type

High Voltage Column — 600 Volt PRV Cells.

RECTIFIER COLUMN TYPE →		1HV Volts	1HV Code	2HV Volts	2HV Code	3HV Volts	3HV Code
Standard Cell Voltages PRV		400	4	300	3	400	4
		500	5	400	4	500	5
		600	6	500	5	600	6
STANDARD Length Column	Number of Cells	100		76		38	
	Number of Modules	50		38		19	
	Air Capacitor (μF)	.0015		.0012		.0010	
	Oil Capacitor (μF)	.0033		.0027		.0015	
	Approx. Weight	5 lbs.		5.9 lbs.		5 lbs.	
MAXIMUM Length Column	Number of Cells	200		154		114	
	Number of Modules	100		76		57	
	Air Capacitor (μF)	.0056		.0039		.0027	
	Oil Capacitor (μF)	.0120		.0100		.0068	
	Approx. Weight	9.4 lbs.		10.9 lbs.		13.7 lbs.	
	Equivalent number of Standard Columns	2		2		3	

*For incremental lengths see Design Engineering Manual SR-370

THE USE OF SILICON ZENER DIODES AS BIAS AND COUPLING ELEMENTS IN AUDIO AND RF APPLICATIONS

The zener diode may be used in audio and r.f. amplifier circuits wherever a source of stable voltage is required. In certain circuits it may prove useful as a switch or limiting device.

Bias

The zener diode is an ideal bias element in amplifier applications. Its function is similar to a battery, however, it requires no maintenance, and cannot damage equipment due to deterioration.

The cathode circuit of a class AB_1 amplifier is shown in Fig. 1. Bias for the stage is developed by cathode current flow through resistor R. Any voltage or current variations will cause a shift in the tube operating point. Although the circuit is degenerative, the effect can create problems where stability is a criteria.

A zener diode may be used in this application to provide a stable operating point. Cathode current flows through the zener diode but, unlike the resistor, a stable bias voltage is developed across the diode and is equal to V_z. Variations in static conditions will change R_z, thereby maintaining the correct bias on the tubes.

The application of zener diodes as bias elements is particularly useful in class B stages. In this type of amplifier the cathode current will increase several hundred percent during peak signal periods. This makes self bias impossible, unless a zener diode is used as in Fig. 2. As in the previous illustration the zener element establishes the correct operating point.

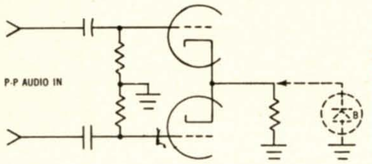


Fig. 1. Push-Pull class AB[1] stage illustrating how the Zener Diode is used to provide fixed bias.

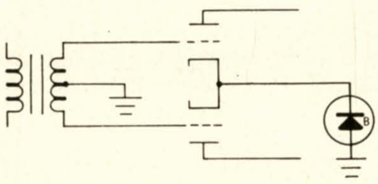


Fig. 2. A zener diode bias Class B stage.

A single-ended class B linear r.f. amplifier is shown in Fig. 3. Ordinarily a grid bias supply would be used with these tubes. The grid current swing is so severe, however, that a regulated supply is mandatory. A zener regulated supply could be used, but the solution in Fig. 3 is far simpler and in many cases less expensive.

In Class B, the diode must dissipate an average power at some point between the static and peak current. The amount of heating will be determined by the wave-form and duty cycle. For Class B audio applications the following equation will provide a liberal safety factor:

$$Pd = V_z \times 0.6 \text{ I peak}$$

A zener diode in the cathode return may also be used in Class C r.f. amplifiers to provide a protective bias, should the drive signal fail.

In high power amplifier circuits the required dissipation may exceed that available in standard zener diode packages. In these situations a transistor (or group of transistors) with suitable dissipation and breakdown ratings may be used as the current passing element. Such a circuit is shown in Fig. 4. The diode dissipation should not exceed one tenth the calculated dissipation of the transistor(s).

The zener element is not confined to bias regulation in vacuum tube circuits. It may also be used with transistors wherever the ultimate in stabilization is required. Fig. 5 illustrates a single PNP amplifier stage, with a zener diode replacing the usual emitter resistor. In this circuit the collector to emitter voltage (V_{CE}) is high enough to provide linear operation. Sufficient current must flow through the zener element to insure operation in the breakdown region.

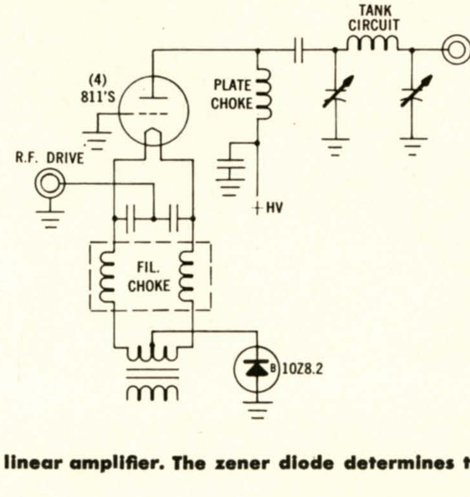


Fig. 3. A class B linear amplifier. The zener diode determines the idling current.

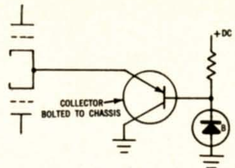


Fig. 4. A transistor may be used to regulate bias when employing low power zener diodes.

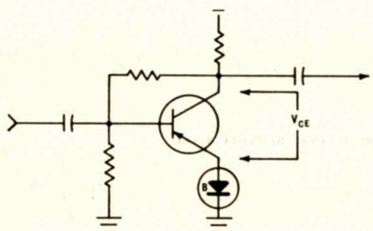


Fig. 5. The zener element may also be used for emitter bias.

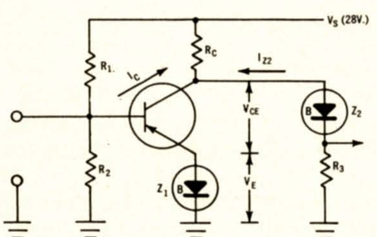


Fig. 6. As an inter-stage coupling element, the zener diode allows direct cascading of stages.

In the preceding examples, the dynamic impedance of the zener diodes will reduce degeneration to such a degree that bypass electrolytics are seldom necessary.

D. C. Amplifiers

A d.c. amplifier presents several knotty design problems, for each stage must operate at progressively higher potentials. If more than two or three stages are used, the associated circuitry becomes rather complex.

The zener diode will provide a design solution, particularly in transistor circuits where the difference in collector and base potentials is relatively small.

A single section d.c. amplifier is shown in Fig. 6. As in Fig. 5, the bias is stabilized with a zener diode. The value of V_{CE} is dictated by linear operation with anticipated voltage changes. The collector current is selected near maximum beta. In this example, 10 volts at 5 milliamperes was selected.

When these stages are cascaded, the voltage drop across R3 (due to I_{Z_2}) must be approximately equal to V_E to ensure adequate bias for the following stage. Therefore V_{Z_2} must have a breakdown equal to V_{CE} which in this case is 10 volts. The current through both diodes should be sufficient to ensure operation in the breakdown region, beyond the knee of the curve. A 3 ma. current through Z2 is adequate.

With these parameters known, the value of V_E (and of course V_{Z_1}) may be determined from the equation:

$$V_E = \frac{I_{z2}}{I_c}(V_s - V_{CE})\left[\sqrt{\frac{I_c}{I_{z2}}+1}-1\right]$$

where; V_E = emitter voltage ($V_E = V_{Z_1}$)
I_{Z_2} = current in Z2 (3 ma.)
I_C = collector current (5 ma.)
V_s = supply voltage (28 v)
V_{CE} = collector/emitter voltage (10 v)

solving; $V_E = 0.6 \times 18 \times 0.65$
$V_E = 7.02$ volts

When V_E is known, the correct value for R_C may be obtained by applying the following equation:

$$R_C = \frac{V_s - V_{CE} - V_E}{I_C + I_{Z_2}}$$

solving; $R_C = \frac{11}{.008}$

$R_C = 1{,}400$ ohms

The resistor R3 may be determined, for both current and voltage are known:

$$R3 = \frac{V_E}{I_{Z_2}} = 2{,}267 \text{ ohms}$$

This figure includes the physical resistance of R3, shunted by the base resistance of the following stage. The bias network consisting of R1 and R2 (Fig. 6) should be adjusted to obtain the required value of I_C.

From the preceding discussion it can be seen that the International Rectifier Corporation MZ-6.8 zener diode would be substituted for Z1, while an MZ-10 could be used for Z2.

RF Circuits

The zener diode may be used in frequency modulation equipment for both automatic gain control and for limiting.

A single diode connected across the coil and voltage decoupling resistor (Fig. 7) will conduct when the signal level exceeds V_z plus the voltage across the resistor. In addition to supplying a degree of limiting, diode conduction places a low impedance in parallel with the coil. This effectively reduces the circuit Q and maintains the signal level in addition to avoiding overload in succeeding stages.

The customary system of limiting in f.m. equipment involves operating one or more stages at low voltage to produce saturation. A more efficient system incorporates the zener diode, and allows the stage to operate at full gain. The circuit utilizes two zener diodes connected in a "back-to-back" configuration as shown in Fig. 8. As soon as the incoming signal exceeds V_z the diodes conduct, effectively clipping the signal and reducing circuit Q.

Amateur Radio Circuits

The human voice contains many low energy peaks; and although they determine modulation percentage to a large degree, the average level is often very low. The effectiveness, or "talk power" of a radiotelephone transmitter can be greatly increased by using a peak or speech clipper to raise the average modulation level. The energy content is increased, but the 100% modulation point is not exceeded.

The characteristics of the zener diode make them well suited as speech clippers in amateur radiotelephone trans-

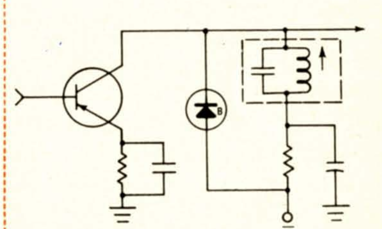


Fig. 7. Glass subminiature zener diodes provide excellent limiting characteristics in transistorized FM receivers.

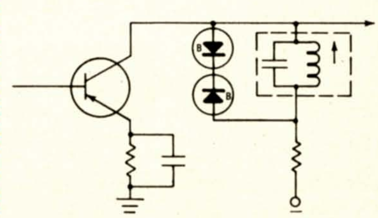


Fig. 8. A double anode version of the FM limiter. It should be noted that the diode junction capacity (10-20 mmfd) will cause detuning, and is a circuit consideration.

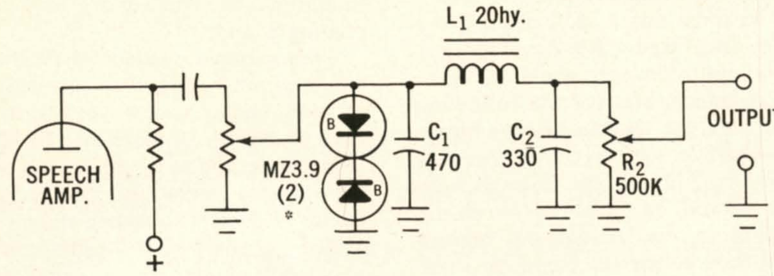


Fig. 9. A zener diode speech clipper, useful in conjunction with amplitude modulated transmitters.

mitters. Such a circuit is shown in Fig. 9. The speech amplifier develops approximately 30 volts of audio from a dynamic microphone. A small portion of this signal is applied to a pair of "back-to-back" zener diodes, which clip any signal peak which exceeds 3.9 volts. The harmonics produced by the clipping action are attenuated by the low-pass filter, consisting of L1, C1, and C2. The desired amount of audio signal is fed to the modulator by adjustment of R2.

The clipper need not be removed from the circuit to eliminate its effect on the voice energy. Simply turn R2 to its maximum clockwise position and control the audio level with R1. The amplitude should not exceed the clipping level and the audio will be unaffected by the zener diode. The desired amount of clipping may be introduced by increasing the setting of R1, while reducing potentiometer R2.

A zener diode may be utilized to switch a simple, tubeless, voice operated relay as in Fig. 10. The sensitivity control (R1) is set just below the point relay pull-in occurs. When the transmitter is modulated, audio peaks exceed V_z, energizing the relay. Capacitor C1 determines the dropout time of the relay. Larger capacitors will cause the relay to hold for a longer time. The relay contacts may be used to control the transmitter power circuits.

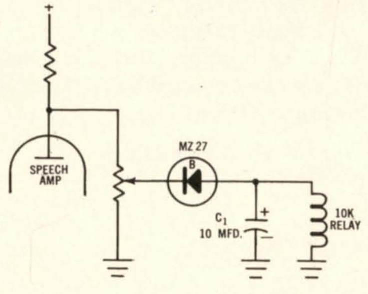
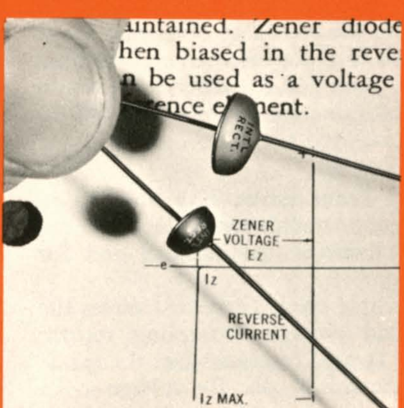


Fig. 10. A simple voice-operated relay circuit for single sideband equipment.

Economy Line Silicon Zener Diodes, 500 MW, 1 Watt and 10 Watt Rated Types

An economy line of "Tri-Sealed" silicon zener diodes substantially lower in cost than standard units are designed specifically for commercial equipment applications. Demonstrating low zener impedance values and very sharp zener "knees," these diodes are available in 500 milliwatt, 1 watt rated and 10 watt series, and standard RETMA 10% voltage steps from 5.6 to 27 volts.

All types embody a new technical advancement in the sealing of zener diode junctions, termed "Tri-Sealed"—a three-layer seal assuring high resistance to humidity, shock, vibration, temperature extremes and other adverse environmental conditions.



For complete details, circle No. 3 on the Information Request Card.

Article Clarifies Meaning of the term "Conversion Efficiency of Solar Cells"

It is widely known that silicon solar cells are extensively used to convert sunlight into electricity and to supply secondary power for space vehicles. Not so widely known, however, is the difficulty of measuring solar cell conversion efficiency and of correctly interpreting and applying the results.

In principle, the conversion efficiency of a solar cell is a simple matter, namely, the ratio of output electric energy to incident radiant energy. But though we have a fair idea of the spectral character of sunlight in space, we cannot very well go out there each time we wish to calibrate a solar cell and measure its conversion efficiency.

Consequently, one has to either make use of the variable sunlight that reaches the earth's surface, or else resort to an artificial light source such as a tungsten filament lamp. The latter method is widely used and has been accepted throughout the industry for the production line testing of solar cells.

Recently acquired data, however, indicate that care has to be exercised in interpreting solar cell measurements under tungsten light. It stems mainly from the fact that there is a wide variation in the spectral response of the solar cells and that the tungsten source and sunlight do not have the same spectral pattern.

Because of the widespread misunderstanding that exists in discussing the conversion efficiency of solar cells, a paper has been prepared by International Rectifier Corporation and is available to interested readers. Circle Information Request Card No. 4 for "Notes on the Conversion Efficiency and Calibration of Silicon Solar Cells."

Other solar cell articles available from International Rectifier Corporation are:

"Silicon Photovoltaic Cells and the Utilization of Solar Energy," C. A. Escoffery, June 1960.
Circle No. 5 on card.

"Temperature Control of Silicon Solar Cells in Space Environment," Werner Luft, June 1960.
Circle No. 6 on card.

"Method for Calculating the Number of Silicon Solar Cells Required for Power Supply of Satellites and Space Vehicles," Werner Luft.
Circle No. 7 on card.

"Photovoltaic Conversion of Solar Energy," C. A. Escoffery, March 1960.
Circle No. 8 on card.

new developments

FOR FAST ACTION ON YOUR INQUIRIES . . . use the new information request card. Just circle it . . . then mail it!

SILICON DIFFUSED JUNCTION 'PLUG-IN' RECTIFIERS

Ruggedized, 500 ma rated silicon 'plug-in' rectifiers utilize completely new diffusion techniques resulting in very low reverse current (200 ua) at rated PRV, a much higher than average surge current rating (50 amps peak, 1 cycle) an exceptionally low forward voltage drop (0.92 volt) . . . and may be rapidly snapped into radio-TV, motor control, audio-amplifier, industrial power supply and other circuits utilizing clip-type rectifier holders.

These new devices provide peak reverse voltage ratings from 200 to 600 volts, and are equipped with heavy-duty threaded stud terminals assuring positive contact in standard clip-type holders. Circuit assemblies that may be rapidly and easily assembled include ½ wave, full wave center tap, single phase bridge, ½ wave and full wave voltage doublers and numerous polyphase circuits. Operating temperature range: —20°C to +130°C.

Circle No. 9 on Card

45 TO 150 AMP RATED "QUAD-SEALED" SILICON RECTIFIERS FOR LOW COST BATTERY CHARGING, INDUSTRIAL POWER USES

Silicon rectifiers capable of withstanding surge currents up to 20 times their nominal current rating (1000 amperes peak at rated full load) are in full production.

Twin series of stud mounted and triangular base "Quad-Sealed" rectifiers are especially recommended for industrial power and battery charging applications where low cost and high surge current capabilities are called for. Each rectifier junction is "Quad-Sealed" by a four-barrier sealant and class H varnish process, thus completely enclosing the assembly in a ruggedized case totally resistant to moisture and contaminants . . . while permitting expansion and contraction of the assembly under wide temperature excursions.

The two new series provide dc output ratings from 45 to 150 amperes; peak reverse voltage ratings from 50 to 600 volts over an operating temperature range from —20°C to +130°C.

Circle No. 10 on Card

HIGH VOLTAGE SILICON TUBE REPLACEMENTS

High voltage silicon plug-in rectifiers directly replace Types 8008 and 872A mercury vapor rectifier tubes. By eliminating the filament transformer and time-delay relay necessary to tube operation, they occupy ½ the space and weigh less than ½ of equivalent tube circuitry.

Rated at 10,000 volts peak reverse voltage and 1250 ma dc output (at 75°C), the ST-9 and ST-10 are equipped with tube bases to allow direct insertion into existing tube sockets. They have an operating temperature range from —65°C to +75°C, and are designed to provide the superior advantages of silicon rectifier operation (no warm-up time, long life, high temperature operation, compact, rugged package) on a wide range of broadcast, TV, short-wave transmitter, radar, airline, industrial RF induction heating and other power communication and industrial applications.

The ST-9 replaces tube type 8008; the ST-10 replaces tube type 872A.

Circle No. 11 on Card

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