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DIODES AND SPECIAL SEMICONDUCTOR ELEMENTS FOR TV SETS (PART 1) SELENIUM RECTIFIER ELEMENTS

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I. INTRODUCTION

The application of selenium rectifiers in television receivers was started by Fuji Electric in 1955 when TV sets were still slowly gaining in popularity. At this time radiator-type selenium rectifier elements were used as power supply rectifiers. Ever since the first steps were taken toward solid state TV receivers, the high reliability and capacity of these elements have become highly valued. As TV circuits have further developed, these elements are not only being limited to simple power supply circuits, but are now also widely employed in various other types of circuits. At present, there is an inseparable connection between TV circuits and selenium rectifiers.

Selenium rectifier elements possess features that make them particularly suitable for use as low current and high voltage, ex. boost voltage elements in horizontal scan circuits. In this respect they surpass all other types of semiconductor elements.

This article will describe the characteristics and features of these selenium rectifier elements. It will also introduce the operation and characteristics of selenium rectifier elements suitable for TV circuits. It is hoped that this will lead to a wider and more effective application of these elements. Naturally selenium rectifier elements are not used solely in TV receivers. Their special features also make them suitable for use in audio equipment and various electronic devices.

II. FEATURES AND CONSTRUCTION OF SELENIUM RECTIFIER ELEMENTS

Typical characteristics of selenium rectifier elements are described below and have the following features when compared with other semiconductor elements. They perform specific operations in various TV circuits.

1) The reverse characteristics are of the soft form. Their surge power absorption capacity is high. Even when there is a breakdown due to surge voltage, it is only partial and the element has the capacity to return to normal characteristics without interruption. As a result, the service life is long.

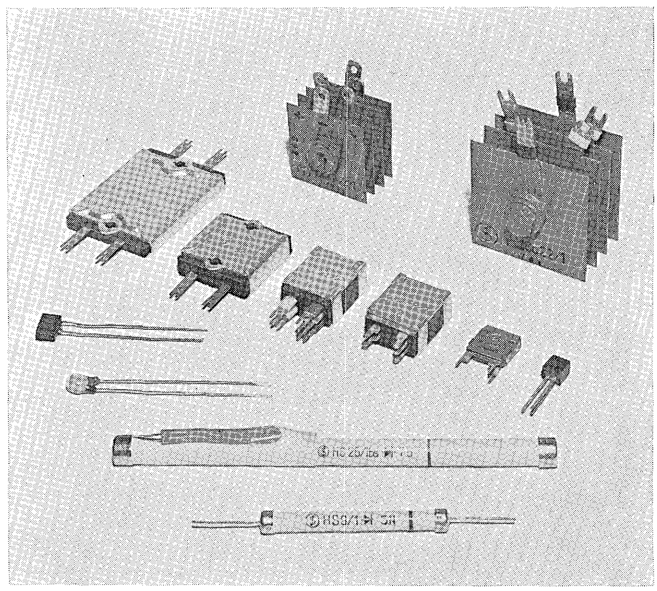


Fig. 1 Selenium rectifier stacks

2) Since the Hall storage effect is not present, these elements can be used in high frequency circuits.

3) Since they can be placed into any area by panting and connected electrically by inserting them without soldering, it is easy to obtain rectifiers whose ratings are suitable for the circuits in request.

4) They can be employed in the open air just as they are or they can be molded directly by means of resins etc.

Selenium rectifiers possess the above features. Fuji Electric selenium rectifiers are made on the basis of cells whose effective areas are between 0.005 cm^2 (0.8 mmϕ) and 800 cm^2. There are several ways to form rectifier stacks from these cells, such as (1) the standard type, i.e. making a hole in the center of the cell and arranging the cells on same axis, (2) the flat packaged type in which the cells are arranged in a case and held together by a spring, (3) the mold type in which the cells are held stationary in a mold and (4) the HS-series high voltage contridge type in which many cells are mounted in series inside a porcelain tube (Refer to *Fig. 1*)

III. CHARACTERISTICS OF SELENIUM RECTIFIERS

1) Forward and reverse characteristics

Typical forward and reverse characteristics of selenium rectifier cells are as shown in *Fig. 2.* The selenium cell is constructed as shown in *Fig. 3.* The junction is between the selenium layer and the Cd-Sn cathode layer. Since the space charge layer extends to the selenium layer, the forward and reverse characteristics of the rectifier depend on the quality of the selenium layer. Due to the fact that the electrical characteristics are influenced by the resistivity of the selenium layer, the type of crystallization, the thickness of the selenium layer etc., selenium of various resistance values is used depending on the characteristics of the rectifier on request. The multilevel vaporization method is employed to make various types of selenium re ctifier elements.

Therefore, the forward voltage drop is the larger, the higher blocking voltage. The elements presently on the market have forward voltage drops of 0.6~1.0 v (100 ma/cm^2) for blocking voltages between 35 and 70 v peak.

Changes in the forward voltage drop with temperature differ according to the type of cell but are usually around 0.3~0.45%/°C. The reverse saturation current also varies with temperature but large variations occur in accordance with formation etc.

2) Formation

It has long been known that the reverse characteristics of selenium rectifier cells vary due to the forming phenomenon. There are carrier traps of various energy level in the crystal and it is thought that the reverse characteristics differ depending on whether or not the charge is trapped in these traps. Therefore, if temperature (forming by thermal stress) and voltage (forming by electrical stress) are applied, the charges which are trapped in carrier traps at energies below the temperature and voltage applied will be discharged and the reverse characteristics will improve. This phenomenon is known as the forming effect. Forming proceeds with operation and also in the manufacturing process, the reverse characteristics can be improved by introducing the formation process.

There is a tendency for the charges to be trapped again and the reverse current to increase when the elements are set aside and not used for long time. The forming proceeds generally in this case however only until the voltage employed for operation is attained. During the period while forming is taking place, operation occurs at a slightly higher reverse current and the reverse power loss increases.

The conditions required for the reverse characteristics in this case are that forming is smoothly completed before thermal runaway of the selenium rectifier elements due to reverse power loss increased with trapped charge occur. In other words, if the selenium rectifiers have the charactercs where the formation precedes always the thermal runaway in pactical use there is no need for more forming to be performed at manufacturing process. Naturally it is essential to consider the amount of current increase during the period which the elements are not used. Therefore, even if the reverse leakage current is outside the specified limits due to non-use or the elements etc., forming will precede until a rather high reverse current is attained.

3) Surge power absorption capacity

When considering the reverse surge power absorption capacity of selenium rectifier elements, it is essential to think of the thermal and electrical breakdown regions separately. In thermal breakdown, loss due to surge power causes heat to be applied to the cells, and when the physically permissible temperature of the selenium cells is exceeded, the cells melt or the quality changes. In such cases, the permissible surge level is a function of time and the breakdown is permanent.

Electrical breakdown occurs if the electric field intensity in the space charge layer exceeds the selenium insulation strength when large voltages are applied. This is because the space charge layer is at the most only 0.1 mm thick. In such cases, the permissible surge level is not related to time. Also the breakdown occurs only in the weakest parts, and only in the part, the energy is lost, and these weak parts become insulators after breakdown and the energy loss is stopped. This therefore has no effect on other parts of the element which continue to operate normally.

In the selenium rectifier elements, electrical breakdown usually occurs before thermal in pratical use, then service life is long. On the other hand

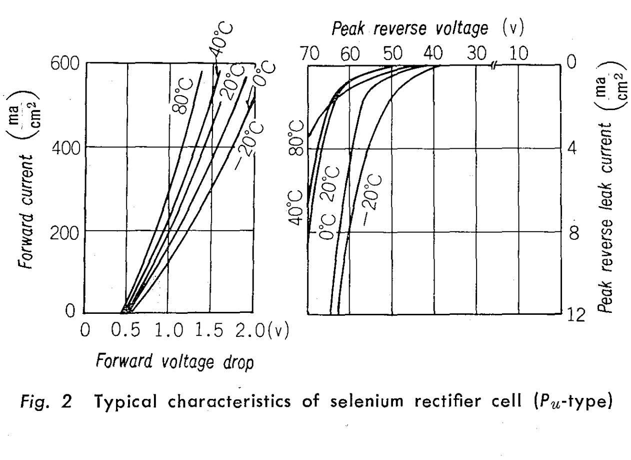


Fig. 2 Typical characteristics of selenium rectifier cell (P_u-type)

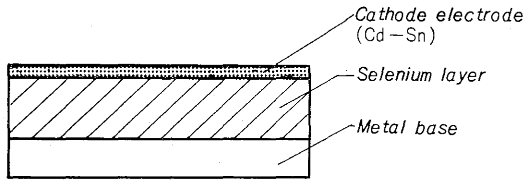


Fig. 3 Section of selenium rectifier cell

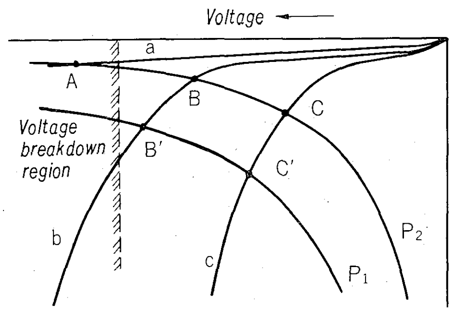


Fig. 4 Surge absorption in diode reverse region

there are also many cases when these surges have a constant energy. For example, if a surge of energy P_2 is absorbed by diodes *a, b* and *c* as indicated in *Fig. 4*, operation is at points *a, b* and *c* respectively. The softer the reverse characteristics, the lower the voltage at which operation occurs and the permissible surge power is large before electrical breakdown. Since the heat capacity of selenium rectifier elements is high and the reverse characteristics are softer than those of other semiconductor elements, therefore the capacity for surge absorption before breakdown is high.

The surge power absorption cacacity is therefore high in these elements, and if breakdown occurs, it is only partial and not permanent. This means that they have excellent overall withstand characteristics in respect to surges. If a surge absober is used, operation will be as shown by curve (*c*) in *Fig. 4*. In this cell, breakdown is always thermal. *Fig. 5* shows the surge absorption capacity of Fuji Electric's ordinary selenium cell and a cell as a surge absorber. Voltage breakdown which is almost completely unrelated to time occurs ordinarilly at 80～100 v.

4) Barrier capacitance and Hall storage effect

The barrier capacitance of selenium rectifier elements varies slightly according to the type but is generally in the range shown in *Fig. 6*. However, since there is no Hall storage effect like that found in monocrystal semiconductors, it is possible to use these elements in high frequency circuits as long as the static capacity due to the effective area and series stacking etc. is regulated to fit the circuit in request. Selenium rectifier diodes are commonly used in 15.75 kHz circuits such as dynamic convergence circuits, dual diode in AFC circuits and high voltage CRT's as well as boost diodes in horizontal beam scan circuits of TV receivers.

5) Frequency dependency of reverse characteristics

The reverse characteristics of selenium rectifier diodes differ considerably depending on the circuit frequency, especially between ac and pure dc. Typical characteristics are shown in *Fig. 7*. In this case, the blocking voltage in the reverse direction with the constant reverse leakage current is $V=V_0+(2\sim 2.5)\log_{10}(f/f_0)$ where V and V_0 are the blocking voltages in respect to frequencies f and f_0.

This property is not only related to the frequency; it is also considered to depend on the ratio between

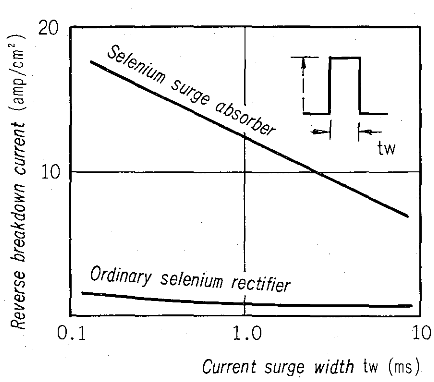


Fig. 5 Surge absorption capacity of selenium cell

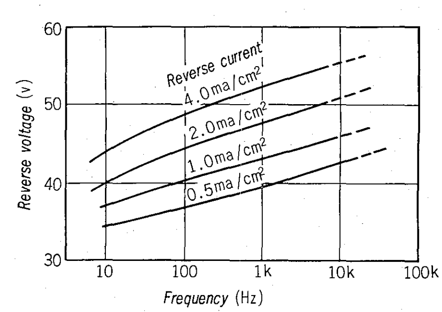


Fig. 7 Frequency dependency of reverse characteristics

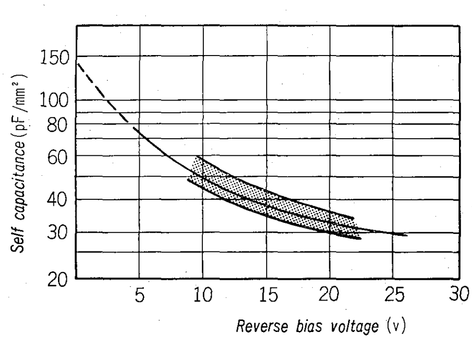


Fig. 6 Barrier capacitance of selenium rectifier cell

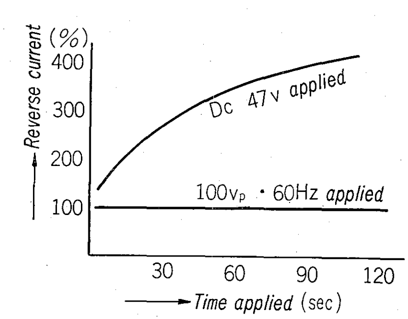


Fig. 8 Drift of reverse characteristics

the rectifier stop time and the forward current flow time. However, if the forward current flow time is over several microseconds during each cycle, the influence of frequency can be considered as predominant.

Therefore, when the selenium rectifier elements are used in circuits in which there is no forward current flow period during each cycle, it is essential at least to give sufficient consideration to the difference between the ac and dc ratings. *Fig. 8* shows the reverse current change in a 100 v ac peak rated element when pure 47 v dc is applied. Therefore, it is necessary to chose the application by considering the reverse characteristics drift due to frequency.

IV. LIFE AND RELIABILITY OF SELENIUM RECTIFIER ELEMENTS

1) Variations in characteristics with operation

The characteristics of selenium rectifier elements vary slightly with operation. The change of the forward characteristics especially is regular and by observing the forward characteristics changes over a period, it is possible to judge whether the conditions under which the element is being used are suitable or not. *Fig. 9* shows a typical drift in characteristics. If this change in characteristics stops in the "A" region, the elements can be used for a long peried (at least in comparison with the life of a TV set), and no problem arises. If the drift lies within the B region, operating conditions can be considered as severe. Using this characteristic it is convenient to judge the element in the circuit suitable or not in short testing periods. However, the effect on the rectifier's external characteristics (out put characteristics etc.) of the element characteristic drift is extremely small. For example, the change in the output characteristics when the forward voltage drop is doubled is only about 10% at the rated resistive load current.

The drift in the reverse characteristic of selenium rectifier elements is as shown in *Fig. 9*. However, the reverse leakage current can vary according to the temperature, the time elapsing after operation, the measuring circuit etc. Since it is difficult to establish a principle in this case, as reference values, reverse characteristics are used. Naturally, when the reverse current increases regularly for a short period, it is necessary to consider this as abnormal.

Therefore, characteristics drifts arise regularly in selenium rectifier elements and when elements with these forward and reverse characteristics are employed some consideration must be given. However, these changes need not be considered in the output characteristics of the rectifier circuit.

2) Operating cell temperature and life

From experience it can be confirmed that cell temperature in operation effects considerably on its service life. However, it is extremely difficult to obtain quantitative relations for semiconductor elements. The active energy of the crystals and impurities in selenium rectifier elements is comparatively low. Therefore taking a temperature of 100°C as a standard, the element is sensitive to this temperature, and on the basis of the previously mentioned characteristics drifts with time, the permissible operating temperature is generally determined from experience as 85°C. However, since the cathode electrode fusion temperature at which the element breaksdown physically is around 200°C, the element can be operated at 90 or 95°C for short periods without abnormalities appearing. Therefore, it is to be considered essential to establish the way in which reliability is dependent on temperature. The results of a step stress test using temperature stress are shown in *Fig. 10*. Whether or not it is suitable to use these results around 85°C must wait for further investigations. However, if judged from the results shown in *Fig. 10*, most of the main group obeys the same failure mechanism up to operating temperatures of 150~160°C and once there is other failure mechanism over the temperature i.e. 165°C. Up to 120°C, there is no problem, but just after the temperature exceeds 120°C, two groups appear. The former is short time failure and the latter is considered to be in accordance with the main failure mechanism, previous experience has shown this result to be almost certain. This relation differs with different types of selenium elements.

One of the means of determining whether the results of the step stress accelerating test are correct or not is the Arrhenius plot. If the changes are assumed

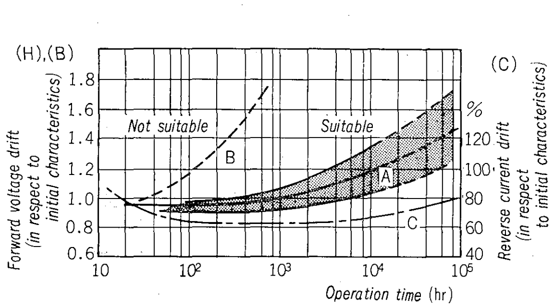


Fig. 9 Drift of selenium rectifier characteristics in operation

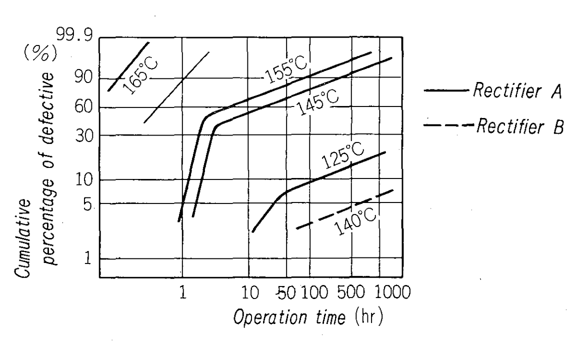


Fig. 10 Life and operating temperature

to be based on chemical changes, from the chemical dynamics standpoint time t required to same changes has a following relation with the temperature T.

$$l_n t = D/T - C \quad \text{where } D \text{ and } C \text{ are constants}$$

When plotting the main group in *Fig. 10* according to the relation between $l_n t$ and l/T, the solid line shown in *Fig. 11* is obtained, which is equivalent to the above equation (It shows the instanteneous failure rate instead of $l_n t$). In this way, it will be also possible to predict the conditions below 120°C which are not shown in *Fig. 10*.

Since the life of the selenium rectifier diode has this type of continuous relation to the temperature, the element does not breakdown instantaneously once the temperature has exceeded the rated value. Then in selenium rectifier selection for circuit, it is over quality to choose the rectifier for a suitable rating under adverse conditions which almost never occur in TV sets. It is enough to choose them under the normal condition. (The failure in *Fig. 10* means the condition in which practical operation is imposible).

8) Humidity resistance

Generally selenium cells and junction parts are treated in such a way that they have a high enough resistance to humidity to be used in the atmosphere without any problems arising, and almost all selenium rectifiers can be employed in this way. Mold type selenium rectifiers also possess sufficient mechanical reinforcement for this purpose.

However, selenium rectifier cells consist of a collection of hexogonal type crystals and when water particles penetrate the crystal boundries, a short circuit occurs between the crystals and the reverse current increases. Even in such cases, when the crystals remain normal and regular damp-proofing is used, this irregularity is slight if the elements are left in normal environmental conditions. When the elements are put into operation, forming proceeds and there is a return to normal characteristics. However, if the penetration of water particles is very high, thermal runaway occurs since the reverse power loss is greater than the forming. Whether abnormalities will occur or not under normal enviromental conditions can be determined by means of a quality check. Fuji Elcc-

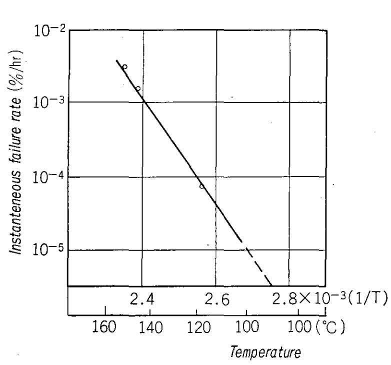


Fig. 11 Arrhenius plot of selenium rectifier in *Fig. 10*

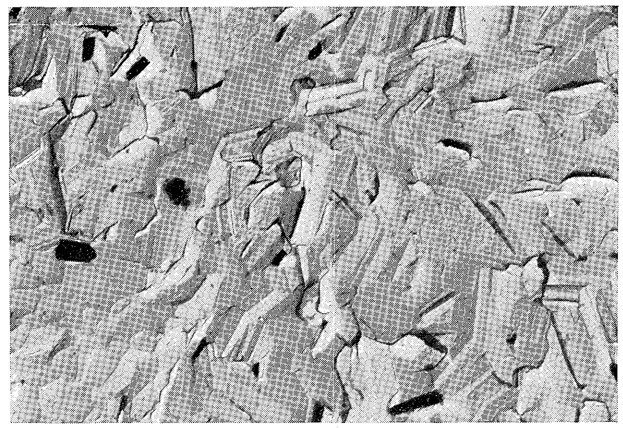


Fig. 12 Crystal arrangement of selenium cell

tric has found from experience that if the degree of change is within the rated range under 40°C, 95% for 200 hr there is no problem.

There are cases when a short circuit will form in weak points but usually these weak points break down during operation and form an insulation so that the other parts continue to operate normally.

However, the condensation of water droplets in the selenium cells during storage or operation should be avoided, in this case it is best to use the mold type rectifiers. It is better generally to avoid atmospheres where the humidity is very heigh.

4) Resistance to the atmosphere

There are few problems when the elements are used in atmospheres which support life, but it is best to avoid atmospheres saturated with NH_3, SO_2, NO_2 and HCl gas.

One material which does have a great influence on deterioration of characteristics is mercury. When the cells are exposed for a few hours to mercury vapor, the selenium forms amalgum and the cell turns almost completely into a resistor.

V. RATINGS AND SET OPERATING POINTS OF SELENIUM RECTIFIER ELEMETS

The ac input voltage, output current, permissible operating temperature etc. determine the ratings of selenium rectifier elements. These have been determined on the basis of the following standards, and for the operating set points. It is necessary to consider the standard values. This is also an effective means in designing.

1) Ac input voltage

For Fuji Electric selenium rectifier elements, the ac input voltage is set so that the reverse loss when operating at 110% of the rated voltage in a 50/60 Hz circuit, is 10% or less of the total loss when operating under rated conditions. Since this value is rather low in respect to the selenium surge breakdown voltage, it is not necessary to take special precautions against surge voltages in normal circuits.

The reverse loss increases in accordance with temperature and the forward loss decreases. Therefore, if the reverse loss is selected at around 10%, the total loss will be getting small no matter if the temperature is raised due to some sort of shock, and operation will be such as to lower the balance point so that stable operation can be attained.

Therefore, it is not necessary to provide margins in respect to the rated values in selenium rectifier elements and there is a comparatively large margin also in respect to surge voltage for the reasons described above.

2) Rated output current

The rated current is set so that the temperature rise due to the total loss when operating at the rated voltage is such that the temperature of the selenium cell at an ambient temperature of 40°C is equal to or less than the permissible operating temperature in principle. However, since there are many conditions which influence the radiation capacity such as the arrangement of the elements, thermal radiation from the atmosphere and heat emanating from the installation tools, a rather large margin should be provided in respect to the rated value and it is therefore advisable to measure the temperature of the selenium cells under actual equipment conditions. In practise, there are many instances of being used above their ratings. The ratings are only meant as a tentative standard.

Since the loss density is small in these elements, it can be measured by a thermocouple. To measure the selenium cell temperature rise, it is sufficient to measure plate temperature rise in the standard type, about 1.2 times the metal case surface temperature rise in the flat-packaged type and about 1.4 times the case of surface temperature rise in the molded type.

3) Permissible selenium cell temperature

As was described in the previous sections concerning cell life, there are many points obtained practically and from experience used in determining the cell operating temperature. However, the life itself is related to the temperature and the lower the temperature, the better. Therefore, if the cells are used at the stipulated value, there will be no problem, but if the temperature is raised for a short period, breakdown will not occur immediately. It is necessary to consider this point when designing the equipment. However, temperatures in excess of 120°C must be avoided since there will be a drift in the characteristics even if the cell is kept under no-load conditions.

VI. SELENIUM RECTIFIER ELEMENTS FOR USE IN TV RECEIVERS

1. Power Supply Circuits

Selenium rectifier elements can be used in main power supplies of transistor TV sets and sub power supplies for transistor in hybrid circuits etc.

Standard types are generally used in the main power supply circuits, while the flat-packaged and grip types are employed mainly in the sub power supply circuits. These can be used with either standard wiring or placed on printed circuit boards. The following arrangements are used.

(for main power supply...single phase bridge connectian)

PT 6 22/1	(1.1 amp 25 v)	Pu 6 22/1	(0.68 amp 30 v)
PT 9 22/1	(1.5 amp 25 v)	Pu 9 22/1	(1.0 amp 30 v)
PT 11 22/1	(1.9 amp 25 v)	Pu 11 22/1	(1.3 amp 30 v)
PT 16 22/1	(2.7 amp 25 v)	Pu 16 22/1	(1.8 amp 30 v)
PT 25 22/1	(4.4 amp 25 v)	Pu 25 22/1	(3.0 amp 30 v)

(for sub power supply 22/1...bridge, for 12/1...center)

Kc 1.3 g 2 2/1	(230 ma)	Kc 1.3 g 12/1	(350 ma)
Kc 2.7 g 2 2/1	(320 ma)	Kc 2.7 g 12/1	(500 ma)
Kc 2 dp 22/1	(400 ma)	Kc 2 dp 12/1	(560 ma)
Eu 2 c 22/1	(200 ma)	Eu 2 c 12/1	(200 ma)
Pu 6 dp 22/1	(680 ma)	Pu 6 dp 12/1	(680 ma)

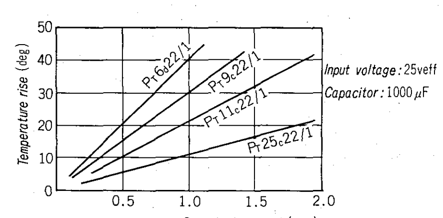
When these selenium rectifier elements are used in power supply circuits, they possess the following features:

1) Since the cells possess large rush current proof, it is not necessary to use a resistor to limit the rush currents which occur when the capacitor charges.

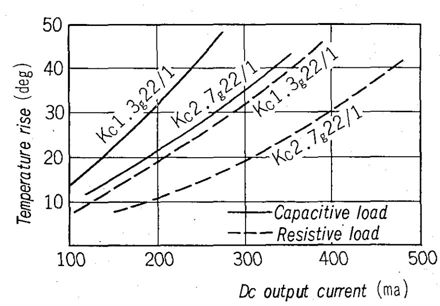
2) Since the surge voltage absorption capacity is high, it is not necessary to employ a parallel capacitor for surge absorption and since the cells have a high withstand against external surge voltages, stability is assured.

3) Since the Hall storage effect is not present, no surge voltages arise during commutation and a capacitor to prevent video noise is not required.

4) Selenium rectifier elements for both sub and main power supply circuits can be arranged on printed circuit boards, and it is easy to construct the equipment since everything is accommodated in a unit.



(a) Temperature rise of main power supply rectifier



(b) Temperature rise of sub power supply rectifier

Fig. 13 Temperature rise of selenium rectifier

The relation between the output current and the temperature rise with free convection is shown in *Fig. 13* (*a*) for PT 6 c 22/1, PT 9 c 22/1 and PT 11 c 22/1 elements for main supply circuits and in *Fig. 13* (*b*) for Kc 1.3 g 22/1 and Kc 2.7 g 22/1 elements for subsupply circuits (there are differences due to thermal radiation from the surroundings etc.).

There is a considerable difference in temperature rises between pure resistive loads and capacitive loads and it is necessary to take precautions since this was a considerable influence on the rated values.

Recently, transistor power supply has been provided by rectification of the output of FBT tertiary windings in transistor TV sets etc. However, in such cases, noise due to the Hall storage effect in the silicon presents a problem and for this reason selenium elements in these sub-power supply circuits are mainly used.

2. Boost Rectifier Circuits

For boost rectification of 100～1000 v such as the focus voltage, the boosted boost circuit, the video brightness voltage etc., obtained by rectification of the 15.75 kHz pulse of the flyback transformer, silicon elements for high frequency are used in many cases, but the selenium rectifier elements shown in *Table 1* are also widely employed. In circuits like the boosted boost circuit of color TV sets where the voltage is comparatively high, selenium rectifier elements are used exclusively. It is also now common to employ only selenium rectifier elements in the focus circuits (4000 v) of color TV sets.

There are several reasons why selenium rectifier elements are used so widely in these boost circuits:

1) They are ideal for high frequency circuits since there is no Hall storage effect.

2) The high surge absorption capacity of selenium rectifier elements is effective against the large surge voltages which arise in boost circuits where the energy back up is considerable due to the flashover of high voltage circuits. These elements can also be coupled to circuits in which the inductance due to the flyback transformer is high.

3) For flashover etc. on the boost output side, there is suitable forward resistance in stacks of several selenium rectifier elements, and it is not necessary to use protective parts (resistors etc.) to keep down flash circuit currents.

4) The price is low and it is easy to obtain elements with the required blocking voltages.

The elements in *Table 1* are ideal for color TV boosted boost circuits since the temperature rise is 10 deg or less.

Regulation during rectification of the 15.75 kHz TV flyback pulse is shown in *Fig. 14*. Since the loss from resistors required to prevent current disturbances due to the Hall storage effect in silicon does not occur with selenium elements, the overall output characteristics are just about the same.

Table 1 **Ratings of Semi-High Voltage Rectifier**

Type	Blocking Voltage	Rated Forward Current
Tc 0.09 m 11/10	470 vp	12.5 ma dc
Lc 0.09 m 11/13	650	7.5
Lc 0.09 m 11/15	750	7.5
Lc 0.09 m 11/20	1,000	7.5
HS 08/1	800	1.0
HS 1.5/1	1,500	1.0
HS7/1～10/1	7～10 kv	1.0

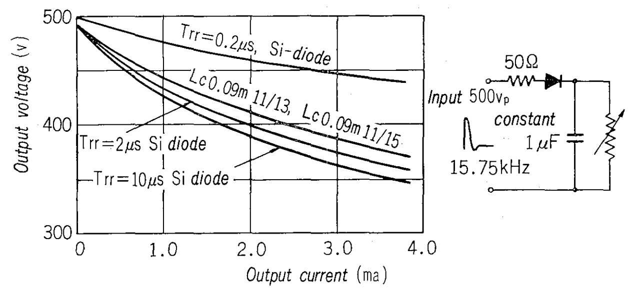


Fig. 14 Output of selenium rectifier in boost voltage rectification

3. Convergence Circuits

In the horizontal dynamic convergence circuits of color TV sets, a porabolic current flows in the coils to correct the beam deflection. Diodes are also used for peripheral compensation. At present, Fuji Electric selenium rectifier elements are used exclusively as dynamic convergence circuit diodes for domestic color TV sets.

The elements used are as follows:

Tc 0.2 m	11/1+12/1	(30 ma/arm)
Kc 0.6 m	2×11/1+12/1	(65 ma/arm)
Kc 1.3 c	3×11/1	(200 ma/arm)
Kc 0.8 c	11/1+12/1	(130 ma/arm)
Kc 2 dp	11/1+12/1	(260 ma/arm)
EH 2c	11/1+12/1	(300 ma/arm)

Since the circuit design standards vary, the same circuit can have various ratings and selenium rectifier elements have the following features which make them ideal for various requirements. For these reasons, their use is gradually increasing.

1) Since there is no Hall storage effect, no noise appears on the picture.

2) Since electrical connections can be formed merely by stacking the elements, and cells of any effective area can be obtained, there is considerable freedom in selecting the current capacity, wiring method and construction and it is easy to accommodate multiple circuits in a single unit.

3) The price is low and they are easy to use since they can be installed on printed circuit boards.

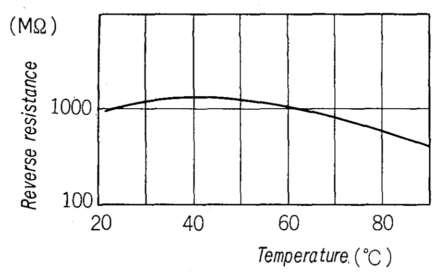


Fig. 15 Temperature dependency of resistance in reverse of T_K 705 selenium rectifier

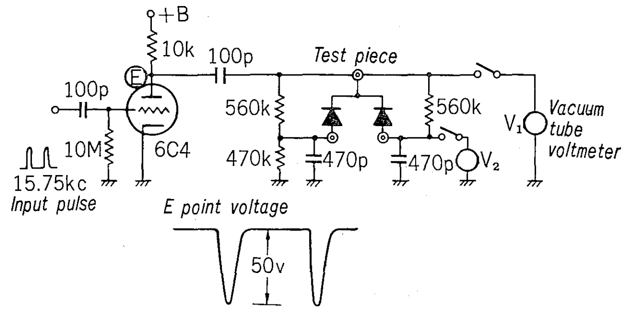


Fig. 16 Dynamic characteristics test circuit of dual diode

As was described previously, the loss density is low in selenium rectifier elements and the rated current can be determined according to the temperature rise. Therefore with circuits like the convergence circuit where the current in each arm is different, there is no problem if the total loss in a unit is within the specified limits. Since the current rating is the value when the average current flowing in each arm is equal, the following relationship should hold for the total losses to be equal when the rating is I_0 and actual current in each arm is i_1, i_2, $i_3 \cdots$

$$N \cdot I_0^{1.5} = \sum_{n-1}^{N} i_n^{1.5} \quad (N \text{ is number of arms})$$

Effective design will be got, if selenium rectifier elements are used according to above relation. When the current unbalance is rather large and large size makes the heat balance uneven, it is necessary to provide compensation.

4. AFC Circuits

In horizontal synchronizing circuits, the phases of the negative synchronizing pulse of the synchronous separator output and the sawtooth wave of the blocking oscillator output are compared. Diodes are used in the discriminator of the synchronized sawtooth wave AFC circuit. Previously, germanium diodes were employed but recently selenium rectifier elements have become almost standard.

The reasons for using selenium rectifier elements in these circuits are that there is less drift in the selenium element characteristics due to temperature than in the reverse characteristics of germanium diodes, and since the reverse resistance is high, circuit operation is guaranteed (See *Fig. 15*).

Fuji Electric has developed a TK 705 m type partial contact selenium rectifier with which it is possible to obtain cells with sufficiently low self capacitance for the circuits and also to keep the characteristics uniform during manufacture. Therefore, a sufficiently wide pull-in range and sharp synchronization can be achieved. With the TK 705 m 12/1 type selenium rectifier elements made by Fuji Electric in AFC circuits, the output voltage in the circuit shown in *Fig. 16* is $V_1 > 8$ v and the balance voltage is $V_2 < 0.02$ v.

These rectifier elements have also recently shown their ability to be employed as signal elements up to in 50~60 kHz. For this reason, their application in stereo multiplex is gradually increasing.

5. High Voltage Circuits

The Fuji Electric HS (US) series of selenium rectifier elements are popular now for rectifying flyback transformer output and obtaining high CRT voltages. Since this HS series has been developed especially for the rectification of high frequency/high voltage currents such as flyback pulses, an especially thin cell is employed in order to lessen stray capacitance to ground and special construction has been provided to make voltage distribution uniform.

The 0.8 kv~30 kv series is used for high voltage rectification in black and white TV sets. These are combined to form a cascade type rectifier as shown in *Fig. 17*. They have also proven their high reliability when used individually for high voltage single rectification. These elements have the following features when compared with previous vacuum tubes:

1) Since the selenium cells can be arranged in multi-layer stacks, there is no flashover in the rectifier and there is no damage to drive transistors in transistor TV sets.

2) Since the surge absorption capacity is high and the elements can be arranged in multi-layer stacks, they posses extremely high reliability as high voltage elements.

3) A heater is not required and the power consumption is low. They are thus ideal in " instant vision " systems.

4) Although they are small, their mechanical strength is excellent.

Due to these features, almost all transistor TV sets employ the HS (US) series and have successfully transistorized the last remaining vacuum tubes to achieve completely solid state TV. Even in vacuum

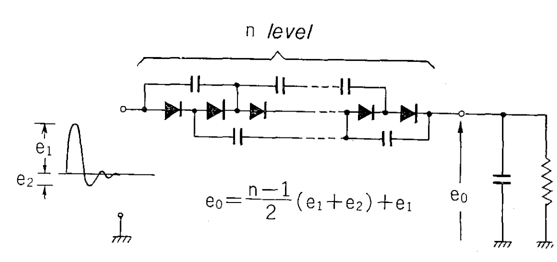


Fig. 17 Connection of cascade rectifier in TV circuit

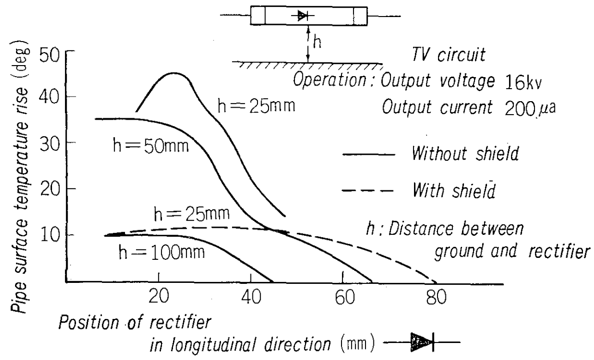


Fig. 18 Temperature rise and stray capacitance

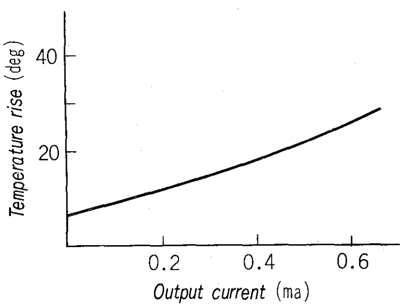


Fig. 19 Temperature rise of HS 25/1 in 15.75 kHz pulse circuit

***Table 2* Standardized Cascade Rectifier in B・W TV**

Rectifier	No. of Strings
HS 1.5/1	13
HS 3/1	5
HS 5/1	3
HS 6/1	3
HS 8/1	3
HS 9/1	3
US 10/1	3

tube TV sets, application of the HS series is gradually increasing due to their proven reliability.

Most of the sets employ the single rectifier high voltage rectification system but the cascade system is also being used now. Up to now, the standardized cascade rectifier shown in *Table 2* has been employed. Recently, investigations have also been carried out on cascade rectification in line operation TV sets which contain no flyback transformers. With these cascades systems, outputs e_0 (no-load) and e'_0 (on-load) are obtained theoretically when the input pulse is as shown in *Fig. 17*. These outputs are expressed as follows:

$$e_0=(n-1)(e_1+e_2)/2+e_1,\quad e'_0=e_0-f(I_0,c)$$

$f(I_0, c)$ is influenced by the capacitance, load current and the pulse waveform.

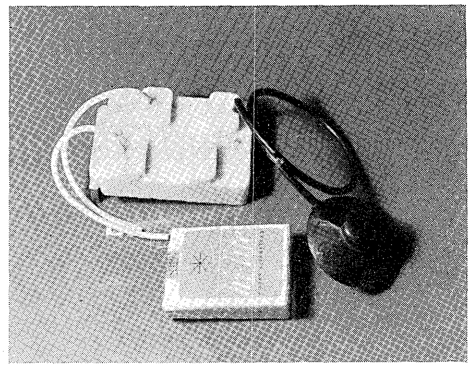


Fig. 20 Cascade selenium rectifier stack

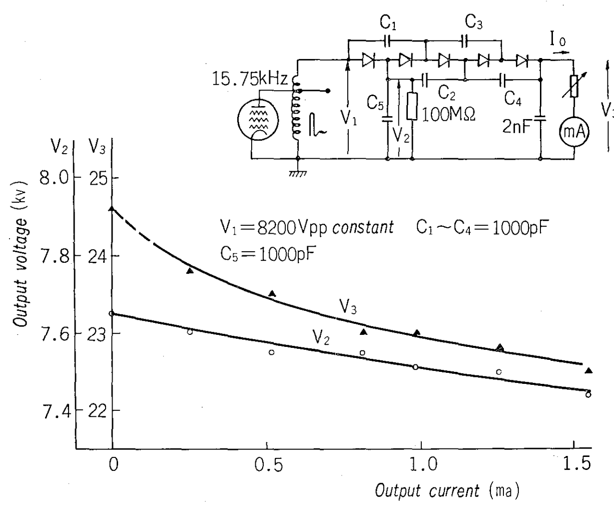


Fig. 21 Output regulation of cascade rectifier

However, in rectifiers with elements arranged in multi-series, voltage distribution unbalances due to stray capacitance to ground always appear, there is a partial temperature rise due to reverse loss and the selenium cells deteriorate. In Fuji Electric tests, the appearance of these phenomena in elements used in 15.75 kHz circuits with output voltages above 10 kv (at 25 mm from the ground) was evident. Therefore, a shield electrode is provided as standard to compensate for stray capacitance to ground in single rectification system elements. A typical example of the effect of the shield electrode on the influence of the stray capacitance to ground is shown in *Fig. 18*. Therefore, it is advisable that the elements are kept as far from ground as possible.

Fig. 19 shows a typical example of the temperature rise conditions due to forward and reverse losses in HS 25/1 elements.

Many investigations are now being conducted into high voltage rectification in color TV sets as it has already been made practical. The cascade system is used at present for most in color TV sets due to circuit and loss considerations.

The cascade rectifier elements used for color TV are the doubler or trippler types. Fuji Electric has completed two series: a trippler type with an input of 10 kv, and a doubler type with an input of 15 and 20 kv. Both series have outputs of 25 kv, 1.5 ma. These elements possess the following features when compared with vacuum tube rectifiers.

1)–4) The same features as rectifier elements for black-and-white TV sets.

5) If the focus voltage is taken from the 1st level when required, voltage regulation is easy since it can be varied by following the high voltage with the focus voltage. A shunt regulator is therefore not necessary.

6) The windings of flyback transformer are reduced and regulation is good.

7) The problem of X-radiation is eliminated.

8) The flyback transformer voltage is low, it is compact, the insulation gap is small and installation is convenient.

Fig. 20 shows an external view of the trippler cascade type and *Fig. 21* shows typical output characteristics for this element. Generally even number of element in cascade is all right in small type. But it is not absolute according to input pulse form. The higher the capacitance of the connecting capacitor the better, but when it exceeds 1000 pF, it exerts a slight influence. Therefore, Fuji Electric uses a 1000 pF capacitor as standard.

6. Other Circuits

Selenium rectifier elements are often used in other circuits such as clamp circuits and converter power supply circuits. In all of these applications, there is sufficient merit as described above.

VII. CONCLUSION

This article has described the essential problem points met in selenium rectifier elements for TV use as well as their characteristics. The suitability of selenium rectifier elements as TV circuit elements has been shown once again. The demand for these elements has and is increasing considerably and it is hoped that this article will help in making these elements more effective and more widely used.

As has been described, there is considerable freedom in the design and manufacture of these elements. When the essential characteristics of the selenium rectifier elements are grasped, the number of circuits in which they can be used will gradually increase. Because of this, these elements will probably be manufactured more and more in the future.