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*Received March 1961*

# **TRAVELING-WAVE TUBE REFLEX TYPE MICROWAVE REPEATERS**

**TOKYO SHIBAURA ELECTRIC CO., LTD.**

# Traveling-Wave Tube Reflex Type Microwave Repeaters

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**D**EVELOPMENT AND MANUFACTURE of traveling-wave tubes of various types and equipment utilizing these microwave tubes have been undertaken by the Company for a long time. Among them are traveling-wave tube microwave repeaters of direct relaying type. However, a more recent product of great significance is a reflex type repeater which will be described in this article. This repeater utilizes the great bandwidth afforded by the traveling-wave tube amplifier, in which the input signal after being amplified at its own frequency is converted into another frequency for further amplification in the traveling-wave tubes. This process may be repeated several times.

As compared with the conventional method of converting the frequency to an intermediate frequency for amplification in the superheterodyne system, the direct relaying traveling-wave tube (TWT) repeater dispenses with microwave tubes for local oscillator, the AFC circuit, and the IF amplifiers to permit extreme simplification of the circuitry and construction, which affords easy adjustment and maintenance.

When, in conjunction with newly developed traveling-wave tubes, the reflex system is applied to TWT microwave repeaters, there is no need for a series of traveling-wave tubes for step-by-step amplification; and the same gain can be obtained with a fraction of the number of traveling-wave tubes that

were formerly necessary. Consequently, great economy is achieved through the application of the reflex system.

## Mechanism of Operation

The principle used in the TWT reflex-type microwave repeater is similar to that involved in ordinary radio receivers utilizing the same vacuum tube for amplification of both high- and low-frequency signals; while the slight difference in frequency of the incoming and outgoing signals of frequency-modulated microwave repeaters is utilized for reflex operation.

In Fig. 1 are given the basic and the equivalent circuit of an FM microwave repeater designed for overall gain of not less than 100 decibels. The input signal  $f_i$  is amplified by traveling-wave tubes No. 1, No. 2 and No. 3 and is passed through the crystal diode mixer Mix 1 for conversion to frequency  $f_i - \Delta f_1$ . After conversion, the signal is again fed into TWT No. 1, No. 2 and No. 3 for amplification, then passed through mixer Mix 2 for conversion to frequency  $f_i - \Delta f_1 + \Delta f_2 = f_{out}$  for further amplification in TWT No. 1, No. 2 and No. 3 before retransmission. The bandpass filters (BPF) constitute the branching circuits for the desired frequencies.

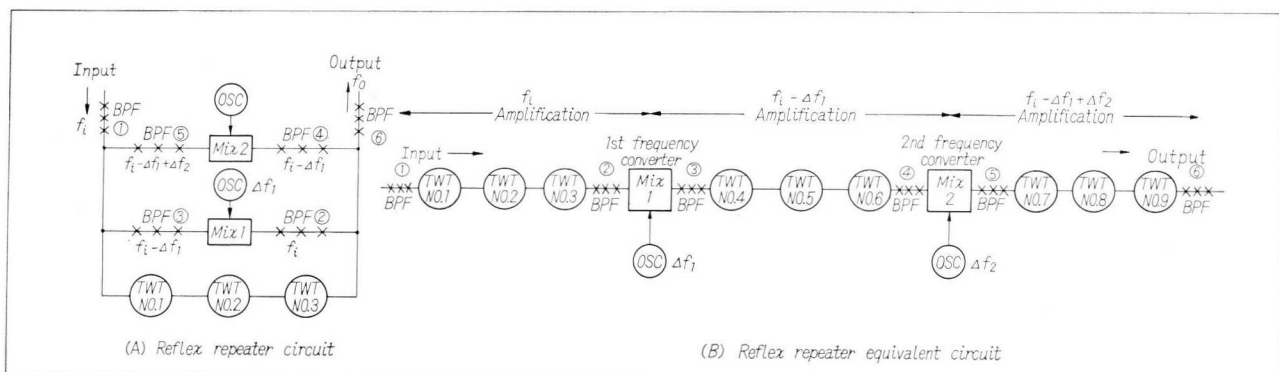


Fig. 1 Reflex TWT microwave repeater circuits

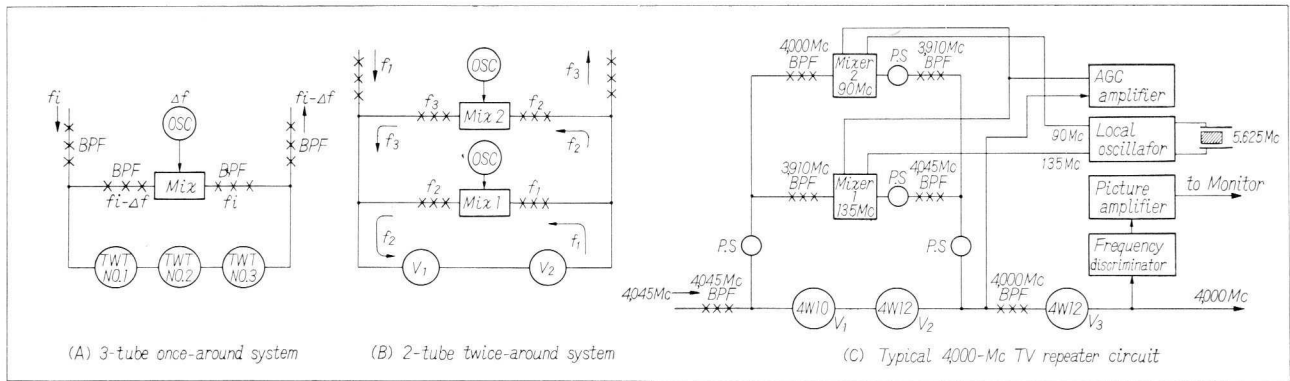


Fig. 2 Reflex TWT microwave repeater circuits

The overall gain obtained by this arrangement is the equivalent of what would be obtained by step-by-step amplification of the three different waves  $f_i$ ,  $f_i - \Delta f_1$  and  $f_i - \Delta f_1 + \Delta f_2 = f_{out}$ , and even when considering the losses occurring in the mixers and band-pass filters, and the relatively low gain due to the use of the traveling-wave tubes No. 2 and No. 3 at a high input level, it is possible to expect as much amplification as when using six or seven traveling-wave tubes in series. Consequently, the reflex system permits reduction of the number of traveling-wave tubes by at least a half.

The circuit shown in Fig. 1 makes use of three traveling-wave tubes for three stages of amplification to perform microwave repeating over a span of about 100 kilometers. Depending on the span and the required overall gain, such arrangements as shown in Fig. 2 can be considered. Fig. 2 (A) uses three traveling-wave tubes for double amplification after single frequency conversion, while Fig. 2 (B) uses two traveling-wave tubes for triple amplification after double frequency conversion. The circuit shown in Fig. 2 (C) uses TWT No. 3 only as a power tube to avoid any adverse effect upon low-level signals through saturation by this tube—an example of TV signal relaying in the 4000 Mc band.

Although it is possible to devise various types of reflex circuits using traveling-wave tubes, information concerning variations in noise, distortion, gain and stability to be caused when using a single traveling-wave tube for repeated amplification by means of frequency conversion is as yet incomplete. As a result of the preliminary experiments carried out by the writers, the following points have been revealed:

(1) When more than two waves of frequency of different levels are simultaneously amplified by a single traveling-wave tube, the saturation caused by the high-level signals will in turn bring a reduction in gain for the low-level signals; and a wider range of automatic gain control is afforded by the reflex method than by conventional means. On the other hand, distortion or oscillation may be caused when operated in a range of high saturation.

(2) Experiments on noise and cross talk when

amplifying high- and low-level FM signals simultaneously indicate that traveling-wave tube amplification is virtually free from noise and cross talk when operated below the saturation point. However, when the input level is high and the amplifier is under saturation, both noise and cross talk worsen. Cross talk between these two signals in case of reflex amplification takes the form of distortion; and it has been learned that, to prevent distortion and high noise level, the traveling-wave tube should be operated so that excessive saturation may not occur. Due care exercised in this direction may help to prevent any bad effect on distortion or noise level.

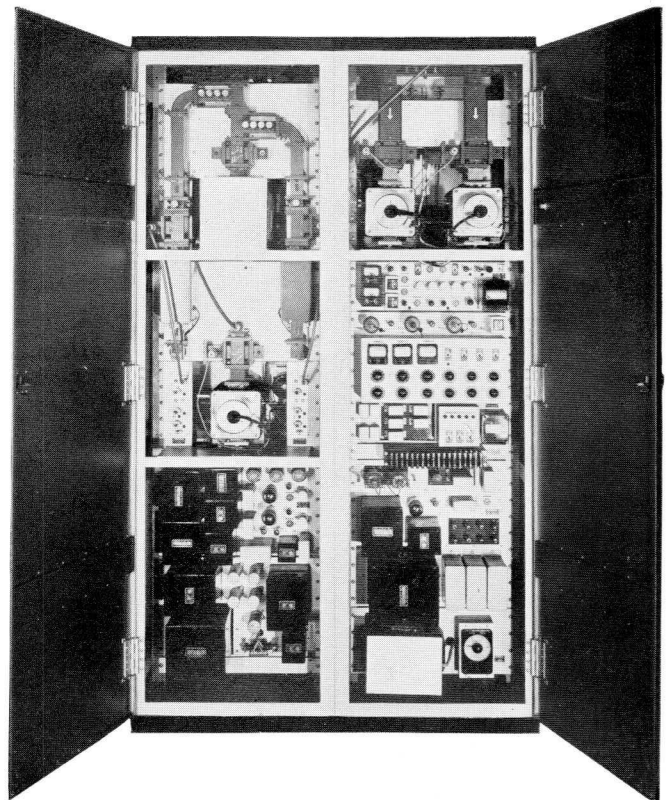


Fig. 3 Reflex-type TWT repeater capable of simultaneously amplifying two different microwave routes

## Reflex Type Microwave Repeaters

### 7,500-Mc FM Microwave Repeater, Type SS-1512A

This apparatus is a product of a further expansion of the ideas explained above, incorporating simultaneous handling of two microwave channels (east- and west-bound channels) by means of a single set of traveling-wave tubes operated on the reflex principle. This arrangement permits a reduction in the number of traveling-wave tubes. The 7,500-Mc band is used, and the repeater is designed for relaying television or radar signals. Fig. 3 is an external view of the equipment, with the reflect portion at the upper left side. The upper right bay contains the output power tubes for the east- and west-bound channels respectively. Fig. 4 is the block diagram of the equipment. As the east- and west-bound channels are subject to different condition of fading, separate automatic gain controls must be effected for each channel. Because the output power tubes amplify high-level signals, separate traveling-wave tubes are provided for each channel to prevent mutual interference. For AGC a piece of ferrite is used in Farady rotation to serve as a microwave variable attenuator, to keep the output virtually constant against the input power variation of 40 decibels.

Both east- and west-bound input signals pass through a branching circuit and enter  $V_1$  (Type 8W20 low-noise traveling-wave tube). After amplification, the signals are further amplified by  $V_2$  (TWT Type 8W22). The output then is divided into east- and west-bound signals which, after passing through their respective AGC, are fed into the frequency converters. Mixing is effected in the converters to obtain transmitting frequency by applying 120 Mc (or 200 Mc) obtained through the frequency multiplication of the outputs of crystal oscillators. After reamplification in  $V_1$  and  $V_2$ , the east- and west-bound signals are separated out by the branching circuit and are separately amplified by  $V_3$  and  $V_4$  before being fed into the antenna. A portion of the output of the

power tubes is detected by a two-cavity frequency discriminator for monitoring the modulation signals.

Power for traveling-wave tubes must be of high stability. Since in this equipment four traveling-wave tubes are employed, the power of high voltage as well as relatively high current is required. Stabilization of such high power would normally call for heavy-duty vacuum tubes; but required stability has been obtained by utilizing magnetic amplifiers in conjunction with small vacuum tubes.

### Performance characteristics

The principal characteristics of this equipment are as follows:

|                          |   |
|--------------------------|---|
| Transmitting frequencies | East-bound 7,380 Mc<br>West-bound 7,420 Mc                |
| Receiving frequencies    | East-bound 7,580 Mc<br>West-bound 7,540 Mc                |
| Relaying system          | All-TWT microwave repeater                                |
| Power source             | 200V $\pm$ 5% a-c, single-phase,<br>50 or 60 cps          |
| Power consumption        | Approx. 1,400 VA  |
| Transmitting output      | Not less than 2 W (repeater<br>output)                    |
| Noise figure             | Approx. 15 dB   |
| Amplification gain       | Not less than 85 dB                                       |
| Amplification bandwidth  | Approx. 20 Mc   |
| Dimensions               | 1,270 mm (w) $\times$ 450 mm (d) $\times$<br>2,000 mm (h) |

Regulation of the power output is done by magnetic amplifiers in conjunction with small vacuum tubes. Figs. 5 and 6 show respectively the output voltage against fluctuations of the line voltage, and the output voltage against fluctuations of the load current.

### 7,500-Mc FM Microwave Repeater, Type SS-1464B

This repeater is designed for operation in the 7,500 Mc band for multichannel communication by single-sideband frequency modulation. Because high-gain traveling-wave tubes are used with the reflex arrangement, a gain of not less than 100 decibels is obtained with only three traveling-wave tubes. The salient features of this equipment are as follows:

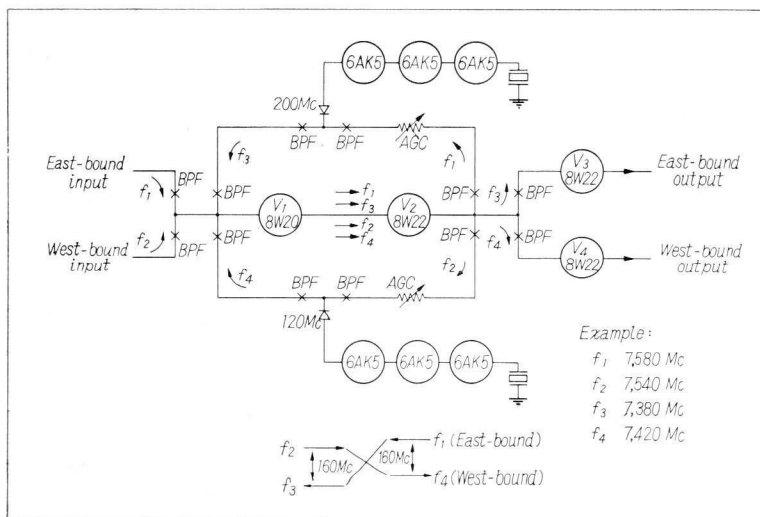


Fig. 4 Block diagram of the reflex-type all-TWT repeater capable of simultaneously amplifying two different microwave routs

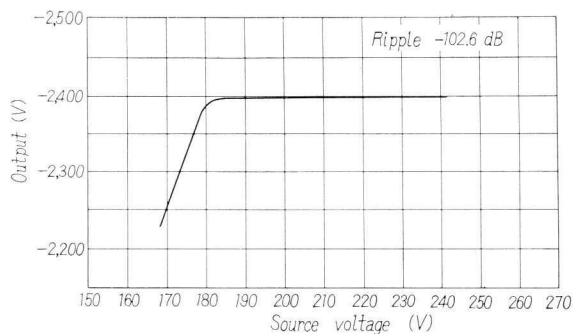


Fig. 5 Stability of the high voltage power source

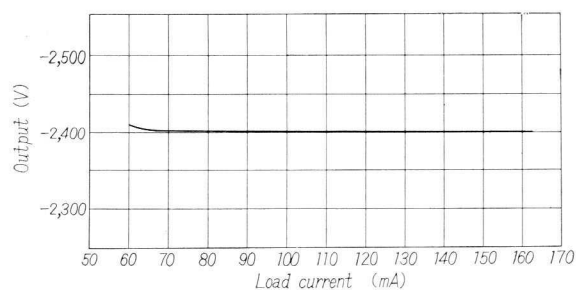


Fig. 6 Voltage regulation of power supply

### Performance characteristics

The principal performance characteristics of this equipment are as follows:

|   |   |
|---|---|
| Frequency band  | 7,425 to 7,745 Mc   |
| Interval between transmitting and receiving frequencies | 160 Mc  |
| Replaying system  | All-TWT microwave repeater  |
| Channel capacity  | 120 channels (plus an extra conversation channel)                 |
| Power source  | 200 V $\pm 5\%$ a-c, single-phase, 50 or 60 cps                   |
| Power consumption                                       | Approx. 0.7 kVA (in service)<br>Approx. 0.3 kVA (stand-by)        |
| Transmitting output                                     | Not less than 3 W, repeater output (not less than 5W, TWT output) |

(1) Because ferrite permanent magnets are used for focusing the beams of the traveling-wave tubes, bulky electromagnets are eliminated to make for compactness and ease of replacement. Furthermore, the power drain of electromagnet excitation is removed.

(2) A compact and efficient circulator is used in the 160-Mc frequency converter to avoid a bad effect on the image frequency. Further, great stability is provided against the deterioration of crystal diode.

(3) Convenience during installation and for maintenance is provided since it is possible to make calls simultaneously to both east- and west-bound directions by the use of the equipment.

(4) A spare repeater is provided for substituting either the east- or west-bound repeater in case of trouble. Substitution can be done either automatically or by remote control from the terminal station.

(5) A compact, serviceable assembly has been worked out, with the equipment housed in a locker type cabinet of 520 millimeters in width, 225 millimeters in depth and 2,350 millimeters in height. All controls are done at the front, so the sets can be positioned against a wall or two sets can be installed back to back. All component units are of the plug-in type, so replacement is simple and quick, while inspection is easy.

Fig. 7 shows the exterior of the equipment. The upper section comprises the amplifier portion of the microwave repeater, while the lower section houses the power supply and control circuitry. Fig. 8 is the block diagram of a microwave repeater, Type SS-1464B. As is clear in the diagram, a reflex circuit is constituted by  $V_1$  (low-noise traveling-wave tube, Type M7855) and  $V_2$  (TWT, Type 8W23). Automatic gain control is effected here by means of the ferrite variable attenuator previously described. Frequency conversion of the order of 160 Mc, the difference between receiving and transmitting frequencies, is also effected. Power amplification is done by TWT, Type 8W23 ( $V_3$ ), to bring the power up to a required level, and the outgoing signal is passed through the waveguide switching and branching circuits to the antenna.

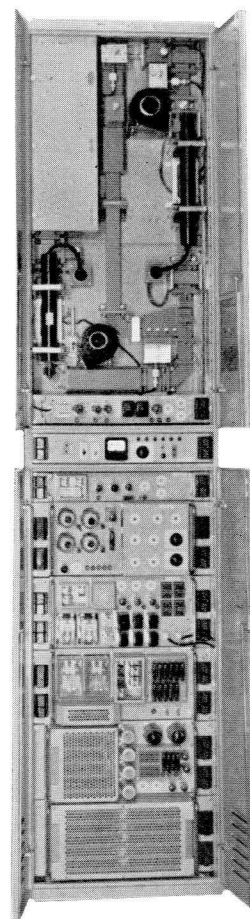


Fig. 7 7,500-Mc traveling-wave tube FM repeater

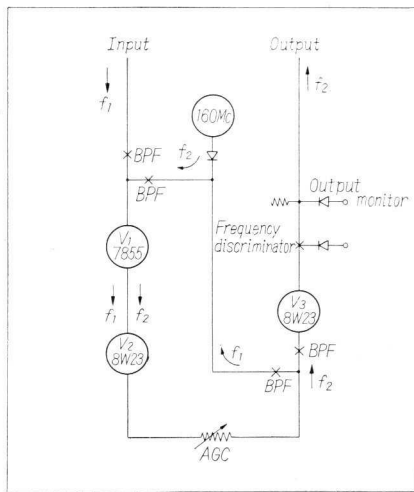


Fig. 8 Block diagram of 7,500-Mc traveling-wave tube reflex type FM repeater

|  |  |
|--|--|
| Noise figure                             | Approx. 12 dB (incl. bandpass filter and isolator losses)                          |
| Amplification gain                       | Not less than 110 dB   |
| Amplification bandwidth                  | Approx. 20 Mc  |
| AGC characteristics                      | Output power fluctuation not more than 2 dB with input ranging from -75 to -35 dBm |
| Conversation channel                     | SSB, using 8 or 36 kc as carrier   |
| Conversation channel input/output levels | Input, -25 dBm; output -15 dBm; 75-ohm coaxial                                     |

### Traveling-Wave Tubes

The traveling-wave tubes which constitute the heart of the TWT microwave repeaters possess the following characteristics:

Because the helix type traveling-wave tube is capable of amplification over a wide bandwidth, it is outstandingly suitable for use in microwave repeaters for multichannel service. Currently, the traveling-wave tube is widely used in many countries as the output power tube in superheterodyne type microwave repeaters, but instances of an all-TWT repeater are relatively uncommon.

The Tokyo Shibaura Electric Company has developed special low-noise as well as high-gain medium-power traveling-wave tubes for use in the reflex type all-TWT microwave repeaters designed by its engineers.

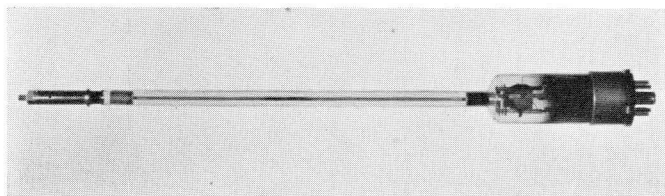


Fig. 9 Solenoid type low-noise traveling-wave tube, 8W20

### Low-Noise Traveling-Wave Tube

As a result of studies made in an effort to reduce the noise figure of traveling-wave tubes, a noise figure of less than 10 dB in the 7.5-Gc band was successfully obtained. The use of such a low-noise tube in the input stage of all-TWT microwave repeaters results, it goes without saying, in great improvement of the signal-to-noise ratio.

The low-noise traveling-wave tubes developed are for the 7.5-Gc band: Type 8W20 is of the solenoid type, while Type M7855 is of the periodic magnet integral type. Their general characteristics are: Gain not less than 25 dB; noise figure not more than 10 dB; waveguide coupling type; uniform field of 700 gauss for the SW20, and periodic fields with peaks of 750 gauss and pitch of 10.4 millimeters for the M7855. External views of these tubes are shown in Figs. 9 and 10.

Type 8W20 was used as the input stage tube in two-way reflex repeaters, but the development of the M7855 "packaged"-type tube to be used in conjunction with the "packaged"-type power tube 8W23 contributed much toward completion of a single-bay reflex type all-TWT microwave repeater. By the use of permanent magnets in the electron beam focusing arrangement, not only did the special power supply for excitation of the solenoids become unnecessary, but the overall size was reduced to approximately one fifth of the former bulk. As can be seen in Fig. 10, the M7855 traveling-wave tube is of the waveguide coupling type. Consequently, special consideration has been directed toward the magnetic field distribution in the transitional region between the electron gun focusing field and the helix circuit magnetic field. The electron gun focusing field is a uniform one maintained by a permanent magnet, while the concentrating fields of the helix portion are created by ring-shaped permanent magnets arranged in alternating polarity to make a periodic field.

### Medium Power Traveling-Wave Tubes

Two types of medium power tubes are currently available: the solenoid type 8W22A and the periodic magnet integral type 8W23 which is the "packaged" type of the 8W22A. With the development of the "packaged" type, it became possible to produce single-bay TWT microwave repeaters to replace the old, bulky and complex two-bay construction.

The 8W22A has been in actual service since February 1958 in the Tokyo-Sendai 7.5-Gc band microwave communication circuit of the Japanese National Railways. Its function is extremely stable, and its service life averages more than 10,000 hours. The general characteristics of this tube are: frequency—7,600 Mc, helix voltage—2,400 V, beam current—30 mA, gain—35 dB, power output—2 W, saturated output—8 W, small signal gain—not less than 37 dB, noise figure—about 25 dB forced air cooling. Its general appearance is shown in Fig. 11.

The "packaged" 8W23 is extremely compact. The

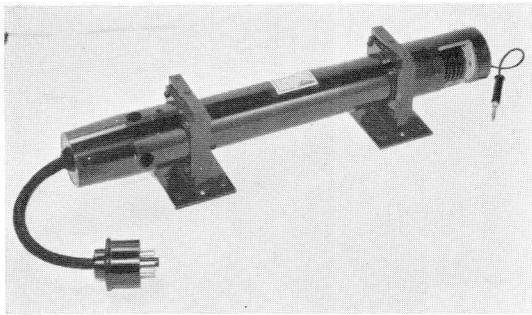


Fig. 10 "Packaged"-type low-noise traveling-wave tube, M7855

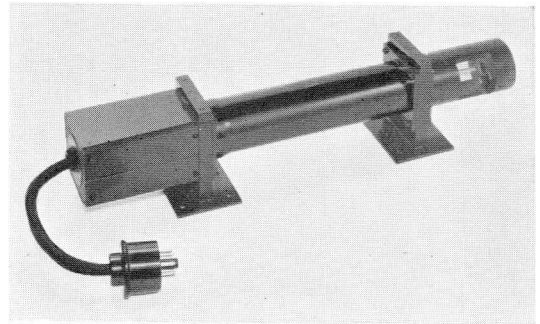


Fig. 11 Solenoid type medium power traveling-wave tube, 8W22A

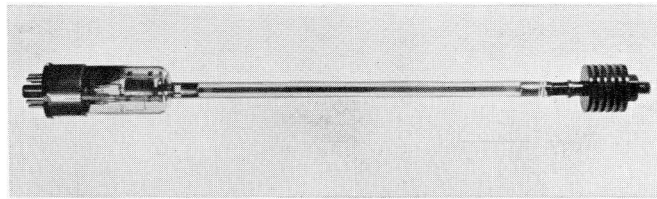


Fig. 12 "Packaged"-type medium power traveling-wave tube, 8W23

general characteristics of this tube are: frequency—7,600 Mc; gain at power output 3 W—35 dB; small signal gain—40 dB, helix voltage—2,550 V, beam current—25 mA, helix current—0.07 mA, saturation power output—6 W, noise figure—about 25 dB; forced air cooling. Its overall length, including the magnet apparatus, is 350 millimeters and it weighs only 2.6 kilograms. It will be put in actual service in 1960 in the microwave lines of the Japanese National Railways (Sendai—Hakodate) and the Electric Power Development Company (Tokyo—Hiroshima). Fig. 12 shows the exterior view of the 8W23.

Since the small signal gain of these medium power tubes is not less than 35 dB, they are suitable for use as amplifier tubes and output power tubes of reflex type microwave repeaters. Particularly the 8W23 has, in addition to its compactness, the advantage of a small signal gain of not less than 38 dB and a noise figure of not more than 25 dB. Consequently, it meets all the requirements for use as traveling-wave tubes for single-bay microwave repeaters. It is also advantageous that mutual interference can be reduced at the time of the simultaneous amplification of two or more frequencies in reflex type microwave repeaters. And furthermore, the gain and the noise figure have high performance characteristics since the signal level in the amplification stage is equivalent to the small signal level in the output power stage.

Production of high-efficiency microwave repeaters

has been facilitated by the development of high performance, "packaged" traveling-wave tubes.

### Conclusion

The reflex repeater system and the traveling-wave tubes developed by Toshiba are greatly advanced in design. However, the basic principles were worked out as early as 1951 to 1954 in collaboration with NHK (Broadcasting Corporation of Japan). Experiments conducted on the Tokyo-Nagoya-Osaka 4,000-Mc TV relay circuit indicated that the TWT reflex system was equal, if not superior, to the conventional super-heterodyne system of relaying. More recently, efforts have been concentrated on the development of the 7,500-Mc band, and the results have been outlined above.

With great advances expected ahead in the design and construction of the traveling-wave tube, a more dependable microwave repeater system—better, simpler and less costly—will make its appearance in the near future.

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