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Worldwide Use of Siemens Traveling-Wave Tubes in Satellite Ground Stations

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The beginning of commercial usage of the Early Bird satellite on June 28, 1965 marked a new era in worldwide communications. The success of the Early Bird experiment put an end to the controversy concerning the feasibility of communicating via synchronous satellites and demonstrates the great potential of satellite repeaters for global communications systems.

Satellite communications system

A satellite communications system consists of a number of earth stations and at least one satellite as an active repeater station. An important item in every earth station is the transmitter, which must supply the power to overcome the considerable path loss between the earth station and the orbiting satellite (200 dB) with the low distortion and low noise essential in satellite communication, and at the same time meet the stringent economic and reliability requirements of commercial communications systems.

This means that the transmitter tube must satisfy special requirements. The choice of tubes for the currently used transmitting frequencies in the 5.925 to 6.425 GHz band is restricted to multi-cavity klystrons and traveling-wave tubes. For the multi-carrier operation needed in modern multi-access satellite repeater systems, broadband traveling-wave tubes offer a distinct advantage.

Siemens recognized the importance of *high-power traveling-wave tubes* in satellite repeater systems at an early date and initiated appropriate devlopment work [1 to 6], and today occupies a leading position in this sector, and most European as well as many non-European earth stations for the Intelsat III system are equipped with Siemens traveling-wave tubes.

Requirements for transmitter tubes for earth stations

Siemens high-power traveling-wave tubes for earth stations are for the most part designed to meet Intelsat III requirements the first global satellite repeater system of the Intelsat organization. Two synchronous satellites will be placed in an equatorial orbit over the Atlantic and another two over the Pacific and the Indian Oceans respectively. By 1970 some 30 earth stations will be in service in the Atlantic area and some 15 in other areas. Each satellite is provided with two transponders with a bandwidth of 225 MHz each which, operating in conjunction with powerful transmitters at the earth stations, allow the simultaneous transmission of 1200 telephone or four television channels.

High-capacity ground stations will be assigned up to three telephone carriers with 120 voice channels each and one television carrier. Earth stations must be able to radiate an rms power of 82 dBW for each 120-channel carrier. Given the conventional antenna gain of 61 dB and feeder losses of about 3 dB, this means a power requirement of about 250 W per 120-channel carrier at the output of the final amplifier stage. The corresponding maximum power requirement for the television carrier is 1.4 kW.

For an earth station with several carriers, the output stage can be circuited in either of two ways. Either a separate output amplifier may be used for each carrier and the amplified carriers interconnected with switching networks before they reach the antenna, or as many carriers as possible may be combined before they reach the output amplifier and then collectively amplified to the required transmitting level. Fig. 2 provides a schematic representation of the two alternatives for a station with three telephone carriers and one television carrier, where only the telephone carriers are collectively amplified for multi-carrier operation.

The decision as to which of the two options is technically and economically more favorable depends greatly on the linearity of the multi-carrier tubes. The main drawbacks of single-carrier tubes are considerable losses

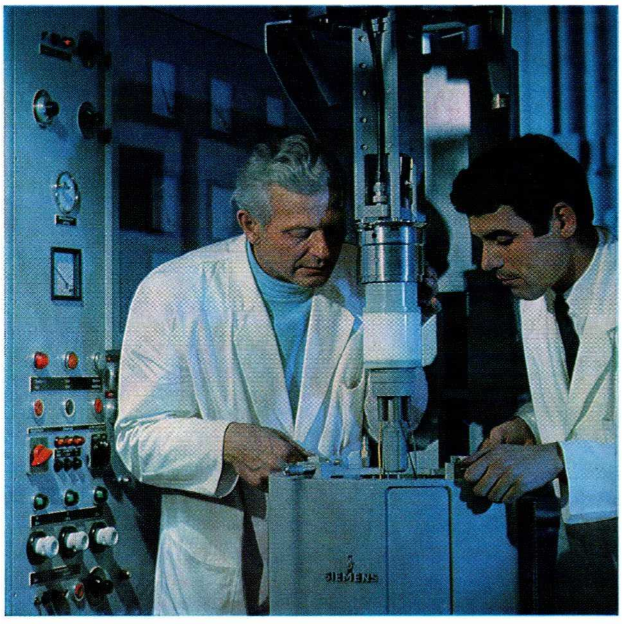


Fig. 1 Siemens traveling-wave tube YH 1045 in test department

Type designation		YH 1040	YH 1041	YH 1042*	YH 1043*	YH 1044	YH 1045	YH 1046
Frequency band	GHz	5.925 to 6.425						
Preferred use		Multi-carrier	Multi-carrier	Single-carrier	Single-carrier	Multi-carrier	Multi-carrier	Multi-carrier
Saturation power	kW	3	5	1	1	8	12	12
Efficiency at saturation power	%	30	30	30	30	30	30	30
Output power per carrier**		450	750	300	150	1500	2000	2000
Delay-line voltage	kV	16	17	16	8.5	19	19	19
Focusing structure		PPM	PPM	PPM	Solenoid S	Solenoid S	Solenoid S	Solenoid S
Coolant		Liquid	Liquid	Air	Air	Liquid	Liquid	Liquid

* Under development ** For a third order distortion factor of −18 dB (measured with two carriers of the same amplitude)
Siemens high-power traveling-wavetubes, for earth stations

in the combining network, lack of flexibility in frequency--changing, complex standby provisions and inferior reliability.

The smallest coupling losses for single-carrier tubes are obtained by using the circuit arrangement with circulators and reflecting filters shown in Fig. 2a, but a full utilization of the frequency band is difficult to realize on account of the finite slope of the filters. This difficulty can be avoided by using 3-dB couplers, but the coupling losses are then considerably greater.

The multi-carrier technique has the advantage of great flexibility and standby provisions. When one tube fails an appropriate changeover operation will apply all traffic to the other tube at somewhat reduced power. Reliability is here greatly superior because there are fewer tubes and simpler control and protection devices.

The multi-carrier technique calls for the use of amplifying tubes with very high linearity [5], minimal gain slope (gain variation in dB per MHz) and AM/PM conversion – both of which determine the nonlinear crosstalk – as well as constant gain over the entire frequency band, minimum variations in group delay as a function of frequency, low harmonic power and a large signal-to-noise ratio [7]. Development work at Siemens in recent years has helped to improve the characteristics of high-power traveling-wave tubes to such an extent that all high-capacity Intelsat III stations are to be equipped with TWT amplifiers for multi-carrier operation.

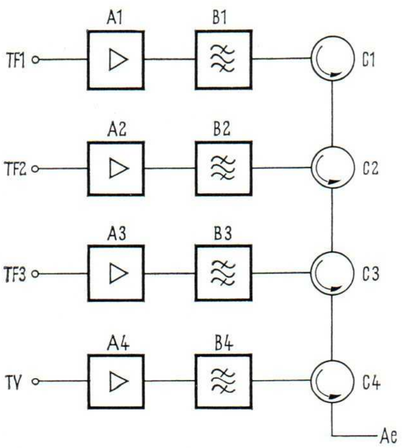
Siemens line of TW tubes

Transmitter manufacturers differ greatly in their specifications for transmitting tubes. This is due not only to the differences in the communications capacity required by the various stations but is also attributable to differences regarding the economically justified technical performance, the reliability requirement and the spare supply philosophy.

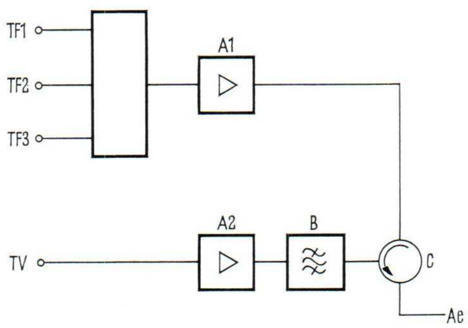
In order to satisfy as many requirements as possible, Siemens offer a broad spectrum of high-power traveling--wave tubes. The available types and their principal characteristics are listed in the Table. The YH 1040 and YH 1042 are focused with a periodic permanent magnet system, a method which offers great advantages with regard to power consumption and reliability. The 12-kW tube YH 1045 (Fig. 1) is the most powerful traveling-wave tube for earth stations currently available on the world market [5, 6]. YH 1042 and YH 1043 – both for medium moderate capacity stations – are still development.

Ground stations with Siemens traveling-wave tubes

The first operational experience with high-power traveling-wave tubes in earth stations was recorded at



a) One tube per carrier



b) One tube for all telephone carriers

TV Telephone carrier inputs
TV Television carrier input
A Output amplifier with traveling-wave tube
B Filters
C Circulators
Ae To antenna

Fig. 2
Output stage for amplifying three telephone carriers and one TV carrier

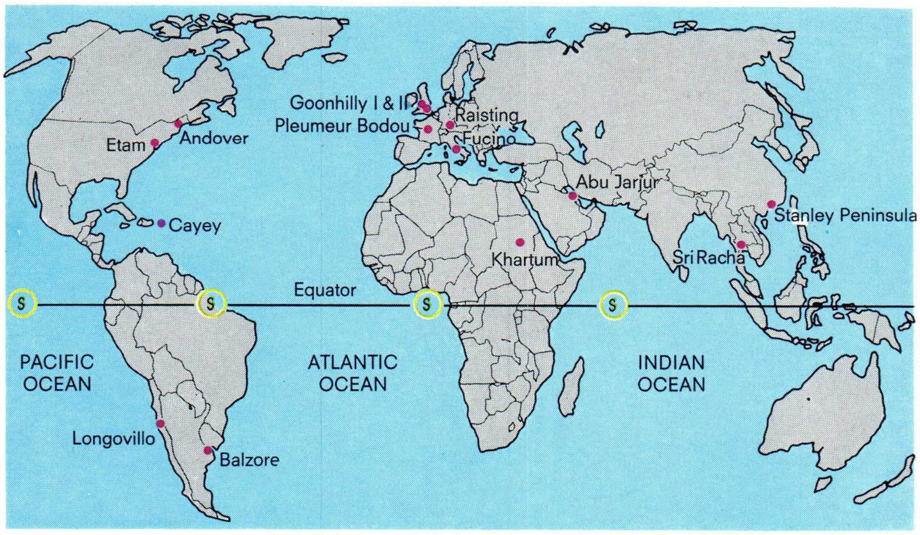


Fig. 3
Worldwide use of Siemens traveling-wave tubes in Intelsat III earth stations

• Earth stations operating or planned with Siemens traveling-wave tubes

(S) Position of satellite repeater projected on equator

the German earth station in Raisting, where Siemens YH 1040 tubes have been in use ever since the station started operation in 1964 [8].

Siemens traveling-wave tubes have since proved their value all over the world. In European earth stations, the Siemens traveling-wave tube YH 1041 is widely used. One of its typical applications is in the Intelsat III system of the Raisting ground station, which is equipped with one YH 1041 for two telephone carriers for up to 120 voice channels each, another YH 1041 for television transmission and yet another YH 1041 as a standby. For large earth stations outside Europe, traveling-wave tubes with higher power ratings such as the YH 1045 and YH 1046 are preferred. Typical for their use is the technique chosen by Marconi for the English Goonhilly II earth station, which is equipped with one YH 1045 for three telephone carriers for 120 channels each and another YH 1045 for the television carrier. If one of these tubes fails, the entire traffic is then serviced by a third standby tube [9].

Fig. 3 shows the worldwide distribution of earth stations which either already use Siemens traveling-wave tubes or have placed an order with Siemens for such tubes.

The establishment of high-capacity stations with multi-carrier facilities for the Intelsat III system has been largely completed. The next stage of expansion will concentrate on small-capacity stations, where traveling-wave tubes will also offer advantages in that their bandwidth greatly simplifies both standby operation and the purchasing of spares. Since the noise levels allowed for Intelsat IV will be still lower and the conservation of bandwidth will be a factor of even greater importance, traveling-wave tubes will again have much to offer.

In the more distant future it will be necessary to use still higher transmitting frequencies for satellite repeater systems. Development work on suitable transmitter tubes for frequencies up to 30 GHz has already started at Siemens.

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