A Compact 4-GHz Linearizer for Space Use

RYUICHI INADA, HIROSHI OGAWA, SUSUMU KITAZUME, AND P. DESANTIS

Abstract —**A compact and lightweight 4-GHz linearizer for satellite TWTA's has been developed by using MIC packages with chip devices. The linearizer is composed of a preamplifier, a predistortion linearizer, and a limiting amplifier, consisting of two, three, and three 25×12.5-mm packages, respectively. It improves the noise power ratio for an FM system by 3 dB and the required C/N for a TDMA system by 4.5 dB compared with the conventional satellite TWTA. A space environmental test and an aging test were successfully performed on the equipment.**

I. Introduction

TWT's are most commonly used in satellite communication systems for their large output power for a reasonable weight and power consumption. In satellite transponders, it is desirable that the TWTA be operated near saturation level. However, the amplitude and phase distortion degrade TWT performances, as seen, for example, in AM/AM conversion and AM/PM conversion. These degraded parameters will cause intermodulation noise and phase ambiguities in transmitting signals and will significantly affect the satellite communication system performance. The linearizing technique is an effective method for reducing this degradation of the TWTA response.

This paper describes the design, construction, and performance of a linearizer for satellite TWT's operating both in SCPC and in TDMA modes. Space qualification tests including accelerated aging tests were successfully performed on the equipment and the results are summarized in Section IV.

II. Linearizer Design

There are several methods to compensate TWTA nonlinearity; of these, feedforward [1], [2] and predistortion [3]–[11] are widely used.

Fig. 1 shows the block diagram of the feedforward and predistortion techniques. In the feedforward method, the input signal is divided into two paths: one for TWT1 and the other for a reference path whose delay time is equal to that of TWT1. The two signals are compared in the error-summing coupler. The error signal is amplified by TWT2, and the output signal of TWT1 is delayed by a time equal to TWT2. The two signals are then combined in an error-injection coupler whose output is the compensated signal. This method is stable, since it contains no closed loops. However, it requires two TWT's and two delay lines, which will increase the overall weight and power consumption. On the other hand, the predistortion circuit can be realized with low-power amplifiers and several passive devices. Thus, it can be compact, lightweight, and have low power consumption. For these reasons, the predistortion type was selected for use in satellite transponders.

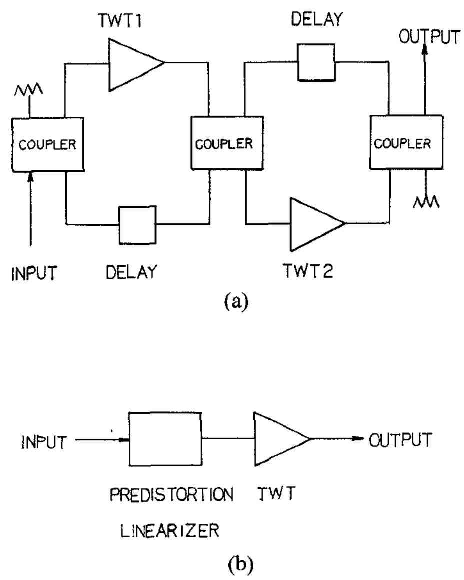

Fig. 1. Block diagram of the (a) feedforward and (b) predistortion methods.

Fig. 2 shows the block diagram of the 4-GHz linearizer. It consists of 3 sections: a preamplifier, a predistortion linearizer, and a limiting amplifier. In the preamplifier section, the input signal is amplified to the level required to drive the predistortion linearizer. Amplitude and phase distortion is generated in the predistortion linearizer section in accordance with the input power level to compensate the nonlinearity of the TWTA. The limiting amplifier section prevents the TWTA from overdrive operation, and constant output power can be obtained above the saturation input level. The predistortion linearizer with the limiting amplifier is called a soft-limit-type linearizer, and it can considerably improve the bit error rate (BER) [3].

Construction of the predistortion linearizer section is shown in Fig. 2. The input signal is divided into two paths: one is the linear route and the other is the distortion route. The signal in the linear path passes through the phase

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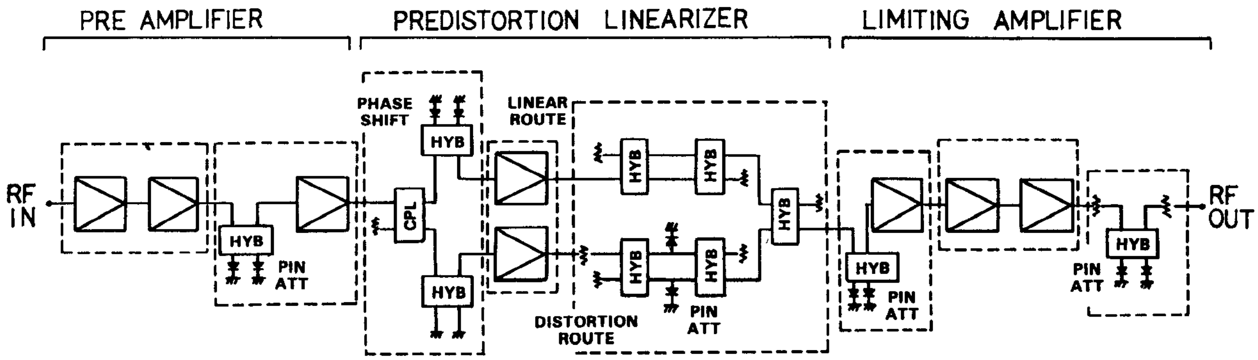

Fig. 2. Block diagram of the 4-GHz linearizer.

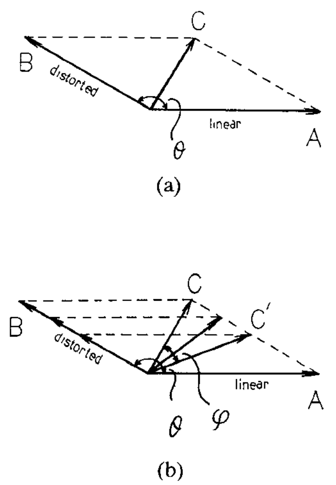

Fig. 3. Vector diagram of the predistortion linearizer for (a) small-signal level and (b) higher signal level.

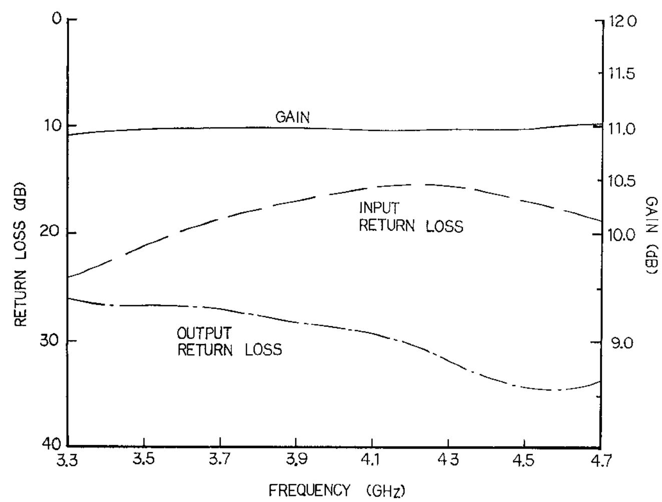

Fig. 4. Gain and return loss of the balanced-type amplifier.

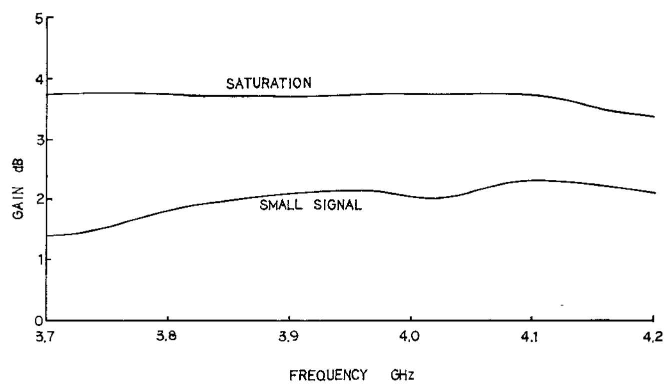

Fig. 5. Gain and gain variation of the linearizer.

shifter and the amplifier, and the signal in the distortion path passes through the amplifier and the p-i-n attenuator. The signals are combined by a hybrid. The vector diagram of the predistortion linearizer is shown in Fig. 3. Vectors $\boldsymbol{A}$ and $\boldsymbol{B}$ show the gain of the linear route and the distortion route, respectively. Vector $\boldsymbol{C}$, which is the vector sum of $\boldsymbol{A}$ and $\boldsymbol{B}$, is the gain of the output signal. A phase difference between the two vectors of about 180° is required to obtain the desired predistortion. For small-signal level, the gain of the linear route and that of the distortion route are constant. Thus, the gain of $\boldsymbol{C}$ is constant and no phase distortion is generated, as shown in Fig. 3(a). When the input power increases to a higher level, the input level of the amplifier of the distortion route approaches the saturation input level; hence, the gain of the distortion route is decreased. On the other hand, the linear route is still at the small-signal level; hence, the linear route gain is constant. Therefore, the gain of $\boldsymbol{C}$ is changed to $\boldsymbol{C}'$, and the phase distortion φ is generated, as shown in Fig. 2(b). The angle θ between $\boldsymbol{A}$ and $\boldsymbol{B}$ can be adjusted by the phase shifter, and the gain of $\boldsymbol{B}$ can be adjusted by the p-i-n attenuator. Therefore, the linearizer can be adjusted for various types of TWTA's.

The linearizer consists of eight MIC packages, as shown by the dotted line in Fig. 2. The first two packages form the preamplifier. The predistortion linearizer is composed of three packages that follow. The last three packages are the limiting amplifier.

The size of each package is 25×12.5 mm, which includes MIC's of 0.381-mm alumina substrate and several chip devices such as GaAs FET's, p-i-n diodes, and varactor diodes. The metal caps are laser welded. Balanced-type amplifiers, p-i-n attenuators, and a phase shifter are used to provide wide-band performances from 3.3 GHz to 4.7 GHz. Fig. 4 shows the typical gain and return loss data of the balanced-type amplifier. The isolators can be eliminated, and a compact and lightweight linearizer is realized.

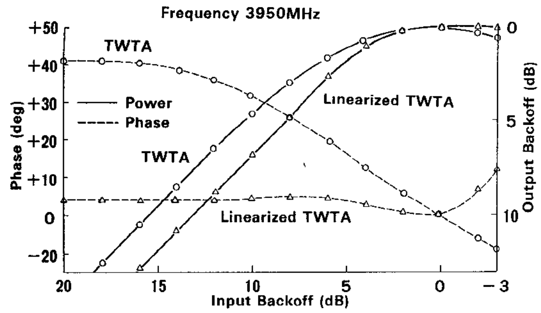

Fig. 6. Input/output power and phase transfer characteristics of the TWTA and the linearized TWTA.

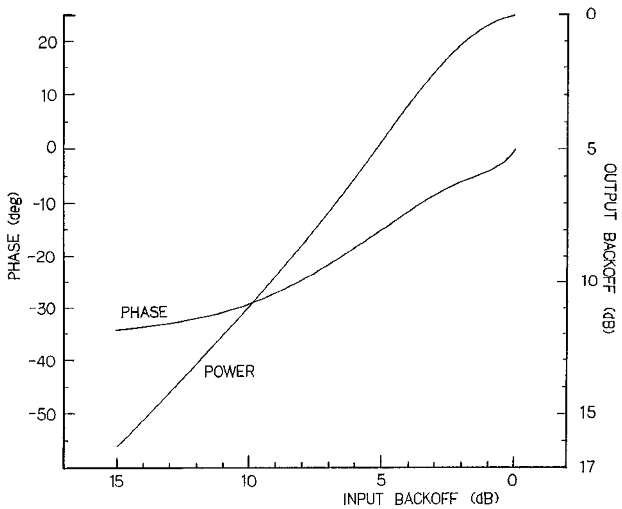

Fig. 7. Input/output power and phase transfer characteristics of the linearizer.

The linearizer contains the RF section, a voltage regulator, and bias circuits in one housing. In the RF section, the MIC packages are connected by microstrip line circuit using Teflon glass substrates. The shielding walls are made to get adequate isolation between input and output of each amplifier. The dimensions of the linearizer are 160 mm in length, 110 mm in width, and 23 mm in height; the weight is 461 g.

III. Performance of Linearizer and Linearized TWTA

The linearizer is adjustable by externally controlling the bias voltage and current of the phase shifter and the p-i-n attenuators in order to compensate for the nonlinearity of the TWTA. The TWTA used in the experiment is a Hughes model 249H, which is the same as the on-board type TWT for INTELSAT-V. The linearizer is temperature compensated over the range from 10°C to 40°C by using the sensistors in the bias circuits of the p-i-n attenuators and the phase shifter.

The gain and gain variation at small signal and saturation are shown in Fig. 5. The gain variation of the linearizer is less than 1 dB p-p from 3.7 GHz to 4.2 GHz.

The input/output power and phase transfer characteristics of the TWTA and the linearized TWTA are shown in Fig. 6. An output backoff of 0 dB corresponds to the saturation output power of the TWTA, and 0-dB input backoff corresponds to the saturation input power of the TWTA and linearized TWTA. The power transfer characteristic of the linearized TWTA is almost linear up to saturation, and constant above saturation. The phase transfer characteristic of the linearized TWTA is sup-

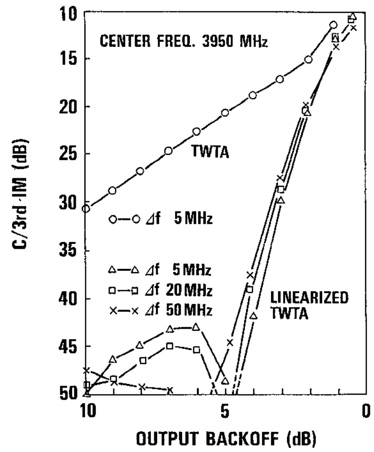

Fig. 8. Third-order intermodulation of the TWTA and the linearized TWTA.

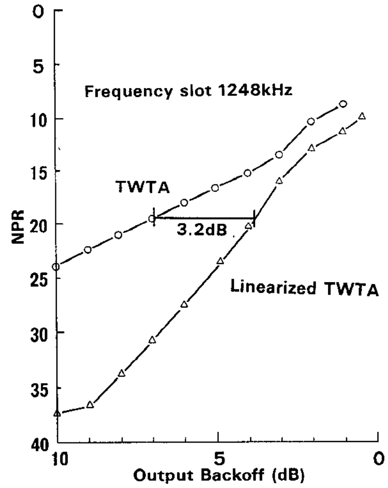

Fig. 9. NPR of the TWTA and the linearized TWTA.

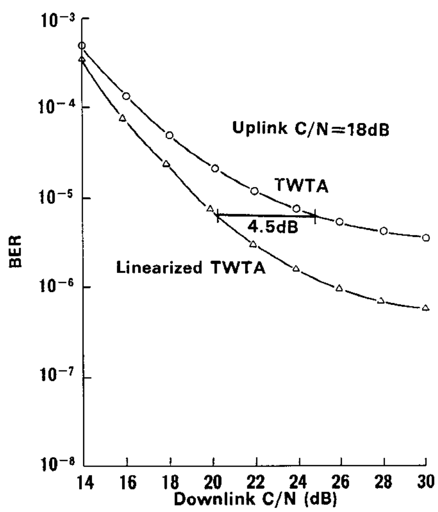

Fig. 10. BER of the TWTA and the linearized TWTA.

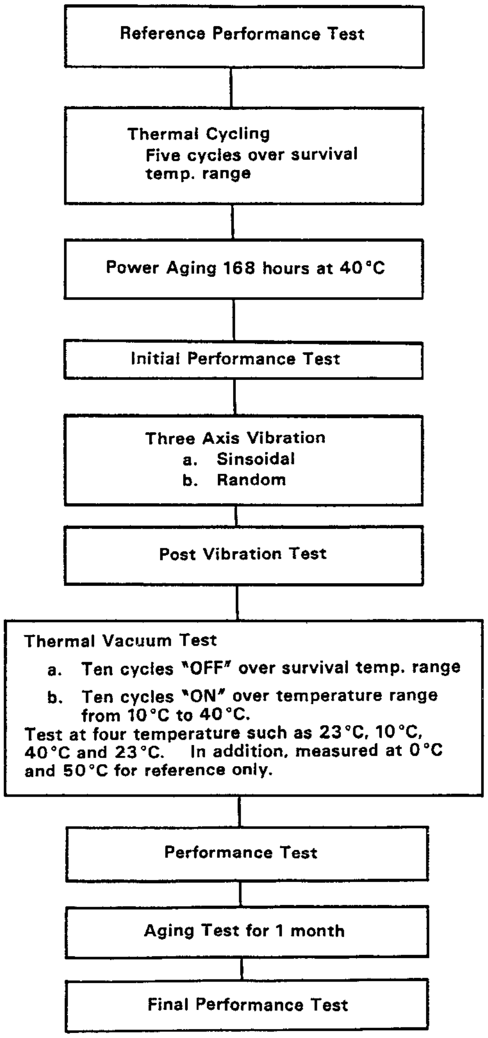

Fig. 11. Test flow of the qualification tests.

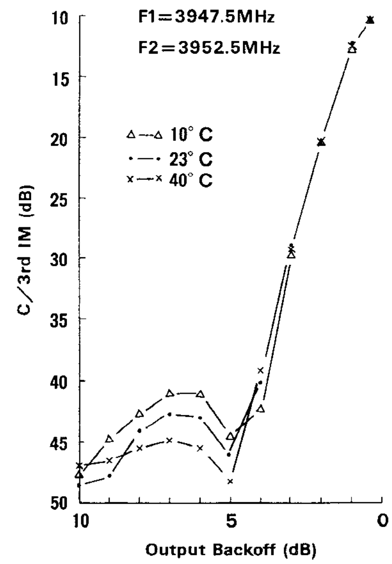

Fig. 12 Third-order intermodulation data at thermal vacuum test.

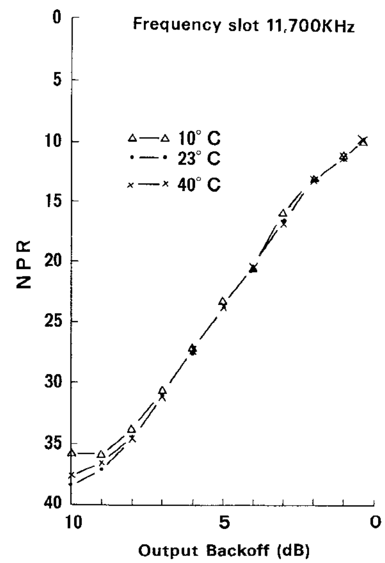

Fig. 13. NPR data at thermal vacuum test.

pressed to less than 5° p-p. The AM/PM conversion is reduced to 0.5°/dB from 3.0°/dB. The input/output power and phase transfer characteristics of the linearizer are shown in Fig. 7. An input backoff of 0 dB corresponds to the input power of the saturation of the linearized TWTA. An output backoff of 0 dB corresponds to the linearizer saturation output. The gain of the linearizer expands as the input power increases. The output power is limited since the linearizer has a limiting amplifier section. The phase variation versus the input power is about 40° opposite to the phase variation of the TWTA. Thus, the phase characteristic of the linearized TWTA is reduced, as shown in Fig. 8, compared with the linearizer.

The third-order intermodulation of the TWTA and linearized TWTA are shown in Fig. 8. The center frequency is 3950 MHz, and separation frequencies of 5 MHz, 20 MHz, and 50 MHz are used. The amount of improvement due to linearization is 23 dB at 4-dB output backoff.

The noise power ratio (NPR) responses are shown in Fig. 9. The linearized TWTA improves 11.6 dB at 7-dB output backoff. Alternatively, the effective power is increased more than 3 dB compared with the same NPR of the TWTA 7-dB output backoff.

Fig. 10 shows downlink C/N versus BER of the TWTA and the linearized TWTA operating at 0-dB output backoff. An NEC 120-Mbit/s QPSK modem was used in the experiment. The values C/N = 25 dB and BER = 7×10^{-6} were chosen as a reference. The resulting downlink CNR of the linearized TWTA is 4.5 dB less than that of TWTA to achieve the identical BER at downlink C/N = 25 dB. Alternatively, the effective power can be increased by 4.5 dB.

IV. Space Qualification Tests

Qualification tests for the linearizer were performed according to the test flow shown in Fig. 11. Before the qualification test, thermal cycling (from −40°C to 75°C, five cycles) and power aging (168 h at 40°C) were performed.

The linearizer was subjected to sinusoidal sweep vibration, random vibration tests, and thermal vacuum tests at

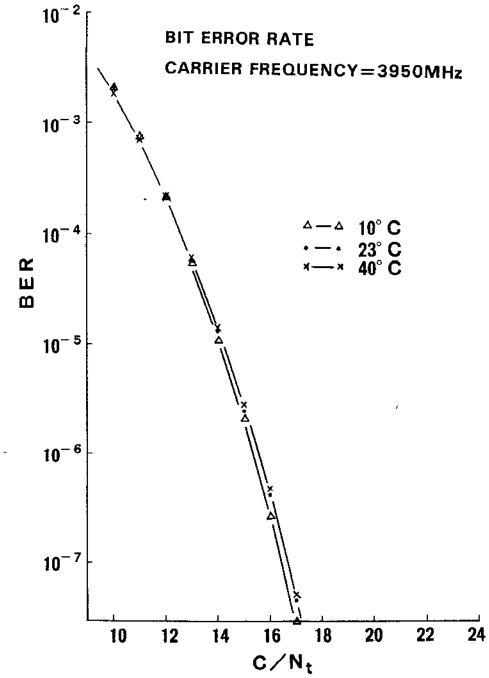

Fig. 14. BER data at thermal vacuum test.

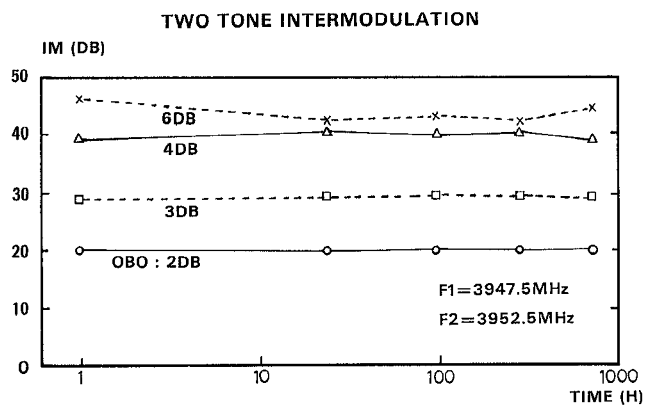

Fig. 15. Trend data of third-order intermodulation of linearized TWTA

the vibration levels and temperatures experienced in actual satellites. During thermal vacuum tests, thermal cycling was performed; ten cycles with power turned off were performed over the survival temperature range (−40°C to 75°C), along with ten cycles with power turned on over the temperature range from 10°C to 40°C. The test results of the linearizer in the thermal vacuum test (TVT) are presented in Figs. 12–14.

The aging test was continued for 720 h at 40°C in room. This condition is equivalent to 4320 h at 23°C. Electrical performance was measured at 24 h, 96 h, 288 h, and 720 h. Trend data are shown in Figs. 15–17, which show that the linearizer is stable with time.

V. Conclusions

A compact, lightweight, and stable linearizer for satellite applications has been developed using MIC packages. It has been shown that the linearizer is stable throughout the

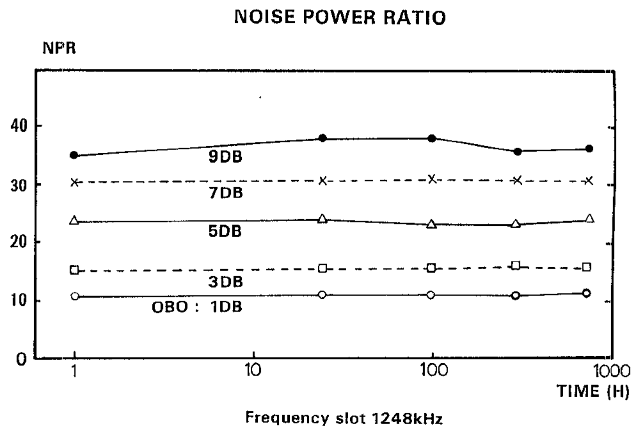

Fig. 16. Trend data of NPR of linearized TWTA.

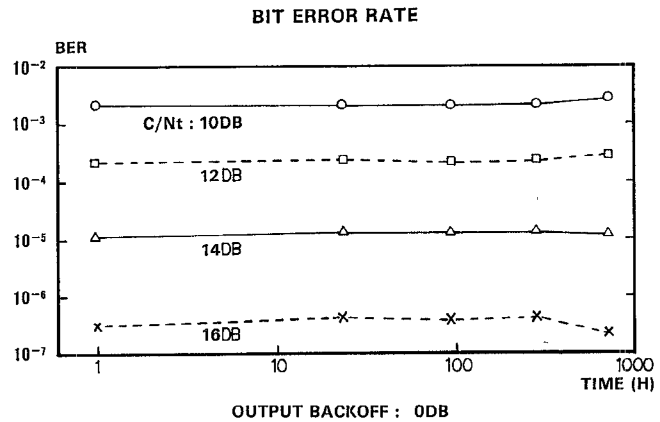

Fig. 17. Trend data of BER of linearized TWTA.

environmental tests, thermal vacuum tests, and aging tests. The linearizer improves the third-order IM, NPR, and BER of a TWTA. It has been shown that the effective power can be increased by as much as 4.5 dB for SCPC and TDMA systems. The linearizer is adjustable for various types of TWT's.

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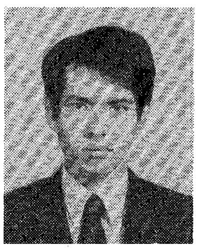

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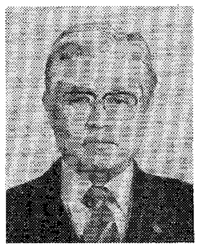

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P. Desantis, photograph and biography unavailable at the time of publication.