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Pulsed Response of a Traveling-Wave Tube

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PULSED RESPONSE OF A TRAVELING-WAVE TUBE

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ABSTRACT

The consequence of frequency-domain multiple access (FDMA) channelization in a satellite communications system is that the ground- and space-based components are often required to operate at reduced output power to prevent the generation of distortions. However, the components of a time-division multiple access (TDMA) satellite system, such as a traveling-wave tube (TWT), can operate at the highest output power because the channelization technique is relatively insensitive to the distortions resulting from saturated operation. A Hughes 30-GHz TWT was tested to determine the suitability of such a device in a TDMA system. Testing was focused on the ability of the TWT to rise up to full power at the leading edge of TDMA bursts, which were simulated by a pulse train. A Wavetek model 8502A peak power meter was used to display and measure the pulsed signal waveform. Measurements of the TWT output signal rise time indicate that the TWT lengthened the rise time by 10 to 20 nsec. Imposing a modulator turn-on time that precedes the data burst by the TWT rise time is a logical approach to coordinating the traveling-wave tube amplifier and modulator specifications.

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INTRODUCTION

Satellite communications systems in orbit today typically implement an analog frequency-domain multiple access (FDMA) channelization. The consequence is that the ground- and space-based components are often required to operate at reduced output power to prevent the generation of distortions. Amplifiers typically exhibit linear characteristics in a low-power operating region and become nonlinear in a high-power (saturated) operating region. Distortions generated by saturated operations include amplitude modulation (AM) to AM, AM to phase modulation (PM), harmonic output power, and intermodulation products. Satellite communications of the future (as well as a select few advanced systems of today) will incorporate digitized information embedded in a time-division multiple access (TDMA) channelization as a mode of operation. Components of the TDMA satellite system, such as a traveling-wave tube (TWT), can operate in the highest output power state because the channelization technique is relatively insensitive to the distortions resulting from saturated operation. Satellite power resources are used most efficiently in a TDMA mode, since the full capabilities of the TWT are being utilized.

In May 1992, the National Aeronautics and Space Administration (NASA) will launch an experimental communications satellite, the Advanced Communications Technology Satellite (ACTS), which has TDMA channelization as its cornerstone. In preparation for the experimentation period, a high-data-rate ground station, the link evaluation terminal (LET), is being developed to exercise a part of the ACTS communications payload. Hughes Electron Dynamics Division in Torrance, California, has loaned to NASA Lewis Research Center an engineering model traveling-wave-tube amplifier (a TWT integrated with a power supply) having a rated saturated output power of 65 W for use in evaluating the performance of the LET system.

One of the many applications of TWT's is radar, in which the pulsed TWT has a low duty cycle. Modulating the gun grid voltage pinches off the electron beam periodically to inhibit TWT output. Performance information on the pulsed mode of operation is generally classified owing to its military applications. Whereas the radar application is strictly carrier transmission and reception, the ACTS TDMA carrier is modulated with information. It would be an interesting experiment to see how a modulated gun grid voltage can work with the carrier modulation in a TDMA system, but typically the TDMA transmitter modulator is relied upon entirely to provide the variable-duty-cycle data burst and the grid voltage is held at an optimum level. Pulse modulation tests were made on the 30-GHz Hughes TWTA to estimate the performance of a TWT in bursted TDMA communications applications.

OVERVIEW OF LET

NASA is sponsoring the development of high-risk satellite communications technology in the ACTS program. It is the goal of NASA to maintain America's preeminence in satellite communications technology by launching the experimental ACTS satellite. Two distinct means of TDMA communications will be available for evaluation; a regenerative transponder, referred to as the "baseband-processor (BBP) mode," and a 900-MHz-wide, satellite-switched trunk transponder, referred to as the "high-burst-rate (HBR) mode."

Hughes Electron Dynamics Division has been contracted by NASA to build three 60-W TWTA's for the LET uplink channel. An electronic power supply, forced-air cooling, and waveguide components will be integrated with a helix TWT to form the TWTA. The helix TWT will have periodic permanent magnet focusing. The engineering model TWTA (serial number 128901) loaned to NASA is pictured in Figure 1. All components of the engineering model TWTA are identical to those of the deliverable TWTA's except the TWT itself (serial number 012), which is a residual from another program.

Contract specifications for the LET TWTA require that the TWTA signal rise to saturated power from zero input power in 400 nsec and fall from saturated power to zero input power in 1000 nsec. These specifications apply to a periodic square wave at 50 kHz. This translates to a 20-μsec period with a 50-percent duty cycle. These generalized TDMA specifications were written without prior knowledge of TWTA performance capabilities.

The LET duty cycle can exceed the written specifications on the LET TWTA. Frame duration is 863 words, or 250 μsec, with a word length of 64 bits. Variable throughput will generate burst lengths ranging from 1.5 μsec for the reference burst only to 229.4 μsec for a maximum throughput of 200 megabits per second (Mbps) plus preamble, reference burst, and overhead. The actual duty cycle will then range from 0.6 to 91.7 percent. A pulsed modulated signal with a 250-μsec period and various pulse widths was used to simulate the bursted signal at the test bench. Pulse widths of 17, 31, 116, and 229 μsec were tested.

In the actual implementation of the LET data burst, Motorola dual-rate serial minimum shift keying (SMSK) modulators will be turned on one-half clock cycle before the TDMA frame reference burst is transmitted. Before the reference burst is present at the modulator, the output signal from the modulator is noise on the carrier. Given that the carrier is present in the LET transmission subsystem, the TWT has one-half clock cycle to rise to the transmitted power level. The one-half clock cycles for the 220- and 110-Mbps bursts are 140 nsec and 280 nsec, respectively.

The specification for 60 W of output power from the TWT was driven by the high attenuation encountered at 30 GHz owing to rain fade events. During clear sky conditions, 10 W will provide enough power to establish a communications link through the satellite. Uplink power control will enable the ground station to overcome rain fade events by increasing the transmitted power to the rated power of 60 W.

OVERVIEW OF MEASUREMENT APPROACH

The TDMA signal was simulated in the laboratory environment and development continued on the LET digital hardware. A Wiltron model 6740B frequency synthesizer that was configured in either the continuous wave (CW) or pulse train mode at the frequency of interest was used to generate the test signal. The internally generated pulse train has complete flexibility to vary the pulse period and the pulse width as the measurement requires. The Wiltron frequency synthesizer has an overshoot specification of less than 10 percent in the pulse train mode. Rise and fall times of the Wiltron-generated pulse signal were specified to be typically 5 nsec with a maximum of 10 nsec.

Key to evaluating the TWTA was the Wavetek model 8502A peak power meter (PPM). This instrument provided the capability to display and measure the pulsed signal waveform. Wavetek detector model 17071 for use with the PPM has a typical rise time of 12 nsec, which was sufficient for meaningful measurement of the TWTA specified rise and fall times. The step response of the low-barrier Schottky diode detectors was less than 10-percent peak-to-peak overshoot with settling to less than 4 percent (peak to peak) in 200 nsec. The rise time for these measurements is defined as the time between the 10-percent power level on the pulse leading edge to the 90-percent power level on the pulse leading edge. Similarly, the fall time is defined as the time between the 90- and 10-percent power levels on the pulse trailing edge. The pulse duration is defined as the time between the 50-percent power levels on the pulse leading and trailing edges. In addition to displaying the pulsed signal, the peak power meter was used in the CW mode to measure the power of a simple tone signal.

Figure 2 shows the test setup used for pulse measurements. The Wiltron carrier frequency was set to 29.37 GHz. A 3-dB coupler was used to monitor the input signal to the TWTA. Hughes bandpass filters were inserted between the 3-dB coupler and the TWTA and also between the 3-dB coupler and the sensor head to attenuate unwanted high- and low-frequency components. The filter typically has 0.6-dB insertion loss in the passband that extends from 29.0 to 30.0 GHz. The skirts of the filter attenuate at a slope of approximately 5 dB per 1.0 GHz. The TWTA output was sampled by a 40-dB coupler with an additional bandpass filter between the coupler and the sensor head. Unused power was dissipated by a high power load.

The first step in the pulse measurement procedure was finding the TWTA saturated operation point. A CW signal at 29.37 GHz drove the TWTA, the power of which was steadily increased until the monitored TWTA output was a maximum. For the second step the signal generator was configured into the pulse mode and the desired pulse characteristics were programmed. The input pulse to the TWTA was observed on the PPM by means of the 3-dB coupler. Graphic display mode parameters were adjusted to show a complete pulse. An internal plot driver made a hard copy of the graphic display and measured the results. The third step was similar to the second step except that the TWTA output signal was displayed and plotted. Every pulse measurement had two plots associated with it, an output pulse display and an input pulse display. Comparing the two displays was the method used to determine how the TWTA performed with a pulse modulation performance input.

Waveguide hardware used in the test setup was first evaluated on an HP8510 network analyzer with a frequency extension to 30 GHz. S-parameter testing information was used to calculate CW power levels at the interface flanges.

A self-calibration routine was performed on the Wavetek PPM before measurement data were taken. A 1.0-GHz, 0.0-dBm calibration signal generated by the PPM was injected into the detector. The instrument stored critical calibration data to compensate the diode detector. Understandably, a measurement error is associated with testing performed at conditions that are removed from the calibration signal. At the 29.0- to 30.0-Ghz range these errors added up to 11-percent (root sum square) total measurement uncertainty.

TEST DATA

The saturation point of the TWTA had to be found for the burst testing. Figure 3 shows the CW output power versus input power characteristics of the TWTA at 29.37 GHz. This particular set of data was taken in a test setup similar to that shown in Figure 2, but HPR8486A sensors were used to measure power. Raw data were processed to account for waveguide losses and sensor head calibration factors and were used to generate the output-power-versus-input-power curve (Fig. 3). The linear region of TWTA operation extended from roughly -10.0 to -25.0 dBm and most likely beyond the measured data. Figure 4 shows that over the linear region of operation, the gain of the TWT was 55 dB $\pm$ 0.4 dB. TWTA saturation occurred at a CW input power of -1.5 to 0.0 dBm. Resulting CW output power was 48.0 dBm, which translates into 64.4 W of output power.

Single-event, Wavetek-generated displays have been reproduced to show the pulse characteristics of both the input and the TWTA output (Figs. 5 to 8). Particular attention was paid to the examination of the rise time. Table 1 summarizes the rise time measurement results; and Table 2, the fall time measurement results.

The LET burst structure is such that the first five words of the burst make up the reference burst. Unsuccessful acquisition of the reference burst means that the demodulators will not be synchronized with the TDMA burst frame and thus the information will be lost. Recall that the LET modulators are turned on one-half clock cycle before the reference burst is transmitted and that 140 and 280 nsec are the one-half clock cycles for the 220- and 110-Mbps bursts, respectively. Measurements showed that the rise time from the TWTA ranged from 24.5 nsec (Fig. 5(b)) to 69.7 nsec (Fig. 8(b)). The range of values implies that the test setup changed slightly with each measurement.

Measured rise and fall times were well within the TWTA specification. A maximum TWTA input signal rise time of 60.1 nsec was measured for the 229-nsec pulse duration (Fig. 8(a)). The corresponding TWTA output signal measurement was 69.7 nsec, which was well within the 400-nsec rise time specification and was even within the 140-nsec worst-case one-half clock cycle. The measured rise time differences were less than 20 nsec, as shown in Table 1. Instrumentation effects and inherent measurement error were the probable causes that lengthened the input leading-edge rise time beyond the expected 10 nsec. The maximum rise time difference introduced by the TWTA was found to be 19.2 nsec when the 31-nsec TWTA input waveform was compared with the corresponding TWTA output waveform. The measured output fall time of the TWTA was slightly shorter in duration than the TWTA input signal fall time for two cases shown in Table 2. Here again instrumentation effects and inherent measurement error were the probable causes of the unusual data. In general, the TWTA responded very quickly to the pulse trailing edge, making the transition from saturated output power to no power in just a few nanoseconds. The maximum TWTA measured output signal fall time of 101.7 nsec was well within the 1000-nsec specification. Therefore, it was concluded that the TWTA contributed very little to pulse distortion in the time domain. What little distortion was found is not expected to affect the LET's burst mode operation.

RECOMMENDATIONS

Measurements made of the pulse rise time indicated that the maximum TWTA contribution to pulse distortion was on the order of 10 to 20 nsec. The broadband instrumentation used was sufficient to test the TWTA against design goals. An improved measurement setup, with detectors designed specifically for the frequency of interest, may reduce measurement error significantly.

The original overspecifications of 400-nsec rise time and modulator turn-on timing were made without prior knowledge of TWTA capabilities. Although turning on the modulator one-half clock cycle before transmitting the TDMA frame reference burst is convenient from a digital hardware perspective, it may be detrimental from a system perspective. High-power carrier noise from the local TWTA before the TDMA reference burst will interfere with the preceding TDMA burst present from a different ground terminal in the same satellite beam. A one-half clock cycle guard time can be imposed on the TDMA timing structure to protect from interference, but this alternative will reduce the overall system efficiency by the loss of one-half of a 64-bit word per frame, or 2000 64-bit words per second. It would be in the best interest of an operational TDMA system to reduce the modulator turn-on timing so that the potential for interference is minimized and overall system efficiency is maximized. A 20-nsec guard time translates into a loss of seven-hundredths of a 64-bit word per frame, or 280 64-bit words per second. Furthermore, the proposed 20-nsec guard time may be eliminated entirely if the TDMA reference burst can be designed to tolerate the noise associated with TWTA rise time during the start of the first of five reference burst words.

Imposing a modulator turn-on time that precedes the data burst by a reasonable TWT rise time is a logical approach to coordinating the TWTA and modulator specifications.

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TABLE 1. - RISE TIME MEASUREMENTS

Pulse duration, nsec	TWTA input signal rise time, nsec	TWTA output signal rise time, nsec	Rise time difference, nsec
17	20.1	24.5	4.4
31	21.3	40.5	19.2
116	49.0	61.5	12.5
229	60.1	69.7	9.6

TABLE 2. - FALL TIME MEASUREMENTS

Pulse duration, nsec	TWTA input signal fall time, nsec	TWTA output signal fall time, nsec	Fall time difference, nsec
17	22.0	26.8	4.8
31	33.8	32.5	-1.3
116	71.2	77.6	6.4
229	104.7	101.7	-3.0

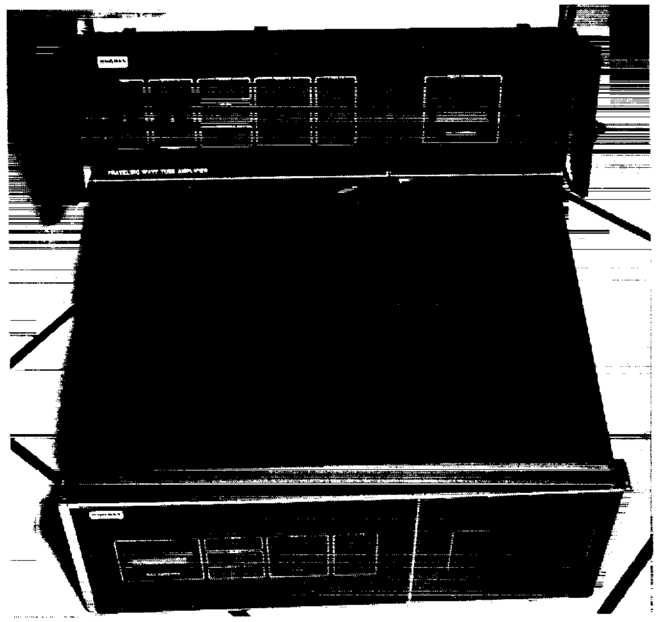

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Figure 1. – Hughes 30-GHz, 65-W engineering model traveling-wave tube amplifier with remote panel.

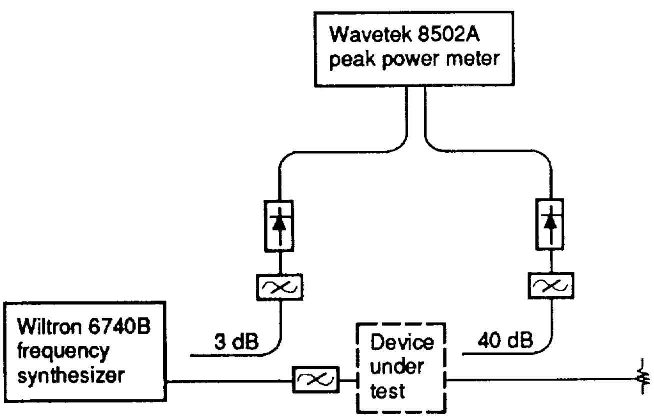


Figure 2. – Pulse measurement test setup.

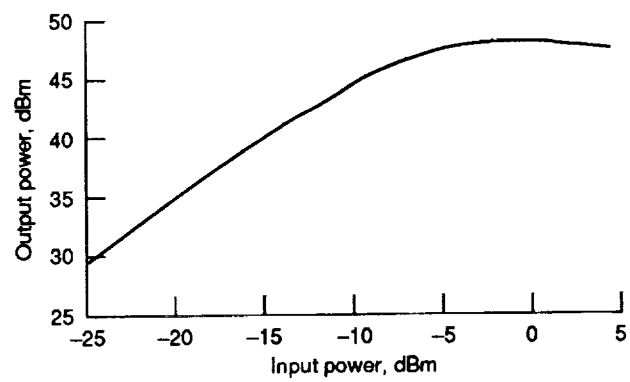


Figure 3. – Output power versus input power for Hughes TWTA.

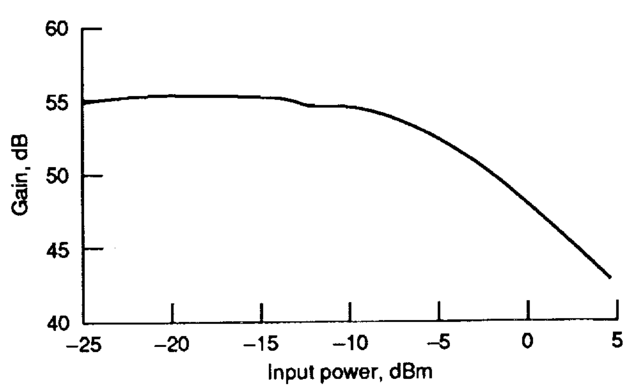
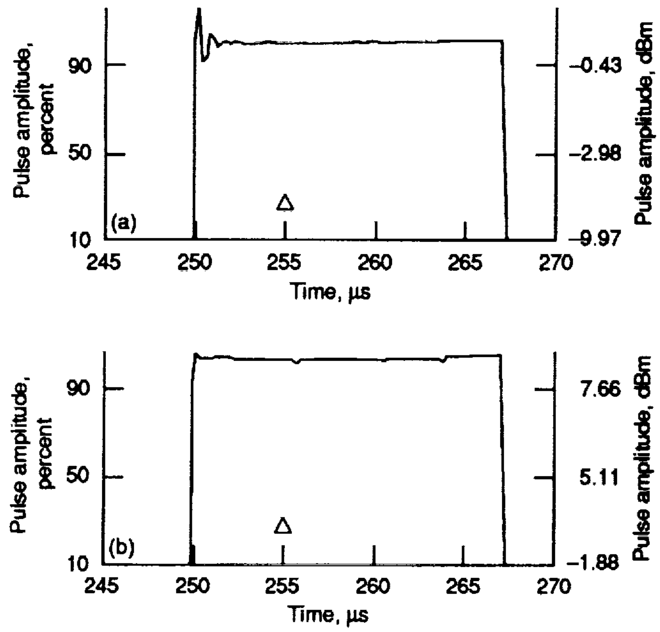
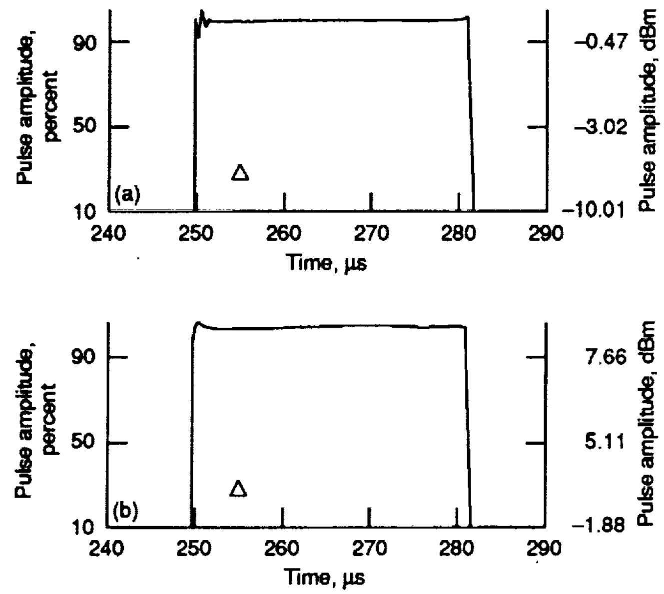


Figure 4. – Gain versus input power for Hughes TWTA.



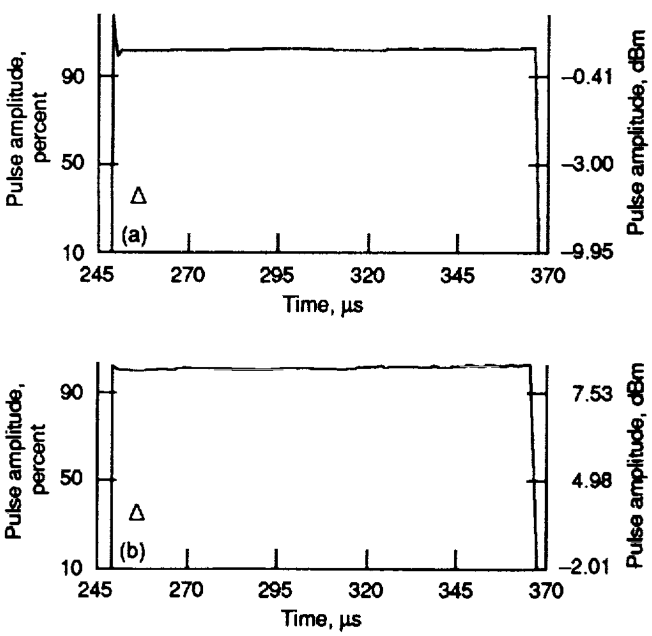
(a) Input (detector A). Cursor power, 0.03 dBm.
(b) Output (detector B). Cursor power, 8.12 dBm.

Figure 5. – 17-µsec pulse width TWTA signals. Cursor delay, 255 µsec.



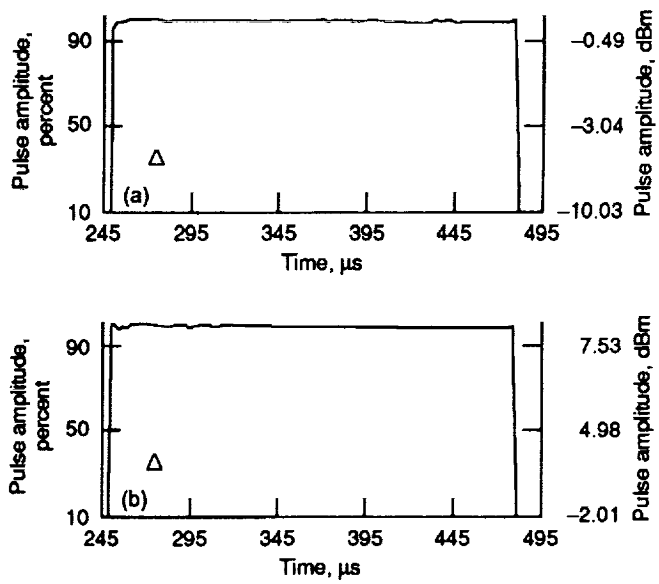
(a) Input (detector A). Cursor power, -0.01 dBm.
(b) Output (detector B). Cursor power, 8.12 dBm.

Figure 6. – 31-µsec pulse width TWTA signals. Cursor delay, 255 µsec.



(a) Input (detector A). Cursor power, 0.05 dBm.
(b) Output (detector B). Cursor power, 7.99 dBm.

Figure 7. – 116-µsec pulse width TWTA signals. Cursor delay, 255 µsec.



(a) Input (detector A). Cursor power, -0.03 dBm.
(b) Output (detector B). Cursor power, 7.99 dBm.

Figure 8. – 229-µsec pulse width TWTA signals. Cursor delay, 275 µsec.

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15. Supplementary Notes

16. Abstract

The consequence of frequency-domain multiple access (FDMA) channelization in a satellite communications system is that the ground- and space-based components are often required to operate at reduced output power to prevent the generation of distortions. However, the components of a time-division multiple access (TDMA) satellite system, such as a traveling-wave tube (TWT), can operate at the highest output power because the channelization technique is relatively insensitive to the distortions resulting from saturated operation. A Hughes 30-GHz TWT was tested to determine the suitability of such a device in a TDMA system. Testing was focused on the ability of the TWT to rise up to full power at the leading edge of TDMA bursts, which were simulated by a pulse train. A Wavetek model 8502A peak power meter was used to display and measure the pulsed signal waveform. Measurements of the TWT output signal rise time indicate that the TWT lengthened the rise time by 10 to 20 nsec. Imposing a modulator turn-on time that precedes the data burst by the TWT rise time is a logical approach to coordinating the traveling-wave tube amplifier and modulator specifications.

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