TRADEX - THE SECOND GENERATION OF SUPER POWER TRANSMITTERS

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The very successful performance attained by the TRADEX UHF Transmitter in the TRADEX radar(1) represents a significant step forward in transmitter capability over previous super-power efforts. Prior to the TRADEX application, UHF super-power was limited to brute-force installations, where long range was of prime importance and relatively coarse target data were perfectly acceptable. The TRADEX radar, in addition to maintaining a requirement for operation at extremely long ranges, incorporates several unique, highly sophisticated concepts.

TRADEX, an instrumentation radar, was developed for ARPA as a major unit of PRESS. It is installed on the island of Roi-Namur in the Kwajalein Atoll of the Marshall Islands. The mission of TRADEX can roughly be defined as an attempt to determine those radar-return characteristics of a body in space which will permit identification of size, shape, materials, etc. - in short, TRADEX is concerned with signature studies on ballistic vehicles in multi-target environments. High resolution is obtained by combining narrow-range gating with doppler-frequency tracking. The techniques associated with this operation impose a new set of

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(1) J. T. Nessmith, "New Performance Records for Instrumentation Radars", Space/Aeronautics, Vol. 38, No. 7, Dec. 1962, pp 85--93.

severe requirements on the Transmitter.

To consider a few of these problems: doppler-frequency tracking and scintillation-spectral measurements around a single spectral line require a high pulse repetition frequency (with its attendant problems) to reduce doppler ambiguities. Also required is an extremely pure transmitted inter-line spectrum to minimize false targets in the frequency domain. System philosophy permitting the use of higher pulse-repetition frequencies (approximately 1500 pps) than those used in long range search applications requires initial resolution of range ambiguities. At these high PRF's, the unambiguous range interval is quite short (approximately 55 miles), so frequent PRF changes are needed to prevent eclipsing of the signal return by the long transmitted pulse. To maintain a pure fine-line spectrum requires a high degree of frequency stability and a low level of modulation by extraneous frequencies or noise. The use of a linear FM pulse expansion technique permits obtaining very high average powers (300 KW) at a reasonable peak power (4 MW). To properly compress this dispersed pulse requires a high degree of intra-pulse phase stability, while pulse-to-pulse phase coherence is required to permit coherent integration. And finally, due to the non-recallable nature of the basic TRADEX target, high reliability is essential, necessitating an extremely sophisticated system of fault protection.

A lineup of conventional gridded tubes in resonant cavity circuitry was selected for the TRADEX application. This selec- was due primarily to the excellent radio-frequency phase-stability and low-noise characteristics of this type device. Some of the other desirable factors leading to the choice of the gridded-tube approach were: high efficiency ($> 50\%$); long life; low operating voltages; self focusing; and a wide tolerance of load mismatches. The gross performance of the transmitter is summarized in Table I.

TABLE I

UHF Transmitter Gross Performance Requirements

Tuning Range	425 Mc $\pm$ 5%
Peak Power Output	4 Mw
Average Power Output	300 kw
Pulse Repetition Frequency	10 steps from 1112 to 1482 pps
Minimum time between PRF changes	2 sec.
Maximum stabilization time after PRF change	4000 microsec.
Pulse duration (50% power)	49.8 microsec.
Pulse Rise Time (10% - 90% voltage)	3 microsec. maximum
Pulse Fall Time (90% - 10% voltage)	5 microsec. maximum
Duty Cycle	0.075 maximum

The amplifier chain accepts a 10 mw peak signal at 60 Mc which has been expanded 50 to 1 in the receiver exciter, and so contains the linear FM sweep. This signal is amplified, hetrodyned to the transmitted frequency, and further amplified to the 4 megawatt output power. The last two amplifier stages are plate pulsed. This is desirable due to the high voltages involved, to reduce interpulse noise, and to assist in fault protection with minimum lost system time. The HPA generates 300 KW average power, 4 Mw peak, at an efficiency in excess of 50% in a single RCA 2054 triode, which is the highest power ever known to be generated reliably by a single device at UHF in an operational radar. Externally, the cavity resembles those used in similar long-pulse, low PRF applications. In TRADEX, air-dielectric quarter-wave blockers are used in all places subjected to high-voltage video pulsing. Dielectric materials such as ceramics, which are generally used in low PRF applications, are quickly destroyed by the high rms video currents associated with the TRADEX PRF.

Due to the nature of the signal to be passed, it was found that conventional methods of specification and measurement were grossly inadequate. To test the TRADEX Transmitter required the development of three major pieces of special test equipment by RCA: a dispersed-pulse simulator; a fine-line spectrum analyzer; and an intra-pulse phase analyzer.

To maintain the gross spectrum of the dispersed-pulse signal requires an instantaneous bandwidth through the amplifier chain of 1.2 megacycles at 1 db down. However, it has been found more useful to specify the envelope shape of the output pulse with dispersed-pulse transmitter excitation. This not only specifies bandwidth but also covers modulator output-pulse characteristics, tuning, ringing in the various pulse circuits, etc. The specification states that amplitude variation through the center 32 microseconds of the 50 microsecond pulse shall not deviate more than 0.5 db from the best smooth-fit curve (defined for this application as being one which decreases monotonically in amplitude from the center maximum to each side). The detected RF pulse is to be -4 ±2 db at ±25 microseconds from the center of the pulse. The final equipment measures less than 0.25 db deviation from the smooth-fit curve, and is very nearly 4 db down at each end.

Measurement of the fine-line spectrum presents more of a problem. Since the open-loop bandpass of the TRADEX doppler-tracking filter is only 10 cps, it is required that the width of each transmitted PRF line be considerably less than this. It is necessary to measure the width of each PRF line as well as the amplitudes of any spurious lines which might appear in the output as false targets. The amplitude of each line is specified as shown in Table II. The actual measurements shown in Table II were made by sweeping a 1.5 cps wide filter slowly between two PRF lines, reading the output in the 1.5 cps bandpass on a chart recorder as previously described.(2) The higher than specified reading at ±8 cps has proven to be due to the finite width of the 1.5 cps filter, not the width of the PRF line. Figure 1 shows the results of actual measurements on the transmitter. It is important to note the scale - the pictures shown cover only ±70 cps around each line, and the next PRF line is 1482 cps away. Slight modulation lines can be seen at ±60 cps around each line. Note that there is no widening evident on the ±1482 cps lines, indicating a high degree of PRF stability. Simultaneous widening of all lines would indicate either frequency instability or low-frequency modulation. The line width specification is shown superimposed on the carrier line.

In utilizing the linear FM expanded pulse it is necessary that some limitation be placed on non-linear phase shift through

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(2) R. F. Koontz, "Fine-grain Spectrum Analysis of Pulsed Microwave Amplifiers", PGMTT Transactions, Vol. MTT-10, No. 6, Nov. 1962, pp 440-454.

the system during the pulse to assure proper compression of the radar return. Linear phase shift in any amount is not a problem, as it is equivalent to a time delay and can readily be compensated. But non-linear phase shift, once introduced into the loop, cannot be removed, producing pulse-envelope distortion. It is necessary that the maximum non-linear phase shift to be introduced be specified for each component of the system (transmitter, receiver, microwave, etc.). The test devised for the TRADEX transmitter has previously been described.(3) The transmitter actually performed much better than expected. The system allows the transmitter to introduce a peak fundamental (defined as one cycle over the pulse duration) non-linear phase component of ±15 degrees, and all harmonics of this fundamental are allowed to deviate ±1.5 degrees. The actual measurements show an absolute peak deviation of 3 degrees for all components, which are attributed to a 2.52 degree fundamental, a 0.5 degree second harmonic, a 0.22 degree fourth harmonic. All other harmonics have negligible components. These are summarized in Table III. Figure II shows a typical run of phase versus frequency for the UHF transmitter. The vertical scale is one degree/cm; the horizontal scale is 10 microsec/cm. The sharp excursions at the beginning and end of each pulse are due to the rise and fall of the modulating pulse. The two pictures show results for: (1) a single pulse

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(3) R. F. Koontz, "Microwave Phase Measurement of Dispersed Pulse Transmitter Systems", Record 1962 WESCON Convention, 22 August 1962.

(phase versus frequency); and (2) an accumulation of pulses (phase versus time).

TABLE II
Spectral Line Width

f cps	Spec db	Meas. db
±2	-3	-10
±5	-20	-24
±8	-40	-35
Interline	-40	-50

TABLE III
Non-linear Phase Distortion

Harmonic	Spec Ø degrees	Meas. Ø degrees
Fundamental	15.0	2.52
2	1.5	0.5
3	1.5	-
Any	1.5	-

One advantage of plate pulsing the high-power stages is the ability to sense and protect against most faults on a pulse-to-pulse basis. For a variety of reasons high power components are prone to arcing. The classical method of protection has been to electronically short-circuit (crowbar) the high-voltage power supply, diverting the fault into a gas tube or spark gap. This type of protection is highly undesirable in an instrumentation radar, as an entire mission can be lost by crowbarring at an inauspicious moment. In the hard-tube modulator, in any situation except switch-tube arcing, the switch-tube grid retains control. Because of that characteristic, any other fault (such as arcing in the RF tube, cavity, waveguide, etc.) can be protected merely by blocking the pulse in progress. It is necessary to crowbar only in the event of a switch tube fault. Fault-sensing logic divides the possible types of faulting into two classes: inter-pulse (IP); and, during-pulse (DP). Appropriate gates are generated in the fault-sensing system to differentiate between these two classes. The various video and RF pulses are sampled, gated as required by either the IP or DP gate, and level-sensed against some predetermined reference. The only IP fault requiring consideration is modulator switch-tube arcing. Hence, should voltage appear at the modulator output during the interpulse it is necessary to crowbar. This is a relatively rare occurence, due to the wide spacings between electrodes in the switch tube and the resultant low gradients encountered. DP faults cover all other possibilities; arcs in the amplifier tube, cavity, waveguide, or antenna. The first two are monitored by measuring pulse-plate voltage and output power against a reference level in the presence of the DP gate. The last two are monitored by measuring reflected power; no gating is required for these two cases.

The circuitry constructed has been found to generate a block trigger within 4 microseconds of a fault, and the modulator output voltage reaches zero in approximately 7 microseconds. Repeated tests simulating arcs into 1 mil aluminum foil have proven the ability to block before any hole can be punctured in the foil. When a fault is detected in system operation, the pulse in progress is immediately terminated. The next pulse is permitted to come through normally; and, should no further faulting occur, operation will proceed with only part of one pulse missing. The effect on the system is negligible. In the event of consecutive, or nearly consecutive, faults, an integrating circuit is used to sum up an effect equal to some predetermined number of faults, usually 3 to 7, in which event triggers will be locked out automatically; there is still no need to crowbar. This is a relatively rare occurence. The effectiveness of the fault sensing system is shown by the history of the TRADEX system. There have been no tube failures to date due to any cause within the jurisdiction of the fault sensing system. Over a 3-year period, including tests prior to shipment, there have been only two tube failures, both due to faulty interlocking in the water cooling system.

The day-by-day effectiveness of this transmitter design, as well as the TRADEX radar in general, is attested by the system performance to date.[(1)] The TRADEX UHF radar was accepted by AMC for ARPA on August 7, 1962 after demonstrating compliance with all specification requirements. Understandably, most results of ICBM missions are classified. Results of satellite tracks, however, have been highly gratifying. It now seems very likely that results gathered from TRADEX over the next few years will lead us into the third generation of UHF super-power transmitters, and it will be interesting to see what direction that takes.

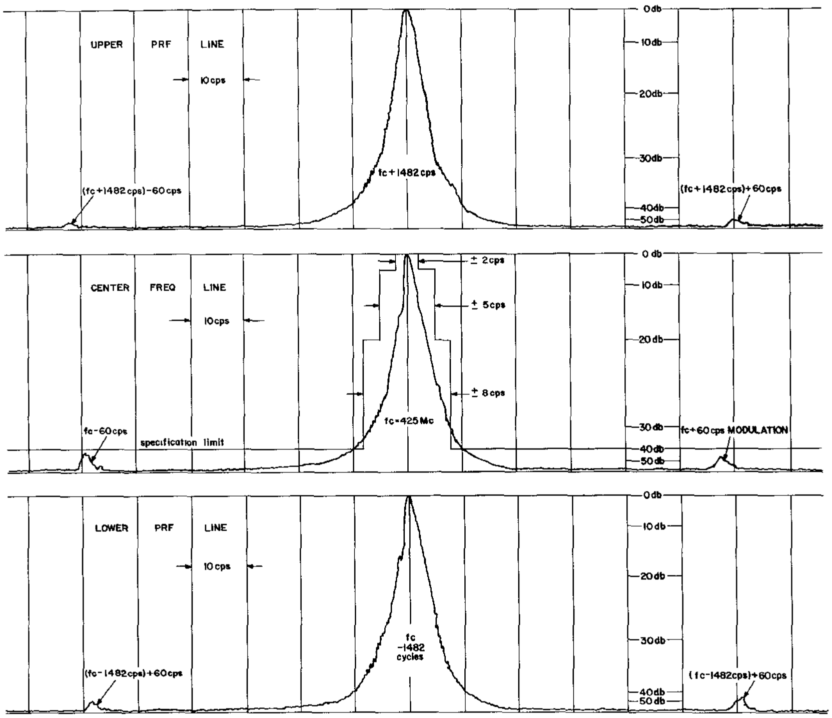
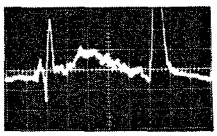
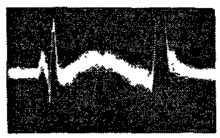


Fig. I - SPECTRAL LINES



1. SINGLE PULSE



2. MANY PULSES

Fig. II - NON-LINEAR PHASE

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