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UHF MODULE TEST AND EVALUATION

Grumman Aerospace Corporation
Bethpage, New York 11714

1 July 1980

Final Report for Period October 1978 — March 1980

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

CONTENTS

CONTENTS (Cont'd)

ILLUSTRATIONS

TABLES

1 - OBJECTIVE

The objective of this test program was to integrate and evaluate the performance of a group of Navy supplied high power solid-state UHF transmit/receive modules with a Grumman Aerospace Corporation (GAC) designed UHF antenna array. Two groups of modules designated for the test were designed and fabricated by the Raytheon and Westinghouse companies under auspices of the Naval Air Development Center (NADC).

2 - SUMMARY

This report covers Level I (T/R Module electrical transfer characteristics) and Level II (system) testing conducted at Grumman between 18 April 1979 and 31 January 1980. The T/R modules tested and evaluated were manufactured by the Raytheon Company. Other required components were supplied by the Control Data Corporation (CDC) and GAC. The purpose of the Level I tests was to determine the transmit electrical transfer characteristics for five (5) Raytheon and seven (7) Westinghouse UHF T/R modules. The Level I tests included module power output measurements, intermodule phase match measurements, intermodule amplitude measurements and pulse jitter measurements at various fixed RF frequencies. The Level II tests consisted of a chirped waveform signal integration and test, multiple module VSWR tests, open-loop one-way antenna transmission test, and electronic scan test. In addition, as part of this contract, a Dynamic Waveform Generator was designed, tested, and integrated with the UHF radar system components. The Dynamic Waveform Generator was used as a system synchronizer for both Level I and Level II testing. The Westinghouse modules were not delivered to GAC and therefore were not tested as originally planned.

The results of the Level I testing for the five (5) Raytheon T/R UHF modules over the required frequency range (420 to 450 MHz) at 15 percent duty cycle are summarized below:

- Peak Power Output - 1.63 to 2.08 kw
- Intermodule Phase Tracking - 16 to 26 degrees
- Intermodule Amplitude Tracking - ±0.48 dB
- Turn-on pulse jitter - <±1 nanoseconds for all five (5) modules.

The results of the Level II testing are summarized below:

- Pulse compression circuit integration and test - for the 820 μsec expanded pulse the range sidelobe levels of the compressed pulse were down a minimum of 28 below the mainlobe response and the receiver dynamic range exceeded the 45 dB performance goal; no useful measurements were obtained with the 410 or 205 μsec pulse widths due to the bandwidth limitations of the GFE pulse compression circuitry in the CDC Analog Signal Processor (ASP).

- Closed loop pulse compression test - the compressed pulse range sidelobes were down 28 dB and the mainlobe 6 dB pulse width averaged 3.5 μsec for the three test frequencies (425, 435 and 445 MHz) used. These results were obtained utilizing a 820 μsec expanded pulse.
- Effect of module mix - not done due to unavailability of Westinghouse T/R modules
- Multiple module closed loop test - the results were comparable to the closed loop pulse compression test above.
- One-way antenna multiple module test - pulse compression response was similar to the closed loop results above
- UHF module electronic scan test - the voltage standing wave ratio (VSWR) ranged from 1.07 to 1.70 for all scan angles and frequencies and again there was no noticeable degradation of the compressed pulses. The dynamic range of the ASP exceeded 50 dB.

3 - LEVEL I UHF MODULE TESTING

Level I UHF Module Testing consisted of module power output, intermodule phase match, intermodule amplitude match and pulse jitter measurements of five Raytheon UHF Transmit/Receive (T/R) modules. For these tests only the transmit portion of the T/R modules was exercised.

Table 1 lists the test equipment used for Level I and Level II testing and the system components tested. Figure 1 is a photograph showing the equipment layout for Level I testing.

3.1 INTERMODULE PHASE MATCH MEASUREMENTS

Intermodule phase match measurements of the driver/power amplifier portion of the T/R modules were made using the test configuration shown in Figure 2. All internal T/R module phase shifters were set to zero for these measurements. Modules were tested in pairs, one being the reference module, the other being the test module. The reference module was kept in the test setup while the other modules were substituted one at a time in the test module position. Phase match was obtained by nulling the output signal of the delta (Δ) port of a 180 degree hybrid by means of a variable phase shifter inserted in the test module path. A variable phase shifter was also present in the reference module path, this phase shifter was set to a convenient value in the middle of its range and was not changed from this value for all phase measurements.

In order to ensure that the phase match difference is due to the T/R modules only, reference system phase measurements were made with the modules removed and module input lines connected to module output lines.

To provide RF drive to the T/R modules, Raytheon supplied a transmit manifold which interfaced with the T/R modules. The phase measurements were made by interfacing a Grumman RF drive signal generating system to the Raytheon transmit manifold. A 2 watt peak pulsed signal at the test RF frequency is required to drive the Raytheon transmit manifold and this signal was provided by Grumman supplied equipment. The 2 watt peak signal was generated by gating the

TABLE 1. LIST OF TEST EQUIPMENT AND SYSTEM COMPONENTS

Test equipment

1. Oscilloscope, Tektronix 475
2. Sorensen SRC 60-35 power supplies (7)
3. HP 8640B signal generator
4. Merrimac 180° Hybrid
5. HP 435A power meters (2)
6. HP 8481A power sensors (2)
7. 300 watt matched loads (2)
8. 20 dB directional couplers (2)
9. 30 dB directional couplers (3)
10. 10 watt power divider
11. AILTECH 727 spectrum analyzer
12. Sample and hold circuit (GAC)
13. Attenuators, various values
14. Various low voltage power supplies
15. High power dividers for antenna feeds (7)
16. 100 Kμf energy storage capacitors (2 per T/R module)
17. 10 watt class A linear amplifier (MPD: LAB 3055-10D)
18. Phase shifter, Narda 3752 (2)
19. Watkins-Johnson mixer (M1J)
20. MPD RF amplifier LLD110
21. HP8472A detector

System components

1. Wing array antenna (GAC)
2. Raytheon T/R modules (5)
3. Control Data Corp. analog signal processor
4. Frequency source and up/down converter (GAC)
5. Dynamic waveform generator (GAC)
6. Raytheon transmit manifold

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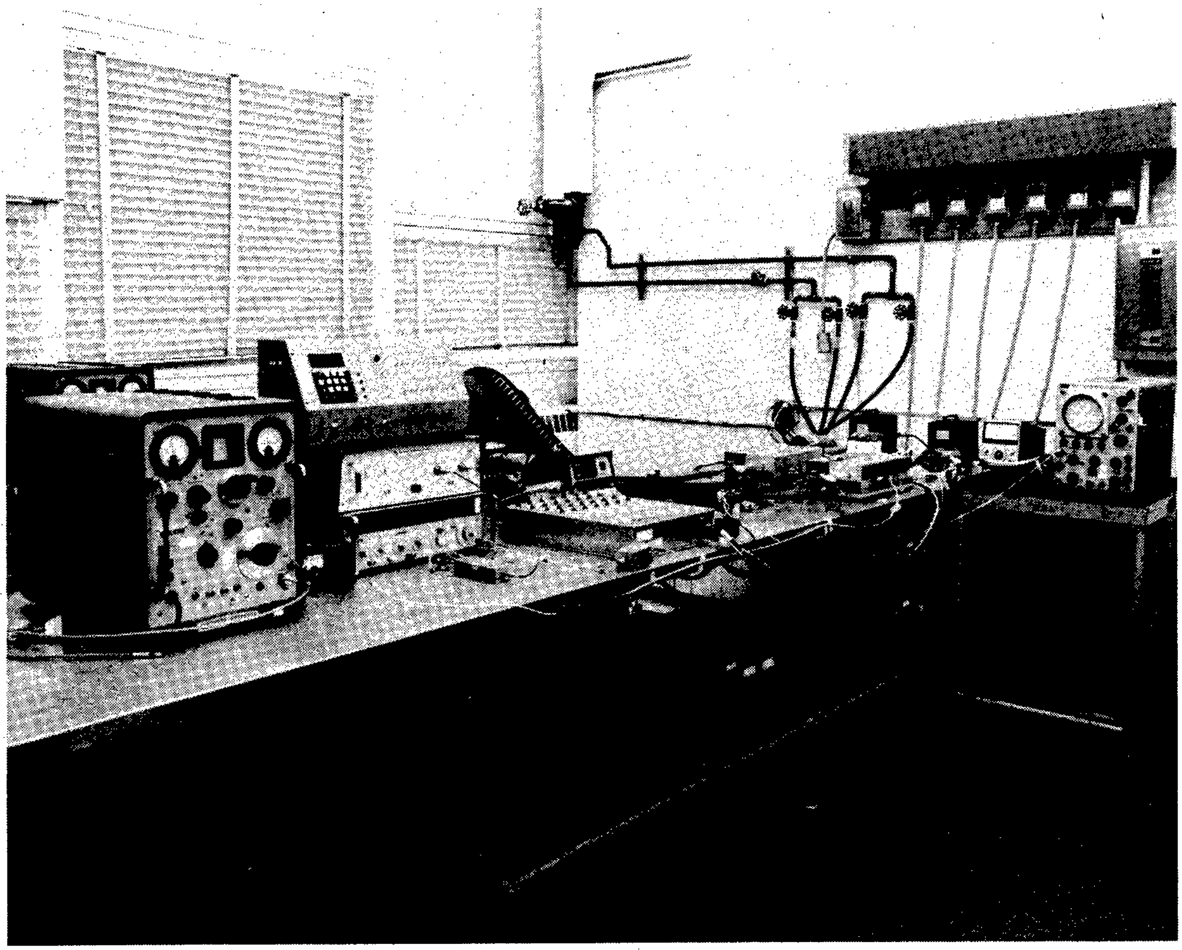

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Figure 1. Level I module test setup.

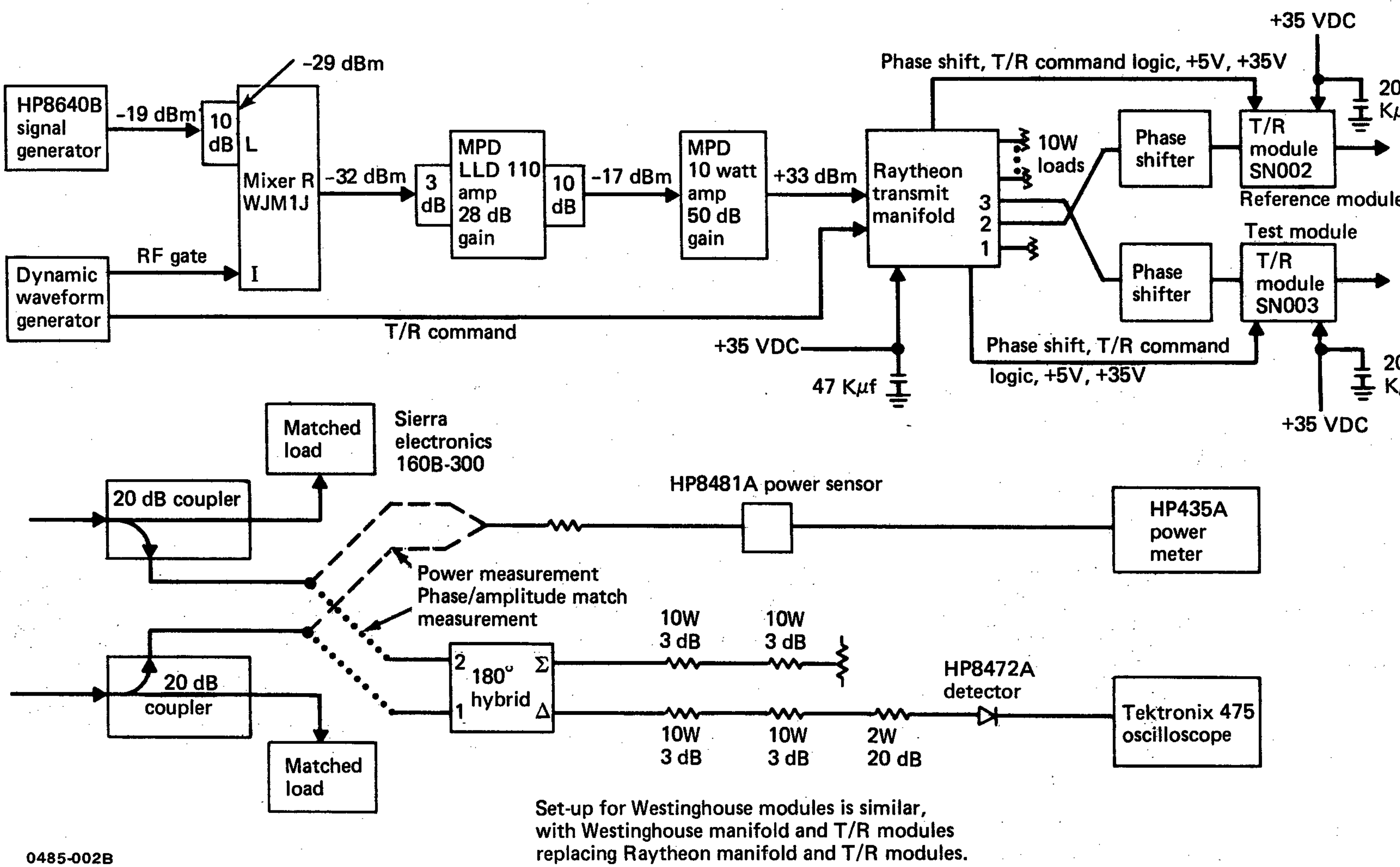

Figure 2. Test configuration for amplitude and phase match and power output measurements for Raytheon modules.

low level RF CW frequency output of a HP 8640B signal generator and amplifying this signal to 2 watts. The Raytheon transmit manifold amplified and divided this signal for distribution to the T/R modules. Each T/R module received approximately 6.25 watts peak from the transmit manifold. The T/R module outputs were 2 KW peak nominal. The transmitter outputs of the reference and test modules were sampled by directional couplers and applied to the inputs of the 180 degree hybrid. The delta (Δ) port output signal, displayed on an oscilloscope, was nulled by varying the test path phase shifter. The phase difference between the reference and test module was obtained by noting the difference between the null readings of the test path phase shifter in the test and reference configurations.

TABLE 2. INTERMODULE PHASE MATCH SUMMARY

Raytheon T/R serial no.	Relative phase (degrees) 420 MHz	435 MHz	450 MHz
SN002 (reference)	0	0	0
SN001	-14.4	-7.8	+5.9
SN003	-19.8	-13.0	+2.3
SN004	+6.4	+12.0	+15.9
SN005	-4.9	+0.3	+11.6
Max variation	26.2	25.0	15.9
Mean	-6.5	-1.7	+7.1
Standard deviation	9.5	8.5	5.9

Above data was obtained with 200K microfarads (nominal) energy storage capacitors and dc voltage of +35 vdc. In addition, the transmit duty cycle was 15 per cent (820 μsec pulse width and 5466.7 μsec pulse repetition interval).

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Table 2 is a summary of the intermodule phase match data and Figure 3 is a plot of intermodule phase match versus frequency. The spread between modules shown in Figure 3 can be reduced by trimming the phase of each module. A theoretical optimized plot is shown in Figure 4. Figure 4 was obtained by displacing the phase shift curves from Figure 3 up or down so that the end point frequency phase shifts are symmetrical with respect to the reference module.

All phase match data was taken at a duty cycle of 15 per cent (820 microsecond pulse width and 5466.7 microsecond pulse repetition interval) at three RF frequencies (420, 435 and 450 MHz) with each module using energy storage capacitors having

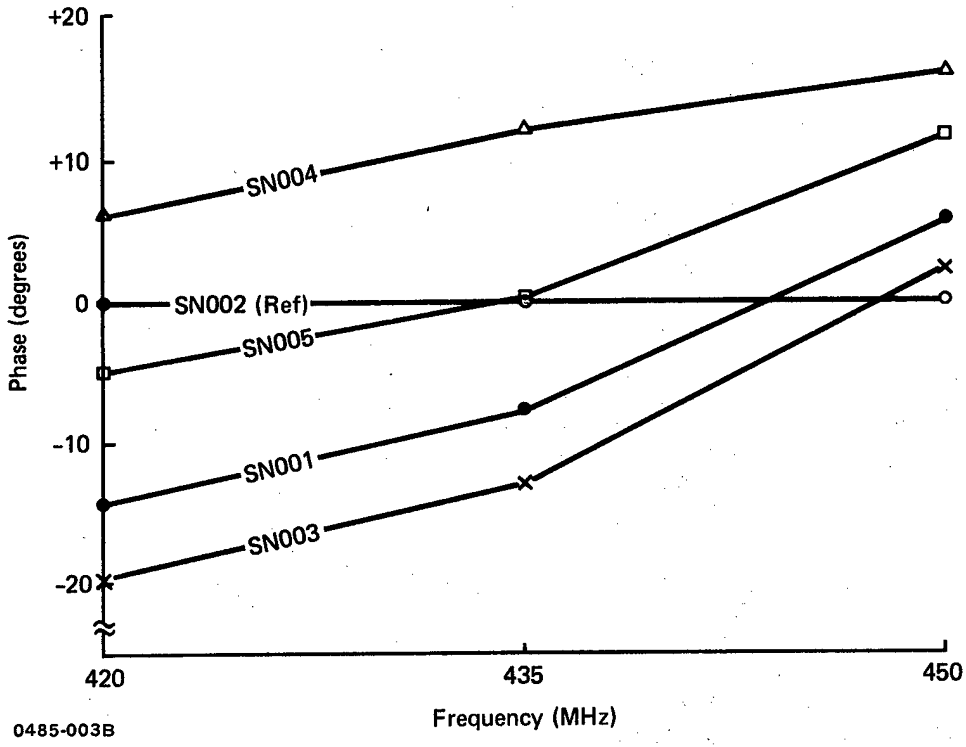

Figure 3. Intermodule phase match vs frequency.

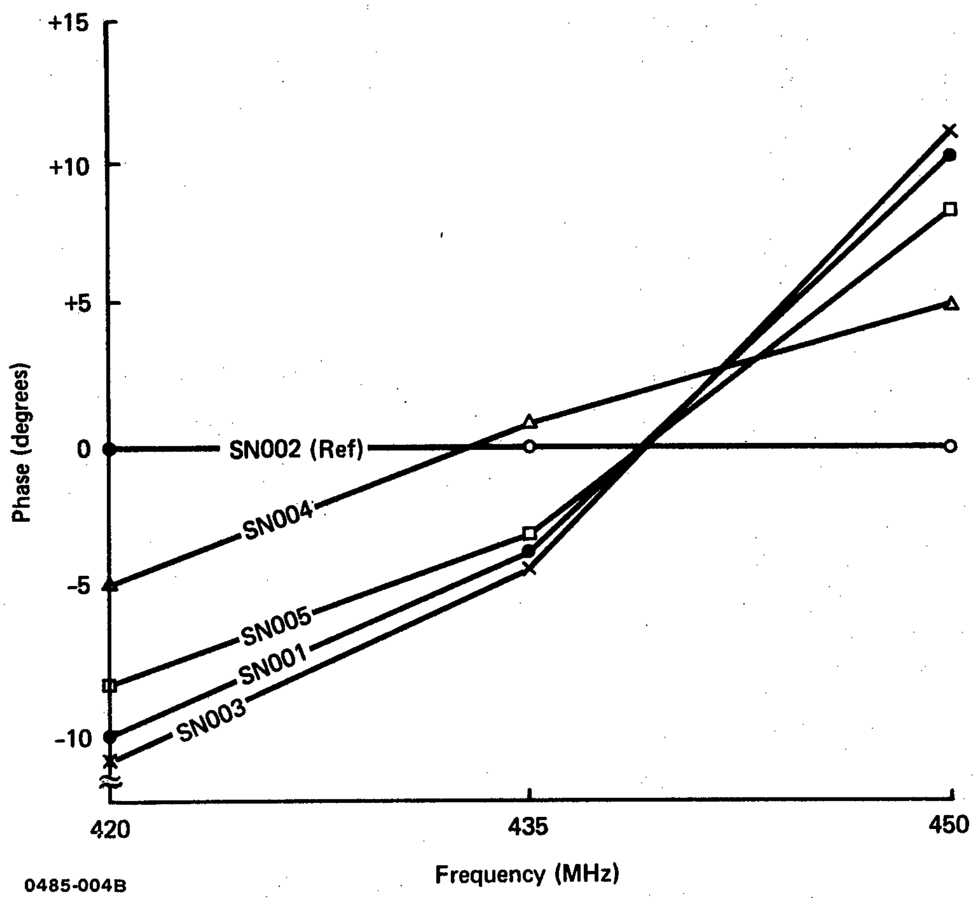

Figure 4. Optimum intermodule phase match.

nominal values of 200K microfarads.

3.2 MODULE POWER OUTPUT MEASUREMENTS

Figure 1 depicts the test configuration for power output measurement and amplitude and phase match measurements. The power to be measured was sampled with a directional coupler at the transmitter output and coupled to a power sensor and power meter. Power readings were made at three RF frequencies, 420, 435 and 450 MHz using a 15 per cent duty cycle (820 microsecond pulse width and 5466.7 microsecond pulse repetition interval).

The output power from all five Raytheon T/R modules SN001, 002, 003, 004 and 005 was measured at 425, 435 and 450 MHz with a dc supply voltage of +35 vdc using energy storage capacitors having a nominal value of 200K microfarads. Results of the power tests are shown in Table 3 and graphed in Figure 5.

In addition several modules were tested with the following conditions: (1) with the dc supply voltage at +35 vdc using an energy storage capacitor of 100K microfarads and (2) with an energy storage capacitor of 200K microfarads and a dc supply voltage of +33 vdc. Table 4 is a tabulation of the power output for several modules with power supply voltage and capacitor value changes. Figure 6 illustrates the power output for serial numbers 001, 002 and 003 with +33 vdc and +35 vdc using 200K microfarad energy storage capacitors.

3.3 INTERMODULE AMPLITUDE MEASUREMENTS

From the module power output measurements documented in paragraph 3.2, the amplitude standard deviations and amplitude maximum deviations for both a particular frequency and across the frequency band were calculated. The amplitude standard deviations at 420, 435 and 450 MHz are 0.18 dB, 0.28 dB and 0.22 dB respectively and the amplitude standard deviation across the frequency band is 0.27 dB. The amplitude maximum deviations at 420, 435 and 450 MHz are 0.55 dB, 0.72 dB and 0.48 dB respectively and 0.96 dB across the frequency band.

3.4 PULSE JITTER MEASUREMENTS

See Figure 7 for the test configuration used for turn-on pulse jitter measurements. The turn-on jitter at the three RF frequencies used (420, 435 and 450 MHz) was less than ±1 nanosecond for all five Raytheon T/R modules (SN001, 002, 003, 004 and 005).

TABLE 3. RAYTHEON T/R MODULE POWER OUTPUTS.

Module serial no.	Frequency (MHz)	Peak power output (watts)	Mean (watts)	Standard deviation (watts)	Maximum deviation (watts)
001	420	1852			
002	420	1721			
003	420	1616			
004	420	1766			
005	420	1789			
	420		1749	79 (0.18 dB)	236 (0.55 dB)
001	435	2036			
002	435	1931			
003	435	1697			
004	435	1777			
005	435	1971			
	435		1882	126 (0.28 dB)	339 (0.72 dB)
001	450	1865			
002	450	1877			
003	450	1695			
004	450	1668			
005	450	1865			
	450		1794	93 (0.22 dB)	209 (0.48 dB)

Mean power output across the band (1808 watts)
Standard deviation across the band (116 watts, 0.27 dB)

Above data was obtained with 200K microfarad (nominal) energy storage capacitors and dc voltage of +35 vdc. In addition the transmit duty cycle was 15 per cent (820 μsec pulse width and 5466.7 μsec pulse repetition interval).

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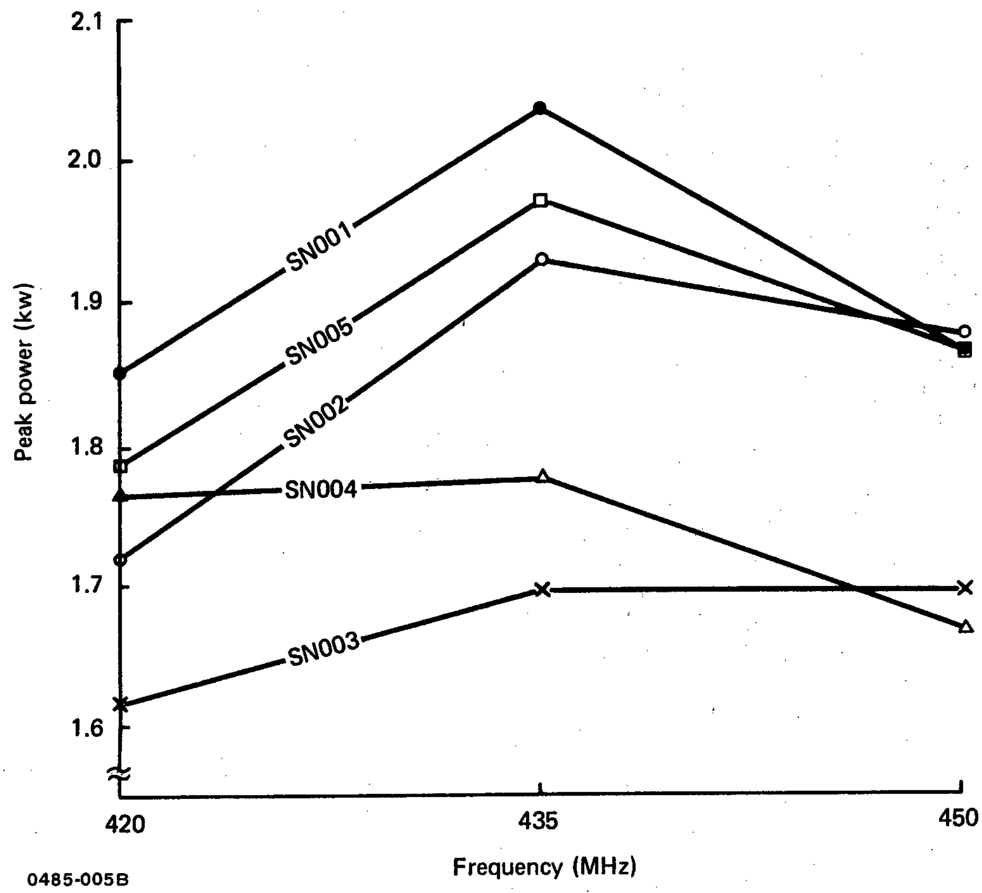

Figure 5. Module peak power vs frequency (15% duty cycle).

TABLE 4. MODULE POWER OUTPUT FOR VARIABLE CONDITIONS.

Module serial no.	Frequency (MHz)	Energy storage capacitor size (Kμf nominal)	Power supply voltage (volts)	Peak power output (watts)
001	420	200	+33	1706
001	435	200	+33	1849
001	450	200	+33	1667
002	420	200	+33	1419
002	435	200	+33	1556
002	450	200	+33	1556
003	420	200	+33	1469
003	435	200	+33	1556
003	450	200	+33	1538
001	420	100	+35	1807
001	435	100	+35	1991
001	450	100	+35	1991
005	420	100	+35	1849
005	435	100	+35	1982
005	450	100	+35	1914

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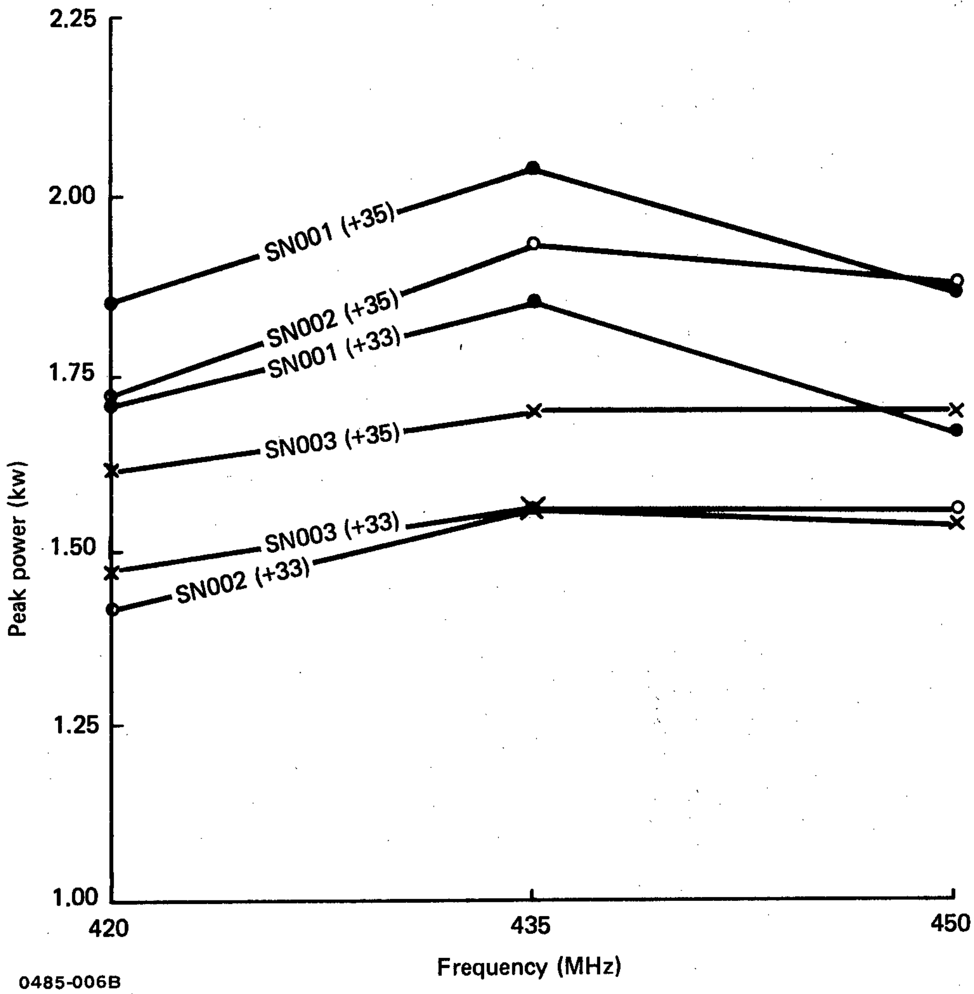

Figure 6. Peak power vs power supply voltage (15% duty cycle).

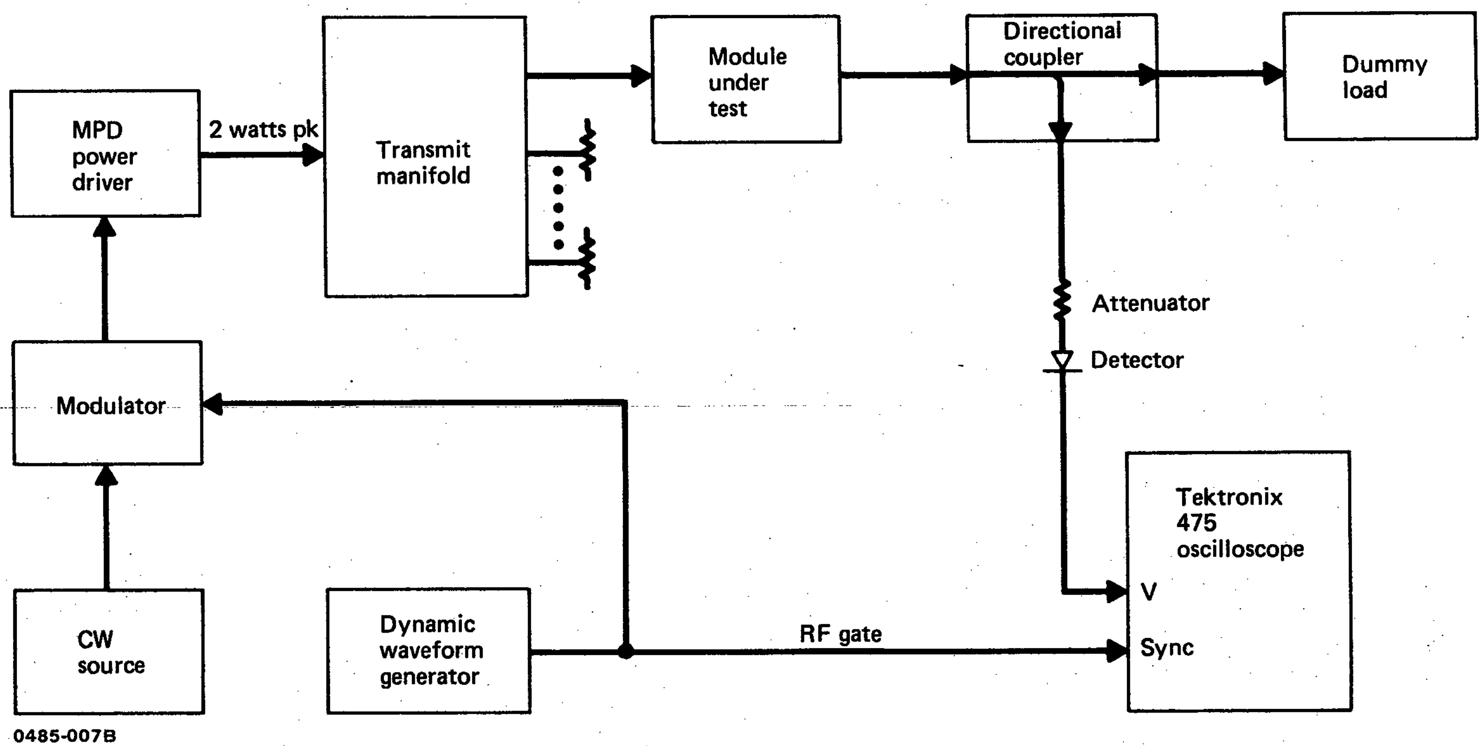

Figure 7. Turn-on pulse jitter test configuration.

4 - LEVEL II UHF MODULE SYSTEM TESTS

The purpose of the Level I tests was to determine the electrical transfer characteristics of the T/R modules. The purpose of the Level II tests was to integrate and operate the T/R modules with the rest of the conformal radar system components i.e., dynamic waveform generator, analog signal processor, frequency source, up/down converter, transmit manifold and antenna.

4.1 DYNAMIC WAVEFORM GENERATOR

4.1.1 Description. The dynamic waveform generator (DWG) has been designed to test the UHF modules with a dynamic waveform that simulates the multi-frequency, multi-PRF pulse trains anticipated for an advanced conformal array surveillance radar system.

It has been packaged for laboratory use as a single unit containing two circuit boards, 15 volt dc power supply, control panel, keyboard, decimal readout, front panel jacks and rear mounted interface connector. It utilizes an external 5 volt, 5 amp lab power supply.

A functional block diagram of the DWG is shown in Figure 8. Front panel controls, indicators and test points are shown in Figure 9. Signal inputs and outputs are listed in Table 5.

Figure 10 is a photograph of the CDC analog signal processor and the dynamic waveform generator.

4.1.2 10 MHz Clock. The dynamic waveform generator is driven by a 10 MHz reference signal derived from the same crystal frequency standard used to provide the 30 MHz COHO reference of the radar system. The 10 MHz reference is shaped to provide a 10 MHz TTL compatible reference for the clock generator and PRI counter.

4.1.3 Clock Generator. The clock generator forms basic timing signals for clocking the ASP pulse expansion and compression unit, the T/R command generator and test instrumentation. A clock having a 200, 400 or 800 ns interval corresponding to the pulse width of 205, 410 or 820 microseconds selected at the front panel is formed and

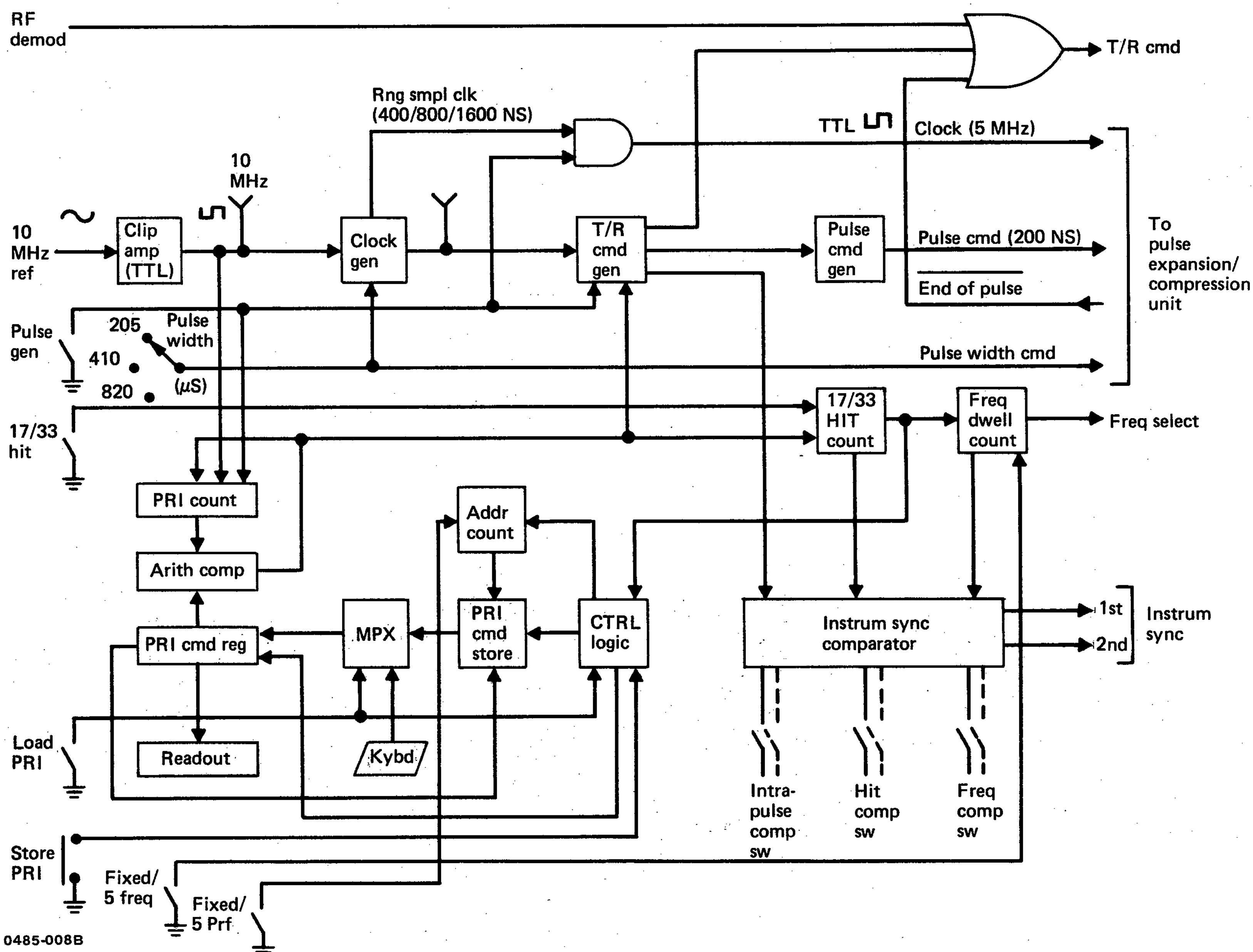

Figure 8. Dynamic waveform generator (freq/Prf/T/R/instrum sync cmd gen).

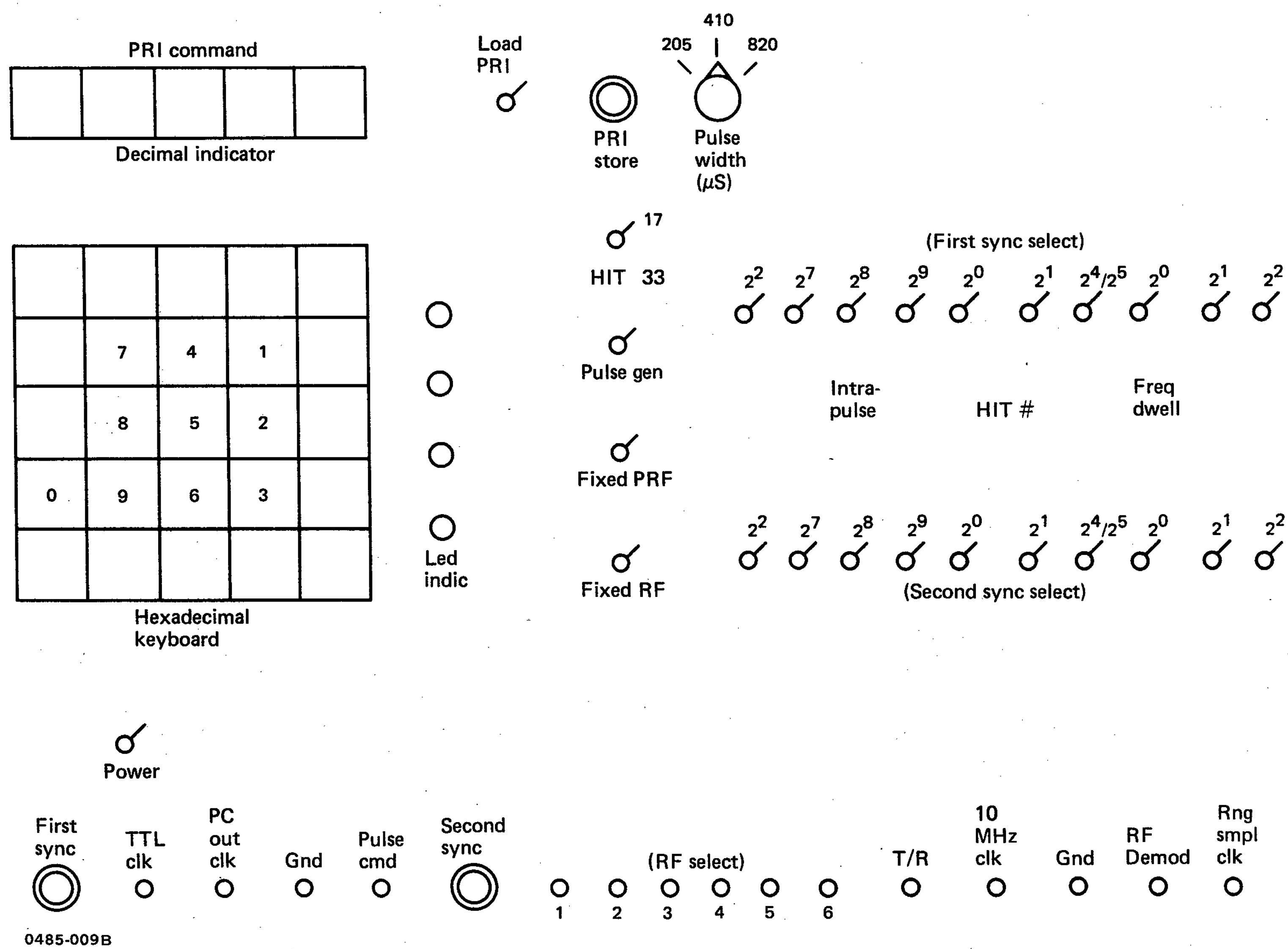

Figure 9. Front panel — dynamic waveform generator.

TABLE 5. DWG SIGNAL INPUTS AND OUTPUTS

DWG signal inputs and outputs are as follows:

Input signal	Function	Source
10 MHz	Reference	Crystal frequency standard
RF demod	Receiver protect	Envelope detector
End of pulse	Receiver protect	Pulse expansion/compression
PC out clock	Test instrumentation	Pulse expansion unit
(panel controls)		
Pulse gen SW	Radar pulse train on/off	Front panel
Pulse length SW	Select 205/410/820 μs	Front panel
	expanded pulse	Front panel
Load PRI SW	Select KBD input	Front panel
Store PRI SW	Load PRI CMD into ram store	Front panel
First sync intra-pulse	Select 1st instrumentation	Front panel
Hit/freq SW	Sync freq, hit #, pulse timing	Front panel
Second sync intra-pulse	Select 2nd instrumentation	Front panel
Hit/freq SW	Sync freq, hit #, pulse timing	Front panel
17/33 Hit SW	Select 17 or 33 pulse	Front panel
	integrated interval	Front panel
Fixed RF SW	Select fixed or 5 freq	Front panel
	sequence	Front panel
Fixed PRF SW	Select fixed or 5 PRF	Front panel
	sequence	Front panel
5 RF select discretes	Freq select	XMTR/RCVR freq synthesizer
TTL clock	5 MHz clock	Pulse expansion/compression unit
Pulse cmd	Initiate expanded pulse	Pulse expansion/compression unit
2 Pulse length discretes	Select 205/410/820 μs pulse expansion	Pulse expansion/compression unit
T/R Cmd	Receiver protect, transmit/ receive mode control	Radar transmitter/receiver system
(test measurement)		
Sync 1, sync 2	Intra pulse/pulse to pulse measurement	Test instru/measurement equip
PC out clock	Pulse compression sampling clock	Test instru/measurement equip
RF demod	Envelope detect	Test instru/measurement equip
10 MHz	TTL Ref clock	Test instru/measurement equip
All above, signals	Instrumentation/test	Front panel test jacks

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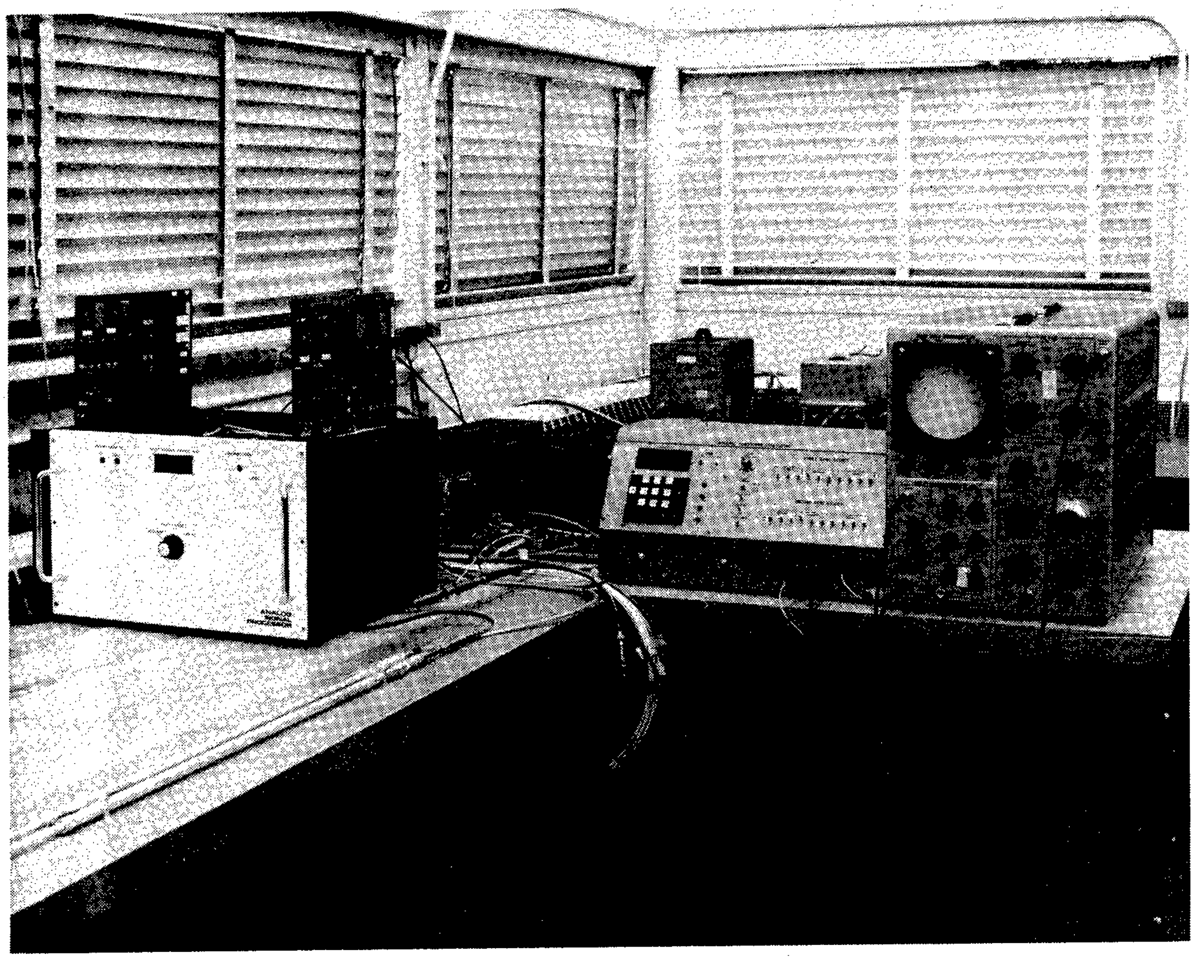

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Figure 10. Analog signal processor and dynamic waveform generator.

fed to the T/R command generator. A 400, 800 or 1600 ns range resolution clock whose interval again corresponds to the selected radar pulse width is made available at the front panel for test instrumentation. The clock generator also forms the "TTL clock" a 50% duty cycle signal which is enabled by the pulse generator switch on the front panel and conditioned by a line driver for transmission to the pulse expansion/ pulse compression unit.

4.1.4 T/R Command Generator. The T/R command generator forms a transmit mode command interval of 8.2 μs + 1040 T/R clock intervals. This is approximately 216, 424 or 840 microseconds duration for the 205, 410 or 820 μs pulse width respectively. The transmit mode begins more than 8 μs before the expanded radar pulse and terminates 16 (1040 - 1024) T/R clocks, i.e., greater than 3, 6 or 12 microseconds after the end of the expanded pulse. The transmit mode command is also initiated and held as long as the RF demodulator or pulse expansion discrete (end of pulse) indicates that an RF pulse is being generated. The T/R command is conditioned by a line driver and distributed to the radar system front end to command transmit or receive mode and protect receiver circuitry during pulse transmission.

4.1.5 Pulse Command Generator. The pulse command generator forms a 200 ns pulse command 8.2 microseconds after the start of the transmit mode. The signal is conditioned and transmitted to the pulse expansion/compression unit.

4.1.6 PRI Command Load and Store. PRI commands are entered by the operator first setting the load PRI switch on. This sets the PRI memory address count to the address of the first PRI command. For fixed PRF operations, only one PRI value (decimal microseconds and tenth microseconds) is entered on the keyboard. For 5 PRF operations the fixed PRF switch is turned off and five PRI values are entered at the keyboard. Each command is entered from the keyboard into the PRI command register, its value confirmed on the front panel decimal readouts, and then entered into PRI command memory by pressing the store PRI button.

4.1.7 Pulse Train Generation. Radar pulse trains are automatically generated after the operator had entered valid PRI commands and then sets the load PRI switch off and the pulse generate switch on. The first step in the automatic sequence is transfer of the first PRI command from PRI command storage to the PRI register. The PRI counter is then enabled and the PRI count is continually compared with the PRI command on an arithmetic and logic unit (ALU). Each time the PRI count equals the commanded value a pulse initiate signal is sent to the T/R command generator and pulse command generator to initialize the transmit mode and command formation of an expanded radar pulse. At the same time the 17/33 hit count is incremented and the next PRI count interval is begun. When the selected 17 or 33 transmit pulses have been generated the hit counter is reset, the dwell count is advanced to select the next RF frequency and control logic initiated to select and load the next PRI command. Front panel switches provide independent selection of a fixed RF or 5 RF sequence and a fixed PRF or 5 PRF sequence. This is accomplished by use of a separate 5 state dwell counter for RF frequency select and a 5 word address counter for PRI command accession.

Two sets of front panel toggles provide independent designation of timing for separate sync signals which can be used to contol instrumentation sampling of two points within the same or separate expanded radar pulses within a pulse train. This is accomplished by two comparison logic networks that generate sync signals when the dwell count matches the selected frequency dwell switch states, the hit count matches the hit switch states and the T/R count matches the selected intra-pulse switch states. Each sync output is TTL compatible and provides a negative going level change at the selected time.

4.1.8 Operational Procedures.

1. Power-on, pulse gen off
2. Load PRI-off
3. For 5 PRF/5 RF pulse train operations
   - Fixed RF-off, fixed PRF-off
   - Load PRI-on, select desired pulse width and 17/33 hits
   - Enter 5 decimal digit PRI command most significant digit first. Each PRI command must be the minimum values indicated below to assure a UHF module duty cycle of 15% or less:
     - $205\mu s$ pulse - PRI $\geq 1,366.7\mu s$
     - $410\mu s$ pulse - PRI $\geq 2,733.3\mu s$
     - $820\mu s$ pulse - PRI $\geq 5,466.7\mu s$
   - Verify the PRI value on the PRI command decimal indicators

- PRI store-press
- Enter/store 4 additional PRI commands per previous three bullets
- Load PRI-off
- Pulse gen-on

  For fixed PRF operations the unit will generate pulses per the first stored PRI command. For fixed RF the unit will generate pulses per the first RF frequency command. Any one of the 6 RF frequencies may be assigned for fixed RF operations via jumpers on the frequency synthesizer interface.

The two sync outputs may be used to select any two points of reference for measurement within the waveform sequence according to the sync frequency, hit number and intrapulse timing select codes indicated in Tables 6, 7 and 8.

TABLE 6. SYNC FREQUENCY SELECTION.

SYNC* Frequency code SW	RF* select
000	1
001	2
010	3
011	4
100	5

If fixed freq is selected only RF Select 1 will be high and Sync frequency Code 000 must be selected if Sync pulse is desired.

*If fixed PRF is selected it is possible to exercise all six RF selects and sync during the 6th RF select is possible by setting sync frequency code switches to 101.

0485-031B

TABLE 7. HIT NUMBER SELECTION.

HIT sync code	HIT no.	
$2^0\ 2^1\ 2^4/2^5$	17 Pulse	33 Pulse
100	1	1
010	2	2
110	3	3
000	16	32
101	17	33

0485-032B

4.1.9 Testing. With a 10 MHz reference signal and +5 Vdc applied, all DWG modes were exercised and the related output signals monitored. The DWG successfully passed all tests.

4.2 PULSE COMPRESSION CIRCUIT INTEGRATION AND TEST

Prior to checking the pulse compression response of the conformal radar system it was necessary to integrate the Control Data Corp. (CDC) analog signal processor (ASP) with the GAC dynamic waveform generator, frequency source and up/down converter.

TABLE 8. INTRAPULSE TIMING SELECTION.

Intrapulse sync		Timing from start pulse (leading edge) pulse length		
$2^2 2^7 2^8 2^9$		204.8 μs	409.6 μs	819.2 μs
0000		0.4	1.2	2.8
1000		1.2	2.8	6
0100		1/8 Selected pulse length		
0010		1/4 Selected pulse length		
0110		3/8 Selected pulse length		
0001		1/2 Selected pulse length		
0101		5/8 Selected pulse length		
0011		6/8 Selected pulse length		
0111		7/8 Selected pulse length		
1xxx	(Added delay of	0.8 μs	1.6 μs	3.2 μs)

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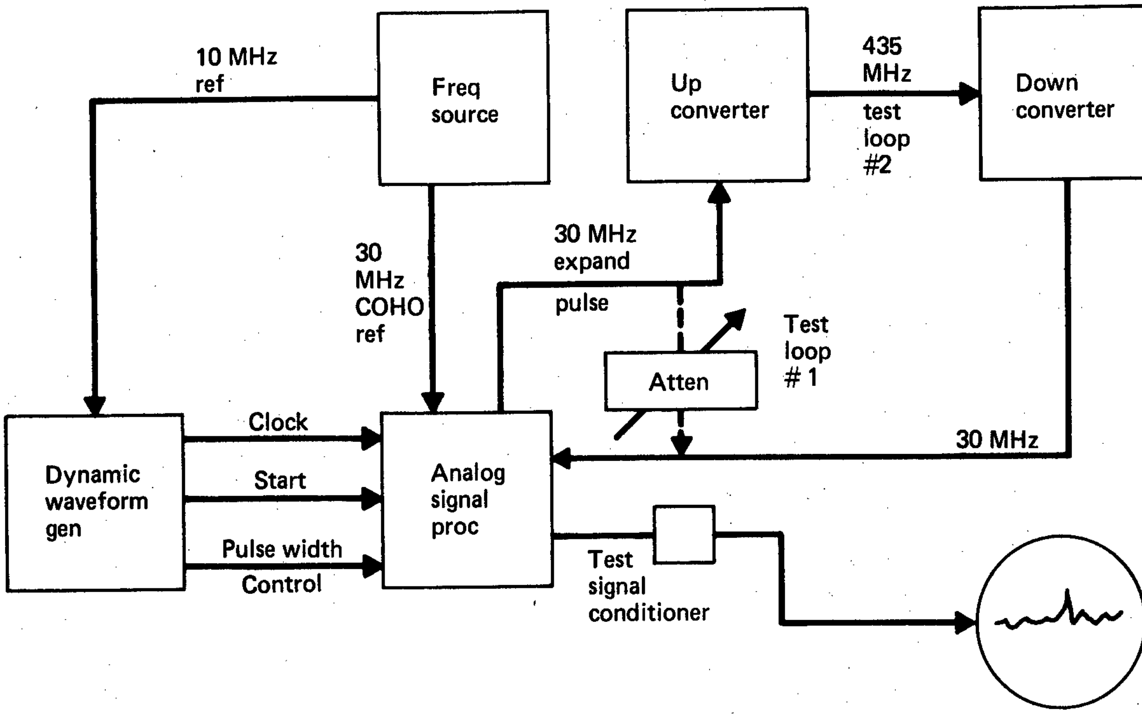
The test configuration is shown in Figure 11 and consists of two test loops. In test loop #1, the ASP is interfaced with: (1) the waveform generator to verify system timing, command and control functions; (2) the frequency source to verify external COHO reference interface; (3) test signal conditioner (sample and hold circuit) and oscilloscope to facilitate dynamic range and range sidelobe measurements; and (4) a variable attenuator connecting the ASP expanded pulse output to the ASP signal input. All observations and measurements were made with the test signal conditioner (sample and hold circuit) connected to the analog signal input of the A/D converter on the ASP pulse compression board. The integration test was performed by connecting the ASP's test target output to its test target input through an attenuator. Using the test target, the ASP's pulse expansion/compression circuitry was optimized.

The next integration test involved loop 2 of Figure 11. The attenuator was removed and the expanded 820 microsecond IF signal from the ASP was up-converted to UHF, down-converted to IF and compressed in the ASP.

For the loop 1 and 2 tests, the ASP adjustments common to all three pulse widths (205, 410 and 820 microseconds) were optimized for 820 microsecond operation to assure best performance (mainlobe to sidelobes >28 dB) for UHF module tests. No adjustments of the 205/410 microsecond pulse width unique pulse expansion/compression filters were made, since earlier tests at CDC indicated somewhat lower mainlobe to sidelobe levels result from operation of the Reticon pulse com-



0485-011B

Figure 11. Analog signal processor integration and test configuration (loops 1 & 2).

pression device at the higher bandwidths.

Results of the loop 1 and loop 2 pulse compression measurements for an 820 microsecond pulse are presented in Table 9.

TABLE 9. PULSE COMPRESSION CIRCUITRY MEASUREMENTS.

Loop	Pulse width (μsec)	Range sidelobes (dB down)	Atten levels (dB) Max*	Min**	Dynamic range (dB)
1	820	29	82	30	52
2	820	29	82	30	52

UHF Frequency 435 MHz

*Maximum attenuation at which a compressed pulse is detectable, signal at peak noise level
**Minimum attenuation at which an undistorted pulse is observed

0485-034B

4.3 CLOSED LOOP PULSE COMPRESSION TEST

The purpose of this test was to determine the difference, if any, between the baseline reference configuration (Figure 11, loop 2) pulse compression response and loop 3 (Figure 12) T/R module closed loop pulse compression response.

The baseline pulse compression response was determined for 425, 435 and 445 MHz and the results are tabulated in Table 10.

This test utilized the transmitter sample of one T/R module at a time rather than the summed samples of two T/R modules as shown in Figure 12. The results of the closed loop test are also tabulated in Table 10 along with the baseline measurements for comparison.

The up converted expanded pulse output of the ASP is amplified in the T/R module, sampled with a directional coupler, receiver down converted and compressed in the ASP.

TABLE 10. BASELINE AND CLOSED LOOP PULSE COMPRESSION.

Test configuration	Module serial no.	RF frequency (MHz)	Energy storage capacitor size (microfarads)	Mainlobe rel amp	Mainlobe 6 dB width (μsec)	Sidelobe rel amp	M/S (dB)
Baseline	N/A	425	200K	29	3.5	1	29.2
Baseline	N/A	435	200K	29	3.5	1	29.2
Baseline	N/A	445	200K	29	3.5	1	29.2
Closed loop	001	425	200K	28	3.5	1	28.9
Closed loop	001	435	200K	28	3.5	1	28.9
Closed loop	001	445	200K	28	3.5	1	28.9
Closed loop	002	425	200K	28	3.5	1	28.9
Closed loop	002	435	200K	28	3.5	1	28.9
Closed loop	002	445	200K	28	3.5	1	28.9
Closed loop	003	425	200K	28	3.5	1	28.9
Closed loop	003	435	200K	29	3.5	1	29.2
Closed loop	003	445	200K	28	3.5	1	28.9
Closed loop	004	425	200K	28	3.5	1	28.9
Closed loop	004	435	200K	27	3.5	1	28.6
Closed loop	004	445	200K	28	3.5	1	28.9
Closed loop	005	425	200K	28	3.5	1	28.9
Closed loop	005	435	200K	28	3.5	1	28.9
Closed loop	005	445	200K	28	3.5	1	28.9
Closed loop	001	435	100K	28	3.5	1	28.9

Note: All the above measurements were made at 15 percent duty cycle (820 microseconds pulse width and 5466.7 microseconds pulse repetition period) and with the dc power supply voltage set to + 35 VDC.

0485-035B

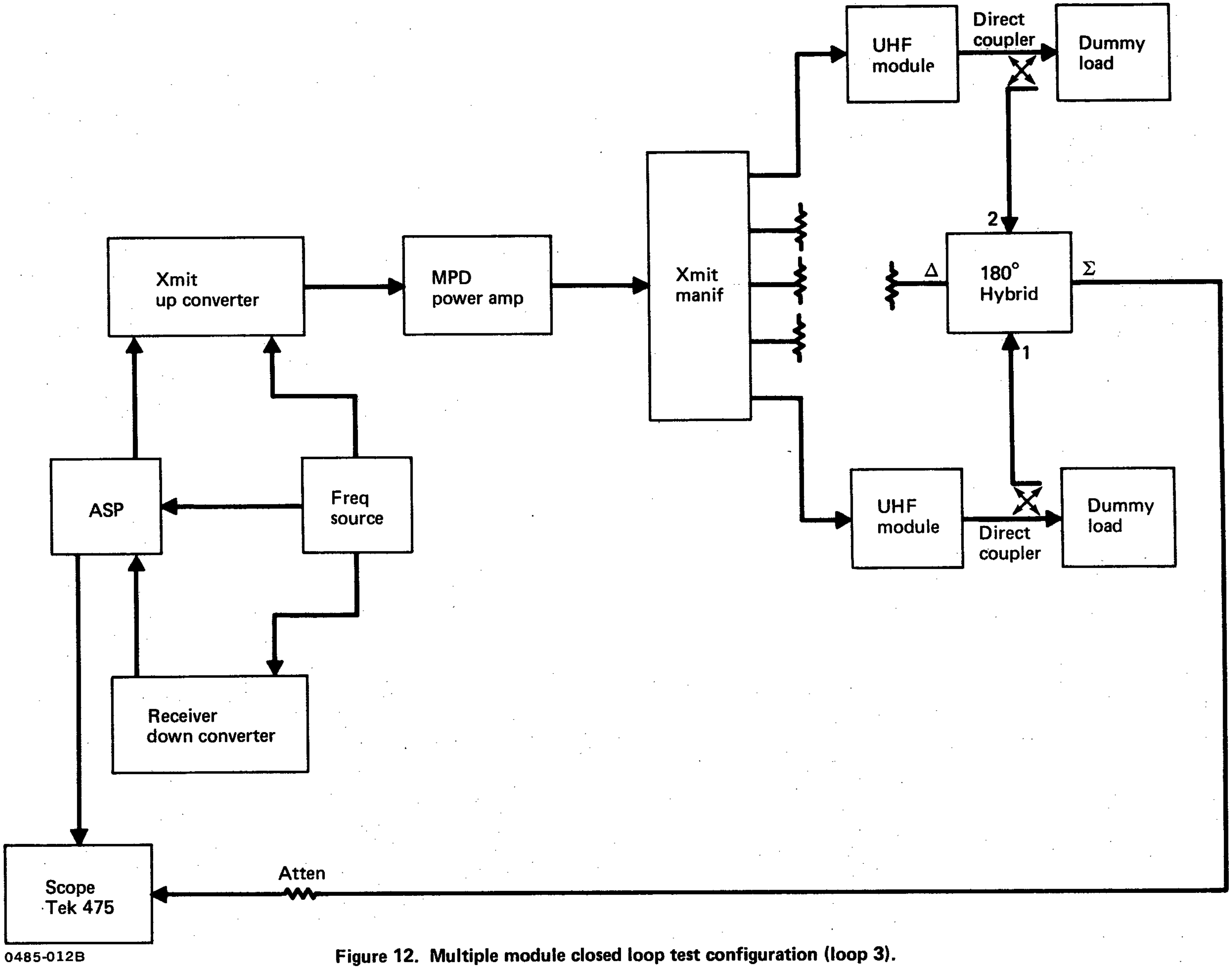
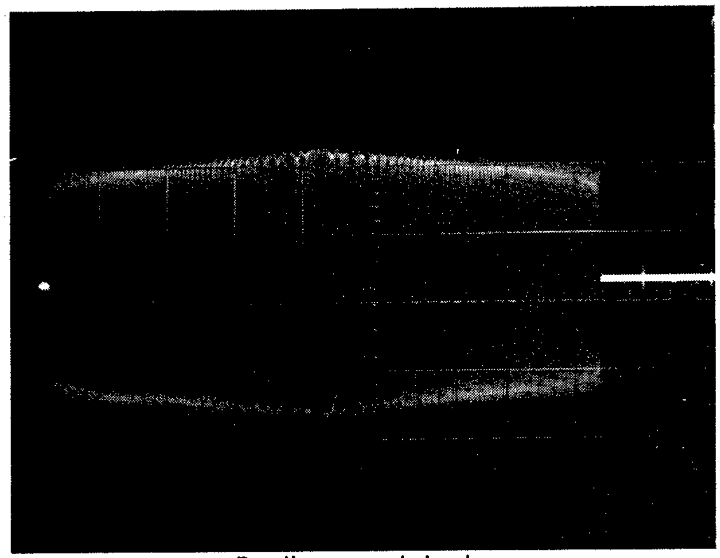


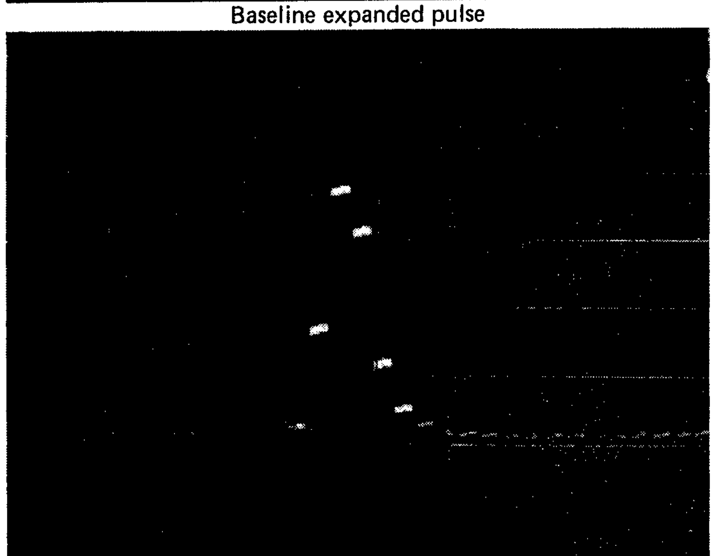
Figure 12. Multiple module closed loop test configuration (loop 3).

In addition to the closed loop tests using 200K microfarad energy storage capacitors an additional test was run on T/R module serial number 001 using an energy storage capacitor of 100K microfarads. The result is also tabulated in Table 10. Figure 13 is a photograph of the baseline (self-test) compressed pulse and expanded pulse.

As can be seen from the data in Table 10, comparable performance was obtained for the closed loop and baseline tests.



Baseline expanded pulse



0485-013B

Baseline compressed pulse

Figure 13. Baseline expanded and compressed pulses.

4.4 MULTIPLE MODULE CLOSED LOOP TEST

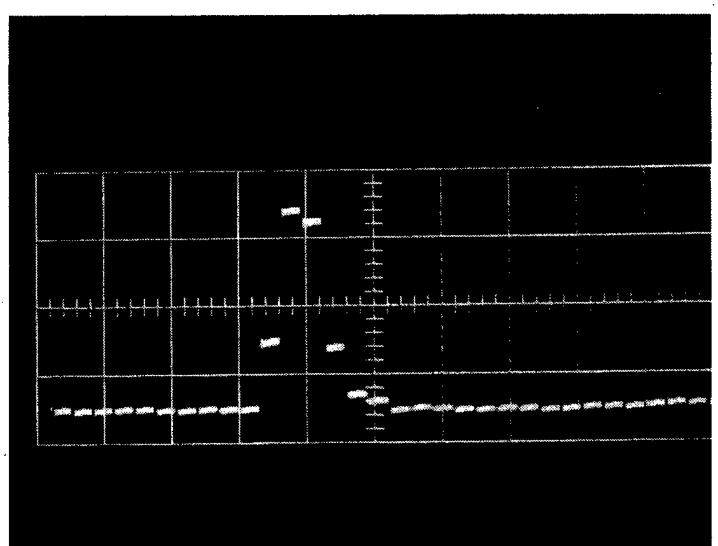
The multiple module closed loop test configuration is shown in Figure 12. The ASP under the control of the dynamic waveform generator produced a 820 microsecond, 30 MHz expanded pulse which was raised to UHF by the xmit up converter and distributed to two Raytheon UHF T/R modules for amplification. The RF signal at the sum port of a 180° hybrid, whose input ports received samples of the RF pulse via directional couplers connected to the T/R modules, was lowered to 30 MHz by the receiver down converter and applied to the ASP for pulse compression.

The output of one of the ASP I and Q quadrature compressed pulse channels was fed to an oscilloscope for display via a sample and hold circuit. The results of these tests are shown in Table 11 below and in the compressed pulse photograph in Figure 14.

TABLE 11. MULTIPLE MODULE PULSE COMPRESSION MEASUREMENTS.

Frequency (MHz)	Mainlobe Amplitude (Cm)	Mainlobe 6 dB pulse width (μsec)	Sidelobe amplitude (Cm)	Mainlobe/sidelobe (dB)
425	2.8	3.5	0.1	28.9
435	2.8	3.5	0.1	28.9
445	2.8	3.5	0.1	28.9

0485-036B



0485-014B 435 MHz, 5 μS/cm

Figure 14. Multiple module closed loop compressed pulse.

4.5 ONE-WAY ANTENNA MULTIPLE MODULE TEST

The one-way antenna test (see Figure 15, block diagram for one-way antenna multiple module and scan tests) was conducted using three Raytheon UHF T/R modules operating at full power radiating through three of the UHF wing array antenna element pairs. A sample of the radiated pulse was received by a single UHF dipole antenna element positioned near the roof top radiation facility. Figures 16 and 17 are photographs showing various portions of the conformal radar system which was used for the high power radiation tests. The Raytheon T/R modules used in this test were SN004, SN005 and SN001 radiating through antenna elements 3, 4 and 5 respectively.

These tests were conducted using a 820 microsecond pulse width and a 5466.7 microsecond pulse repetition interval (15 percent duty cycle) at RF frequencies of 425, 435 and 445 MHz. The results of these tests are summarized in Table 12, one-way antenna test results and Figure 18, one-way antenna test compressed pulse.

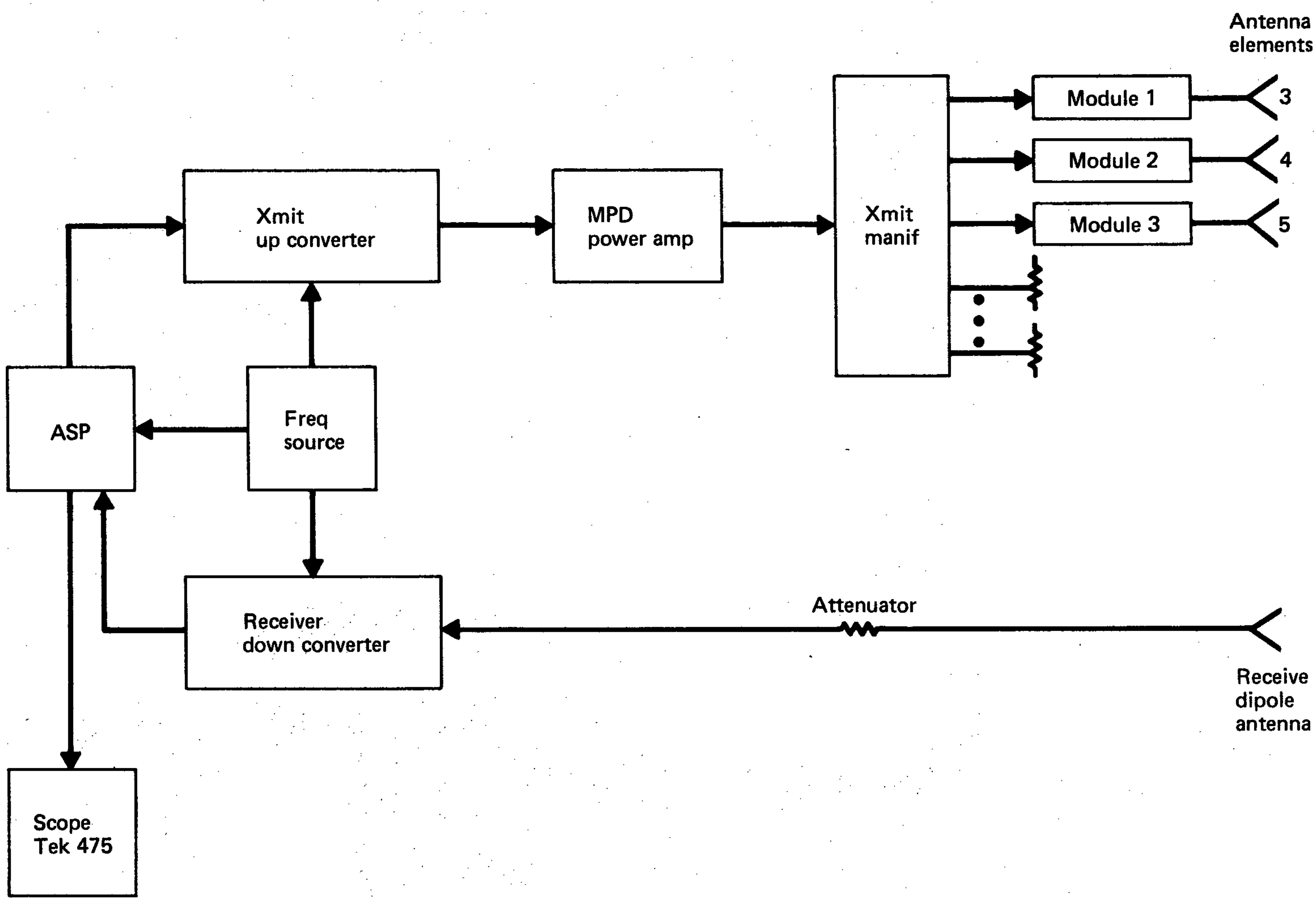
4.6 UHF MODULE ELECTRONIC SCAN TEST

The UHF module electronic scan test was conducted utilizing three Raytheon T/R modules and a GAC designed and constructed antenna. See Figure 15 for the diagram of the test setup.

The three T/R modules radiated at full output power through the three central elements of a seven element antenna array. Reflected power measurements and compressed pulse measurements were made while the antenna scan angle was varied between -40 and +40 degrees by means of manually switched low power phase shifters located in the T/R modules. The reflected power data was used to determine the antenna voltage standing wave ratio (VSWR) of the central antenna element pair and the compressed pulse data was used to determine mainlobe and sidelobe levels and 6 dB pulse widths.

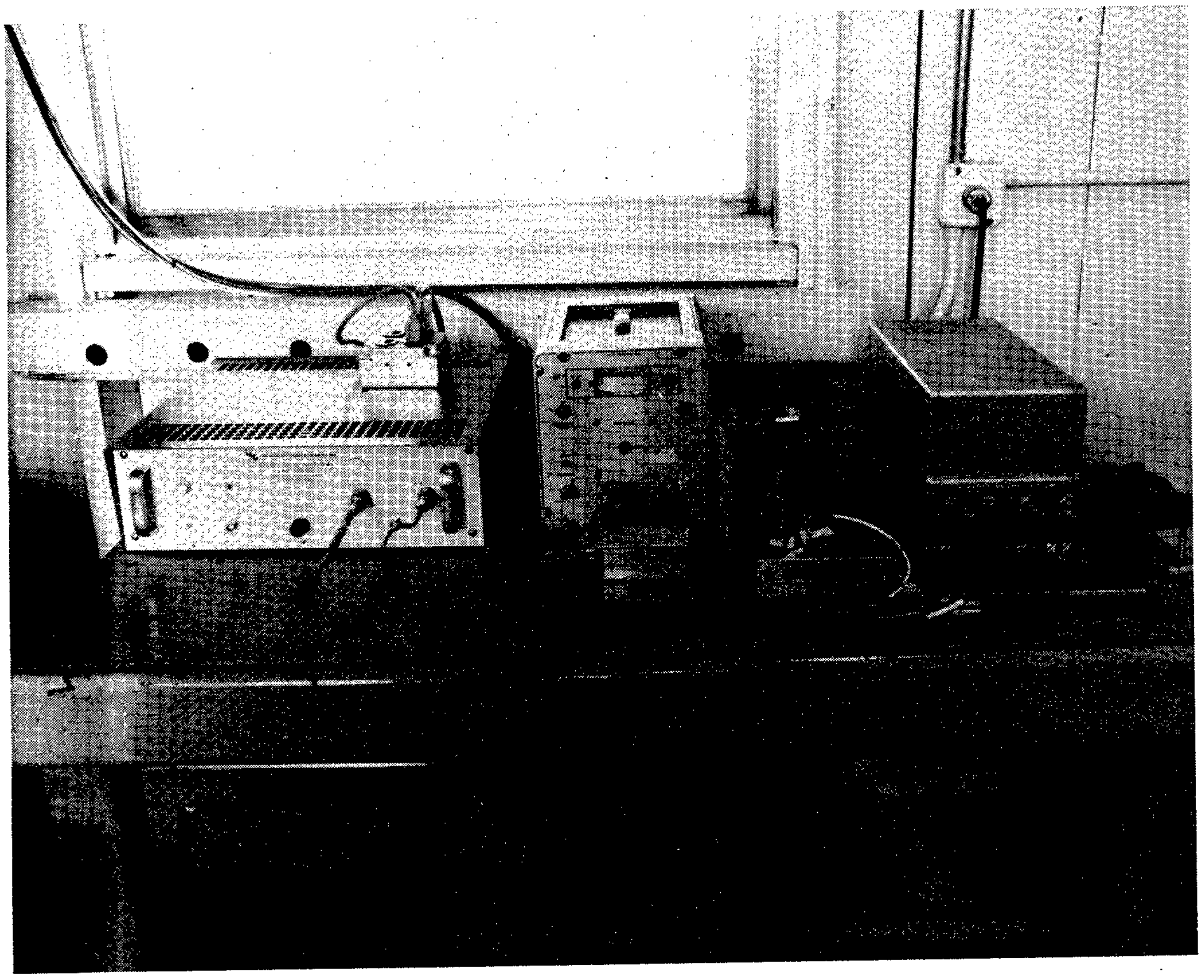
The results of the electronic scan test are summarized in Tables 13 and 14. Figure 19 is a graph showing the VSWR at RF frequencies of 425, 435 and 445 MHz plotted versus antenna scan angles.

The radiated 820 microsecond expanded UHF pulse was received with a UHF dipole antenna located near the roof top high power radiation test facility. The received UHF pulse was down converted in the receiver down converter (see Figure 15) and compressed in the analog signal processor (ASP).



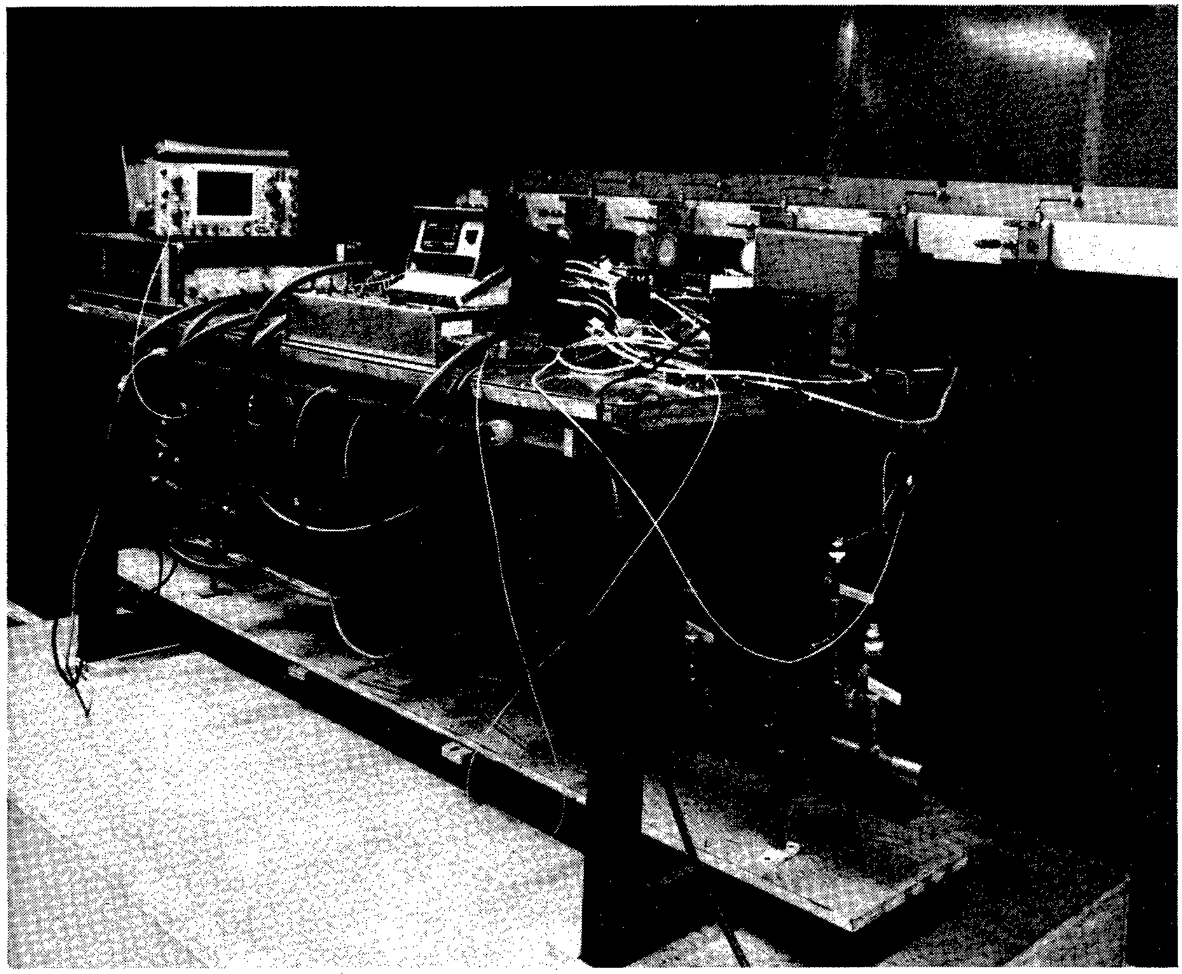
0485-015B

Figure 15. Block diagram for one-way antenna multiple module and scan tests (loop 4).



0485-016B

Figure 16. Frequency source, up/down converter and MPD power amplifier.



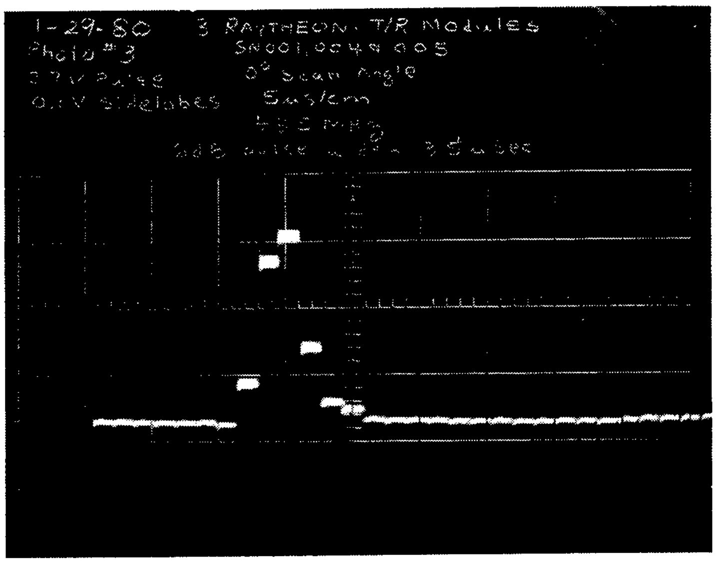
0485-017B

Figure 17. Roof-top high power radiation setup.

TABLE 12. ONE-WAY ANTENNA TEST RESULTS.

Frequency (MHz)	Mainlobe Amplitude (Cm)	Mainlobe 6 dB pulse width (μsec)	Sidelobe amplitude (Cm)	Mainlobe/sidelobe (dB)
425	2.8	3.75	0.1	28.9
435	2.7	3.5	0.1	28.6
445	2.7	3.5	0.1	28.6

0485-037B



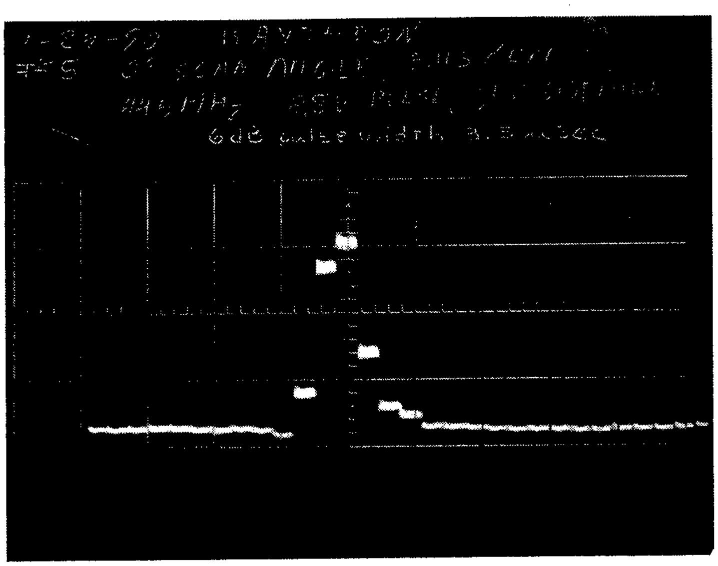


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Figure 18. One-way antenna test compressed pulses.

TABLE 13. ANTENNA VSWR VERSUS SCAN ANGLE AND RF FREQUENCY.

Frequency (MHz)	-40°	-30°	-20°	-10°	0°	+10°	+20°	+30°	+40°
425	1.23	1.24	1.24	1.26	1.26	1.26	1.24	1.24	1.23
435	1.10	1.21	1.29	1.41	1.43	1.37	1.25	1.17	1.09
445	1.09	1.22	1.46	1.68	1.70	1.65	1.44	1.18	1.07

0485-038B

TABLE 14. PULSE COMPRESSION RESPONSE (MAINLOBE/SIDELOBE RATIO, dB).

Frequency (MHz)	-40°	-30°	-20°	-10°	0°	+10°	+20°	+30°	+40°
425	29.5	29.5	28.9	>28.3	28.9	28.9	>28.3	29.2	28.9
435	29.2	>28.3	29.5	29.5	28.6	29.5	>28.3	28.9	28.3
445	>28.3	29.2	>28.3	>28.3	28.6	>28.3	>28.3	28.6	29.5

0485-039B

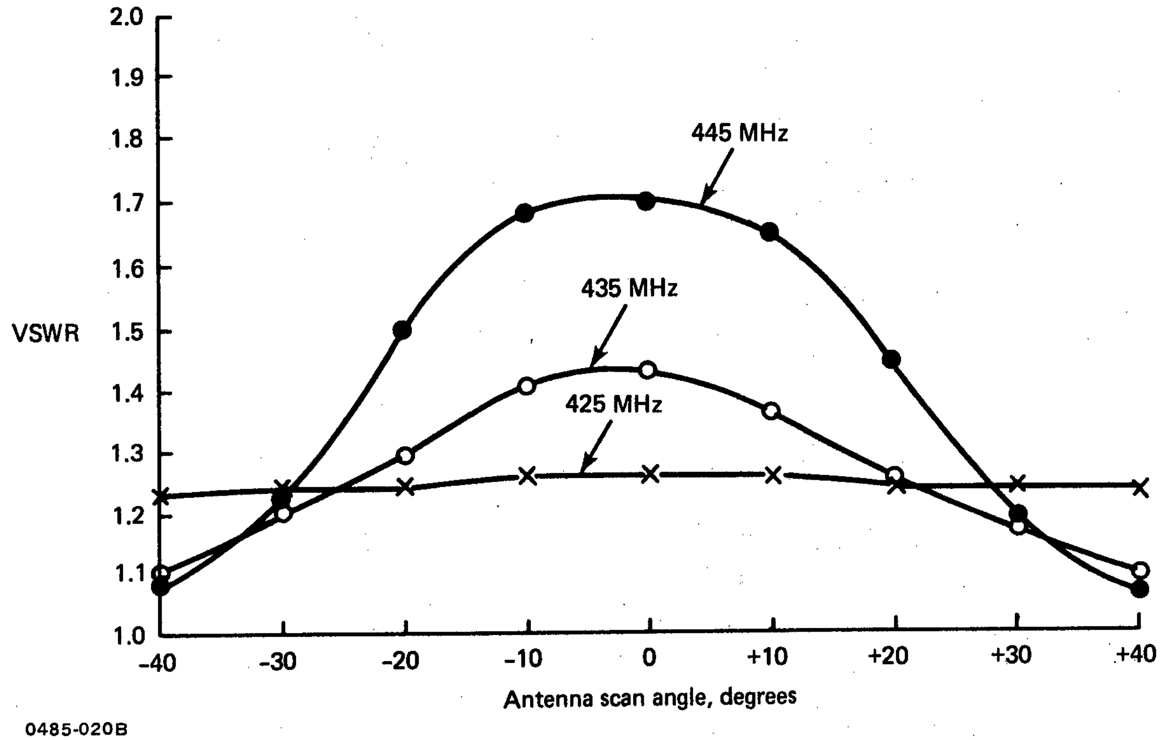
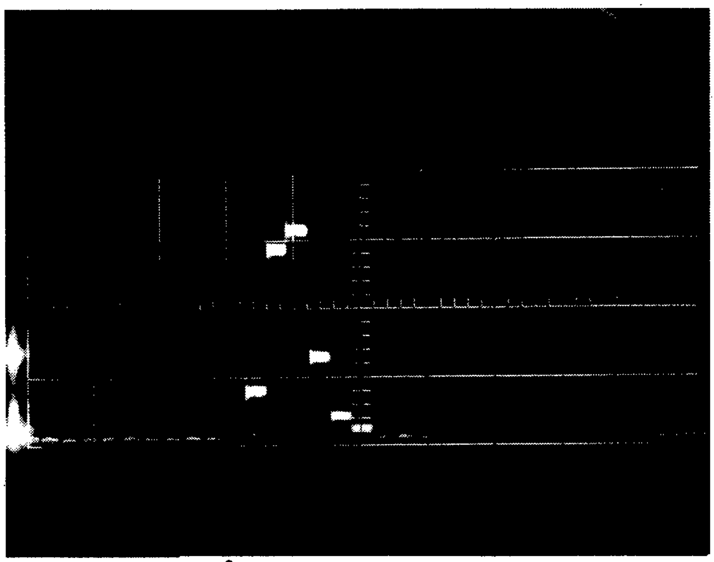
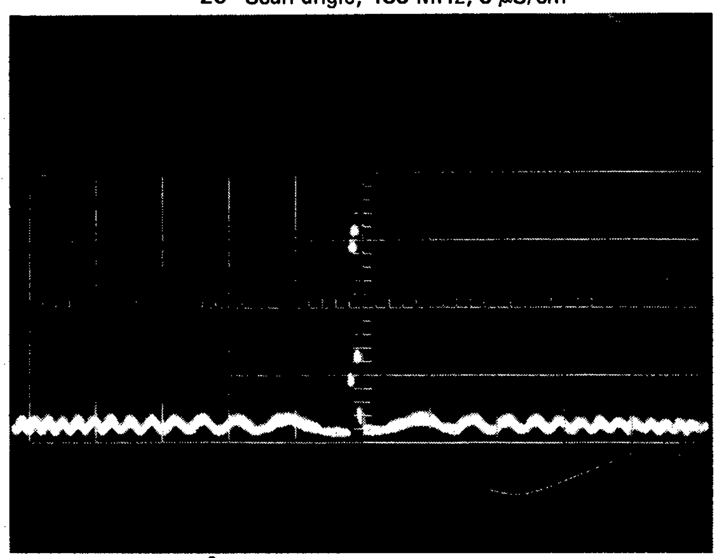


Figure 19. Antenna/UHF module VSWR measurements.

The I channel component of the compressed pulse was sampled and held and displayed on an oscilloscope for visual observation. Several photos of the compressed pulse were taken at various scan angles and RF frequencies. Samples of this data are included in Figure 20. The compressed pulse mainlobe to sidelobe ratio exceeded 28.3 dB for all cases.



-20° Scan angle, 435 MHz, 5 μS/cm



0485-021B +10° Scan angle, 425 MHz, 50 μS/cm

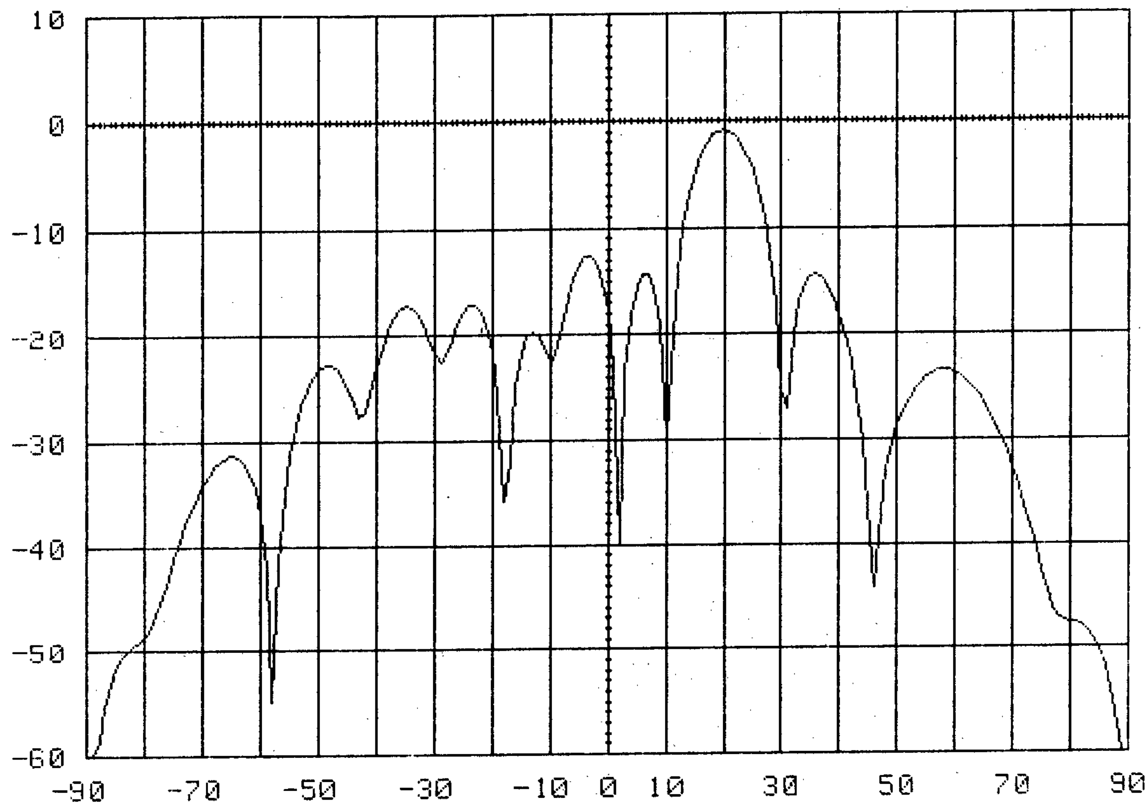
Figure 20. Electronic scan compressed pulses.

5 - SYSTEM EFFECTS AND PREDICTIONS

5.1 ANTENNA ARRAY PATTERN PREDICTIONS

The transmit phase and output power tracking errors were measured for five (5) Raytheon UHF T/R modules at three (3) RF frequencies, 420, 435 and 450 MHz. Phase and power standard deviations were calculated using these measurements and assuming a guassian error distribution. The phase and power standard deviations in conjunction with the phase shifter quantization RMS error and antenna weighting were used to predict probablistic transmit antenna patterns. Three antenna patterns (Figures 21, 22 and 23) were plotted. Figure 21 is the pattern for a twelve (12) element antenna with uniform weighting, four (4) bit phase shifter, module phase and power test measurement standard deviations at 435 MHz and a scan angle of 20 degrees. Figure 22 has the same parameters as Figure 21 except that the modules are assumed to have perfect phase and power tracking and the phase shifter is assumed to have an infinite number of bits. The transmit antenna pattern of Figure 21 is representative of the pattern expected for the Phase I Wing Array Demonstrator System and should be adequate for the required tests.

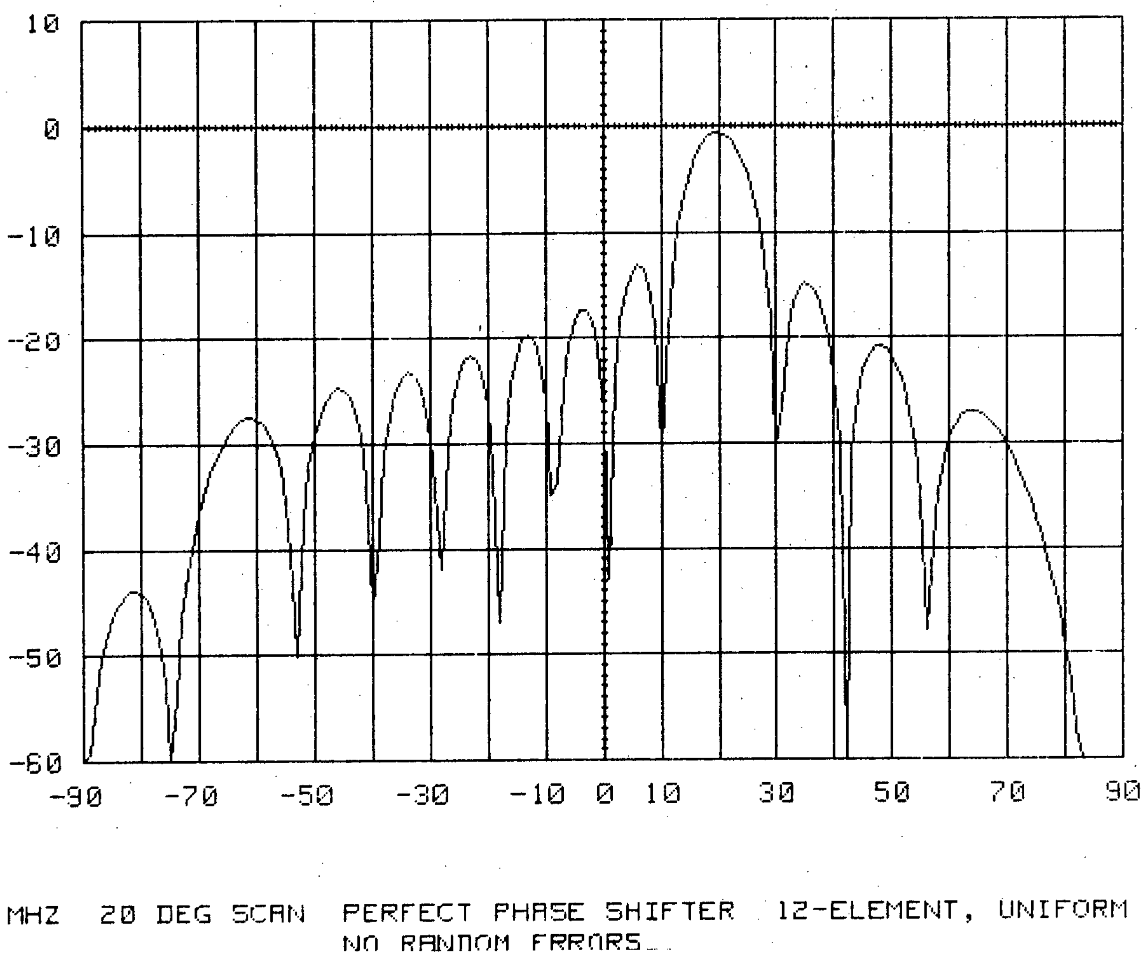
For Phase II, it is expected that other than uniform weighting will be used to reduce the sidelobe levels and optimize the transmit antenna pattern. An example of this is depicted in Figure 23, which represents the pattern of a 16 element antenna at 435 MHz and a 20 degree scan angle utilizing a phase shifter with an infinite number of bits and a 1/4, 1/4, 1/2, 1/2, 1, 1, 1, 1, 1, 1, 1, 1, 1/2, 1/2, 1/4, 1/4 transmit taper. As can be seen, the sidelobe level is down approximately 20 dB in Figure 23 versus 11 dB in Figure 21. Other tapers will also be evaluated before a final decision is made.



435 MHZ 20 DEG SCAN 4-BIT PHASE SHIFTER 12-ELEMENT, UNIFORM

0485-023B

Figure 21. Phase I antenna array transmit pattern prediction.



0485-024B

Figure 22. Optimum phase I antenna array transmit pattern.

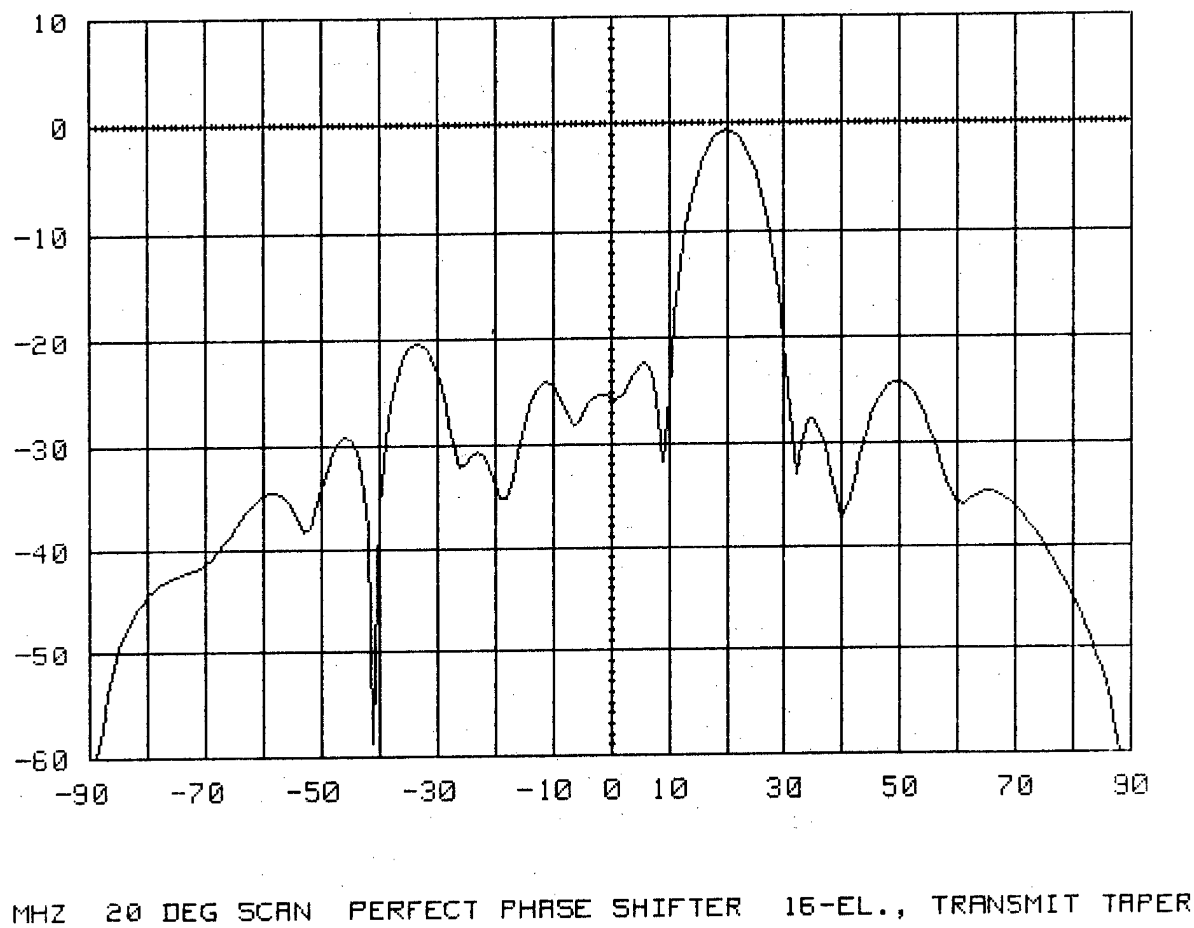


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Figure 23. Phase II antenna array transmit pattern prediction.

6 - CONCLUSIONS/RECOMMENDATIONS

The conformal radar system, consisting of the Raytheon T/R modules, ASP, frequency source, up/down converter, dynamic waveform generator, transmit manifold, MPD power amplifier and antenna was successfully integrated and operated.

The five module phase spread ranged from 16 degrees to 26 degrees at 450 MHz and 420 MHz respectively. However with phase trimming the phase spread of the five modules can be reduced to 11 degrees at both 420 MHz and 450 MHz (see Figure 4).

The mean peak power output of the modules across the frequency band of 420 to 450 MHz at 15 per cent duty cycle was 1808 watts. Although this was below the individual module specification of 2000 watts, the maximum variation (0.96 dB) for all modules across the frequency band was within the specification of 1.0 dB. One module achieved a power output of 2000 watts or greater at 15 per cent duty cycle and 435 MHz and two other modules had power outputs just under 2000 watts.

Based on observed overall performance, the Raytheon T/R modules should be adequate for Phase 1 (wing array demonstrator) testing. However, if possible, several discrepancies which were uncovered during Level I testing should be corrected prior to Phase 1 testing. These discrepancies are enumerated below:

- RF leakage thru power connectors affects test equipment/sensor responses
- T/R module drivers intermittent at low temperature
- Phase match of modules exceeds specification

The dynamic waveform generator was exercised through all its modes and provided the required system synchronization. For future use, a circuit will be incorporated to limit the transmit duty cycle to a maximum of 15 per cent.

High power radiation thru the wing array antenna and electronic phase scanning were successfully accomplished. The voltage standing wave ratio with high power operation was well below acceptable limits at all scan angles and RF frequencies, ranging from a high of 1.70 to a low of 1.07 (see Table 13).

APPENDIX A

A.1 PHASE MATCH TEST DATA

RAYTHEON T/R module serial numbers 002 and 001

Date	Frequency (MHz)	Phase error (degrees) intrapulse time (μs)			Heat sink temperature °C	
		10	410	820	SN002	SN001
10/10/79	420	-11.7	-10.7	-10.0	24	24
10/10/79	420	-17.4	-16.3	-15.8	22	23
10/17/79	420	-12.0	-10.3	-10.1	27	27
12/3/79	420	-18.6	-17.2	-17.1	27	27
12/3/79	420	-15.9	-13.7	-13.0	27	27
12/3/79	420	–	-13.5	–	28	28
12/3/79	420	–	-16.3	–	27	27
12/6/79	420	-18.6	-16.9	-17.1	27	28
Mean	420	-15.7	-14.4	-13.9	–	–
10/10/79	435	-5.1	-5.0	-5.0	24	24
10/10/79	435	-9.3	-9.7	-9.2	22	23
10/17/79	435	-5.5	-5.1	-3.9	27	27
12/3/79	435	-10.8	-10.3	-9.9	27	27
12/3/79	435	-8.1	-7.3	-6.2	27	27
12/3/79	435	–	-7.2	–	28	28
12/3/79	435		-10.1		27	27
12/6/79	435	-8.3	-8.0	-7.8	27	28
Mean	435	-7.9	-7.8	-7.0	–	–
10/10/79	450	+9.9	+9.2	+8.8	23	23
10/10/79	450	+6.9	+5.8	+6.3	22	24
10/17/79	450	+9.8	+9.2	+9.0	26	27
12/3/79	450	+3.2	+2.4	+3.0	27	27
12/3/79	450	+6.9	+6.9	+6.8	27	27
12/3/79	450	–	+7.4	–	28	28
12/3/79	450	–	+4.1	–	27	27
12/6/79	450	+2.7	+1.8	+1.5	27	28
Mean	450	+6.6	+5.9	+5.9	–	–

0485-040B

RAYTHEON T/R module serial numbers 002 and 003

Date	Frequency (MHz)	Phase error (degrees) intrapulse time (μs) 10	410	820	Heat sink temperature °C SN002	SN003
10/2/79	420	-18.1	-18.2	-17.8	22	21
10/12/79	420	-19.2	-20.0	-19.5	24	25
10/16/79	420	-19.8	-20.8	-20.1	25	25
10/8/79	420	-17.9	-18.1	-17.9	27	27
10/13/79	420	-21.7	-21.7	-21.2	31	31
Mean	420	-19.3	-19.8	-19.3	–	–
10/2/79	435	-7.0	-11.3	-11.1	22	21
10/12/79	435	-9.9	-13.6	-13.5	24	24
10/16/79	435	-10.6	-14.2	-14.1	25	25
10/8/79	435	-7.9	-11.5	-11.9	27	27
12/13/79	435	-12.4	-14.4	-14.3	31	31
Mean	435	-9.6	-13.0	-13.0	–	–
10/2/79	450	+3.2	+2.9	+3.2	22	21
10/12/79	450	+2.0	+2.3	+2.6	25	25
10/16/79	450	+1.6	+1.6	+1.5	25	25
10/8/79	450	+2.9	+2.3	+2.2	27	28
12/13/79	450	+2.3	+2.4	+2.4	31	31
Mean	450	+2.4	+2.3	+2.4	–	–

0485-041B

RAYTHEON T/R module serial numbers 002 and 004

Date	Frequency (MHz)	Phase error (degrees) intrapulse time (μs) 10	410	820	Heat sink temperature °C SN002	SN004
10/24/79	420	+2.9	+6.2	+7.2	26	25
12/6/79	420	+2.7	+6.5	+6.8	26	26
Mean	420	+2.8	+6.4	+7.0	–	–
10/24/79	435	+7.7	+12.4	+13.1	26	26
12/6/79	435	+7.1	+11.6	+12.7	26	26
Mean	435	+7.4	+12.0	+12.9	–	–
10/24/79	450	+17.6	+16.4	+16.2	26	26
12/6/79	450	+16.5	+15.4	+14.8	26	26
Mean	450	+17.1	+15.9	+15.5	–	–

0485-042B

RAYTHEON T/R module serial numbers 002 and 005

Date	Frequency (MHz)	Phase error (degrees) intrapulse time (μs) 10	410	820	Heat sink temperature °C SN002	SN005
10/22/79	420	-5.5	-3.1	-2.3	27	28
10/23/79	420	-4.1	-1.6	-0.7	28	28
12/10/79	420	-9.6	-7.0	-6.8	27	28
12/10/79	420	-8.5	-5.7	-5.4	28	27
12/10/79	420	-10.0	-6.9	-6.8	29	28
Mean	420	-7.5	-4.9	-4.4	–	–
10/22/79	435	-2.6	+1.4	+1.7	27	27
10/23/79	435	-0.6	+1.9	+2.8	27	27
12/10/79	435	-4.9	-0.3	-0.1	27	28
12/10/79	435	-3.7	-0.2	+0.1	28	27
12/10/79	435	-5.7	-1.1	-0.7	29	28
Mean	435	-3.5	+0.3	+0.8	–	–
10/22/79	450	+13.6	+14.2	+15.0	26	26
10/22/79	450	+13.5	+14.7	+16.0	26	26
12/10/79	450	+8.4	+10.6	+10.4	27	28
12/10/79	450	+8.2	+9.8	+10.8	28	27
12/10/79	450	+6.8	+8.9	+9.1	29	28
Mean	450	+10.1	+11.6	+12.3	–	–

0485-043B

A.2 VSWR DATA

Frequency (MHz)	Scan angle (degrees)	Reflected power (+dBm)	Incident power (+dBm)	VSWR
425	0	44.11	62.96	1.26
425	+10	44.11	62.96	1.26
425	+20	43.61	62.96	1.24
425	+30	43.51	62.96	1.24
425	+40	43.31	62.96	1.23
425	-10	44.11	62.96	1.26
425	-20	43.61	62.96	1.24
425	-30	43.51	62.96	1.24
425	-40	43.41	62.96	1.23
435	0	48.03	63.13	1.43
435	+10	47.03	63.13	1.37
435	+20	44.03	63.13	1.25
435	+30	41.23	63.13	1.17
435	+40	36.03	63.13	1.09
435	-10	47.73	63.13	1.41
435	-20	45.23	63.13	1.29
435	-30	42.73	63.13	1.21
435	-40	36.93	63.13	1.10
445	0	51.24	62.94	1.70
445	+10	50.75	62.94	1.65
445	+20	48.04	62.94	1.44
445	+30	41.24	62.94	1.18
445	+40	33.24	62.94	1.07
445	-10	51.04	62.94	1.68
445	-20	48.34	62.94	1.46
445	-30	42.74	62.94	1.22
445	-40	35.74	62.94	1.09

0485-044B

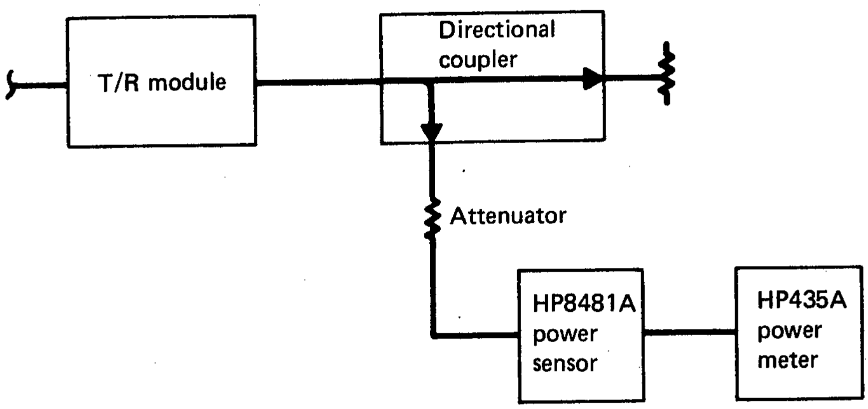
A.3 TEST EQUIPMENT AND COMPONENT CALIBRATION INFORMATION

Test equipment used for these tests that normally requires calibration was calibrated by the Grumman standards laboratory. In addition, components such as attenuators and directional couplers were calibrated in the conformal radar laboratory at the appropriate UHF frequencies utilized.

A.4 SAMPLE CALCULATIONS

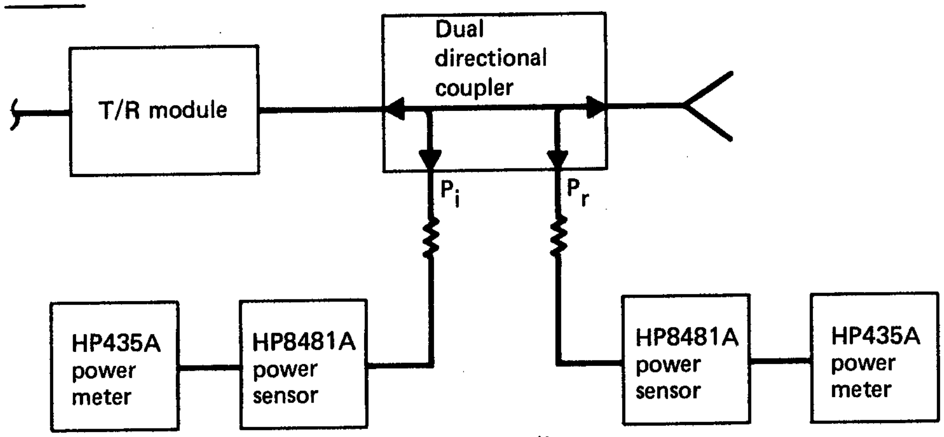
Figure 24 demonstrates the methods used for calculating T/R module power output and T/R module/antenna VSWR.

Output power



HP435A power meter reading	+ 8.50 dBm
Correction for attenuator	+ 25.60 dBm
Correction for directional coupler	+ 20.20 dBm
Correction for 15% duty cycle	+ 8.24 dBm
Correction for 33 out of 34 pulses	+ 0.13 dBm
	+ 62.67 dBm (1849 watts peak)

VSWR



$$\mathrm{VSWR} = \frac{1 + (P_r/P_i)^{1/2}}{1 - (P_r/P_i)^{1/2}}$$

P_i = + 62.96 dBm (1977 watts)

P_r = + 44.11 dBm (25.8 watts)

$$\mathrm{VSWR} = \frac{1 + (25.8/1977)^{1/2}}{1 - (25.8/1977)^{1/2}} = 1.26$$

0485-022B

Figure 24. Sample calculations.