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ATC-91

The Transportable Measurements Facility (TMF) System Description

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16. Abstract

This report describes the MIT Lincoln Laboratory Transportable Measurements Facility (TMF), a special purpose beacon interrogator patterned after the Discrete Address Beacon Sensor. This van-mounted experimental beacon system includes all ATCRBS/DABS reply processing and monopulse processing, but not other DABS processing. It was developed to collect data at various locations in the United States so that candidate DABS sensor antenna and processing could be evaluated in a real environment.

The TMF has been installed and operated at:

Logan Airport (Boston)
Deer Island, MA (near Logan)
Washington National Airport (DCA)
Philadelphia Int. Airport (PHL)
Clementon, NJ (near Philadelphia)
Los Angeles Int. Airport (LAX)
Brea, CA (25 miles east of LAX)
Salt Lake City, UT (SLC)
Layton, UT (near Salt Lake City)
Las Vegas Airport (LAS)
Green Airport, Warwick, RI

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SYSTEM DESCRIPTION

1.0 INTRODUCTION

The Transportable Measurements Facility (TMF) is a special purpose beacon interrogator patterned after the Discrete Address Beacon Sensor* including all ATCRBS/DABS reply processing and monopulse processing, but less all other DABS processing. It was developed to collect data at various locations in the United States so that candidate DABS sensor antenna and processing could be evaluated in a real environment.

The facility was designed with sufficient flexibility to support: monopulse performance evaluation at different sites using different antennas, antenna/site characterization, ATCRBS-mode and DABS-mode processor evaluation, and DABS-based ATC and ATARS system studies.

In order to accomplish the primary task of accumulating a broad data base for the ATCRBS processor evaluation effort, the facility was initially designed as an ATCRBS interrogator and monopulse receiver with the capability of direct digital recording on computer tape of the ATCRBS downlink pulse environment. Subsequently the TMF was modified to include the capabilities of transmitting a DABS-Only All-Call interrogation waveform in order to characterize DABS uplink and downlink performance. The TMF has the capability of preadjusting the recorder interval as well as the PRF in order to match the particular ATCRBS fruit-environment level to the capability of the recording system. The design of the TMF does not include processing capability beyond the video pulse quantizer for reply detection or generation of target reports and tracks. These functions, operating on output data recorded by the TMF, are performed in non-real-time at the Lincoln Laboratory DABS computer facility.

In order to determine the effect of various antenna characteristics on DABS/ATCRBS performance under different site conditions the TMF was designed to operate with a variety of antenna systems. Although the primary antenna system for the TMF is an ASR-7 antenna with integral beacon feed, it has employed a Cossor developmental antenna, a Hazeltine open array, and the FAA ATC-309C "hogtrough" antenna.

The TMF has been installed and operated at the following locations:

Logan Airport (Boston)
Deer Island, Mass (near Logan)
Washington National Airport (DCA)
Philadelphia Int. Airport (PHL)
Clementon, NJ (near Philadelphia)
Los Angeles Int. Airport (LAX)
Brea, CA (25 miles east of LAX)
Salt Lake City, UT (SLC)
Layton, UT (near Salt Lake City)
Las Vegas Airport (LAS)
Green Airport, Warwick, RI

*As specified in FAA-ER-240-26A.

2.0 OVERALL SYSTEM DESCRIPTION

The Transportable Measurements Facility (TMF) consists of (Fig. 1):

Antenna with pedestal, tower and supporting flatbed trailer
Equipment trailer
Mobile power unit

The primary antenna for the TMF is an ASR-7 airport surveillance radar antenna whose radar feed has been modified to incorporate an integral radar/beacon feed. Supporting this antenna is an ASR-7 antenna pedestal with its drive system modified to enable a constant rotation rate of 15 rpm. The antenna tower used most often is an 18 foot structure mounted atop the flatbed trailer. Additional tower structure is also available to permit a maximum antenna platform height of 54 feet (Fig. 2).

A block diagram of the TMF is shown in Fig. 3. The electronic units shown in this figure are housed in racks mounted along the roadside of the equipment trailer. This equipment consists of:

Beacon transmitters with transmit waveform generator
(a front panel view is shown in Fig. 4)
Receiver/monopulse processor (Figs. 5 and 6)
Video processor (VPQ) (Fig. 7)
A/D Converters (Fig. 7)
Timing subsystem (Fig. 7)
Recording subsystem

Also mounted on the trailer roadside near the forward entry door are the PPI and A-scope displays, as shown in Fig. 8.

The transmitter used in the TMF is part of an UPX-6 interrogator. It is capable of generating 2 KW peak power at a duty cycle of 0.15% and is used primarily for the interrogation of ATCRBS transponders. In addition to the UPX-6, the TMF employs an APX-76 transmitter unit to generate a DABS-only All-Call interrogation. The APX-76 is capable of generating a 30 μsec pulse of 2 KW peak at a maximum PRF of 100.

The transmit waveform generator produces various video waveforms necessary to modulate the transmitter, outputting the selected transmit waveform upon receipt of a zero-range trigger from the PRF counter. The waveform generator can also produce a preselected sequence of any four modulation waveforms. It also functions to provide either an SLS switch control pulse for P2 transmission via the omni antenna or, in the absence of an SLS switch, a separate P2 pulse for modulating an auxilliary P2 transmitter. The waveform generator provides transmit mode status for recording purposes.

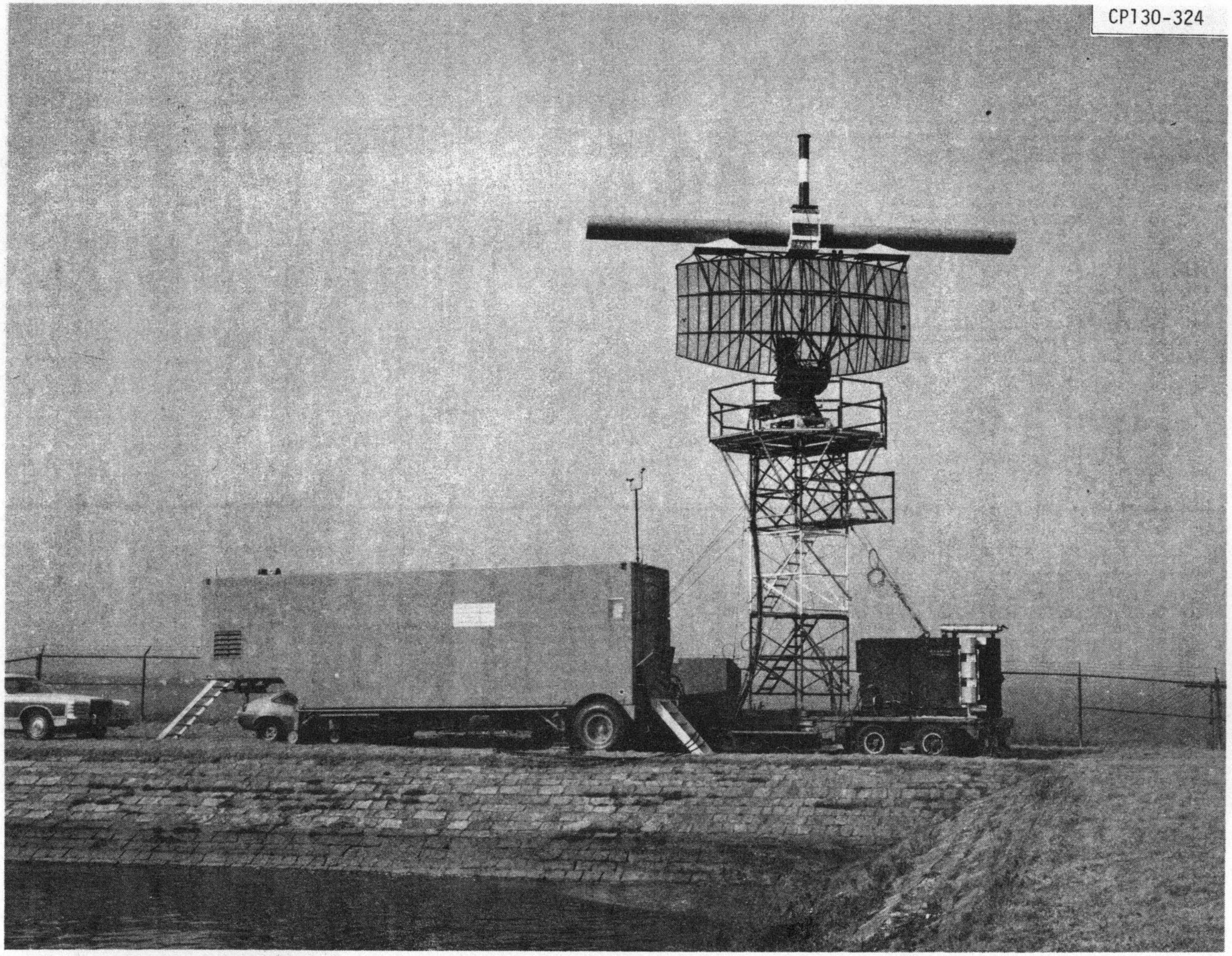

Fig. 1. Transportable Measurements Facility (TMF) with short tower.

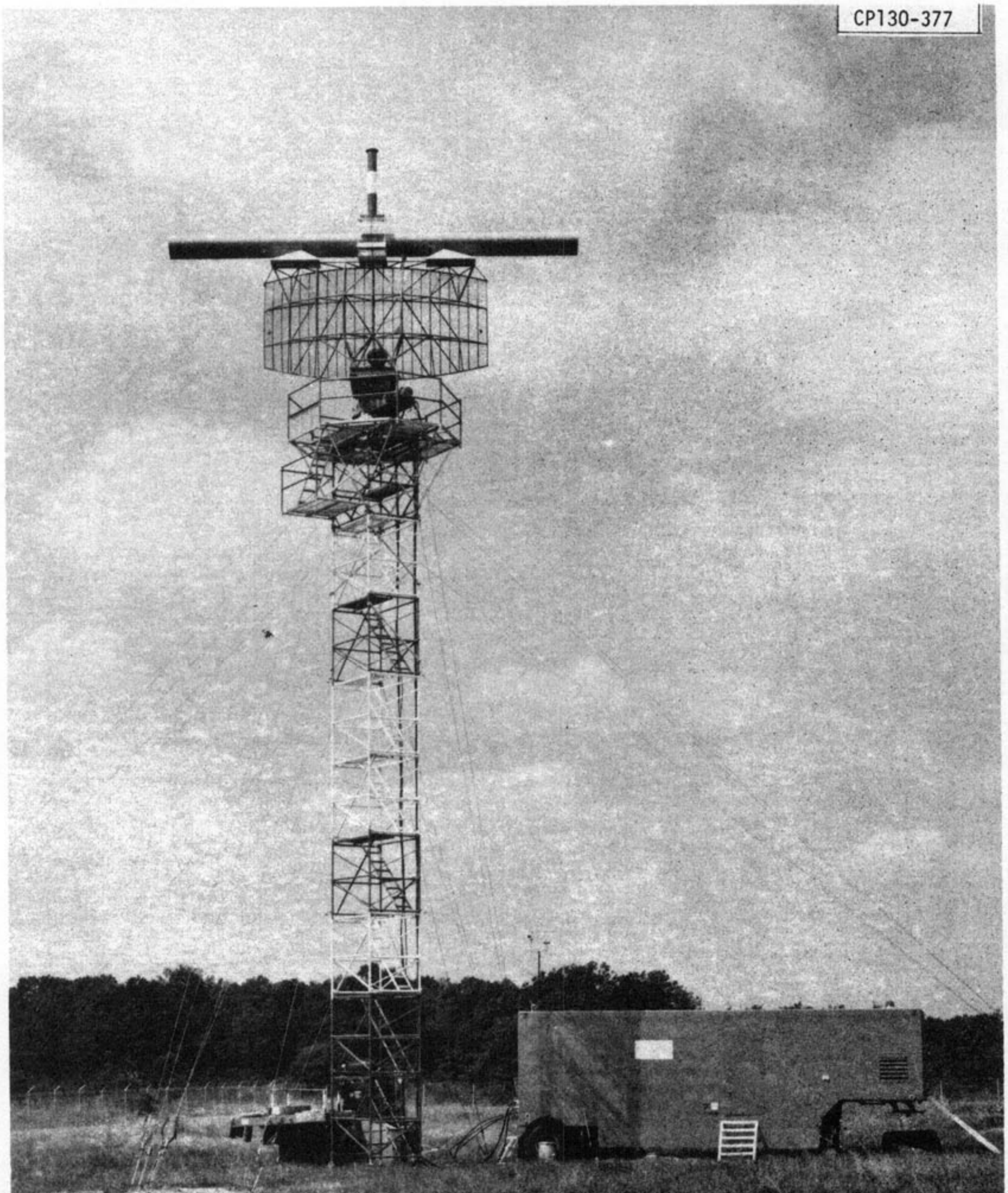

Fig. 2. Transportable Measurements Facility (TMF) with high tower.

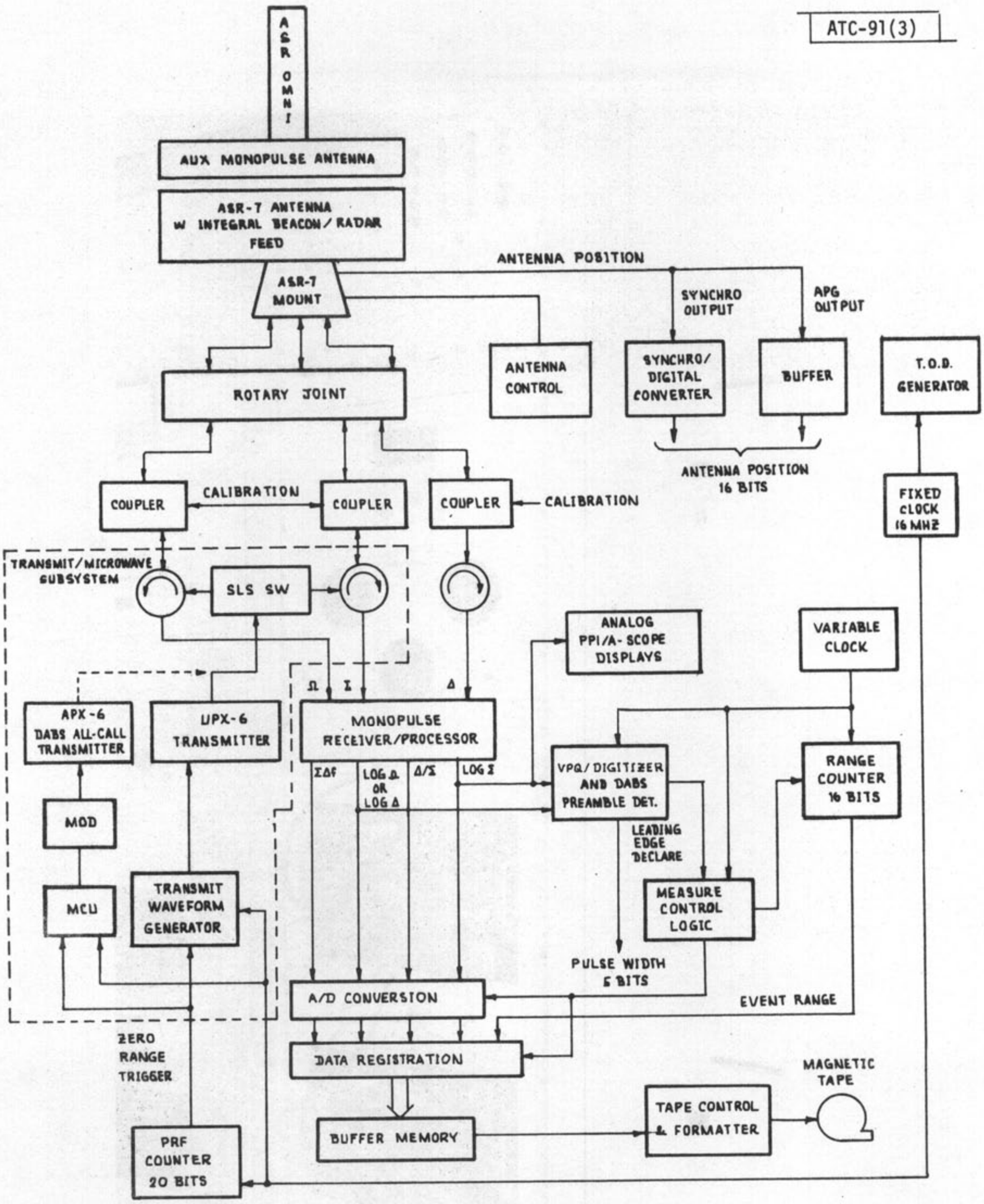

Fig. 3. Transportable measurements facility simplified block diagram.

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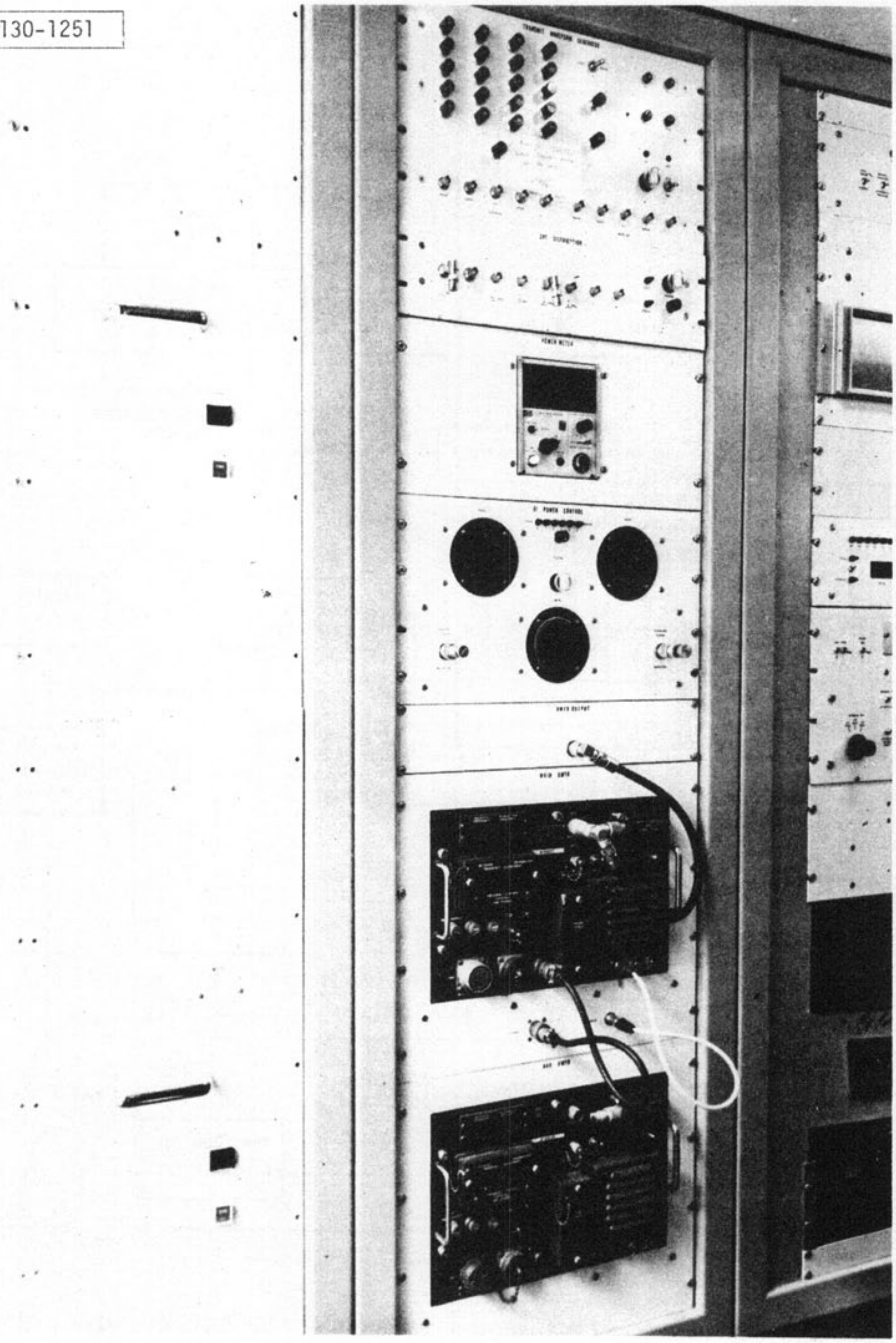

Fig. 4. Beacon transmitters with transmit waveform generator (panel view).

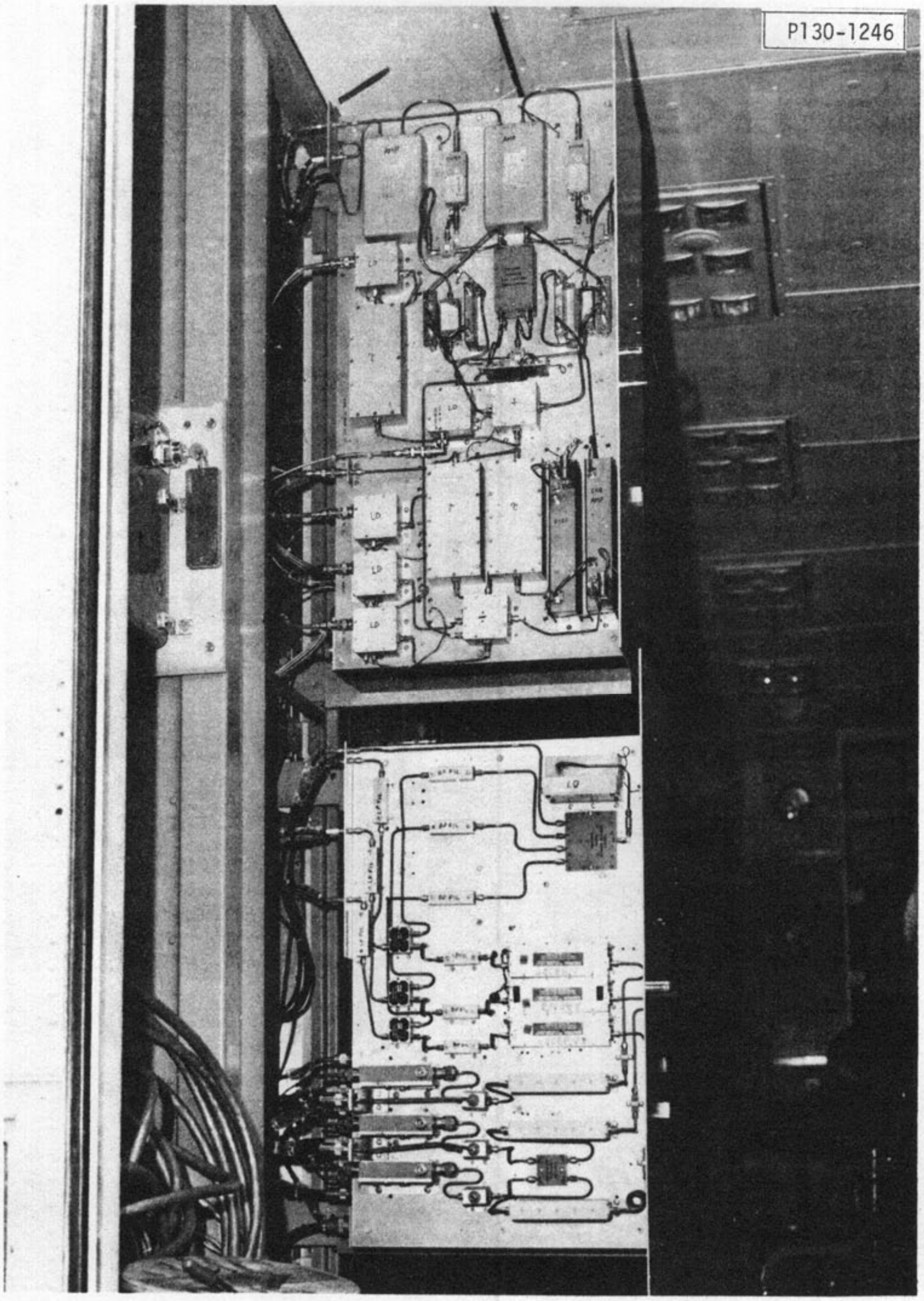

Fig. 5. Receiver/monopulse processor (left/top view).

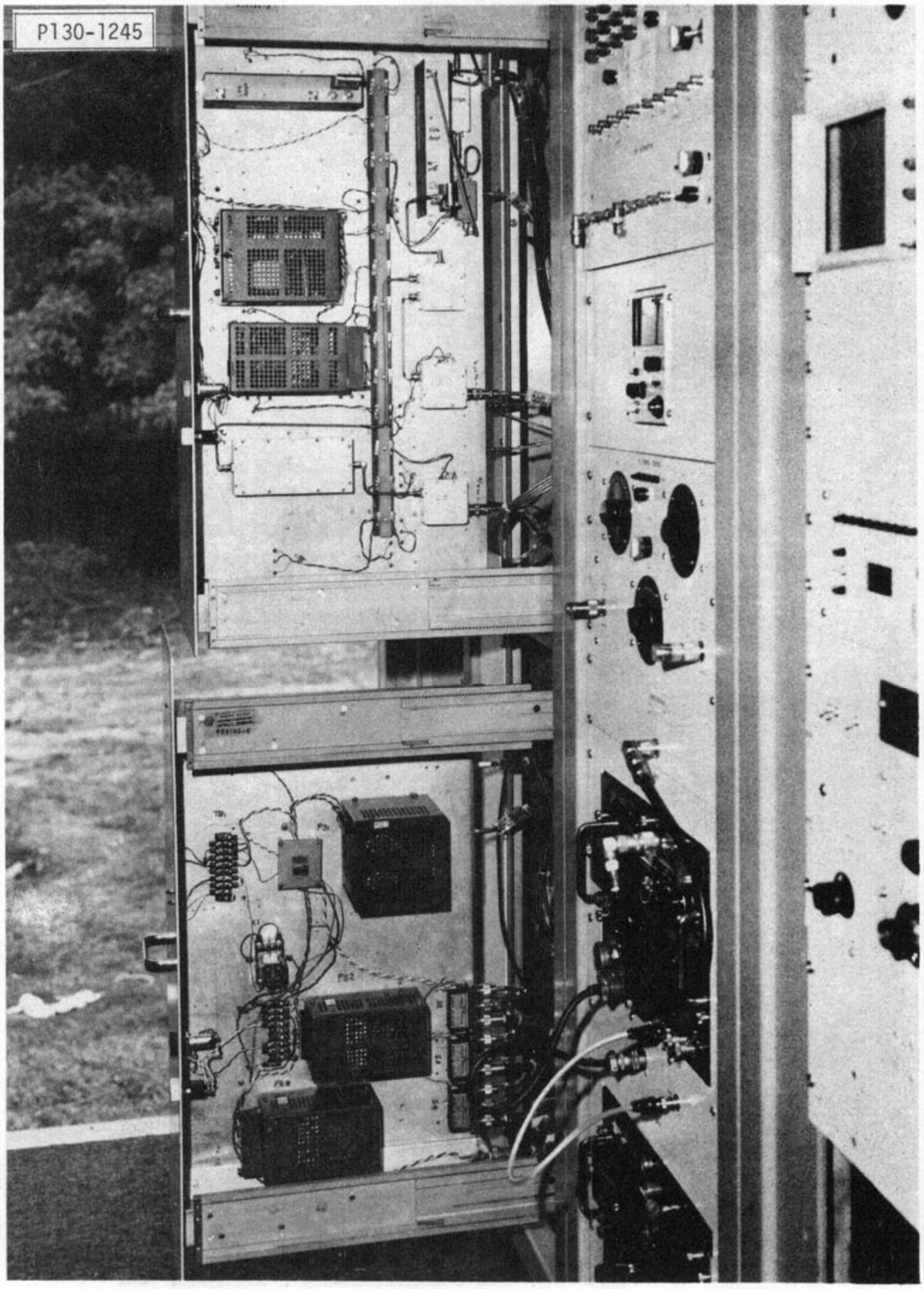

Fig. 6. Receiver/monopulse processor (right/bottom view).

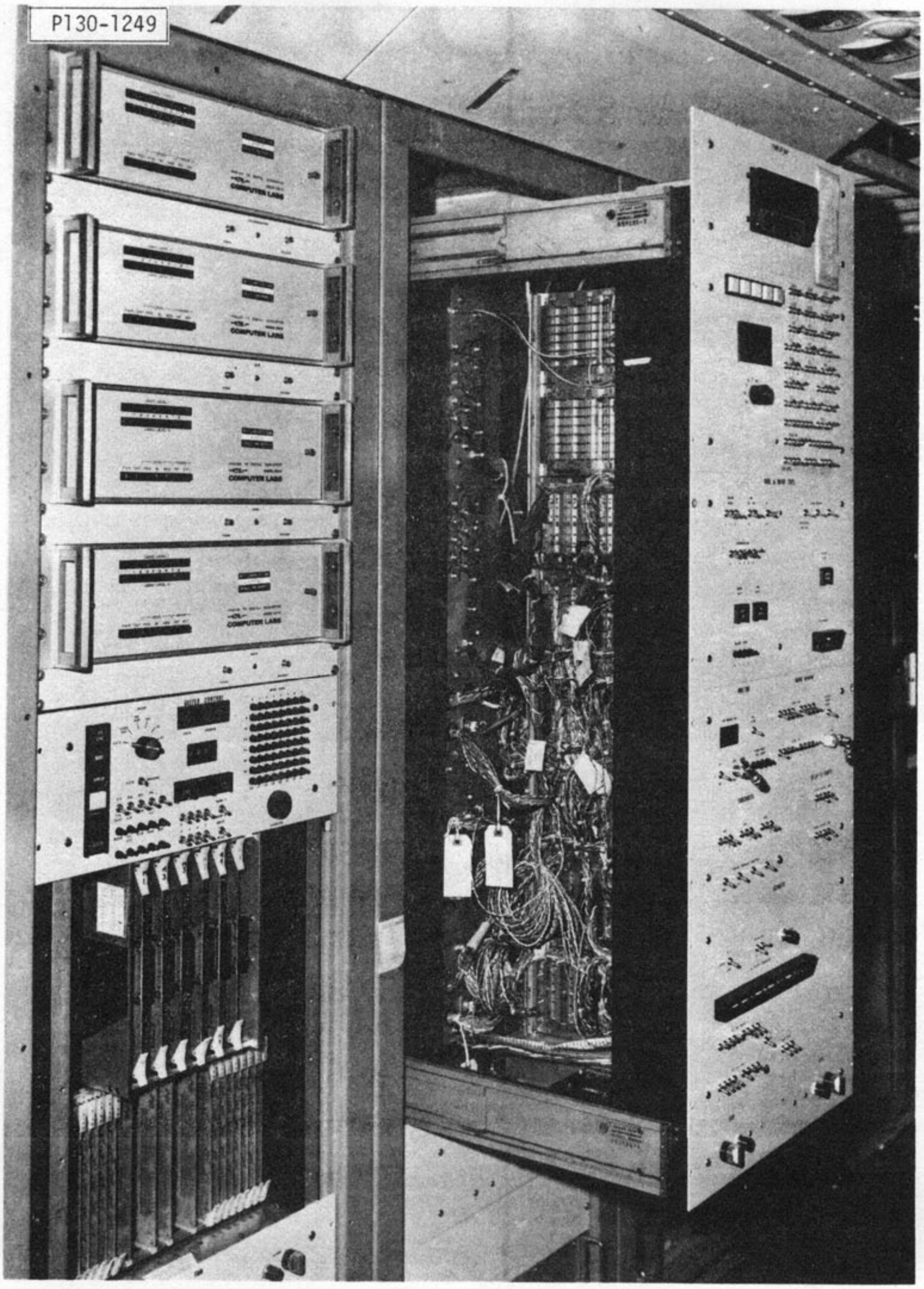

Fig. 7. Video processor (VPQ) with timing subsystem (withdrawn from rack); analog to digital converters (4).

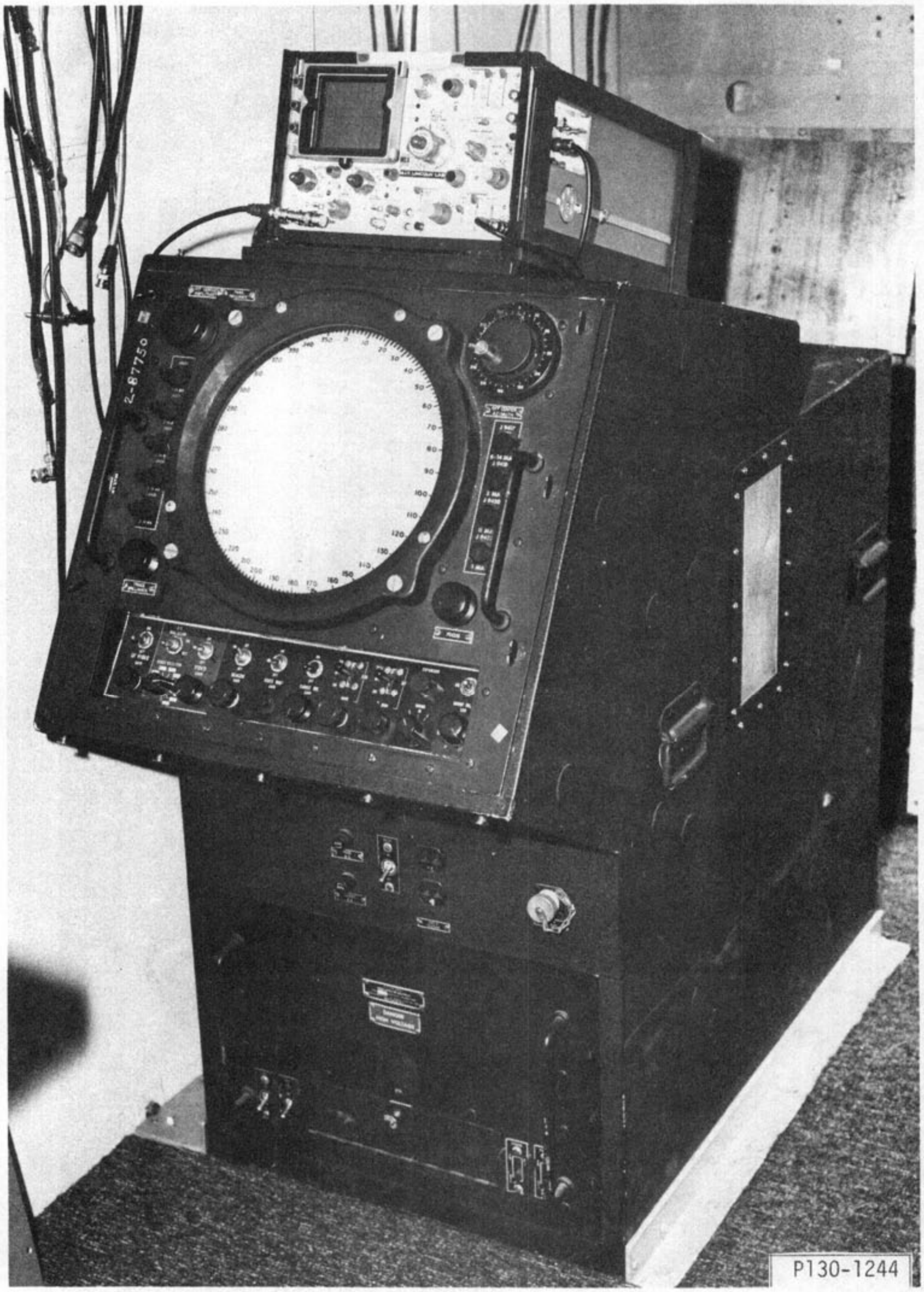

Fig. 8. PPI and A-Scope displays.

The transmit signals are routed via the SLS switch and circulators to the directional antenna and to the omni antenna.

A 3-channel L-band rotary joint transfers sum, difference and omni signals between the antenna and the interrogator/receiver. A 14-bit azimuth pulse generator, driven by the rotary joint, is the primary source of antenna azimuth data.

The received signals (sum (Σ), difference (Δ) and omni (Ω)) are processed in a three channel, half-angle, monopulse receiver. The advantage of the half-angle processor over other types is its lack of ambiguities in the monopulse error function over an azimuth region of nearly ±1 beamwidths. The receiver has an overall noise level of approximately -97 dBm and a dynamic range in excess of 65 dB.

The log sum, log omni and monopulse error outputs from the monopulse processor are fed to analog-to-digital converters. An amplitude limited output signal from the sum channel log detector is used to drive a frequency discriminator for downlink frequency measurements. The log sum signal is also fed to the video pulse quantizer (VPQ) for video processing. The ATCRBS VPQ in the TMF is basically the same design as suggested in the FAA DABS sensor ER. The log sum video pulses are processed in the analog and digital portions of the VPQ to produce leading edge and pseudo leading edge declarations whenever the characteristics of the input pulses satisfy certain criteria associated with S/N, risetime and relative amplitudes of overlapping pulses. Each edge declaration is then used to initiate, via the sample control logic, a single encode command to the A/D converters for sampling of the log sum, log omni and monopulse error pulses. Another mode of operation allows a free-running sampling of the A/D converters for 21.2 μsec duration based on the occurrence of a leading edge. The next leading edge after the 21.2 μsec sampling period reinitiates the process.

A range count is generated and recorded at the time of leading and pseudo-leading edges.

The quantized sum signal (QΣA) derived in the analog portion of the VPQ is also fed to a DABS preamble detector to detect the presence of DABS downlink replies. A detected preamble initiates a free-running sampling period which includes the DABS reply data block. The DABS free run duration is approximately 120 μsec.

The log sum and log omni A/D converters have 7-bit resolution and the monopulse error converter has 8-bit resolution. The receiver bandwidth is 10 MHz for the log omni, monopulse error and the log sum A/D converters. The A/D converter used for digitizing the discriminator output signal has 6-bit resolution.

The outputs of the A/D converters along with the other pulse-by-pulse information such as range count, leading edge or pseudo leading edge type and pulse width are buffered in a high speed memory and then transferred to tape. The memory size is 512 64-bit words.

Time-of-day, boresight azimuth and transmit mode are recorded on a sweep by sweep basis and experiment parameters, modes and other information are recorded once per experiment in the header record.

The recording system utilizes IBM-compatible magnetic tape recording with a capability of 1600 CPI at 125 ips. The effective recording bandwidth is on the order of 150 K bytes/sec. The received data during a 100 mile recording interval is on the order of 800 bytes at a peak input rate of 45 nsec per byte. The recording interval per sweep, and the PRF, can be manually adjusted so that either parameter can be maximized while still matching the fruit environment to the capability of the recording system.

Two different clock sources are used. A fixed clock frequency of 16 MHz drives the time-of-day (TOD) generator, the PRF counter from which the zero-range trigger is derived, and the transmit waveform generator. A selectable clock frequency of 24/1.45 MHz, 26/1.45 MHz or 28/1.45 MHz is used in conjunction with the VPQ, the pulse width counter and the range counter. The A/D strobe control logic uses one-half the VPQ clock frequency.

3.0 DETAILED DESCRIPTION OF SUBSYSTEMS

3.1 Pedestal and Tower Structure

The TMF uses an ASR-7 type pedestal whose gearing has been modified by the vendor to rotate the antenna at 15 RPM instead of the normal 12.6 RPM. The pedestal contains a 10:1 and 1:1 synchro system which drives the deflection circuitry of the PPI CRT indicator. The synchro outputs are also converted to a digital azimuth word in a 16 bit synchro-to-digital converter. The output of the converter is used as a backup antenna position indicator for the azimuth pulse generator.

The TMF rotating joint contains three L-Band coaxial channels in the 1020 to 1100 MHz frequency range with a capability of handling 1 KW peak power and 50 W average power. The phase tracking between the three channels are within ±2 degrees. The rotating joint drives a photo-optical azimuth shaft encoder to generate the primary 14 bit azimuth position information.

Two separate tower configurations are used to support the TMF antenna. The primary tower structure (Fig. 1) consists of three 6-foot sections of collapsible scaffolding mounted on a flatbed trailer. This arrangement positions the ASR-7 integral feed approximately 24 feet above ground level. The other configuration uses nine of the 6-foot sections, as illustrated in Fig. 2, to place the ASR-7 integral feed approximately 60 feet above ground level. The tower is mounted directly on the ground and uses an anti-twist arrangement of guy wires attached to the upper two tower sections to reduce torsional rotation to a level consistant with the required azimuth accuracy.

3.2 Antenna

A modified ASR-7 antenna with integral feed developed by Texas Instruments is the primary antenna system for the TMF. The modification consisted of adding an L-Band dipole feed array to the existing S-Band feed horn structure as illustrated in Fig. 9. The secondary L-Band antenna patterns from the 17.5 foot by 8.9 foot ASR-7 reflector exhibit a 4 degree beamwidth in azimuth and a cosecant squared shape in elevation. The vertical beam was positioned such that the peak-of-beam occurs approximately 5 degrees above horizon. Vertical roll-off at horizon is 1.8 dB/degrees, the gain is 25 dB and the largest sidelobe level is approximately 25 dB down. Figure 10 illustrates an azimuth monopulse pattern for the ASR-7 with integral feed as measured at the horizon. Other antenna systems that have been used with the TMF have been the British Cossor Antenna, the Hazeltine 4-foot open array and an ATCBI Hog-trough. The Cossor Antenna, which was modified by the vendor for monopulse, was used almost as extensively as the ASR-7 to provide comparative data with an antenna that has minimum vertical apperture and an integral control pattern. The Cossor is mounted atop the ASR-7 reflector as shown in Figs. 1 and 2. An RF switch assembly above the rotating joint provides a convenient means of transferring operation from one antenna to another.

3.3 Transmitter/Microwave Subsystem

Figure 11 is a block diagram of the transmitter chain and microwave system. The Transmit Waveform Generator, shown in more detail in Fig. 12 provides the P1, P2, P3, and P4 pulse amplitude modulation to the TMF interro-gation transmitter upon receipt of a zero range trigger from the PRF counter. An SLS switch command is derived and sent to the SLS switch to divert the transmitted P2 pulse to the omni antenna.

A separate P2 output is available in the event that an auxiliary omni transmitter is used in place of an SLS switch.

The various interrogation modes available from the transmit waveform generator are:

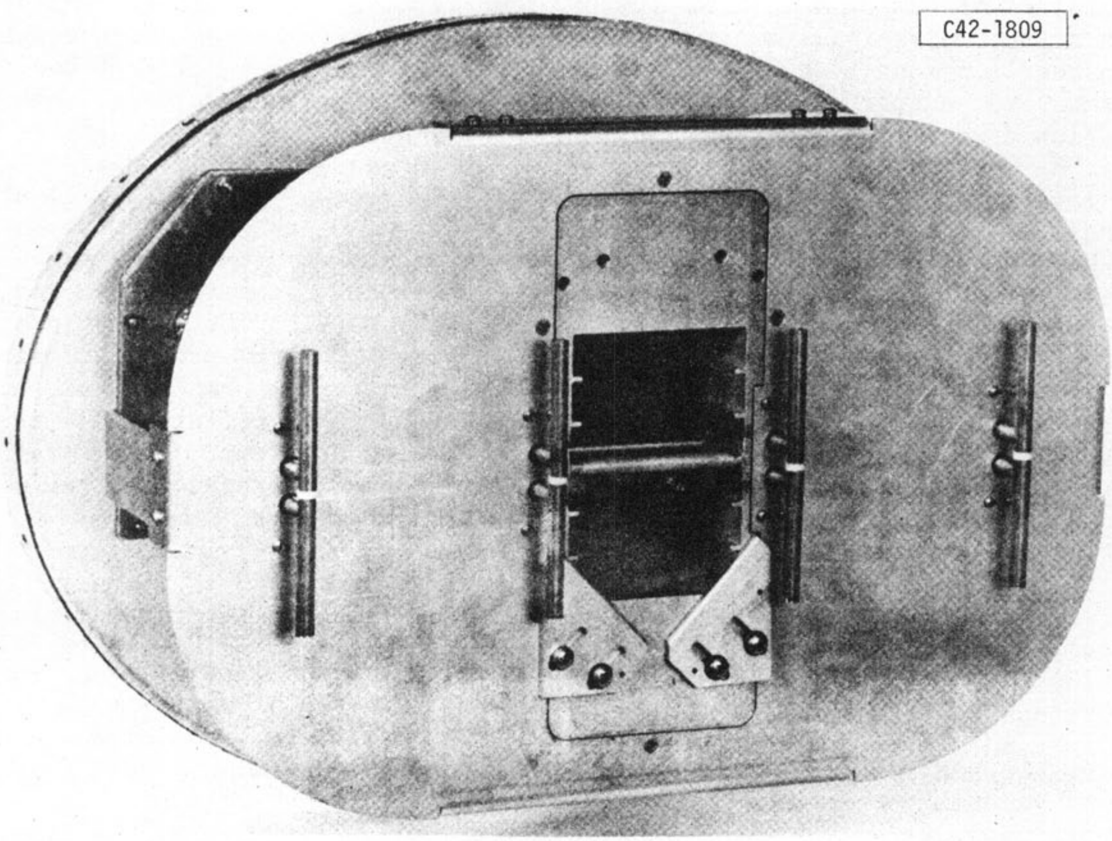

Fig. 9. ASR-7 integral feed.

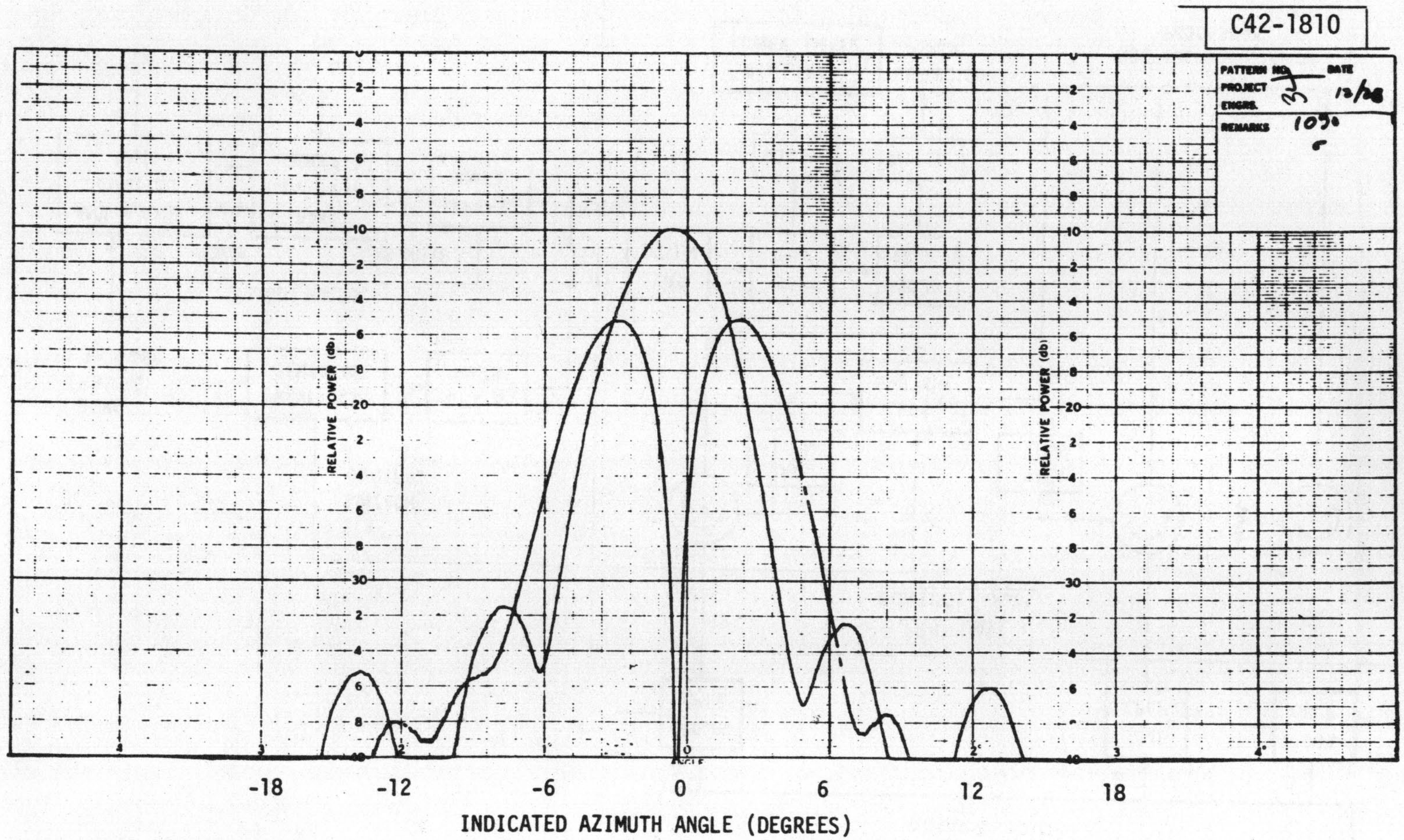

Fig. 10. Azimuth monopulse patterns at 1090 MHz over the elevation coverage range 0.0 degrees elevation.

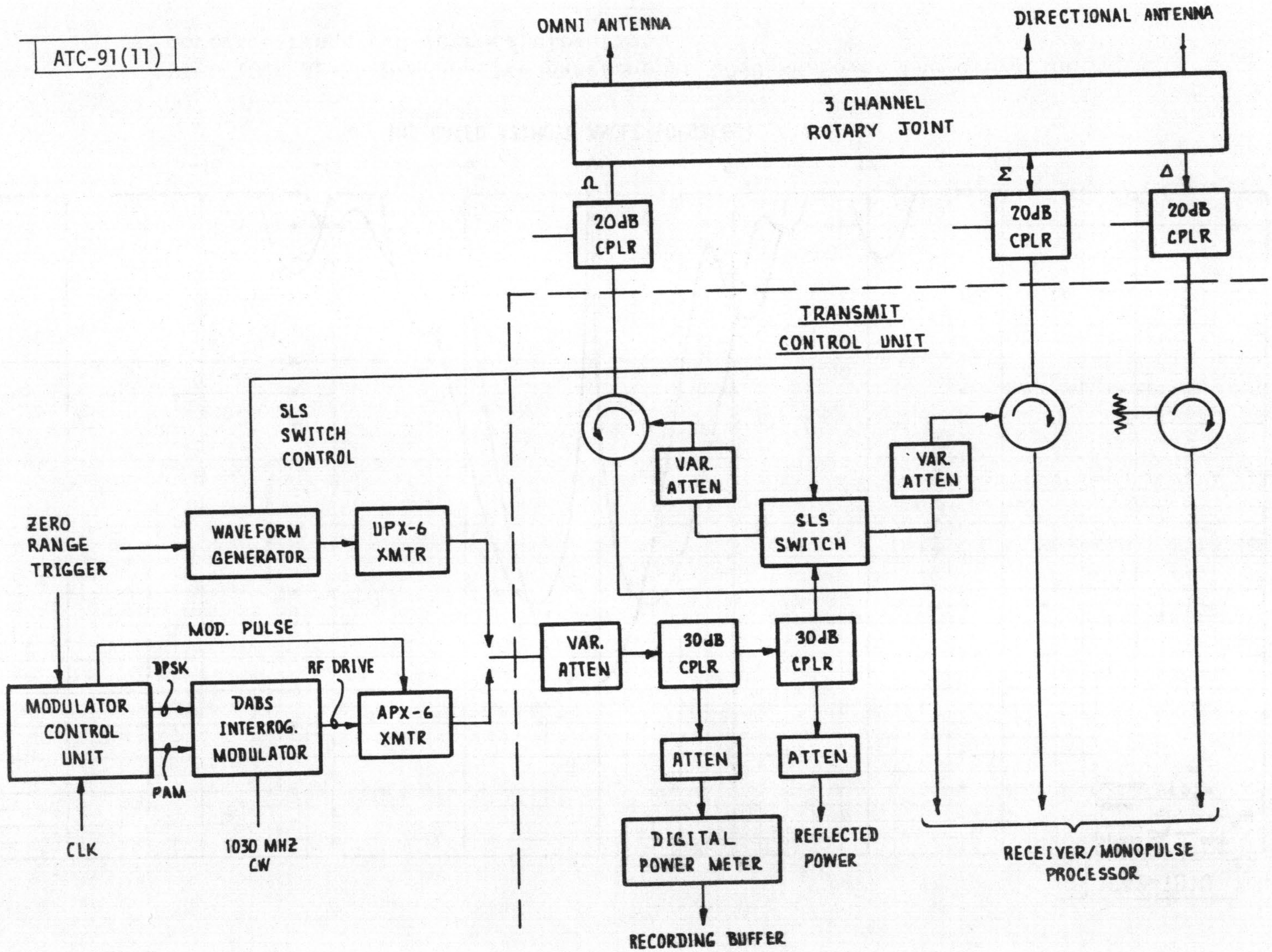

Fig. 11. Transmitter/microwave block diagram.

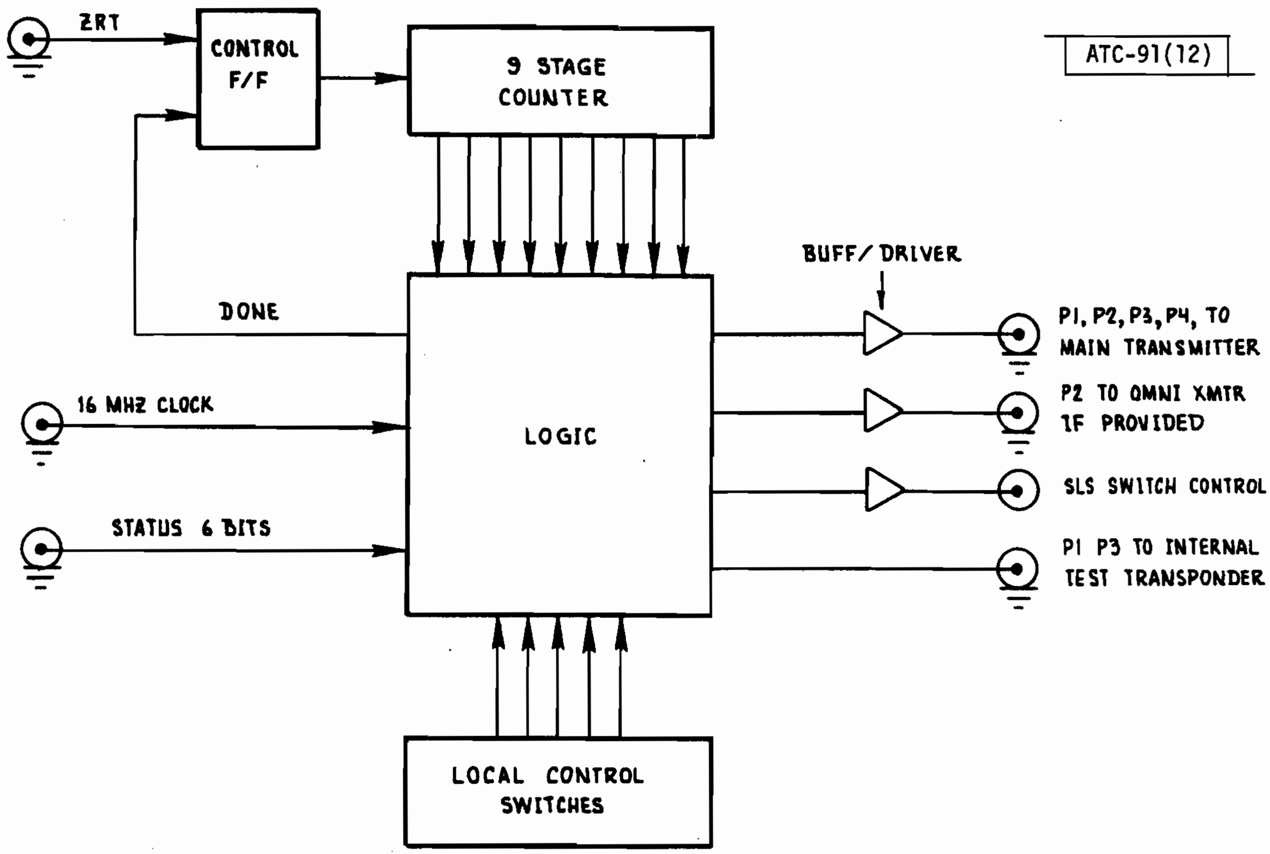

Fig. 12. Transmit waveform generator.

3A
3A alternating with C
C
D
ATCRBS/DABS All-Call (3A)
ATCRBS/DABS All-Call (C)

In addition to the manual selection of any one of the above modes, the waveform generator has the capability of generating preselected sequences of different interrogation modes. A switch matrix allows the selection of up to four of the above modes for transmission on four successive interrogation periods.

The Transmit Waveform Generator also supplies six bits of transmit mode status to the recording system.

The transmitter portion of a UPX-6 Interrogation Unit is employed as one of the TMF transmitters. It receives the amplitude modulation pulses from the waveform generator to produce the transmit waveform of 2 KW peak power at 1030 MHz. The transmitter is crystal controlled with a frequency stability of ±200 KHz and has a duty cycle capability of 0.15%.

A second transmitter in the TMF is used to generate a DABS-Only All-Call interrogation for DABS link experiments. The transmitter portion of an APX-76 interrogator, modified to allow both an input from an external RF Source and an external video modulating pulse, is used to generate the DABS waveform. The APX-76 is capable of producing 3 KW of peak power with a 30 μsec pulse width. Selection of either transmitter requires a manual connection to the input of the Transmit Control Unit (MCU). Upon receipt of a ZRT and a DABS-Only All-Call enable, the Modulator Control Unit provides the necessary amplitude and phase modulation signals to the DABS Interrogation Modulator (DIM). The MCU also generates the transmitter gating pulse for the APX-76. A crystal controlled 1030 MHz CW Signal from the receiver local oscillator is used in the DIM to generate the modulated RF waveform. The DIM consists of a double balanced mixer which produces the DPSK phase modulated DABS data field and a high speed diode switch which produces the DABS preamble pulses and the data field pulse. The DABS address field consists of all 1'a which will elicit responses from all DABS Transponders.

A variable attenuator on the transmitter output serves both to limit the peak power at the circulators to their rated peak of 1 KW and also as a means of varying transmit power in support of experiments. 30 dB directional couplers following the variable attenuator enable measurements to be made of forward and reflected power levels. A digital power meter, used to measure average power, has a BCD output to allow recording of the power level.

The transmitter waveform is fed to an SLS switch which upon command of the Waveform Generator routes the P2 pulses to the omni antenna and the remaining pulses to the directional antenna. Variable calibrated attenuators in the omni and directional antenna paths following the SLS switch enable relative adjustment of the omni and mainbeam power levels for experimental purposes. Directional couplers are employed in the sum and difference and omni channels to enable insertion of receiver test and calibration signals.

The transmit and receive losses of the microwave system are:

Transmit Losses

Sum	3.60 dB
Omni	3.85 dB

Receiver Losses

Sum/Difference	1.60 dB
Omni	1.85 dB

3.4 Monopulse Receiver/Processor

3.4.1 Overall Operation

The TMF employs a 3-channel receiver for reception and processing of the monopulse sum (Σ), monopulse difference (Δ) and omni (Ω) signals from the antenna. The sum and difference channels are arranged in a modified Bell Labs monopulse processor configuration (termed a half-angle processor) to provide a video output signal that is monotonically related to the angle-of-arrival of the received signal relative to the antenna boresight angle. The half-angle processor enables an unambiguous measurement of arrival angle over a region of nearly ± 1 beamwidths about the boresight angle*. Operation of the omni channel is straightforward and provides a logarithmic video output for received sidelobe suppression. A detailed block diagram of the monopulse receiver/processor is shown in Fig. 13; overall characteristics are summarized in the table at the end of this section.

There are two basic monopulse receiver configurations which could be used to determine target direction. One involves a direct comparison of the Σ and Δ signal amplitudes which are related to the arrival angle by virtue of the monopulse antenna patterns. The amplitude comparison scheme is subject to errors as a result of gain instabilities in the receiver components, and additionally, provides a limited region of unambiguity about boresight. The second configuration determines angle-of-arrival by comparing the phase between two signals derived from the antenna Σ and Δ signals. The half-angle processor specified for DABS and used in the TMF is based on the phase comparison approach. Its operation is described as follows.

*See D. Karp, M. L. Wood, "DABS Monopulse Summary," Project Report ATC-72, pp. 3-12, Lincoln Laboratory, M.I.T. (4 February 1977), FAA-RD-76-219, DDC AD-A038157/4.

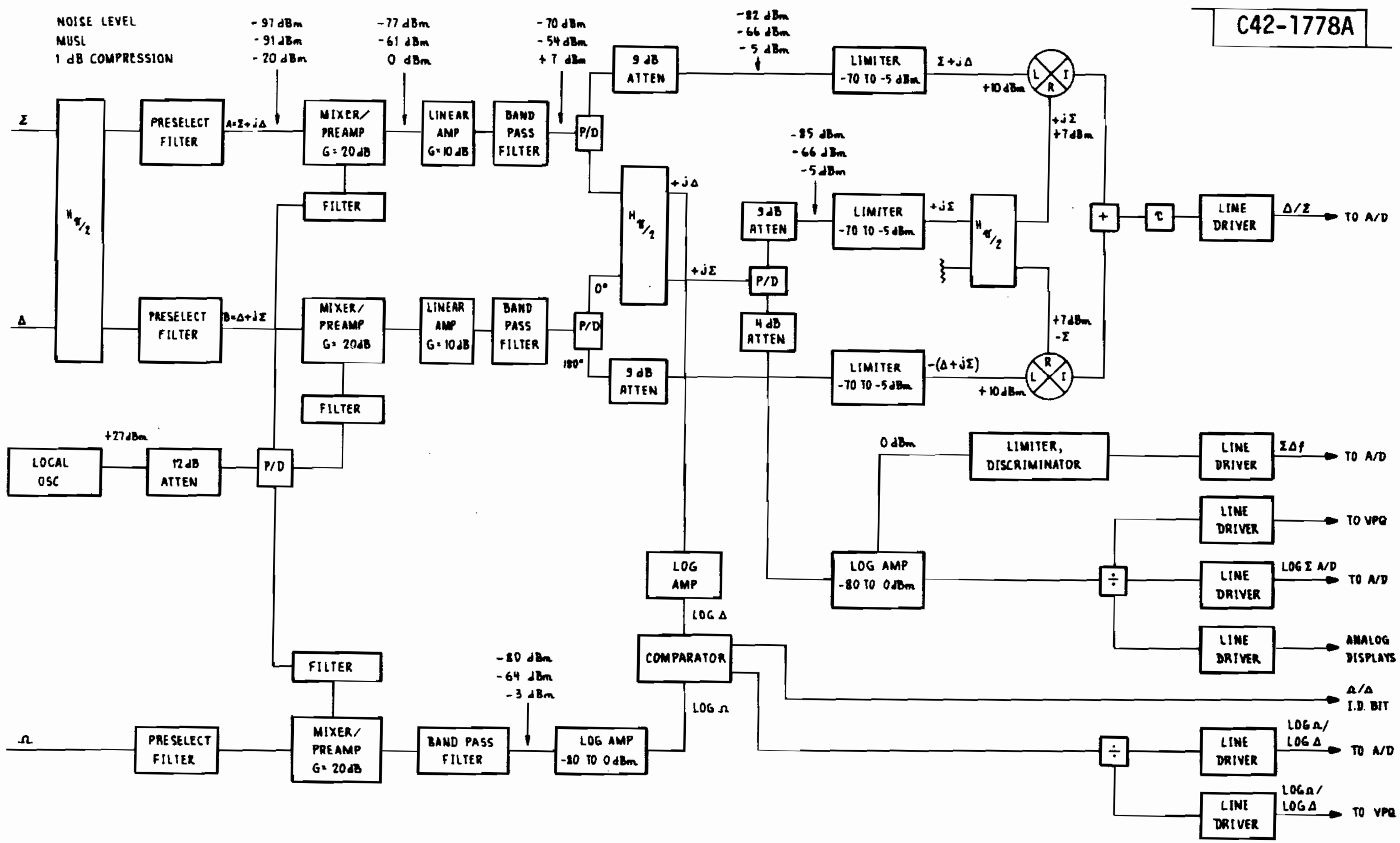

Fig. 13. Monopulse receiver/processor block diagram.

The Σ and Δ signals from the antenna are first fed to an RF summing device (90° hybrid). This device generates two complex signals, A and B, consisting of the vector addition of Σ and Δ:

$$A = (\Sigma + j\Delta)/\sqrt{2}$$

$$B = (\Delta + j\Sigma)/\sqrt{2}$$

The phase difference, ϕ, between the vectors A and B is a function of the ratio Δ/Σ or off-boresight angle and may be expressed :

$$\phi = 2 \tan^{-1} (\Delta/\Sigma)$$

The measurement of the quantity $2 \tan^{-1} (\Delta/\Sigma)$, and therefore off-boresight angle, can be obtained by comparing the phase between A and B.

A problem occurs in comparing A directly to B when the off-boresight angle approaches each Σ and Δ crossover point (as $\Delta \rightarrow \Sigma$ the phase difference between A and B approaches 90°). Near the crossover point the phase detector characteristic desensitizes and provides a measurement corrupted by noise. Beyond the crossover point the measurement becomes ambiguous. To overcome this problem signals A and B are each phase compared separately with a Σ reference signal derived by recombining A and B as illustrated in Fig. 13. Thus two independent measurements of $\tan^{-1} (\Delta/\Sigma)$ are obtained by determining the phase between the signal A and $+ j\Sigma$ in one channel, and between the signal B and $-j\Sigma$ in the other. Each phase detector channel is considered a "half-angle" processor which will allow an unambiguous and less noisy measurement well beyond the crossover point since the relative phase between A or B and the reference is always less than 90° from the boresight value. The A, B and reference channel relative phasing is adjusted to provide a phase detector zero output voltage for a target at boresight. The bipolar nature of the phase detector (i.e., a positive or negative output voltage about boresight) allows a resolution of the sense of the off-boresight angle.

The two identical phase detector outputs are then summed to form a video output voltage that is a monotonic function of the ratio Δ/Σ. Although each channel alone is capable of providing the proper output, using both channels avoids any loss in signal to noise ratio and additionally reduces by one half the channel phase errors that would accompany a single output.

The monopulse video output voltage when applied to a monopulse calibration table relating arrival angle to monopulse video provides the azimuth estimate.

MONPULSE RECEIVER CHARACTERISTICS

Noise Level	-97 dBm (Referred to mixer input)
Dynamic Range	60 dB min (A, B, and Σ ref. channels) 77 dB min (Log Σ and Log Ω)
Center Frequency	1090 MHz
Differential Channel Gain Match	± 1 dB
Differential Channel Phase Match	± 5°
Gain Linearity	± 1 dB over Dynamic Range

3.4.2 Detail Operation

Signals A and B are translated to 60 MHz by phase-matched, double-balanced mixer-preamplifiers. The mixer-preamplifiers, each with noise figure of 8.2 dB and gain of 20 dB, are followed by a linear 10 dB amplifier whose function is to adjust the dynamic range of the signals such that they are compatible with the limiters and log amplifiers.

The bandpass filters are 5-pole Bessel filters serving to limit the 3 dB bandwidth of the overall receiver channel to 8 MHz.

Following the filters, each of the A and B signals is split in a power divider and fed to limiters as well as to another 90° hybrid. The function of the second hybrid is to recombine the A and B signals in order to recover the sum signal for use both as a reference for the phase detectors and to provide a log sum output. A 180° power divider in the B signal channel and a third 90° hybrid in the sum reference channel serve to provide the proper phase relationships between the main and reference signals at the phase detectors.

The A, B, and Σ reference signals are fed through phase-matched, hard limiting, amplifiers which have a dynamic range of 65 dB. The purpose of the limiters is to desensitize the off-boresight angle measurement to processor channel amplitude variations.

The outputs of the limiting amplifiers drive two double balanced mixers which serve as phase detectors to produce bipolar error signals monotonically related to Δ/Σ or the off-boresight angle. The two outputs are equal and in phase, and when added together will double the sensitivity of the monopulse slope. The error signal is then fed via a line driver to an analog-to-digital converter.

The recombined sum signal from the second 90° hybrid is also fed to an 80 dB dynamic range logarithmic amplifier and then via line drivers to the VPQ for leading edge detection, to an analog-to-digital converter and to analog displays. A limited IF signal is also available from the sum channel log amplifier. This signal is fed to a limiter/discriminator unit for measurement of downlink frequency deviations from the nominal 1090 MHz center frequency. The discriminator characteristic is linear over a ± 8 MHz region about the center frequency. The output of the discriminator is then fed via a line driver to an A/D converter.

The received omni signal is fed through a preselector filter to a double-balanced mixer-preamplifier for conversion to 60 MHz. The signal is than band-limited to 8 MHz and detected in an 80 dB dynamic range logarithmic amplifier. The recombined difference signal from the second 90° hybrid is used in conjunction with the omni signal to provide a composite received sidelobe suppression (RSLS) function. The IF difference signal is detected in a logarithmic amplifier and compared with the detected omni signal in a "greatest value" comparator. The larger of the two signals is then fed via line drivers to the VPQ for RSLS purposes and to the A/D for recording. The comparator also provides a Log Δ/Log Ω identification bit for recording.

The local oscillator signal is derived from a stable 1030 MHz source and distributed to each of the mixer-preamplifiers and to the DABS transmit modulator through isolation filters. The purpose of the LO filter is to prevent crosstalk at 1090 MHz between each of the three receiving channels.

3.5 Video Processor

A block diagram of the analog and digital portions of the ATCRBS video processor (VPQ) is shown in Fig. 14. With some exceptions the VPQ design is identical to that suggested in the DABS sensor engineering requirement.

The analog pulse quantizer operates on the log sum signal from the receiver to produce three output signals that are quantized in amplitude to two levels. These three signals are quantized sum video, quantized positive slope and quantized negative slope. A quantized sum video signal is generated whenever the input signal exceeds a fixed threshold. This fixed threshold can be adjusted over a range of approximately -86 dBm to -65 dBm and is normally set at -82 dBm. The quantized slope signals are generated whenever the slope of the input signal exceeds a preset rate in either the positive or negative direction. An additional feature in the analog pulse quantizer not specified in the sensor ER is the capability of operating with a floating sum video threshold. Designed to eliminate quantization of multipath reflections, this floating threshold is adjusted to be 20 to 30 dB below the peak value of the log sum video input and will remain so for the length of a reply. When operating in the variable threshold mode, the variable threshold and the fixed threshold are compared in "greatest value" circuit to insure that a minimum threshold value is always present.

The output signals from the analog pulse quantizer are fed to a digitizer which generates clocked binary output data streams for both leading and trailing pulse edges. Leading and trailing edge declarations are based on a set of algorithms embodied in the ATCRBS VPQ. The clock frequency used to drive the digitizer is selectable from one of the following:

24/1.45 MHz, 26/1.45 MHz, or 28/1.45 MHz

depending on the requirements of a particular experiment.

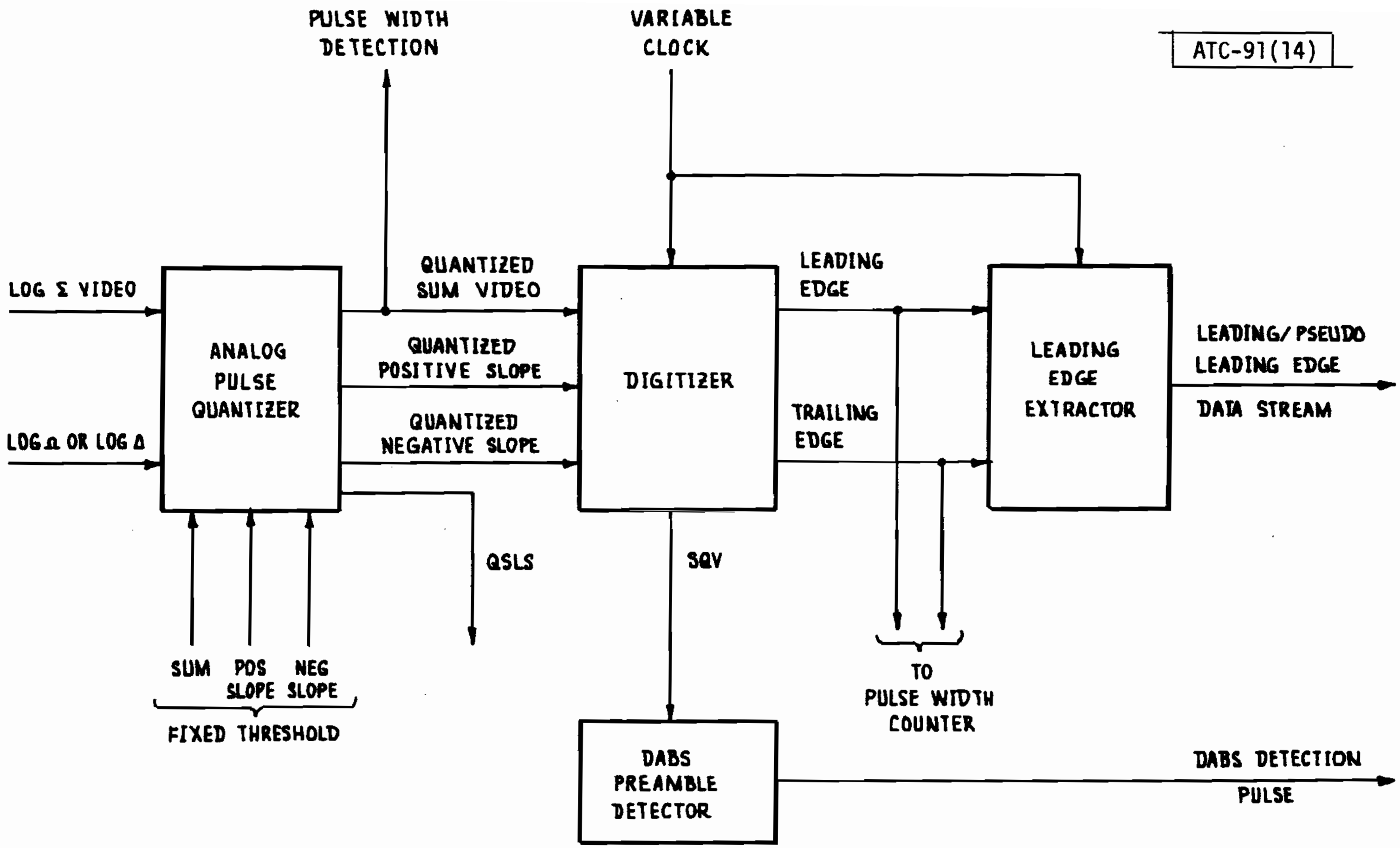

Fig. 14. Video processor.

The digitizer outputs (leading edge and trailing edge declarations at full selected clock rate) are fed to a Leading Edge Extractor which generates a pseudo-leading-edge for an overlapping pulse and rejects pulses whose leading and trailing edges are separated by a single sample. The output of the digitizer is also fed to a DABS preamble detector for detection of a DABS reply. The output of the Leading Edge Extractor is a serial data stream (ΣLE) consisting of directly-declared and pseudo-declared leading edges. This data stream and the associated leading edge and pseudo-leading edge is fed both to the range counter for generation of a range word associated with the leading edge event and to the sample control logic for strobing of the A/D converters. Edge declaration and sampling may be performed at one-half clock frequency if this mode is selected. In the DABS mode of operation the output of the DABS preamble detector is fed to the range counter for generation of a range word associated with the DABS preamble and to the sample control logic for strobing of the A/D convertors.

The leading and trailing edge declarations from the digitizer are also fed to a counter for generation and recording of pulse width. This pulse width counter always runs at the full value of the clock rate selected.

3.6 Analog to Digital Conversion

The following A/D converters are included:

Converter	Signal to be Converted	Resolution	Bandwidth
Computer Labs 5810	log Σ	7 bits	10 MHz
Computer Labs 5810	log Ω or log Δ	7-8 bits	10 MHz
Computer Labs 5810	Δ/Σ	8 bits	10 MHz
Computer Labs 5810	down-link frequency	6 bits	10 MHz

The encode command to all A/D converters is generated synchronously with the selected Range Counter/VPQ clock, and the resultant output(s) is (are) sent to the data buffer for recording on magnetic tape. Figure 15 illustrates the flow in the TMF Recording System.

If the experiment in progress is operating in the "edge event" mode, then the VPQ makes clock-synchronous edge declarations. For a leading edge declaration, a counter counts the number of clock cycles specified in the manually-settable "Leading Edge Delay-to-Sample" parameter and then generates a synchronous "encode" command to the four A/D converters. The resulting "Data Ready" pulses from the A/D's cause the digitized results to be transmitted to the magnetic tape data buffer and subsequently written on tape. For a pseudo-leading-edge declaration, the counter counts the number of clock cycles specified in the manually-settable "pseudo-leading-edge delay-to-sample" parameter and then generates a synchronous "encode" command to the four A/D converters, etc.

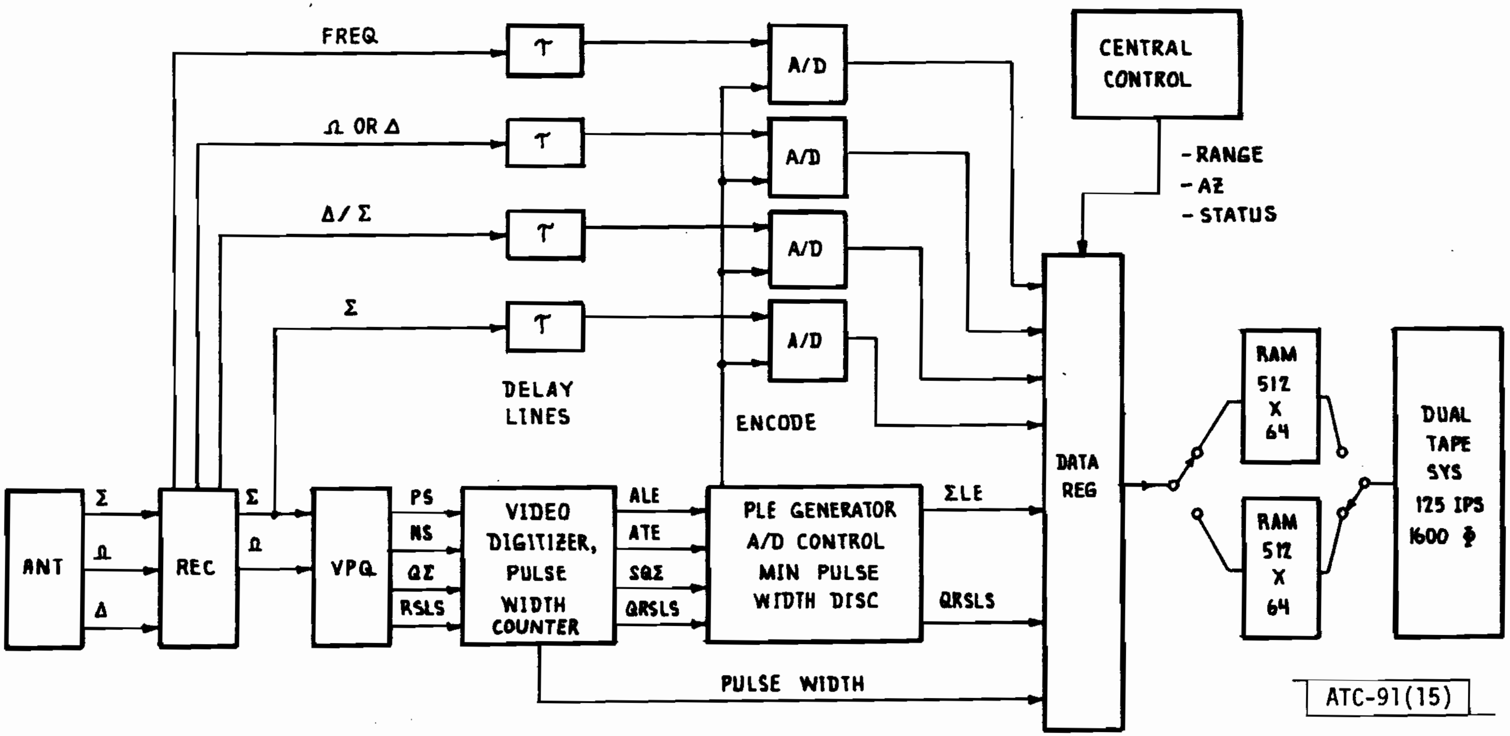

Fig. 15. TMF Data Acquisition System.

If the experiment in progress is operating in the "free-running" mode, then the VPQ makes clock-synchronous edge declarations. When a leading edge is declared, a burst of synchronous "encode" commands are generated for the log Σ A/D and Δ/Σ A/D, one every other clock cycle for a period sufficient to bracket the assumed ATCRBS reply (21.3 μs ± 0.1). In the DABS mode of operation, a burst of encode commands for the log Σ A/D is generated for a period sufficient to bracket the DABS reply data field (approximately 120 μsec.) The burst of DABS encode commands are initiated based on the detection of a DABS preamble.

The resulting 16-bit sample consisting of 7-bit digitized log Σ, 8-bit digitized Δ/Σ, the VPQ ΣLE bit stream output, and the QSLS bit are assembled into larger words and transmitted to the magnetic tape data buffer and subsequently written on tape. The first such assembled group includes the range counter value at the beginning of the sampling period.

3.7 Timing Subsystem

There are two timing systems built into the TMF. The first system is based on a fixed 16 MHz clock and is used for general timing purposes including Time-of-Day (TOD), Pulse Repetition Frequency (PRF), and Zero Range Trigger (ZRT) for the Transmitter Waveform Generator (TWG). The TOD indication is manually synchronized to WWV to the nearest 0.5 second. Pseudo random jitter may optionally be imposed on the ZRT.

The second timing system consists of three clocks at the following frequencies: 16.552 MHz, 17.931 MHz, and 19.310 MHz (24/1.45 μs; 26/1.45 μs, 28/1.45 μs). For a given experiment, any one of these clocks may be selected. The selected clock is used to drive the Range Counter, the Video Pulse Quantizer (VPQ), the Pulse Width counter, and the Leading Edge and Pseudo-leading Edge delay-to-sample counters for the A/D converters.

The range counter is initialized each sweep by the zero range trigger from the 16 MHz clocked PRF counter. Selected clock frequency, sampling at full or 1/2 clock, PRF Period, Leading Edge delay-to-sample, pseudo-leading edge delay-to-sample, range window open, and range window close are all manually-settable timing parameters (see Section 3.8).

3.8 Parameter Control

A number of variable parameters are available in conducting experiments with the TMF. Facilities exist in the TMF for manually setting up these quantities prior to the initiation of an experiment. The selection state of these variable parameters is automatically recorded on magnetic tape as part of the first record to be written at the beginning of an experiment. Varying these parameters during the course of an experiment is prevented by logical inhibit circuits.

Those experimental parameters which are variable in the TMF together with a description of their limits are listed in Table 1.

TABLE 1

TMF MANUALLY-SETTABLE VARIABLES

Item	Variation	No. Bits to be Recorded
Experimental Number	Coded binary log # assigned to given experiment	3
Experiment Site Location	Coded binary # assigned to site	5
Antenna Type	Antenna selected for particular experiment, including antenna(s) external to the TMF	3
Transmit SLS Mode	0 = No SLS; 1 = SLS active	1
Interrogator Power Level	2 KW peak, max., to 20 dB below max	3-4
Major Mode	00 = Normal interrogation; 01 = Spotlight/low PRF; 10 = Spotlight/no PRF; 11 = Free-running	2
Interrogation Mode-Consecutive Sweep Pattern	Choice of ATCRBS mode 3A, C, D, and All-Call mix, individually specified in up to 4 consecutive sweeps	12 or 16
Pseudo-Random PRF Jitter (Mode)	Pseudo-random delay of $(2^n-1) \times 4$ μsec for n = 5, 6, 7, and 8 inserted in ZRT generation; 0 = not active; 1 = active	1
Selected Clock for Range Counter, VPQ and LEDTS	00 = 16.552 MHz (24/1.45); 01 = 17.931 MHz (26/1.45); 10 = 19.310 MHz (28/1.45); 11 = 16.000 MHz	2
Sampling 1/2 Clock (mode)	0 Full selected clock; 1 = 1/2 selected clock	1

TABLE 1 (Con't)

Item	Variation	No. Bits to be Recorded
Leading Edge Delay-to-	Units of selected clock period over range 2-8 (nominal setting near 300 nsec)	3
Pseudo-Leading Edge Delay-to-Sample (to A/D Control)	Units of selected clock period over range 3-9 nominal setting near 300 nsec)	3
Open Range Window	Matches 8 most significant bits of range counter; range in approx. 1 mile increments to over 200 mi.	8
Close Range Window	Matches 8 most significant bits of range counter; range in approx. 1 mile increments to over 200 mi.	8
Start/Stop Range Window on A-Scope Delayed Sweep (Mode)	0 = A-Scope delayed sweep has no effect on RW. 1 = A-Scope delayed sweep affects range window	1
VPQ Threshold Setting	- 85 dB to -64 dB in steps of 3 dB	3
Floating Threshold (Mode)	0 = Log Σ threshold fixed; 1 = Log Σ threshold floating	1
Floating Threshold Setting	-50 dB to -20 dB in steps of 5 dB	3
Sensitivity Time Control Mode	0 = STC inactive; 1 = STC active	1
QSLS Threshold Setting	+10 dB to -11 dB in steps of 3 dB	3
Edge Suppression of QSLS	0 = Disabled; 1 = Enabled	1
Azimuth Accuracy	00 = 16-bit; 01 = 14-bit; 10-12 bit	2
Azimuth Type Select	0 = APG; 1 = Synchro converter	1

TABLE 1 (Con't)

Item	Variation	No. Bits to be Recorded
Buffer and Tape System Saturation Recovery Mode	Modes relating to what system does after saturation of the data patch is detected	2
P2 XMTR 'Omni' (TWG)	Which XMTR P2 pulse is selected (when there are two XMTRS-main and omni)	1
Test XPDR On	0 = Test XPDR off; 1 = Test XPDR on	1
North Correction	Input to azimuth register to correct for difference between pedestal zero azimuth and true north	16

3.9 Buffer and Recording

The data buffer and recording portions of the TMF consists of a dual "ping-pong" semiconductor buffer memory system and a magnetic tape recording system consisting of a formatter/controller and a 9-track tape drive capable of producing industry-standard computer tapes.

The characteristics of each of the buffer memories are as follows: configuration-512 words of 64 bits each, read access time-100-150 nanoseconds, write cycle time-100-150 nanoseconds. Thus, each buffer memory contains storage for 4096 8-bit characters or the data for one block (record) on tape. The bandwidth of the buffer memory (40-53 megabytes per second) must be considerably higher than that of the magnetic tape system since one of the principal reasons for the buffer memory is to act as the means of smoothing "bursts " in the real-time data so that they can then be written on tape via the start-stop tape drive.

During a typical experiment, the dual buffer memory will collect the asynchronous real-time digitized data and then provide it to the tape system for recording, using the so-called "ping-pong" buffer. Input data is strobed into a buffer at completely asynchronous rates. When one buffer is filled, the input data stream is transferred to the second buffer and the tape drive activated. The digital control causes the contents of the first buffer to be written on tape as a block (record). The tape drive is stopped to await the filling of the second buffer. In this way, the digital control will switch back and forth between the two buffers, writing the information in blocks the size of a buffer. A partly filled buffer at the end of an experiment is written on tape as a standard size block with the end of the block padded out with zeros.

The characteristics of the tape system are as follows: density-1600 bytes per inch, phase encoded; tape speed-125 inches per second; start and stop time-approximately 3.0 milliseconds each; 200 kilobytes per second maximum data rate (1 byte includes 8-bits). With a block (record) size of 4096 bytes, the average sustained recording rate of the tape system is approximately 150 kilobytes per second. The magnetic tape system contains all logic and functions necessary for reading and generating ANSI format compatible tapes.

3.10 Equipment Housing

The instrumentation comprising the measurements facility is housed in a 32-foot semitrailer. A large flat bed trailer to haul the antenna and necessary support equipment is also utilized.

The van, which is air conditioned and equipped with air-suspension is divided into two sections. The forward section, located over the trailer hitch, is about seven feet long and contains two air conditioning units. The after section, about 25 feet long, has permanently mounted equipment racks, almost two thirds of its length and located along the port side. One air conditioning unit supplies the equipment racks with a forced airflow from the top with an air return along the bottom of the racks. The other air conditioning unit supplies the remainder of the van which has a work bench mounted in the center of the starboard side. The remainder of the van is clear space except for a protected entryway around the side door. Access to the van is through two doors, located at the back end and the starboard side. Access to the air conditioning section is through a door on the front end.

A large compartment under the right side of the trailer holds the necessary power and other cables. Power is fed to the trailer through a connector plate located in the rear of the trailer and is filtered before distribution.

The antennas are carried on an auxillary flatbed trailer along with the pedestal, pedestal adapter, 30 KW diesel generator, 20 KW stepdown transformer, large tool box necessary to repair and maintain above the collapsible antenna tower with necessary guys and anchors.

4.0 TMF OPERATING MODES AND DATA RECORDING

Table 2 lists TMF operating modes which can be selected to satisfy an experimental requirement. The data automatically recorded on magnetic tape during the course of an experiment are listed in Table 3. The list is divided into five groups according to the type of word to be recorded. Word types are defined below:

1. Parameters - the first data recorded at the beginning of an experiment in the initial record of the tape file is experiment identification data and the values of almost all the manually-settable parameters (see Note below).

2. Beginning-of-Sweep - data at the beginning of each sweep at ZRT time.

3. Edge-Event - data related to each VPQ-identified edge event in all major modes except "Free-Running Sample" mode.

4. Free-Run - Assembled 16-bit samples taken during an edge-event- or DABS Preamble-initiated sampling period in the "Free-Running Sample" major mode. First assembled work also contains Range Counter value at beginning of sampling period.

5. Time-Mark - time base indication generated by Range Counter overflow when running in either "Spotlight" major mode.

Note: See Table 1 for a detailed description of experimental parameters and their limits.

5.0 MEASUREMENT CAPABILITIES

5.1 ATCRBS Processor Evaluation

One of the original purposes of the TMF was to record ATCRBS data in realistic traffic environments. A reply processor design study used TMF data to evaluate the performance of particular processing algorithms and compared its real world performance with the performance of computer simulated processors. ARTS III processor data obtained at field sites near the TMF sites, were also compared with the reply processor output data.

TABLE 2

TMF MAJOR MODES

MODE TYPE		E.E./F.R.
Normal Edge Event		Edge Event
Spotlight/Low PRF		Edge Event
Spotlight/No PRF		Edge Event
Free-Running Sample		Free-Run*
Alternate	Normal Edge Event	Edge Event
	Free-Running Sample	Free-Run*
Calibration		Edge-Event

*Any free-running sample mode will be in ATCRBS terms unless the DABS option is selected and all DABS conditions met.

TABLE 3

TMF DATA RECORDED DURING EXPERIMENTS

By Word Type

1) By Parameter Word	No. of Bits
Experiment Number	8
Physical Location Number of Experiment Site	5
Antenna Type	3
Interrogator Power Level (Average)	4
Transmit SLS Mode	1
Major Mode	2
Interrogation Mode Consecutive Sweep Pattern	16
Interrogaror PRF Period-BCD	12
Pseudo-Random PRF Jitter (Mode)	1
Selected Clock for Range CTR, VPQ and LEDTS	2
Sampling at 1/2 Clock Frequency (Mode)	1
Leading Edge Delay-to-Sample (To A/D Control)	3
Pseudo-Leading Edge Delay-to-Sample (To A/D Control)	3
Open Range Window	8
Close Range Window	8
Start/Stop Range Window on A-Scope Delayed Sweep (Mode)	1
VPQ Threshold Setting	3
Floating Threshold (Mode	1
Floating Threshold Setting	3
QSLS Threshold Setting	3
Edge Suppression on QSLS-Spotlight Major Modes Only (Mode)	1
Azimuth Accuracy	2
Azimuth Select (APG or Synchro Converter)	1
Buffer and Tape System Saturation Recovery Mode	2
P2 XMTR 'Omni'	1
Test XPDR On	1
Word Type	3
STC (Mode)	1

2) By Beginning-of-Sweep Word

Time-of-Day (TOD) to Nearest 10 millisecs (BCD)	28
Antenna Boresight Azimuth	16
Interrogation Mode This Sweep	3
Word Type	3

TABLE 3 (Continued)

TMF DATA RECORDED DURING EXPERIMENTS

By Word Type

3) By Edge-Event Word	No. of Bits
Range Counter	16
Edge Type (Actual Leading/Pseudo-Leading)	1
Log Σ A/D Converter Output	7-8
Log Ω A/D Converter Output	7-8
Δ/Σ A/D Converter Output	8
Pulse Width*	5
Down-Link Frequency	6
QSLS Bit	1
Word Type	3

4) By Free-Run Word

In the 'Free-Running Sample' major mode, sampling is initiated either by VPQ detection of a leading edge or DABS preamble detection and continues at the selected clock rate for enough clock cycles to guarantee sampling a complete ATCRBS reply (> 21.2 μs, which includes the time for extra-wide pulses), or a complete DABS reply data block (~ 120 μsec). Sampling is then reinitiated by the next leading edge or preamble detection, etc. Each ATCRBS or DABS sample contains the following data:

Sample (16-bit sub-word)	No. of Bits
Δ/Σ A/D Converter Output	8
Log Σ A/D Converter Output (MSB)	6
VPQ ΣLE Bit Stream	1
QSLS Bit	1

Several 16-bit samples are assembled into 64-bit 'Free-Run' words to be recorded. The first such word contains:

Range Counter	16
Sample	16
Sample	16
Word Type (including first indication)	4

*Pulse width is recorded as part of the 'Edge-Event' word for the last declared leadinge edge (actual or pseudo) prior to the trailing edge declaration. Pulse width in other 'Edge-Event' words is to be set.

TABLE 3 (Continued)

TMF DATA RECORDED DURING EXPERIMENTS

By Word Type

	No. of Bits
Succeeding words assembled during the sampling period contain:	
Sample	16
Sample	16
Sample	16
Word Type (including not first indication)	4
5) By Time Mark Word	
Word Type	3

The TMF was designed with the following capabilities for support of the reply processor study:

a. Sampling Control

The Video Pulse Quantizer (VPQ) and the A/D converter sampling control logic for sampling ATCRBS replies operate as follows. Sampling of the Σ, Ω and Re (Δ/Σ) channels occurs at approximately 250 $\pm\ \sigma$ nanoseconds after the declaration of a leading edge or pseudo leading edge by the VPQ. The values of the samples are nominally 250 $\pm$ 10 and 300 $\pm$ 10 nanoseconds for leading and pseudo-leading edges, respectively. These values are controllable over a range from about 100 to 400 nsecs in steps of the TMF clock period, i.e., σ equal to $-3 < \sigma < +3$ clock periods, where σ is increments of whole clock periods.

The basic clock in the TMF has a frequency producing 24 periods per 1.45 µsecs (16.552 MHz). The VPQ is sampled at 16.55 MHz with the output edge stream selectable at a 16.55 MHz or 8.28 MHz rate. The selection of either mode has no effect on any other aspects of the TMF and only effects the timing accuracy of edge declarations by the VPQ. Time-of-arrival and pulse length measurements are always based on the 16.55 MHz edge stream produced by the VPQ.

b. Sample Rate Flexibility

The TMF digital logic was designed to insure that the VPQ, A/D converter sampling, and range counter are operative independent of the specific basic clock frequency driving the TMF digital logic. The TMF can also select frequencies of 13/1.45 MHz and 14/1.45 MHz, or twice these values, to allow flexibility in reply processor performance tradeoffs at different sampling rates.

c. Sampling Range Interval Control

The capability of selecting predefined range interval during which data can be recorded is provided. This option allows limiting the amount of recorded data particularly when specific data objectives exist.

d. Free Running Sampling Mode

To allow for a more detailed evaluation of particular reply characteristics a free running sampling mode at 8.27 MHz is provided. This mode is manually selectable to provide both the A/D converter outputs of the Σ (6 bits) and Re (Δ/Σ) (8 bits) channels as well as the one bit VPQ output. Sampling is initiated by detection of a leading edge and continues for 21.2 µsecs. Sampling is then reinitiated by the next leading edge detection after the previous 21.2 µsec interval has ended. The state of the range counter at the first leading edge detection is also recorded.

This mode is selected to provide a short burst of higher resolution data to allow for evaluation of hardware performance and an expanded view of environmental effects on the received waveforms. The inclusion of this mode increased the maximum sampling rate specification for the Σ and Re (Δ/Σ) A/D converters from about 5 MHz which is imposed by the normal sampling mode to a 10 MHz rate.

e. Data Recording

The data tape recorded by the TMF is compatible with basic FORTRAN READ statements on the IBM 370 or SEL 8600 computers.

The first data record on tape contains a list of parameter settings which have been selected and are constant for the data run contained in the tape. The parameter list recorded in that record includes (1) Sampling frequency, (2) Sampling mode, (3) Range interval for recording, (4) A/D converter sampling delays and (5) Transmitted power.

Associated with each interrogation generated by TMF, the following information is recorded: (1) Time-of-day (LSB = 0.01 seconds), (2) Prf, (3) ATCRBS transmission mode, (4) SLS mode, and (5) Azimuth encoder reading (14 bits).

At the declaration of each leading edge or pseudo-leading edge by the VPQ, the TMF records: (1) Range count at the time of edge detection (16 bits), (2) 7-bit A/D converter samples for the Σ and Ω and 8-bit A/D converter samples for the Re (Δ/Σ) channel, (3) the type of edge declared by the VPQ (leading or pseudo-leading edge) and (4) a single bit sample of QSLS taken coincident with the declaration of each leading edge by the VPQ. The QSLS stream is produced by an analog comparison of the log Σ to log omni signal levels and indicates a one when the ratio indicates a mainbeam reply. Additionally the width of the pulse defined by the number of range counts between the leading and trailing edges is recorded.

f. Synchronization of the TMF with ARTS III

The processor study used ARTS III extractor tapes recorded while TMF data was being taken in order to compare the performance of the ATCRBS processing in a DABS sensor with that of a currently used system. To properly use the ARTS III data capability is included in the TMF to synchronize time-of-day to within a fraction of a scan (~ 1 second).

5.2 Additional Capabilities

a. Measurement of Reply Frequency

It is desirable to be able to measure and record the response of a single beacon-equipped aircraft to multiple interrogations. A capability of "spotlighting" the antenna on a particular aircraft is therefore included in which the received pulse stream is recorded continuously. Interrogation by the TMF occurs at a low (~ 10 per second) PRF rate. To eliminate all but mainbeam replies it is possible to suppress the recording of any pulse for which the QSLS bit is set.

b. Jittered Interrogation Mode

The TMF provides a means for jittering the interrogation time in order to eliminate synchronous interference with other interrogations and to test a possible DABS sensor mode of operation. The interrogation times are established by the insertion of a pseudo-random delay following each periodic trigger.

c. DABS Link Performance

The TMF provides a means to evaluate DABS link performance by the transmission of ATCRBS/DABS All-Calls, or DABS-only All-Calls and the reception of DABS replies using the rapid sample mode triggered by a DABS preamble detector.