NRL Report 6021

NRL SMALL TRANSPONDER

Security Systems and Avigation Branch
Electronics Division

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ABSTRACT

This report describes a very light (under 10 pounds) IFF transponder developed at the Naval Research Laboratory for use in unmanned airframes to provide continuous tracking by existing IFF ground equipment for these target drones. Considerable cost, weight, size, and equipment complexity have been eliminated by a new approach combining tuned-radio-frequency and crystal video techniques. The two feasibility models described in this report have been successfully operationally tested both at the Naval Air Development Center (NADC), Johnsville, Pennsylvania, and with the SAGE complex at Tyndall Air Force Base, Florida. Test data and a proposed production specification are included in the Appendixes.

PROBLEM STATUS

This completes the work on this phase of the problem; other phases are continuing.

AUTHORIZATION

NRL Problem 52R03-05
BuWeps Task RM 4400-007/652-1/S417-BO-01

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NRL SMALL TRANSPONDER

INTRODUCTION

The problem of identifying and tracking target drones has increased with the reduction in size and increase of speed of these unmanned vehicles. Along with these changes the instrumentation demands have increased, yet the allowable weight, size, and power source for these functions has been reduced. Since the Mark X IFF system has come to be widely used for tracking of aircraft, and Mode 3/A of this system is used for air traffic control by the FAA, it has been proposed that an IFF transponder be incorporated in the drones so that they may be identified and tracked. The cost, size, weight, and power requirements of all transponders in use or under development was excessive. After a conference at NRL concerning these problems, NRL proposed an approach which would provide a transponder that would possibly satisfy all of the requirements. On the basis of this proposal, the Bureau of Naval Weapons asked* NRL to develop two feasibility models of this transponder.

In Fig. 1, both existing AN/APX-6B and AN/APA-89 equipment and the NRL transponder are shown. Although the performance of the two equipments is very similar, several items of difference should be noted:

AN/APX-6B; AN/APA-89		NRL Transponder
2229 cu in.	Volume	231 cu in.
53 lb	Weight	<10 lb
355 watts	Input power	<20 watts
115 volts, 400 cycles, 24 volts dc	Input voltages	24 volts dc

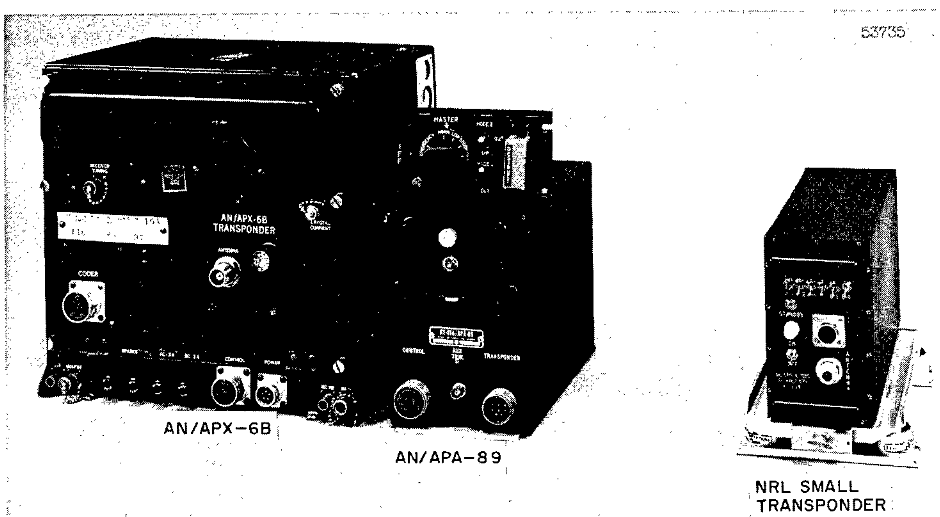

Fig. 1 - Comparison of the AN/APX-6B and the AN/APA-89 to the NRL small transponder

*WEP TASK RM-4401 002/652-1/F017-08-002

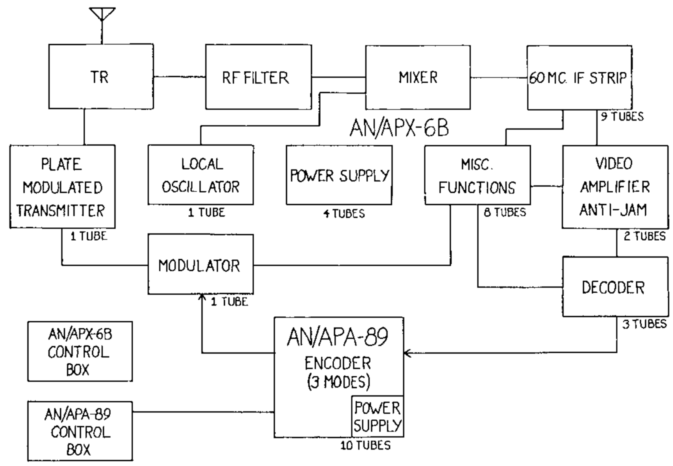

Fig. 2 - The AN/APX-6B transponder and the AN/APA-89 encoder

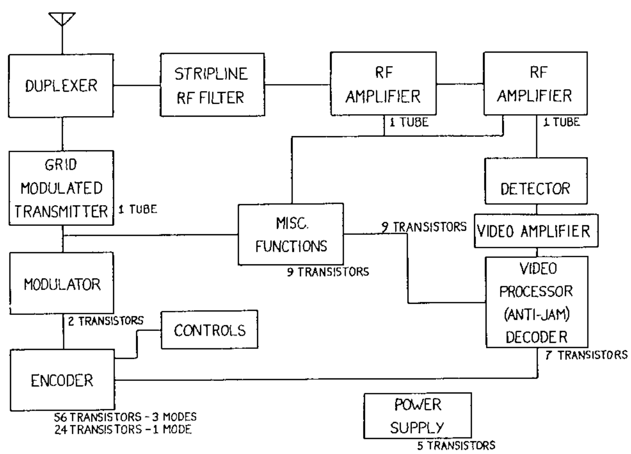

Fig. 3 - The NRL small transponder

To achieve the above major reductions in size, weight, and input power required not only the use of transistors but many innovations as well. If one compares the two block diagrams, Figs. 2 and 3, many of the new approaches will be evident. As can be seen the existing equipment is a conventional superheterodyne with a plate modulated transmitter. In comparison the NRL equipment is not a superheterodyne. It is a tuned-radio-frequency, crystal-video receiver. By the proper choice of gain in these sections, savings in cost, volume, and input power can be achieved without loss of performance. This approach eliminates the costly i-f strip, mixer, and local oscillator, and the problems which they present. By the employment of a special grid-modulated transmitter, developed under NRL's direction, the bulky, troublesome plate modulator can be replaced by a simple two-transistor modulator with greatly improved performance. As the function of each individual block is discussed in detail in the following section of this report, other new developments will be presented.

RF HEAD

Figure 4 is a bench-test setup of the entire rf head used in the NRL transponder. The unit consists of a duplexer, strip-line 1030-Mc/sec filter, two 1030-Mc/sec rf amplifiers, a video detector, and a grid-modulated 1090-Mc transmitter. The transponder receiver must be capable of replying to interrogations at a level of -71 dbm. Since crystal video receivers are not able to accommodate signals this small, the rf amplifiers must supply, depending upon many variables, some 20 to 40 db of gain to provide a signal level which can be detected. In operation, the 1030-Mc signals are fed from the duplexer, which provides isolation from the transmitter, to the strip line filter (Fig. 5). This bandpass filter provides rejection to unwanted signals and with the two rf amplifiers (Fig. 6) results in an overall passband shown in Fig. 7. For the passband of the two feasibility models, see Appendix A. The rf amplifiers employ 8058 nuvistor triodes in grounded-grid amplifiers. The plates are at dc ground and the cathodes and grids are operated at -100 to -106 volts. This provides a double benefit. First, the dc ground provides an excellent heat sink for the tube, and, second, power can be secured from the modulator supply. Although the grids are at rf ground and operate at -100 to -106 volts dc, they are available for control signals such as blanking, suppression, and receiver sensitivity. Matching between various rf components, such as the strip line amplifier and crystal, is accomplished by the stub lengths between the components. The detector is a standard IN21BR tuned to 1030 Mc/sec and biased to achieve the best sensitivity.

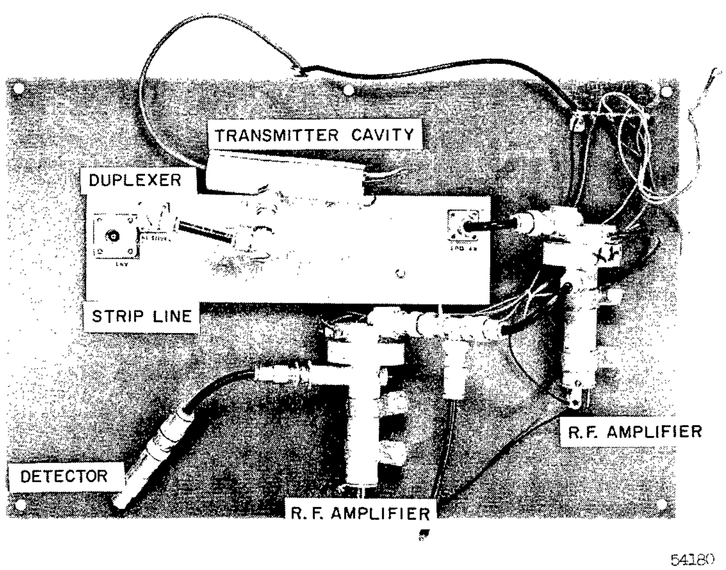

Fig. 4 - The XN-1 model of the rf unit

The transmitter (Fig. 8), which was developed by RCA under NRL's direction, is similar in construction to the well-known radiosonde units. It is designed as a throw-away component, which will greatly reduce replacement time as well as cost. The cavity is operated at +1000 volts with the cathode grounded and the grid at -80 volts. Modulation is achieved by driving the grid to zero during each pulse. The frequency is 1090 Mc/sec. Excellent pulse shape and amplitude has been obtained, as shown in Fig. 9.

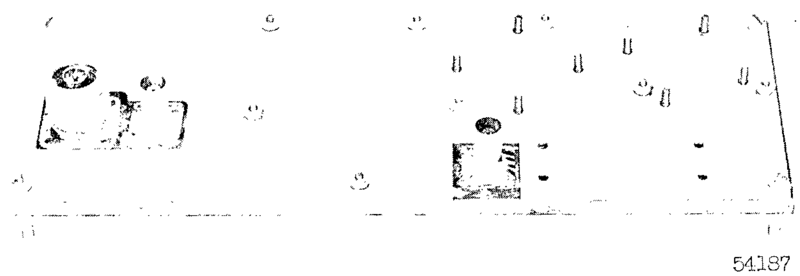

Fig. 5 - The XN-4 strip line

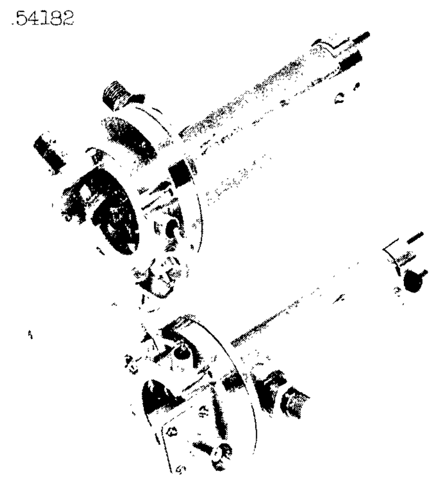

Fig. 6 - Two aluminum rf cavities

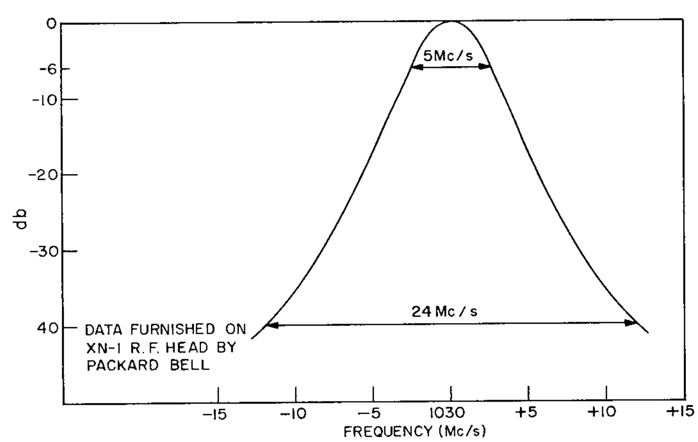

Fig. 7 - The rf response of the NRL small transponder

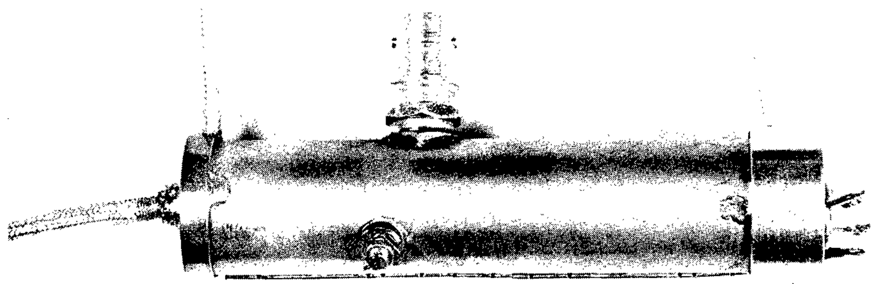

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Fig. 8 - Transmitter cavity

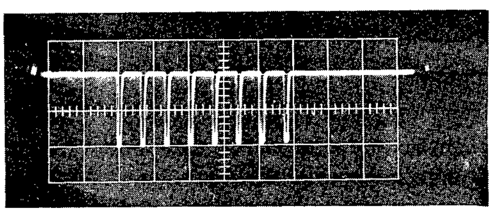


Fig. 9a - Detected reply train, code 77. Horizontal scale: 5.0 μsec/cm.

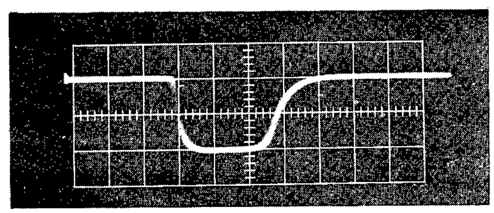


Fig. 9b - Single detected reply pulse. Horizontal scale: 0.2 μsec/cm.

VIDEO AMPLIFIER

Since a tuned-radio-frequency crystal-video approach was chosen for this transponder, a high gain video amplifier is necessary to reduce the requirements for rf amplification to a minimum. Although there was no requirement for side-lobe suppression existing at the time the program was started, it was felt that this may be a requirement in production equipment. To operate in an environment of side-lobe suppression, the receiver must retain relative amplitude information over an rf dynamic range of 50 db above the minimum triggering level. However, the square law characteristic of the detector produces a much higher dynamic range of the detector video output voltage. The video amplifier must compress this wide dynamic range to a range which can be handled by conventional video processor circuits without seriously distorting pulse shape. Additional requirements are high gain, low noise, and high saturation.

Within the limits of this development, the amplifier shown in Fig. 10 meets the requirements. It has low noise, high gain, and dynamic range adequate to handle the entire dynamic range of rf signal input without saturation or a change in rf amplifier gain. Further, it complements the detector, giving overall an approximately logarithmic gain characteristic.

To avoid the difficulties of amplifier stages which are both nonlinear and low noise, the very high level signals are separated from the low level signals at the video amplifier input. Low level signals are amplified linearly to a point where noise is no longer a

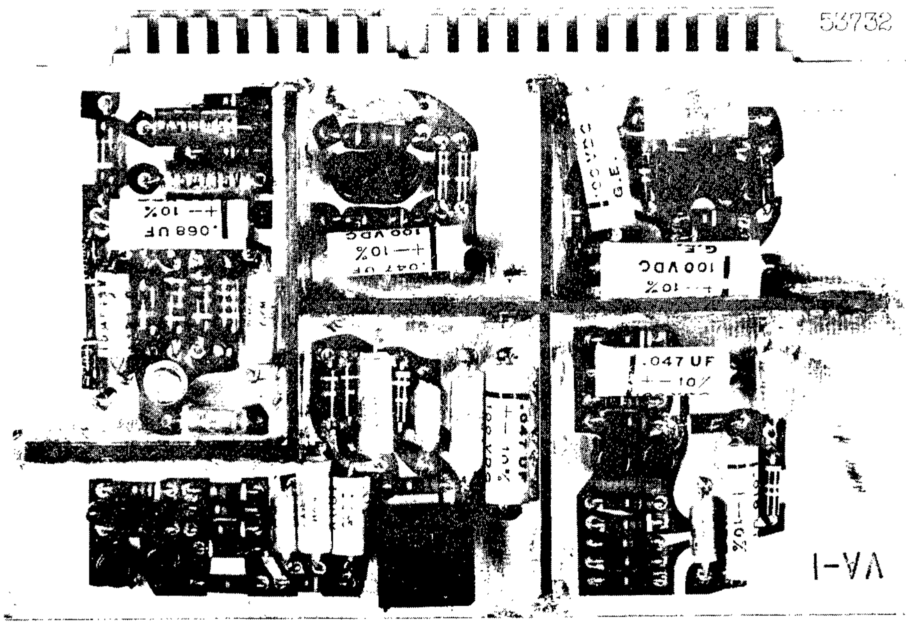


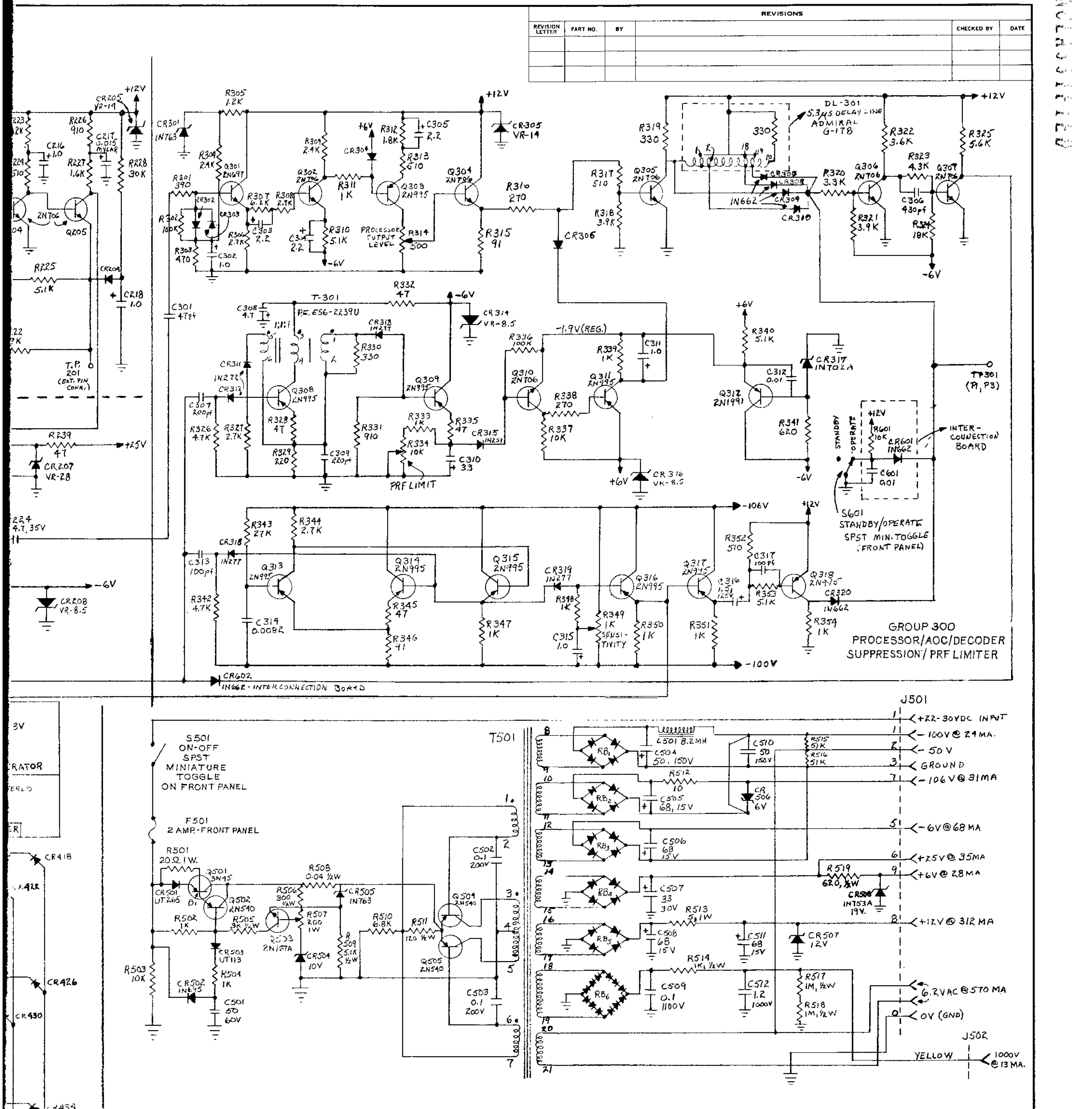
Fig. 10 - Video amplifier board

problem and then amplified in a nonlinear manner. The high level signals are amplified logarithmically in a separate channel and then added to the output of the first channel. This sum is then amplified linearly to provide 1 to 15 volt pulses into a 200-ohm load.

In order to attain the best efficiency and temperature stability, the crystal detector operates with a slight forward bias. This is provided by R201 and R203 (Fig. 11). The detected video is initially amplified by Q201. The performance of this stage largely determines the overall amplifier noise figure. Negative feedback through R205 reduces the input impedance to 200 ohms and assures a stable bias point and a stable gain. The use of metal film resistors in this stage is necessary to obtain the best possible noise figure. CR202 is normally conducting but will be reverse-biased for large input signals, thus preventing Q201 from saturating and limiting the output of the low level channel. As CR202 becomes reverse biased, CR201 becomes forward biased, thus providing a second path for input current and, with R203, maintaining the input impedance at about 200 ohms.

In the next stage of the low level channel, Q202 and Q203 operate together as an amplifier with R213 providing negative feedback as well as establishing the proper bias condition. The amount of negative feedback depends on the extent that CR203 defeats the negative feedback signal at the emitter of Q203. For low level signals, the majority of the signal current from the emitter of Q203 flows through CR203 and is bypassed to ground, so that the resulting gain is high. For higher level signals, CR203 is increasingly reversed biased, so that more signal current from Q203 emitter flows through R213 and R216, resulting in a decrease of average gain. The low level gain is controlled by how close CR203 is to cutoff in the absence of any signal, and thus is adjustable with R217. The following stage containing Q204 and Q205 is similar in operation.

With high level inputs, the voltage across CR201 bears a logarithmic relationship to the input voltage. This voltage is then simply amplified by Q207 and Q206 and added to the output of the low level channel. The sum of the two channels then continues to follow an approximate logarithmic pattern.



NOTES:

1. UNLESS OTHERWISE NOTED:
   - A. ALL DIODES FD100
   - B. ALL RESISTANCES IN OHMS ±5% 1/4 WATT
   - C. ALL CAPACITANCES IN MICROFARADS ±10%
   - D. ALL TRANSISTORS AS DESIGNATED
2.
   - A. SR = SENSISTOR
   - B. TM = THERMISTOR
   - C. RB: BRIDGE RECTIFIER, ENCAPSULATED
   - D. MF = INDICATES METAL FILM RESISTOR
   - E. NC = NO CONNECTION

DETAIL NO.	DESCRIPTION	MATERIAL SPECIFICATIONS	NO. REQ'D

LIST OF MATERIAL

SIGNATURES		DATE	BLDG.	ROOM	PHONE
DESIGNED	L.T. RHODES		58	121	2416
DRAWN	J.P. BYRNE	'63 30 MAY	58	107	2656
APPROVED Checker	W Beiles	'63 30 MAY			

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SECURITY CLASSIFICATION: UNCLASSIFIED

TOLERANCES
UNLESS OTHERWISE SPECIFIED
DECIMAL DIMENSIONS = ±.005
FRACTIONAL DIMENSIONS = ±1/64
ANGLE DIMENSIONS = ±2°

NRL SMALL TRANSPONDER

SCALE: | ASSEMBLY DRAWING NO | DRAWING NO. 2340

mall transponder

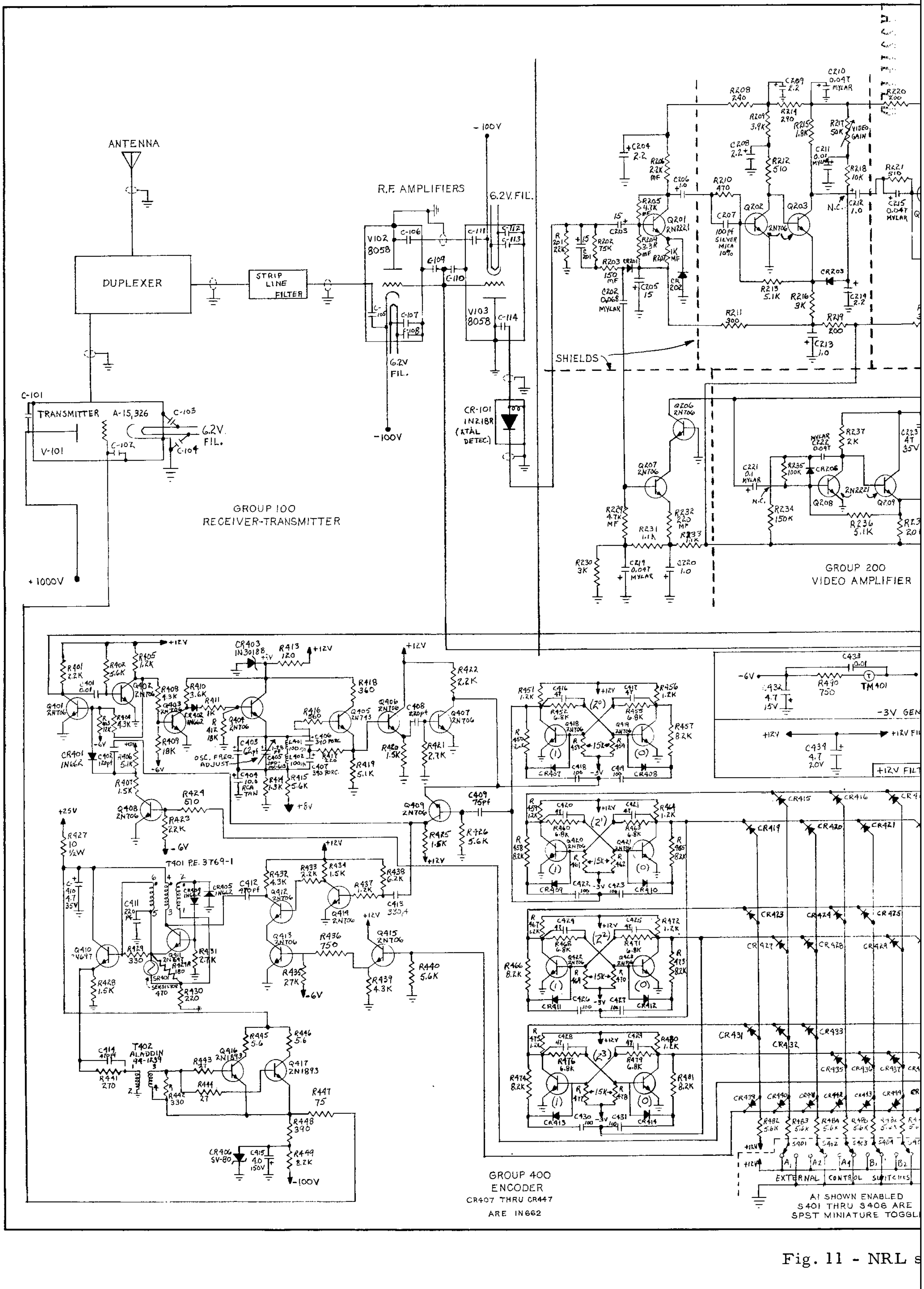
ANTENNA
DUPLEXER
STRIP LINE FILTER
R.F. AMPLIFIERS
6.2V FIL.
-100V
SHIELDS
TRANSMITTER A-15,326
CR-101 IN21BR (XTAL DETEC.)
GROUP 100
RECEIVER-TRANSMITTER
+1000V
GROUP 200
VIDEO AMPLIFIER
-3V GEN
+12V FIL
OSC. FREQ. ADJUST
T401 P.E. 3769-1
T402 ALADDIN 49-1239
EXTERNAL CONTROL SWITCHES
A1 SHOWN ENABLED
S401 THRU S406 ARE
SPST MINIATURE TOGGL
GROUP 400
ENCODER
CR407 THRU CR447
ARE IN662

Fig. 11 - NRL s

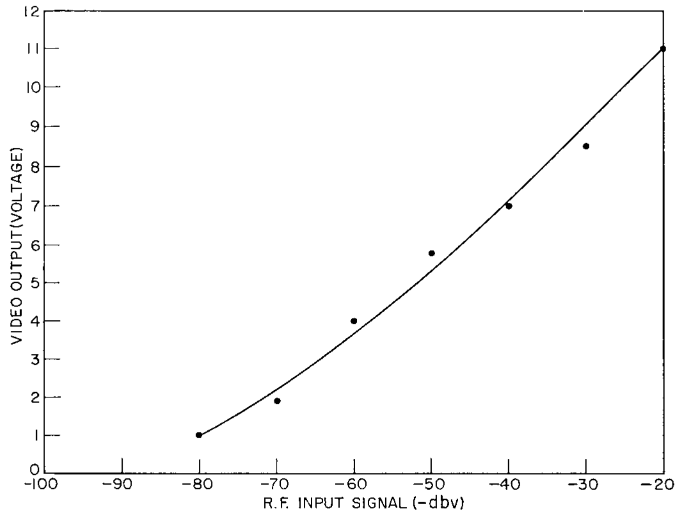

Fig. 12 - The rf and video dynamic range

RC filters on the power supply to the low level stages, excellent grounding, and shields between each stage are used to prevent feedback paths which could cause spurious oscillations. The use of a common base configuration for Q206 isolates the output of the high level channel from the input and prevents oscillation from feedback through the high level channel. With these basic precautions, the amplifier is very stable and has shown no tendency to oscillate.

Even very minute changes in base level, if they occur in the early stages, can be very noticeable, since they are amplified far more than the pulse peaks. To minimize this effect, the low level stages must have excellent low frequency response. This requirement becomes less in later stages, and some base line restoring is provided by CR206.

After the two channels have been added, they are amplified by Q208 and Q209 to the required 1 to 15 volt output level across 200 ohms.

The logarithmic gain characteristic of this amplifier makes a measurement of noise figure most difficult. Measurements from a linear amplifier with a similar input stage indicates that it is between 5 and 6 db. From the overall transponder performance, it is estimated that the noise figure is 7 db or less. The detector has a square-law characteristic almost throughout the required 50-db rf dynamic range, so that the video amplifier must handle a 100-db dynamic range of input voltage without saturation, reducing this to less than 26 db video output. The overall dynamic characteristic from antenna input to video output, shown in Fig. 12, exceeds 50 db. If a more logarithmic output is required when a side-lobe suppression circuit is added, there are changes which can be made to shape the overall curve to provide the desired performance.

The auxiliary circuits are all combined on one board (sometimes called the suppression board), shown in Fig. 13. This board consists of the video processor, decoder, encoder trigger, reply rate limiter, and suppression circuits. Maintenance adjustments include Decoder Tolerance Adjust, PRF Limit Adjust, and RF Sensitivity Adjust – all located along the top edge of the board. Each of the auxiliary functions are discussed separately in the order that an input signal moves through the overall transponder. The operation can be followed in Fig. 11.

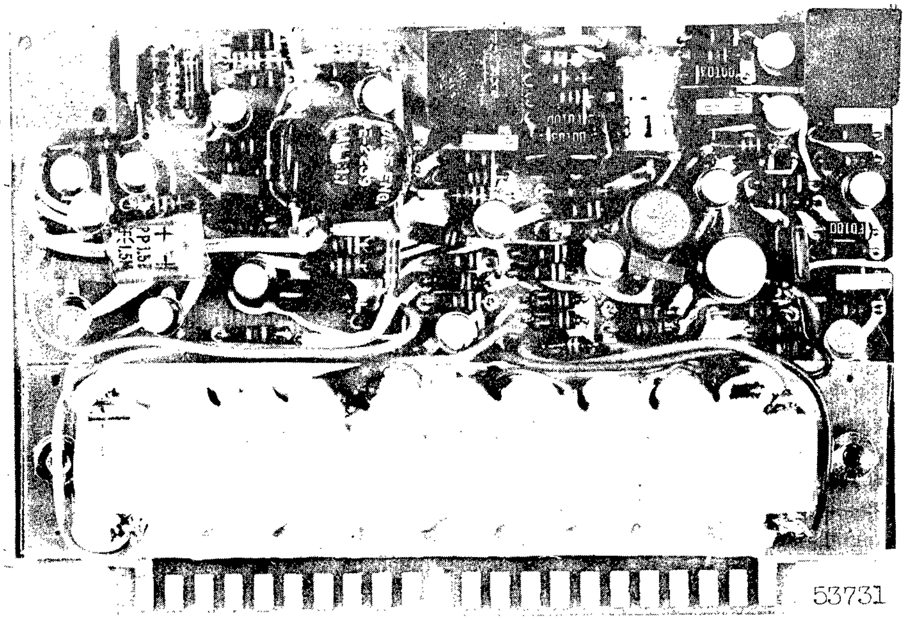

Fig. 13 - Suppression board

VIDEO PROCESSOR

The video processor circuit compresses the 20 to 30 db dynamic range of the video (1 to 15 volts approx.) amplifier to produce video signals of constant amplitude suitable for use by the decoder. The processor output pulse width is constant for changes in input video amplitude and is determined entirely by the pulse width of the rf interrogation pulses. The video signal to noise ratio is improved down to video levels approaching 3 db above tangential. Video processing is performed on a pulse-for-pulse basis without the use of regenerative circuits, so that there is no tendency under operational conditions to quantize input noise.

The processor is based on the use of passive circuit elements for video pulse standardization of amplitude and shape. Its operation is not dependent upon a fast fall time on incoming pulses and therefore can tolerate a certain excess trailing edge in pulses. The pulse width of the output is based on the time interval between the first 5 to 10% of the leading edge and the first 5 to 10% decrease of the trailing edge of the video pulse. A comparison of input and output processor signals are shown in Fig. 14 for various input levels. The basic circuit shown in Fig. 15 can be described as follows. Resistor R_1 and capacitor C_1 form a series RC time constant whose dc output level is initially equal to the positive voltage from battery E. CR_1 limits the maximum positive-going output signal due to a positive video input pulse to a voltage approximately equal to the diode barrier voltage. Any excess input pulse voltage above this amount is absorbed momentarily as a voltage drop across R_1, then charges C_1 shortly after the input pulse reaches a peak level. As the instantaneous voltage begins to drop at the input pulse trailing edge, CR_1 stops conduction and CR_2 limits the maximum negative-going output spike. C_1 then discharges through R_2 so the output voltage can recover to the battery voltage +E.

The output pulse amplitude and shape is roughly independent of input video amplitude and shape over approximate 30 db variation of the input pulse amplitude. Use of the basic pulse standardizer circuit to obtain the processed video output signal is shown in block

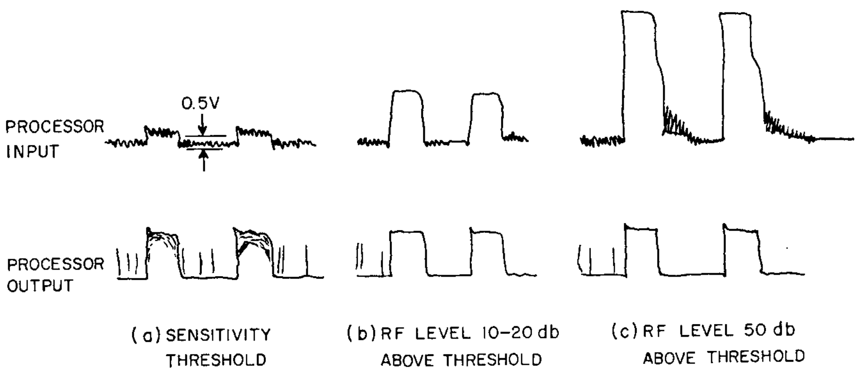

Fig. 14 - Comparison of processor input and output signals

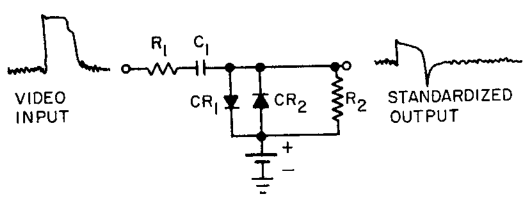

Fig. 15 - Basic pulse standardizer

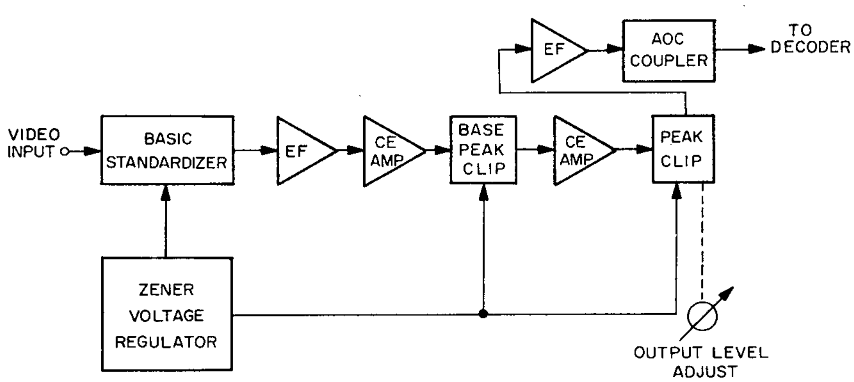

Fig. 16 - Complete video processor

diagram form in Fig. 16. A zener voltage regulator is used to stablize the bias base clip and peak clip levels so that the processor output level and shape remains the same over supply variations and temperature changes. The standardized output is processed by suitable peak and base clipping and is amplified to produce approximately 2 volts into a 91-ohm load. The processor output level is adjustable to set the desired decoder coincidence zone. The processor output is coupled through a series coupler network to the input of the decoder. The coupling network is part of a clamp circuit used with the automatic overload circuit (AOC). It results in a variation of processor output level with AOC bias. This circuit will be discussed later.

DECODER

Processed video is decoded by means of a passive delay line and coincidence circuit. A negative trigger is produced from a proper decode to activate the encoder. The delay line is also a component on the printed circuit board. Decoding and spike suppression are performed in the same operation, so that processed video pulses of the proper spacing but narrower than 0.3 microseconds do not produce a decode pulse over the dynamic range of the transponder. In addition, the STANDBY-OPERATE switch and a portion of the internal suppression function is performed in the decoder.

The decoder can be described as follows (referring to Fig. 11): the processed video input is amplified and inverted to drive the delay line. Three taps are brought out of the delay line in addition to the input and output terminations. These taps, together with the delay line input, supply pulse inputs to a diode AND circuit which in turn drives two common emitter amplifiers, Q306 and Q307. The AND circuit consists of the four low source impedance connections to the delay line, the diodes, resistors R320 and R321, and the negative supply. The four diode AND circuits can be considered as two ANDs which in turn are ANDed together at the diode cathodes. The circuit consisting of the 0.0 and 0.3 microsecond taps and their associated diodes produces an output shortened by 0.3 microsecond only when the pulse is at least 0.3 microsecond wide. The second two taps operate in a similar manner, so that the combined circuit produces an output only when pulses at least 0.3 microsecond wide have the proper spacing.

During normal interrogation signals, CR601 and CR320 are biased well beyond cutoff so that they do not affect decoding performance. After a valid interrogation has been received and the encoder triggered, the suppression gate generator applies a positive gate to diode CR320 and inhibits the decoder for the suppression gate length (120 microseconds). A +12-volt bias is applied to diode CR601 by switching a toggle switch on the front panel of the transponder to the STANDBY condition, thereby inhibiting all decoding functions and replies.

The decoder supplies a trigger to the coder sufficient for full firing of the transmitter for interrogation spacings within 0.2 microsecond of nominal, while no firing occurs for spacings of more than 1.0 microsecond from nominal, measured for rf levels from 3 to 50 db above the minimum trigger level. Detailed characteristics appear in Appendix A.

SUPPRESSION

The suppression circuit performs the combined functions of receiver sensitivity control by means of the negative grid bias on the rf amplifiers, and suppression of the rf amplifiers and the decoder for a fixed time interval following the leading edge of the reply encoder negative clock gate. The suppression circuit consists of Q314 to Q318.

In Figure 11, the negative clock gate from the reply encoder is differentiated to trigger a negative suppression gate of approximate 120 microseconds duration, produced by the monostable multivibrator consisting of Q313, Q314, Q315, and associated components. Transistor Q313 is a common base amplifier whose collector is connected to the input of two cascaded emitter followers Q314 and Q315. The emitter of Q313 is connected to the top of voltage divider R345 and R346, which is in turn driven by the output of the same two emitter followers. As Q313 is initially heavily conducting, the voltage difference between its collector and emitter is small, so that Q315 is almost cut off and Q314 is entirely cut off. A negative trigger applied to the base of Q314 causes Q313 to be turned off slightly. This process is regenerative through Q315, Q314, and voltage divider R345 and R346 to Q313, so that Q313 is rapidly cut off. C314 charges through R343 until Q313 can conduct again and the circuit returns to its stable state.

The negative gate is fed through CR319 and superimposed upon the adjustable bias at the base of Q316 to produce a composite signal at the rf amplifier grids which is negative with respect to -100 volts, the rf amplifier cathode voltage. The negative gate is also coupled through Q317, amplified and inverted in Q318, and applied through CR320 to suppress the decoder for approximately 120 microseconds.

AUTOMATIC OVERLOAD CONTROL

The automatic overload control (AOC) in this equipment limits the reply rate to some adjustable maximum which is independent of reply code content and interrogation level. This method was chosen because the transponder would be flown in areas where no jamming existed. In this environment, several interrogators could all secure sufficient replies from the unmanned air frame to track its position. (Where interference does exist, this method would not be preferred.) The AOC action is accomplished by developing a dc control bias which is a function of the number of reply trains, using this bias to damp the decoder input, momentarily shutting off encoder triggers. Since this is applied at an earlier stage than the sensed stage and because the constants are properly chosen, the desired quasi-random countdown does not discriminate against any single interrogator when several are in operation. The AOC bias can be adjusted from 500 to 2000 replies per second. As the reply rate approaches the prf limit setting, the bias increases rapidly and the replies are momentarily stopped.

Operation of the AOC circuit can be described as follows (referring to Fig. 11): Q308 is a 7-microsecond blocking oscillator triggered by the differentiated negative gate of the encoder clock.

These blocking-oscillator pulses drive emitter follower Q309 and charges C310 through R335. The time required for C310 to discharge through R333 and R334, the prf limit control, is long compared with charging time, so that the negative dc voltage across C310 is proportional to the prf. At low reply rates, Q310 and Q311 are conducting. As the rate increases and the dc voltage on C310 becomes more negative, Q310 begins to cut off. This in turn starts to cut off Q311, which is so biased as to cut off rapidly with further increases of the prf, so that the voltage across R339 decreases toward ground potential. As a result, CR306, normally reverse biased at low prf rates, conducts on the video pulses to the decoder and together with R316 inhibits the input to the decoder. After a very short interval of time, following decoder inhibiting action by the AOC circuit, the bias on CR306 again allows a few interrogations through, causing the AOC circuit to react once again and allowing replies to be transmitted in quasi-random bursts. Q312 is used as a regulator to stabilize this circuit under all conditions.

ENCODER

The encoder (Fig. 17) consists of a gated LC oscillator, a sequence generator, a blocking oscillator, a bootstrap modulator, and several diode transistor gates (Figs. 18 and 19). The shaped pulses from the gated oscillator are fed into the sequence generator which develops eight sequentially related outputs. The preselected outputs are collected on an OR bus, amplified, and strobed with shaped timing pulses. The output of this AND circuit triggers the blocking oscillator, which generates pulses of the proper amplitude and width for driving the modulator. The modulator output is of the correct polarity and amplitude for triggering the transponder transmitter. The eighth output of the sequence generator is also strobed and the output of this AND circuit is used to reset the clock gate. Waveforms at several points in the encoder are illustrated in Fig. 19.

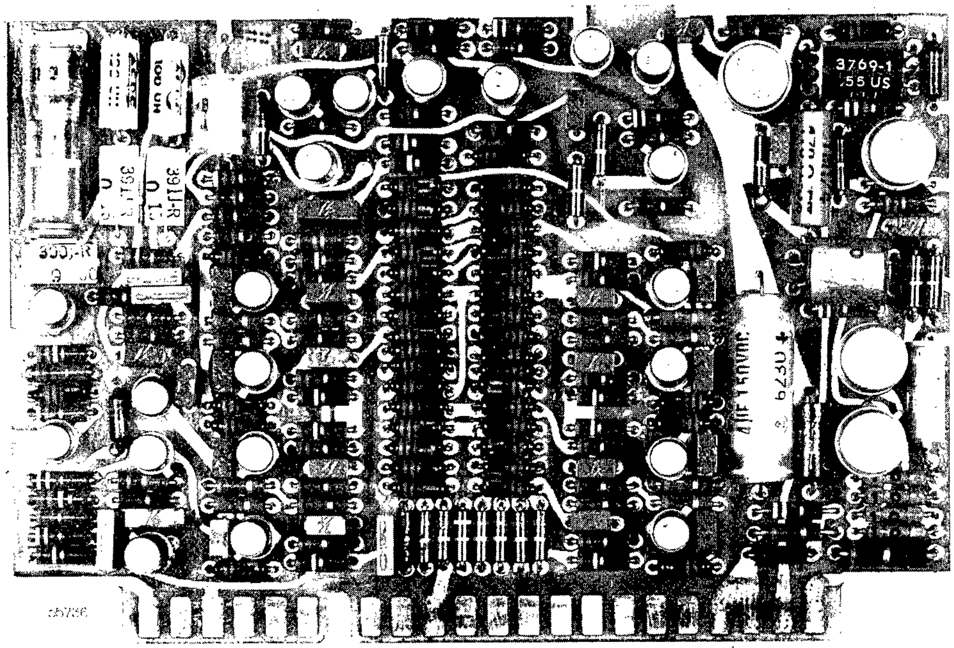

Fig. 17 - Encoder board

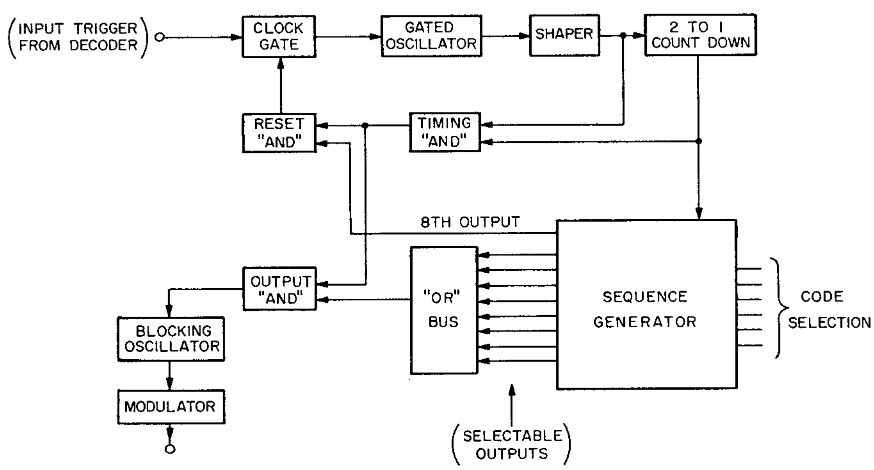

Fig. 18 - Encoder

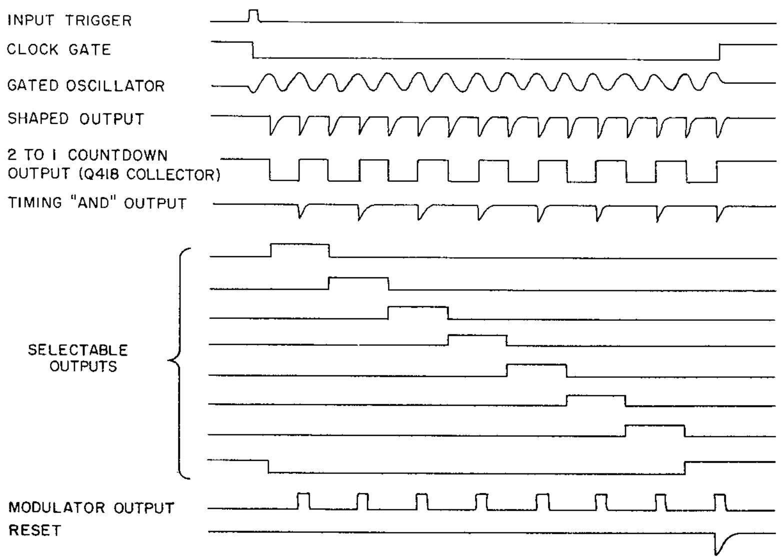

Fig. 19 - Encoder waveforms

The sequence of encoder operation begins when a clock start trigger is received from the interrogation decoder (see Fig. 11). The negative trigger at the collector of Q401 is coupled through C_{401} to the base of Q402, turning Q402 off. The positive gate at the collector of Q402 biases on Q403, and the negative gate at its collector biases off the oscillator clamp Q404 through diode CR402. The oscillator consisting of Q405 and the LC tank, is excited and oscillates at 689.6 ± 1.5 kc/sec. The oscillator is compensated to maintain this frequency from -55°C to +75°C. Prior to receiving a clock start trigger, Q404 is conducting and clamps the oscillator tank, preventing oscillation. The oscillator output from emitter follower Q406 is coupled through C408 to amplifier Q407, which shapes the oscillations into sharp negative clock pulses at its collector. The clock pulses, which are spaced 1.45 microseconds, are coupled into the countdown flip-flop consisting of Q418 and Q419. Initially, Q418 is nonconducting and Q419 is conducting. The odd-numbered clock pulses turn Q419 off and Q418 on (Fig. 11). The negative transients at the collector of Q418 trigger the sequence generator. Each triggering advances the generator one sequence. The even-numbered clock pulses turn Q418 off and Q419 on. The positive transients at the collector of Q418 are coupled to the base of Q409 through C409, enabling Q409 to conduct for the duration of the negative clock pulses at its emitter. The negative triggers at the collector of Q409 are inverted by Q414 and applied to the base of Q412 as timing pulses to strobe the selected outputs of the sequence generator. The sequence generator consists of three flip-flops and a twenty-four-diode matrix. The enabled matrix outputs are collected through diodes CR439 to CR447 and coupled through emitter follower Q415 to bias on Q413 for the desired time periods. When both Q413 and Q412 are forward biased, a negative trigger is generated at the collector of Q412. This trigger is coupled through C412 to the collector of Q411 and triggers the blocking oscillator consisting of Q411 and T401. The output of the blocking oscillator is coupled through emitter follower Q410 to the bootstrap modulator consisting of Q416, Q417, and T402. The output of the modulator is a train of 100-volt pulses spaced 2.9 microseconds. At the time of the last (eighth) output of the sequence generator, Q408 is biased on through diode CR446, the back bias is removed from diode CR401, and the negative strobe pulse from Q409 resets the clock gate generator. The oscillator is now clamped off, all flip-flops have returned to the reset state, and the encoder is ready for another cycle of operation.

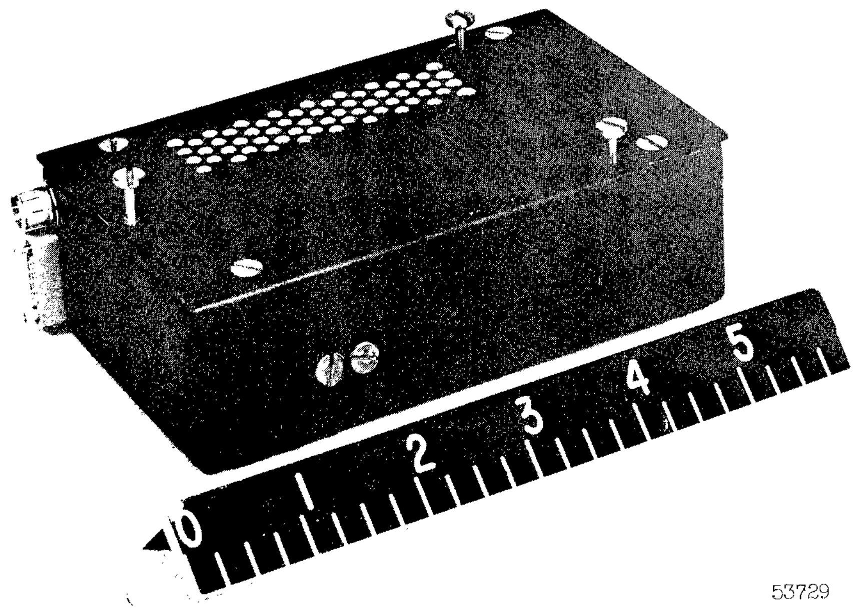

Fig. 20 - Power supply

POWER SUPPLY

The power supply (Fig. 20) is a conventional dc to dc type with zener regulation as required. In. Fig. 11 one can see that Q501, Q502, Q503, and CR504 form a series regulator providing approximately 18 volts dc for an input of 22 to 30 volts dc. This 18 volts dc feeds Q504 and Q505, the switching transistors, for T501 power transformer. Bridge rectifiers are used on all outputs. Although the circuits in the transponder are designed to tolerate ±10% voltage change, the regulated supply reduces the effect on performance under conditions of severe environment.

MECHANICAL CONSIDERATIONS

The transponder is housed in a dust cover 3-1/2 × 6 × 11 inches (not allowing for extension of front panel fittings) and may be pressurized for 70,000 feet altitude with the same dimensions. The KD2B-1 missile target is pressurized, and a transponder installation with a dust cover would be adequate. All controls pass through pressurized fittings on the front panel. Although all flight tests, mentioned in this report, were carried out with the dust cover fastened rigidly to the air frame, the dust cover will adapt to the shock-vibration mount MT-1063/APA-89. The transponder chassis is mounted to the front panel. Access to the three printed-circuit electronic boards and one spare is through a hinged, captive-screw-retained cover plate. All boards are 3-1/8 × 4-3/4 inches and keyed for correct insertion. Double-sided conductors and plated-through holes are employed, and, with conventional mounting of parts, there is an average parts density of 9 per square inch. The strip line is a conductive pattern etched on 1/8-inch double-sided Teflon printed-circuit boards with copper-foil-shielded edges. Antenna feed is by a special N-type fitting; transmitter and rf amplifier feeds are standard BNC fittings. The strip line is clamped between the left side of the transponder chassis and a clamping plate. RF cable construction is important as to lengths and assembly detail. The crystal holder is modified to adapt to a RG-180/U miniature rf cable. Also, the crystal shorting stub must be soldered at both ends to allow the crystal holder to work in the extreme low temperature range. A cap and shielded cable were added to the anode end of the transmitter cavity and a filter cap for the filament and grid end. The transistorized power supply is of modular construction and may be detached from the main transponder chassis by three captive screws. The main chassis is black anodized and serves as the main heat sink.

BENCH TESTS AND PROPOSED SPECIFICATIONS

The results of bench tests is given in Appendix A. From this it can be seen that the equipment meets the requirements in the areas of weight, size, power output, frequency, pulse spacing, decode tolerance, sensitivity, and functions. At the time this equipment was designed, as stated earlier in this report, there was no requirement for side-lobe suppression. Recently, however, there have been agreements reached which modify the U.S. National Standard in several areas, including side-lobe suppression. These changes are reflected in the proposed specifications, Appendix B.

FLIGHT TESTS

Both feasibility models of the NRL small transponder have been installed in aircraft and operated with several ground stations. The aircraft were of type F9F based at NADC, Johnsville, Pennsylvania. After successful flights out of Johnsville and Andrews Air Force Base, the transponders were installed in another F9F and operated with the Sage complex in a demonstration at Tyndall Air Force Base, Florida. In all range tests the equipment operated to radar horizon and, although mounted directly to the air frame without benefit of shock and vibration isolation, operated satisfactorily. Antenna cables and rf fittings on this cable were a problem, however, due to the minimum-change-type installation allowed.

ACKNOWLEDGMENTS

The authors would like to acknowledge the excellent cooperation and help of the personnel at the Naval Air Development Center, Johnsville, Pennsylvania, and Tyndall Air Force Base, Panama City, Florida, and especially Mr. J. McGlone of NADC and Captain J. P. Foster, Jr., 4750 Test Squadron, Tyndall Air Force Base who arranged for and directed the flight tests.

The writers would also like to recognize the help and cooperation of the following who under contract supplied components for this development under the direction of NRL.

RCA Tube Division, Harrison, N.J., for the transmitter cavity.

Packard-Bell, Los Angeles, for the first receiver components.

Admiral Corp., Chicago, Illinois, for the dc-to-dc power supplies.

Admiral Corp., Palo Alto, California, for the delay lines.

Lastly, the authors would like to acknowledge the outstanding cooperation, help, and efforts of many other members of the Security Systems and Avigation Branch, Electronics Division at NRL, without whom this program could not have been completed.

APPENDIX A

SMALL TRANSPONDER BENCH TESTS, MODEL NO. 1

RECEIVER

Normal Sensitivity

Interrogation Pulse Width	Sensitivity (dbv)		
	22.0*	26.0*	30.0*
0.7 μsec	-83.8	-83.8	-83.8
0.8 μsec	-83.8	-83.8	-83.8
1.2 μsec	-84.8	-84.8	-84.8

*Line voltage (volts dc).

The rf sensitivity control will reduce the gain more than 60 db.

Conclusion – The National Standard requires a sensitivity between -82 dbv and -90 dbv with a nominal value of -84 dbv. The proposed production specification for this transponder has tightened this requirement to read at least -84 dbv under standard conditions. The underlined figure in the above table is the sensitivity under standard conditions and is within reading and equipment accuracy tolerances of the production requirement.

The requirement for adjustment of sensitivity down to -80 dbv is met by the rf gain control.

The sensitivity is stable with variation of the line voltage and the interrogation pulse width.

Triggering Bandwidth

Signal Level	Bandwidth (Mc/sec)		
	22.0 V DC	26.0 V DC	30.0 V DC
6 db > MTL*	6.6	6.6	6.6
40 db > MTL	34.3	34.3	34.3

*MTL = minimum triggering level for 90% replies.

Conclusions – The production specification requires greater than 7 Mc/sec bandwidth at -6 db and less than 25 Mc/sec at -40 db. Some improvement would be required to meet these limits. The center of the -6 db frequencies was 1029.8 Mc/sec, meeting the less than ±1 Mc/sec limit.

Internal Signal Isolation

The absence of a local oscillator eliminates this source of undesired antenna radiation. Transmitter harmonic radiation has not been measured at NRL.

Automatic Overload Control

The AOC in this transponder has a sharp cutoff action; that is, there is no noticeable reduction in sensitivity before the threshold is reached.

The threshold is adjustable from 275 to 3350 replies per second.

The sensitivity reduction above threshold is in excess of 60 db.

There is no undesirable interaction when signals are mixed.

The present circuitry has no positive protection against exceeding a 1.0% duty cycle slightly, if the threshold is adjusted beyond about 3200 replies per second.

Conclusion – The AOC meets all production specification requirements except the 1.0% duty-cycle limitation, and a simple design change will limit the upper threshold limit to below 3200 replies per second.

Antijamming Provisions

Signal Level	Interference Level	Reduction of Replies		
		CW	AMCW	Pulse ¶
3 db > MTL	7 db < MTL	0%	§	0%
10 db > MTL	MTL	0%	§	0%
20 db > MTL	17 db > MTL	*	§	0%
30 db > MTL	27 db > MTL	†	§	0%
40 db > MTL	37 db > MTL	‡	§	0%
50 db > MTL	47 db > MTL	‡	§	0%

*At a cw interference level of 12 db > MTL, there is no reduction of replies but an occasional extra reply (trigger on noise) immediately following the suppression gate. At the specification limit of 3 db < signal, synchronized replies are reduced about 50% and sufficient extra replies are caused to raise the reply rate to the countdown threshold, which was set at 1200 replies per second.

†At 12 db > MTL (18 db < signal), the noise-triggered replies begin, increasing until the countdown threshold (1200) is reached at 12 db < signal.

‡About same results as in the preceding footnote. Increasing the signal does not override jamming.

§The effect of 400-cycle, 30% modulation is to increase the jamming effect about 2.0 db; that is, a jamming signal 2.0 db weaker causes the same result.

¶The pulse jamming signal recommended in the production specification was used, i.e., a 4-μsec pulse at 500 pps, free running.

In all the antijam tests the interrogation rate was 300 prf.

Conclusion – No antijam circuitry was incorporated in this model and as shown above it does not meet all the requirements of the production specification.

Internal Suppression

For a second signal 3 db > MTL the suppression period is 120 μsec. Due to the rather slow decay of the suppression gate, a second signal 30 db > MTL will retrigger in about 108 μsec.

Conclusion – Both these figures are within specifications; however, a sharper decay characteristic is desirable and should be no design problem.

Decode Tolerance

RF Pulse Width (μsec)	Begins To Fire (μsec)	Full Firing (μsec)	End of Full Firing (μsec)	End of Firing (μsec)
		3 db > MTL		
0.7	-0.58	-0.33	+0.22	+0.38
0.8	-0.63	-0.43	+0.32	+0.46
1.2	-0.98	-0.78	+0.58	+0.72
		50 db > MTL		
0.7	-0.49	-0.34	-0.26	+0.31
0.8	-0.62	-0.50	+0.32	+0.37
1.2	-1.00	-0.91	+0.69	+0.76

Note: (-) indicates less than the nominal 5 μsec, (+) means greater than.

Conclusion – Annex B* states there shall be full firing for pulse shifts of ± 0.2 μsec, no firing for greater than ± 1.0 μsec shift. The production specification requires full firing also for ± 0.2 μsec, but no firing for greater than ± 0.6 μsec. This model meets the requirements of Annex B, but not those of the production specification in every instance, especially with the very wide (1.2 μsec) interrogation pulse.

Wide and Narrow Pulse Discimination

Narrow Pulses, 3 db > MTL – With proper code and spacing, firing is reduced to 90% with a pulse width of 0.32 μsec. At 0.3 μsec, firing is reduced to 50%. At 0.22 μsec, replies are reduced to 0.

Narrow Pulses, 50 db > MTL – Firing is reduced to 90% with a pulse width of 0.15 μsec, the minimum obtainable on the test set used.

Wide Pulse – With a single pulse 10 μsec wide, no effect is noted from MTL to about 30 db > MTL, at which level about five replies per second are noted. At 40 db > MTL, 70% replies are seen. At 50 db > MTL, about 90% replies are seen.

Conclusion – These results are not compatible with the production specification or Annex B.

Random Triggering Rate

All the tests in the report were performed with sensitivity adjusted for no random firing.

*"Annex B, Military characteristics for the IFF Mark X (SIF) System."

TRANSMITTER

Power Output

Under nominal conditions, peak power output was measured at 347 watts. Line voltage variations had no measurable effect on power. The worst effects of a 3.5-db VSWR caused a decrease to 276 watts and an increase to 355 watts. The decrease in power when the duty cycle is increased from 0.1% to 1.0% is so small it cannot be measured accurately.

Conclusion – Satisfactory

Frequency

There is no measurable frequency shift with a change of input voltage. The worst phases of a 3.5-db VSWR pulled the 1090 Mc/sec reference frequency to 1084.7 Mc/sec and 1095.9 Mc/sec.

Conclusion – This VSWR pulling exceeds the allowable limit of ± 3.0 Mc/sec.

RF Pulse Shape

The following individual pulse characteristics were measured:

Rise time	0.03 μsec
Decay time	0.14 μsec
Width	0.50 μsec
Overshoot	2.0%.

Conclusion – These characteristics are well within the limits of Annex B.

Pulse Train Characteristics

Spacing – The clock oscillator is easily adjusted for perfect spacing and is very stable. Line voltage shifts from 22 to 30 volts have no effect on spacing. The same is true of duty-cycle changes up to and including 1.0%, also code configurations.

Power – There is no measurable pulse-train droop with duty cycle or code change.

Jitter – The following measurements were made on range jitter of replies:

30 db > MTL	$\pm$ 0.01 μsec
10 db > MTL	$\pm$ 0.02 μsec
6 db > MTL	$\pm$ 0.03 μsec
3 db > MTL	$\pm$ 0.04 μsec.

Delay – The transponder delay was measured as 2.50 μsec at 3 db > MTL and 2.30 μsec at 30 db > MTL.

Conclusion – These characteristics all exceed the requirements of Annex B except the delay, which is borderline. This can be easily corrected by inserting a small delay in an appropriate place.

COLD TEMPERATURE TEST

Individual subassemblies in the transponder were subjected to high and low temperature tests in the process of design. The exceptions to this are the processor-decoder card and the power supply. Those assemblies tested met requirements over a range of -54°C to at least +75°C.

No hot run was performed on the complete transponder. This was due to the fact that the power supply had not been heat tested, and since it was the only unit available at the time, it was felt unwise to risk damaging it and delaying forthcoming flight tests. A cold test at -54°C yielded the following observations:

1. The maximum reply pulse shift was 0.05 μsec.

2. The maximum transmitter drift was 4.3 Mc/sec.

3. The maximum peak-power reduction was 0.4 db.

4. The maximum receiver center-frequency shift was 0.6 Mc/sec.

5. The receiver sensitivity increased 3.5 db by the time -30°C was reached. At this point a detector malfunction caused erroneous readings. After correcting this, normal operation was resumed.

6. At -54°C, loss of beta in the power supply switching transistors caused it to cease operating.

APPENDIX B

PROPOSED MILITARY SPECIFICATION
RADAR IDENTIFICATION TRANSPONDER SET AN/APX-( )

1. SCOPE

1.1 Scope – The AN/APX-( ) equipment described herein is an airborne transponder for use in conjunction with a system of electronic identification. The equipment shall provide automatic radar identification of an airborne vehicle so equipped to all suitably equipped challenging aircraft, surface ships, and ground forces operating within the operational range of the system.

1.2 Classification – The AN/APX-( ) equipment shall be of one type and shall consist of the following:

Unit	Type Designation	Max. Allow. Size (Inches) Excluding Connectors			Max. Allow. Wt. (Lb)
		W	H	D	
Coder-Receiver Transmitter	KY( )/APX-( )	3-1/2	6	11	10

1.3 Auxiliary Equipment – The equipment shall be designed to operate within itself without any additional equipment except an antenna assembly, not to be supplied. System design shall be compatible with the following items:

Antenna Assembly	AS/133 APX
Antenna Assembly	AT-741/A

2. APPLICABLE DOCUMENTS

2.1 General – The following documents of the issue in effect on the date of invitation for bids, form a part of this specification to the extent specified herein:

Specifications
Military

MIL-C-172	Cases; Bases, Mounting; and Mounts, Vibration (for Use With Electronic Equipment in Aircraft)
MIL-E-4682	Electron Tubes and Transistors, Choice and Application of
MIL-W-5088	Wiring; Aircraft, Installation of
MIL-E-5400	Electronic Equipment, Aircraft, General Specification for
MIL-T-5422	Testing, Environmental, Aircraft Electronic Equipment
MIL-E-5272	Environmental Testing, Aeronautical and Associated Equipment, General Specification for

MIL-I-6181	Interference Limits, Tests and Design Requirements, Aircraft Electrical and Electronic Equipment
MIL-P-17555	Preparation for Delivery of Electronic Electrical and Electro-Mechanical Equipment and Associated Repair Parts
MIL-T-18303	Test Procedures; Preproduction and Inspection for Aircraft Electronic Equipment, Format for
MIL-N-18307	Nomenclature and Nameplate for Airborne Electronic and Associated Equipment
MIL-E-19600	Electronic Modules, General Specification for
MIL-C-26482	Connectors, Electric, Circular, Miniature, Quick Disconnect

Standards
Military

MIL-STD-145	Test Points and Test Facilities, Design Standard for
MIL-STD-439	Electronic Circuits
MIL-STD-704	Electric Power, Aircraft, Characteristics and Utilization of
MS 25245	Connections, Input Power Airborne Electronic Equipment; 28-Volt DC, 115-Volt Single-Phase AC, 115/200-Volt 3-Phase AC, or Combinations

2.2 Availability of Documents

(1) When requesting specifications, standards, drawings, and publications, refer to both title and number. Copies of applicable specifications required by contractors in connection with specific procurement functions may be obtained upon application to the Commanding Officer, Naval Supply Depot, Code CDS, 5801 Tabor Avenue, Philadelphia, Pa.

2.3 Precedence of Documents – When the requirements of the contract, this specification, or applicable subsidiary specifications are in conflict, the following precedence shall apply:

(1) Contract - The contract shall have precedence over any specification.

(2) This Specification - This specification shall have precedence over all applicable subsidiary specifications. Any deviation from this specification, or from subsidiary specifications where applicable, shall be specifically approved in writing by the procuring activity.

(3) Referenced Specifications - Any referenced specification shall have precedence over all applicable subsidiary specifications referenced therein. All referenced specifications shall apply to the extent specified.

3. REQUIREMENTS

3.1 Parts and Materials – In the selection of parts and materials, fulfillment of major design objectives shall be the prime consideration. In so doing, the following factors shall govern.

(1) Part and material requirements shall conform to specification MIL-E-5400.

(2) In the design of the equipment, consideration shall be given to the division of the units into nonrepairable modules or subassemblies. The size and amount of circuitry to be included in each module must be approved by the procuring activity. Each module will be treated as a single part and nonstandard part approval therefor must be obtained. The parts and materials used within the expendable module must be equal to or superior to that required by MIL specifications for similar items, but MIL standard items need not necessarily be used. The module as a whole must pass electrical and environmental requirements. Drawings used for the purchase or construction of the module must be sufficiently complete to permit the construction of the module by other than the original manufacturer. Nonrepairable modules must be designed for long, reliable service. A mean time to failure of 5000 hours should be the reliability goal per module.

3.1.1 Nonstandard Parts and Materials Approval - Approval for the use of nonstandard parts and materials shall be obtained as outlined in specification MIL-E-5400.

3.1.2 Electron Devices - Electronic tubes and semiconductor devices shall be selected in accordance with MIL-E-4682.

3.1.3 Design Objectives - Minimum size and weight, simplicity of operation, ease of maintenance and an improvement in the performance and reliability of the specific functions beyond the requirements of this specification are objectives in the design of the equipment specified herein. The use of materials, parts, and processes other than those required by specification MIL-E-5400 shall be investigated, and when it appears that a substantial reduction in size and weight or improvement in simplicity of design, performance, ease of maintenance, or reliability can be gained by their use, a request for approval of a nonstandard part shall be submitted to the Bureau of Naval Weapons for consideration. Each request shall be accompanied by complete supporting information.

3.1.3.1 Design for Mechanical Production - Design shall be directed toward the use of circuits which offer possibilities for mechanical production in accordance with specification MIL-E-5400. The contractor shall investigate and use, where suitable, those circuits given in MIL-STD-439.

3.1.4 Plug-In Assemblies - The use of easy disconnect plug-in assemblies, or electronic modules in accordance with specification MIL-E-19600, of one or more related circuits shall be investigated with a view toward reduction of size and weight, simplification of operation and maintenance, or improvement in performance.

3.1.5 Connectors - Miniature, quick disconnect circular connectors conforming to the applicable requirements of specification MIL-C-26482 shall be utilized.

3.2 General Design and Construction

3.2.1 General - The equipment shall conform with all the applicable requirements of specification MIL-E-5400 for design, construction, and workmanship unless otherwise specified herein.

3.2.2 Weight - The total weight of the equipment shall be a minimum consistent with good design and shall not exceed 10 pounds.

3.2.3 Standard Conditions - The following conditions shall be used as a basis to establish normal performance requirements and for making laboratory bench tests on the equipment.

Temperature	Room Ambient (30°C ± 10°C)
Altitude	Normal Ground
Vibration	None
Humidity	Room Ambient up to 90 Percent Relative Humidity
Input Power Voltage	27.5 ± 0.5 V DC.

3.2.4 Service Conditions – The equipment shall operate satisfactorily under any of the service conditions or reasonable combinations of service conditions as specified in specification MIL-E-5400 for class II equipment, except as modified herein.

3.2.4.1 Vibration – The equipment shall operate satisfactorily with no vibration isolator when subjected to the vibration requirements of curve I of MIL-E-5400 except that acceleration shall be ±9 g in all planes.

3.2.4.2 Temperature – The equipment shall operate satisfactorily when subjected to the temperature requirements of table II of MIL-E-5400.

3.2.4.3 Altitude – The equipment shall operate satisfactorily when subjected to the altitude requirements of table II of MIL-E-5400.

3.2.4.4 Shock – The equipment shall operate satisfactorily when subjected to the shock requirements of paragraph 3.2.21.6.1 of MIL-E-5400 except that the maximum shock shall be 20 g.

3.2.4.5 Salt Spray – The equipment shall withstand salt spray in accordance with procedure I of specification MIL-E-5272.

3.2.5 Pressurization – The entire equipment shall be pressurized in accordance with specification MIL-E-5400, paragraph 3.2.18 to a pressure of 5 psig at sea level.

3.2.6 Operational Stability – The equipment shall operate with optimum performance for 10 hours, continuously or intermittently, without the necessity for readjustment of any controls.

3.2.7 Operating Life - The equipment shall meet the following operating conditions:

3.2.7.1 Reliable Operating Life – The equipment shall have a reliable operating life of at least 200 hours with reasonable adjustment and servicing. Parts requiring servicing and replacement at the end of this interval shall be specified by the manufacturer.

3.2.7.2 Total Operating Life – The equipment shall have a total operating life of 1,000 hours with reasonable servicing and replacement of parts. Parts requiring replacement during this interval and the life of subject parts shall be specified by the manufacturer.

3.2.8 Cabling and Connections

3.2.8.1 Cables and Connectors – The equipment shall provide for the use of cables and connectors in accordance with specification MIL-E-5400.

3.2.8.2 Interconnecting Cables – The equipment shall operate satisfactorily using external wiring in accordance with the applicable requirements of specification MIL-W-5088. The external wiring shall be unshielded, except that a minimum number of the individual wires may be shielded when demonstrated as necessary to meet the interference control requirements, and provided the assembly of the cable to its plug may be easily accomplished. External mating connectors shall be supplied as a part of the equipment.

3.2.9 Input Power Requirements – The equipment shall meet all the applicable requirements of specification MIL-STD-704 and shall give specified performance from the following power source with characteristics as defined in specification MIL-STD-704 having limits as specified hereinafter. The power shall not exceed the specified amounts.

(1) DC power, 28 volts, 1.25 amps (subject to consideration of paragraph 6.2.1 of specification MIL-STD-704)

3.2.9.1 Grounded Input – The negative of the dc power source may be grounded externally with no adverse effects on the equipment.

3.2.10 Input Power Connection – The input power connection shall be in accordance with MS 25425.

3.2.11 Overload Protection – Overload protection for the equipment shall be provided in the equipment. All parts and circuits of the equipment which are likely to carry an overload due to any failures or poor adjustments shall be proportioned to withstand such overload without permanent damage to the equipment or shall have suitable protective devices. The use of fuses and other protective devices shall be held to a minimum.

3.2.11.1 High Voltage Delay – If necessary to meet the requirements of paragraphs 3.2.6 and 3.2.7, automatic provisions shall be incorporated within the equipment to prevent the modulator from applying pulses to the transmitter until the tube cathodes have been heated. The design of this automatic warmup provision shall be such as to function (recycle) in event of a failure of the primary dc power supply.

3.2.11.2 Undervoltage Protection – The equipment shall not be damaged by voltages below the minimum specified herein and shall automatically resume normal operation when the voltage returns within limits.

3.2.12 Moisture and Fungus Resistant Treatment – Equipments shall be fungus proofed by selection of parts and materials as nonnutrient for fungus or by treatment of the parts and materials prior to their use in the equipment so that overall spraying of the equipment is not necessary.

3.2.13 Nomenclature and Nameplates – Nomenclature assignment and nameplate approval for equipment identification shall be in accordance with specification MIL-N-18307.

3.2.14 Interchangeability – The equipment shall be designed to meet the interchangeability requirements of specification MIL-E-5400.

3.2.15 Provisions for Maintenance and Field Testing – The equipment shall be designed to provide for ease of maintenance to the greatest extent practicable by utilizing chassis test points and test facilities in accordance with specifications MIL-E-5400 and MIL-STD145

3.2.15.1 Compatibility With Existing Test Equipment – The equipment shall be compatible with the following radar test sets: (1) AN/UPM-98, (2) AN/UPM-99, and (3) AN/UPM-6B with AN/UPA-39.

3.2.15.2 High Voltage Protection – When the operation or maintenance of equipment employing potentials in excess of 1000 volts requires that these voltages be measured, the equipment shall be provided with test facilities such that all these high voltages may be measured at potential levels of less than 1000 volts relative to ground.

3.2.16 Radio Interference Control – The nature of radio interference generation is such that serious consideration must be given this problem in the earliest practical stages of design and development so that the generation of radio interference by the equipment and the vulnerability of the equipment to radio interference shall be satisfactorily controlled within the limits of specification MIL-I-6181.

3.2.17 Form Factor – The equipment shall be as compact as possible without sacrificing economy, shall meet the materials, bonding, shielding, and performance requirements of MIL-C-172, and shall not exceed 3-1/2 in. wide by 11 in. long by 6 in. high.

3.3 Performance

3.3.1 Receiver – The receiver shall be of the tuned-radio-frequency crystal-video type incorporating at least two stages of radio frequency amplification prior to the crystal detector.

3.3.1.1 Radio Frequency Characteristics

3.3.1.1.1 Frequency Range – The receiver is to be of the fixed frequency type and shall be factory-set to 1030 Mc.

3.3.1.1.2 Bandwidth – The overall bandwidth as measured at the crystal detector shall be greater than 7 Mc at 6 db down from maximum response and less than 25 Mc at 40 db down from maximum response. The overall bandwidth at 50 Mc shall be down at least 60 db. The overall selectivity curve shall be approximately gaussian in shape, and these characteristics shall be maintained over a sensitivity control range from 82 db below 1 volt to 90 db below 1 volt as well as over a dynamic range of at least 50 db, above a set -84 dbv.

3.3.1.1.3 Bandwidth Stability – The receiver bandwidth shall not be more than 10 percent from the minimum specified in 3.3.1.1.2 under all combinations of service conditions. The center of the receiver bandwidth shall be within ±1 Mc of the frequency to be received.

3.3.1.2 Receiver Protection – The receiver and all other components of the receiver-transmitter shall not be damaged by the transmitter power, or external signals up to 10 volts peak amplitude and average power of -20 dbm directly applied to the antenna terminal.

3.3.1.3 Internal Signal Isolation – Internal signals delivered by the transponder into a 52-ohm resistive load terminating the antenna terminal of the equipment, with the exception of the transponder, transmitter, shall not be stronger than -40 dbv with a design goal of -50 dbv except that the requirements of 3.3.1.1.2 shall be met.

3.3.1.4 Sensitivity – The receiver reply sensitivity for 90% firing as measured at the antenna receptacle under normal test conditions and at a frequency of 1030 Mc shall be at least 84 db below 1 volt when the interrogation pulses shall be supplied by a 50-ohm generator calibrated in terms of a closed circuit voltage. The sensitivity shall not decrease to less than 82 db below 1 volt in any combination of specified service conditions. An internal means shall be provided for adjusting sensitivity between 82 db below 1 volt and 90 db below 1 volt. This adjusted level shall be designated as normal sensitivity.

3.3.1.5 Noise Figure – The receiver shall be designed so that a minimum of self-generated noise will be present in the receiver output. Under no conditions shall the overall receiver noise figure exceed 15 db.

3.3.1.6 Automatic Overload Control – The equipment shall limit the number of received pulse train interrogations as follows.

(1) Limiting shall be by gain reductions in such a manner as to give preference to stronger signals. Gain reduction shall be at least 50 db when the receiver is adjusted for normal sensitivity.

(2) Limiting shall occur at an adjustable rate of 500 to 1800 replies per second. This is defined as the basic reply rate. This shall be factory set to 1200 replies per second.

(3) The automatic overload control shall also provide limiting which will limit the transmitter to a maximum duty cycle not to exceed 1 percent.

3.3.1.7 Echo Effects – The equipment shall operate in the presence of echoes of the interrogating signals and side-lobe suppression control pulses in accordance with the following:

(1) An echo of extraneous pulse which follows an interrogation pulse of 0.5 μsec or more in width (not to exceed 1.3 μsec) and at a spacing of 2 μsec shall not trigger a reply when it is 9 db or more below the level of interrogation pulse if the interrogation pulse is less than -24 dbv. The interrogation pulse frequency for this test shall be within ±1 Mc of the 1030 Mc.

(2) The transponder shall recover to within 3 db of normal sensitivity 15 μsec following the reception of a 1-μsec pulse at a level 50 db above the minimum triggering level.

3.3.1.8 Antijamming Provisions – The receiver shall be capable of operating through jamming which consists of simple cw, amcw, random-spaced pulses, and regular spaced pulses of any spacing, as follows:

(1) If the interrogating signal to which the equipment shall reply is between 3 and 10 db above the normal triggering level, an interfering signal 10 db from the interrogating signal shall not reduce the number of replies by more than 50 percent.

(2) If the interrogating signal is between 20 and 50 db above the normal triggering level, an interfering signal of at least 3 db down from the interrogating signal shall not reduce the number of replies by more than 50 percent.

3.3.1.9 Reduction Ratio – The reduction in the number of responses to the interrogating signal is the ratio expressed in percent of the actual number of replies to the expected number of replies. The measured replies shall be those which are synchronous with the test interrogation.

3.3.1.10 For test purposes, noise-modulated cw signals (or random spaced pulses) shall have a bandwidth of 10 Mc and a duty cycle (peak to average power rate) of 10 to 25 percent. A small amount of noise may be superimposed on a small amount of cw signal (partially suppressed carrier system).

3.3.1.11 For tests specified in 3.3.1.8 (1) and (2), the following type of interfering signals shall be used:

(1) Pulse width: not less than 1.5 μsec nor more than 4.0 μsec.

(2) Rise time: less than 0.2 μsec.

(3) Decay time: more than 0.5 μsec.

(4) Interfering repetition rate: 40 to 500 pulses per second.

3.3.1.12 Precedence – The requirements for antijamming described above or the requirements for the operation of a decoder without automatic gain stabilization or before automatic gain stabilization becomes effective shall take precedence over requirements for maintaining the normal triggering level within ±6 db.

3.3.2 Decoder – Under normal operating conditions in response to double pulse interrogations of normal characteristics the decoder shall:

(1) Cause the encoder to generate a reply in accordance with the selected code.

(2) Initiate an internal suppression gate to inhibit further decoding for a period of 100 to 125 μsec.

(3) Respond to interrogations spaced ±0.2 μsec from ideal spacing.

(4) The decoder shall not respond when double pulse interrogations are spaced ±0.6 μsec from ideal spacing.

(5) The interrogation pulses shall have a duration of 0.8 ± 0.1 μsec, a rise time of 0.1 μsec or less, and a decay time of 0.2 μsec or less.

(6) Normal MODE 2 spacing shall be 5.0 μsec and a decoder output pulse shall trigger the codes of paragraph 3.3.3.

(7) Normal MODE 3 spacing shall be 8.0 μsec and a decoder output pulse shall trigger the codes of paragraph 3.3.3.

The interrogation pulses shall have a duration of 0.8 ± 0.1 μsec, a rise time of 0.1 μsec or less and a decay time of 0.2 μsec or less. Ideal pulse separations shall be 5 μsec and 8 μsec. The decoder shall not respond when the double pulse interrogation is spaced ±0.6 μsec from ideal spacing. Pulse width of less than .7 μsec or more than 1.2 μsec shall not operate the decoder. The equipment shall work with pulse widths from 0.7 μsec to 1.2 μsec.

3.3.2.1 Decoder, Side Lobe – Under normal operating conditions in response to side-lobe interrogations of nominal characteristics, the decoder shall generate a suppression gate of sufficient length to inhibit replies to interrogations for 35 ± 10 μsec.

3.3.2.1.1 Inhibiting Characteristics – The suppression gate shall be generated when the amplitude of the control pulse is equal to or larger than the first interrogation pulse and the suppression gate shall not be generated when the amplitude of the first interrogation pulse is 9 db or more than the amplitude of the control pulse.

3.3.2.1.2 Sensitivity – The sensitivity of the circuit that recognizes (decodes) side-lobe reception shall be at least equal to that of the interrogation decoder (for the condition of 100-percent side-lobe decoding) but not more than 3 db above that of the interrogation decoder. (NOTE: One-hundred-percent side-lobe decoding is defined as 100-percent rejection of side-lobe interrogations. The requirements for IFF National Standards shall be met for side-lobe suppression.)

3.3.2.1.3 Range – These functions shall be performed as specified over at least a 50-db range of signal levels.

3.3.2.3 Decoder, Single Pulse – The equipment shall not respond to a single pulse interrogation of any duration provided that:

(1) A pulse carries no ripples comparable to normal interrogation.

(2) No cw capable of producing beats comparable to normal interrogation is present.

3.3.3 Coder – In response to the decoded output from the receiver, the coder shall produce pulse trains available to modulate the transmitter. Either or both MODE 2 and MODE 3 decodes shall produce the same pulse train.

3.3.3.1 Coder Output Pulse Selection – The coder shall be designed to permit the front panel selection of any one of 128 codes by means of seven toggle switches. The switches shall be labeled A1, A2, A4, X, B1, B2, and B4.

3.3.3.2 Reply Selection – No replies shall be transmitted unless an appropriate switch on the transponder has been actuated. A MODE 2 standby switch and a MODE 3 standby switch shall be provided.

3.3.4 Transmitter

3.3.4.1 Tuning Range and Frequency Adjustment – The transmitter shall be designed for single-frequency operation and shall be adjusted at the factory to 1090 Mc. The transmitter adjustment will allow adjustment of the transmitter at least ±15 Mc from this frequency.

3.3.4.2 Frequency Stability – The transmitter frequency shall remain within ±3 Mc of the stated 1090-Mc frequency under all service conditions, including mismatching at the antenna connection of the transponder and variation of the interrogation rate.

3.3.4.3 Power Output – The transmitter shall be capable of delivering a minimum of 24-dbw-peak rf power and a maximum of 27-dbw-peak rf power (as averaged over a rf pulse) to the antenna jack. These limits shall hold over all combinations of operating and environmental conditions. Such power shall be delivered at the adjusted frequency of 1090 Mc with a duty cycle up to and including 1 percent. Normal power shall be set to 300 to 350 watts by the contractor.

3.3.4.4 Duty Cycle – The power supply modulator transmitter and other circuitry shall be designed for 1-percent-duty-cycle continuous operation. However, for service life evaluation, the test shall employ an average duty cycle of 0.5 percent with operation at 1-percent duty cycle not to exceed 10 minutes per hour.

3.3.4.5 Modulation Capabilities – The pulse width variation with any supply train shall be 0.08 μsec or less, and the amplitude droop shall be 1 db or less.

3.3.4.6 RF Transmitter Change – Replacement of the tube and/or rf portion of the equipment to obtain specified transmitter performance shall not require more than one adjustment beyond the usual tuning adjustment.

3.3.5 Test Facilities – Each plug-in as well as each function shall be provided with built-in test points to allow in-position functional checking and servicing. The plug-in assemblies shall operate in any equipment, and service by module exchange shall be a requirement of this equipment.

3.3.6 General

3.3.6.1 Warmup Time – The maximum warmup time for the equipment measured from the application of the transmitter high voltage shall be 1 minute under standard conditions and 3 minutes at extreme service conditions. All performance requirements shall be met in these times except as noted herein.

3.3.6.2 Receiver-Trainsmitter Delay – The delay between the second interrogation pulse received at the antenna terminal and the first coded reply pulse delivered to the antenna terminal shall be between the limits of 3.0 ± 0.5 μsec. This shall be measured with a signal 6 db above normal sensitivity.

3.3.6.3 Range Jitter – The maximum range jitter in the equipment shall not exceed 0.1 μsec.

3.3.6.4 Standby – In the standby condition, all rf transmissions shall be inhibited. Normal receiver and decoder functions shall be performed.

3.3.6.5 Electrical Connections, External – All input and output and test wiring as outlined below shall be terminated on the front panel by suitable connectors. Each connector shall be clearly identified.

3.3.6.5.1 Control and Power – All control and power type wiring shall be terminated in an AN-type connector mounted at the lowest practical position.

3.3.6.5.2 Signal Wiring – All video, trigger, or rf wiring shall be terminated in coaxial type connectors. The transponder antenna feed connector shall be type N.

3.3.6.5.3 Test Wiring – Test wiring shall be provided to an AN-type connector for checking voltage, power supply outputs, etc.

Additional test wiring shall be provided to assist in fault isolation, adjustment and performance monitoring, with special emphasis to isolating faults to a particular major circuit element, such as the receiver decoder.

Test signals which may be useful in remote monitoring shall be brought out on coaxial-type connectors. The proposed connectors shall be submitted for review and approval by the Bureau of Naval Weapons.

4. QUALITY ASSURANCE PROVISIONS

4.1 General – Equipment shall be subjected to the following tests to determine conformance with all the applicable requirements: (1) Design Approved Tests; (2) Acceptance Tests.

4.1.1 Responsibility for Inspection – Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any commercial laboratory acceptable to the Government. The government reserves the right to perform any of the inspections set forth in the specifications where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.2 Design Approval Tests – Design approval tests shall be conducted on one or more sample equipments to determine whether the design of the equipment meets the requirements of all the applicable specifications and whether any design changes are necessary prior to the fabrication of any additional equipment. Design approval tests shall consist of the following: (1) Contractor's Demonstration Tests; (2) Service Approval Tests.

4.2.1 Contractor's Demonstration Tests – Contractor's demonstration tests shall be accomplished under the responsibility of the contractor and shall be conducted in accordance with the approved test procedures of paragraph 4.4. The Inspector of Naval Material and the Bureau of Naval Weapons may designate a representative to witness or supervise the tests, when so desired. Contractors not having laboratory facilities to conduct all tests satisfactorily shall obtain either the services of a commercial testing laboratory or written approval from the Bureau of Naval Weapons to omit that portion of the tests which cannot be conducted. The data obtained by the contractor in conducting these tests shall be included with the design data submitted with the equipment for service approval testing.

4.2.2 Service Approval Tests – At the completion of the contractor's demonstration tests and when requested by the Bureau of Naval Weapons, the equipment shall be delivered to a specified government laboratory for additional testing. This additional testing may consist of duplicating tests previously conducted and such other tests deemed necessary to determine compliance with all applicable design and performance requirements.

4.2.2.1 Accessory Material – In addition to the complete equipment submitted for design approval testing, the contractor shall submit the accessory material and design data specified in paragraph 6.3.

4.2.3 Scope of Tests – Design approval tests shall include all tests deemed necessary to determine that the equipment meets all the requirements of this specification and the contract. Design approval tests shall include testing in accordance with specifications MIL-T-5422 and MIL-I-6181. The design approval test shall include flight testing the equipment, when so desired by the Bureau of Naval Weapons. All design and test data shall indicate the physical and electrical characteristics of the equipment and establish that the equipment meets satisfactorily all requirements of this specification.

4.2.4 Design Sample Approval – Approval of the design sample shall be by the Bureau of Naval Weapons upon satisfactory completion of all tests. No additional equipment shall be delivered prior to the approval of the design approval sample. Prefabrication of any equipments prior to the approval of the design approval sample is at the contractor's own risk. The approved design approval sample will be returned to the contractor for his use in the fabrication and testing of the additional equipment to be submitted for acceptance under the contract.

4.3 Acceptance Tests – The contractor shall furnish all samples and shall be responsible for accomplishing the acceptance tests. All inspections and testing shall be under the supervision of the Government Inspector. Contractors not having testing facilities satisfactory to the Bureau of Naval Weapons shall engage the services of a commercial testing laboratory acceptable to the Bureau of Naval Weapons. The contractor shall furnish test reports, in duplicate, showing quantitative results for all acceptance tests required. Such reports shall be signed by an authorized representative of the contractor or laboratory, as applicable. Acceptance or approval of material during the course of manufacture shall not be construed as a guarantee of the acceptance of the finished product. Acceptance tests shall consist of the following: (1) Individual Tests; (2) Sampling Tests.

4.3.3 Individual Tests – Each equipment submitted for acceptance shall be subjected to an individual test. These tests shall be adequate to determine compliance with the requirements of material, workmanship, and operational adequacy. Each equipment in production shall be subjected to the tests in paragraphs 3.3.

4.3.2 Sampling Tests – Sampling tests shall be conducted on equipments selected by the Government Inspector and which have successfully passed the individual tests. These tests shall be conducted on a quantity as approved by the Bureau of Naval Weapons. Sampling tests shall be more extensive than the individual tests and may include any of the tests of paragraph 4.2.2 deemed necessary by the inspector to determine that the equipment offered for acceptance continues to be equivalent in performance and construction to the approved service approval model.

4.4 Test Procedure – The procedure and methods for conducting design approval tests and acceptance tests shall be prepared by the contractor and sent to the Bureau of Naval Weapons for approval. The right is reserved by the Bureau of Naval Weapons or the Naval Inspector to modify the tests or require any additional tests deemed necessary to determine compliance with the requirements of this specification or the contract. The proposed test procedure shall be submitted in sufficient time to permit its review by the Bureau of Naval Weapons and all necessary revisions by the contractor prior to the start of any tests. Specification MIL-T-18303 shall be used as a guide in preparing test procedures.

4.5 Presubmission Testing – No item, part, or complete equipment shall be submitted by the contractor until it has been previously tested and inspected by the contractor and found to comply, to the best of his knowledge and belief, with all applicable requirements.

5. PREPARATION FOR DELIVERY

5.1 General – All major units and parts of the equipment shall be preserved, packaged, packed, and marked for the level of shipment specified in the contract or order in accordance with specification MIL-P-17555. The preservation shall be Method II of MIL-P-116, for level A packaging.

6. NOTES

6.1 The radar identification Transponder Set is intended for utilization in aerial targets for use in conjunction with a system of electronic identification and recognition. When properly installed in such an aerial target, the equipment shall provide automatic radar identification of that target to all suitably equipped, challenging aircraft, surface ships, and ground forces operating within the operational range of the system.

6.2 Test Values – Normal and limiting values of performance data shall be determined at input voltages of 22 and 30 volts as well as at 27.5 ± 0.5 volts dc. These voltage values are to be used in testing the equipment at installation points for compliance with minimum acceptable standards of performance.

6.3 Accessory Material and Design Data – The contractor shall furnish, in addition to the complete equipment furnished for design approval tests, the data required by the procurement activity.

6.4 Definitions – The following definitions concern the general characteristics of information employed or processed by the equipments of a specific radar identification system. The subject system, by means of a pulse coded radio frequency transmission from one equipment (the interrogator) solicits pulse coded identification information from a second equipment (the transponder). Unless further amended by the individual specification paragraphs, these definitions shall apply.

6.4.1 Interrogation – An interrogation of two or more radio frequency pulses transmitted by an interrogator set.

6.4.2 Reply – A reply is a radio frequency pulse or pulse group transmitted by a transponder set as a result of an interrogation.

6.4.3 Interrogation Transmission Characteristics – The following definitions apply to interrogation pulse trains.

Number of Pulses	Pulse Spacing (μsec)	Pulse Width (μsec)	Rise Time (μsec)	Decay Time (μsec)
2	5 ± 0.1	0.8 ± 0.1	0.1 or less	0.2 or less
2	8 ± 0.1	0.8 ± 0.1	0.1 or less	0.2 or less

6.4.3.1.1 Interrogation Side-Lobe Suppression – The interrogation side-lobe suppression consists of a single pulse spaced 2.0 ± 0.15 μsec from the first pulse of an interrogation pair and having the following characteristics: (1) pulse width, 0.8 ± 0.1 μsec; (2) rise time, 0.1 μsec or less; (3) decay time, 0.1, μsec or less.

6.4.4.1 Framing Pulses – Framing pulses are two basic pulses spaced 20.3 ± 0.1μsec. ST designates the first framing pulse. SP designates the last framing pulse.

6.4.4.2 Information Pulse – An information pulse is a pulse contained between framing pulses and located within ±0.05 μsec of its referenced position.

6.4.4.3 Pulse Position – The pulse position is a time restricted location of an information pulse referenced from the first framing pulse, measured for leading edge to leading edge at half voltage points of pulses concerned. Each position shall be designated by a letter plus a number with the exception of the X pulse position, which has no number.

6.4.4.4 Pulse Train – A pulse train is a group of basic pulses in specified pulse positions resulting from one interrogation.

6.4.4.4.1 Code – A code is a combination of information pulses designated by a code number.

6.4.4.5 Code Number Assignments – Pulses assigned the group letters and subscript numbers are spaced in increments of 2.9 μsec, measured leading edge to leading edge at half voltage points. The X pulse, used for special identification purposes, is spaced 10.15 μsec from the leading edge of the first framing pulse. Each information pulse shall be within ±0.05 μsec of its referenced position. The pulse positions referenced from the leading edge of the first framing pulse shall be as follows:

Pulse	Position from First Framing Pulse (μsec) (Figure 1)
A1	2.9 ± 0.05
A2	5.8 ± 0.05
A4	8.7 ± 0.05
X	10.15 ± 0.05
B1	11.6 ± 0.05
B2	14.5 ± 0.05
B4	17.4 ± 0.05
SP	20.3 ± 0.10

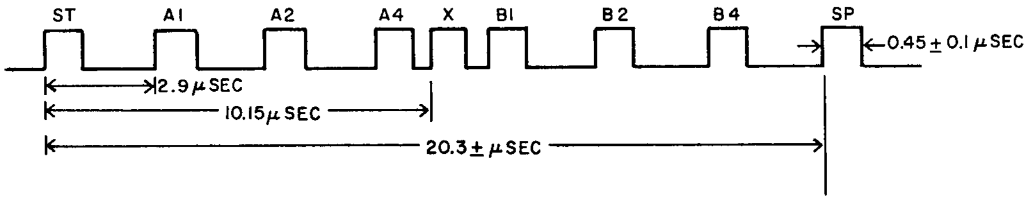

Fig. B1 - Code Waveform

6.4.4.5.1 Code Numbers - The appropriate code number is obtained by adding the numbers of each group where an information pulse appears. The digits obtained to be arranged in the group order AB to form the particular two-digit code number. (For example, if only the A1 and B2 pulses were present, the code number would be 12. If the X pulse were also present, the code number would be 12X.) Numbers 00X through 77X designate 128 codes.

6.4.5 Standard Trigger Pulse Characteristics

(1)	Polarity	Positive
(2)	Duration	1.0 to 10 μsec
(3)	Amplitude	20 ± 5 volts
(4)	Termination	75 ± 5 percent ohms
(5)	Rise Time	0.2 μsec or less
(6)	Decay Time	0.5 μsec or less

6.4.6 Standard Video Pulse

(1)	Polarity	Positive
(2)	Amplitude	2 ± 0.5 volts
(3)	Termination	75 ± 5 percent ohms

6.4.7 Pulse Characteristics

6.4.7.1 Pulse Amplitude - Pulse amplitude is the maximum voltage amplitude of the pulse or the rf pulse envelope.

6.4.7.2 Pulse Amplitude Jitter - Pulse amplitude jitter is the variation of the pulse amplitude of successive pulses caused by unintentional effects within the equipment expressed in percent of the average of the pulse.