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FR-3470

THE MTI CONVERSION UNIT FOR SR-3 AND SPS-6 RADARS

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THE MTI CONVERSION UNIT FOR SR-3 AND SPS-6 RADARS

T. H. Chambers and R. E. Ellis

May 20, 1949

Approved by:

A. A. Varela, Head, Search Radar Branch
L. A. Gebhard, Superintendent, Radio Division II

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ABSTRACT

The MTI Conversion Unit for the SC-SK series radars has been redesigned for application to the newer SR-3 and SPS-6 radars. This new system achieves a cancellation ratio of 30 db and includes velocity compensation by coherent oscillator phase rotation. Although performance tests are not complete, it is expected to give a subclutter visibility of 25 to 28 db for speeds below 30 knots and 20 to 25 db for speeds from 30 to 40 knots.

PROBLEM STATUS

This is an interim report on this problem; work is continuing.

AUTHORIZATION

NRL Problem R02-24R
(BuShips Problem S1055R-C)

THE MTI CONVERSION UNIT FOR SR-3 AND SPS-6 RADARS

INTRODUCTION

Problem

With the obsolescence of the SC-SK radar systems and the general trend toward higher frequencies in the air-search radar field, this Laboratory redesigned the MTI Conversion Unit, previously developed for the 200-Mc SC-SK systems, for use with the 1300-Mc SR-3 and SPS-6 radars. This modification included a broadening of the bandwidths to meet the needs of the shorter pulse of the new systems and also included velocity compensation by coho shift because the new system had a speed of peak response of only 64.5 miles per hour.

This report will not go into detail on velocity compensation[1] but will describe in general terms the velocity compensator and other components of the equipment.

References

The present report will include no discussion of the theoretical considerations underlying the development of an MTI system. For these considerations, reference is made to NRL Report R-3246,[2] on MTI theory in general, and to NRL Report R-3426 (footnote 1) for the theory underlying velocity compensation.

NRL Report R-3065[3] is also of interest since it describes the pressurized mercury delay line used in this system.

THE MTI SYSTEM - DESIGN CONSIDERATIONS

General

The MTI system applied to the SR-3 and SPS-6 radars (Figure 1) is of the coherent pulse doppler type using a mercury delay line storage element in the cancellation process.

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[1] Covered in detail in Confidential NRL Report R-3426, "A Velocity Compensator for MTI," by T. H. Chambers, March 2, 1949.

[2] Chambers, T. H., "The MTI Conversion Unit for SC-SK Series Radar," NRL Report R-3246, March 2, 1948. Confidential.

[3] Chambers, T. H., "A Pressurized Mercury Delay Line for Fleet Service," NRL Report R-3065, April 28, 1947. Confidential.

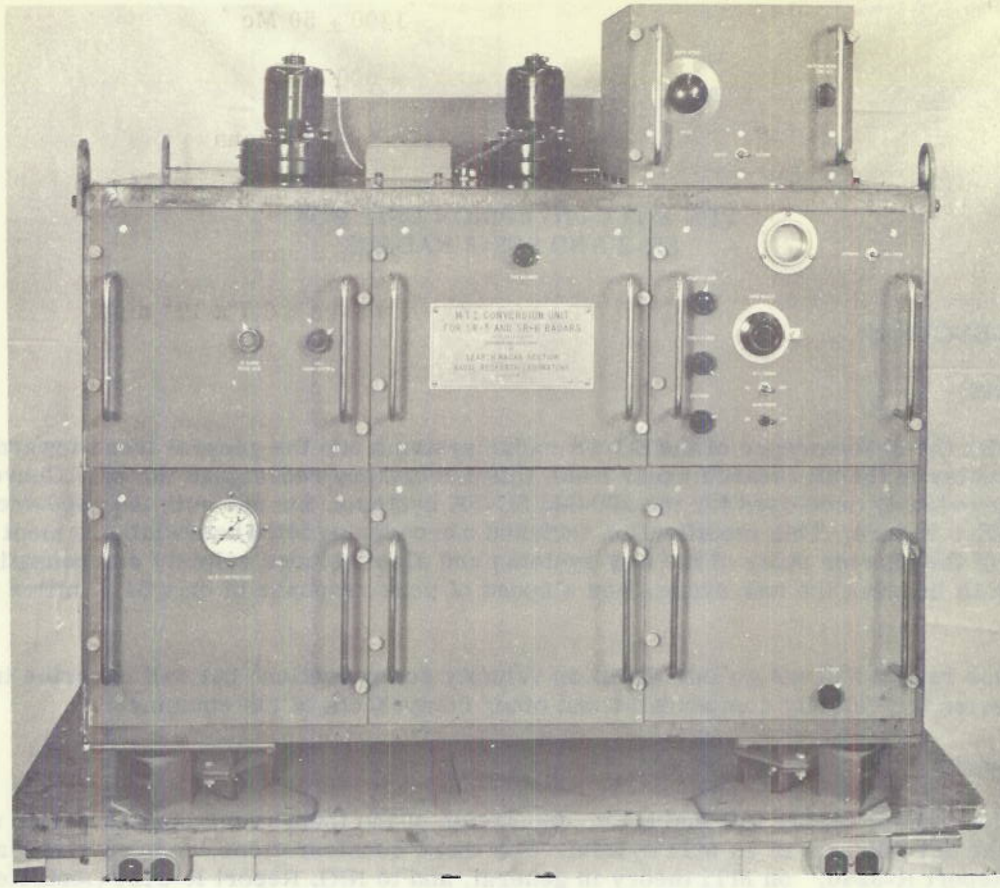

Fig. 1 - The MTI Conversion Unit for SR-3 and SPS-6 Radars

It is in general similar to the system used with the SC-SK series radars, differing mainly in the bandwidth of the various circuits and in the addition of velocity compensation by coho shift.

The pulse width of the now obsolete SC-SK MTI was 2 microseconds, hence a bandwidth of 1 Mc was satisfactory for i-f and carrier circuits and a bandwidth of 500 kc was satisfactory for video circuits. In the SR-3 and SPS-6 radars, the pulse width is 1 microsecond, requiring a bandwidth of 2 Mc in i-f and carrier circuits and a bandwidth of 1 Mc in video circuits.

Again, in the SC-SK system, velocity compensation by selection of parameters was possible, but in the SR-3 and SPS-6 system, the condition for this method of compensation is not met, and velocity compensation must be introduced by means of coho phase rotation.

System Parameters

The parameters of the SPS-6 radar (the parameters of the SR-3 are the same except for antenna beamwidth) which influence the design of the MTI Conversion Unit are as follows:

f_o = radar system frequency = 1300 ± 50 Mc

PRF = pulse repetition frequency = 500 cps

θ_b = antenna beamwidth = 3.10° = .054 radians

θ_e = antenna effective clutter beamwidth; $\theta_b \lessdot \theta_e \lessdot 2\theta_b$ [4]

N = antenna rotation speed = 1.25 or 5 rpm

c = velocity of electromagnetic waves = 6.7×10^8 mph

R = subclutter visibility = 31.6 (30 db)

and it is desired to maintain this subclutter visibility at ship's speeds up to

ν_s = ship's speed $\lessdot$ 40 knots (46 mph).

By use of equation 13, footnote 2,

$$V^{(n)}_{null} = \frac{n(PRF)c}{2f_o},$$

we may calculate the speed for the first null in response ($V^{(1)}_{null}$).

$$V^{(1)}_{null} = \frac{1 \times 500 \times 6.7 \times 10^8}{2 \times 1.3 \times 10^9}$$

$$= 129 \text{ mph},$$

or, the first peak in response ($V^{(1)}_{max}$) will occur at 64.5 mph.

Fundamental System Limitations

Of the system limitations considered in footnote 2, only two are fundamental. Consider first the limitation due to antenna scanning speed. From equation 23.1, footnote 2,

$$R_{max} \lessdot \frac{(PRF)\theta_b}{15\ N}.$$

When N = 5,

$$R_{max} \lessdot \frac{500 \times 3.1}{15 \times 5} = 20.6, \quad \text{or} \quad R_{max} \lessdot 26 \text{ db}.$$

Thus, a scanning rate of 5 rpm will limit subclutter visibility to 26 db. The scanning rate, if reduced to 1.25 rpm, will allow 38-db cancellation and hence will not be a limiting factor.

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[4] θ_e, the effective clutter beamwidth of the radar antenna, is the width of the antenna beam at the points at which clutter just reaches limit level in the receiver. Thus, it is dependent not only on the width of the antenna beam, but also on the slope of the skirts of the antenna beam, the limit level of the receiver, and the clutter strength. For 30-db limit level, it will equal θ_b for 36-db clutter and will, for ordinary antenna patterns, be about 2.0 θ_b for 80-db clutter.

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Consider now equation 28a, footnote 1, for the limitation due to velocity compensation.

$$R_{max} \leqslant \left| \sin \frac{\pi \nu_s \sin \frac{\theta_e}{2}}{V_{null}^{(1)}} \right|^{-1}$$

$$R_{max} \leqslant \left| \sin \frac{\pi \times 46 \times \frac{.054}{2}}{129} \right|^{-1} = 33.3$$

or

$$R_{max} \leqslant 30.4 \text{ db.}$$

This factor will not limit subclutter visibility for clutter levels up to 36 db, but at higher clutter levels (where θ_e becomes larger) and at high ship speed, it will be a limiting factor. For 70-db clutter, it will limit the subclutter visibility to about 22 db for a ship's speed of 40 knots and to 26 db for a speed of 25 knots.

Requirements for Velocity Compensation

Reference is made to equation 16.1a, footnote 1, for the frequency shift which must be developed by the velocity compensator.

$$f_s \simeq \frac{2 \nu_s f_o}{c} \cos \theta_r$$

$$f_s \simeq \frac{2 \times 46 \times \cos \theta_r}{6.7 \times 10^8} \times 13 \times 10^8 = 178 \cos \theta_r \text{ cycles/sec.}$$

The velocity compensator must therefore be capable of shifting the coho signal a maximum of $\pm$ 178 cycles per second. This shift must be under the automatic control of the relative antenna bearing angle, being a linear function of the cosine thereof.

The accuracy to which this shift must be made is given by equation 107.1, footnote 1, as

$$\Delta f_s \leqslant \frac{(PRF)}{\pi R_{max}},$$

or

$$\Delta f_s \leqslant \frac{500}{\pi \times 31.6} = 5 \text{ cps.}$$

Thus the coho frequency shift must be accurate to within 5 cps if it is not to limit subclutter visibility.

Construction

Since the new MTI system is to be a redesign of the earlier equipment used with the SC-SK radars, it is mechanically similar to that system. One unit (the trigger unit) has been retained unchanged except for the remounting of some of the decoupling resistors to secure better ventilation. Two other units retain the original basic chassis and power

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supplies, but have a new sub-chassis carrying the rebuilt signal-handling circuit. The other three units have been completely rebuilt, and a new unit has been mounted on top of the main frame. Since cooling was one of the most serious problems in the original SC-SK MTI system, all units have been turned on their sides to allow free flow of air upward past the chassis, and blowers have been installed to remove the heated air.

System Connection

The conversion unit has on its top a junction box where all connections to the radar are made. These connections are as follows:

Description	Cable Number
Power	
115V 60~	02
115V 60~	03
Relative Bearing Synchro	
R_1	96
R_2	97
S_1	57
S_2	58
S_3	59
Ground	01
Transmitter R.F.	C44
Local Oscillator	C43
I.F. Input	C32
Trigger Output	B43
PPI Video	80M
"A" Scope Video	41M

The conversion unit does not have a built-in r-f system or i-f preamplifier, but is supplied with a 30-Mc i-f signal from the output of the radar system i-f preamplifier. This MTI system supplies only an MTI video signal. It does not have provision for supplying a normal video signal, and therefore the normal radar receiver is left in operation when the MTI system is in use.

THE MTI CONVERSION UNIT

The MTI I-F and Coho Unit

The MTI i-f and coho unit is shown as unit no. 1 in Diagram 1.* A schematic representation is shown in Diagram 2 and photographs in Figures 2 and 3.

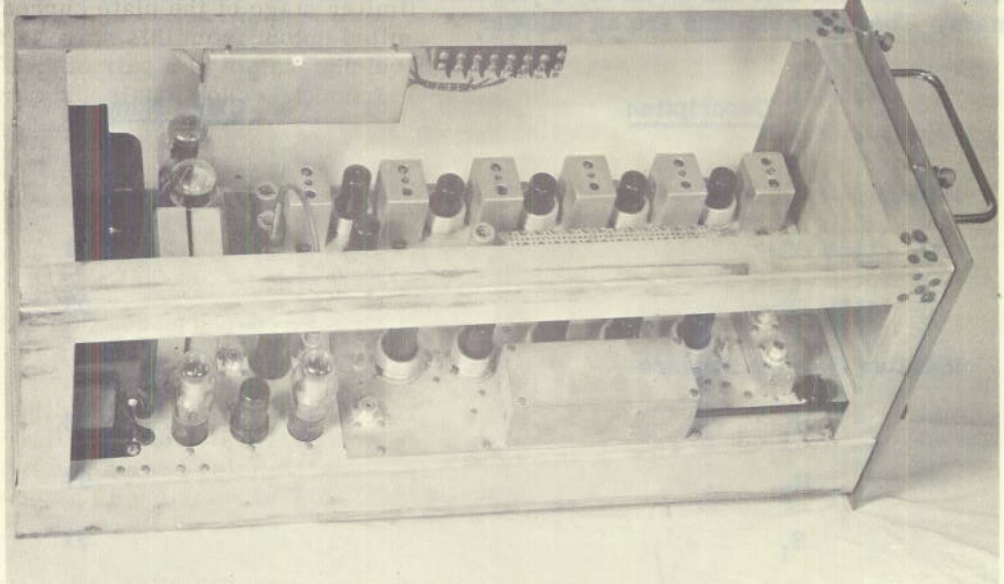

Fig. 2 - The MTI I-F and Coho Unit - Unit No. 1

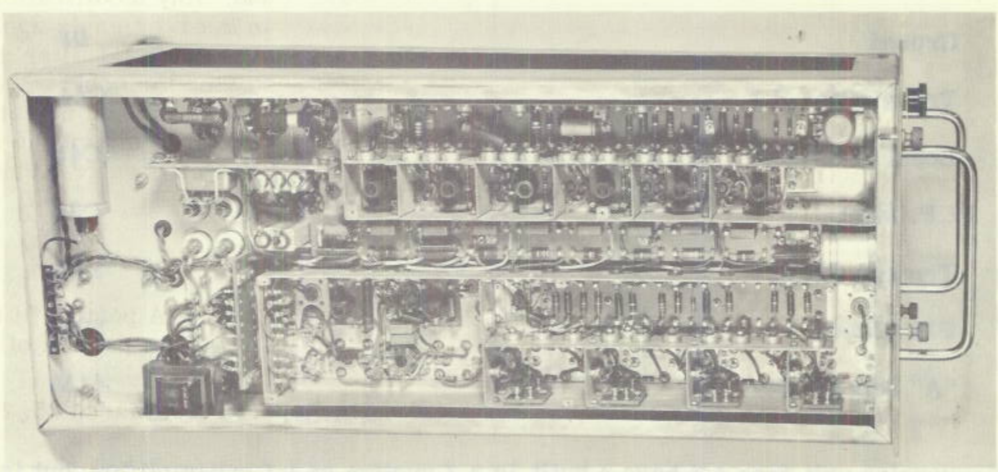

Fig. 3 - The MTI I-F and Coho Unit (Bottom View)

* All diagrams are located at the end of the report.

This unit consists of two major parts, the MTI i-f amplifier which includes tubes V-101 through V-110 and their associated circuits and the coherent oscillator strip with tubes V-111 through V-115 and their associated circuits. The MTI i-f amplifier will be discussed first.

A 30-Mc signal from the radar system receiver is fed over cable C32 into a three-stage i-f amplifier which uses double-tuned transformers in conjunction with type 6AC7 tubes. Gain control is applied to the grid returns of the second and third stages in the form of a negative voltage from a low-impedance cathode follower (to insure rapid recovery). The output from this amplifier is fed into a 6AC7 limiter stage of the plate current saturation type using regulated screen voltage. The limited output from this stage is fed through a double-tuned transformer into the coho-injector which consists of a pair of 6AG7 tubes (V-105 and V-106) connected for balanced operation from the echo signals and single-ended operation from the coho signal. The secondary of the transformer from the limiter stage is connected to deliver signals of opposite polarities to the grids of the coho-injector tubes, thus giving balanced operation from the echo signals. The coho signal is applied, through an impedance-matching network, to the cathodes which are connected together. In this way, in-phase coho voltages are combined in the two sections of the coho-injector with the out-of-phase echo-signal voltages.

The signals from the coho-injector are fed into a balanced-phase-detector through a coupling network arranged to give independent control of the resonant circuits for signal and coho outputs. (The double-tuned transformer and tube capacities form the resonant circuit for the push-pull echo-signal output. The tube and transformer capacities and the coil-to-ground from the center tap of the secondary of the transformer form the resonant circuit for the parallel coho signal.) The phase-detector consists of two 6AL5 tubes (V-107 and V-108) connected back-to-back and through individual load resistors to a common i-f filter and output load resistor.

The phase-detector operates in the following manner. Any variation in the amplitude of either the echo signal or the coho signal will result in the same relative change in the i-f signal level fed to the two halves of the phase-detector. Because of the manner of connection of the two 6AL5 tubes, such a change will result only in altered circulating current in the individual load resistors and will give no output to ground. Any modification in phase of the echo signal, however, will result in a different change in the i-f signals applied to these detectors and will thus yield a current flow to ground through the i-f filter and output load resistor. This current flow develops across this load resistor the coherent video signal which is fed, through a stage of video amplification, to cable D41. It should be noted that because of the back-to-back operation of the 6AL5 detectors and since either one may have the greater amplitude, the resultant signal may be either positive or negative; thus, the coherent video signal is bi-polar.

The balanced phase-detector is treated in footnotes 2, 5, 6, and 7.

The coherent oscillator strip operates in the following manner. A portion of the radar receiver local oscillator voltage (fed to the unit over cables C43) and a portion of the radar

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[5] Selove, W., "Notes on MTI Receivers," MIT Rad. Lab. Report 1010, March 25, 1946. Restricted.

[6] "Modification Kit MX-662/TPL-1," Sperry Report No. 5251-2077, May 1947. Confidential.

[7] Hollywood, J. M., "Blindness Conditions in MTI Radar Systems," Airborne Instruments Laboratory Report No. 329-1, Part 3, Appendix A, April 1947. Confidential.

transmitter pulse (fed to the unit over cable C44) are applied through a resistance network to a 1N21B crystal detector. The output of this crystal detector, a 30-Mc signal pulse containing information as to phase and frequency difference between the local oscillator and the transmitter r-f pulse, is amplified to high level by a two-stage amplifier, using 6AC7 tubes coupled with single-tuned circuits, and applied to the grid of a 6AG7 phasing tube. This phasing tube is operated with a fixed-grid-bias, slightly greater than cut-off, and has its plate circuit coupled through a condenser to the tank circuit of the coherent oscillator. In operation this phasing tube is cut off during the time between transmitter pulses and acts only as a small fixed capacity across the coherent oscillator tank circuit. Also during this period, the plate resistor, which is made high enough in value to prevent excessive loading of the coho tank circuit, charges the coupling condenser to power supply voltage. When the transmitter fires, the amplified pulse of i.f. is of sufficiently high level to drive the phasing tube into class-C operation, thus delivering a high-level pulse of i.f. to the tank circuit of the coherent oscillator to lock it in phase. The voltage level of this pulse is sufficient to satisfy the requirements set forth in equation 29, footnote 2, so that the phasing of the coherent oscillator does not limit the performance of the system.

The coherent oscillator consists of a 6AC7 tube connected as an electron-coupled oscillator using a high-Q 30-Mc tank circuit tunable (from the front panel) by $\pm$ 1 Mc. The stability of the oscillator is adequate to satisfy equation 30, footnote 2, and therefore it places no limitation on subclutter visibility. The coho-signal from the oscillator plate is fed through a single-tuned network to a 6AG7 limiter driver stage, and then over cable C38 to the velocity compensating unit (unit no. 2).

The built-in power supply for this unit is electronically regulated and supplies all voltages with the exception of a negative 75_V bias-voltage and a gain-control voltage which are fed in from unit no. 2.

The Velocity Compensation Unit

The velocity compensation unit, and the theory underlying its operation are discussed in some detail in footnote 1; therefore the section which follows will be limited to a simple description of the circuit used.

The velocity compensator is shown pictorially in Figures 4 and 5, and schematically in Diagram 3. At the upper left-hand side of this diagram will be seen the two beating oscillators (V-202 and V-215) which develop the coho compensating signal. These two oscillators are operated at 4 kc, this frequency being chosen because it is high enough to allow a reactance tube to vary the frequency of the variable oscillator the required $\pm$ 180 cps and still low enough to attain the better than 5 cps stability required. It will be noted that both oscillators are identical (with the exception of the reactance tube) and employ a type 6SC7 tube in a balanced connection which uses a high-Q ($Q > 100$) toroid[8] tank circuit. The use of toroids proved to be mandatory in this application since the variable frequency oscillator must be able to pass smoothly through zero-beat with the fixed frequency oscillator without tending to lock-in with it and the toroids were the only coils in which direct mutual coupling between coils did not cause locking-in when the variable oscillator was within 5 to 10 cps of the fixed oscillator. The reactance tube (V-201), also balanced, is a type 6SN7 tube and has proved easily capable of providing the necessary frequency shift.

It should be noted here, that in the system constructed at this Laboratory using regulated plate and heater power, and with the circuit shown, no difficulty has been experienced

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[8] NRL Coil Shop Specification No. 3477.

with respect to oscillator stability. After a five-minute warm-up period, the oscillators may be adjusted to zero-beat and will remain within about 2 cycles of each other for the entire day with no tendency to lock-in.

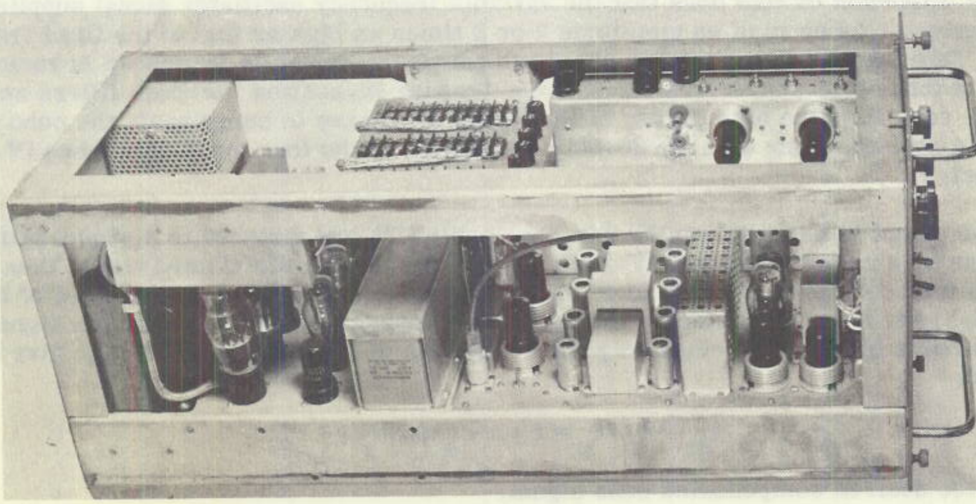

Fig. 4 - The Velocity Compensation Unit - Unit No. 2

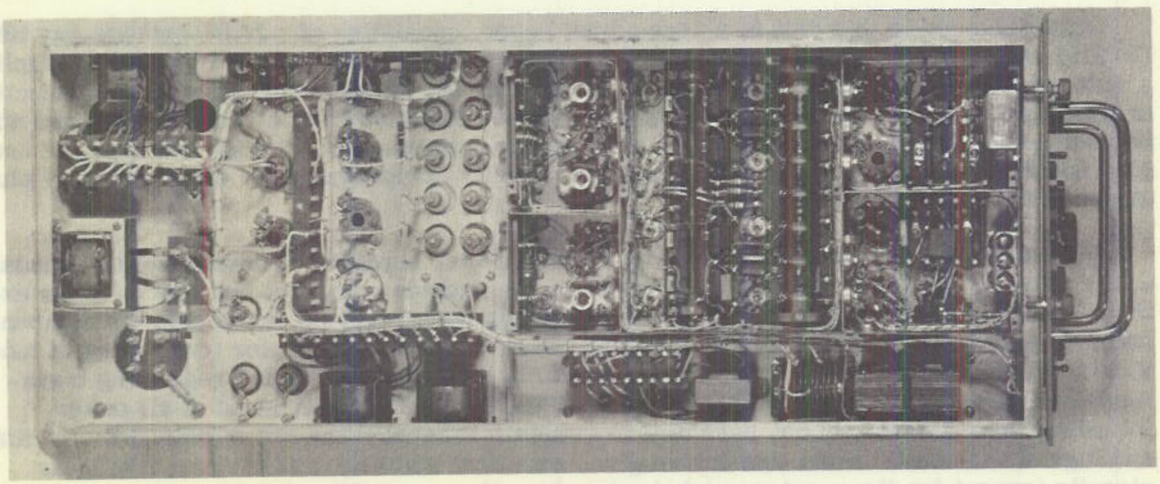

Fig. 5 - The Velocity Compensation Unit (Bottom View)

The output of the fixed frequency oscillator is fed through a buffer tube (V-216) to a phase-splitting delay line of the lumped-constant M-derived low-pass filter type. The four outputs of this delay-line are fed to resistance-capacitance L-section filters to allow amplitude and phase correction for delay-line losses and inaccuracies.

The output of the variable frequency oscillator is fed through a buffer stage (V-203) to transformer T_1. This transformer [9] consists of an iron core with five spaced universal

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[9] NRL Coil Shop Specification No. 3500.

wound coils on its center leg. The center coil is the primary and the other windings are the four secondaries, each of which is connected in series with one of the delay-line outputs and thence to one of the four converter tubes (V-204 to V-207 incl.).

It is important to note here that the variable frequency oscillator signal supplied to these converter tubes is of an amplitude 2 or 3 times as high as that of the fixed frequency signal. This tends to suppress any change in converter output as frequency is varied. The outputs of these four converters are then fed through Pi-section low-pass filters and, after filtering, constitute the four phases of the signal necessary to compensate the coho (f_s) which are applied, along with the 30-Mc coho signal, to the four modulator tubes (V-208 to V-211 incl.).

Coho signal is brought into the unit over cable C38 and matched to a phase-splitting delay-line by a cathode follower (V-212). This delay-line, a distributed wound line, supplies the four coho phases to the four modulator tubes. After these four phases of the coho signal (f_c) have been modulated by the appropriate phases of the compensation signal (f_s), they are recombined in the common plate connection of the modulator tubes to give the resultant,

$$f_{cc} = f_c - f_s = f + k\,\nu_s \cos\theta_r .$$

This is the desired compensated coho signal.

Before leaving this unit, the signal is amplified and limited by V-213 to remove any amplitude variations which might result from circuit imperfections or differences in modulator tubes. The signal is matched in a Pi-section network to the 50-ohm output cable (C39).

Also included in this unit is a zero adjust scope, consisting of a 2AP1 cathode-ray tube (V-219) and two dual frequency deflection amplifiers (V-217 and V-218) arranged to amplify a video signal fed in at TP-1 or TP-2, or, to amplify the 30-Mc coho signal when connected in lines C38 and C39. Ordinarily, the scope will be connected in this latter fashion and will be used to check and adjust the zero of the velocity compensator. It may, however, be used for checking the low frequency circuits of the velocity compensator (or other units) by plugging test leads in TP-1 and TP-2.

All power for this unit is supplied by built-in power supplies. These supplies furnish + 300 volts for all plate circuits, -300 volts for the cathode-ray tube, and -75 volts for external use. It will be noted that all power (including heater power) to the velocity compensator is regulated; the plate power, by means of an electronic regulator (consisting of tubes V-221, V-222, and V-223) and the heater power, by means of the "Sola" regulating transformer visible in the upper left-hand corner of Figure 4. This regulation of all power, including heater power, is not essential to maintain accuracy; the use of balanced circuits and high-Q tank coils in the oscillators gives excellent stability, and the use of similar circuits (except for the reactance tube) minimizes the possibility of them drifting different amounts or in different directions. Regulation of all power, however, provides insurance against trouble caused by the severe line-voltage fluctuations sometimes encountered.

The front panel of this unit contains the major operating controls for the entire conversion unit. These controls are as follows:

Operating Controls	Balance Controls	Velocity Compensator Controls
Main Power on-off	Through-channel gain	Zero adjust - operate switch
MTI Power on-off	Delayed-channel gain	Zero adjust
MTI Gain		

The Compensation Control Unit

The compensation control unit is shown as unit no. 7 in the block diagram (Diagram 1). A schematic diagram of this unit is shown in Diagram 4 and a photograph is shown in Figure 6. The unit consists of two 6SN7 tubes (V-701 and V-702) operated as two pairs of back-to-back gated rectifiers and their associated circuits. It receives information as to relative antenna bearing and ship's speed, and supplies d-c compensation control voltages to the velocity compensating unit (unit no. 2).

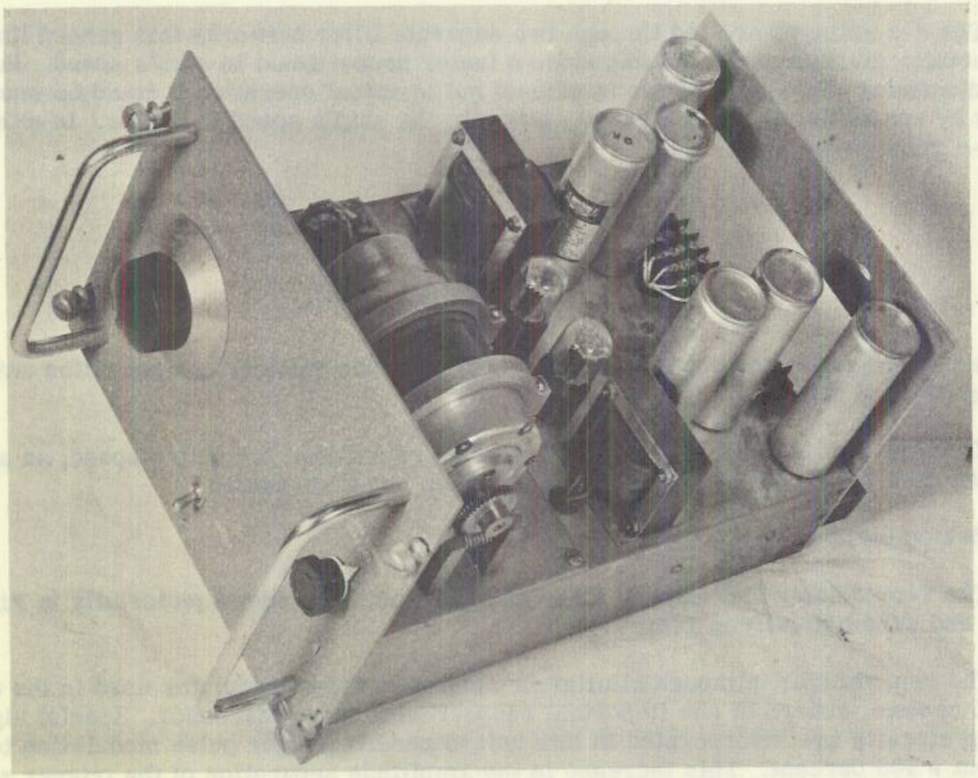

Fig. 6 - The Compensation Control Unit - Unit No. 7

In operation the unit receives the relative antenna bearing information from the ship's synchro line. The excitation voltage intended for the rotor of the 5CT synchro is supplied to the primary of a biasing transformer which applies equal in-phase gating voltages to the grids of all four rectifiers. The synchro rotor is operated in the fixed position which gives maximum voltage for a relative antenna bearing of 0° or dead ahead; thus, the amplitude of the 60 cycle rotor voltage is

$$A_3 = k_3 \cos \theta_r .$$

This voltage is fed through a transformer, the secondary of which is connected for balanced operation to both pairs of back-to-back rectifiers, so that the voltage applied to each pair of rectifiers is equal in amplitude but opposite in polarity. With this arrangement of bias and supply voltages, one of the rectifiers will be cut off and the other rectifying in each pair, and the d-c voltage output from the two pairs will be of equal amplitude but of opposite polarity. As the phase of the rotor voltage changes, the rectification switches from one tube to the other in each of the back-to-back rectifier pairs, thereby preserving the sign of cos θ_r. The amplitudes of the two d-c voltages from the rectifiers are

$$A_{5.1} = k_5 \cos \theta_r$$

and,

$$A_{5.2} = -k_5 \cos \theta_r.$$

The d-c voltages are fed through two separate filter networks into ganged linear potentiometer multipliers which introduce a factor proportional to ship's speed. In this unit the adjustment of the multipliers is manual but in actual operation it could be made automatic by connecting through a servo system to the ship's speed indicator. In either case the d-c voltages become

$$A_{1.1} = k_1 \nu_s \cos \theta_r$$

and,

$$A_{1.2} = -k_1 \nu_s \cos \theta_r.$$

These two compensation control voltages are fed to the velocity compensation unit over cables D21 and D22.

This unit has three front panel controls: an adjustment for ship's speed; an antenna bearing zero set; and a switch for ship's motion, ahead or astern.

The Remodulator Unit

The remodulator and through video unit (unit no. 3) is shown pictorially in Figures 7 and 8 and schematically in Diagram 5.

The remodulator, although similar in general to the remodulator used in the earlier SC-SK system, differs in one important respect from its predecessor. Special high-level pulsing circuits are incorporated in this unit to permit trigger pulse modulation to a level of about + 500 percent. This increase in the amplitude separation of the trigger and video modulation levels, together with special circuits to prevent double triggering (built into the delayed trigger carrier amplifier and to be described with it) insures absolute stability of the trigger system.

The through video channel is similar to the equivalent unit included in the SC-SK system, differing only in the use of transitionally-coupled double-tuned coupling transformers which will better match the pass band of the through video channel with that of the delayed video channel.

In the remodulator channel, the first tube (V-301) is the carrier oscillator operating at 15 Mc. It is electron-coupled through a single-tuned circuit to a buffer amplifier (V-302). The output of this buffer amplifier is split in phase by a balanced transformer to drive the push-pull output stage (V-303 and V-304) which is operated linear class-B. This stage is grid-modulated by the degenerative video amplifier (V-305) with video signal from incoming line D41. The output of the modulated class-B amplifier is fed to the delay-line transmitting crystal over a network which consists of a push-pull primary, link-coupled into a 100-ohm coaxial line (C45) which is terminated in the link-coupled resonant secondary used to step the line impedance up to a level satisfactory to feed the transmitting crystal. The use of a

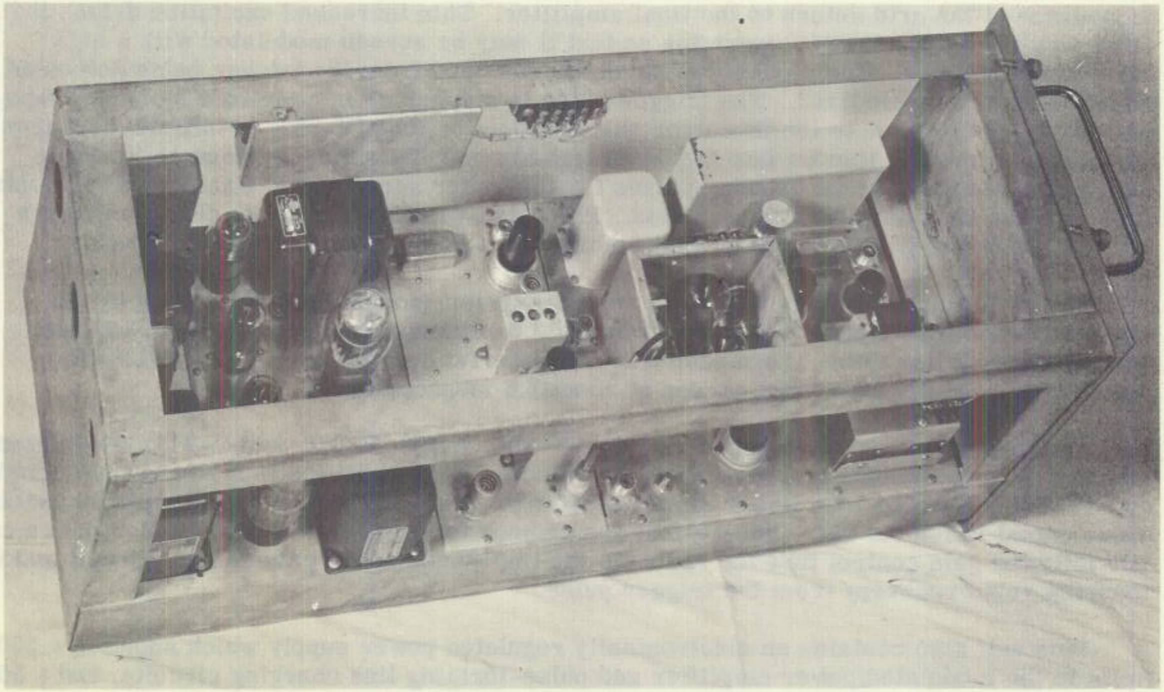

Fig. 7 - The Remodulator Unit - Unit No. 3

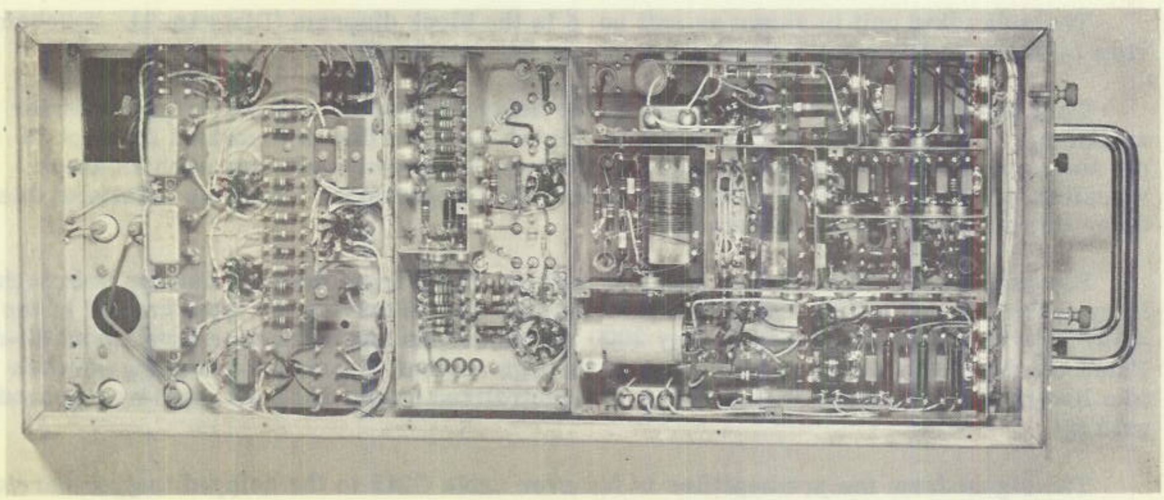

Fig. 8 - The Remodulator Unit (Bottom View)

100-ohm line allows impedances to be correctly matched while maintaining coefficients of coupling (at the ends of the line) such that the over-all coefficient of coupling will give the desired pass band. This circuit is equivalent to a double-tuned transformer.

To apply the high level trigger pulse modulation to this carrier excitation of the final stage is increased by screen pulsing the buffer amplifier and simultaneously reducing the impedance of the grid return to the final amplifier. This increased excitation drives the final amplifier into class C operation so that it may be screen modulated with a high level positive pulse. The modulating pulse is developed from the trigger pulse delivered to this unit over cable B143. The trigger pulse is stepped up in amplitude by pulse transformer T_1 and applied to the thyratron pulse modulator tube (V-307) to initiate discharge of the pulse-forming line L_1 into the pulse transformer T_2 which develops on its three secondary windings the modulating pulses for the buffer screen grid, final amplifier control grid, and the final amplifier screen grid. The pulse-forming line L_1 is charged through choke T_3 between pulses in the normal fashion for a d-c resonant charging circuit.

The remodulator delivers about 14 volts of carrier, modulated $\pm$ 80 percent by the coherent video signal and + 500 percent by the 2.5-microsecond trigger pulse, into the 100-ohm output line C45. The modulation characteristic of the unit is essentially flat below 1 Mc, and the 3-db point occurs at about 1.5 megacycles.

The through video unit consists of tubes V-308, V-309, V-310, and V-311. Modulated carrier of reduced level is delivered to it by cable C145, amplified in a single stage amplifier (V-308), detected by a linear diode detector (V-309), and the resultant negative undelayed video signal is fed out over line D141 by the cathode follower (V-310). Tube V-311 is a cathode follower gain control tube for reducing the impedance of the gain control circuit and thus insuring rapid recovery from the trigger pulse.

This unit also contains an electronically regulated power supply which supplies + 560 volts to the modulated power amplifier and pulse-forming line charging circuits, and + 300 volts to all other circuits. Gain control voltage and -75 volts are fed in from unit no. 2.

The Delay Line Unit

The delay line unit is shown as unit no. 4 in the block diagram (Diagram 1). A schematic view is shown in Diagram 6 and photographs in Figures 9 and 10.

This unit consists of two major parts, the delay line and the delayed trigger carrier amplifier. The delay line is a five-channel folded mercury line pressurized to about 35 psi and is mechanically rugged enough to withstand shipboard conditions such as shock, vibration, pitch, and roll with little or no effect on its operation. Complete details of this delay line will be found in footnote 3.

Electrically, the high-level modulated carrier signal from the remodulator is brought in by cable C45 and is link-coupled to the resonant circuit driving the input crystal of the delay line; it is delayed approximately 2000 microseconds and reduced in level about 80-db. From the delay line output crystal, it goes through another impedance-matching network to a low-noise preamplifier consisting of a neutralized triode 6AK5 followed by a grounded grid 6J4.

The signal from the preamplifier is fed over cable C245 to the delayed trigger carrier amplifier consisting of four single-tuned stages using 6AC7 tubes and having a bandwidth of about 2.5 megacycles. The gain control, which is gated, will be discussed later. The signal from the preamplifier is fed through a broad-band Pi-network to the first amplifier stage (V-401) which serves both as a cathode follower to supply a signal to the delayed video carrier amplifier (over cable C345) and as the first stage of the staggered triple-tuned delayed trigger carrier amplifier. The second and third stages are 6AC7 tubes (V-402 and V-403) operating linearly, and the fourth stage (V-404) is a 6AG7 clipper operated in class-C. By operating the latter stage in this manner, the carrier and video modulation are in the near cut-off region of the tubes characteristic and are suppressed, while the high-level

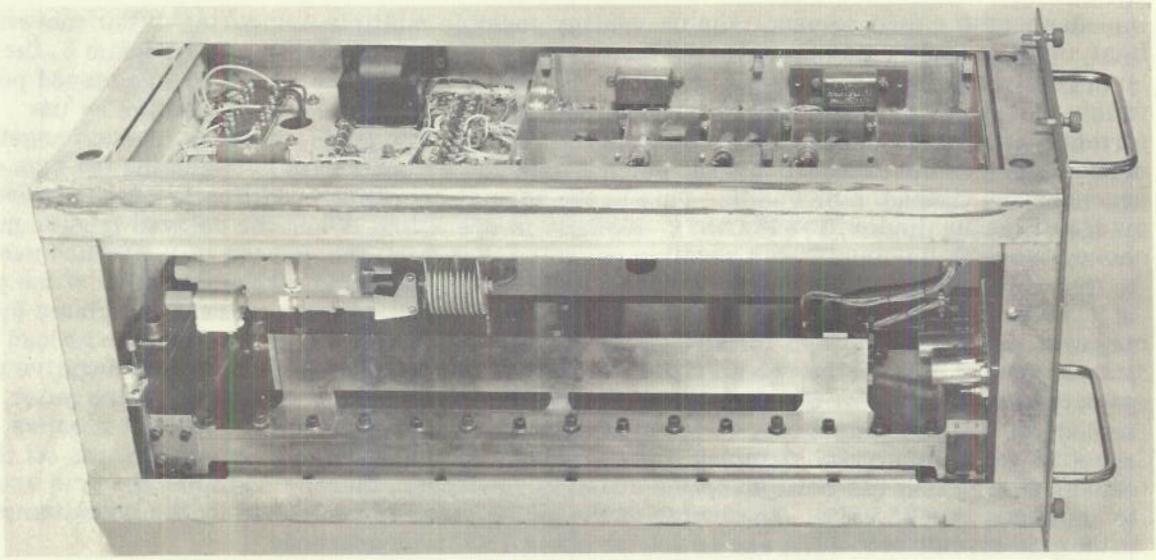

Fig. 9 - The Delay Line Unit - Unit No. 4
View of Pressurized Mercury Delay Line

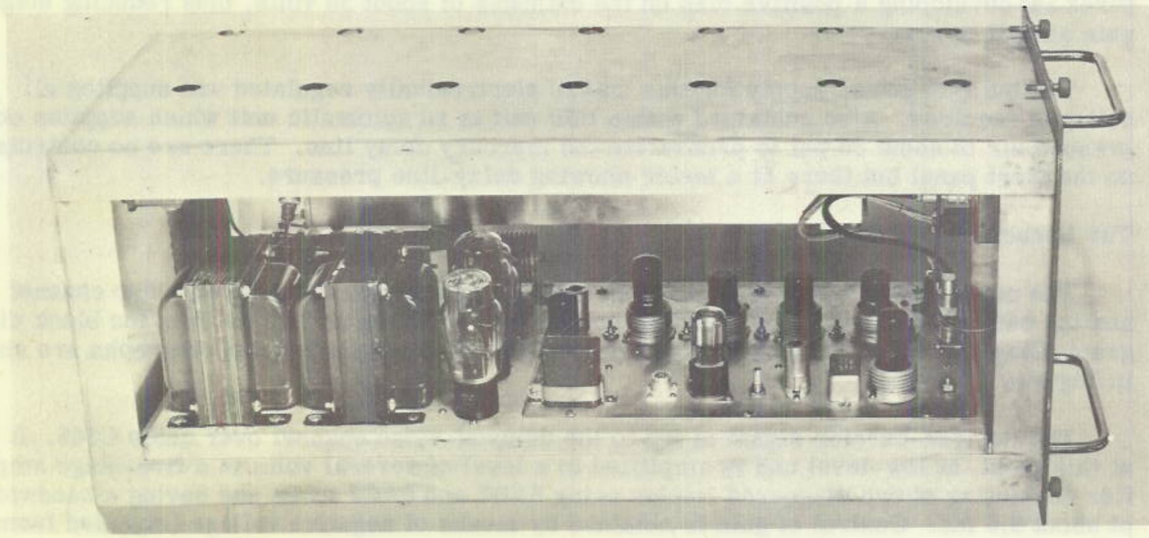

Fig. 10 - The Delay Line Unit - Electronic Circuits

trigger signals are in the near zero-bias region of the tubes characteristic and are strongly accentuated. The signal from the last amplifier stage is fed into a detector, the output of which is positive in polarity, and is fed to another clipper, again operated class-C, to further suppress the video signal in preparation for the clipping which will be done in the trigger unit (unit no. 6) to completely separate the trigger pulse from the composite signal. The output from this channel is the delayed trigger pulse and is fed to unit no. 6 over cable D341.

The gain of the delayed trigger carrier amplifier is gated in such a manner that immediately after the delayed trigger carrier pulse passes through, the amplifier is cut off for about 1500 microseconds, thus preventing possible multiple-triggering of the conversion unit. This gating is accomplished in the following manner. Referring to Diagram 6, the cathodes of the second and third stages (V-402 and V-403) of the amplifier are biased positive by means of the gain control tube (V-409) and the grids are biased positive by the dividing network composed of resistances R_1 and R_2. The grids, however, remain negative with respect to the cathodes and the normal gain can be controlled by adjusting the bias on the cathodes through tube V-409. This is the normal operating condition in which neither of the clamping diodes (V-408A and V-408B) is in operation. When the delayed trigger pulse passes through the amplifier a positive pulse is taken from the cathode of V-406 and used to fire a one-shot multivibrator (V-407A and V-407B) generating a negative pulse at the plate of V-407B. This pulse causes the clamping diode, V-408B, to draw current and clamp the negative pulse peak to zero voltage, in effect short circuiting the grid returns to ground and putting cut-off bias on the two amplifier stages. The clamping diode holds the negative pulse peak to zero voltage for the duration of the multivibrator pulse. At the end of the pulse, the cathode of the clamping diode, V-408B, returns to a positive potential. When it reaches about 25 volts the second clamping diode V-408A starts drawing current and drains off the excess charge that has built up on the coupling condenser, thereby clamping the grid returns to about positive 25 volts. The length of the gating pulse is controlled by the potentiometer in the grid circuit of V-407A and is set for about 1500 microseconds.

The manual gain control tube (V-409) is cut off for maximum gain. Under this condition the combined plate current of V-402 and V-403 is about 26 milliamperes, developing a bias on the cathodes of about 26 volts. As the amplifier gain is decreased, the gain control tube draws increasing current until at minimum gain it is drawing about 35 milliamperes and developing a positive bias on the cathodes of about 35 volts, thus reducing stage gain almost to zero.

The built-in power supply for this unit is electronically regulated and supplies all voltages required. Also contained within this unit is an automatic unit which supplies compressed air of about 35 psi to pressurize the mercury delay line. There are no controls on the front panel but there is a meter showing delay-line pressure.

The Cancellation Unit

The cancellation unit, which consists of two major parts, the delayed video channel and the cancellation and video distribution channel, is shown as unit no. 5 in the block diagram (Diagram 1). A schematic diagram is shown in Diagram 7 and photographs are shown in Figures 11 and 12.

The delayed-carrier signal is fed to the delayed-video channel over cable C345. It is, at this point, at low-level and is amplified to a level of several volts in a five-stage amplifier consisting of two staggered triples using 6AB7 and 6AC7 tubes and having a bandwidth of about 2.5 Mc. Control of gain is obtained by means of negative voltage (supplied from a low-impedance cathode follower to insure rapid recovery) applied to the grid returns of the second and third stages.

The delayed-carrier signal from the last i-f stage is fed into a 6AL5 detector at a level of 8 to 10 volts, thus operating the detector on a linear portion of its characteristic. The output from the detector, the delayed-video signal, is fed through a lumped constant LC delay network, which has a delay of 2 microseconds, into a cathode follower stage. The function of the LC delay network will be discussed in connection with the trigger unit (unit no. 6). The output from the cathode follower stage (the delayed coherent-video signal) is of such a polarity that an increase in modulated carrier level causes a positive output. It is fed into the second part of this unit, the cancellation and video distribution channel (over cable D241) where it is added in a resistance network to the undelayed video signal of opposite polarity (cable D141) to secure cancellation of fixed targets. The resultant signal is a bi-polar video signal representing the moving targets only and fed through a

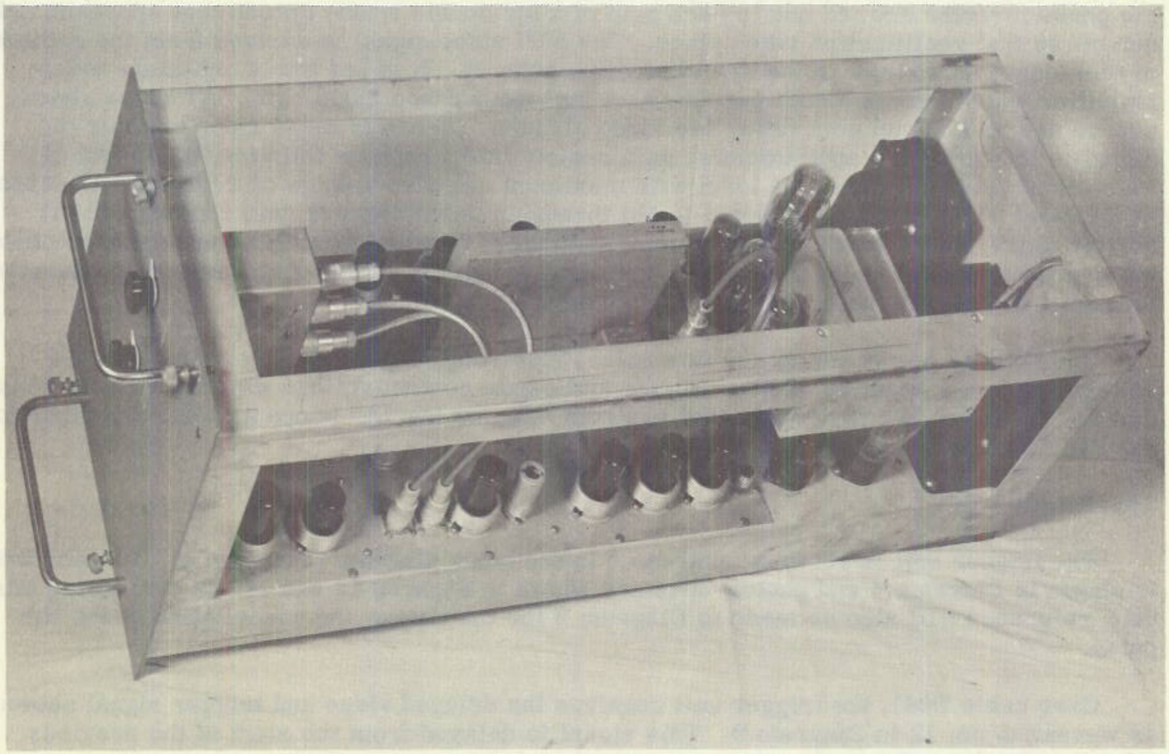

Fig. 11 - The Cancellation Unit - Unit No. 5

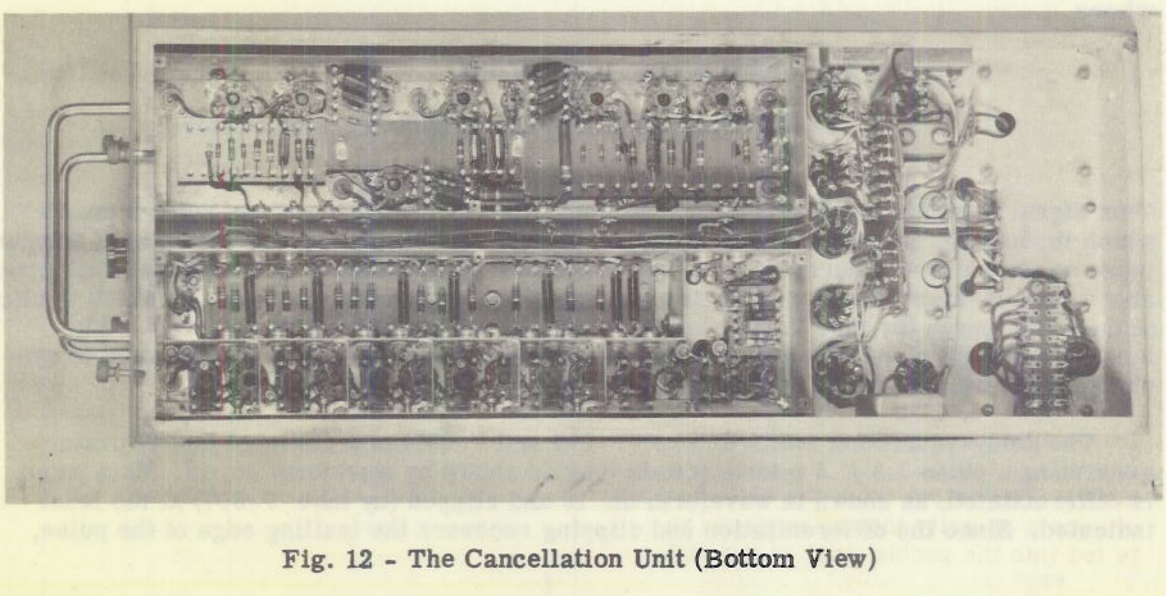

Fig. 12 - The Cancellation Unit (Bottom View)

stage of video amplification to a low-pass filter which removes the uncancelled high-frequency components and helps limit the over-all system bandwidth to about 1.25 megacycles. From the low-pass filter it is fed through another stage of video amplification into a phase inverter of the degenerative cathode-follower type. The two outputs from the phase inverter are fed one to each grid of a 6J6 double triode operated at approximately cut-off so that rectification takes place. The MTI video signal is derived from the cathode of this stage; it is single sided and of positive polarity. It is fed into a one-stage video amplifier which serves a dual purpose as a high-impedance (5000 ohm) "A" scope signal source and as a signal source for two video circuits. In one of these video circuits the signal is fed through a potentiometer gain control into a cathode follower, the output of which is at 75-ohm impedance level with maximum negative voltage of 2 for the "A" scope. In the other video circuit the signal is fed through a potentiometer gain control, a 6SH7 limiter stage, then into a cathode follower the output of which is at 75-ohm impedance level with a maximum of + 5 volts for PPI. Since the gain control of this video circuit is operated through a limiter, its action is that of a "Gamma" control.

The built-in power supply for this unit is electronically regulated and supplies all voltages except a negative 75 bias voltage and a gain control voltage which are fed in from unit no. 2. There are two front panel controls, one for the "A" scope gain and the other for the PPI "Gamma" control.

The Trigger Unit

The trigger unit is shown as unit no. 6 in the block diagram (Diagram 1). Its schematic is shown in Diagram 8 and photographs are shown in Figures 13 and 14. In discussing this unit, reference will also be made to Diagram 9 for the timing and cancellation of the Nth pulse.

Over cable D341, the trigger unit receives the delayed video and trigger signal shown as waveform no. 12 in Diagram 9. This signal is delayed from the start of the previous trigger pulse by a time

$$T_1 = T_L + a,$$

where

T_L = delay line delay time, and

a = 0.3 microsecond (delay in detector output filters).

This signal is partially differentiated and amplified (in V-601) to give waveform no. 13 which is, in turn, clipped at the level shown (by tube V-602) to recover the delayed trigger pulse as shown in waveform no. 14. This delayed trigger pulse is differentiated with a very short time constant (waveform no. 15) and amplified to give waveform no. 16 which is clipped at the level shown (by tube V-604) to give the pulse shown as waveform no. 17. This last differentiation and clipping gives a pulse of very short duration which is used to synchronize the delay-equalizing multivibrator.

The delay-equalizing multivibrator (V-605 and V-606) is a one-shot multivibrator generating a pulse 1.3 ± .5 microseconds long as shown by waveform no. 18. This pulse is differentiated, as shown in waveform no. 19 and clipped (by tube V-607) at the level indicated. Since the differentiation and clipping recovers the trailing edge of the pulse,

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the resultant pulse lags the preceding synchronizing pulse by

$$T_2 = T_L + (.3 + 1.3 \pm .5) \text{ microsec}$$

or,

$$T_3 = T_L + (1.6 \pm .5) \text{ microsec.}$$

This pulse initiates a blocking oscillator (V-608) which develops the actual trigger pulse which is fed through cathode followers V-609 and V-610 and through isolating filters to the radar transmitter modulator and the remodulator (unit no. 3). The isolation filters add an additional delay of 0.4 microseconds, making the total delay around the trigger loop

$$T = T_L + (2.0 \pm 0.5) \text{ microseconds.}$$

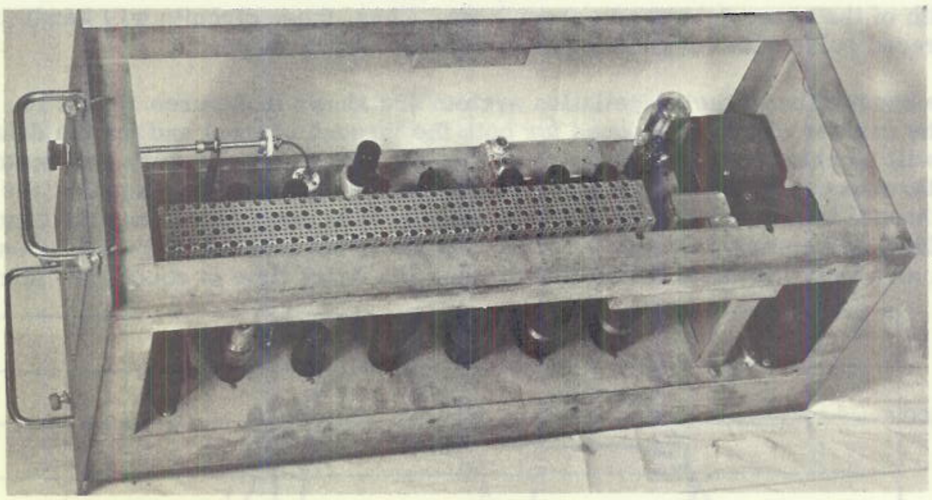

Fig. 13 - The Trigger Unit - Unit No. 6

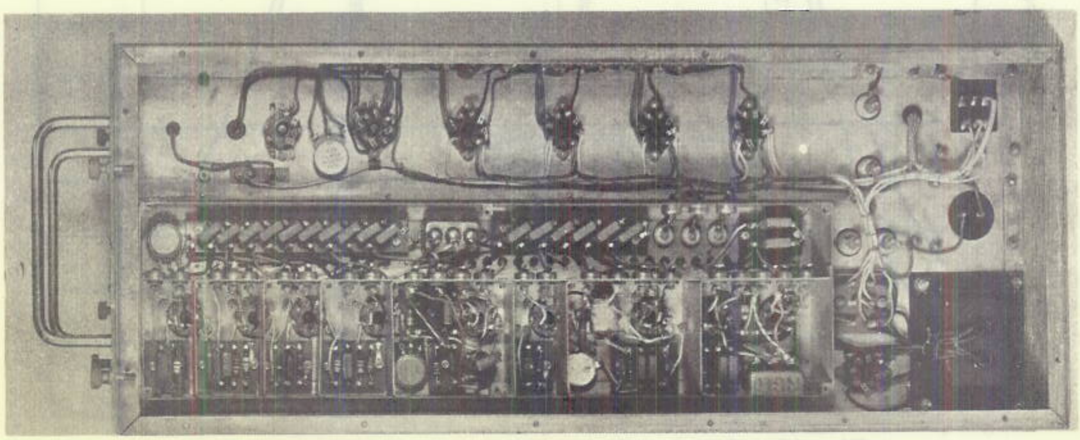

Fig. 14 - The Trigger Unit (Bottom View)

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Consider the cancellation of a given echo. Obviously, for cancellation to take place, the delay in the delayed channel must be $T_L + 2.0$ microseconds (the $\pm$ 0.5 microsecond is used to balance the system exactly). Thus the two-microsecond LC delay line (unit no. 5) mentioned earlier, is added in the delayed video channel.

All power for this unit, with the exception of a negative 75-volt bias (fed from unit no. 2), is supplied by a built-in electronically regulated power supply. This unit has one front panel control, the multivibrator adjustment which acts as the time balance control.

SYSTEM CHARACTERISTICS

System Bandwidths

The i-f bandwidth of the MTI i-f strip and phase detector is about 3.0 Mc and the video bandwidth of the phase detector is about 2 Mc. Thus, these circuits will handle a one-microsecond pulse with very little deterioration of pulse shape.

The bandwidths of the cancellation system are shown in Figures 15 and 16. Figure 15 shows the carrier channel response for both the through channel and for the delayed channel. It will be noted that the passbands of these two channels are very well matched except for the three notches in the passband of the delayed channel. These notches are due to cross-channel interference in the delay line (caused by poor fit between the channels and the cover plate) and appear only on cw. When a pulse is fed into the line, this cross-talk appears as a very low level (40 db down) ghost at a delay time of about 1200 microseconds.

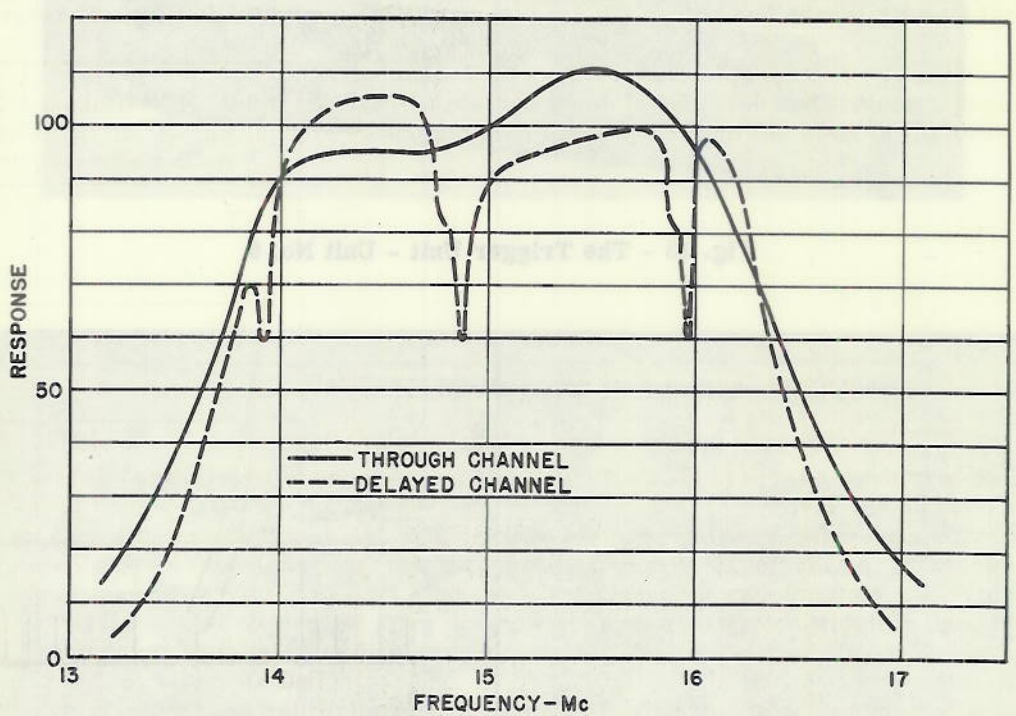

Fig. 15 - Carrier System Response Characteristics
MTI Conversion Unit for SR-3 and SPS-6 Radars

Figure 16 shows the over-all video response of the two channels. It will be noted that they are well matched.

Cancellation Ratio

The cancellation ratio of the cancelling system was measured by feeding a one-microsecond pulse into the remodulator over cable D41. This pulse gave a somewhat pessimistic measurement since it had steeper sides and was thus richer in high-frequency components than a radar echo.

The actual measurement was made by adjusting the input pulse to the desired polarity and level and then adjusting the cancelling system to best cancellation. Residual pulse energy was then measured. The delayed channel was then inactivated and the input pulse reduced in level to give the same output pulse energy. This reduction in level was equal to the cancellation ratio.

The cancellation ratio was found to be as follows,

Level	Positive Pulse	Negative Pulse
5 volts	33 db	31 db
10 volts	33 db	30 db
20 volts	31 db	28 db

Thus, the average cancellation ratio is 31 db.

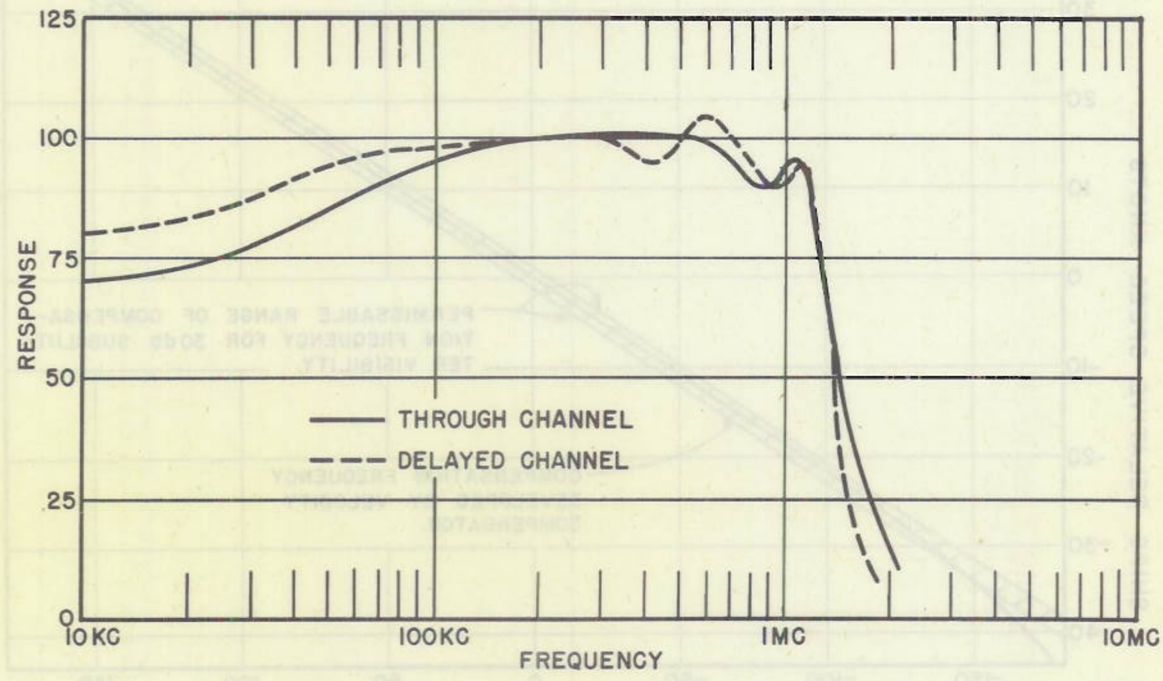

Fig. 16 - Video Response Characteristics - Cancellation System of MTI Conversion Unti for SR-3 and SPS-6 Radars

Attention is called to the fact that this is a true cancellation ratio. Limiting is not used to give an apparent cancellation ratio much higher than the true cancellation ratio.

Velocity Compensation

The performance of the velocity compensator is shown in Figure 17. It will be seen that the accuracy of compensation is such that a 30-db subclutter visibility may be maintained up to about 33 knots and that at 40 knots a subclutter visibility of about 25 db may be realized.

System Stability

The stability of all components of the system is excellent. After a few minutes of warm-up, all components are sufficiently stable to maintain their characteristics within the limits required for 30-db subclutter visibility for many hours without need for re-adjustment.

System Performance

Complete performance test results will be reported separately after the test equipment has been completed and analysis measurements made. Test equipment for measuring subclutter visibilities under conditions duplicating those of a moving radar has not as

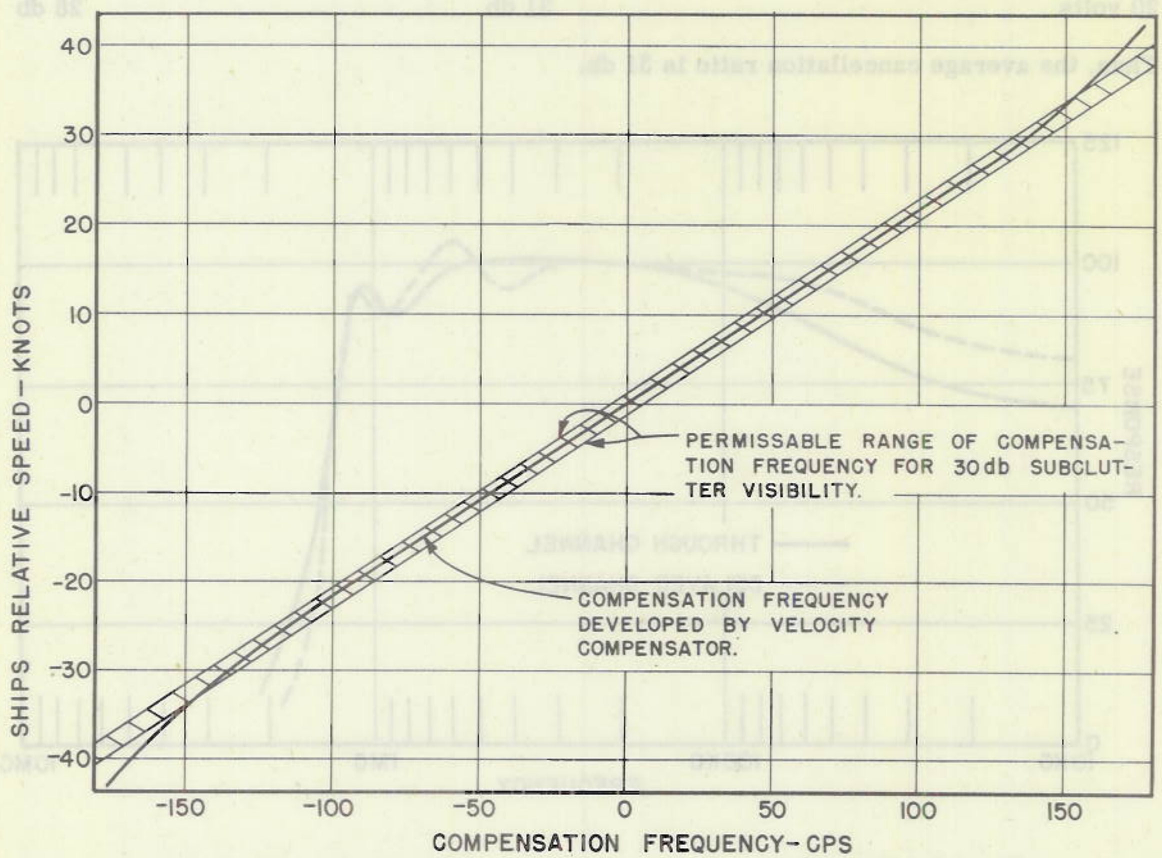

Fig. 17 - Compensation Frequency - CPS

yet been completed. However, preliminary tests in conjunction with the partially completed test equipment indicate that MTI system performance will be about as expected. Thus, subclutter visibility will probably be 25 to 28 db at speeds up to about 30 knots and will then drop off to 20 to 25 db as speeds increase to 40 knots.

* * *

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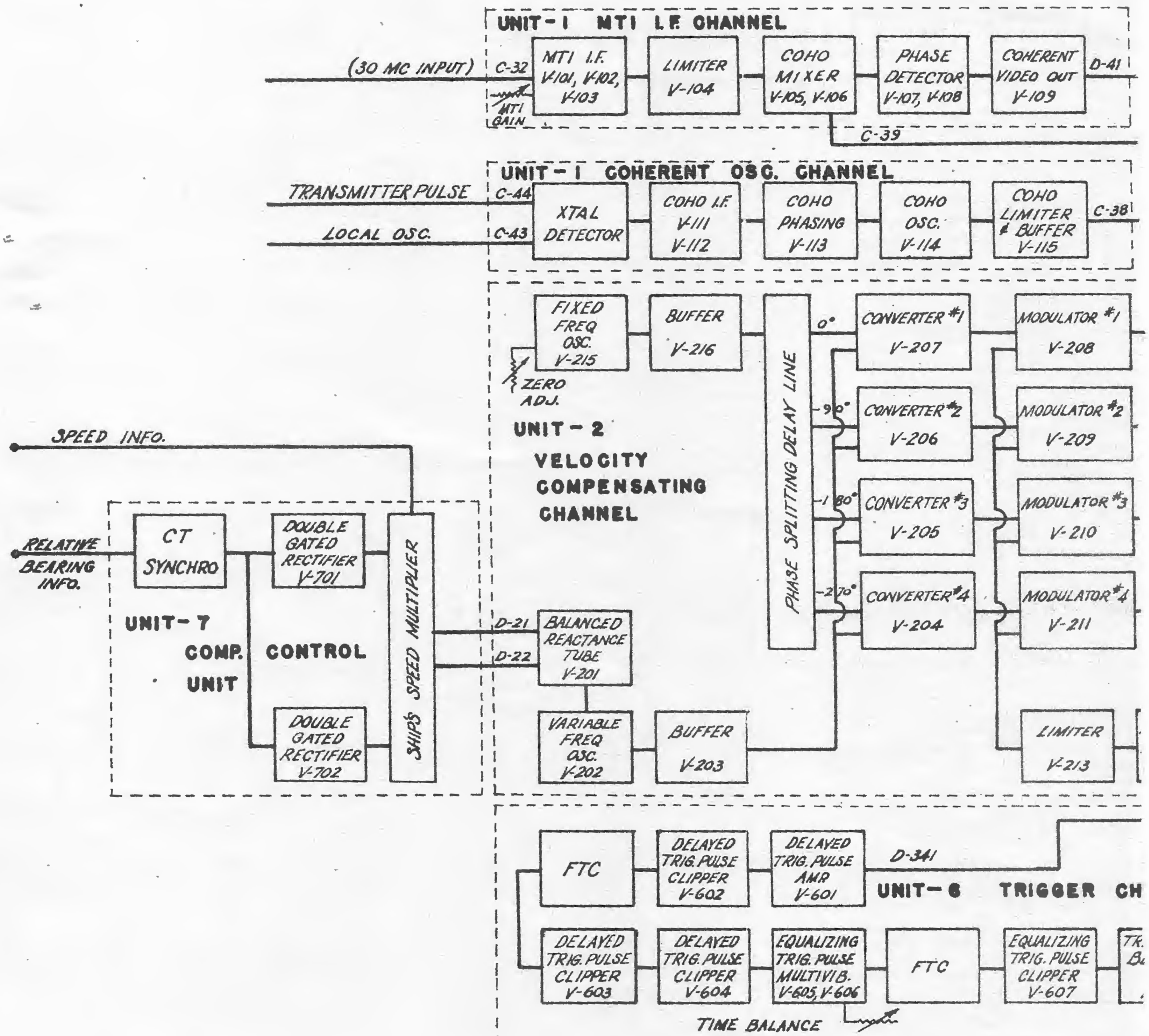

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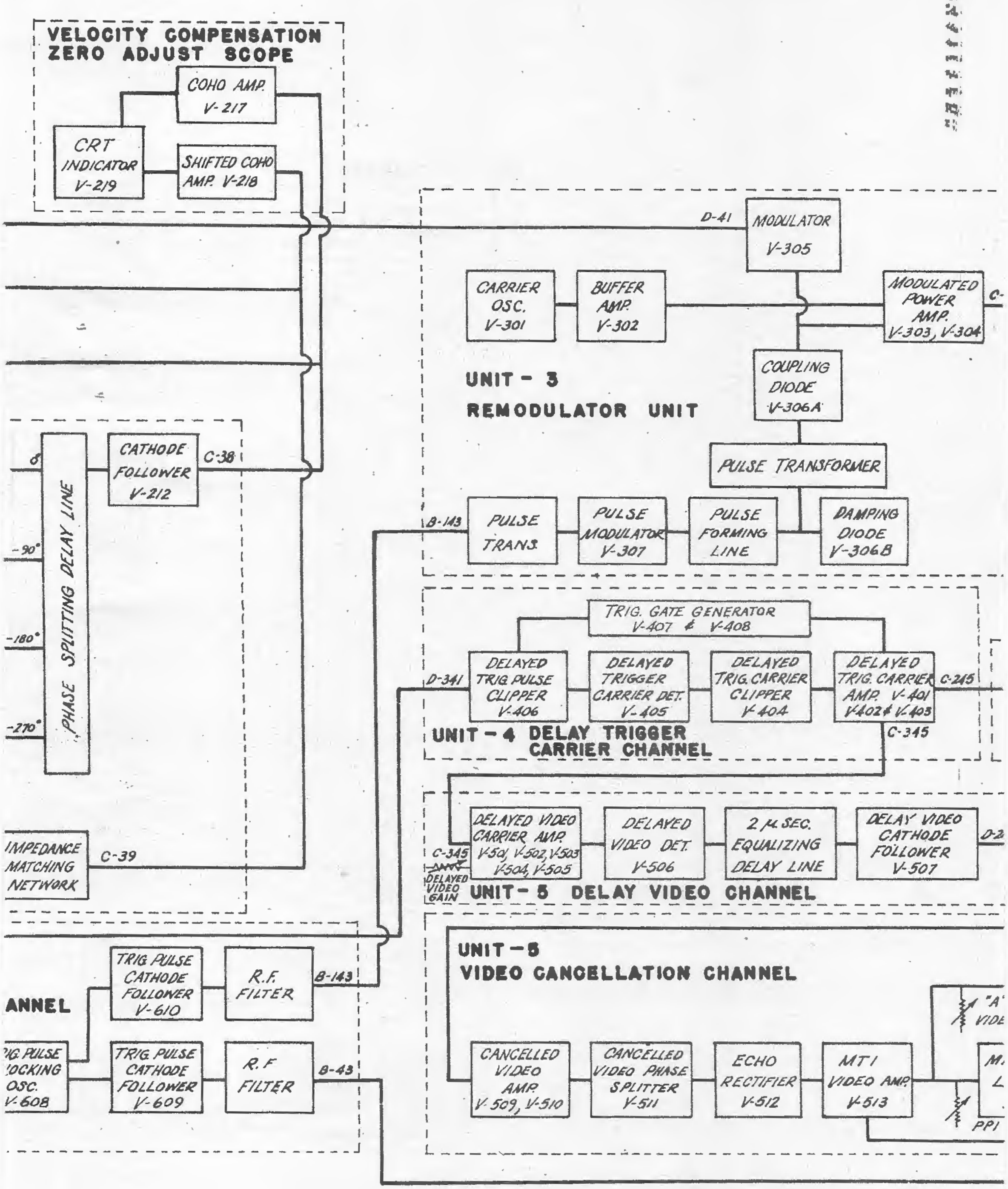
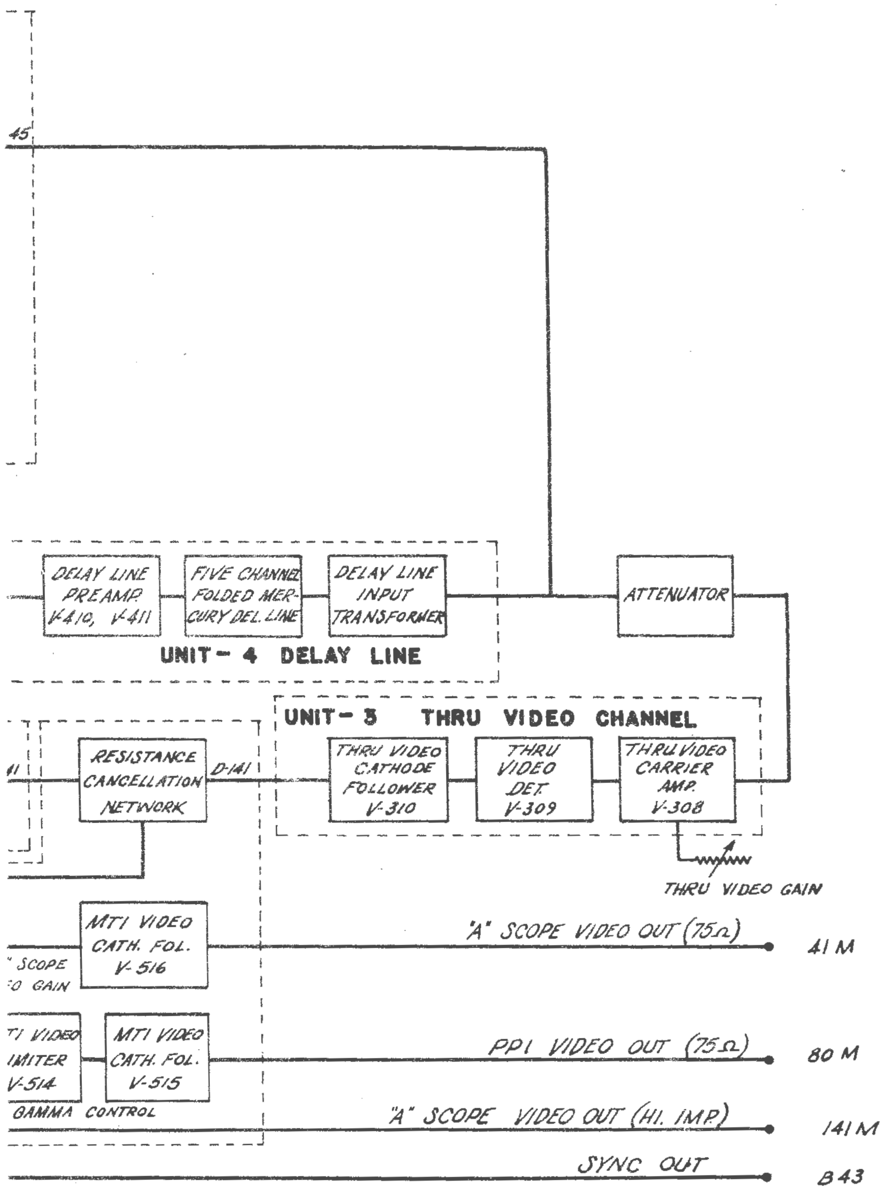


...am 1 - Block Diagram - MTI Conversion Unit for SR-3 and SPS-6 Radars


45
DELAY LINE PREAMP. V-410, V-411
FIVE CHANNEL FOLDED MERCURY DEL. LINE
DELAY LINE INPUT TRANSFORMER
UNIT - 4 DELAY LINE
ATTENUATOR
UNIT - 3 THRU VIDEO CHANNEL
RESISTANCE CANCELLATION NETWORK
D-141
THRU VIDEO CATHODE FOLLOWER V-310
THRU VIDEO DET. V-309
THRU VIDEO CARRIER AMP. V-308
THRU VIDEO GAIN
MTI VIDEO CATH. FOL. V-516
"A" SCOPE VIDEO OUT (75Ω)
41 M
MTI VIDEO CATH. FOL. V-515
V-514
GAMMA CONTROL
PPI VIDEO OUT (75Ω)
80 M
"A" SCOPE VIDEO OUT (HI. IMP.)
141 M
SYNC OUT
B43

CO[redacted]

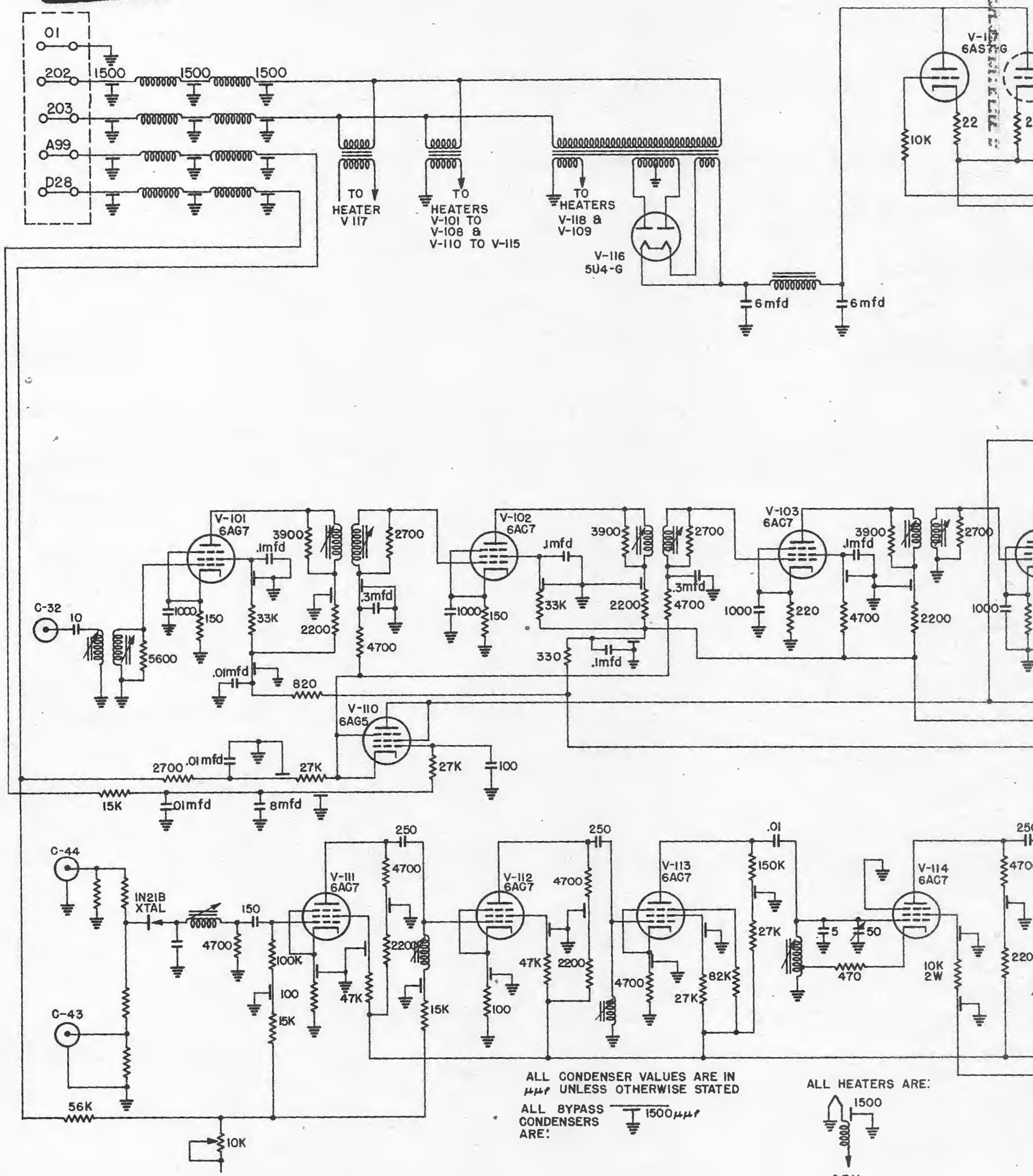


Diagram 2 - MTI I-F Amplifier and Cohere

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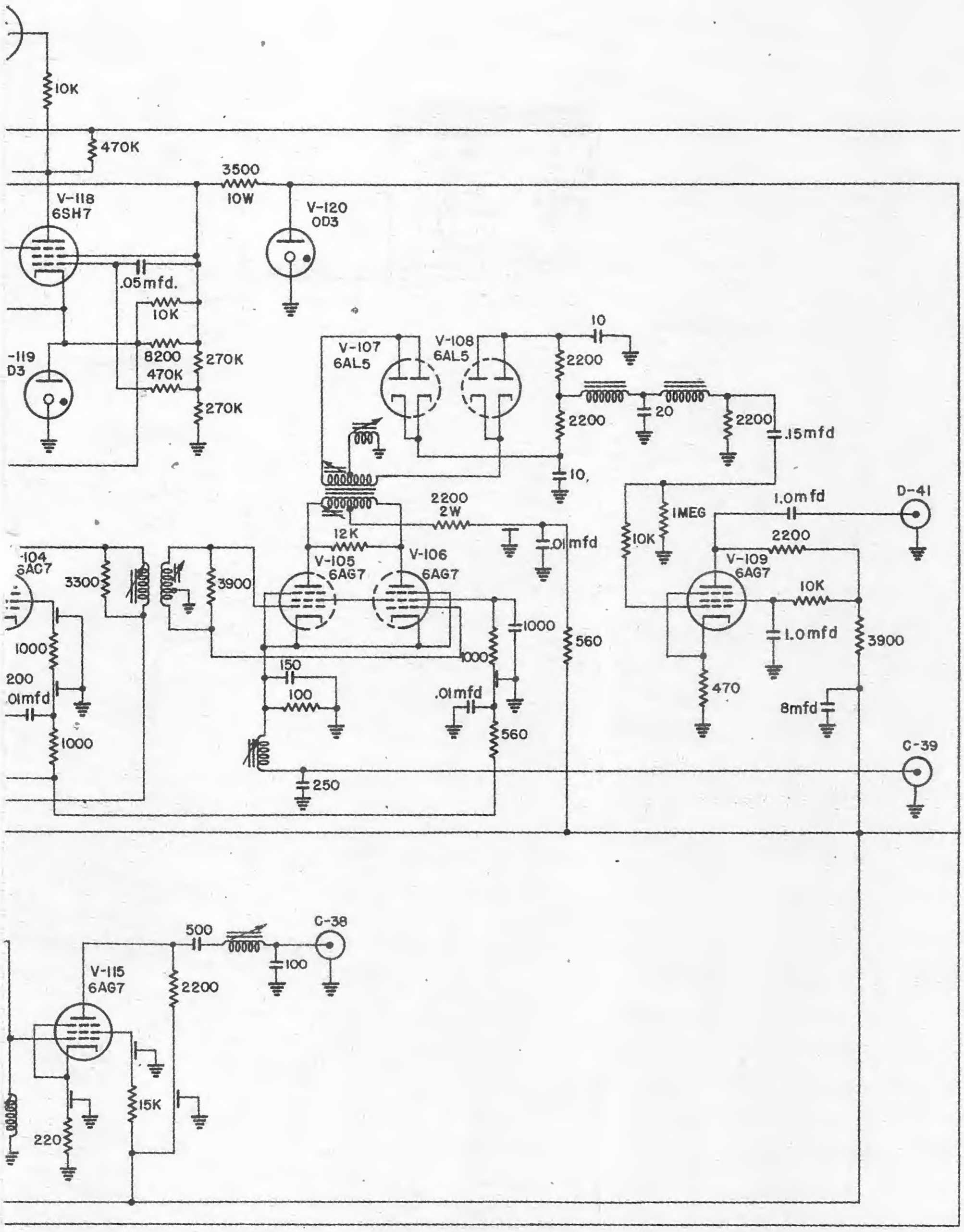

ɪnt Oscillator, Unit #1

[redacted]

REF. DWG. NO.

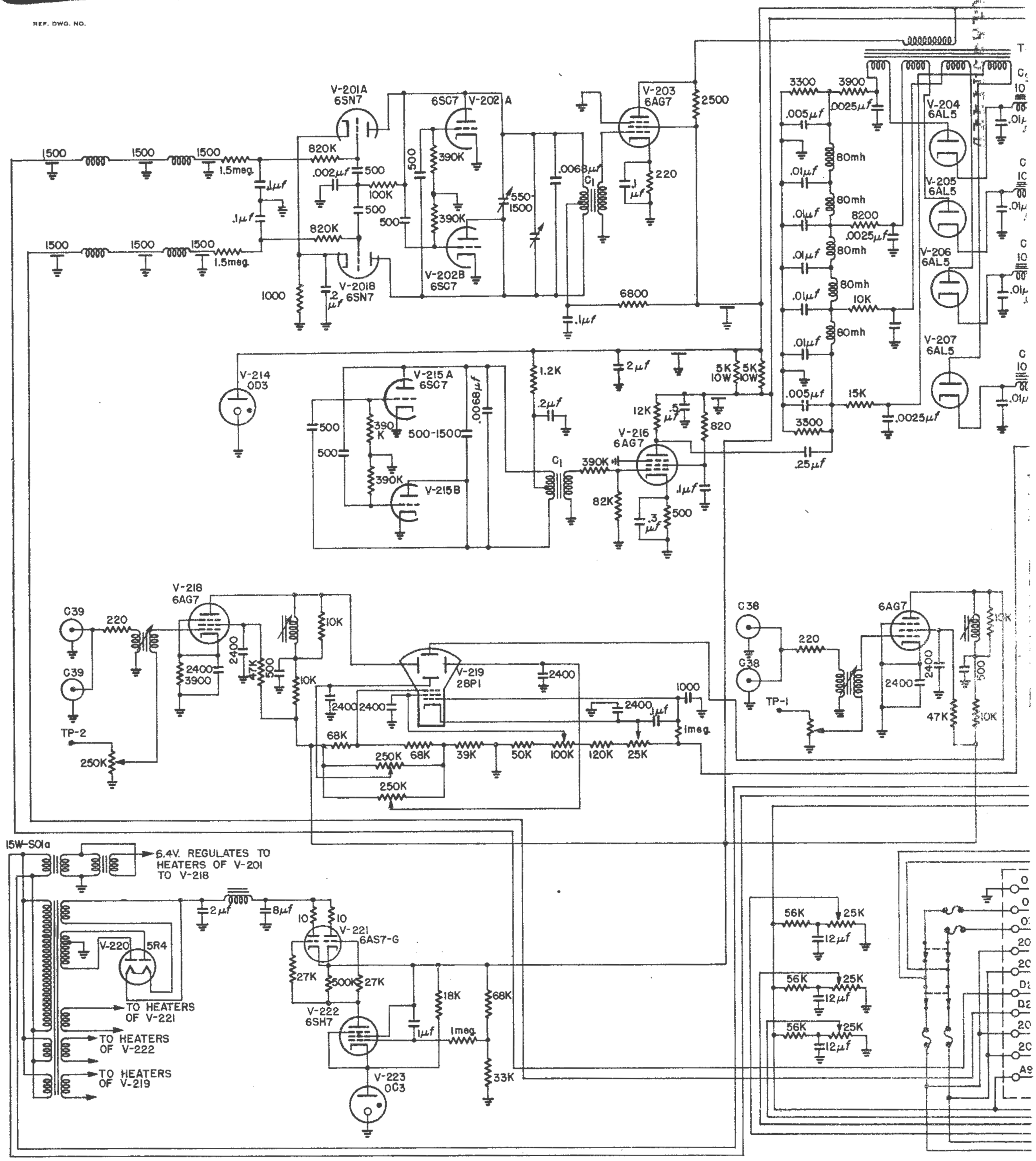

Diagram 3 - The Velocity Compensator Uni

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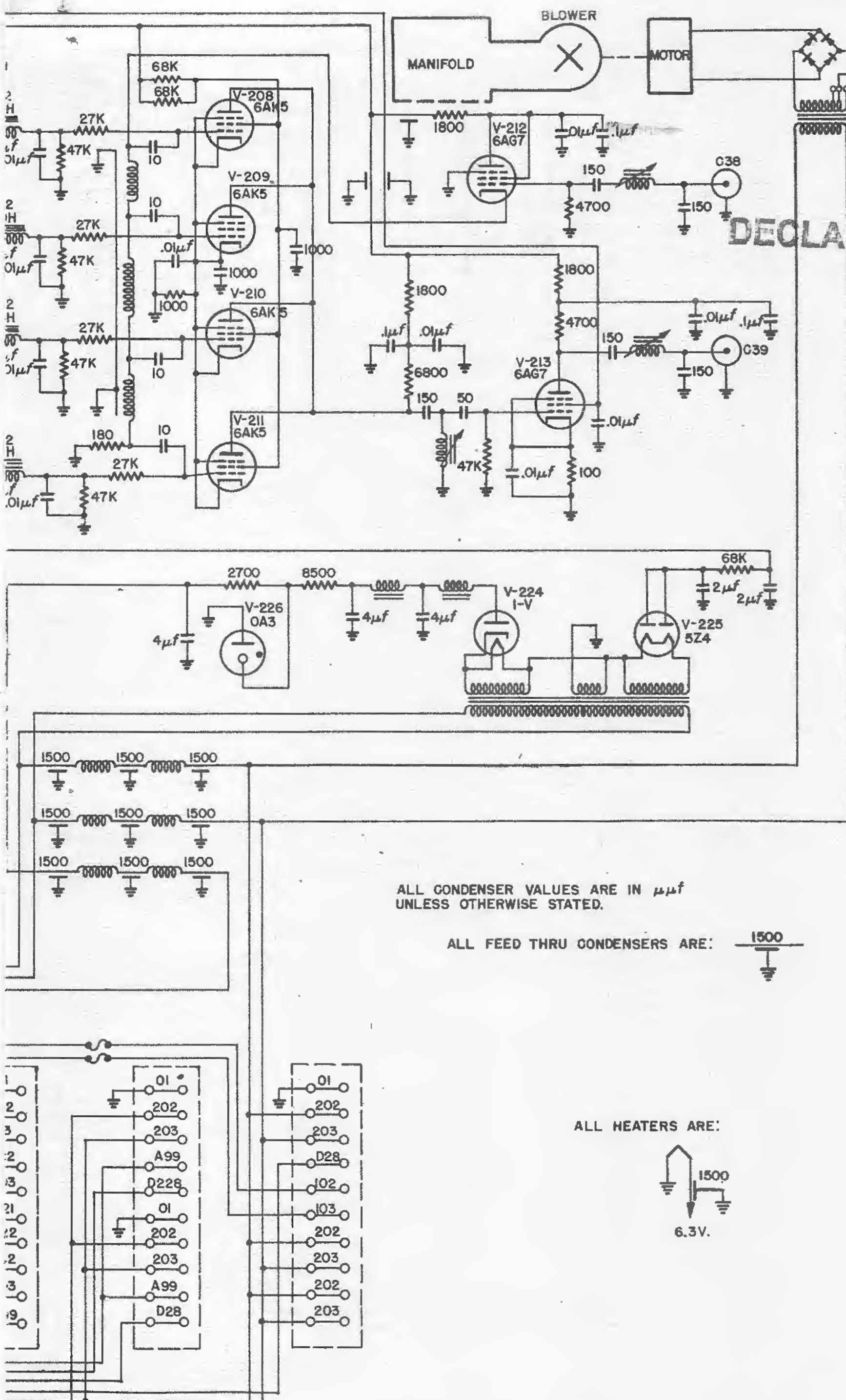
BLOWER
MANIFOLD
MOTOR
V-208 6AK5
V-209 6AK5
V-210 6AK5
V-211 6AK5
V-212 6AG7
V-213 6AG7
V-224 1-V
V-225 5Z4
V-226 0A3
C38
C39
ALL CONDENSER VALUES ARE IN $\mu\mu f$ UNLESS OTHERWISE STATED.
ALL FEED THRU CONDENSERS ARE: 1500
ALL HEATERS ARE: 1500
6.3V.

, Unit #2

[redacted]

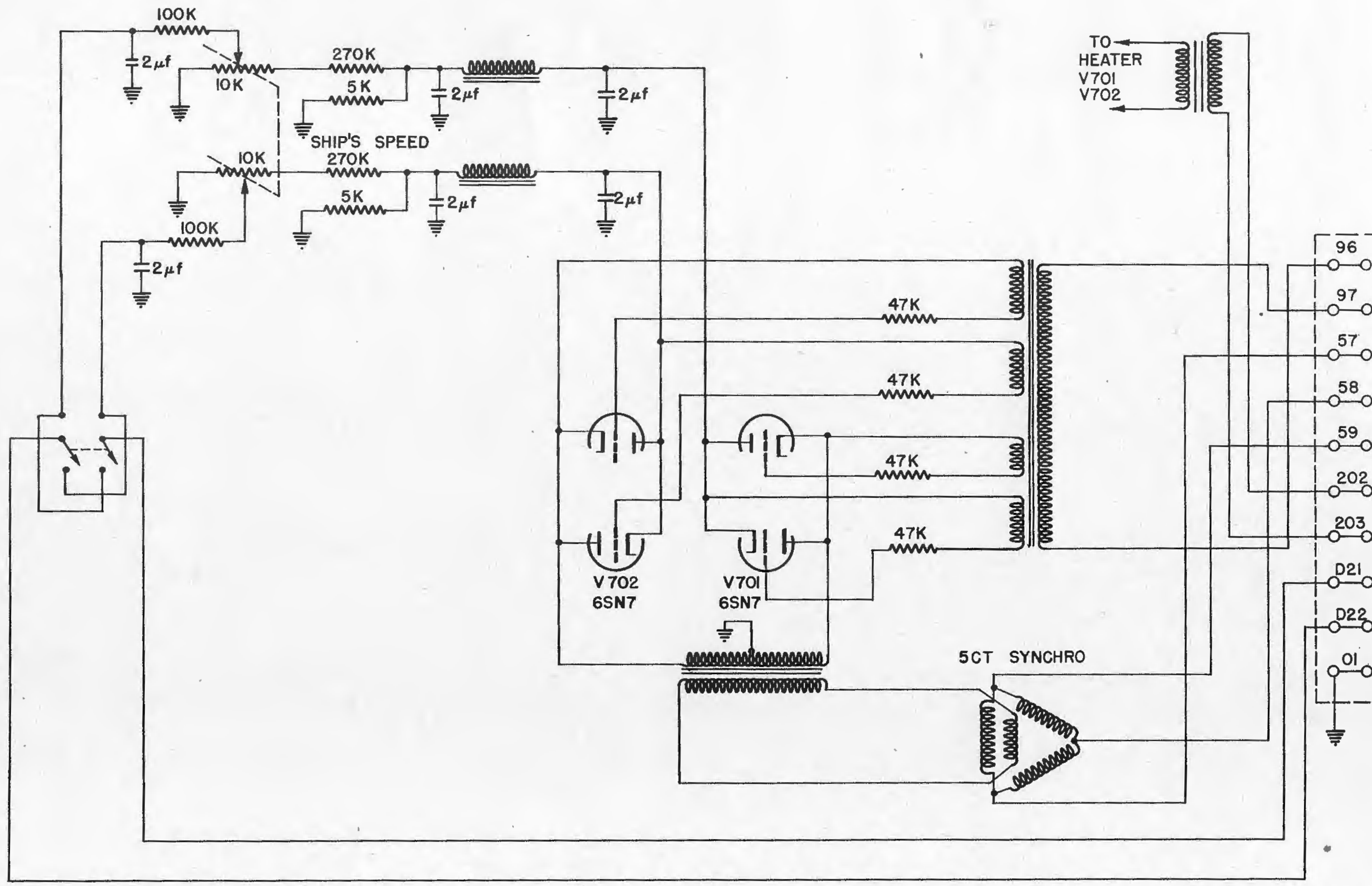

Diagram 4 - Compensation Control Unit, Unit #7

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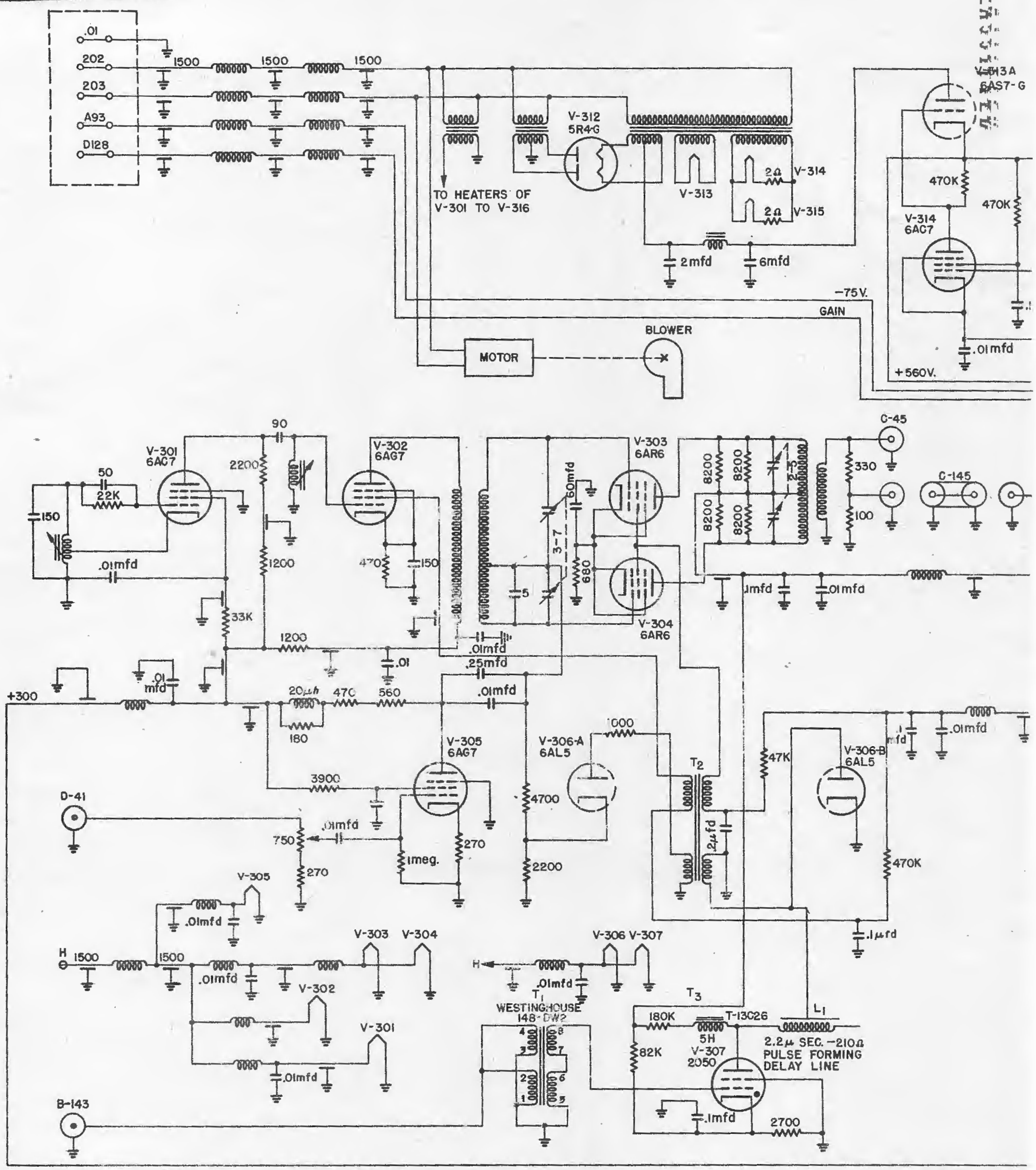

Diagram 5 - The Remodulator Ui

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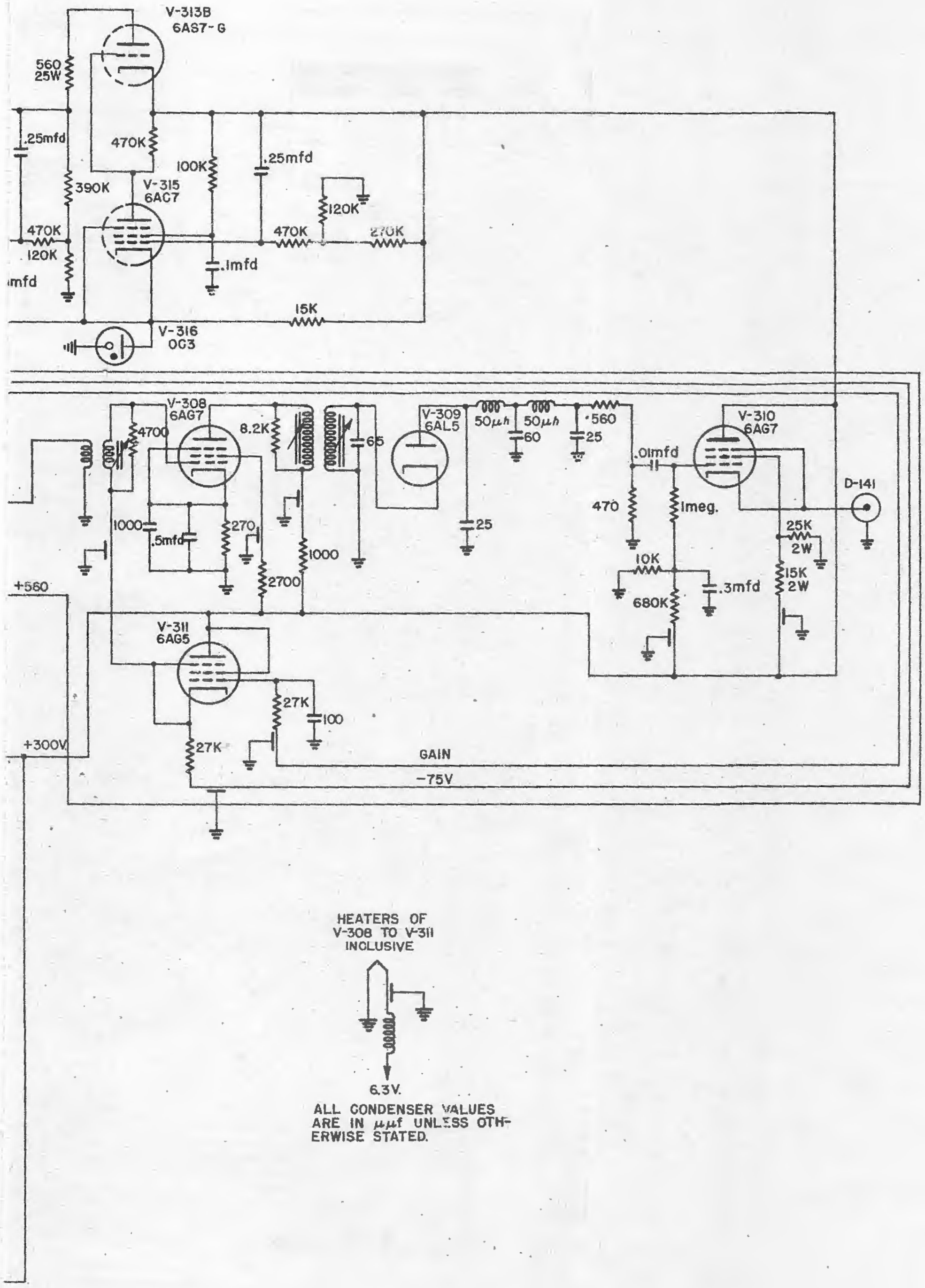
V-313B
6AS7-G
560
25W
.25mfd
470K
100K
.25mfd
390K
V-315
6AC7
120K
470K
120K
470K
270K
.1mfd
mfd
15K
V-316
OC3
V-308
6AG7
4700
8.2K
V-309
6AL5
50µh
50µh
560
65
60
25
.01mfd
V-310
6AG7
D-141
470
1meg.
1000
.5mfd
270
1000
25
25K
2W
10K
.3mfd
15K
2W
2700
680K
+560
V-311
6AG5
27K
100
+300V
27K
GAIN
-75V
HEATERS OF
V-308 TO V-311
INCLUSIVE
6.3V.
ALL CONDENSER VALUES
ARE IN µµf UNLESS OTHERWISE STATED.

nit, Unit #3

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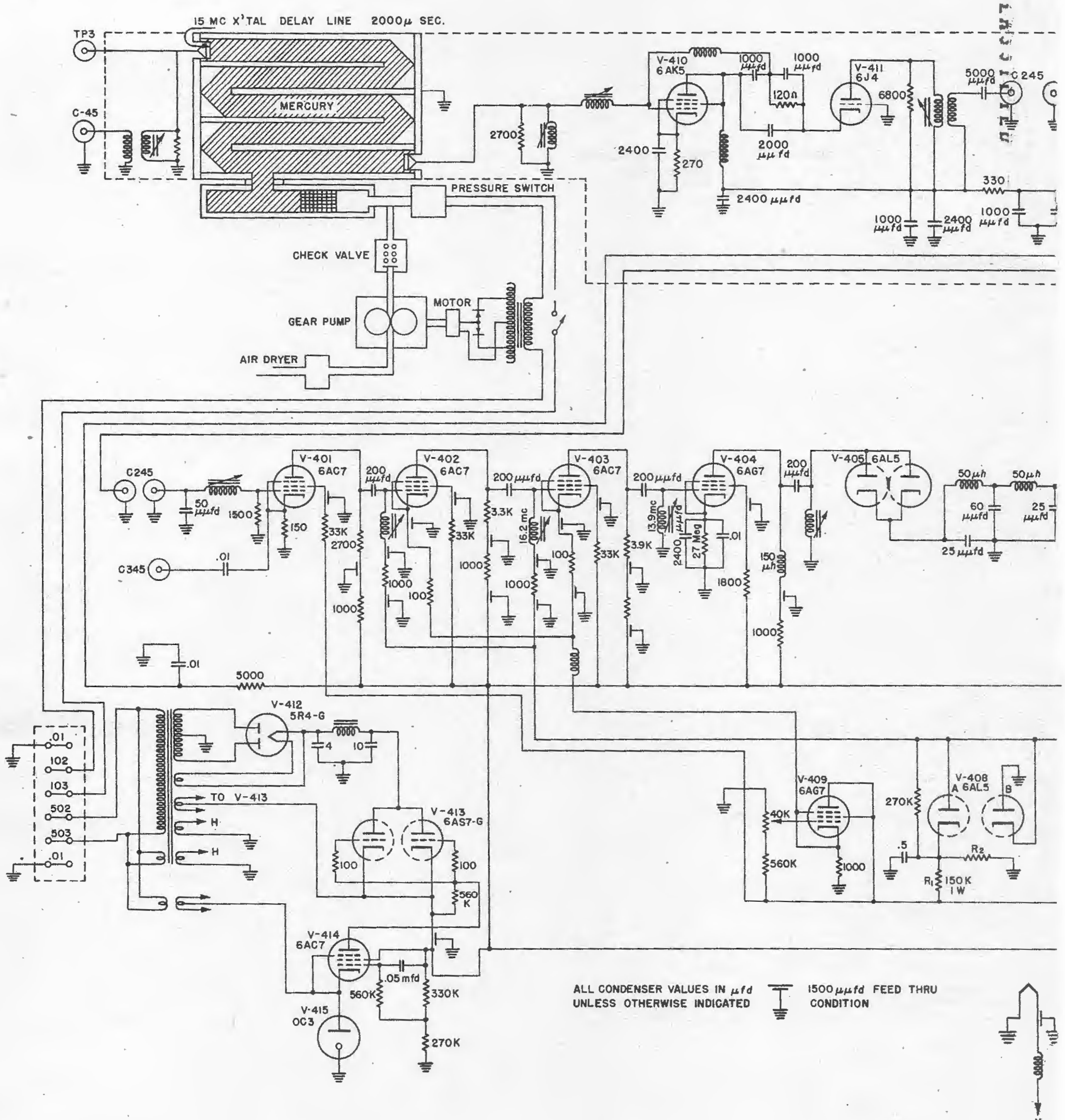

Diagram 6 - The Delay Line Unit, Unit #4

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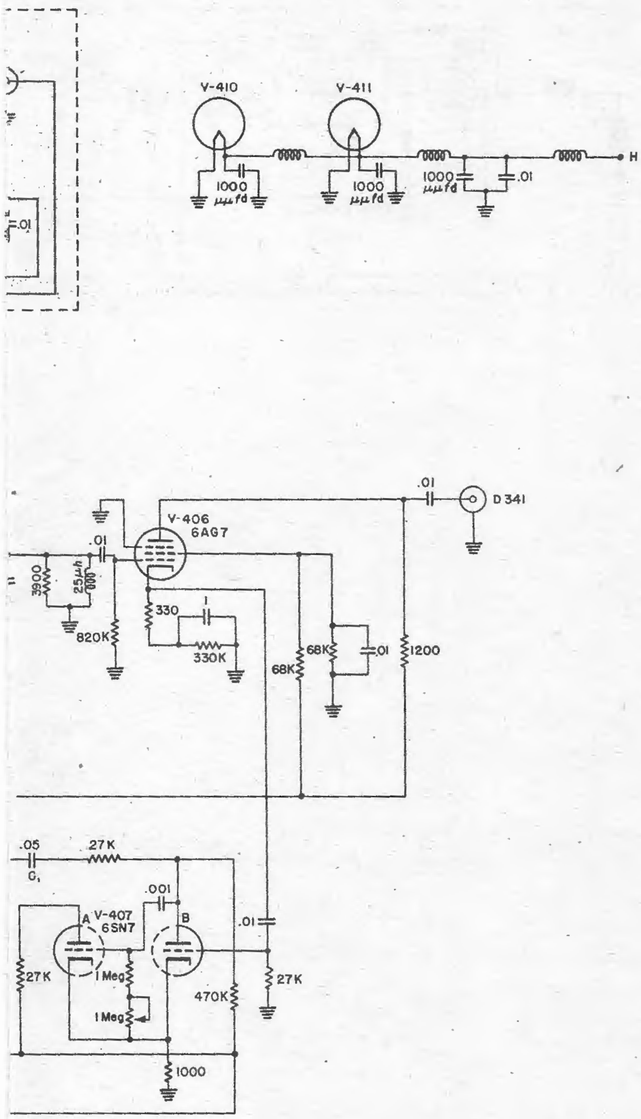

ALL HEATERS UNLESS
OTHERWISE INDICATED

[redacted]

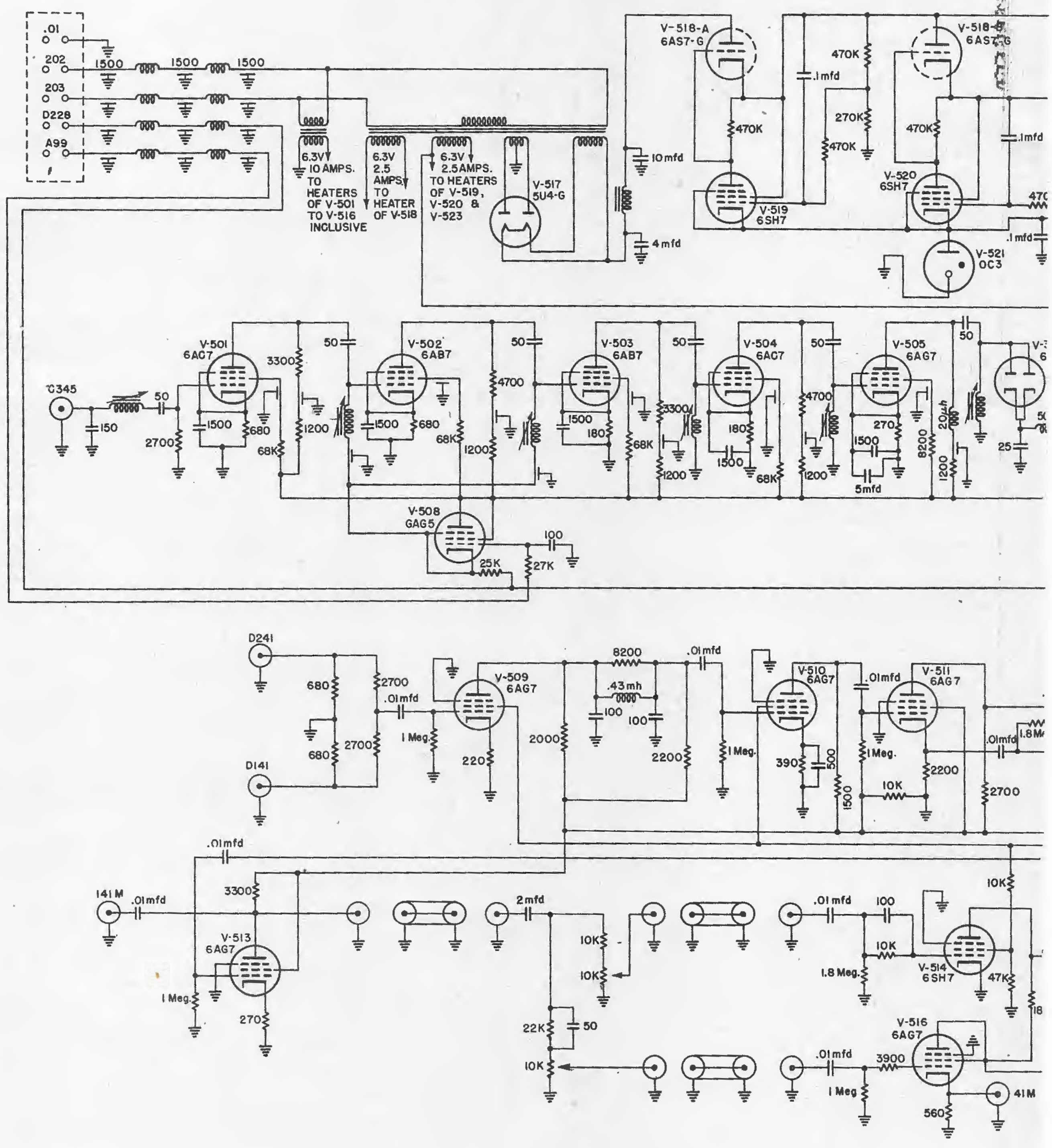

Diagram 7 - The Cancellation Uni , Unit #5

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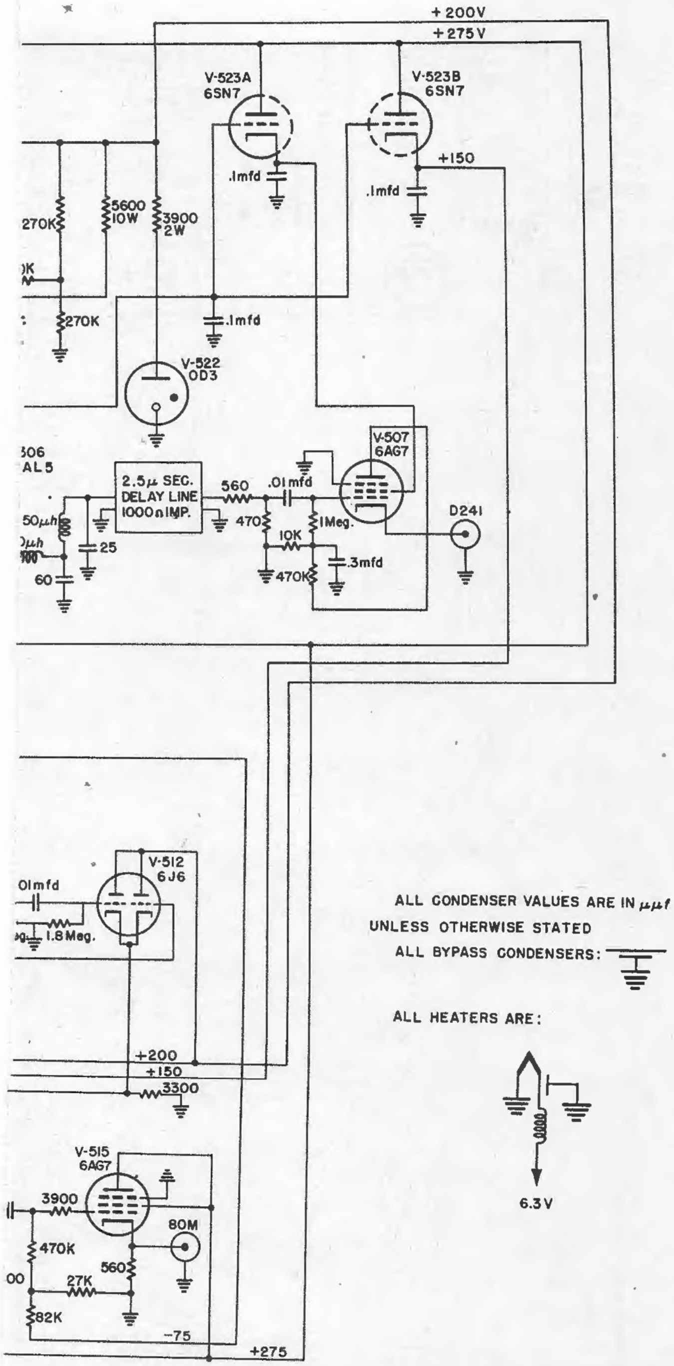
+200V
+275V
V-523A
6SN7
V-523B
6SN7
+150
.1mfd
270K
5600
10W
3900
2W
270K
V-522
OD3
2.5μ SEC.
DELAY LINE
1000Ω IMP.
560
.01mfd
470
1Meg.
10K
470K
.3mfd
V-507
6AG7
D241
50μh
25
60
V-512
6J6
.01mfd
1.8 Meg.
+200
+150
3300
V-515
6AG7
3900
470K
560
27K
82K
80M
-75
+275
ALL CONDENSER VALUES ARE IN μμf
UNLESS OTHERWISE STATED
ALL BYPASS CONDENSERS:
ALL HEATERS ARE:
6.3V

[redacted]

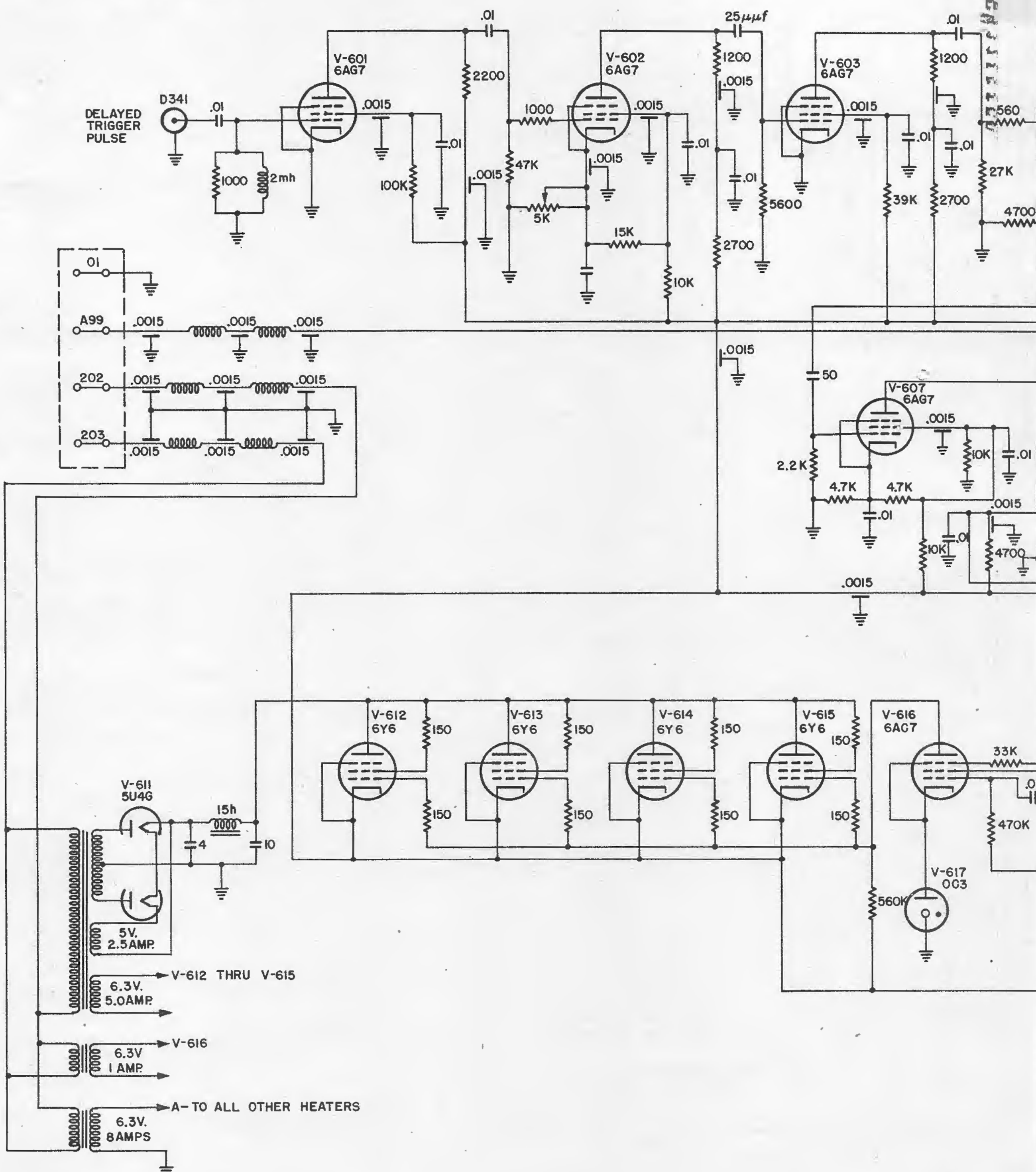

Diagram 8 - The Trigger Uni

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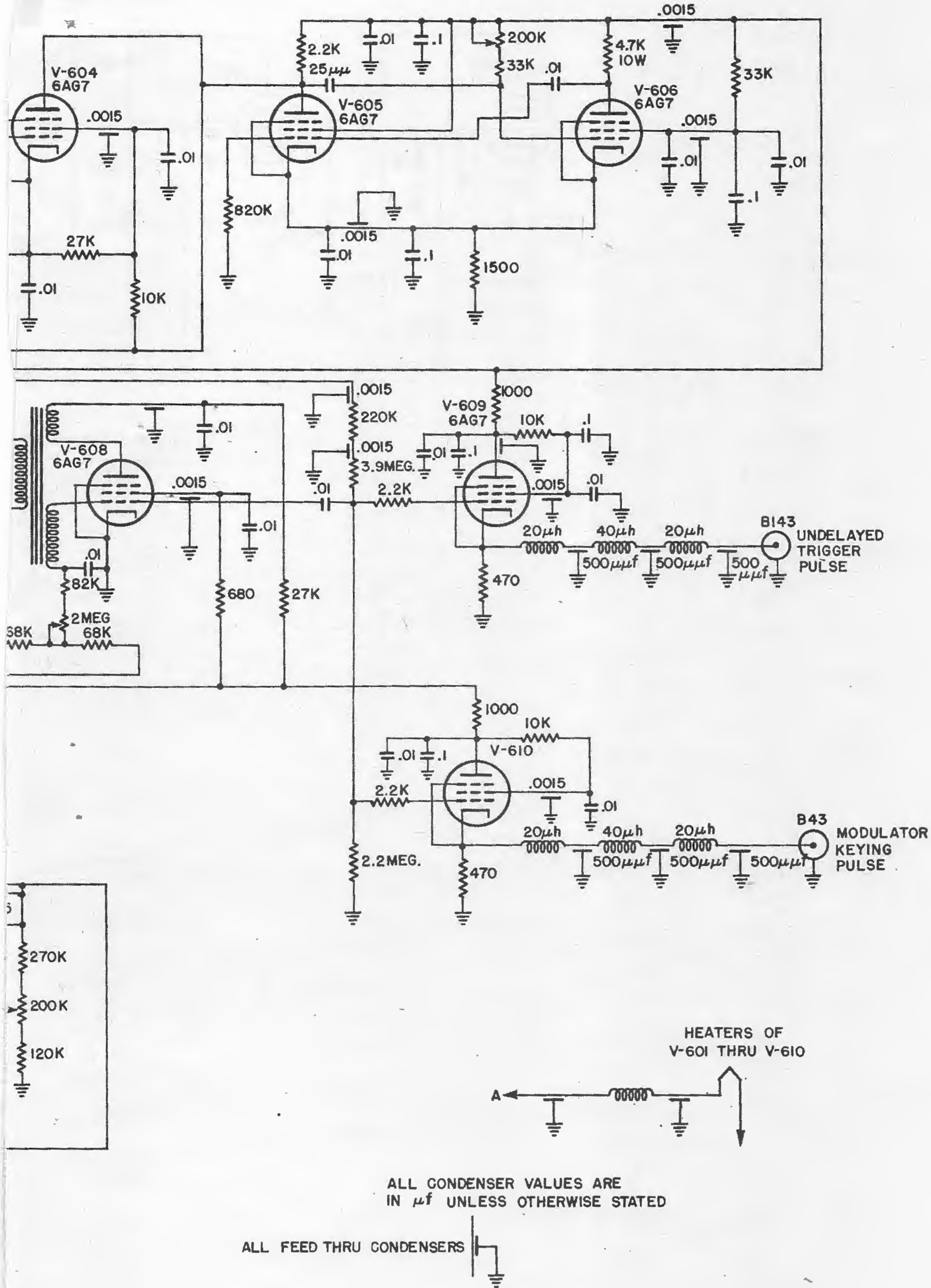
V-604
6AG7
V-605
6AG7
V-606
6AG7
V-608
6AG7
V-609
6AG7
V-610
B143
UNDELAYED
TRIGGER
PULSE
B43
MODULATOR
KEYING
PULSE
HEATERS OF
V-601 THRU V-610
ALL CONDENSER VALUES ARE
IN μf UNLESS OTHERWISE STATED
ALL FEED THRU CONDENSERS

Unit #6

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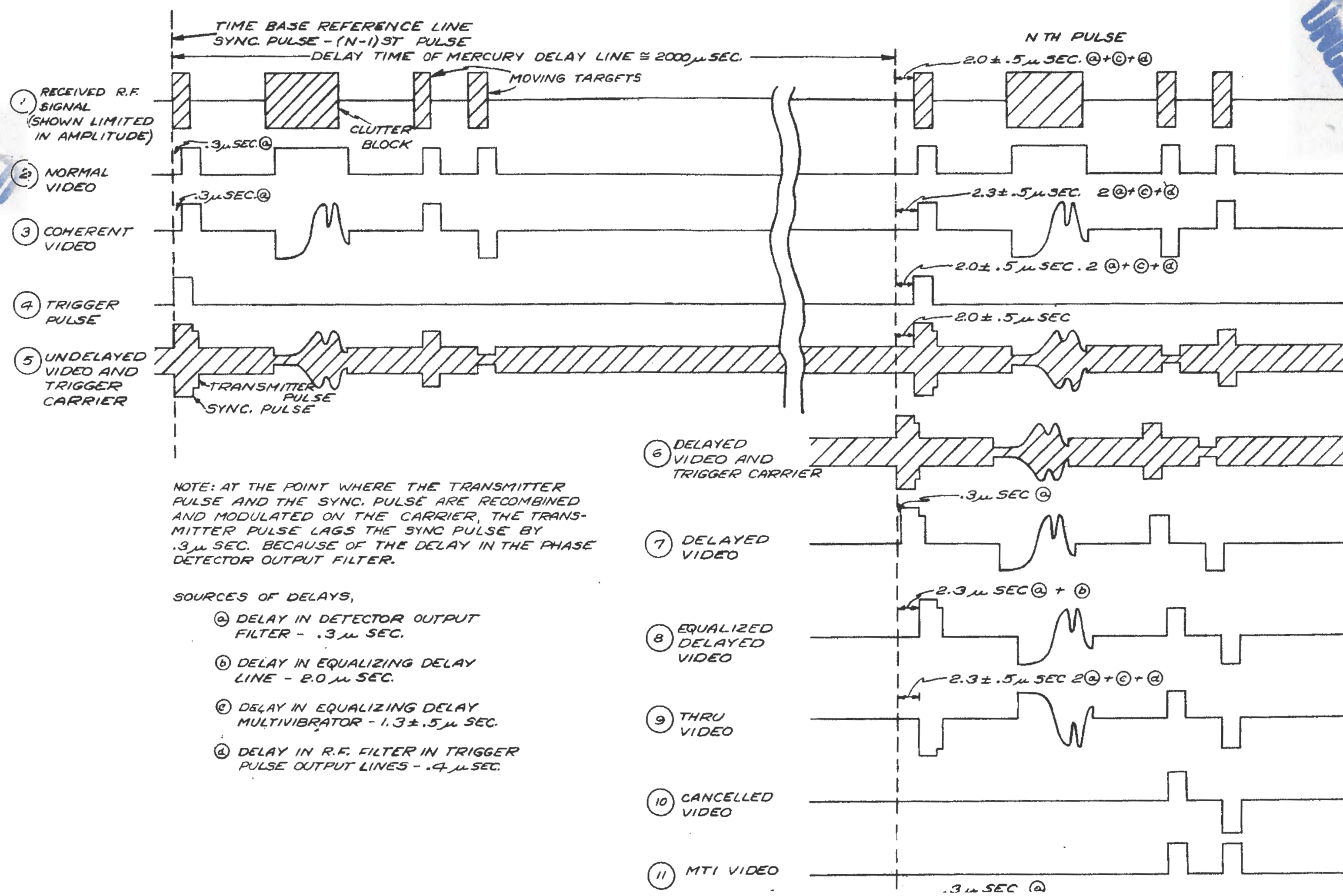

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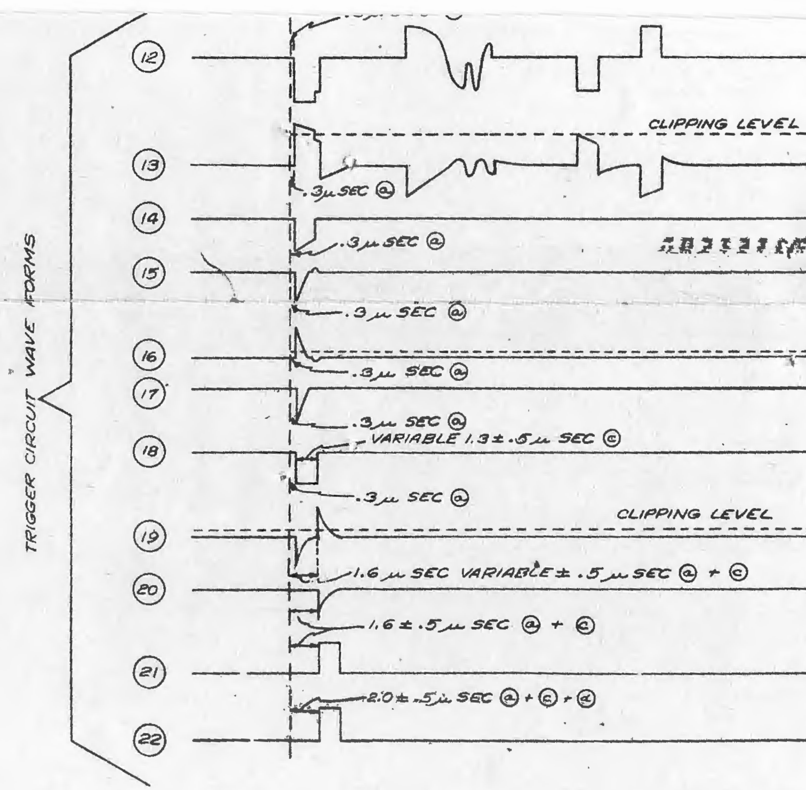
Diagram 9 - Timing and Cancellation
of the Nth Pulse



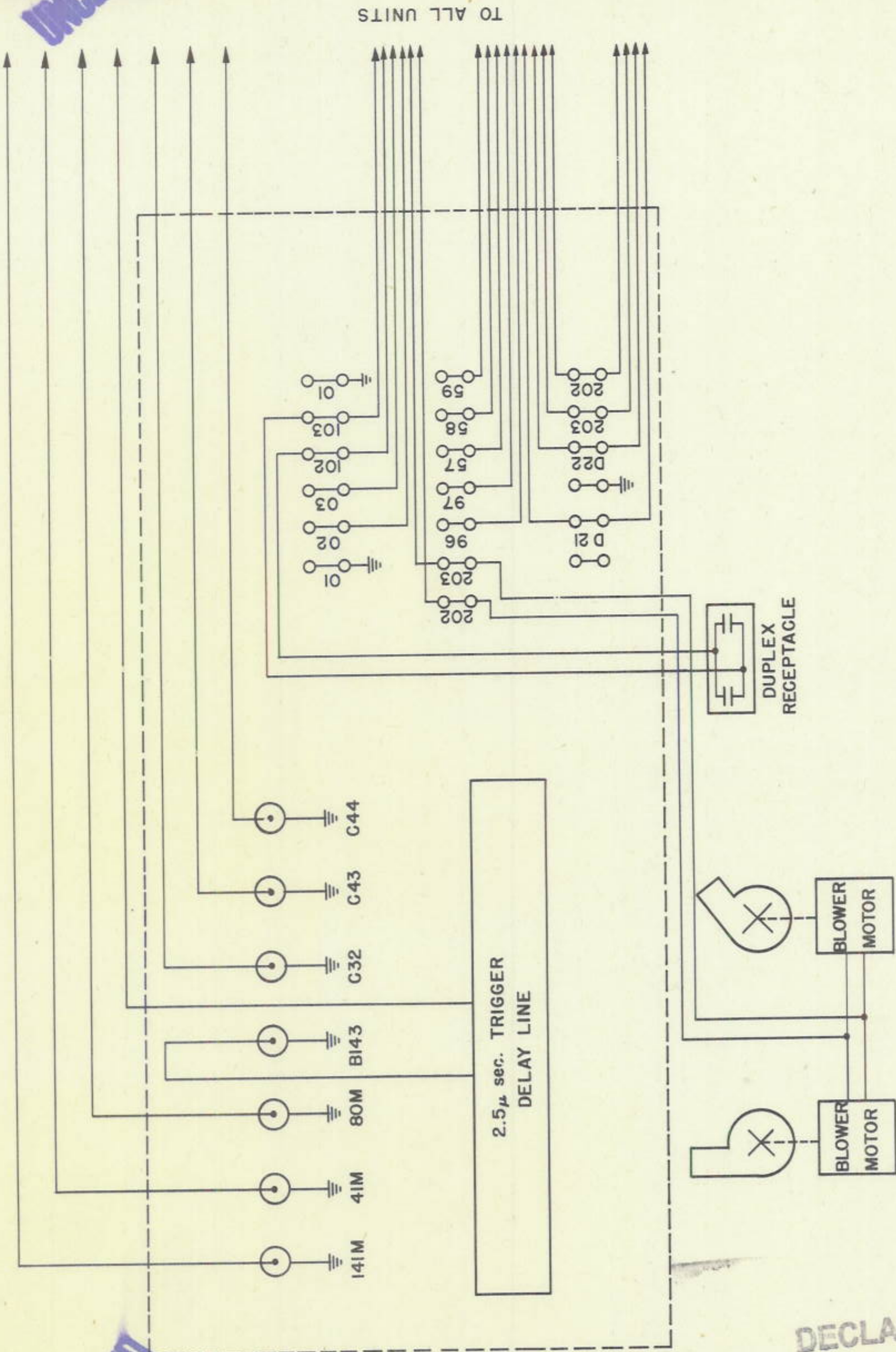


Diagram 10 - Junction Box Wiring

PRNC-2338-8-23-49-200