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NRAO INTERFEROMETER PHASE LOCK LOOP OPERATING-SERVICE REPORT

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OPERATING-SERVICE REPORT

PREFACE

This report should supply the basic operating and service information for the NRAO interferometer phase lock loop; a separate report on the design and initial evaluation of the phase lock loop is forthcoming; in addition, internal report No. 21 can provide background information.

Credit should be given to C. Cooper, R. Ervine, W. Shank and J. Ware and M. Barkley and others for their efforts to produce a working system.

NRAO INTERFEROMETER PHASE LOCK LOOP OPERATING-SERVICE REPORT

John E. Bringe

I. OPERATING DESCRIPTION

The purpose of this system is to provide correction for changes of phase between a pair of locations of local oscillator power; the system should introduce no additional information to the overall receiving system. Specifically, phase coherence is desired between the local oscillator signals present at the mixer injection ports.

The NRAO phase lock system has been designed to maintain phase coherence between the local oscillator signals present at the inputs to X2 frequency multipliers (in the front end boxes) which in turn feed the mixers. The purpose of this arrangement is to simplify phase ambiguity problems and permit the use of a lower frequency in a cable system where the cable losses are only half as many decibels for the frequency which is half the mixer local oscillator injection signal.

As of this date, the equipment is operated as a measuring system to measure phase difference between the two telescopes' control rooms. If adequate space was available in the front-end boxes, it would be a simple task to relocate the phase comparator-driver-output amplifier combinations. At the present, space appears to be inadequate unless the driver-output amplifiers are separated from the phase comparator. Use of remote drivers may not present major problems, but at least one of each pair of output amplifiers should be in each front-end box because of the low signal levels at the output of the phase comparators.

As a measuring system, relatively accurate phase measurements can be made between control rooms or between one control room and one front-end box mounted phase comparator but the unknown phase variation of an additional cable is added when measurements between two front-end boxes are attempted.

Because of internally generated phase errors, the system must be operated closed-loop which means that the controlled phase shifter must be removed from the receiving system's local oscillator sub-system. This is accomplished by placing the phase shifter between the sampling coupler and the phase comparator. Since the system maintains fixed phase relationships between internal locations of the phase comparators, the system "output" will give a measure of the sum of the phase changes between the phase shifter input and the remote phase comparator plus certain phase shifter characteristics changes. This, of course, reduces the accuracy of measurements.

The design of the phase lock system is based on the simple principle of properly combining and using two phase measurements, one between "A" and a signal derived from "B" and sent to near "A", and the other between "B" and a signal derived from "A" and sent over the same path as the first transmission to near "B". If we consider Θ as the phase difference between "A" and "B" and ϕ as the phase shift introduced by the transmission, one measurement will give us the sum and the other the difference. Depending on the point of reference taken, two actual signals are obtained; the result is as follows in any case:

$$\text{One output} = f[\pm(\phi + \Theta)]$$

$$\text{Other output} = f[\pm(\phi - \Theta)]$$

$$\Sigma = f[\pm(\phi + \Theta)] + f[\pm(\phi - \Theta)]$$

$$\text{Difference} = f[\pm(\phi + \Theta)] - f[\pm(\phi - \Theta)]$$

Four possibilities are possible from either of the above expressions, namely, $\pm 2\Theta$ and $\pm 2\phi$; therefore, in the actual system connections this fact must be taken into account. In system operation, reference is made to a "sum" and "difference" which is based on a previously chosen system reference and is used for consistency.

The "Phase Lock System Block Diagram I" shows the system information flow. Due to the large distance between the phase comparators, cable losses require the use of "Repeaters" at periodic intervals. Since a time-shared cable system was chosen (to minimize interference and maximize accuracy), it is desirable to use the same amplifiers in the bidirectional transmissions to maintain bilateral characteristics. This is accomplished by using single amplifiers in a diode switching bridge as later described.

II. EQUIPMENT DESCRIPTION

The "Phase Lock System Block Diagram II" shows the system equipment (the remaining diagrams go down to the circuit level as needed). Also, a system's eye view is given of the locations where AC power is introduced into the system and where DC blocks are located to prevent system ground loops and/or permit subsystems to function properly. The blocks used separate both inner and outer conductors.

The "Phase Comparator" receives the local oscillator signal through the "L" port and compares this signal with the comparison signal received through the "C" port. In the "+" comparator, comparison is made when the switch drive is positive; in the "-" comparator, comparison is made when the switch drive is negative. To accomplish this, the diode switch drives are reversed in the "-" comparator. The output obtained through BNC 2 is adjusted by R5 to compensate for different detector sensitivities primarily caused by different values for the matched loads which are used to provide near-square law operation. The 10 dB pad is used to equalize power levels (it also provides a DC return path), whereas the 3 dB pad is used to provide a DC return path in a convenient broadband package. The DC blocks permit the use of a single ended 40 V P-P switch driver. To provide constant switch drive level, a clipper is used ahead of the switch driver.

The "Decoding Matrix" processes the phase measurements and provides correction voltages for the phase shifters in addition to providing feedback loop phase correction, level adjustments, metering, and open-closed loop control. Two of the Dymec DC amplifiers have modified M2 plug-ins which provide dual input capability. (A third input is also available as can be seen in the M2 before-after modification diagram.)

The "Detector" (there are two) consists of a sampling bridge, a holding circuit and an offset adjustment. The sampling pulse is transformer coupled which provides voltage gain and isolation. By using capacitive coupling, diode clamping action and proper current limiting and loading, the drive requirements are minimized. The offset adjustment is used to balance out feed-through from the sampling pulse and feed-through from the phase comparators.

The "Phase Shifter" includes a TWT unit plus the auxiliary equipment necessary to provide filtering, quiescent condition optimization and AGC action; most of the latter equipment is in the TWT control module — the primary exception is the AGC amplifier (which has a modified M2 plug-in) which is a result of referencing the output level to the input level.

The "TWT Unit" consists essentially of a packaged collection of power supplies connected to a programming panel in addition to a control unit and the TWT itself. Practically any desired interconnection of power supplies can be obtained by simply changing programming panel connections. Also, various TWT's can be used and they are fully protected through the control unit. Grid control is obtained by voltage programming the grid supply; helix control is obtained by voltage programming the helix-collector buck supply. This procedure is necessary because the ground of the programming voltage must be connected to the positive terminal of the controlled supply. The 2 K ohm resistors are used to speed-up response time. In addition, the buck supply load insures current flow if D1 (which is a protection for the buck supply) is inhibiting buck supply reverse current flow.

The "Switch Unit" can be seen to have the same basic RF switching circuitry as the phase comparators; its purpose is to permit bidirectional transmission and amplification when an amplifier is connected to the indicated ports. Here, again, 400 Mc low-pass filters are used to improve isolation by reducing the RF leakage from the drive ports of the AEL SNB 855 diode switches. General diode characteristics are: Conducting loss of less than 0.7 dB, RF isolation $\approx$ 45 dB, and drive port RF leakage $\approx$ 30 dB down. As noted, only one switch unit has connections for trombones; this unit is used to control the bidirectional characteristics.

The "Clock" is described in the "General Block Diagram", the "Clock Truth Table", and the "Clock Timing Diagram" plus a logic diagram. Outputs are a 1 kc square wave which is fed to the system through a power amplifier and 90 ohm triax cable and a sampling pulse which provides sampling during the center third of the square wave; as shown, two possible phasings are available. Adjustments are few; the line driver is operated on X10 gain and the input level is adjusted via a potentiometer (not shown). Also, capacitive coupling is used to remove the DC component. A potentiometer is also used at the sampling pulse output to limit drive to the following pulse amplifier. It should be noted that the logic is based on a suggestion by C. Bare and 3C digital cards are used.

The "Switch Driver Input Clipper" is designed to provide a constant level square wave output of about 4.4 V P-P with an input of about 18 V P-P. In addition, the input impedance should be large compared to 90 ohms so that the unit can bridge a 90 ohm line; with this circuit it is about 1 K ohm. Regulation is obtained by using the forward drop characteristics of the 1N456 silicon diodes.

The "Line Amplifiers" (which are not shown in diagram form) consist of a ceramic tube lumped circuit unit feeding a Melabs circulator. Center frequency is 1347 Mc, bandwidth is 40 Mc (flat response) and gain is about 34 dB. Heater power and 200 V anode voltage comes from solid state DC power supplies. The 200 V is obtained by cascading two Kepco PAX100-0.1 modules which are shunted with protective diodes; time delay circuitry is also included.

UTC isolation transformers are used as necessary to minimize capacity coupled "ground loops"; voltage regulation of the line is obtained by using Sola non-harmonic static regulators which provide sufficient performance at low cost with reliable performance.

The packaging of the system makes operation and maintenance easy; along with the modular interchangeability, everything is very accessible. Complete use of HP combining cases is used to permit modules of various sizes with RF (type N) connectors on the front and low frequency (type BNC) push type connectors on the rear. The "Central Rack" diagram shows some of the general concepts plus the layout of the bulk of the phase lock system equipment. Separate cases contain the two phase comparators along with their switch driver and output amplifiers. The TWT units which are individually located in half racks are the only others with the exception of the repeaters which consist of two cases, one containing a switch unit and driver, and the other a line amplifier and power supply.

III. INITIAL SETUP REQUIREMENTS

At the present time, 85-1 is used as the control location; therefore, most of the equipment is located there — this normally includes the central rack, the two TWT units and recording facilities. The phase comparator cases are located as required, and repeaters are used in locations as necessary (generally in huts along the baseline).

The connection of the system can readily be deduced from the diagrams including the central rack layout. In regard to the BNC connectors on the back of modules, the numbers referred to are the ones derived by starting with (1) at the top left and counting up to 4N where N is the multiple of 1/3 module involved; then, continue with the lower row in the same direction.

The following wiring list for the rear of the central rack should aid the interested:

CRC 1

(Central Rack Case 1)

HP 467A output (6) to switch unit input (1).

HP 467A input (5) from BNC to dual triax-BNC adaptor.

One triax to single triax-BNC with BNC connected to one output (7) of HP 467A line driver in CRC (6).

Other triax to line cable (triax).

Power to isolation transformer B.

CRC 2

Power to isolation transformer A.

CRC 3

Θ TWT control module

(2) to (Θ) TWT grid power supply control.

(4) to (Θ) TWT helix power supply control.

(5) to input (1) of amp ③ in CRC 4.

(6) to output (4) of amp ③ in CRC 4.

(7) to input (2) of amp ③ in CRC 4.

(8) to output (4) of amp ⑥ in CRC 4.

CRC 3 (Continued)

ϕ TWT control module

(2) to (ϕ) TWT grid power supply control.

(4) to (ϕ) TWT helix power supply control.

(5) to input (1) of amp ① in CRC 4.

(6) to output (4) of amp ① in CRC 4.

(7) to input (2) of amp ① in CRC 4.

(8) to output (4) of amp ④ in CRC 4.

Detector Module

(1) thru 10 μfd to single BNC-triax adaptor, traix to 85-1 triax cable.

(5) thru 10 μfd to single BNC-triax adaptor, triax to 85-2 triax cable.

(2) to output of 465A (2) in CRC 5.

(6) to output of 465A (2) in CRC 5.

(4) to input (1) of amp ② in CRC 4.

(8) to input (1) of amp ⑤ in CRC 4.

Note: (1) and (5) are detector inputs; (2) and (6) are sampling pulse inputs and (4) and (8) are the detector outputs.

CRC 4

① thru ⑥: 1, 2, 3 are inputs; 4 is output.

Dymec amp ③ — see CRC 3.

Dymec amp ① — see CRC 3.

Dymec amp ② output (4) to Σ meter and input (1) of amp ⑥ and input of X(1/2) attenuator (CRC 5).

Dymec amp ⑤ output (4) to difference meter and input (2) of amp ④ and input (1) of amp ④.

CRC 4 (Continued)

Dymec amp ④ output (4) (already connected to the TWT control module) connect to ϕ meter.

Dymec amp ⑥ output (4) (already connected to the TWT control module) connect to Θ meter.

Power to isolation transformer B.

CRC 5

X(1/2) attenuator output connected to input (2) of amp ⑦.

Dymec amp ⑦ output (1) connected to input (2) of amp ⑥ in CRC 4.

Power to isolation transformer B.

HP 465A input (1) to sampling pulse output (1) of clock in CRC 6.

Power to isolation transformer B.

CRC 6

HP 467A input (5) connected to square wave output (4) of clock.

HP 467A output (6) connected to single triax-BNC adaptor, thence to remaining triax line cable.

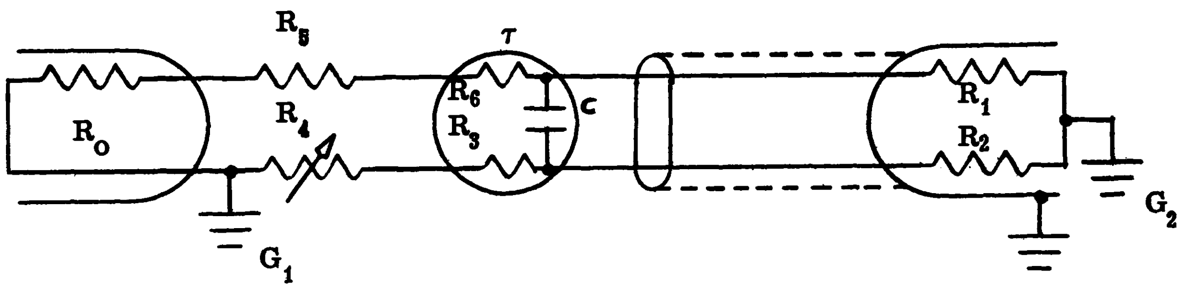
Power to isolation transformer B (also clock power).

(Clock: 4, 12 are square wave outputs; 1, 9 are corresponding sampling pulses (+)).

Additional connections include those made from the outputs of the Θ and ϕ DC amplifiers to recorders (either directly or via long cables). Since the main time constants are in the TWT units, time constants of about 1/2 second must be used between the amplifiers and recorders to give a true picture. A very important area to consider concerns grounding problems. The diagrams show most of the equipment used to prevent problems; the exceptions are the isolation transformers which supply power to the repeaters and phase comparator cases. When making connections to recorders, a two-conductor shielded cable should be used with the adaptation made at the amplifier-time constant; the recorder amplifier should have differential input. Since the amplifier grounds are at different potentials, it is important that recorder grounds are connected correctly.

The following connection is suggested as a way to minimize problems:

Output Amplifier | Recorder Amplifier



$R_3 = R_6$ combined with C gives τ.

If R_0 is very small, add R_5 so that R_4 is a reasonable value. Also, if any attenuators are added, they should be symmetrical like the τ which is shown; R_4 is adjusted to give a fine balance.

In regard to levels, adjustments are made with RF pads to provide subsystem operation at optimum levels. The phase comparator should have inputs of 1.5 mw and 0.15 mw at the "L" and "C" ports, respectively. It should be noted that a power meter should measure 1/2 (0.15) mw for "C" because of the 50 percent duty cycle. The TWT's give better operation at certain levels; therefore, pads are used as needed. A 10 dB and 14 dB pad is used to adjust levels with the present equipment. The 10 dB pad also permits the ϕ TWT to operate at the same level throughout the switching cycle, i.e., 0.15 mw input. The repeater spacing is determined by the levels involved and since amplifier gain less switch unit loss give approximately 30 dB gain, the repeaters closest to the phase comparators should have about 20 dB of cable loss between themselves and the phase comparators and 30 dB of loss between repeaters. When the 1 5/8" Spir-o-line cable (for which this system was designed) is used, 20 dB gives about 600 m and 30 dB gives about 900 m of cable.

IV. OPERATING ADJUSTMENT PROCEDURE

Subsystem Adjustments

The various subsystems should be adjusted for optimum operation prior to attempting system adjustments; although, once made, adjustments would tend to be needed only if there were component changes.

There are basically four areas of adjustments: Phase comparators, the clock, the switch drivers, and the TWT units. The phase comparators can be balanced by first terminating the "C" port and applying 1.5 mW (1347.5 Mc) to the "L" port and adjusting R5 for zero output. After noting the dial indication, terminate the "L" port and apply 0.15 mW (1347.5 Mc) to the "C" port and adjust R5 for zero output. The final setting is then the average of the two readings (the two readings are indicative of hybrid unbalance).

The clock has two types of adjustments — frequency and level; the frequency should be about 6 kc for the multivibrator but this is not critical; screwdriver adjustment is available on the MV-30 card. The level adjustments are available through the front panel with a long screwdriver; the square wave level should be adjusted to give 4 V P-P at the input to the line driver and the sampling pulse should be adjusted to prevent saturation of the HP 465A pulse amplifier on the 20 dB gain setting. The remaining HP 467A's, which are switch drivers, are gain adjusted to give outputs of 40 V P-P.

The TWT's should have the quiescent levels established to mid-operating range with zero inputs from the TWT control modules. The operating range of the helix-collector buck supply is 100 to 200 volts, whereas generally the best operating range for the grid supply is 20 to 100 volts. An adjustment which gets more involved with other subsystems is the selection of the proper pads in the AGC loop in the TWT control module. Except for physical considerations, one pad can be zero; the other is selected to give true AGC action with a minimum of ALC action for the desired operating levels and quiescent conditions. It should be noted that the normal method of voltage programming is not used which would not provide fail-safe operation. The normal method would permit programming circuit open-looping if external cables were disconnected; the method used actually injects current into the power supply bridge. Hence, the power supplies do not go to maximum output level when cables are disconnected; they go to their quiescent states instead.

System Adjustments

The following procedure applies exactly when the system is used for phase measurements between 85-1 and 85-2 control rooms with LO levels of 1.5 mW and 1.0 mW at the "L" ports of the "+" and "-" phase comparators, respectively. Under these conditions, the Θ phase shifter is out of the LO path and 0.15 mW is required from the sampling coupler at 85-1.

Since system gain is proportional to RF levels, operation with LO sample phase comparator inputs in the normal range of 1.0 mW to 1.5 mW requires proportionate changes in gain adjustments to satisfy accuracy and stability requirements.

System adjustments should start with the following initial conditions:

1. The system should be completely connected and operational.
2. Loop switches should be open.
3. Sum, difference, Θ and ϕ DC amplifier gain switches should be set at zero.
4. Both AGC DC amplifier gains should be X11,000.
5. The phase reversal DC amplifier should be at X2 gain.
6. The meters should be mechanically zeroed.

The following two steps need to be performed only when the system is initially connected at a particular antenna separation or with the passage of several months.

1. With the system LO RF power off, adjust the sum meter to zero with the sum detector offset control as the sum Dymec amplifier gain switch is progressively increased to X100; return to X0 gain.
2. Adjust the difference meter to zero with the difference detector offset control as the difference Dymec amplifier gain switch is progressively increased to X100; return to X1 gain and apply RF power.

The following adjustments are made periodically as needed:

1. Adjust ϕ trombone for a maximum on the sum meter with the sum Dymec gain switch set so that the reading is < full scale.
2. Adjust the difference trombone for a maximum on the difference meter with the difference Dymec gain switch set so that the reading is < full scale and the polarity is identical to (1).
3. Repeat (1) and (2).
4. Adjust the sum and difference Dymec gains so that the negative maximums give full scale indications when gain switches are set at X100; reduce gain switches to X10.
5. Adjust the ϕ trombone for zero on the ϕ meter.
6. Adjust the Θ trombone for zero on the Θ meter.
7. Repeat (5) and (6) as necessary.
8. Set the ϕ Dymec amplifier gain to X7.
9. Set the Θ Dymec amplifier gain to X10.
10. Close loop switches.
11. If the Θ and/or ϕ meters move a large amount, the adjustments are giving the wrong mode. This may be corrected by adjustment of the Θ and/or ϕ trombone; if not, open the loop and adjust the Θ and/or ϕ trombone to the next cyclic zero of the meters; this may require returning to step (1).
12. System stability check: It should be possible to slowly increase either ϕ or Θ gains by a factor of ten before the system becomes unstable. If this is not possible, the gain(s) should be reduced accordingly; conversely, gain(s) should be increased to maintain system accuracy if the stability margin is greater. It should be noted that system performance is enhanced by having maximum gains in the Θ loop at the expense of lower ϕ gains since the effect of ϕ error on Θ is second order, whereas Θ gain gives a first order effect on Θ which is the primary controlled parameter.

V. MAINTENANCE

Although the system presently in use is phototypical, the design criteria followed included requirements for reliability, ease of operation and maintenance, compactness, use of previously purchased equipment and adaptability for expansion; limits were in the time and monetary domains. In addition, off-the-shelf factory designed equipment is used wherever possible.

As a result of the approach followed, system reliability is enhanced by the extensive use of solid-state devices, top-grade batteries and mechanical units, and over-load indicators and fail-safe design procedures.

Elapsed time indicators (motor driven) are included in only the TWT units. It is recommended that electrolytic type elapsed time indicators be installed in other areas; they are available at relatively low cost for use on panels or directly on printed circuit cards.

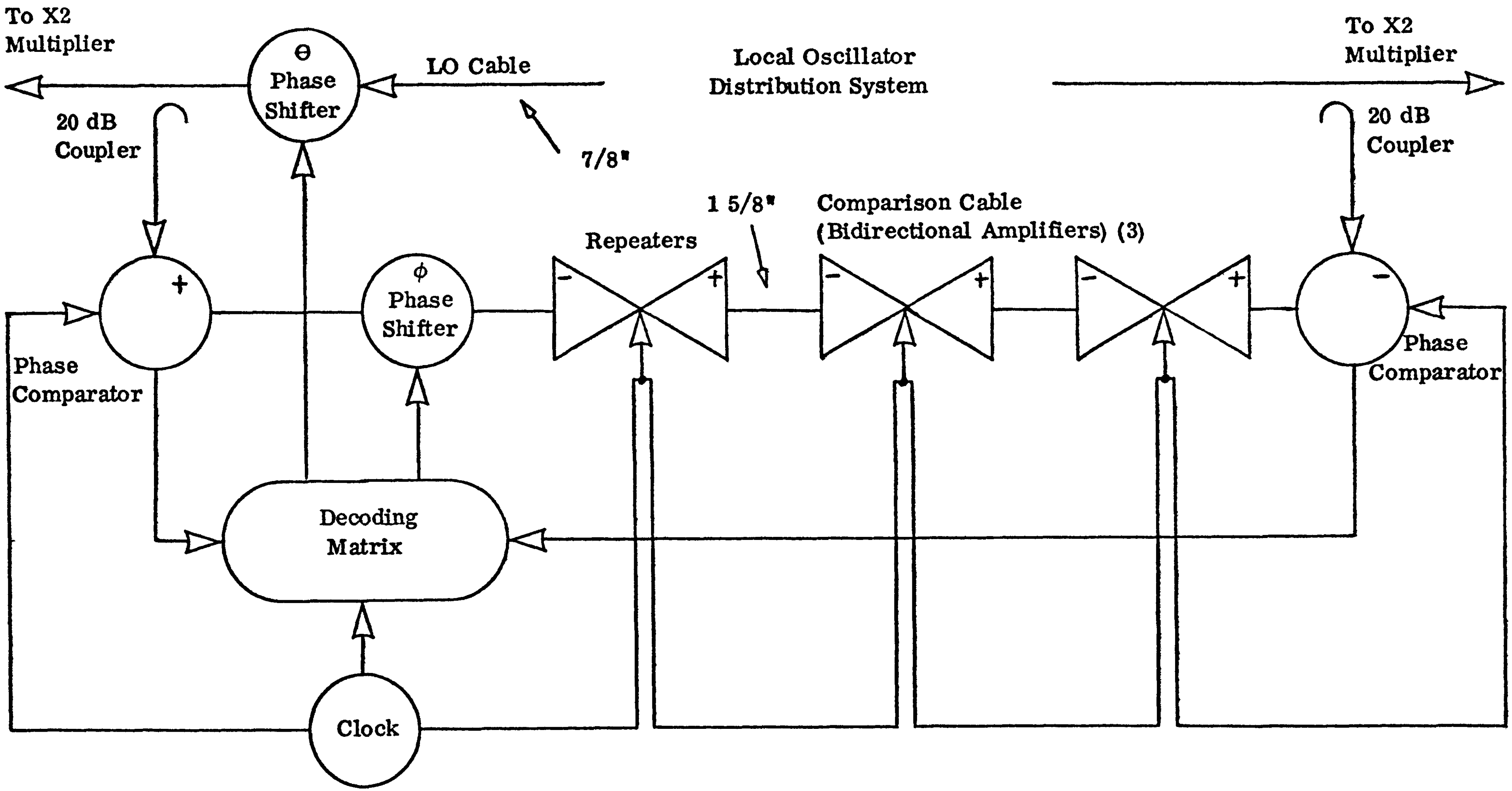
The mechanical service problems are primarily the cleaning of the blower/fan filters of the C-COR amplifiers and the TWT units, the oiling of the TWT units' fans, and the lubrication of the trombone setters and the trombones themselves.

The system batteries, of course, require periodic replacement; they are located in the TWT control modules and the detector module. Some batteries in the control modules are rarely used; these can be replaced yearly. The others should be replaced every three months.

Other service problems are created by the relatively few vacuum devices and heating element type devices. The C-COR line amplifiers contain three vacuum tubes; their replacement requires circuit adjustments. Also, there are series pass tubes in the TWT supplies in addition to the TWT's themselves. Replacement of these is straightforward.

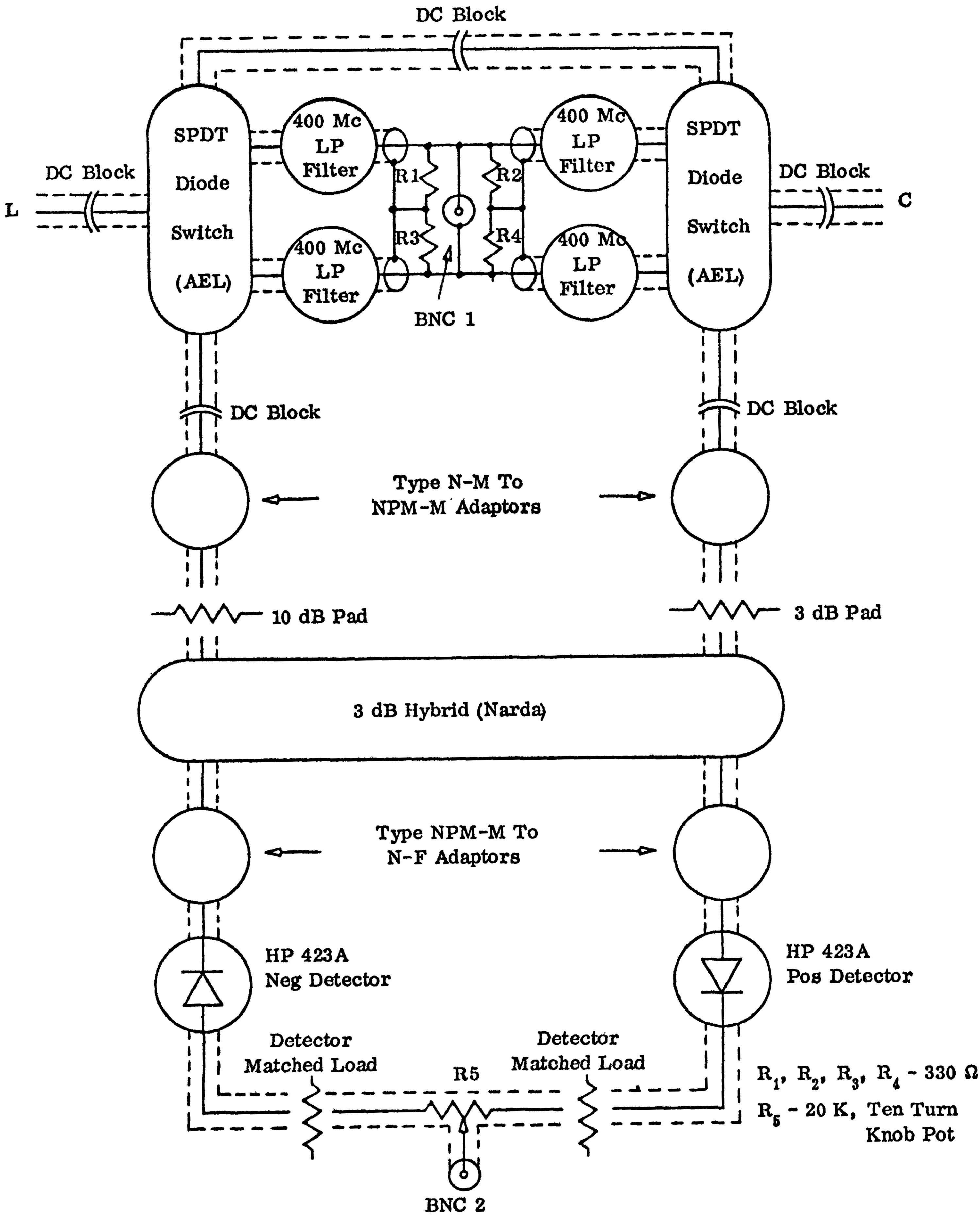
There are tube-type time delay relays in the TWT units (on the TWT control chassis) and the C-COR amplifier power supplies. It should be noted that although the other panel indicators are independent devices, the panel indicator of the clock power supply affects the supply's performance.

VI. LIST OF DIAGRAMS



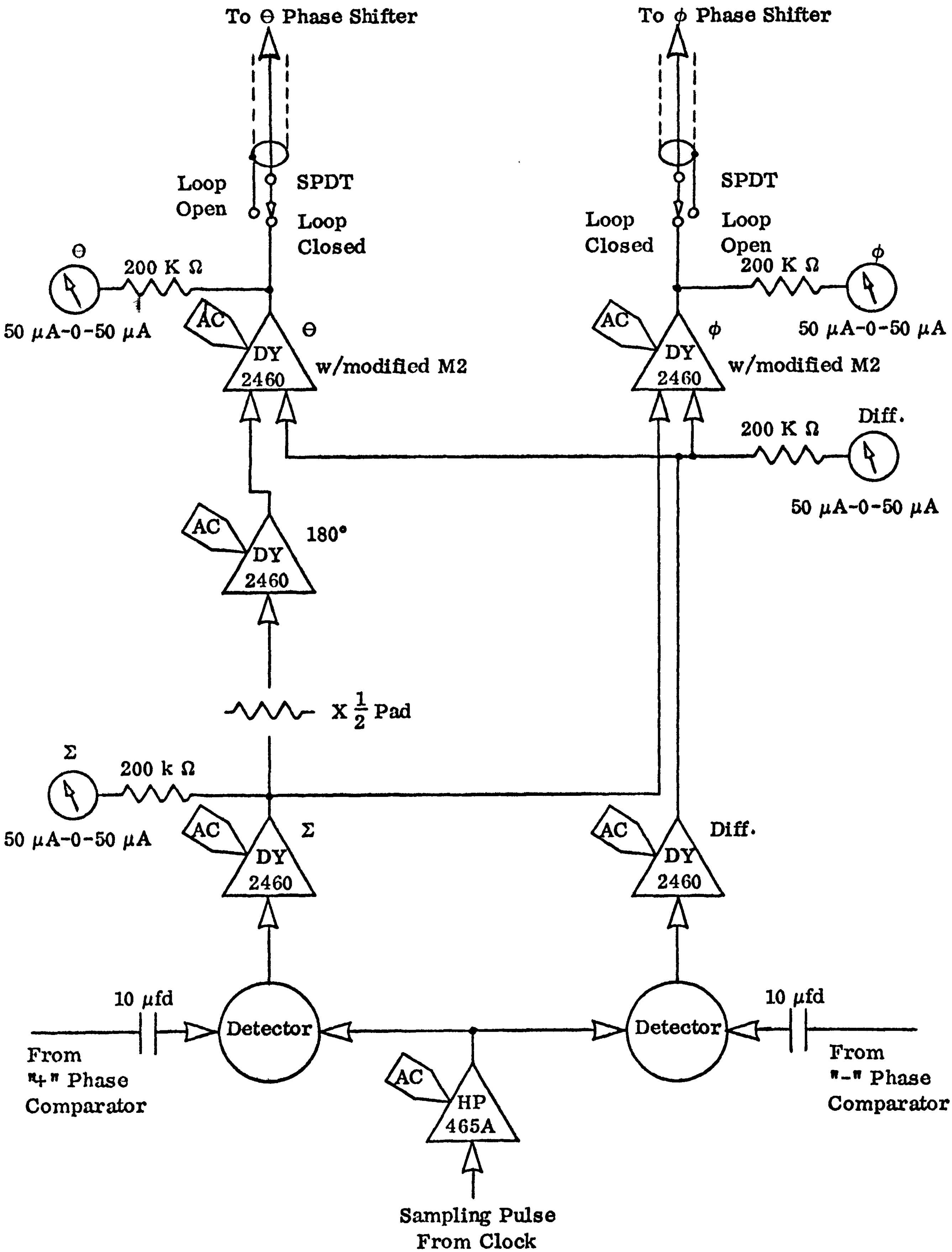
1 — PHASE LOCK SYSTEM BLOCK DIAGRAM I

2 — PHASE LOCK SYSTEM BLOCK DIAGRAM II



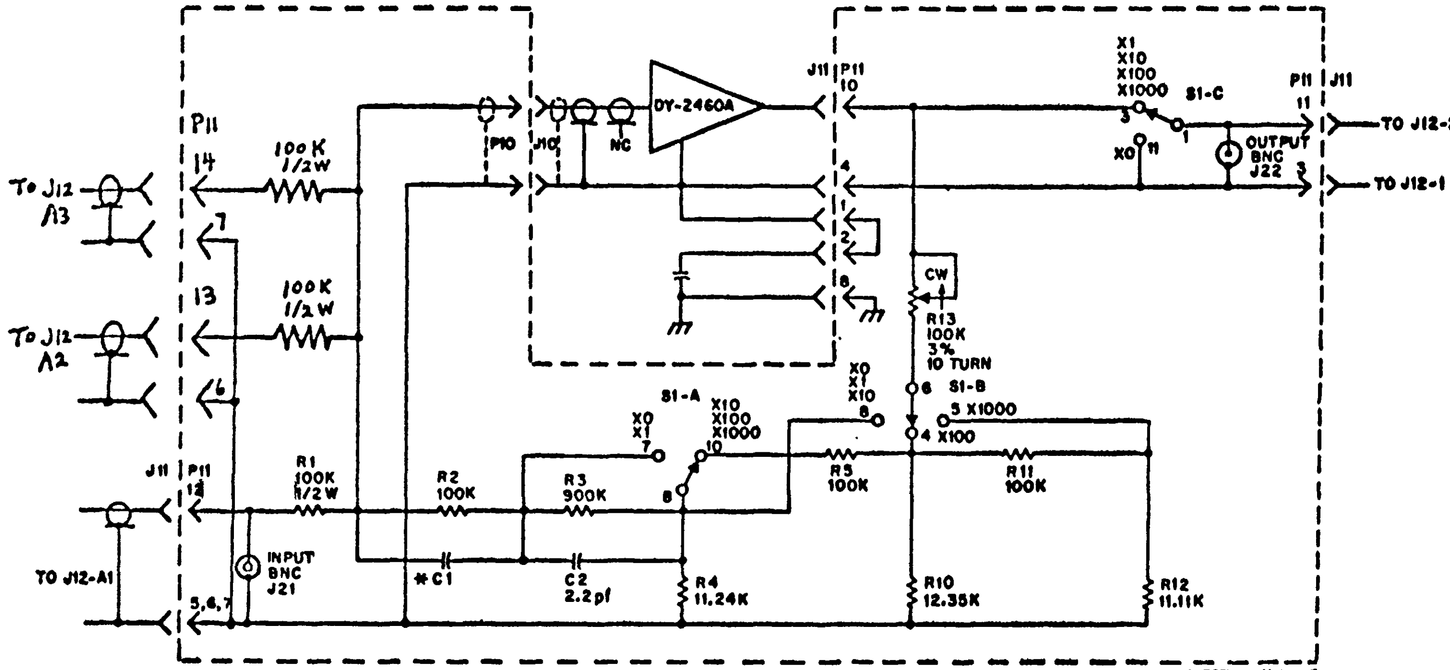
3 — PHASE COMPARATOR (+)

J.E.B.



4 — DECODING MATRIX

J.E.B.



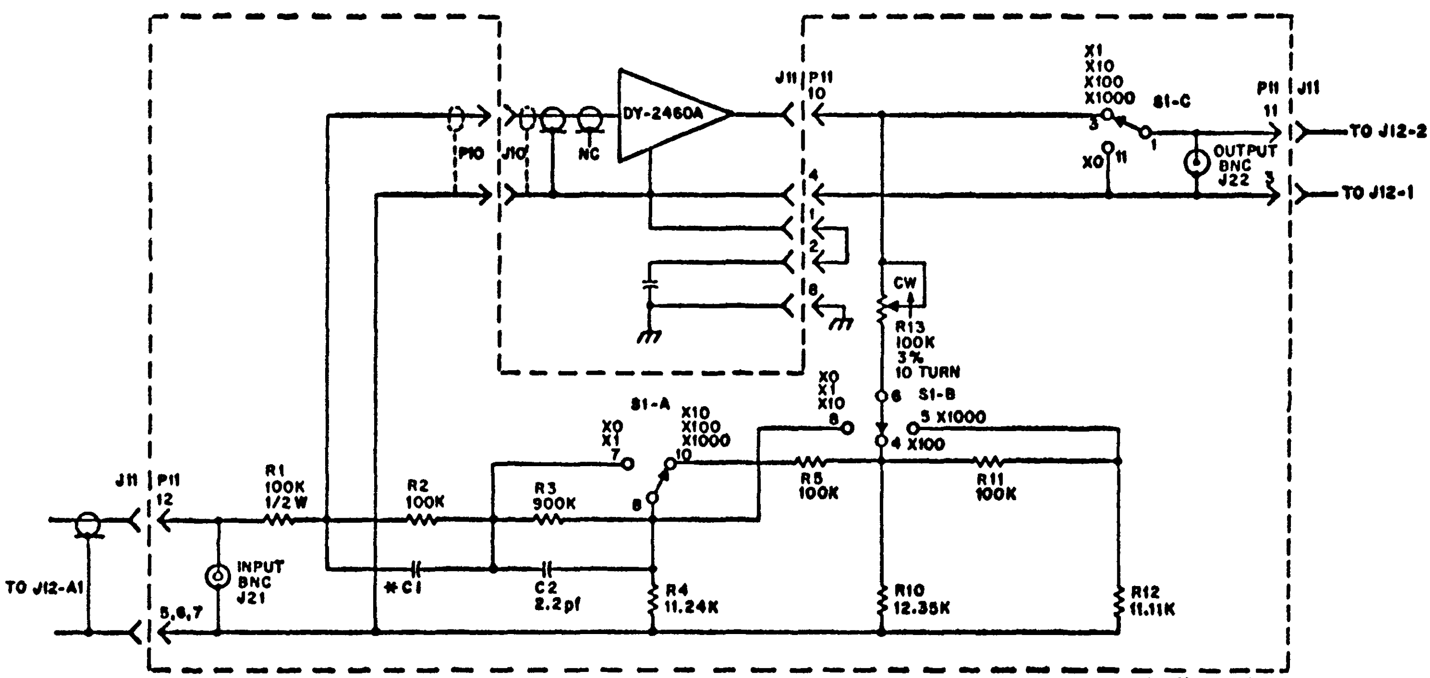
ALL RESISTORS 0.1%, 0.1W, TC<±15PPM/°C, NON-INDUCTIVE WIREWOUND EXCEPT AS NOTED

* SELECTED IN TEST

C2441-1001

MODIFIED M2 BENCH USE PLUG-IN

John E. Bruyer
Sept. 3, 1965



ALL RESISTORS 0.1%, 0.1W, TC<±15PPM/°C, NON-INDUCTIVE WIREWOUND EXCEPT AS NOTED

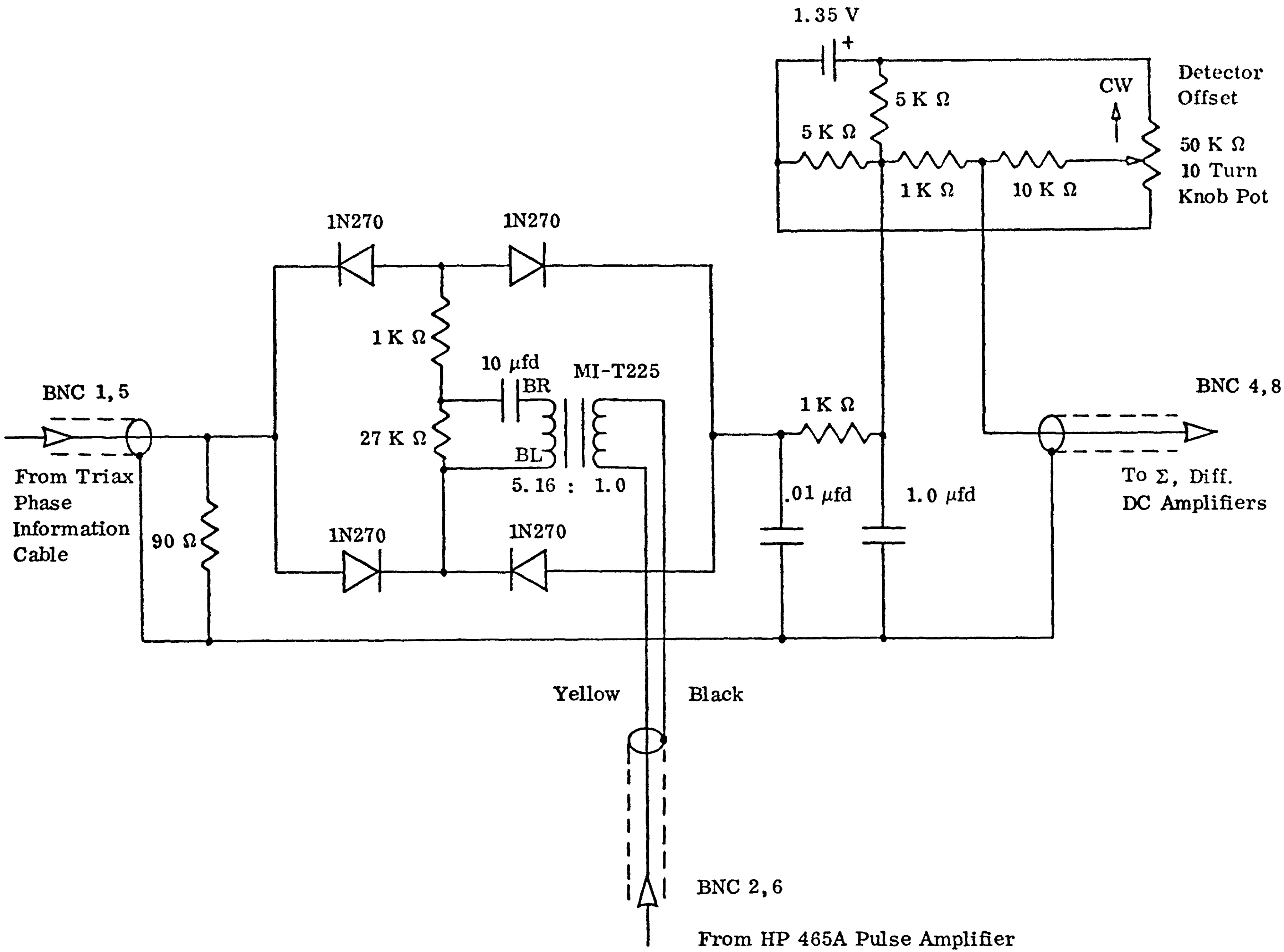
* SELECTED IN TEST

C2441-1001

M2 BENCH USE PLUG-IN

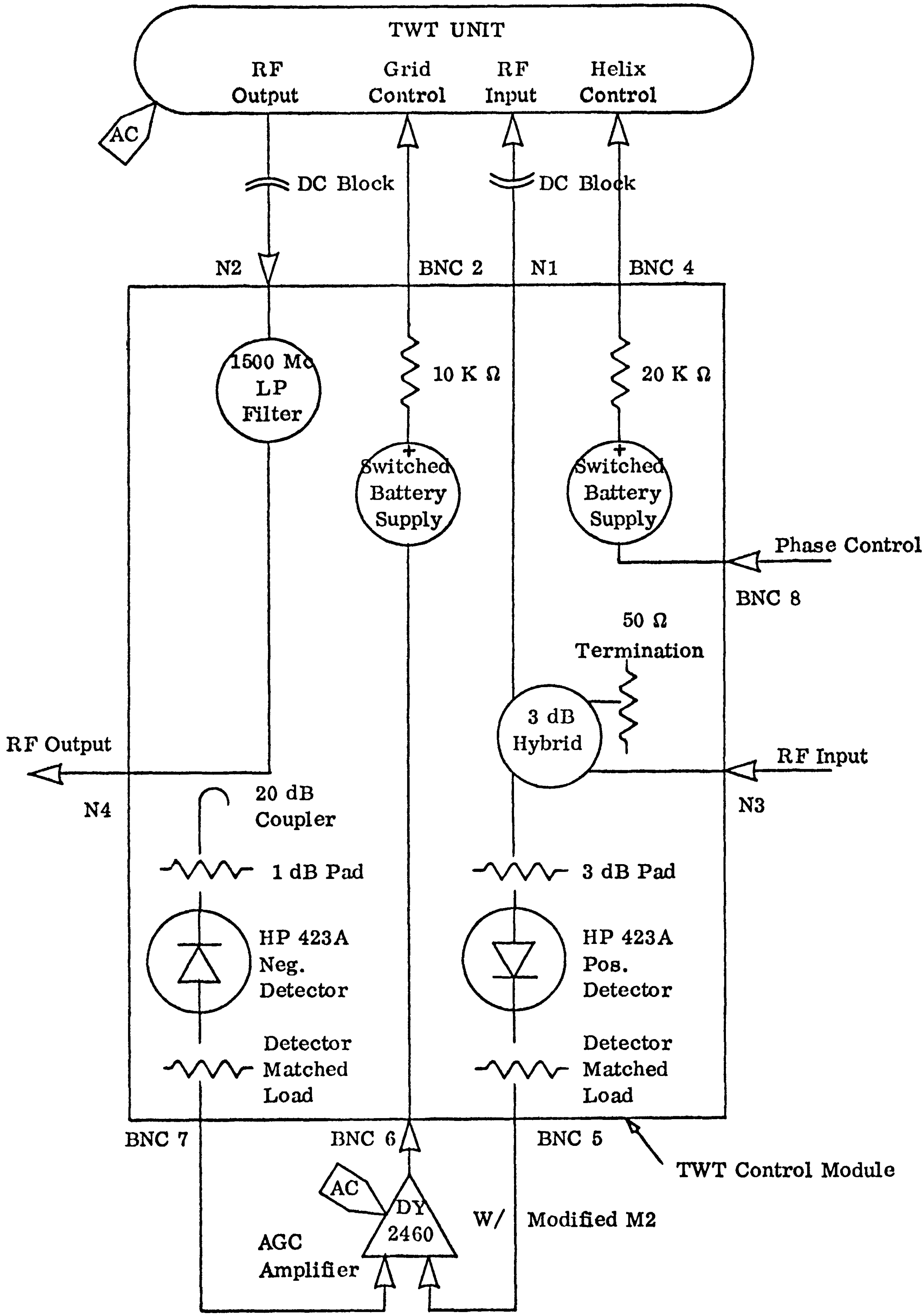
5 – M2 MODIFICATION

JEB



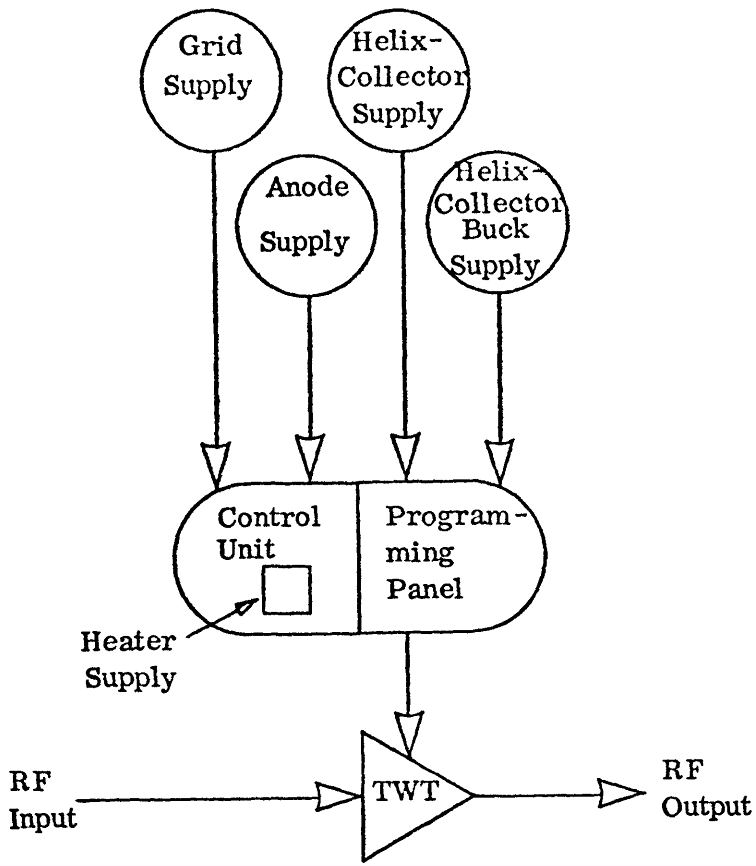
6 — DETECTOR

J.E.B.

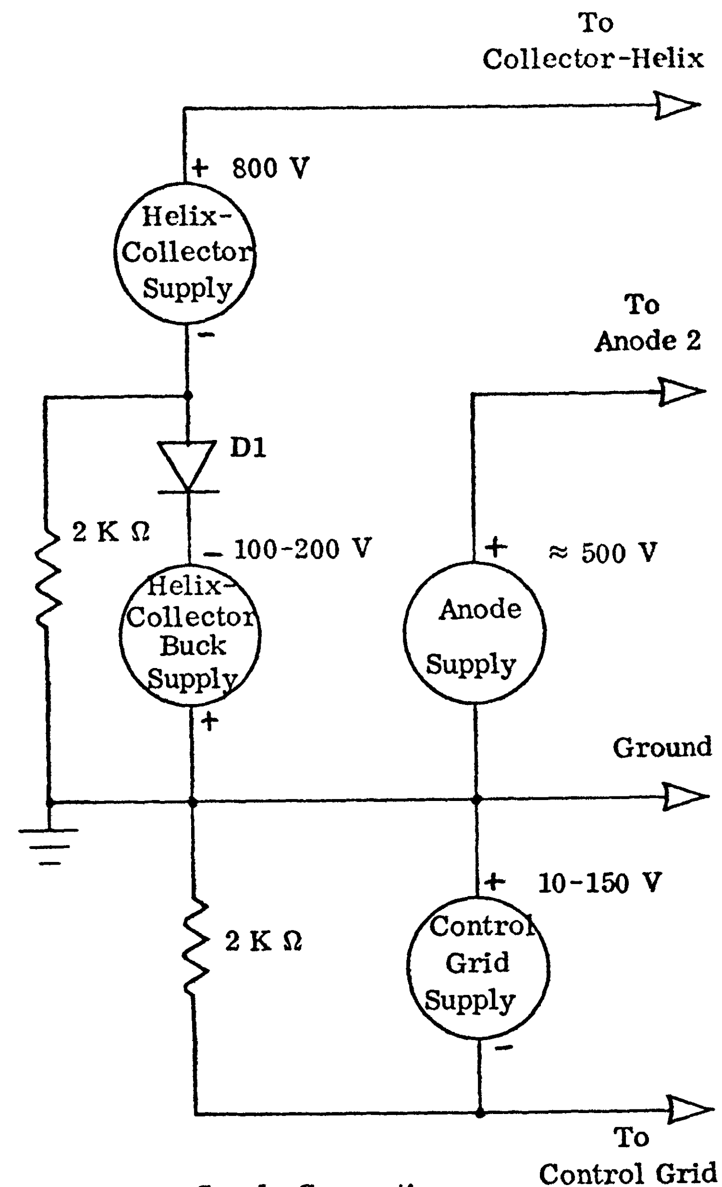


7 — PHASE SHIFTER

J.E.B.



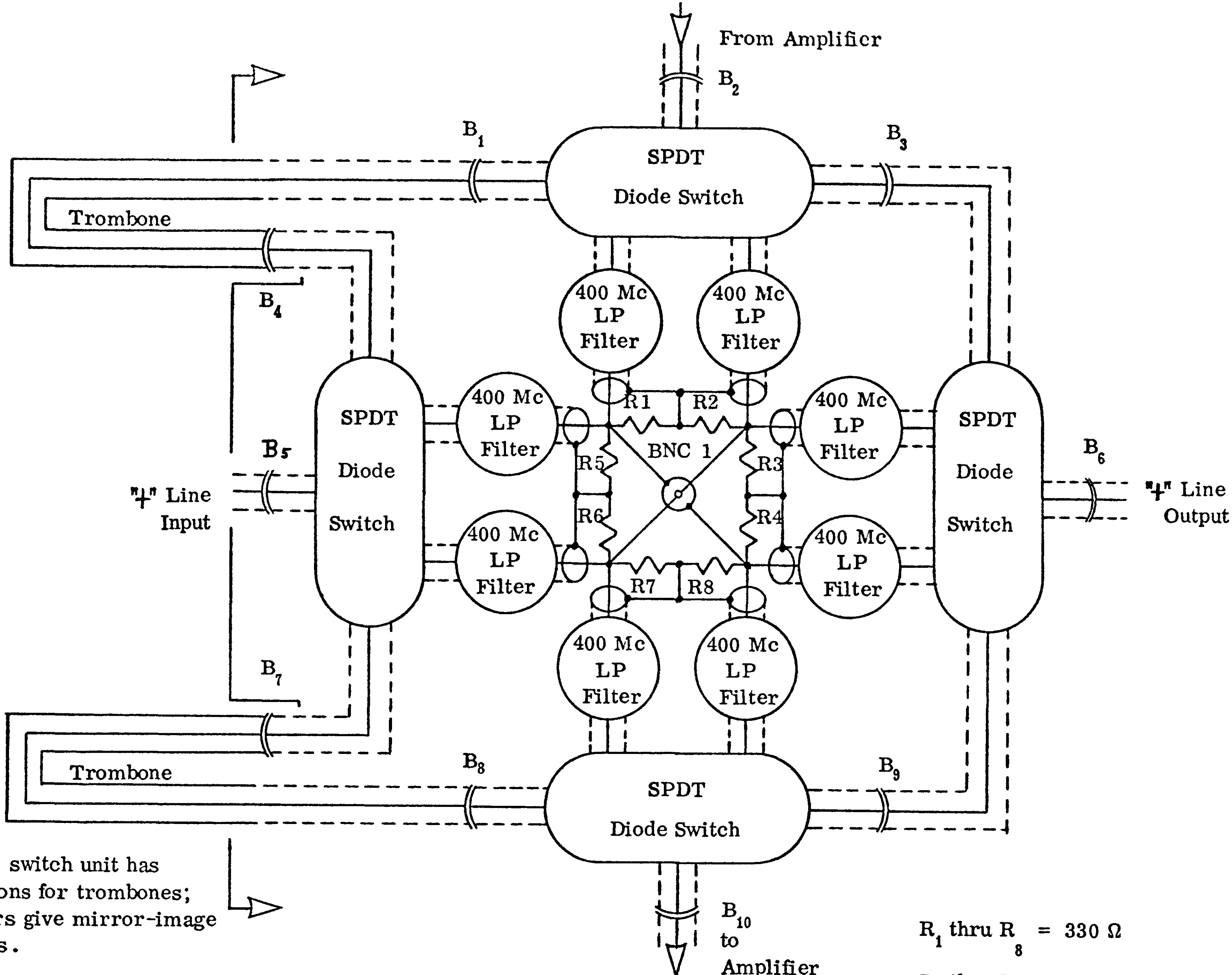
"System" Diagram



Supply Connection

8 — TWT UNIT

J.E.B.



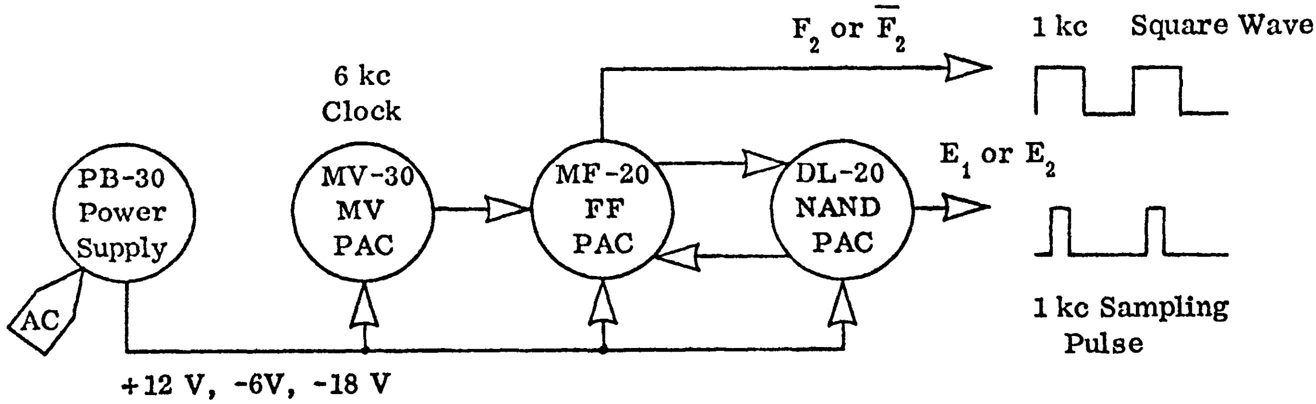
Only one switch unit has connections for trombones; the others give mirror-image diagrams.

R_1 thru R_8 = 330 Ω

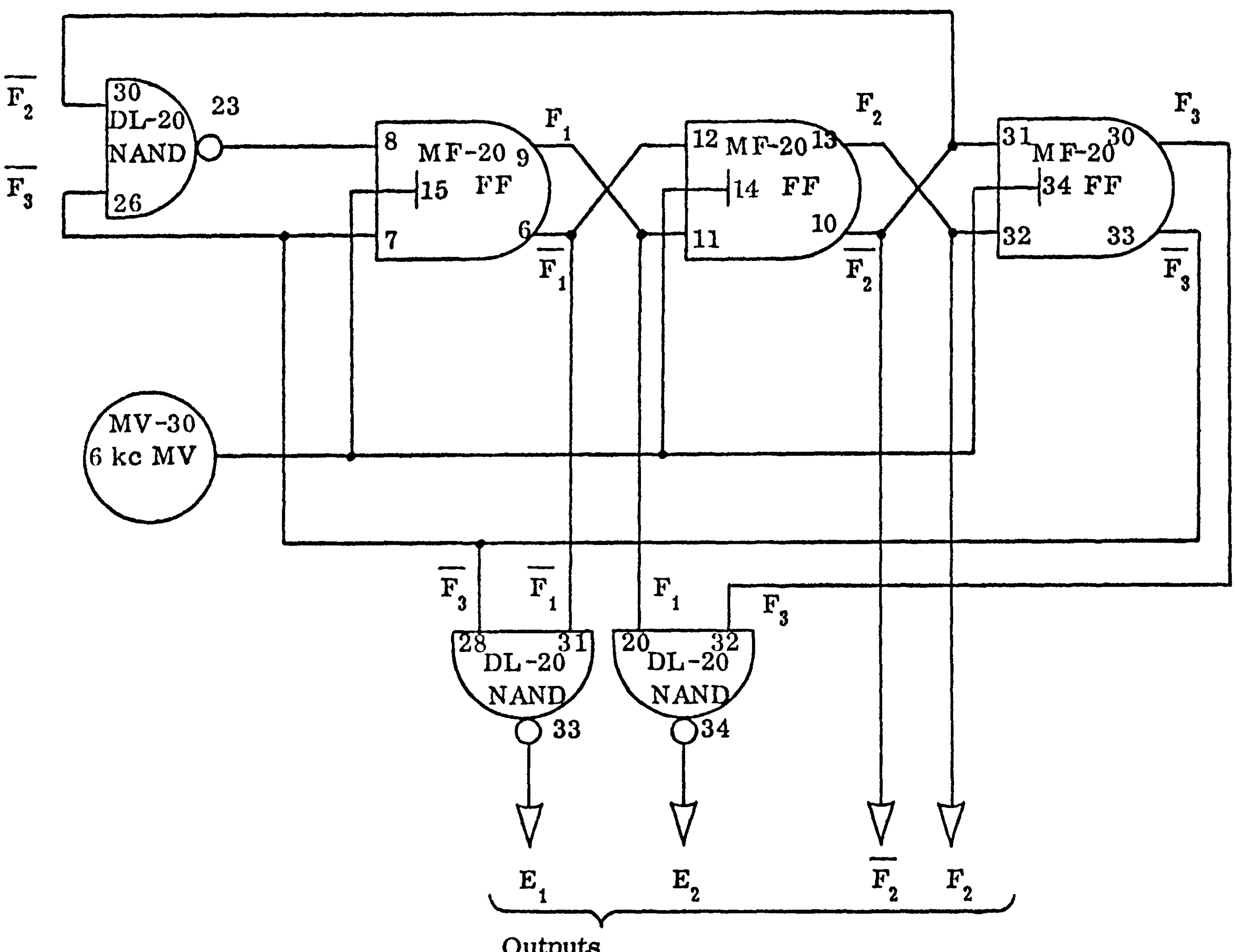
B_1 thru B_{10} = DC Blocks

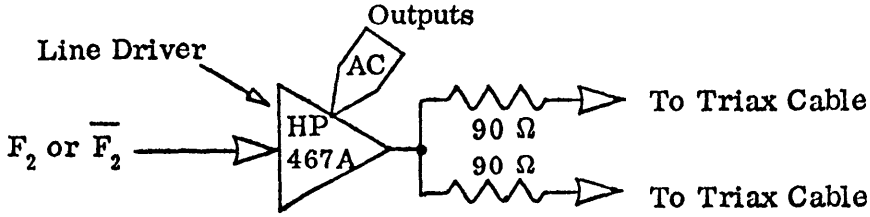
9 — SWITCH UNIT

J.E.B.



General Block Diagram

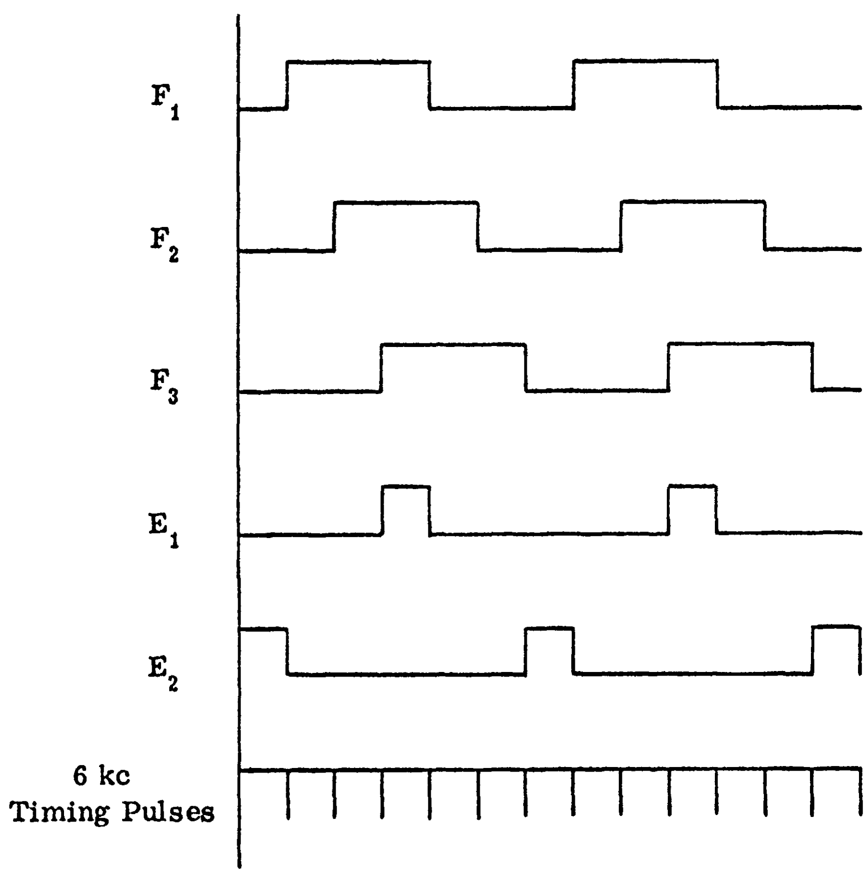




J.E.B.

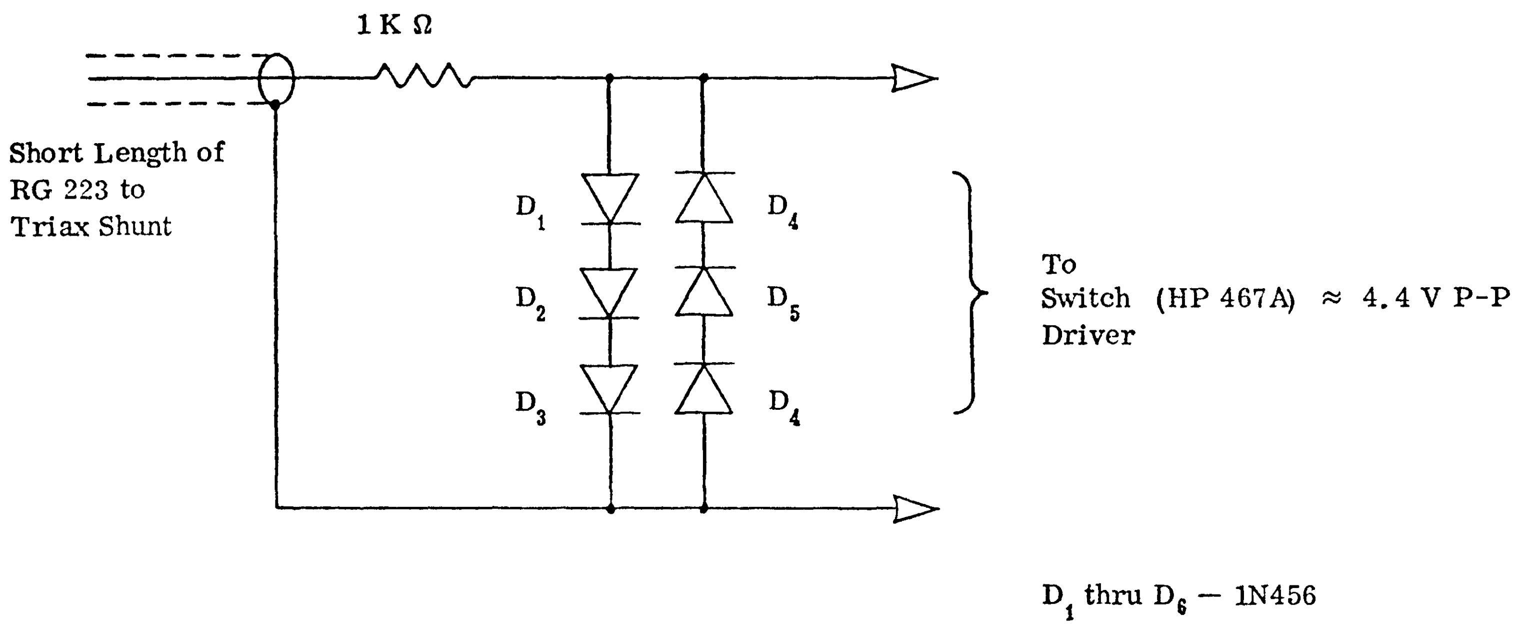
	F_1	F_2	F_3	Interval
	0	0	0	1
	1	0	0	2
	1	1	0	3
	1	1	1	4
	0	1	1	5
	0	0	1	6
	0	0	0	1

CLOCK TRUTH TABLE



11 — CLOCK TIMING DIAGRAM

J.E.B.



12 — SWITCH DRIVER INPUT CLIPPER

J.E.B.