NRL Report 5980

RADIO-INTERFEROMETER ANALOG PHASE-CHANNEL COMBINER (MOD II) FOR UNAMBIGUOUS SPACE ANGLE MEASUREMENTS IN THE NAVY SPACE SURVEILLANCE SYSTEM

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CONTENTS

ABSTRACT

The Navy Space Surveillance System, developed at the Naval Research Laboratory for the purpose of detecting nonradiating earth satellites, forms a radio fence along a great circle across the southern part of the United States. Four receiving sites alternate with three transmitting sites to form the fence. The transmitting stations illuminate satellites with radio energy as they cross the fence. The angle of arrival of the reflected signals is measured at each receiving station by a compound radio interferometer. These signals yield a multiplicity of channels of information which are normally recorded on paper, read, and resolved. Operationally, the resolution is done by a computer, but the angle of arrival can also be resolved by using slide rules and/or tables.

With the increasing satellite population, the number of fence crossings has increased considerably. Automation in the detection process is needed to facilitate the identification and sorting of satellites from each other (and from refuse) if a large backlog of data is to be avoided. The purpose of this report is to describe an electronic system, called the Mod II phase-channel combiner, which automatically combines several noisy phase channels into one quiet channel, with two additional channels being available for vernier readout.

The basic technique used in the Mod II phase-channel combiner is as follows. In the Space Surveillance System station electronics, the phase displacement for each channel is carried by a separate 1-kc signal. For combining purposes, each of these 1-kc signals is translated to a new frequency proportional to the interferometer baseline length, thus normalizing each of the phase channels. This is done by heterodyning the 1-kc signal with a set of reference frequencies derived from the precision oscillator in the station clock. The space angle solution is obtained by coincidence determination of the zero crossings of the above baseline frequencies. Pulses are generated at each zero crossing and monitored in an AND gate circuit. This circuit produces an output for the duration that the pulses from all the new baseline frequencies are in time coincidence. The time displacement of this coincidence pulse from a reference pulse is proportional to the sine of the space angle. This time displacement is detected and transformed into a dc voltage by an analog phase meter for presentation on a recorder, or it is digitalized and fed to a computer. The accuracy of this system is related to the longest baseline in the group.

PROBLEM STATUS

This is an interim report on one phase of the problem; work is continuing on this and other phases.

AUTHORIZATION

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INTRODUCTION

The U.S. Navy Space Surveillance System for the detection of nonradiating earth satellites forms a radio fence along a great circle across the southern part of the United States (1,2). The fence consists of four receiver sites and three continuous-wave (cw) transmitter sites, the latter alternately located between the receiver sites. Both the transmitters and the receivers use fan-type coplanar antenna beams wide in the east-west plane and narrow in the north-south plane. The cw transmitters illuminate the satellite, and radio-interferometer techniques are incorporated at the receiver sites to determine the satellite's position in the east-west and north-south planes. The receiving sites are located at San Diego, California, and Elephant Butte, New Mexico, in the west, and at Silver Lake, Mississippi, and Fort Stewart, Georgia, in the east (Fig. 1). A data-transmission system links the surveillance receivers to NRL, Washington, D.C., and to the Operations Center at the Naval Weapons Laboratory (NWL), Dahlgren, Virginia.

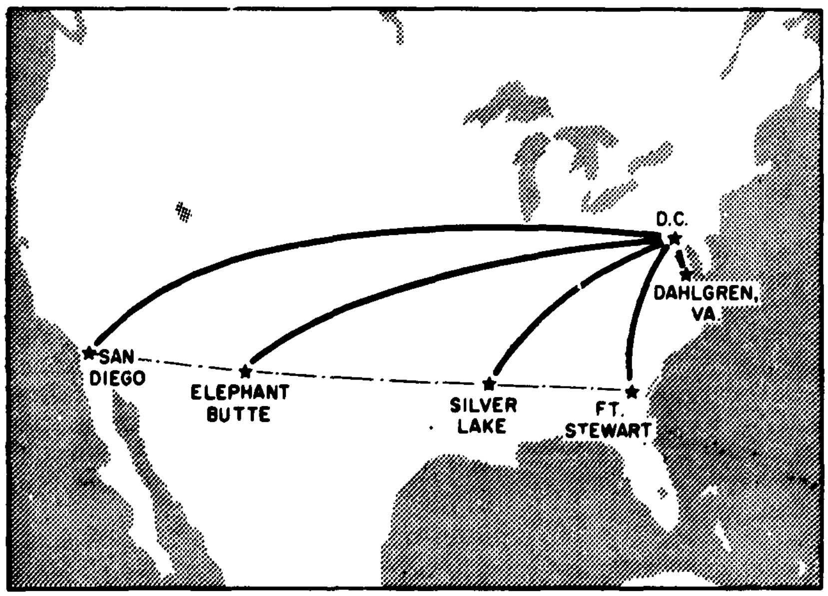


Fig. 1 - Location of the NRL Space Surveillance receiving stations showing the data-transmission lines to Washington, D.C., and Dahlgren, Va.

The angle of arrival of the reflected radio energy is measured at each receiver site by a compound radio interferometer (one that has many antenna pairs) which yields a multiplicity of channels of phase data. These data are fed to the data-transmission line (3) and ultimately transmitted to the Operations Center at NWL, Dahlgren, Virginia, for processing. At the Operations Center the data are recorded on paper in real time and are subsequently read and then analyzed by a computer. Two IBM 7090 computers located at NWL are being instrumented into the system to automatize this operation.

Due to some practical limitations in antenna spacings, the phase channels are individually ambiguous in depicting the angle of arrival of the signals. Therefore it is necessary to make at least some cursory analysis of the data from several phase channels to establish the authenticity of the signals on these channels. This procedure becomes very time-consuming inasmuch as the number of fence crossings has increased with the increasing satellite population.

The purpose of this report is to describe an electronic system which automatically combines several phase channels into one unambiguous channel. This single channel depicts the angle of arrival of the radio energy from the satellite in real time. The angular resolution of the system is a function of the most accurate interferometer channel used in the combiner. When the phase-channel combiner is used at the receiving sites, there is the added advantage of saving channels on the data-transmission line from each site to the Operations Center. Other data, such as doppler and phase rate, can then be added to the overall information received from each site by utilizing the data-transmission channels so released.

OPERATION OF THE SPACE SURVEILLANCE SYSTEM

The Navy Space Surveillance System operates as follows. Continuous-wave radio energy radiated into space from the transmitter sites is reflected from objects to the receiving sites. The transmitting antennas provide illumination in a narrow fan-shaped beam which is coplanar with similar receiving-station beams. The position of a reflecting object in the common antenna patterns is determined by measuring the angle of arrival of the reflected signals by means of interferometers at two of the receiving sites. At each of the receiving stations the data from the phase-measuring equipment are transmitted, in real time, on telephone lines to NRL and to the Space Surveillance Operation Center located at NWL, Dahlgren, Virginia.

The antenna field associated with a receiving site is arranged in pairs of antennas with spacings selected so as to provide the desired degree of accuracy and to eliminate ambiguity. By means of amplifiers and converters, signals from an antenna pair are reduced in frequency, with phase preservation, and the phase difference is compared with a precise stable oscillator as reference. After being filtered, the phase-carrying signals are applied to analog phase meters. The output of the phase meters is recorded, along with universal time, to obtain a permanent record of the time and position of the satellite. The signals are phase coherent with respect to each other, varying in phase with respect to the stable reference oscillator as a function of the satellite's instantaneous position in space and the distance between the antenna pairs.

A typical pair of antennas and the geometry of the situation are shown in Fig. 2. Signals are shown arriving from satellite S. Because of its great height as compared with the baseline distance d between antennas, the rays are essentially parallel. It is clear from the figure that energy reaching antenna B will arrive later than at antenna A. The amount of this phase-front delay is

$$\phi = \frac{2\pi d}{\lambda} \sin \theta$$

where

ϕ = the electrical phase delay (degrees)

d = the electrical spacing between the antennas (in terms of λ)

λ = wavelength of the received signal

θ = the angle of arrival measured from zenith (space degrees).

By instrumenting the antennas with phase-measuring receivers, the space angle θ is measured as a voltage analog in ϕ. It is noted that when d, the antenna spacing, is equal to or greater than $\lambda/2$, the determination of θ becomes ambiguous; on the other hand, the angular resolution is proportional to d. For example, the derivative of

$$\phi = \frac{2\pi d}{\lambda} \sin \theta$$

is

$$d\phi = \frac{2\pi d}{\lambda} \cos \theta \, d\theta ,$$

so the angular resolution is

$$\frac{d\phi}{d\theta} = \frac{2\pi d}{\lambda} \cos \theta .$$

Note that $d\phi/d\theta \rightarrow Kd$ as $\cos \theta \rightarrow 1$, near zenith.

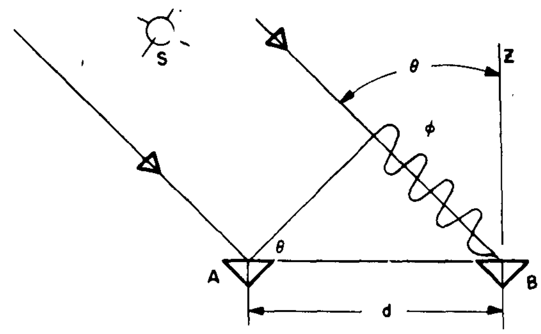


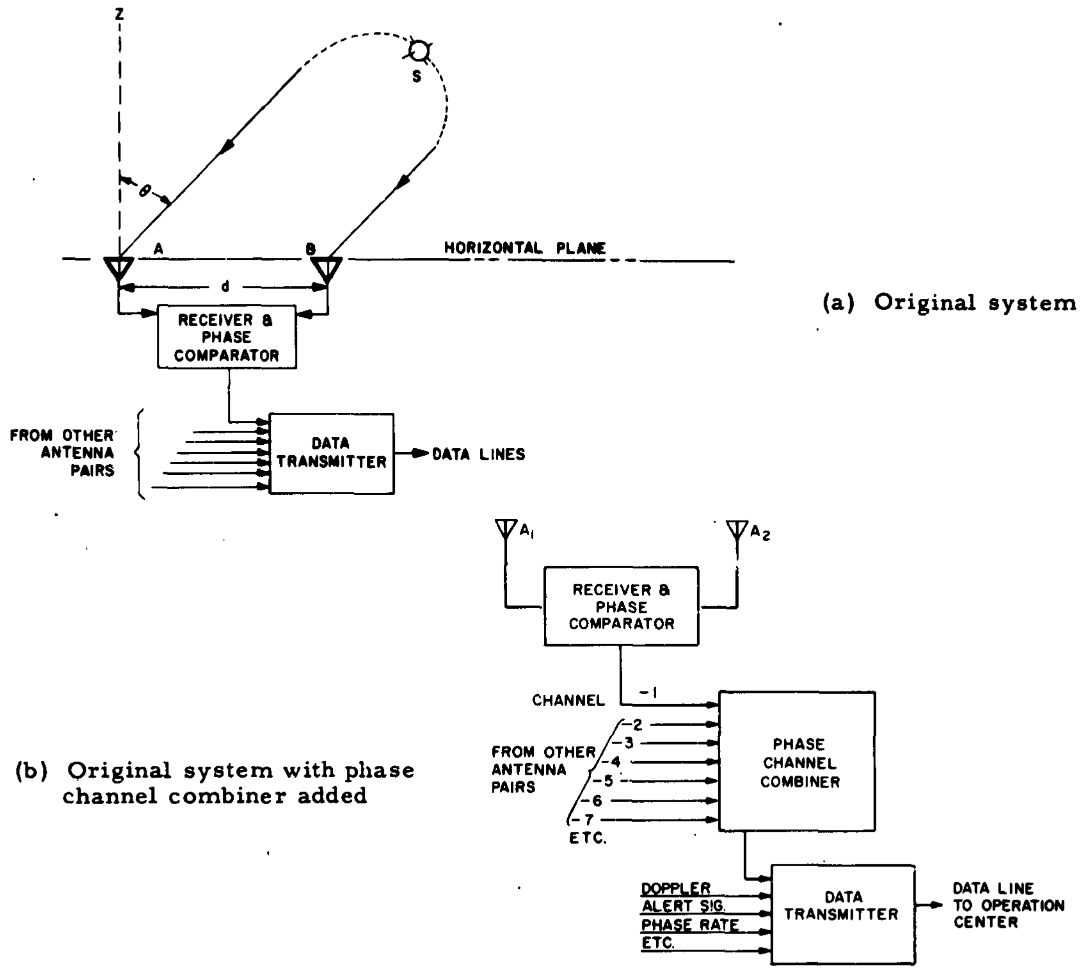
Fig. 2 - Basic geometry involved in the Space Surveillance System with respect to a pair of receiving antennas

In order to take advantage of the resolution improvement obtained by long baselines while circumventing the problem of ambiguity, many pairs of antennas are used, spaced so that signals from each successive pair can be correctly deduced from the signal of the previous pair, when taken in the order from the shortest baseline to the longest.

In summary, it is noted that a pair of antennas provides phase signals for one data channel and that the channels must be analyzed sequentially for an unambiguous solution (see Appendix A). The surveillance system incorporates many pairs of antennas to achieve the required angular resolution. Figure 3 illustrates the relationship between the phase-channel combiner and the surveillance system. Figure 3(a) shows the original procedure by which signals from the various antenna pairs go directly into the data-transmission system to be relayed to Washington, D.C., and Dahlgren, Va.; Fig. 3(b) shows seven channels passing through the combiner, where they are consolidated and then fed to the data transmitter.

THE MOD II PHASE-CHANNEL COMBINER

The combiner presently in operation combines the first five baselines (16, 20, 52, 60, and 128 ft) in one group, the next two baselines (392 and 520 ft) into a second group, and, finally, the four longest baselines (520, 1040, 2080, and 5200 ft) in a third group. The combiner operates as follows: In the Space Surveillance System station electronics, the phase displacement for each channel is carried by a separate 1-kc signal (see Appendix B). For combining purposes (Fig. 4), each of these 1-kc signals is translated to a new frequency proportional to the baseline length, thus normalizing each of the phase channels. This is done by heterodyning the 1-kc signal with a set of reference frequencies derived from the precision oscillator in the station clock as opposed to the technique used in the Mod I Combiner (4). The space angle solution is obtained by coincidence determination of the zero crossings of the above frequencies. Pulses are formed, generated at each zero crossing, and monitored in an AND gate circuit. This circuit produces an output for the duration that the pulses from all the new baseline frequencies are in time coincidence. The time displacement of this coincidence pulse from a reference pulse is proportional to the sine of the space angle. This time displacement is detected and transformed into a dc voltage by an analog phase meter (see Fig. B2, Appendix B) for presentation on a recorder, or it is digitalized and fed to a computer. The accuracy of this system is proportional to the longest baseline in the group. The first group consisting of five basel[illegible], with the most accurate being the 128-ft baseline. The second



(a) Original system

(b) Original system with phase channel combiner added

Fig. 3 - Illustration of how the phase-channel combiner fits into the original space surveillance system

group consisting of two additional baselines (392 and 520 ft) with the 520-ft line being the precision-determining channel. This second group is combined with the same technique used in combining the first group, and the coincident pulse so derived is gated into a second AND gate. The latter's output pulse is fed to a second analog phase meter, yielding a second analog of the sine of the space angle but, in this case, with much greater precision. Similarly, the third group (520 to 5200 ft) is also combined; the three groups are then gated to a third phase meter. The latter yields, therefore, the maximum precision output since it contains the signal from the longest baseline in the system.

In summary, therefore, the net result of this combining technique is an output signal which is the unambiguous analog of the sine of the space angle and has the accuracy and resolution of the longest baseline being combined.

The high accuracy of the combiner output is obscured when it is recorded on a single recorder channel; therefore, a vernier readout on this output has been provided by generating two additional virtual signal outputs (5). These two signal channels (x10 and x100) can be recorded alongside the combiner output channel. The additional vernier channels essentially magnify the readout resolution.

The first two groups of channels use 100 cps as a base frequency for heterodyning the 1-kc system frequencies to new baseline frequencies; the third group operates on a base frequency of 1000 cps. The reason for this change in frequency follows shortly in the text. The new baseline carrier frequencies are listed in Table 1.

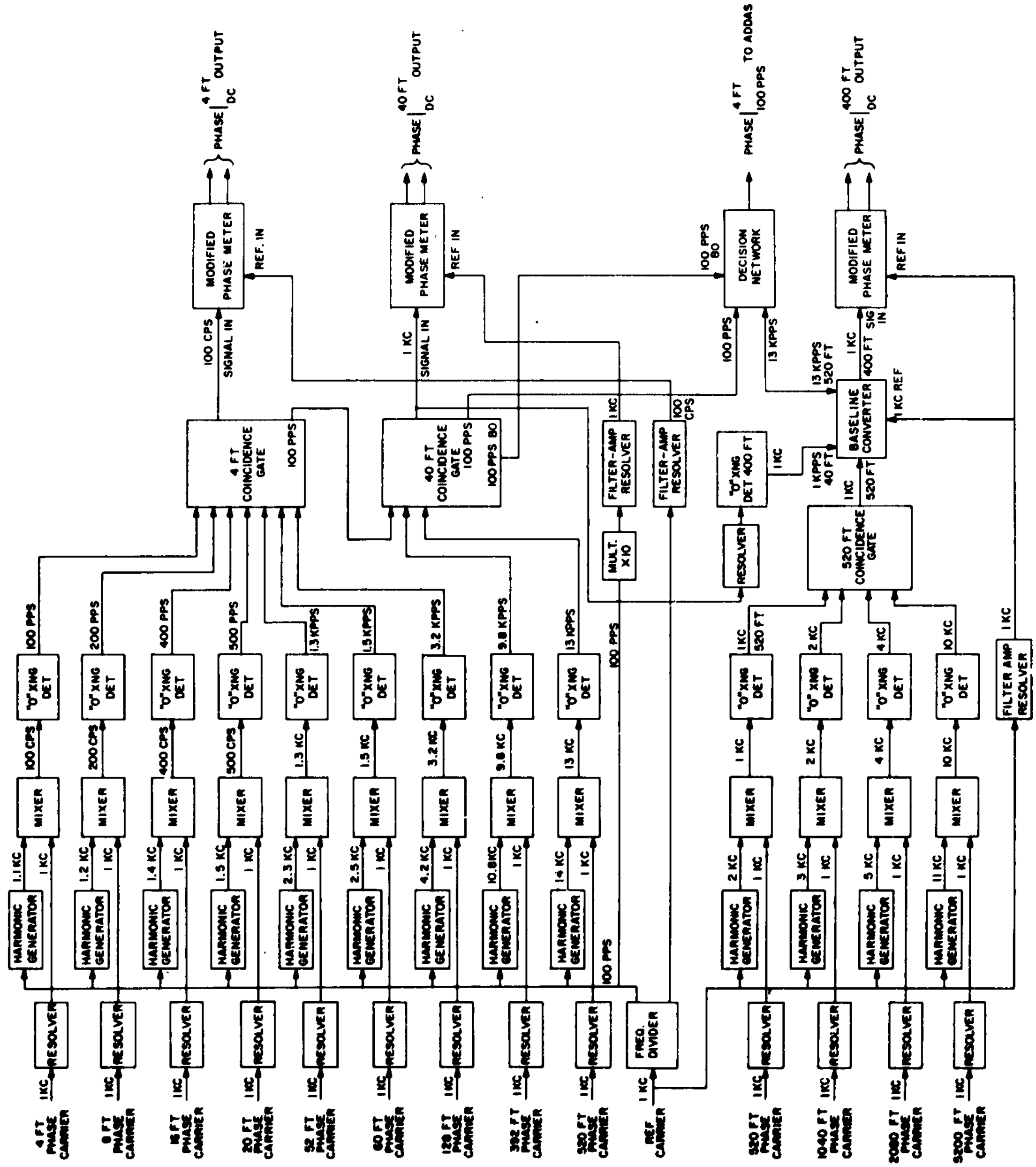


Fig. 4 - Phase-channel combiner block diagram

Table 1
New Baseline Frequencies Generated by Heterodyning the 1-kc System Frequencies with the Precision Clocks at the San Diego, Silver Lake, and Elephant Butte Receiving Sites

Baseline (ft)	New Phase-Carrying Frequencies (cps)	Pulse Width (ms)†	Pulse Width (ms)‡
4*	100	4.4	---
8*	200	2.2	---
16	400	1.0	0.63
20	500	0.8	0.45
52	1300	0.33	0.154
60	1500	0.29	0.133
128	3200	0.13	0.0625
128	3200	0.13	0.13
392	9800	0.04	0.04
520	13000	0.03	0.03
520	1000	0.440	0.440
1040	2000	0.220	0.220
2080	4000	0.110	0.110
5200	10000	0.044	0.044

*The 4- and 8-ft baselines apply to the San Diego, Calif., site only.
†Pulse width for the combiner at the San Diego, Calif., station.
‡Pulse width for the combiners at the Silver Lake, Miss., and the Elephant Butte, N.M., stations.

Inspection of the three groups of frequencies in Table 1 shows that if the frequency were to keep on increasing as the baseline length increased, the frequency would be 130 kc at the 5200-ft baseline. Since this is a rather high frequency, calling for undue rigor in the accompanying pulse circuitry, it was decided to establish a new reference of 1 kc for the third set of baselines. (Attention is called to the fact that each group of combined baselines, after the first, combines the output signal from the first group and the longest baseline of the previous set, as shown in Table 1 and Fig. 4. This is to prevent readout ambiguity.)

As each of the new phase-carrier frequencies passes through respective zero-crossing detectors, a pulse is formed which feeds the corresponding AND gate circuit for the particular group of channels being combined. The width of each of these pulses is shown in Table 1 alongside the new carrier frequencies.

Combiners at Silver Lake, Miss., Elephant Butte, N.M., and San Diego, Calif., incorporate frequencies and pulse widths as shown in Table 1. The Ft. Stewart, Ga., site, on the other hand, has a different set of antenna baselines; consequently, the combiner uses different heterodyne frequencies and pulse widths. These are shown in Table 2.

Table 2
New Baseline Frequencies Generated by Heterodyning the 1-kc System Frequencies with the Precision Clock at the Ft. Stewart Receiving Site

Baseline (ft)	New Phase-Carrying Frequency (cps)	Pulse Width (ms)
16	400	0.590
24	600	0.280
28	700	0.260
68	1200	0.130
136	3400	0.050

As noted in Tables 1 and 2, the width of the coincidence pulses are different for each baseline. The width used, in each case, is determined as follows: Theoretically the width of the pulse for the shortest baseline can be just short of one-half period of the frequency used for the next longer baseline in the system (see Fig. 5). If this plan is followed throughout all baselines, coincidence of all pulses can occur at only one time. However, tests indicate that a maximum pulse width of about 40 percent of the next higher baseline period gives better combining results. The 10 percent difference gives looser design tolerances in the individual circuits, but does not compromise system accuracy since the longest baseline pulse controls the final readout circuits. Also, the longest baseline pulse requires no tailored width since the monitoring analog phase meter triggers on the leading edge of this pulse.

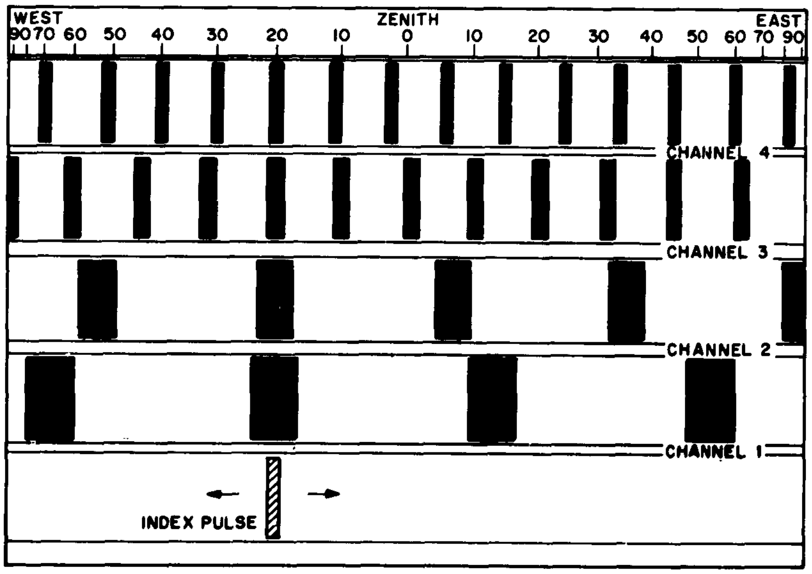


Fig. 5 - Photographs of a model used to demonstrate the action of the coincidence pulses. Coincidence is shown on Fig. 5 at 20 degrees west of zenith. A similar action occurs for signals arriving east of zenith.

LABORATORY TESTS OF THE COMBINER

Earlier versions of phase-channel combiners combined only a few channels, and it was practicable to use a laboratory signal simulator to test the combiner operation (4). However, as more and more channels were added to the combiner, the signal simulator — which consists of many motor-driven phase resolvers — became inadequate to simulate the Space Surveillance System signals. For this reason, later laboratory tests were limited to essential calibrations and a check of the individual circuits involved.

A sample laboratory recording of the use of a four-channel signal simulator is shown in Fig. 6. The sawtooth waveforms shown are the outputs of the monitoring analog phase meters for the 16, 20, 52, and 60-ft baselines, respectively, as read from the top of the figure toward the bottom. The bottom channel is the combiner output which, as noted, is a single-sweep unambiguous signal. Its trace covers the ordinate scale once, whereas the other channels do so many times. The waveforms so generated are noise free and considered ideal, i.e., representing the strong signal level case. Random amplitude-noise was added to the simulated waveforms to test the signal-to-noise resolving power of the combiner. (Granted that phase noise would have been more appropriate, it was not readily available in the laboratory.) The combiner was found to hold synchronization and signal output well below a signal-to-noise ratio of one. Circuit inertia (integration time) was found to be negligible, being masked primarily by the mass of the recorder writing pens. Drift, jitter in the pulse circuitry, and reliability of operation over extended periods were deemed adequate for field operation. However, it was recommended that a system electrical check should occur twice each 24 hours of operation.

FIELD TESTS OF THE COMBINER

The Mod II combiner, consisting of the first group of channels up through the 128-ft baseline, is now operational at all of the Space Surveillance sites. Its signal output has been substituted for the first four baselines, making angle readout somewhat easier, as well as releasing three data channels from each site for other data. Recorded data is shown in Figs. 7, 8, 9, and 10. Figure 7 shows a typical satellite signal recording. AGC (signal strength) is recorded on the bottom channel (channel 1), and coded-time marks are shown along the bottom edge of the record. The combiner output for a virtual 4-ft baseline is on channel 2,* with an alert signal on an auxiliary pen between channels 1 and 2. The space angle is determined simply by measuring the percent deflection of this channel signal above its zero reference line and then looking up the angle corresponding to this deflection in Table 3. The remaining channels are the uncombined phase reading channels. Attention is directed to the noise-free combiner signal on channel 2 which supports the fact that noise is reduced proportional to the longest baseline involved. For example, if the longest baseline combined were the 128-ft baseline, the noise would be reduced by 32 over that which would appear on a recorded 4-ft baseline. (The above assumes equal noise levels on all baselines.)

During the writing of this report, two Extended and Long-Baseline Combiners were completed. One was shipped to the San Diego, Calif., station in April-May 1963, and the other to the Silver Lake, Miss., site and tested for about one week with satellite signals under field conditions. The results of the field tests were found satisfactory, and the Extended and Long-Baseline Combiners were put on the data line, replacing the usual phase signals from the system with virtual signals arranged into three channels, namely, the 4-, 40-, and 400-ft baselines. The angle readout of this combination is explained more fully in Appendix G.

*See Appendix C, page 32, for explanation of offset.

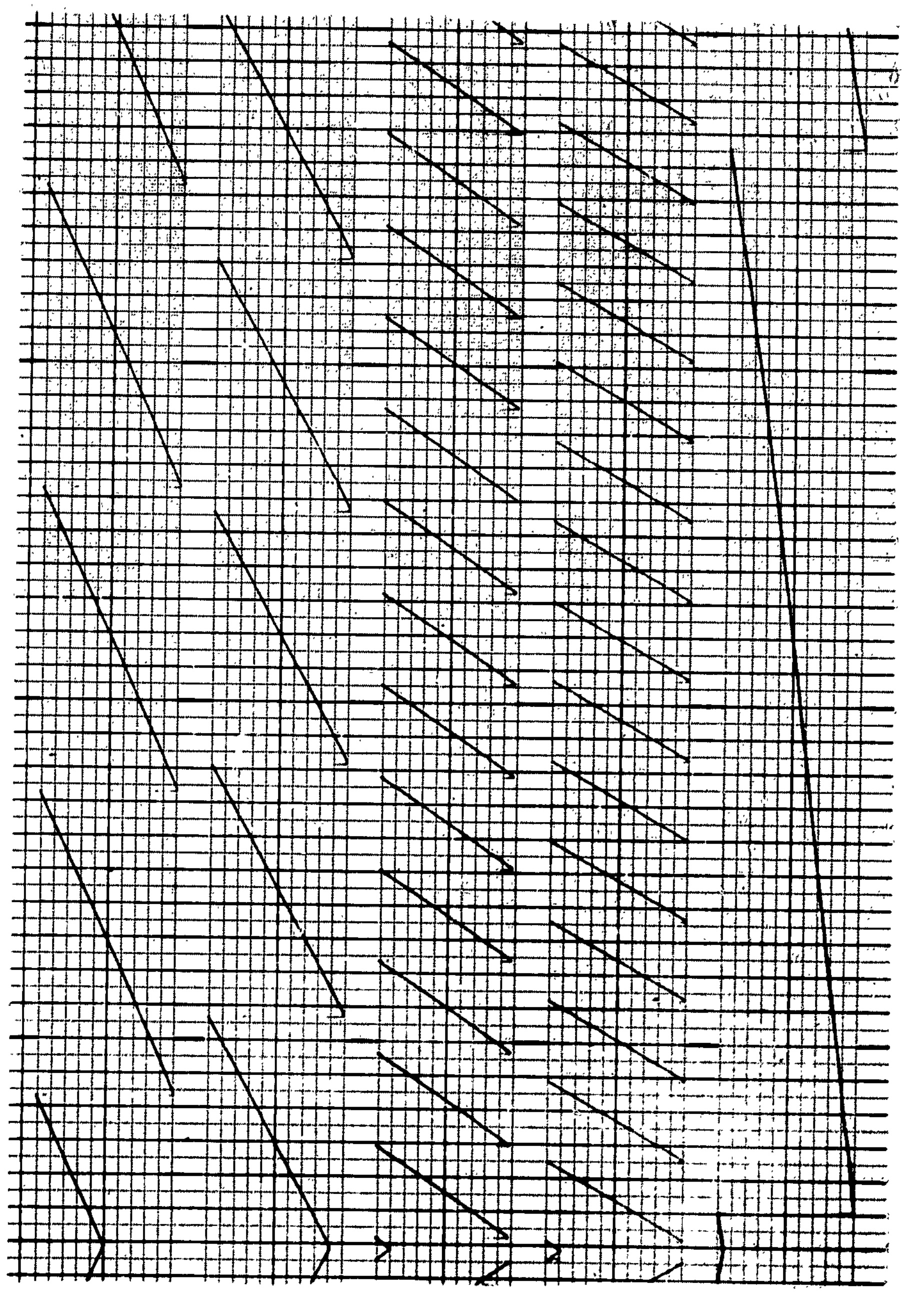


Fig. 6 - Recording of the output of a laboratory signal simulator generating four channels of the Space Surveillance System (16-, 20-, 52-, and 60-ft baselines, as read from the top), and the combined resultant (bottom channel) achieved by use of the Mod II phase-channel combiner

Table 3
Space Angle vs. Percent Deflection

Defl. (%)	Space Angle (West)	Defl. (%)	Space Angle (West)	Defl. (%)	Space Angle (East)	Defl. (%)	Space Angle (East)
0	90.00	26	28.69	51	1.15	76	31.33
1	78.52	27	27.39	52	2.29	77	32.68
2	73.74	28	26.10	53	3.44	78	34.06
3	70.05	29	24.83	54	4.59	79	35.45
4	66.93	30	23.58	55	5.74	80	36.87
5	64.16	31	22.33	56	6.89	81	38.32
6	61.64	32	21.10	57	8.05	82	39.79
7	59.32	33	19.88	58	9.21	83	41.30
8	57.14	34	18.66	59	10.37	84	42.84
9	55.08	35	17.46	60	11.54	85	44.43
10	53.13	36	16.26	61	12.71	86	46.05
11	51.26	37	15.07	62	13.89	87	47.73
12	49.46	38	13.89	63	15.07	88	49.46
13	47.73	39	12.71	64	16.26	89	51.26
14	46.05	40	11.54	65	17.46	90	53.13
15	44.43	41	10.37	66	18.66	91	55.08
16	42.84	42	9.21	67	19.88	92	57.14
17	41.30	43	8.05	68	21.10	93	59.32
18	39.79	44	6.89	69	22.33	94	61.64
19	38.32	45	5.74	70	23.58	95	64.16
20	36.87	46	4.59	71	24.83	96	66.93
21	35.45	47	3.44	72	26.10	97	70.05
22	34.06	48	2.29	73	27.39	98	73.74
23	32.68	49	1.15	74	28.69	99	78.52
24	31.33	50	0.00	75	30.00	100	90.00
25	30.00						

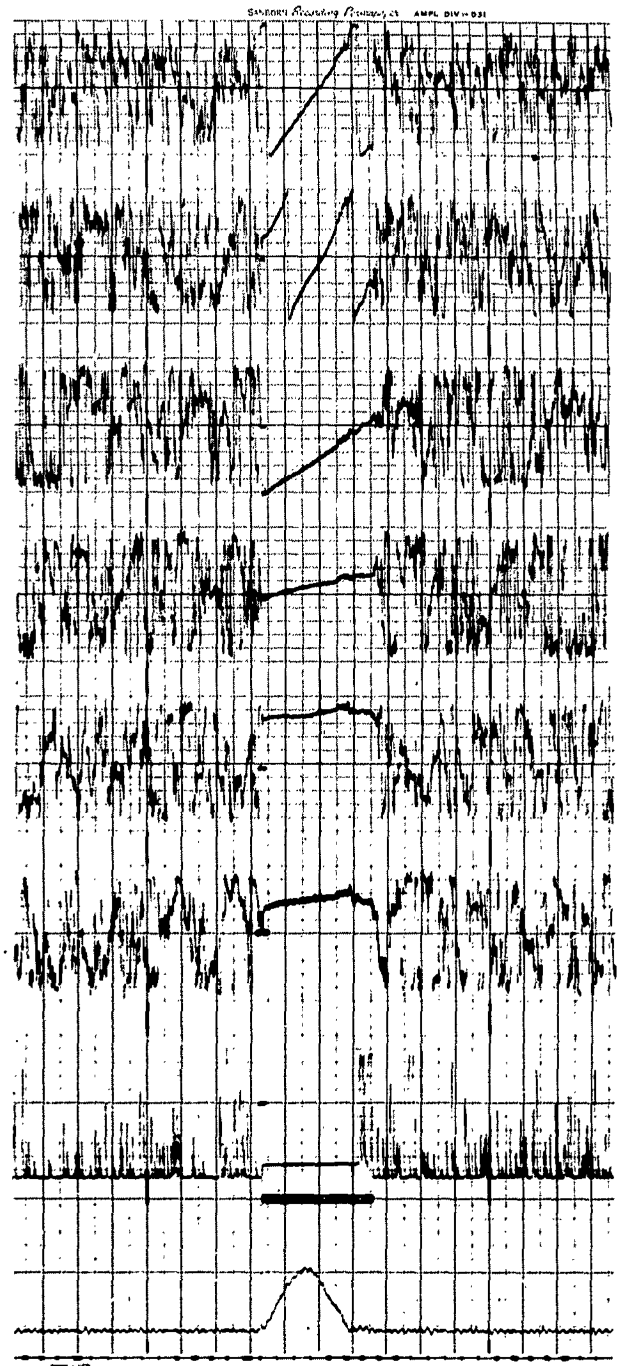


Fig. 7 - Typical satellite-pass recording of agc signal, shown on channel one (bottom), and combiner output, shown on channel 2, which reads 66.93 degrees west of zenith, as determined from Table 3

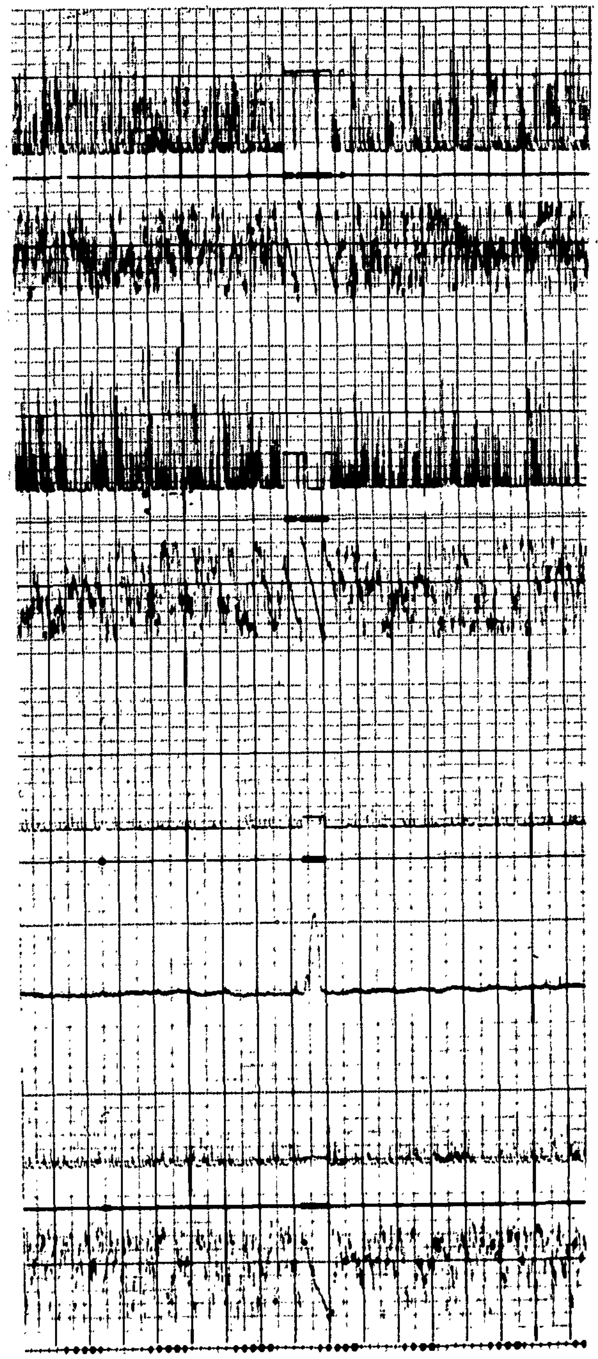


Fig. 8 - Four-station coincidence recording with combiner signals on channels 2, 4, 6, and 8 (as read from the bottom up)

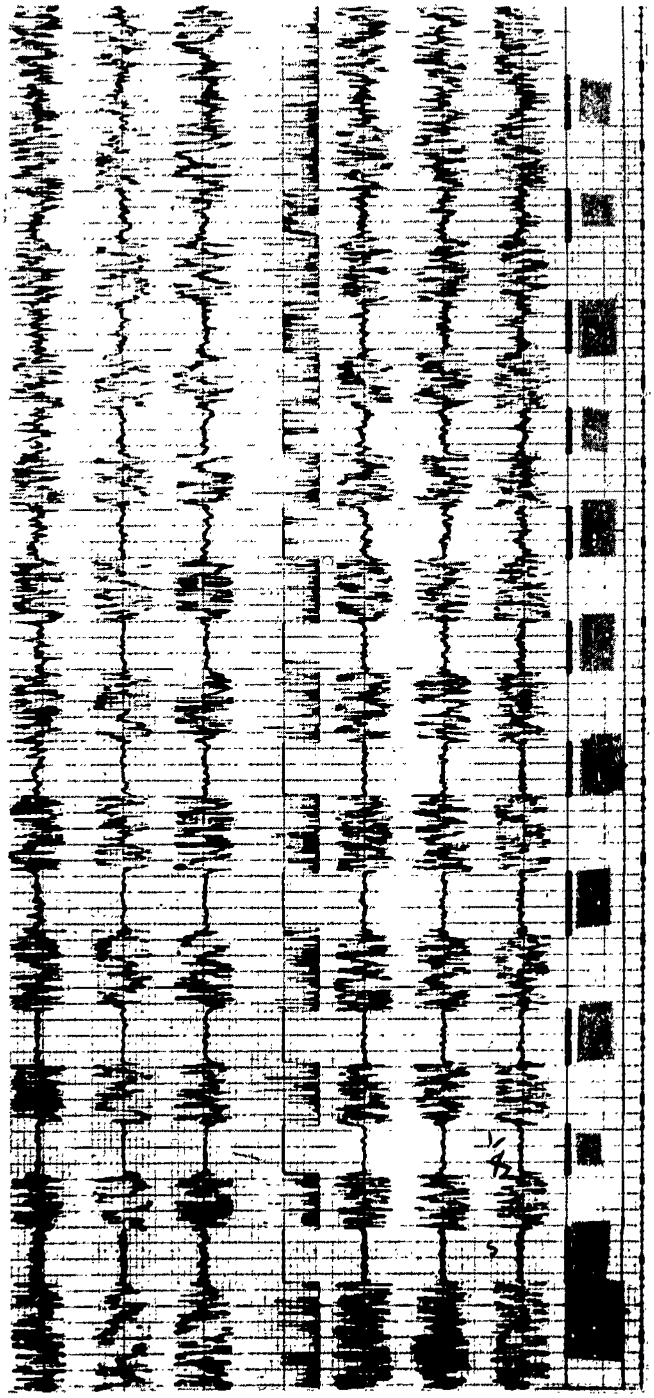


Fig. 9 - Recording of sensitivity test. Agc signal strength is on channel 1 (bottom); combiner is on channel 5.

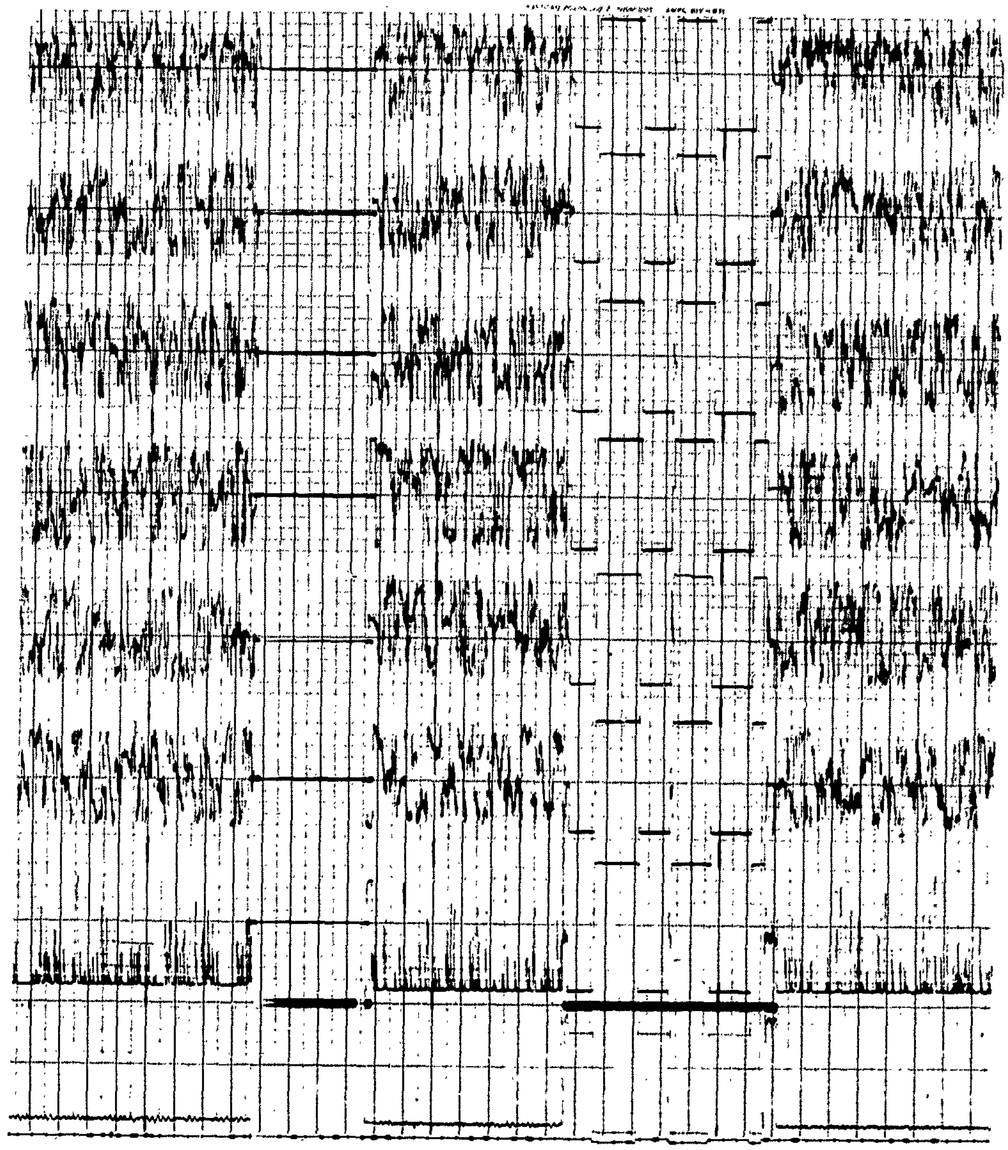
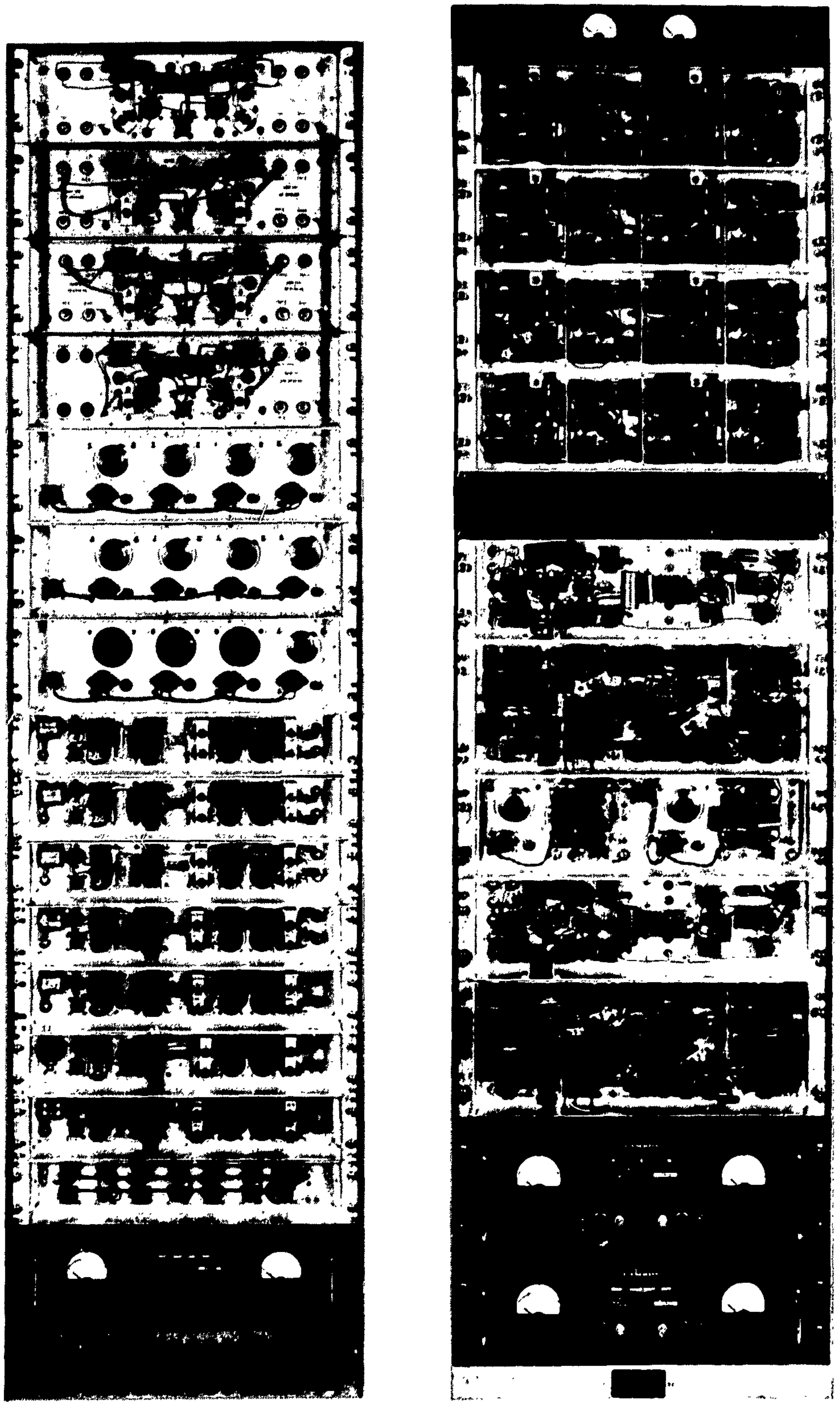


Fig. 10 - Calibration recording with combiner signal on channel 2

CONCLUSIONS

The new-phase channel combiner (shown in photographs in Fig. 11) for combining phase channels from a compound radio interferometer has advantages over the prototype combiner. It is simpler electronically than the original combiner concept (4) because simulated sawtooth signals are not required and synchronization is inherent between channels. The latter is possible because all of the generated new phase-carrying frequencies are derived from a common source, the stable station clock frequency.

In summary, the tedious problem of data reduction associated with a multibaseline radio interferometer is reduced to a simple direct readout operation without loss of accuracy, resolution, or time.



(a) (b)

Fig. 11 - Phase-channel combiner showing (a) heterodyne-circuitry and (b) pulse-circuitry

FUTURE WORK

Future plans call for the combining of the N-S baselines. Most of the circuit work is completed for this job. Signals from the N-S set of combined baselines can be used in conjunction with the E-W group to determine the direction the satellite is traveling with respect to the fence, as well as to give data on the velocity vector by determining the phase rate of the signals (Fig. 12).

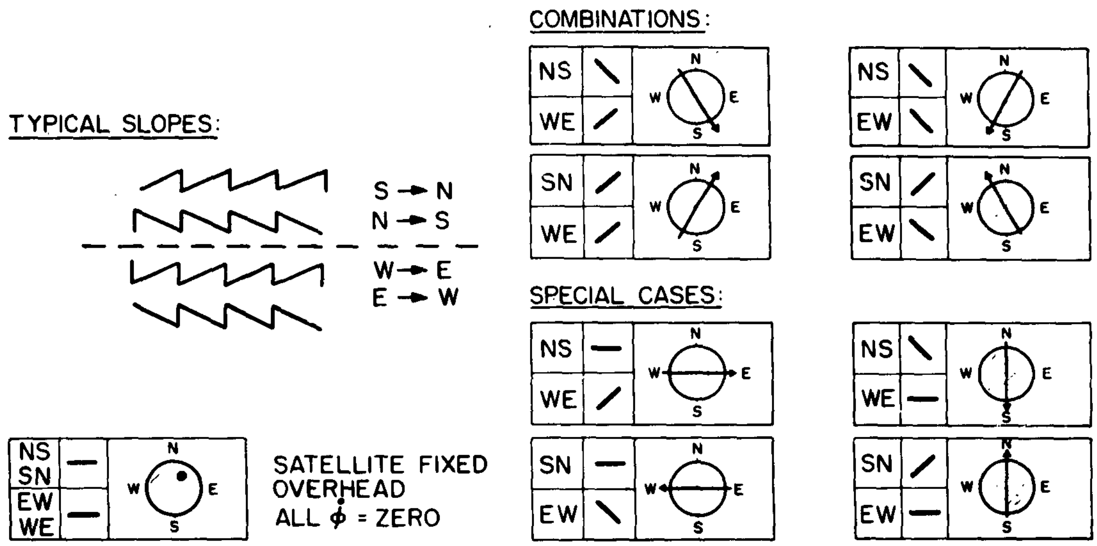


Fig. 12 - The direction of a satellite's pass through the fence as determined from the slopes of the phase signals

Any combiners for a new radio fence, or an addendum to the present Space Surveillance System, would probably be simpler to design since the baseline lengths could be preassigned, thus allowing more convenient heterodyning ratios. By grouping the various baselines harmonically, the new phase-carrying frequencies — which are proportional to each baseline — would be easier to generate. Magnification of each baseline would also be simplified for vernier readout.

Further sophistication may be introduced by having each phase-carrying frequency generated initially at predetection level. An improvement in the signal-to-noise ratio would result because the signal would not have to pass through postdetection heterodyning circuitry.

For digitizing the phase reading, the reference pulse of the system can be used to trigger a pulse counter, set in its internal mode, and the space angle indicating pulse can be used to stop the count. This train of pulses — the number being proportional to the space angle — can be converted to a binary (or other) code and directed to magnetic tape as required for computer automation. By using a high pulse repetition rate in the counter, good resolution can be obtained (Fig. 13).

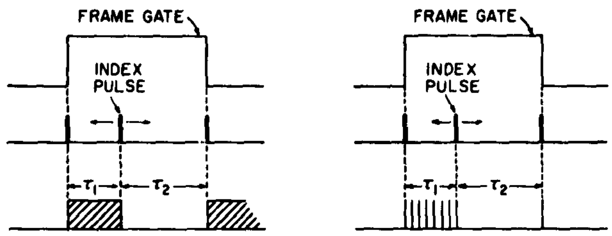


Fig. 13 - Waveforms pertaining to two combiner outputs: (a) the analog phase meter and (b) the pulse count

ACKNOWLEDGMENTS

The authors are particularly indebted for the support and advice of their supervisor, Mr. R. L. Easton, head of the Space Surveillance Branch; for the technical counsel of Mr. L. O. Hayden and D. W. Lynch; for the design and construction of the heterodyne sections of the combiner by Messers. R. Zirm, R. Brescia, and J. Perlman; for the assistance of Mr. R. Moore who designed the decision circuitry (not discussed in this report) and, c ;rwise, was of valuable assistance in the field and laboratory; for the excellent cooperation of the managers and personnel at the field stations, especially during the initial trial and evaluation tests of the combiners; and lastly, for the cooperation of the officers and men at the Navy Space Surveillance Operations Headquarters, Dahlgren, Virginia, under Commanding Officer, Captain E. Van Ribbink, and his executive officer, Commander R. Carr.

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APPENDIX A

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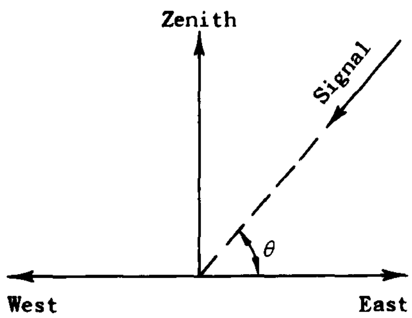
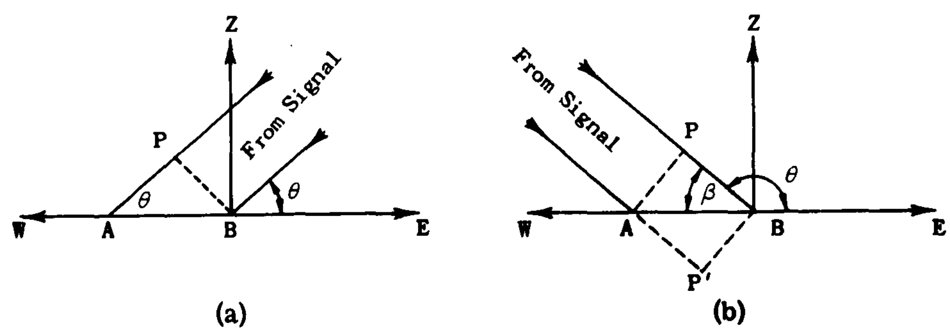
Space Surveillance Branch

A REVIEW OF THE PHASE PROBLEM IN THE SPACE SURVEILLANCE RADIO-INTERFEROMETER SYSTEM

The following treatment of the phase relationships in the radio interferometer was worked out by the writer partly for self-familiarization with the mathematical relationships involved, and partly to deduce a basis for the design of electronics for processing the phase data. A mathematical form was obtained which appears convenient for processing the data with existing basic types of electronic circuitry.



Since the transmitted and received signal is confined essentially to a plane, one coordinate is sufficient to describe the direction of arrival of these signals. This coordinate, the angle θ in the first sketch, is measured from the eastern horizon and ranges from 0 to 180 degrees. In the second sketch it is seen that for signals arriving from the east, $\cos\theta = PA/BA$; for signals arriving from the west, $\cos\theta = \cos(180 - \beta) = -\cos\beta = -PA/BA$, where PA is the difference in path length for signals arriving from a great distance at A and B, and BA is the spacing between the two antennas under consideration. $\cos\theta$ is a single-valued function over the range of 0 to 180 degrees and proves to be convenient to use as a coordinate in lieu of the angle θ. This is done later in the discussion.



For any choice of baseline

$$\cos\theta = \frac{\text{Difference in Path Length}}{\text{Baseline}}.$$

Expressed in electrical degrees, $\cos\theta$ becomes

$$\cos\theta = \frac{n(360) + \Phi}{m(360) + \Psi}$$

where

$$|\cos\theta| \leq 1 ,$$

$$n = 0, \pm 1, \pm 2, \text{ etc.},$$

and

$$m = 0, 1, 2, \text{ etc.}$$

The phase delay angles Φ and Ψ account for the part of the path length and baseline, respectively, which is not an integral multiple of 360 degrees. In terms of wavelength, $\cos\theta$ becomes

$$\cos\theta = \frac{n + \phi}{B} ,$$

where

$n = 0, \pm 1, \pm 2, \pm 3$, etc., and

ϕ is the nonintegral part of path length difference in wavelengths,

B is the baseline in wavelengths and fractional parts thereof.

If we have, for example, three baselines B_1, B_2, and B_3, then

$$\cos\theta = \frac{n_i + \phi_1}{B_1}$$

$$\cos\theta = \frac{n_j + \phi_2}{B_2}$$

$$\cos\theta = \frac{n_k + \phi_3}{B_3}$$

where $|\cos\theta \leq 1|$ and the subscripts on the n's are meant to indicate that each n goes through a different set of values for a given baseline B. The phase delay angles ϕ_1, ϕ_2, and ϕ_3 are determined by observation in each case, and B_1, B_2, and B_3 are known constants of the system. This leaves the four unknowns θ, n_i, n_j, and n_k. The number of unknowns will exceed the number of equations by one for any number of baselines. To solve these equations some additional restrictions must be imposed. Suppose n_i can be uniquely determined from ϕ_1. This allows the following solution of this set of equations to be obtained:

$$n_j = \left(\frac{n_i + \phi_1}{B_1}\right) B_2 - \phi_2$$

$$n_k = \left(\frac{n_j + \phi_2}{B_2}\right) B_3 - \phi_3$$

$$\cos\theta = \left(\frac{n_k + \phi_3}{B_3}\right) .$$

The first two equations may be considered approximate and are used to determine the correct integers to use for n_j and n_k. The last equation is considered exact. The above procedure is essentially what is carried out by slide rule methods and necessitates sufficient accuracy in determining the n's so that the error ϵ in the value of n is less than 0.5.

A plot of ϕ in fractions of wavelength against the space angle θ is given in Fig. A1 for baselines of 4, 24.4, 28.4, and 52.8 ft.* From Fig. A1 it is readily seen that on the 4-ft base line

$$n_1 = 0 \quad \text{if} \quad 0 < 90°$$

and

$$n_1 = -1 \quad \text{if} \quad 0 > 90°.$$

Similarly,

$$n_2 = n_3 = -1 \quad \text{if} \quad \theta = 90 + \epsilon$$

and

$$n_2 = n_3 = 0 \quad \text{if} \quad \theta = 90 - \epsilon,$$

provided that ϵ is sufficiently small. These values of the n's are necessary to satisfy the condition

$$|\cos \theta| \leq 1 .$$

Careful attention to the 24.4- and 28.4-ft baselines shows that:

IF	THEN
$0.56 \leq (\phi_3 - \phi_2) \leq 1.0$	$90° < \theta < 180°$
$0.00 \leq (\phi_3 - \phi_2) \leq 0.42$	$0° < \theta < 90°$
$-0.42 \leq (\phi_3 - \phi_2) \leq 0.00$	$90° < \theta < 180°$
$-1.00 \leq (\phi_3 - \phi_2) \leq -0.56$	$0° < \theta < 90°$.

These phase difference categories could be used to isolate the correct region of the sky, and other criteria (e.g., precise values of θ_2 and θ_3) could be used to determine a more precise direction in the sky. However, the process seemed more involved than another approach which has been pursued.

If we take the derivative with respect to θ of

$$\cos \theta = \frac{n + \phi}{B_1},$$

*As discussed in the main body of this report, the subsequent system design now uses only integral values for baseline lengths.

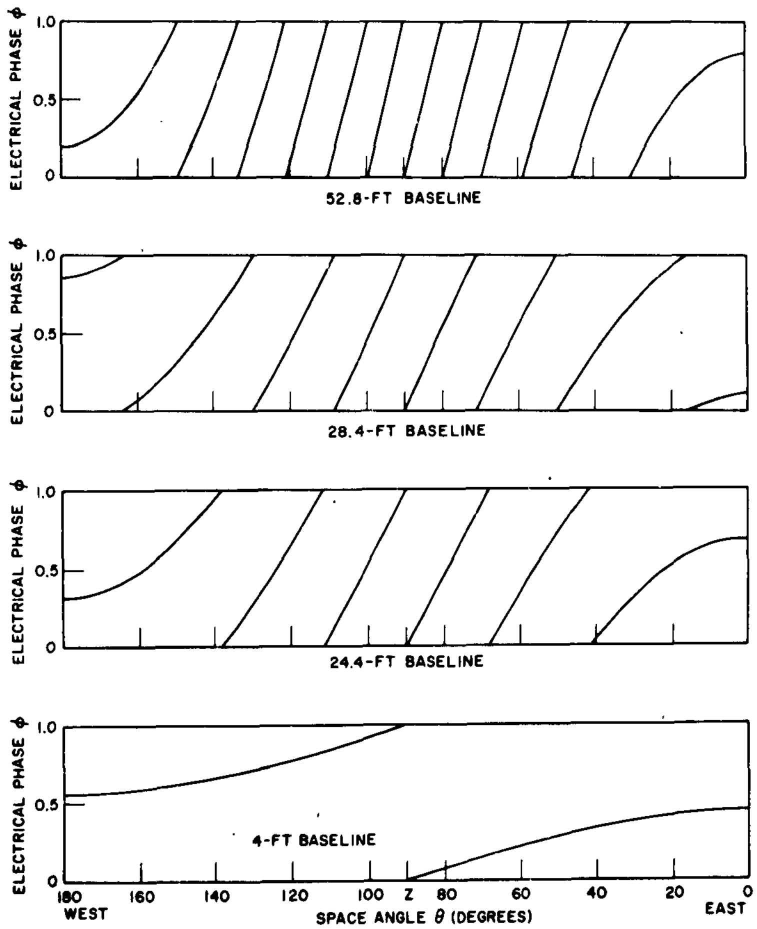


Fig. A1 - Electrical phase delay ϕ (in terms of wavelength) vs space angle θ measured from the eastern horizon. The data shown are for four different baselines.

we obtain

$$\frac{d\phi}{d\theta} = -B \sin \theta$$

in which we may call $d\phi/d\theta$ the phase angle resolution. This shows that resolution depends directly on the baseline B and on the sine of the angle from which the signal arrives. If the magnitude of the resolution for a signal arriving from the zenith is B, the resolution from 30 degrees above the horizon is 0.5 B and from 10 degrees is 0.17 B, which shows a rapid deterioration of resolution as the signal approaches the horizon. If we compare the resolution for two baselines,

$$\frac{d\phi_1}{d\theta} = -B_1 \sin \theta = \phi_1'$$

and

$$\frac{d\phi_2}{d\theta} = -B_2 \sin \theta = \phi_2',$$

we obtain

$$\frac{\phi_1'}{\phi_2'} = \frac{B_1}{B_2}.$$

This shows that the relative resolution is independent of θ, and if noise levels do not enter differently, the proper spacing for satisfactory identifications of the values of the n's are the same for all angles of arrival.

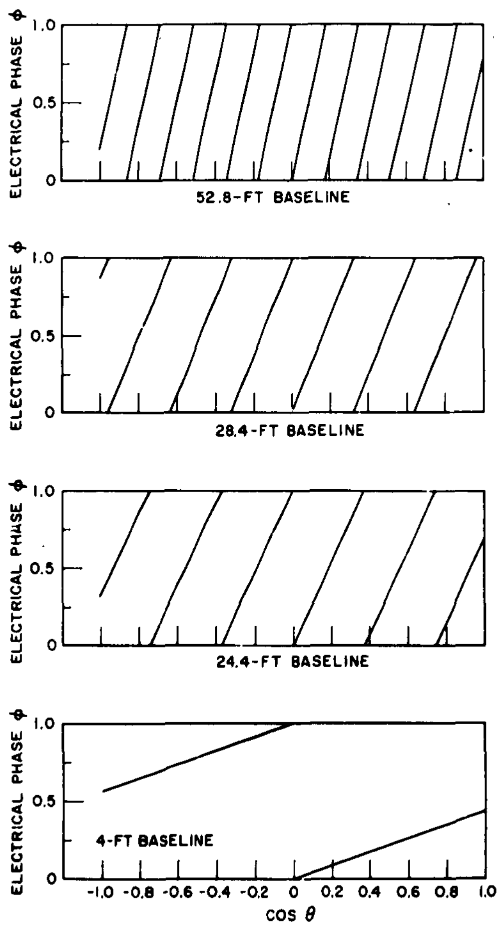


Fig. A2 - Electrical phase delay ϕ (in terms of wavelength) vs cosine of the space angle. These plots illustrate the linear relationship between cos θ and ϕ, given by

$$\cos\theta = \frac{n + \phi}{B},$$

for the different baselines indicated.

From the plots in Fig. A1 it is apparent that the slope of the function $\phi(\theta)$ is not constant; in fact it depends on sin θ. Reference to the equation

$$\cos\theta = \frac{n + \phi}{B}$$

shows that the relationship between cos θ and ϕ is linear, and if we use cos θ as one variable, we obtain the linear plots shown in Fig. A2. This is an appreciable simplification and gives us a parameter (cos θ) which is equally as useful as the angle θ itself.

The range of error in plots of θ and cos θ between zenith and horizon is given in Figs. A3 and A4 (top). In Fig. A3 we assume that noise and calibration error cause a total error in the baseline phase reading of as much as ±25 percent. If we consider signals arriving from various angles between 0 to 90 degrees it is found that the indicated signal for a 4-ft baseline could lie anywhere between the dashed lines. For signals near the eastern horizon, the error could cause apparent arrival from the west and vice versa. On the same graph is shown the range in indicated angle for a 24.4-ft baseline with the same maximum phase error (±25 percent). It is evident that three distinct solutions for the angle of arrival would be possible. Using the same phase error, plots were made in Fig. A4 with cos θ as the variable. Until now we have considered a shift in phase from 360 to 0 degrees to take place at the zenith for all baselines. Since differences in line length, etc., cause cross-over, as seen by measuring instruments, to be displaced one way or another, this condition would not ordinarily obtain in the output phase readings. However, with the linear plots obtained when cos θ is used as the independent variable, such effects can readily be taken into account by shifting the appropriate plot of ϕ horizontally until the values agree with the values observed on the instruments.

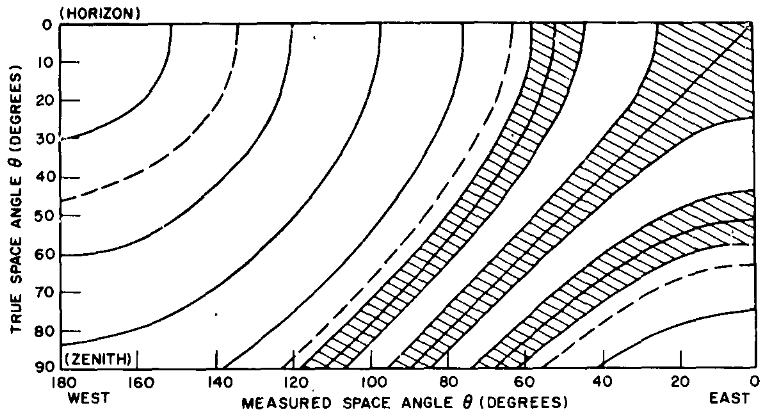


Fig. A3 - Range in error (cross-hatch) for the measured space angle θ between zenith and horizon, assuming a phase error of ±25%. Individual lines (dashed lines for 4-ft baseline; solid lines for 24.4-ft baseline) indicate the possible values of the measured space angle for an assumed "true" space angle.

From the linear plots shown in Fig. A4, a criterion for maximum tolerable phase error versus increase in baseline spacing may be deduced. In particular, from

$$\cos\theta = \frac{n + \phi}{B}$$

it is clear that the range of error in $\cos\theta$ for a ±25-percent error in ϕ is equal to

$$(\cos\theta_+ - \cos\theta_-) = \frac{n + \phi + 0.25}{B}$$

$$- \frac{n + \phi - 0.25}{B} = \frac{0.50}{B} .$$

Thus, the error in $\cos\theta$ is inversely proportional to the length of the baseline. Since $\cos\theta$ is multivalued, except when the baseline is less than a halfwave length, we must not allow more than one of the bands such as are shown for the 24.4-ft baseline on Fig. A4, to fall in the cross-hatched region for the 4-ft baseline of Fig. A4. If we consider ±25-percent phase error in the coarse baseline and no error at all in the next longer baseline, no ambiguity will exist if

$$\frac{n + 1 + \phi}{B_{m+1}} - \frac{n + \phi}{B_{m+1}} > \frac{0.50}{B_m} ,$$

or

$$B_{m+1} < 2B_m .$$

Normally, the phase error will be different for each baseline. Generalizing, the range of error R for the m-th baseline is

$$R = \frac{2\Delta\phi_m}{B_m} .$$

The requirement for unambiguous identification of the next longer baseline B_{m+1} is

$$\frac{2\Delta\phi_m}{B_m} = \frac{(n+1) - \Delta\phi_{m+1}}{B_{m+1}} - \frac{n + \Delta\phi_{m+1}}{B_{m+1}}$$

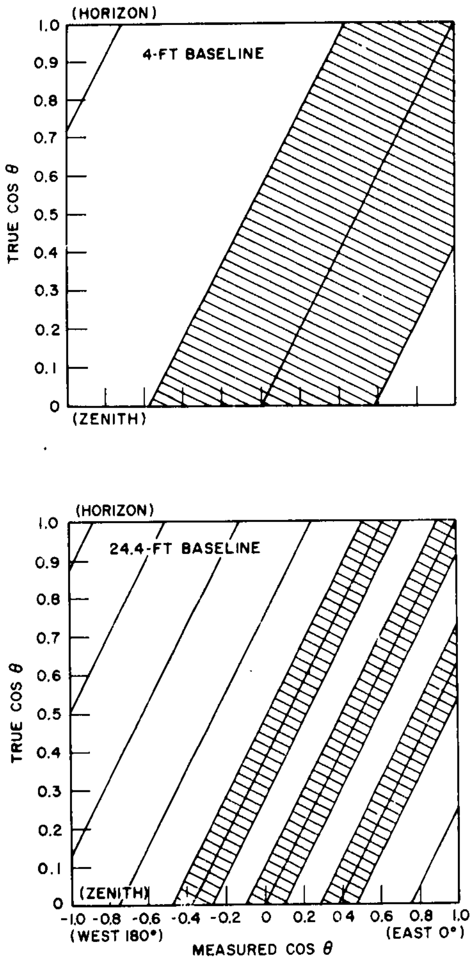


Fig. A4 - Range in error (cross-hatch) for the measured value of cos θ between zenith and horizon, assuming a phase error of ±25%. The data are for the 4-ft baseline (top) and the 24.4-ft baseline (bottom). Individual lines indicate the possible measured values of cos θ for an assumed "true" value of cos θ.

which, when solved for B_{m+1}, yields

$$B_{m+1} < \frac{B_m}{2\Delta\phi_m}\left(1 - 2\Delta\phi_{m+1}\right).$$

Inspection of the above shows that if $\Delta\phi_m \to 0$, B_{m+1} could be indefinitely extended without ambiguity. In fact, if this were the case, the coarse baseline would be adequate for fine resolution. $\Delta\phi_m$ must always be of appreciable magnitude. Another case worth considering is when $\Delta\phi_{m+1} = \Delta\phi_m$. The above equation reduces to

$$B_{m+1} < B_m\left(\frac{1}{2\Delta\phi_m} - 1\right).$$

To get an idea of reasonable spacings in baseline values, a tabulation of B_{m+1}/B_m is given for a few values of $\Delta\phi$ below,

$\Delta\phi_m$	B_{m+1}/B_m (Maximum Values)
0.25	1
0.10	4
0.05	9
0.01	49

The table indicates that a 25-percent error in phase is the limiting value where unambiguous resolution is not permitted by going to longer baselines. For smaller values of phase error, the maximum ratio of successive baseline spacings increases approximately as

$$\frac{1}{2\Delta\phi_m}.$$

APPENDIX B

PHASE PRESERVATION THROUGH THE SPACE SURVEILLANCE RECEIVING SYSTEM

The antenna field associated with the receiver section is arranged in pairs of antennas with selected spacings in order to provide the desired degree of accuracy and to eliminate ambiguity. Figure B1 is a block diagram of a typical receiver for one pair of antennas. Each antenna is connected to the input of a preamplifier, the output of which is fed to a converter. One converter receives a 119.295-Mc signal from local oscillator number 1, to mix with the 108.015-Mc signal from its associated antenna; the other converter receives a 119.294-Mc signal from local oscillator number 2, to mix with the signal received from the second antenna of the pair. It is noted that the two local oscillators are locked at a difference frequency of 1 kc. This difference in the two local-oscillator frequencies is phase locked with a 1-kc standard reference frequency from the precision time clock oscillator (maintained at 1 kc by the varactor circuit). The output signals from the pair of converters are added and amplified in a single i-f channel, thereby reducing differential phase shift. The i-f signals have frequencies of 11.280 Mc and 11.279 Mc.

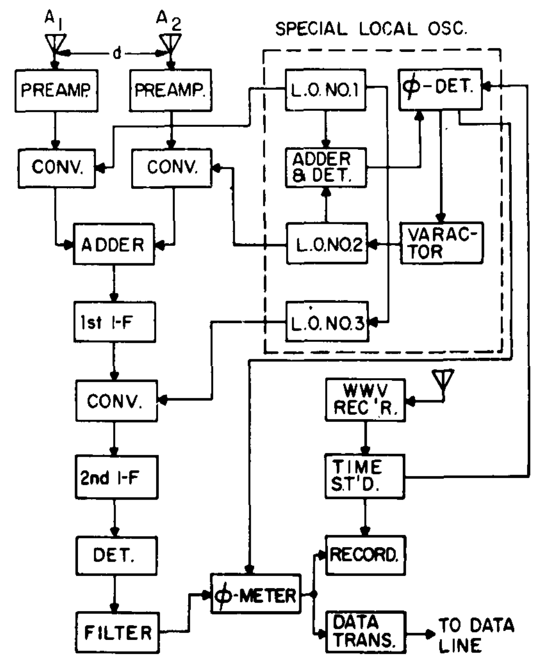


Fig. B1 - Space Surveillance receiving system for one pair of antennas

The 1-kc difference frequency is maintained in the first i-f amplifier. The pair of i-f signals is fed to a mixer circuit and beat with the third local-oscillator signal with a frequency of 11.735 Mc. This produces two new i-f signals having frequencies of 455 kc and 456 kc. These are amplified in a second i-f amplifier, detected, and filtered to produce the 1-kc difference frequency which has a phase with respect to the 1-kc reference determined originally by the relative phase of the incoming signals at the antennas. The 1-kc signal so produced is compared with the 1-kc reference signal in the phase meter. The output of the phase meter is recorded along with coded universal time signals. Other pairs of received signals are treated in like manner.

The following analysis traces the electrical phase difference between signals of an antenna pair through the receiving system. The symbols used have the following definitions:

ϕ is the electrical phase difference, which is proportional to the angle-of-arrival, with $0 < \phi < \pi/2$

$E_1 \sin(\omega_1 t + \phi)$ is the signal on A_1 (108.015 Mc)

$E_2 \sin(\omega_1 t)$ is the signal on A_2 (108.015 Mc)

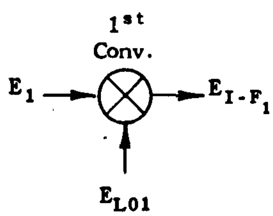
$E_{L01} \sin(\omega_2 t)$ is the signal from local osc. 1 (119.295 Mc)

$E_{L02} \sin(\omega_3 t)$ is the signal from local osc. 2 (119.294 Mc)

$E_{L03} \sin(\omega_4 t)$ is the signal from local osc. 3 (11.735 Mc).

The first-converter output (11.280 Mc) for E_1 from antenna A_1 is

$$E_{I-F_1} = E_1 \sin(\omega_1 t + \phi)\, E_{L01} \sin \omega_2 t.$$



Since

$$\sin x_1 \sin x_2 = \frac{1}{2}\left[\cos(x_1 - x_2) - \cos(x_1 + x_2)\right], \tag{1}$$

then

$$E_{I-F_1} = \frac{E_1 E_{L01}}{2}\left\{\cos\left[\omega_2 t - (\omega_1 t + \phi)\right] - \cos(\omega_1 t + \phi + \omega_2 t)\right\},$$

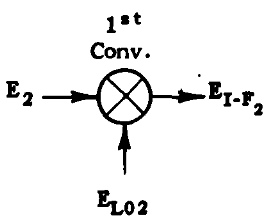
where the last term is filtered out. Thus,

$$E_{I-F_1} = \frac{E_1 E_{L01}}{2}\cos(\omega_2 t - \omega_1 t - \phi). \tag{2}$$

Note: Conversion results in difference frequency and change in sign of phase angle ϕ.

The first-converter output (11.279 Mc) for E_2 from antenna A_2 is

$$E_{I-F_2} = E_2 \sin(\omega_1 t)\, E_{L02} \sin(\omega_3 t).$$

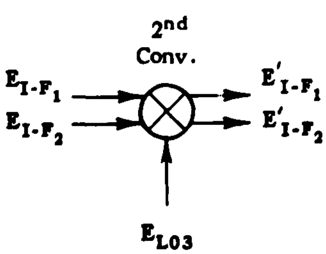


Using Eq. (1), as given above, gives

$$E_{I-F_2} = \frac{E_2 E_{L02}}{2}\left[\cos(\omega_3 t - \omega_1 t) - \cos(\omega_3 t + \omega_1 t\right] \tag{3}$$

where the last term is filtered out.

The second-converter outputs (455 and 456 kc) are obtained as follows. The inputs from the first converter to the second converter are



$$E_{I-F_1} = \frac{E_1 E_{L01}}{2}\cos\left[\omega_2 t - (\omega_1 t + \phi)\right] \tag{4}$$

and

$$E_{I-F_2} = \frac{E_2 E_{L02}}{2}\cos(\omega_3 t - \omega_1 t) \tag{5}$$

as given by Eqs. (2) and (3) above. When these inputs are combined with the input from local oscillator number 3,

$$E'_{I-F_1} = \left(E_{I-F_1}\right)\left(E_{L03}\right) \sin \omega_4 t = \frac{1}{2}\left(\frac{E_1\ E_{L01}}{2}\right)\left(E_{L03}\right)\left[\cos(\alpha-\beta) - \cos(\alpha+\beta)\right],$$

where the last term is filtered out and

$$\alpha = \omega_4 t$$

$$\beta = \omega_2 t - \omega_1 t - \phi .$$

The relation shown in Eq. (1) was used to obtain this result. Finally,

$$E'_{I-F_1} = \frac{1}{4} E_1\ E_{L01}\ E_{L03} \cos(\omega_4 t - \omega_2 t + \omega_1 t + \phi) \tag{6}$$

and

$$E'_{I-F_2} = \frac{1}{4} E_2\ E_{L02}\ E_{L03} \cos(\omega_4 t - \omega_3 t + \omega_1 t) . \tag{7}$$

Adding E'_{I-F_1} and E'_{I-F_2} across a linear element and using

$$\cos A + \cos B = 2 \cos \frac{1}{2}(A+B) \cos \frac{1}{2}(A-B) ,$$

the resultant voltage to the detector is

$$\begin{aligned} E &= E'_{I-F_1} + E'_{I-F_2} \\ &= \frac{1}{4} E_1\ E_{L01}\ E_{L03} \cos(\omega_4 t - \omega_2 t + \omega_1 t + \phi) \\ &\quad + \frac{1}{4} E_2\ E_{L02}\ E_{L03} \cos(\omega_4 t - \omega_3 t + \omega_1 t) . \end{aligned}$$

At this point, letting all the values of E be equal to one gives

$$E = \frac{1}{4}(\cos A + \cos B) = \frac{1}{2} \cos \frac{1}{2}(A+B) \cos \frac{1}{2}(A-B)$$

where

$$A = \omega_4 t - \omega_2 t + \omega_1 t + \phi \quad \text{and} \quad B = \omega_4 t - \omega_3 t + \omega_1 t.$$

Then,

$$E = \frac{1}{2} \cos \frac{1}{2}\left[2\omega_4 t + 2\omega_1 t - (\omega_2 t + \omega_3 t) + \phi\right] \cos \frac{1}{2}(\omega_3 t - \omega_2 t + \phi) . \tag{8}$$

Inserting specific numerical values for the ω's,

$\omega_1 = 2\pi$ (108.015 Mc)

$\omega_2 = 2\pi$ (119.295 Mc)

$\omega_3 = 2\pi$ (119.294 Mc)

$\omega_4 = 2\pi$ (11.735 Mc),

and omitting the 2π in $\omega = 2\pi f$, Eq. (8) becomes

$$E = \frac{1}{2}\cos\frac{1}{2}\left(2(11.735) + 2(108.015) - (119.295 + 119.294) + \phi\right)$$

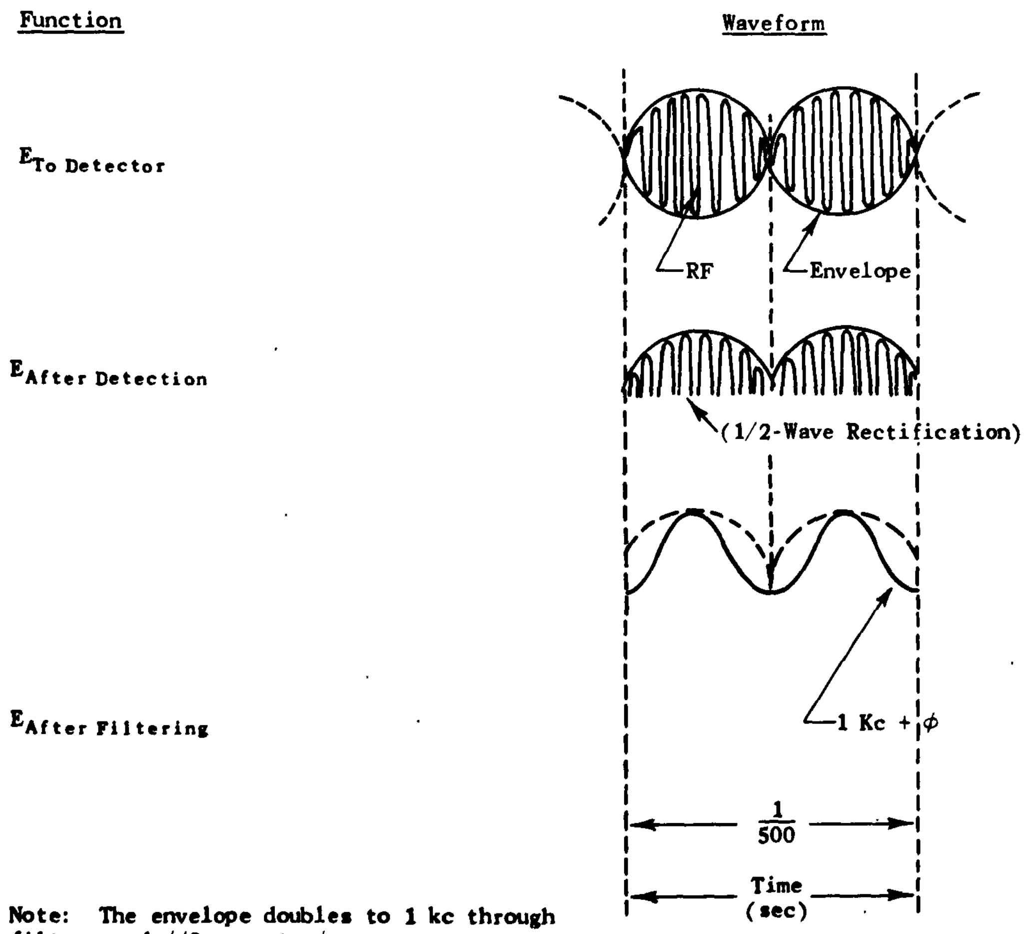
$$\times \cos\frac{1}{2}(119.294 - 119.295 + \phi)$$

$$= \frac{1}{2}\cos\left(0.4555 + \frac{\phi}{2}\right)\cos\left(-0.500 + \frac{\phi}{2}\right),$$

where t has been arbitrarily set equal to unity. Thus,

$$E = \frac{1}{2}\cos\underbrace{\left(\omega_{HF} + \frac{\phi}{2}\right)}_{rf}\cos\underbrace{\left(-\omega_{LF} + \frac{\phi}{2}\right)}_{envelope}. \tag{9}$$

The steps leading to Eq. (9) are illustrated in the sketch below.



Note: The envelope doubles to 1 kc through filter, and $\phi/2$ goes to ϕ.

Finally, we let the waveform labeled 1 kc + ϕ be given by $E_s \sin(\omega t + \phi_s)$, where

E_s = the phase-carrying signal

ϕ_s = the electrical phase difference, which is proportional to the angle-of-arrival,

and compare this signal to the reference signal $E_R \sin \omega t$ in a phase-measuring circuit. The phase-measuring circuit is shown in Fig. B2.

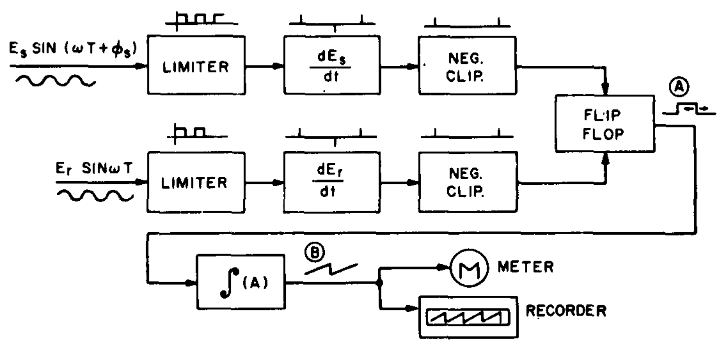
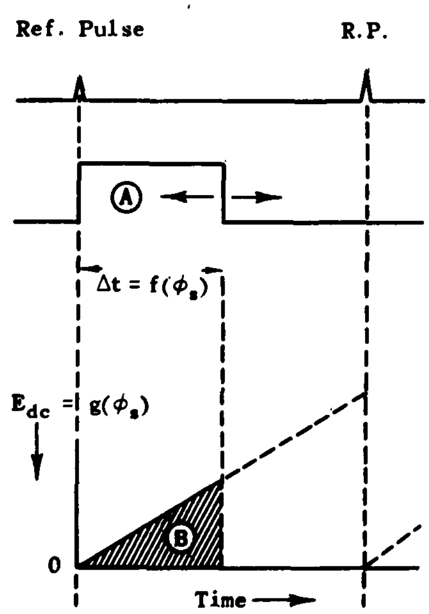


Fig. B2 - Simplified block diagram of analog phase measurement



Waveform "A"

Position of trailing edge is a function of relative phase between $E_s \sin(\omega t + \phi_s)$ and $E_R \sin(\omega t)$.

Waveform "B"

Amount of E_{dc}, due to integration of waveform A, is proportional to ϕ_s and is recorded.

This process is carried out for each pair of antennas in the surveillance system.

APPENDIX C

ALIGNMENT PROCEDURE FOR THE REGULAR COMBINER*

EQUIPMENT TURN-ON PROCEDURE

1. Allow thirty-second warmup time on all filaments before applying dc potentials to the equipment.

2. Allow four-hour warmup time on the equipment before performing the alignment procedures.

3. Use a Tektronix 535 scope, with type 4 trace plug-in, and Hewlett Packard model 522B electronic counter for alignment.

FREQUENCY CHANGER ALIGNMENT

Harmonic Generator Adjustment

a. Connect the HP522B counter to each output of the harmonic generators and adjust the frequency vernier capacitors for frequencies of 1400, 1500, 2300, 2500, 4200, 10800, and 14000 cycles per second.

b. Connect the external trigger of the Tektronix 535 to the pulse monitor output on the fractional frequency generator chassis.

c. Connect the channel A probe successively to each harmonic generator output and continue the frequency vernier adjustment until that output is phase locked (stationary on the scope) with the monitor pulse.

Mixer Chassis Adjustment

a. Connect the channel A probe to pin No. 1 of the mixer transformers (UTC A-21) on the signal mixer chassis. Adjust the input gain pots for input signal levels of 3 volts peak to peak.

b. Connect the channel A probe to the mixer output (junction of 50-ohm pot wiper and 820-$\mu\mu f$ capacitor). Successively short out the input of each mixer transformer input and adjust its corresponding 50-ohm balance pot for minimum output.

PULSE CIRCUITRY ALIGNMENT

Zero-Crossing Detector

a. Connect the channel A probe to V3B pin 8 on each zero-crossing detector chassis. Use internal synch. on the scope. Expand the trace until the leading edge of the squared sine wave is clearly visible on the scope. Adjust the 25k blocking oscillator pot until the first negative pulse occurs at the positive-going zero crossing.

*Combining the first 7 baselines.

b. Connect the channel A probe to the output of the zero-crossing detector chassis.

Adjust capacitor C1 for pulse widths according to the following table.

Baseline (ft)	Carrier Frequency (cps)	Pulse Width (msec)
16	400	1.0
20	500	0.8
52	1300	0.33
60	1500	0.29
128	3200	0.13
392	9800	0.04
520	13000	0.03

Coincidence Gate Alignment

a. Place the equipment into ref. cal. position and connect channel A probe to J4 of the pulse coincidence gate chassis. Connect channel B, C, and D probes to J3, J2, and J1. Use the external trigger for the scope from the monitor pulse output of the fractional frequency generator. Expand the scope sweep and center the pulse from channel A on the scope. Adjust the resolvers corresponding to the signals on J1, J2, and J3 until the pulses on channel B, C, and D probes are centered about the same vertical line as the pulse on channel A.

b. Connect channel B probe to V4 pin 8. Adjust the coupling capacitor between V3 pin 1 and pin 7 until the output pulse width is equal to that on channel A.

Analog Phase Meter Alignment

a. The analog phase meter in this equipment has been modified by the addition of a zero-crossing detector in place of the reference pulse input. The zero-crossing detectors can be by-passed by using the pulse input jacks. Therefore, either or both phase and reference signal inputs can be sinusoidal or pulse functions. In any case, the phase meter can be calibrated by the usual methods used in calibrating the Space Surveillance System phase meters.

SANBORN RECORDER CALIBRATION

Construct A Calibration Card

An ordinary blank 3 x 5 file-type card can be used. Draw a short line in the center of the card and place the card on one channel of the Sanborn permapaper. Move the card to align the center line with the 57-percent position on the permapaper. Draw a line on the card to coincide with the zero-percent position on the permapaper. Move the card to align the center line with the 43-percent position on the permapaper. Draw a line on the card to coincide with the 100-percent position on the permapaper. Move the card to align the center line with the 50-percent position on the permapaper and permanently fix the card in position. The outside lines are 114 percent apart, and this distance is equivalent to a half-wavelength baseline. The 100-percent range on the Sanborn channel now is equivalent to a four-foot baseline. Remove the reference signal to the phase meter and position the Sanborn stylus to coincide with one outside card marker. This position represents a space angle of 120.7°E. Reconnect the reference signal and remove the phase carrier signal on the phase meter. Adjust the recorder amplifier gain until the stylus coincides with the other outside card marker. This position represents a space angle of 120.7°W. Reconnect the phase carrier signal. Zero percent now represents 90°E and 100 percent represents 90°W.

Set a ref. cal. into the equipment. Adjust the reference signal resolver until the recorder stylus coincides with the 50-percent position on the permapaper. Place the equipment into normal operation.

APPENDIX D

ALIGNMENT PROCEDURE FOR THE LONG-BASELINE COMBINER

EQUIPMENT TURN-ON PROCEDURE

The equipment turn-on procedure is identical to that for the regular baseline combiner equipment (Appendix C).

FREQUENCY CHANGER ALIGNMENT

Harmonic Generator

a. This equipment does not contain a frequency divider unit.

b. Synchronize the sweep circuits of a Tektronix 535 scope with CA dual-trace plug-in unit to the 1-kc reference source. Successively connect the channel A probe to the 2, 3, 5, and 11 kc outputs of the harmonic generator chassis. Use a Hewlett Packard model 522B electronic counter to check frequency at each output.

c. Adjust the 1-kc reference input potentiometer to obtain a stable correct frequency output on all jacks.

Mixer (Ring Modulator)

a. The alignment procedures for the mixer chassis in this equipment are identical to the procedures used for the regular combiner equipment. Connect the 1-kc reference to all 1-kc phase-carrier inputs for the remaining alignment.

BASELINE COMBINER ALIGNMENT

Zero-Crossing Detector

a. The alignment procedures for the zero-crossing detectors in this equipment are identical to the procedures used for the regular combiners (Appendix C). The additions shown in the following table should be made to the schedule in the third step of those instructions.

Baseline (ft)	Carrier Frequency (cps)	Pulse Width (μsec)
520	1000	440
1040	2000	220
2080	4000	110
5200	10,000	44
10,400	20,000	22

Coincidence Gate Alignment

a. The preliminary alignment procedure for the AND coincidence gate in this equipment is identical with steps a and b of the regular combiner (Appendix C).

b. Set up the scope for delayed sweep as follows: Connect the scope B trace trigger input to the 100-pps output of the frequency divider chassis in the frequency changer rack. Connect a lead from the delayed trigger output to the A trace trigger input. Set the B trace trigger-mode trigger slope on AC External Plus. Set the A trace trigger-mode trigger slope on AC External Plus. Set the A and B trace stability controls to preset the trigger level controls to the plus side. Set the A trace sweep time base selector to 10 microseconds per centimeter. Set the delay time multiplier to 0.20 turn. Set the B trace sweep time base selector to 1.0 millisecond per centimeter. Connect channel A probe to the 100-pps 4-foot pulse output of the 4 foot AND gate chassis in the regular equipment. The pulse width of this output should be 60 microseconds. Connect channel B probe to the zero-crossing detector output of the 40-foot (generated) channel. (This latter zero-crossing detector, in the long-baseline equipment, generates a 1-kpps signal from the 1-kc output of the 40-foot coincidence gate chassis.) The pulse width of the output is 60 microseconds. Adjust the delay time multiplier to center the 100-pps 4-foot output on channel A probe on the scope graticule. Adjust the 40-foot resolver to center the 1-kpps zero-crossing detector output on the scope graticule. (Use the same vertical line for centering the outputs on both channel A trace and channel B trace probes.) Successively connect the channel B scope probe to the zero-crossing detector outputs of the 520- through 5200-foot baseline channels and adjust the corresponding resolver (in the long-baseline rack) until the pulse on the channel B probe is centered on the same vertical line as the pulse on channel A probe. These latter adjustments are normal operational adjustments and should be checked each time the normal combiner alignment is checked.

DATA TRANSLATOR ALIGNMENT

Baseline Converter

It will be necessary to remove the chassis from the rack for alignment purposes, but normal signal connections should be maintained.

a. Resolver Adjustment

Connect channel A probe to the plate of the resolver circuit amplifier tube. Manually rotate the resolver dial and simultaneously adjust the 100k bridge balance pot for minimum amplitude modulation of the output.

b. Mixer Adjustment

Connect channel A probe successively to the cathodes of the cathode-follower drive tubes of the ring modulator mixers. Adjust the 0.5-megohm pot in the grid circuit of the cathode follower for a 5 to 7 volt peak-to-peak output voltage at the cathode. Connect a shorting lead from the grid to ground on each cathode-follower driver, successively, and adjust the corresponding 250-ohm ring modulator mixer potentiometer for minimum output of the mixer.

c. Zero-Crossing Detector Adjustment

Connect the channel A probe to the cathode of the cathode-follower driver for the blocking oscillator of the zero-crossing detector. Use internal synch. on the scope. Expand the scope sweep until the positive-going leading edge of the squared waveform is clearly discernible. Adjust the 25k blocking oscillator pot until the leading edge of the negative pulse on the squared waveform coincides with the positive-going zero-crossing point. Adjust the zero-crossing detector output pulse width to 15 microseconds.

d. AND Gate Blocking Oscillator Adjustment

Set up the scope for delayed sweep as shown by step a of the coincidence gate alignment instructions. Use the 100-pps reference base pulse output for the external synch. Set the A trace time base selector to 10 microseconds per centimeter and the B trace time base selector to 1.0 millisecond per centimeter. Connect channal A probe to the pulse output of the 40-foot zero-crossing detector. Connect channel B probe to the pulse output of the 520-foot zero-crossing detector of the baseline converter (this chassis). Adjust the delay time multiplier to center the 40-foot pulse on channel A probe on the scope graticule. Adjust the 520-foot resolver on the baseline converter chassis to align the leading edge of the pulse on channel B probe with the leading edge of the pulse on channel A probe.

Reconnect channel A probe to the 400-foot 1-kc output. Depress the 520-foot zero-crossing detector inhibit pushbutton on the front panel of the baseline converter chassis. Adjust the 25k pot in the AND gate blocking oscillator circuit until the output on channel A probe disappears. Reconnect the channel B probe to the output of the 40-foot zero-crossing detector. Depress the pushbutton on the 16-foot zero-crossing detector. If the 40-foot zero-crossing detector output scope channel B probe does not disappear, readjust the blocking oscillator threshold pot until this output does disappear. Continue the adjustment of the 25k and gate blocking oscillator pot until the output on channel A probe disappears. Reconnect the channel A probe to the 40-foot zero-crossing detector output and channel B probe to the 520-foot zero-crossing detector output (on baseline converter). Adjust the delay time multiplier to center the channel A probe 40-foot pulse on the scope graticule. Adjust the 520-foot resolver on the baseline converter chassis to center the 520-foot pulse on channel B probe on the scope graticule. The latter two centering adjustments are normal operational adjustments and should be checked each time the normal combiner alignment is checked and for alignment of the decision gate that follows.

Decision Gating Network

a. Precising AND Gate

With the 40-foot 1-kpps and 520-foot 13-kpps signals centered as indicated by the last two adjustments of the baseline converter and gate chassis, with the scope at the same setting, and with external synch. on 100-pps reference base, connect channel A scope probe to the cathode-follower output of blocking oscillator number 2. Depress the 520-foot zero-crossing detector pushbutton on the baseline converter chassis and adjust the 25k blocking oscillator number 2 threshold pot until the pulse output on channel A probe disappears. Depress a pushbutton on one of the regular baseline reduction unit zero-crossing detectors so as to inhibit the 4-foot 100-pps signal and continue the pot adjustment until the output on channel A probe disappears.

b. Single-Shot Delays

The delay single shots differ from the single shots used elsewhere in the baseline combiner equipment. The outputs of the delay single shots are negative pulses for positive pulse inputs. Connect channel A probe to the output plate pin number 6 of one-shot-delay number 1. Connect channel B probe to the output plate pin number 6 of one-shot-delay number 2. Adjust capacitor C3 on one-shot-delay number 2 for a negative-going output pulse width of 50 microseconds. Set pot R1 on one-shot-delay number one to middle range and adjust capacitor C1 for a negative-going output pulse width of approximately

72 microseconds. Adjust pot R1 until the positive-going trailing edge of the pulse output on one-shot number 1 coincides with the positive-going trailing edge of the pulse output on one-shot number 2. Connect channel A probe successively to the outputs of blocking oscillators number 1 and number 3. Adjust the corresponding threshold pot in the blocking oscillator to prevent free-running and spurious operation.

c. Single-Shot Gates

Connect channel A probe to the output of one-shot number 3. Connect channel B probe to the output of one-shot number 4. Adjust capacitor C2 on one-shot number 3 for a positive-pulse width of 40 microseconds. Adjust capacitor C4 on one-shot number 4 for a positive-pulse width of 20 microseconds. These pulse widths are optional and are for identification purposes only. The positive-going leading edge of either pulse determines final readout accuracy.

d. Supplanting Gate

Connect channel A probe to the cathode of the cathode-follower output of the supplanting AND gate. There should be no output with all signals applied. Depress the 520-foot 13-kpps inhibit pushbutton on the baseline converter chassis. The output pulse of the supplanting gate should be 40 microseconds wide.

e. OR Gate

Connect channel A probe to the cathode of the OR gate cathode follower. The pulse output should be 20 microseconds wide. Depress the 520-foot 13-kpps inhibit pushbutton on the baseline converter chassis. The output pulse should now be 40 microseconds wide.

Adjust the threshold pot on blocking oscillator number 4 to prevent free-running and spurious operation. Adjust capacitor C5 on one-shot number 5 for a pulse width of 50 microseconds. The latter pulse width is optional and can be changed to accommodate the ADDAS equipment.

APPENDIX E

OUTLINE FOR UNCOMBINED-DATA REDUCTION

SANBORN RECORD PROCESSING

Preparation of the Sanborn Records

Unroll a length of Sanborn permapaper on a long table. Reverse-fold the paper (accordian style) in lengths of approximately two and one half feet.

Assembly of the Paper for Reading Data

Open one fold of the Sanborn permapaper. Turn the record to place the time marks toward the reader. The time marks are the equal-amplitude periodically spaced stylus deflections at the outer margin of one side of the Sanborn permapaper. In this position the bottom line on each channel represents zero percent. The top line represents 100 percent. Each channel contains 50 divisions on 8-channel paper and 10 divisions on 16-channel paper. The readings are made along the lines in a direction transverse to the paper length. Each 8-channel-paper division represents two percent of electrical phase shift; each 16-channel-paper division represents 10 percent of electrical phase shift.

Reading the Phase Data

The time readout occurs every ten seconds. Each readout consists of five groups of time marks (see Fig. E1). The first group on the left-hand side represents tens of hours and contains at least two, and no more than four, marks. Two marks indicate zero times ten hours; three marks, ten hours; and four marks, twenty hours. The second group from the left represents hours and contains one to ten marks to indicate zero to nine hours. The third group represents tens of minutes and contains one to seven marks. The fourth group represents minutes and contains one to nine marks. The last group represents tens of seconds and contains one to seven marks.

The first channel on an 8-channel record is the agc channel. When a satellite crosses the interferometer fence, the agc level changes. The point of maximum change indicates a main-lobe fence crossing. The reading is made from data which occurs in this time interval.

The other channels represent electrical phase shift on baseline in the following order:

The 16-foot EW (east-west), 20-foot EW, 52-foot EW, 60-foot EW, 128-foot EW, 520-foot EW, and the 400-foot NS (north-south).

The 16-channel record contains similar information from two receiving sites. Each channel of data is appropriately designated at the beginning and end of each record.

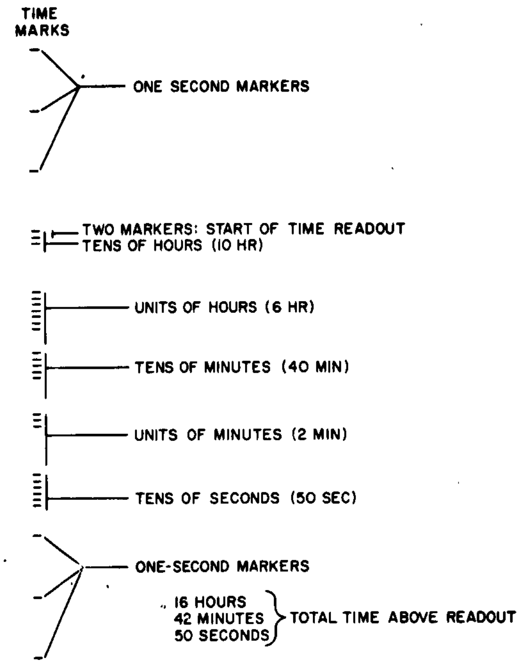


Fig. E1 - Format of time marker readout

Reading the Data from the Records

The data is read on the transverse ordinate at the time where the 400-foot NS channel crosses at 50 percent electrical phase shift. This point is the plane through the center of the fence.

This data should be corrected by comparison with the zero and 100 percent calibrations that occur on each channel of the record at one-hour time intervals. The corrected data are recorded, as shown on the sample form sheet of Table E1.

USING THE INTERFEROMETER TABLES

Preparation of Data for Use with the Tables

The data must be operated on before a space angle can be obtained from the tables. The process consists of generating a 4-foot and an 8-foot east-west baseline and referencing the data to the point of fence crossing.

The 4- and the 8-Foot Baseline

The 4-foot baseline is computed by subtracting the 16-foot phase reading from the 20-foot phase reading. The 8-foot baseline is computed by subtracting the 52-foot phase reading from the 60-foot phase reading. In cases where the 16- and 52-foot reading is greater than the 20- and/or 60-foot reading, add 100 percent to the 20- and/or 60-foot reading and complete the computation.

Referencing the Remaining Data

The data is referred to the point of fence crossing by adding 50 percent to all readings which are less than 50 percent and by subtracting 50 percent from all readings which are more than 50 percent. This latter operation does not apply to the data of the 4- and 8-foot baseline discussed above.

Tabulation

Tabulate the data derived in the two subsections above on table paper, as shown by Table E2.

The Table Outline

The interferometer tables contain several columns of information for each baseline represented. The first left-hand column under each baseline heading contains the electrical phase shifts to the closest 1 percent for satellite crossings west of zenith. The second column contains electrical phase shifts for satellite crossings east of zenith. The

Table E1
Sample Form Sheet of Data Corrected by Comparison With
Zero- and 100-Percent Calibrations on Each Channel of the Record

Silver Lake Data Report													
Time (Zebra)	Radiate Bounce	$\lambda/2$ (%)	16' (%)	20' (%)	52.8' (%)	60.8' (%)	400' NS (SN, NS)	Sp. $\angle(\lambda/2)$ (°)	Sp. $\angle$(Calc) St. R (°)	Predict (°) {SN NS}	Satellite Code	Predict Time (Zebra)	Remarks
12 Dec. 1960, 1000Z to 1400Z, 8-Channel Combiner No. 2													
11344	Bnc	73	35	52	30	62	SN	27.39E	27.8E	19E SN	27	11353	
11520	Bnc	99	15	68	31	12	NS	78.52E	82.5E	---	---	---	
13041	Rad	70	0	38	61	20	---	23.58E	23.8E	60E NS	29	13042	Wk. Sig.

remaining columns are a tabulation of possible space angle positions of the satellite for any particular electrical phase shift reading. The number of angle columns increase with the baseline length.

Obtaining the Space Angle

Use the data derived in "Tabulation" above. Begin with the derived 4-foot baseline electrical phase data. Enter the tables and select the space angle which corresponds to the phase reading. List this angle on the table paper mentioned in "Tabulation." If the phase reading occurs in the first left-hand column, suffix the angle with a W (for west). If the phase reading occurs in the second left-hand column, suffix the angle with an E (for east). If the phase reading occurs in the west column on the 4-foot baseline, then the west columns must be used for entering phase data from the remaining baseline. A similar procedure applies to the east column.

Perform the above step on the derived 8-foot baseline electrical phase data of "Tabulation."

Continue this procedure with all derived baseline electrical phase data. However, in the latter case select the space angle which occurs nearest to the space angle from the previous steps.

In cases when the data derived from the 4- and 8-foot baseline do not yield consistent space angles, record both possible space angles. The space angle resulting from the longest baseline data is the more correct angle of satellite crossing.

Record the latter angle on the form sheet. Also check the prediction schedule to identify the satellite by code and prediction angle. Record this information and the time difference between actual time of crossing and predicted crossing time. Use time to make the satellite identification.

Table E2
Preparation of Data for Use with the Interferometer Tables and Slide Rule

Calculation of the 4' and 8' baselines			
		+100	
52	(20')	12	(60.8')
-35	(16')	-31	(52.8')
17	(4')	81	(8')

Referencing the remaining data

(16') : 35 + 50 = 85

(20') : 52 + 50 = 102 - 100 = 2

(52') : 30 + 50 = 80

(60') : 62 + 50 = 112 - 100 = 12

USING THE INTERFEROMETER SLIDE RULE

Preparation and Assembly of Data

The preparation of the data for use with the interferometer slide rule is identical to the methods described in the first four subsections under the previous section.

Description of the Slide Rule

The slide rule contains several indexing slide bands and a movable cursor (see Fig. E2). Each baseline in the interferometer system is represented by a slide band on the slide rule. Each slide band contains one red vertical mark. The slide bands representing the 8-foot and longer baselines also contain from one to many black marks. The red mark on each slide band can be independently positioned by manual control of the slide band wheels located on either end of the slide rule proper. Directly above each slide band is an index scale. All scales are located in the center of the slide rule proper. Each scale represents 100 percent of electrical phase displacement on its respective baseline channel. The space angle scale is located at the bottom of the slide rule proper. The zenith point is located in the center of the scale. Space angles west of zenith are read from the left-hand part of the scale and space angles east of zenith are read from the right-hand part. The cursor contains a long vertical hair line in its center. Several short vertical lines are located on either side of the hair line. Each set of short lines corresponds to the baseline directly under it.

Obtaining the Space Angle

Use the data derived in "Tabulation" of the previous section. Begin with the derived 4-foot baseline electrical phase data. Position the red mark on the 4-foot baseline slide band under the index scale reading that corresponds to the electrical phase data. Repeat this procedure for the remaining data.

After all data has been entered into the slide bands of the rule, move the cursor to position the long vertical hairline in the half part of the rule containing the red 4-foot marker and the quarter of the rule containing one of the 8-foot markers (red or black). Next position the hairline over the nearest group of markers (red and/or black) on the remaining baseline slide bands which have the smallest deviation from the long vertical hairline. Finally, position the hairline directly over the marker on the slide band of the longest baseline in which data has been entered. The nearest markers on the remaining baselines should not deviate more than 25 percent of electrical phase displacement on the respective baselines from this final hairline setting. The reading under the hairline on the space angle scale is the correct space angle of the satellite's position.

Record the above angle on the form sheet (Table E1). Also check the prediction schedule to identify the satellite by code and prediction angle. Record this information and the time difference between actual time of crossing and predicted crossing time. Use time to make the satellite identification.

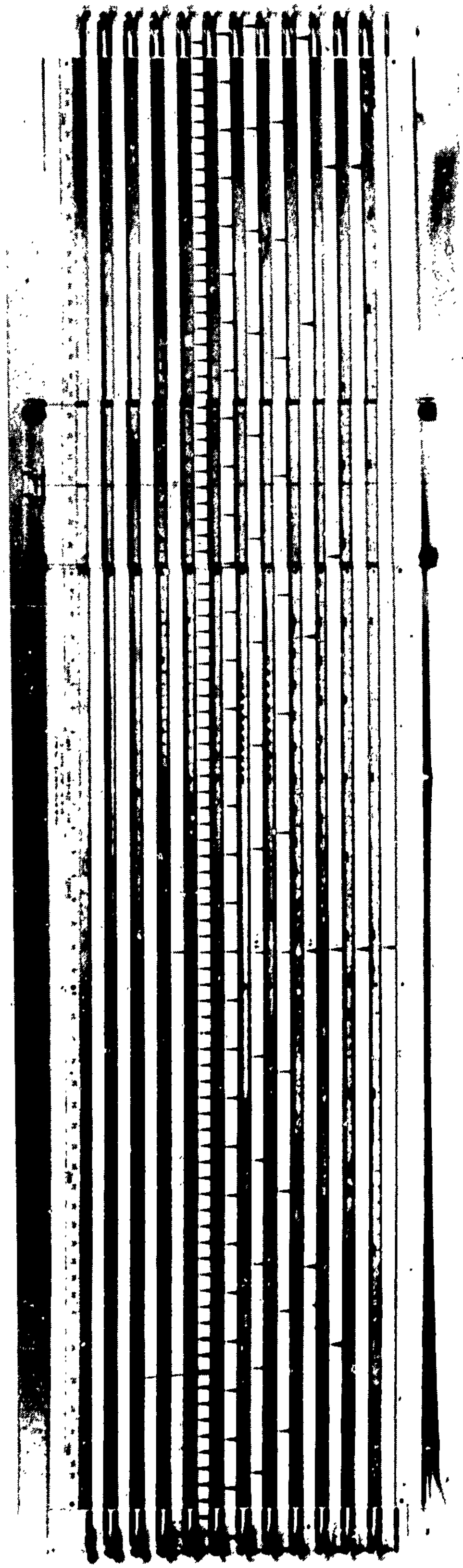


Fig. E2 - 12-channel interferometer slide rule (approximately 5 ft long)

APPENDIX F

CIRCUIT DIAGRAMS FOR THE COMBINER

CONTENTS

Heterodyne Circuitry*

Pulse Circuitry†

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*See Fig. 11(a) of main text.
†See Fig. 11(b) of main text.

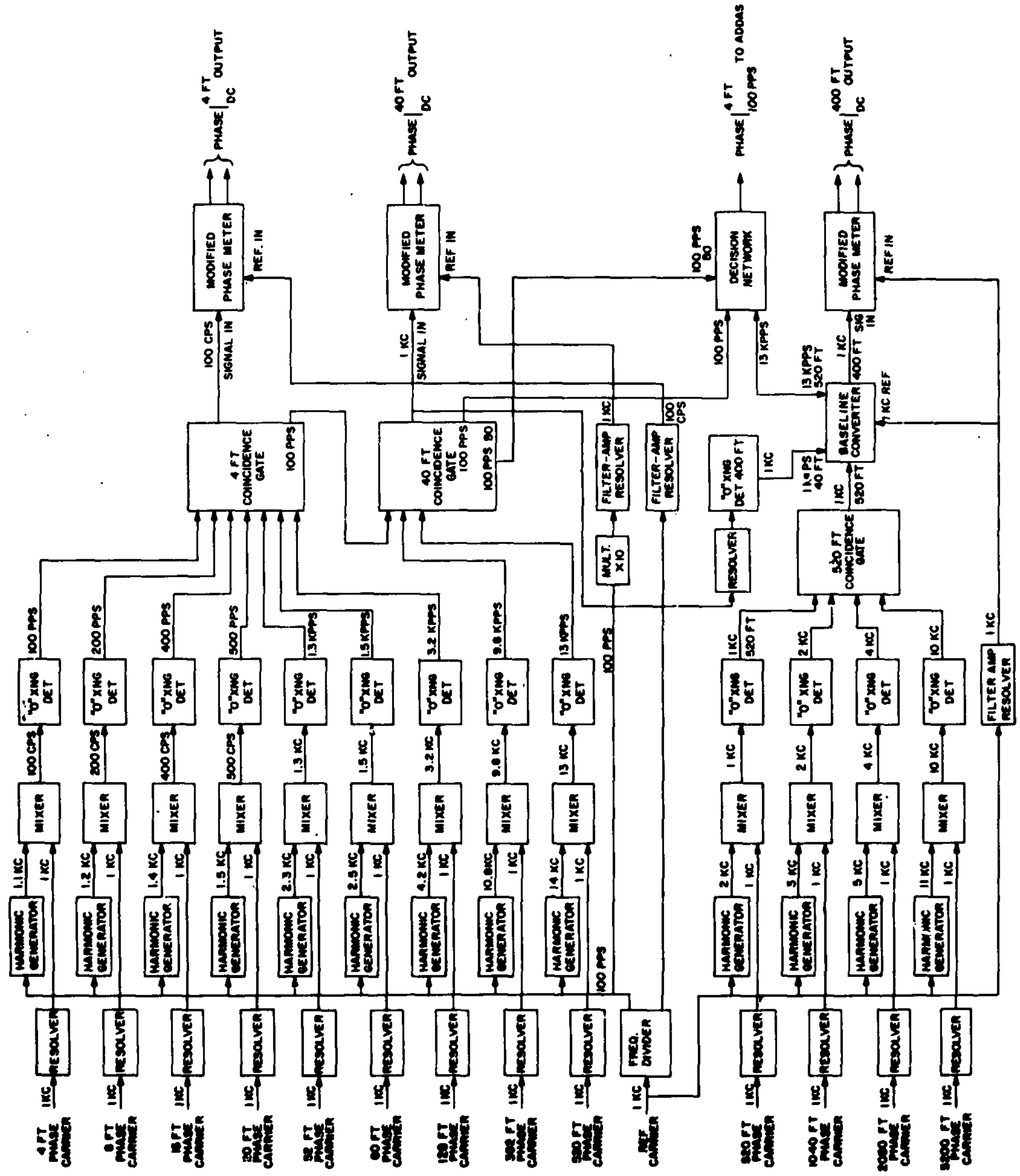

MODIFIED PHASE METER
4 FT COINCIDENCE GATE
40 FT COINCIDENCE GATE
520 FT COINCIDENCE GATE
DECISION NETWORK
BASELINE CONVERTER
FILTER-AMP RESOLVER
MULT. X10
FREQ. DIVIDER
HARMONIC GENERATOR
MIXER
"0" XING DET
RESOLVER
TO ADDAS
REF CARRIER
4 FT PHASE CARRIER
8 FT PHASE CARRIER
16 FT PHASE CARRIER
20 FT PHASE CARRIER
32 FT PHASE CARRIER
60 FT PHASE CARRIER
128 FT PHASE CARRIER
320 FT PHASE CARRIER
1040 FT PHASE CARRIER
2080 FT PHASE CARRIER
5200 FT PHASE CARRIER

Figure F1

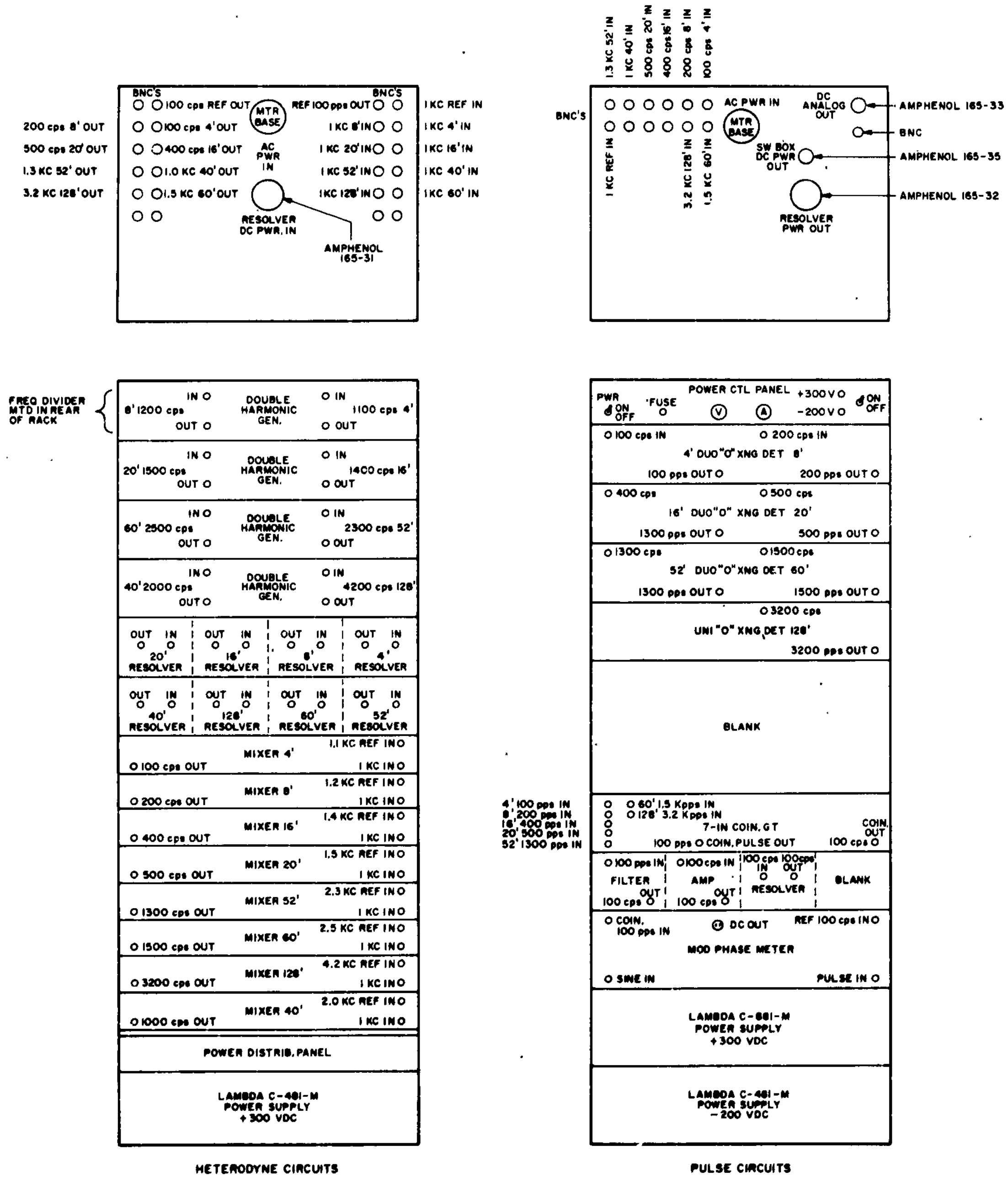

BNC'S
100 cps REF OUT
MTR BASE
REF 100 pps OUT
1 KC REF IN
200 cps 8' OUT
100 cps 4' OUT
1 KC 8' IN
1 KC 4' IN
500 cps 20' OUT
400 cps 16' OUT
AC PWR IN
1 KC 20' IN
1 KC 16' IN
1.3 KC 52' OUT
1.0 KC 40' OUT
1 KC 52' IN
1 KC 40' IN
3.2 KC 128' OUT
1.5 KC 60' OUT
1 KC 128' IN
1 KC 60' IN
RESOLVER DC PWR. IN
AMPHENOL 165-31
1.3 KC 52' IN
1 KC 40' IN
500 cps 20' IN
400 cps 16' IN
200 cps 8' IN
100 cps 4' IN
AC PWR IN
DC ANALOG OUT
AMPHENOL 165-33
BNC
SW BOX DC PWR OUT
AMPHENOL 165-35
AMPHENOL 165-32
1 KC REF IN
3.2 KC 128' IN
1.5 KC 60' IN
RESOLVER PWR OUT
FREQ DIVIDER MTD IN REAR OF RACK
8' 1200 cps
DOUBLE HARMONIC GEN.
1100 cps 4'
20' 1500 cps
1400 cps 16'
60' 2500 cps
2300 cps 52'
40' 2000 cps
4200 cps 128'
IN
OUT
20' RESOLVER
16' RESOLVER
8' RESOLVER
4' RESOLVER
40' RESOLVER
128' RESOLVER
60' RESOLVER
52' RESOLVER
MIXER 4'
1.1 KC REF IN
100 cps OUT
1 KC IN
MIXER 8'
1.2 KC REF IN
200 cps OUT
MIXER 16'
1.4 KC REF IN
400 cps OUT
MIXER 20'
1.5 KC REF IN
500 cps OUT
MIXER 52'
2.3 KC REF IN
1300 cps OUT
MIXER 60'
2.5 KC REF IN
1500 cps OUT
MIXER 128'
4.2 KC REF IN
3200 cps OUT
MIXER 40'
2.0 KC REF IN
1000 cps OUT
POWER DISTRIB. PANEL
LAMBDA C-481-M POWER SUPPLY +300 VDC
HETERODYNE CIRCUITS
POWER CTL PANEL
PWR ON OFF
FUSE
+300 V
-200 V
100 cps IN
200 cps IN
4' DUO"O" XNG DET 8'
100 pps OUT
200 pps OUT
400 cps
500 cps
16' DUO"O" XNG DET 20'
1300 pps OUT
500 pps OUT
1300 cps
1500 cps
52' DUO"O" XNG DET 60'
1500 pps OUT
3200 cps
UNI "O" XNG DET 128'
3200 pps OUT
BLANK
4' 100 pps IN
8' 200 pps IN
16' 400 pps IN
20' 500 pps IN
52' 1300 pps IN
60' 1.5 Kpps IN
128' 3.2 Kpps IN
7-IN COIN. GT
100 pps
COIN. PULSE OUT
COIN. OUT
100 cps
100 pps IN
100 cps IN
FILTER
AMP
RESOLVER
OUT
COIN. 100 pps IN
DC OUT
REF 100 cps IN
MOD PHASE METER
SINE IN
PULSE IN
LAMBDA C-881-M POWER SUPPLY +300 VDC
LAMBDA C-481-M POWER SUPPLY -200 VDC
PULSE CIRCUITS

Figure F2

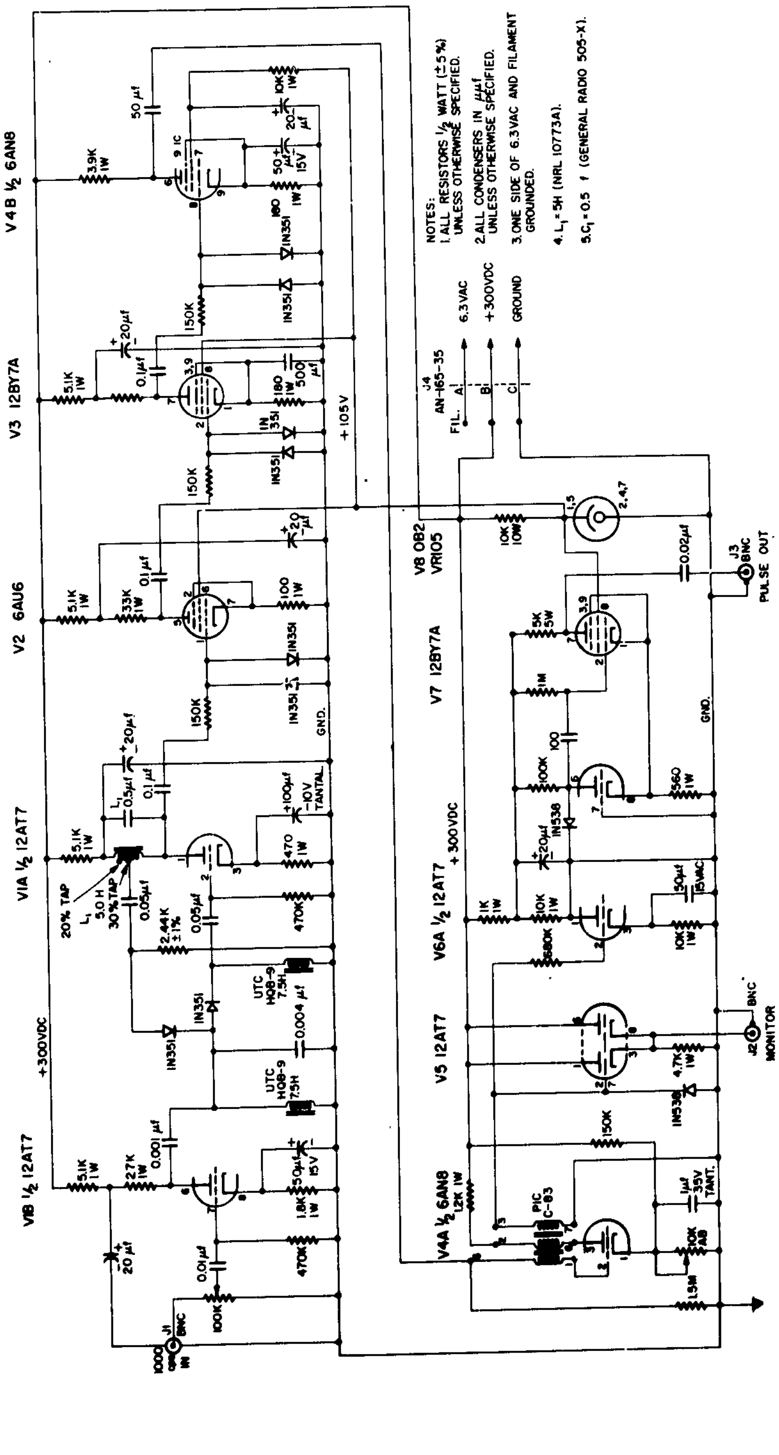
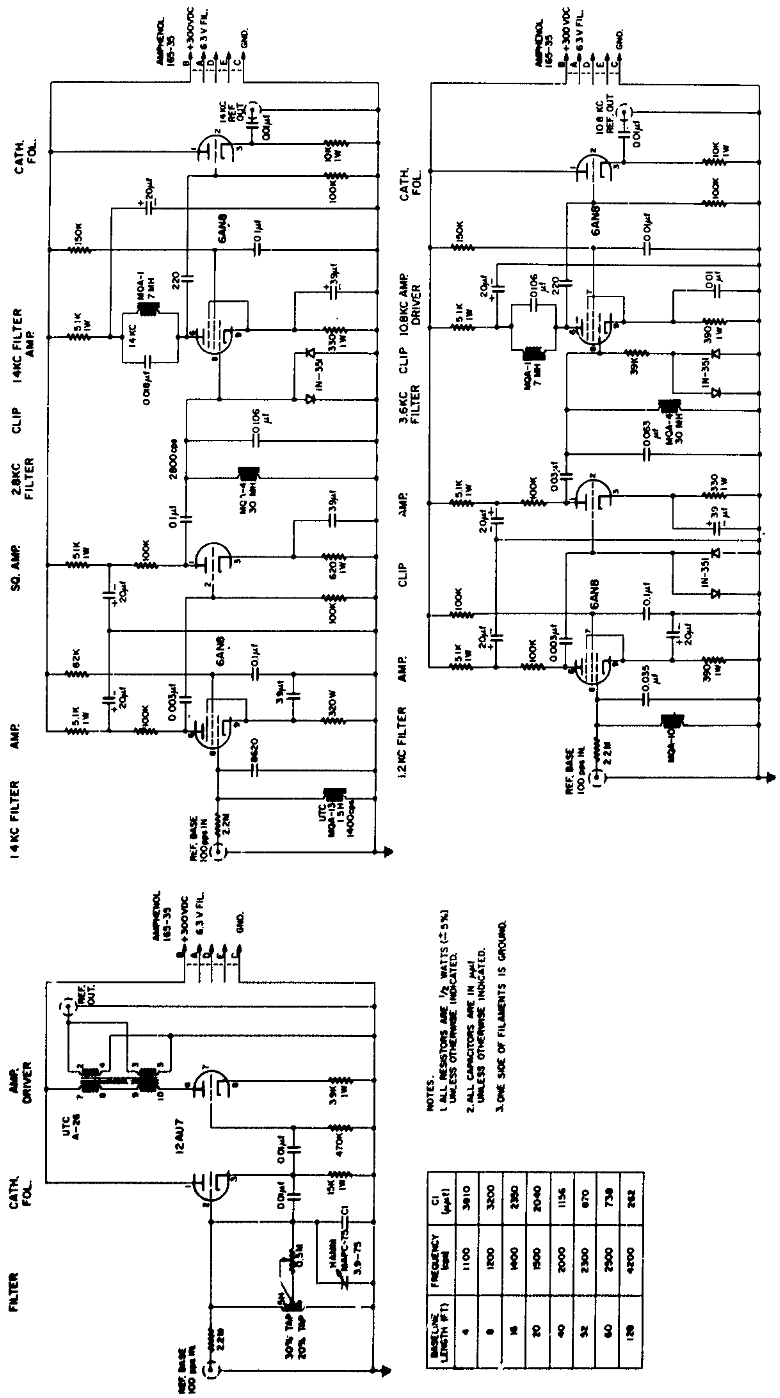

V1B ½ 12AT7
V1A ½ 12AT7
V2 6AU6
V3 12BY7A
V4B ½ 6AN8
V4A ½ 6AN8
V5 12AT7
V6A ½ 12AT7
V7 12BY7A
V8 OB2 VR105
+300VDC
+105V
GND.
J1 BNC IN
J2 BNC MONITOR
J3 BNC PULSE OUT
J4 AN-165-35
6.3VAC
+300VDC
GROUND
NOTES:
1. ALL RESISTORS ½ WATT (±5%) UNLESS OTHERWISE SPECIFIED.
2. ALL CONDENSERS IN μμf UNLESS OTHERWISE SPECIFIED.
3. ONE SIDE OF 6.3VAC AND FILAMENT GROUNDED.
4. L1 = 5H (NRL 10773A).
5. C1 = 0.5 f (GENERAL RADIO 505-X).

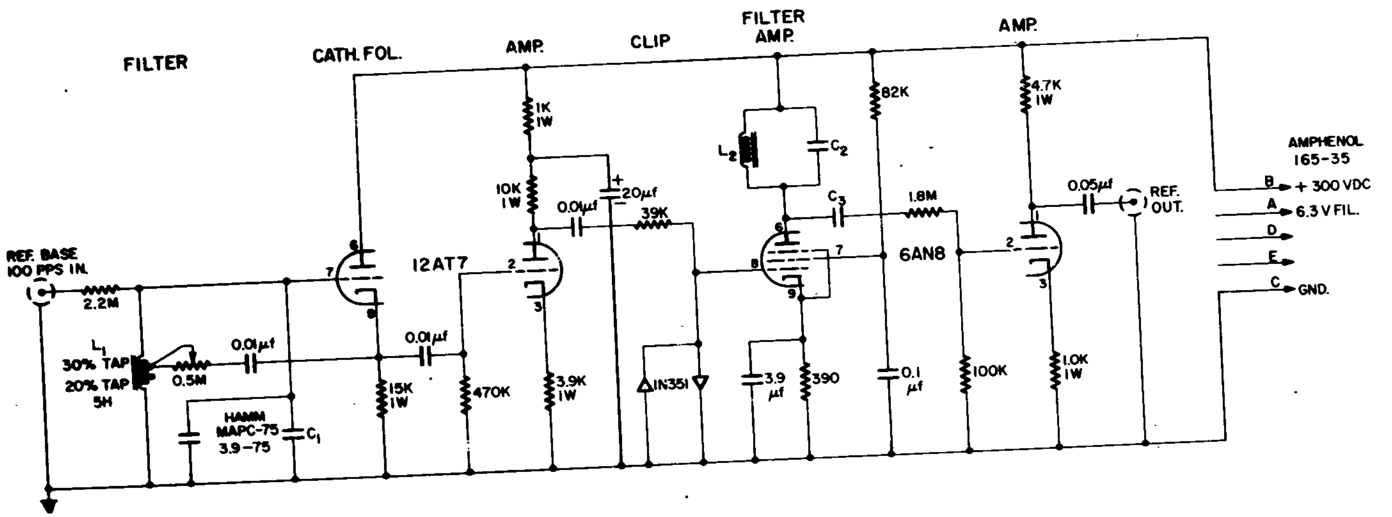
Figure F3



NOTES:
1. ALL RESISTORS ARE ½ WATTS (±5%) UNLESS OTHERWISE INDICATED.
2. ALL CAPACITORS ARE IN μμf UNLESS OTHERWISE INDICATED.
3. ONE SIDE OF FILAMENTS IS GROUND.

Baseline Length (FT)	Frequency	C1 (μμf)
4	1100	3810
8	1200	3200
16	1400	2350
20	1500	2040
40	2000	1156
52	2300	870
60	2500	738
128	4200	262

Figure F4(a)



BASELINE LENGTH (FT)	FREQUENCY (cps)	L_1* (H)	C_1 ($\mu\mu f$)	L_2† (H)	C_2 (μf)
			2350	1H MQA-12	0.013
16	1400	5	2000	0.5 H MQA-10	0.02
24	1600	5	1800	0.5 H MQA-10	0.018
28	1700	5	1500	0.5 H MQA-10	0.01
52	2300	3	1000	120 MH, MQA-7	0.01
136	4400	1.27	2000	30 MH, MAQ-4	0.022
204	6100	0.3	1000	12 MH, MQA-2	0.015
440	12,000	0.176	5000	12 MH, MQA-2	0.0078
616	16,000	0.176			

*MGF AT NRL

†MGF AT UTC

NOTES:

1. ALL RESISTORS ARE 1/2 WATT (±5%) UNLESS OTHERWISE INDICATED.
2. ALL CAPACITORS ARE IN $\mu\mu f$ UNLESS OTHERWISE INDICATED.
3. ONE SIDE OF FILAMENTS IS GROUND.

Figure F4(b)

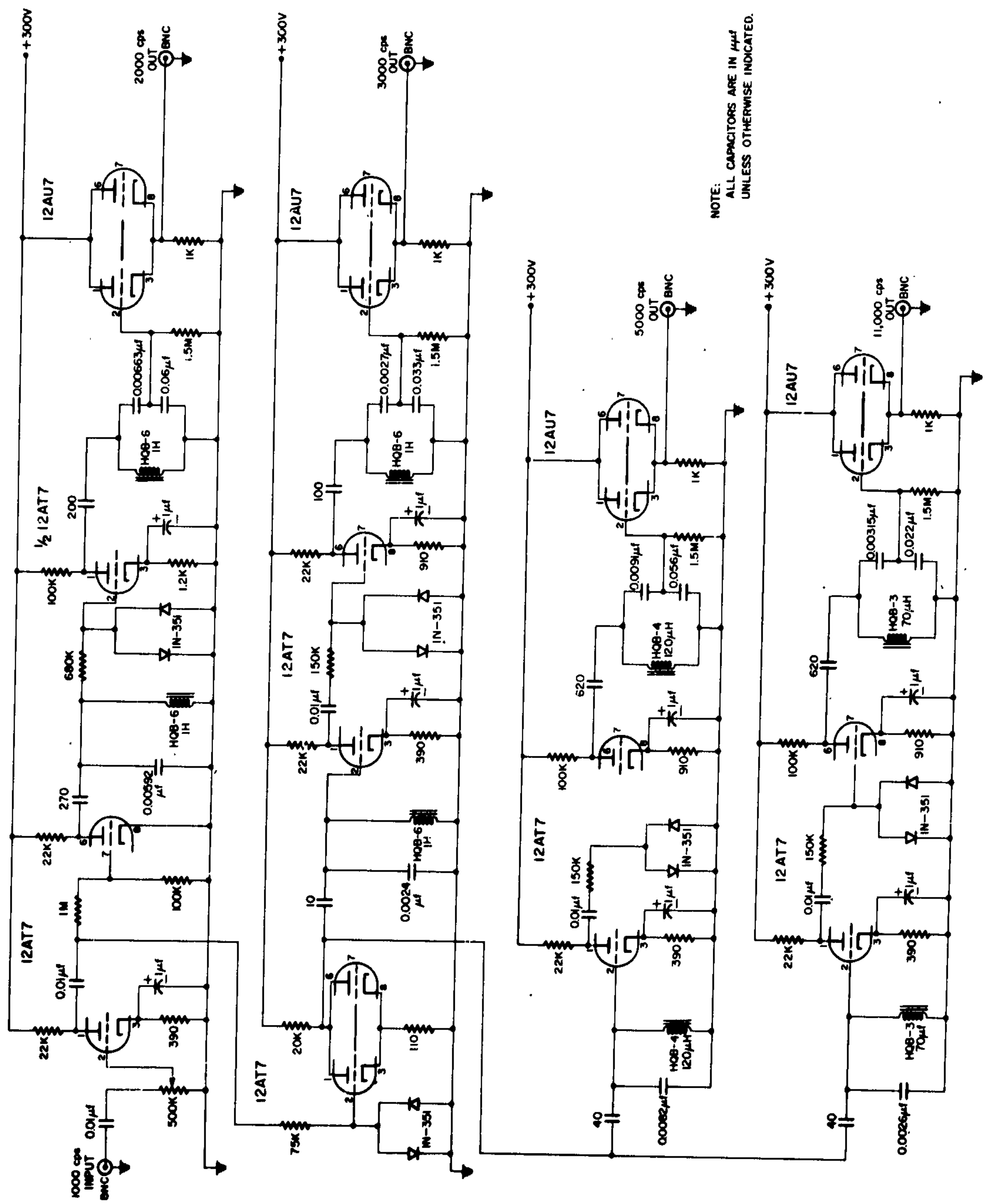
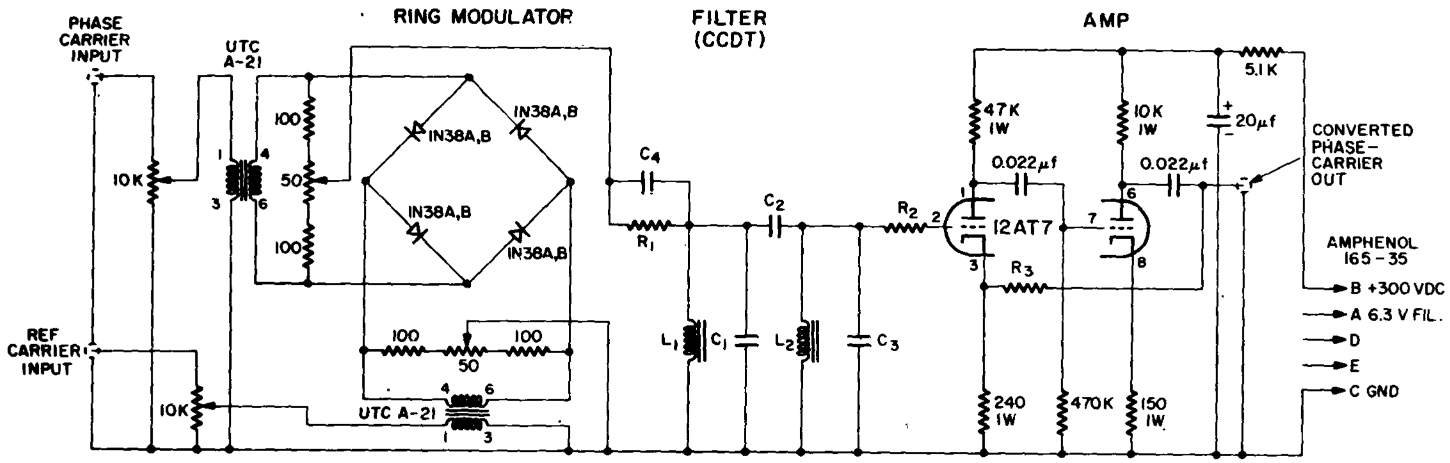

1000 cps INPUT BNC
2000 cps OUT BNC
3000 cps OUT BNC
5000 cps OUT BNC
11,000 cps OUT BNC
+300V
12AT7
1/2 12AT7
12AU7
HQB-6 1H
HQB-4 120μH
HQB-3 70μH
IN-351
NOTE: ALL CAPACITORS ARE IN μμf UNLESS OTHERWISE INDICATED.

Figure F4(c)



BASELINE LENGTH FT.	FREQUENCY (cps)	$L_1 = L_2$ MFG. BY UTC.	R_1 (K)	C_4 (pf)	C_1 (μf)	C_2 (pf)	C_3 (μf)	R_2 (K)	R_3 (K)	
4	100	1.5H MQA-13	22	0	1.65	5×10^5	1.65	2.2	1000	
8	200	1.5H MQA-13	22	0	0.4	60000	0.38	2.2	220	
16	400	7.5H HQB-9	680 ∞	0 820	0.02	1000	0.02	2.2	110	
20	500	7.5H HQB-9	∞	750	0.013	150	0.013	2.2	110	
24	600	3.5H HQB-8	680	0	0.02	1000	0.02	2.2	110	FT. STEW.
28	700	3.5H HQB-8	680	0	0.015	1000	0.015	2.2	110	FT. STEW.
40	1000	1.0H MQB-6	220	0	0.0225	2000	0.0225	2.2	22	
52	1300	1.0H HQB-6	220 ∞	0 680	0.015	910	0.015	2.2	110	
60	1500	2.0H HQB-7	∞	470	0.0056	68	0.0056	2.2	110	
128	3200	1.0H HQB-6	∞	220	0.0026	33	0.0026	2.2	110	
136	3400	120.0MH HQB-4	33	0	0.02	620	0.02	10.0	110	FT. STEW.
204	5100	70.0MH HQB-3	33	0	0.015	620	0.015	10.0	110	FT. STEW.
392	9800	0.25H MQE-9	∞	82	0.0011	15	0.0011	2.2	110	
440	11000	20.0MH HQC-5	22	0	0.01	390	0.01	10.0	110	FT. STEW.
520	13000	150.0MH MQE-8	∞	33	0.001	12	0.001	2.2	110	
616	15400	10.0MH HQC-4	22	0	0.01	390	0.01	10.0	110	FT. STEW.

NOTES:

1. ALL RESISTORS 1/2 WATT (±5%) UNLESS OTHERWISE INDICATED.
2. ALL CAPACITORS ARE IN μμf UNLESS OTHERWISE INDICATED.
3. ONE SIDE OF FILAMENTS IS GROUND
4. POTENTIOMETERS ARE BRACKET-MOUNTED ON WIRING SIDE OF CHASSIS.
5. FILTER L_1, C_1, C_2, L_2, C_3 AND R_1 OR C_4 IS CRITICALLY COUPLED.

Figure F5

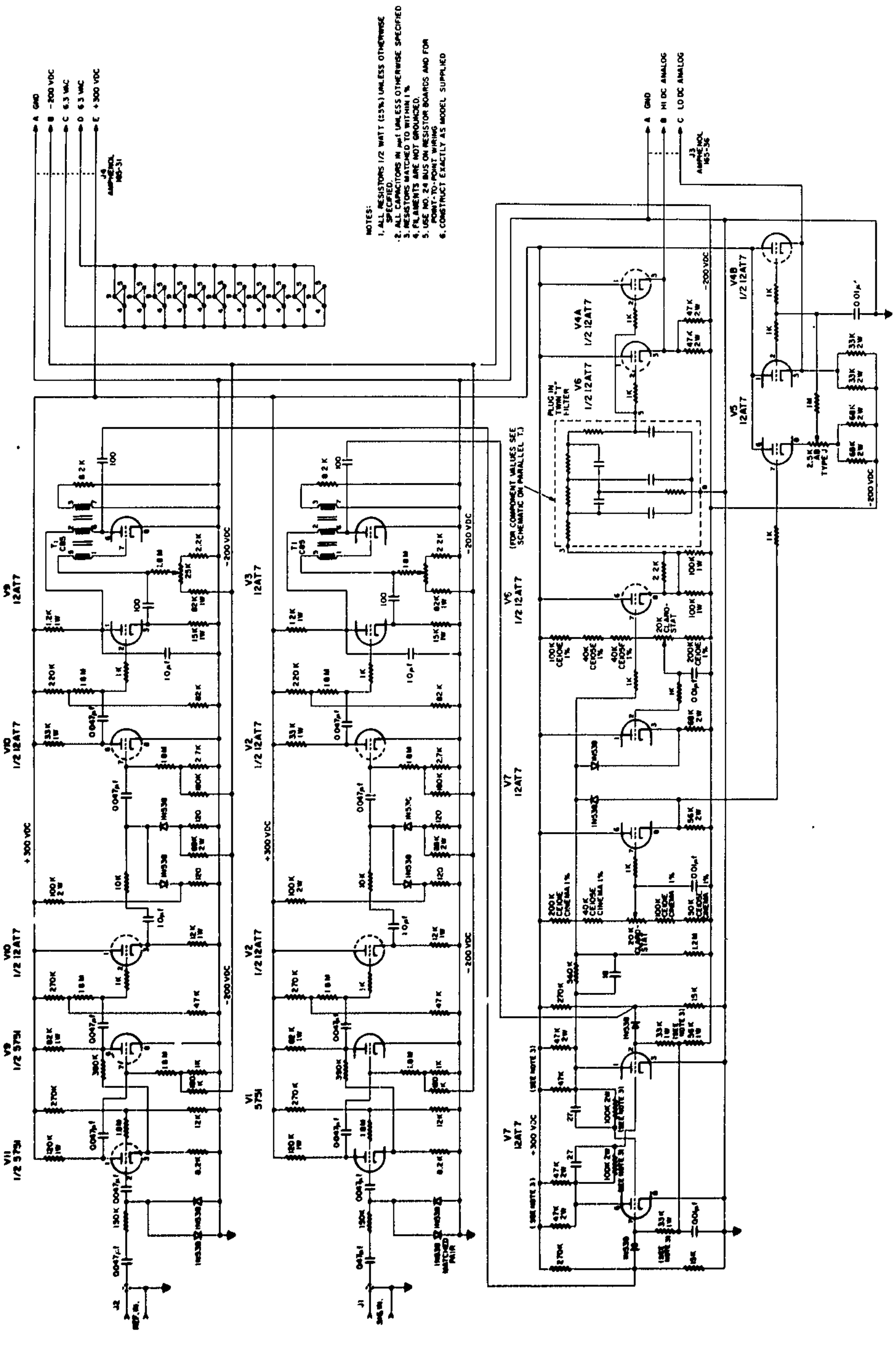
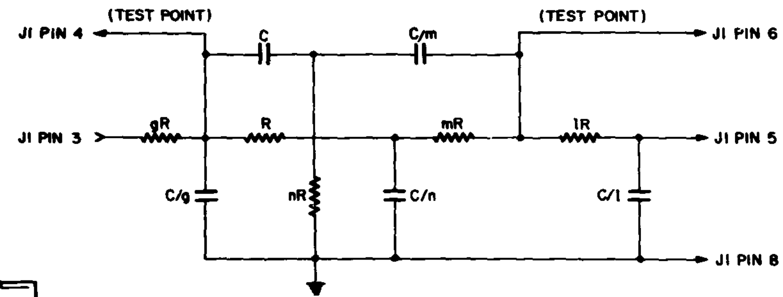
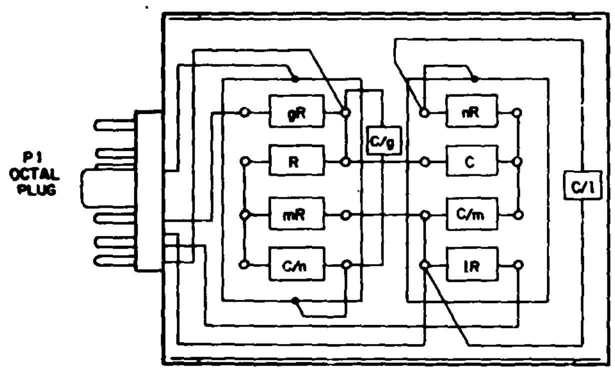


Figure F6



1⅝" x 2⅛" x 2⅝" MINIBOX



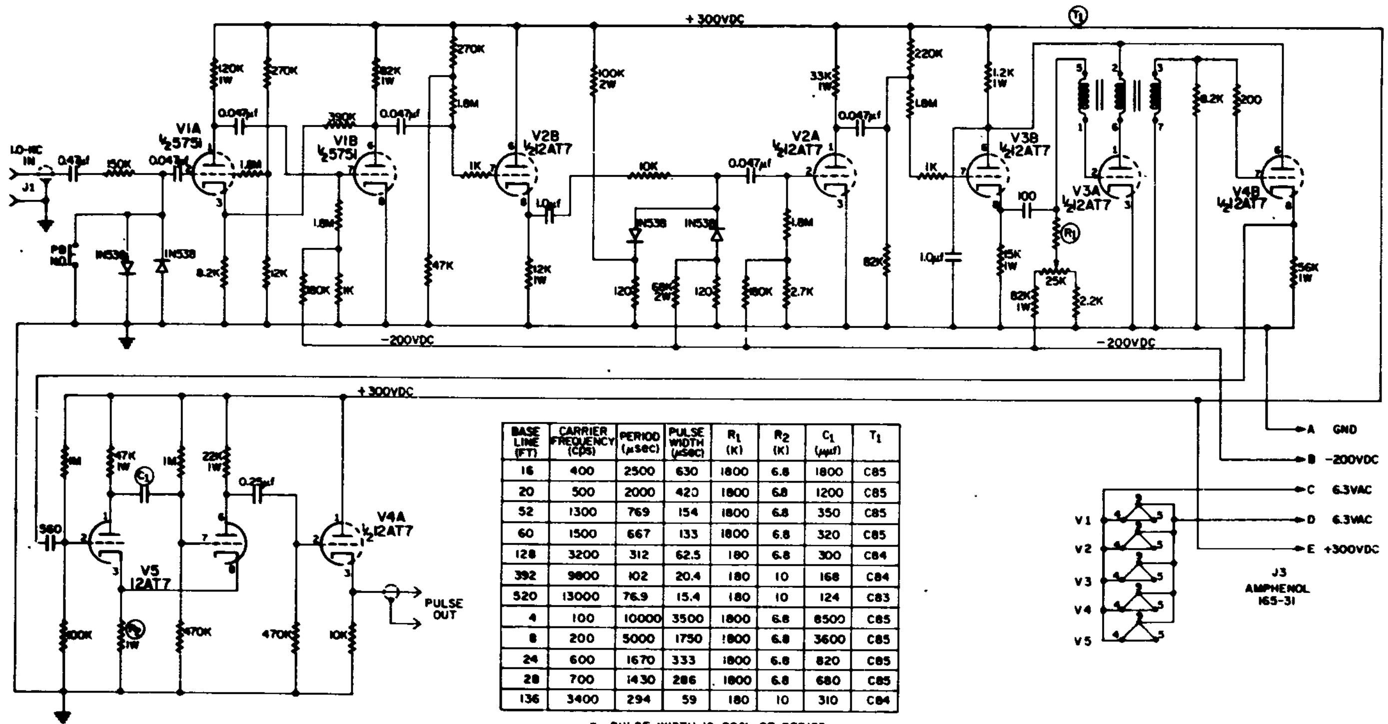
WIRING LAYOUT

SCHEMATIC
AND
TABLE

PARA-METER	VALUE OF PARAMETER AT FREQUENCY INDICATED				
	100 cps	500 cps	1000 cps	10,000 cps	3200 cps
g/R (K)	100K	100K	100K	100K	100K
C/g (μμf)	15,000	22,000	1500	91	1500
R (K)	330	100	100	82	100
mR (K)	330	100	100	82	100
nR (K)	160	47	47	47	47
C (μμf)	4700	3300	1500	91	500
C/m (μμf)	4700	3300	1500	91	500
C/m (μμf)	10,000	6800	3000	180	1000
1/R (M)	1.0	1.0	1.0	1.0	1.0
C/1 (μμf)	1500	2200	160	0	2200

NOTES:
1. ALL RESISTORS ARE / WATT (±5%).
2. ALL CAPACITORS ARE 5% (GOLD) MICA EXCEPT FOR μf VALUES WHICH ARE PAPER.

Figure F7



BASE LINE (FT)	CARRIER FREQUENCY (CPS)	PERIOD (μsec)	PULSE WIDTH (μsec)	R_1 (K)	R_2 (K)	C_1 (μμf)	T_1
16	400	2500	630	1800	6.8	1800	C85
20	500	2000	420	1800	6.8	1200	C85
52	1300	769	154	1800	6.8	350	C85
60	1500	667	133	1800	6.8	320	C85
128	3200	312	62.5	180	6.8	300	C84
392	9800	102	20.4	180	10	168	C84
520	13000	76.9	15.4	180	10	124	C83
4	100	10000	3500	1800	6.8	8500	C85
8	200	5000	1750	1800	6.8	3600	C85
24	600	1670	333	1800	6.8	820	C85
28	700	1430	286	1800	6.8	680	C85
136	3400	294	59	180	10	310	C84

• PULSE WIDTH IS 20% OF PERIOD

BASE LINE (FT)	CARRIER FREQUENCY (CPS)	PERIOD (msec)	PULSE WIDTH (msec)	R_1 (m)	R_2 (K)	C_1 (μμf)	T_1
520	1000	1.0	0.4	1.8	6.8	1200	C85
1040	2000	0.5	0.2	0.18	6.8	310	C85
2080	4000	0.25	0.1	0.18	6.8	210	C84
5200	10000	0.1	0.04	0.18	10	160	C83

• PULSE WIDTH IS 40% OF PERIOD

NOTES:

1. ALL RESISTORS ½WATT (±5%) UNLESS OTHERWISE SPECIFIED.
2. ALL CAPACITORS IN μμf UNLESS OTHERWISE SPECIFIED.
3. FILAMENTS ARE NOT GROUNDED.
4. USE POINT TO POINT WIRING, USE #24 BUS WIRE.
5. CONSTRUCT EXACTLY AS MODEL SUPPLIED.

Figure F8

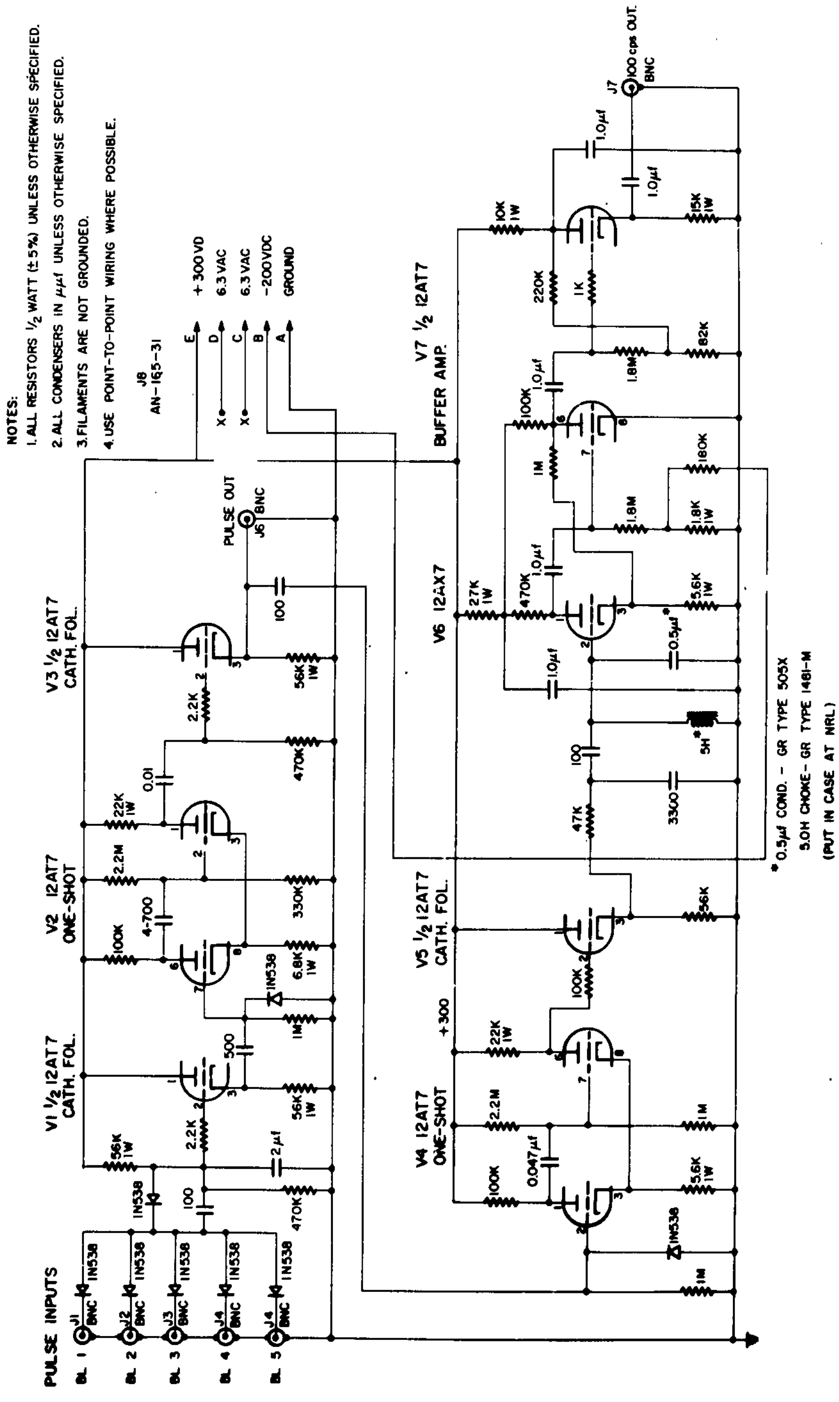

NOTES:
1. ALL RESISTORS 1/2 WATT (±5%) UNLESS OTHERWISE SPECIFIED.
2. ALL CONDENSERS IN μμf UNLESS OTHERWISE SPECIFIED.
3. FILAMENTS ARE NOT GROUNDED.
4. USE POINT-TO-POINT WIRING WHERE POSSIBLE.
J8 AN-165-31
+300VD
6.3VAC
6.3VAC
-200VDC
GROUND
PULSE INPUTS
V1 1/2 12AT7 CATH. FOL.
V2 12AT7 ONE-SHOT
V3 1/2 12AT7 CATH. FOL.
PULSE OUT J5 BNC
V4 12AT7 ONE-SHOT
V5 1/2 12AT7 CATH. FOL.
V6 12AX7
V7 1/2 12AT7 BUFFER AMP.
J7 100 cps OUT. BNC
* 0.5μf COND. - GR TYPE 505X
5.0H CHOKE - GR TYPE 1481-M
(PUT IN CASE AT NRL)

Figure F9

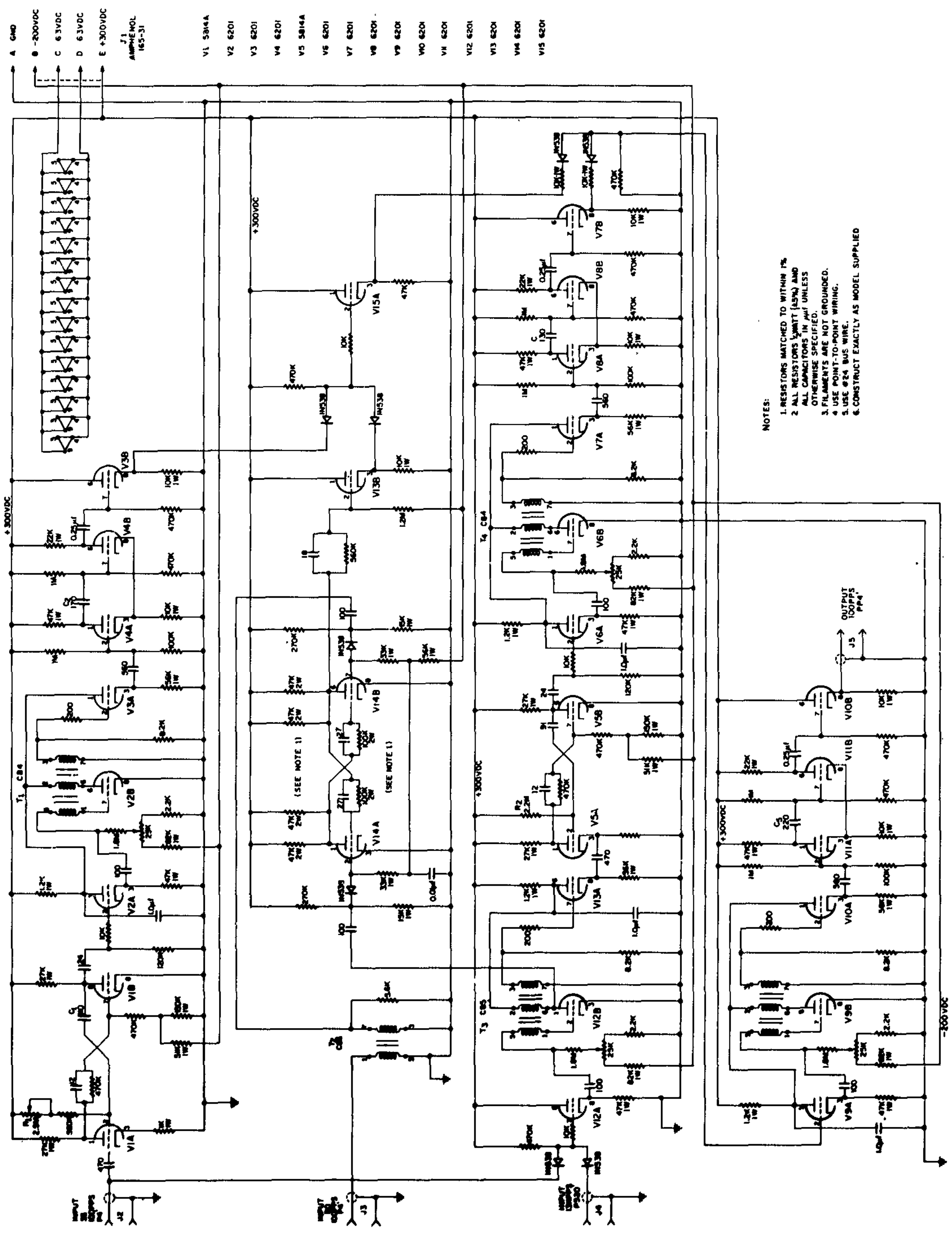


Figure F10

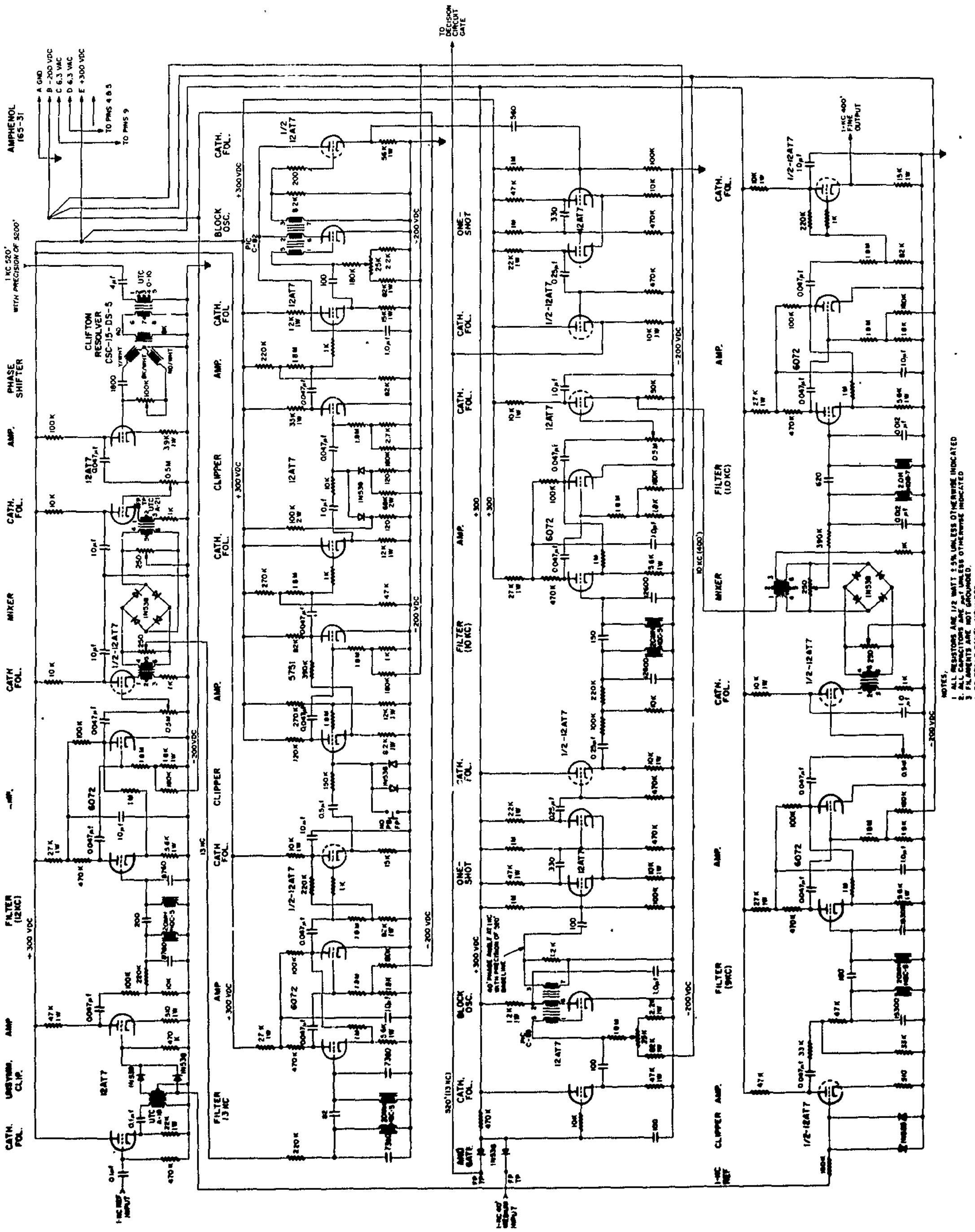


Figure F11

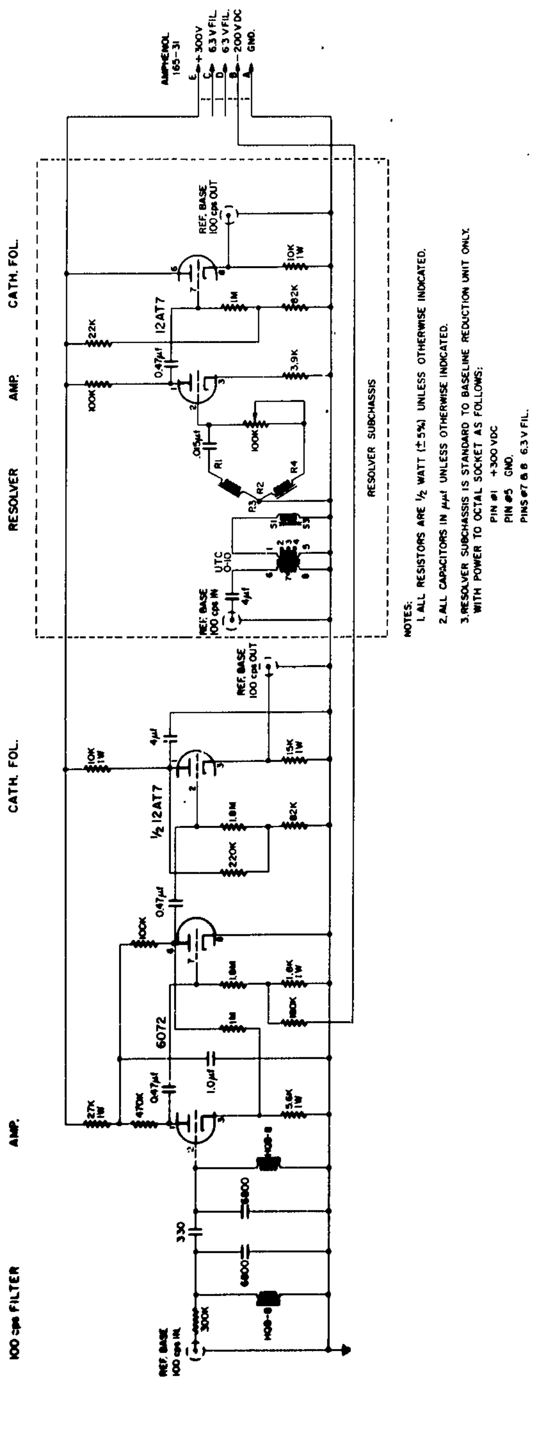

100 cps FILTER
AMP.
CATH. FOL.
RESOLVER
AMP.
CATH. FOL.
RESOLVER SUBCHASSIS
6072
1/2 12AT7
12AT7
AMPHENOL 165-31
+300V
6.3 V FIL.
6.3 V FIL.
-200 VDC
GND.
REF. BASE 100 cps IN
REF. BASE 100 cps OUT
NOTES:
1. ALL RESISTORS ARE 1/2 WATT (±5%) UNLESS OTHERWISE INDICATED.
2. ALL CAPACITORS IN μμf UNLESS OTHERWISE INDICATED.
3. RESOLVER SUBCHASSIS IS STANDARD TO BASELINE REDUCTION UNIT ONLY. WITH POWER TO OCTAL SOCKET AS FOLLOWS:
PIN #1 +300 VDC
PIN #5 GND.
PINS #7 & 8 6.3 V FIL.

Figure F12

APPENDIX G

OUTLINE FOR COMBINED-DATA REDUCTION (LONG-BASELINE COMBINER)

SANBORN RECORD CHANNEL ALLOCATION

The long-baseline combiner generates three outputs consisting of 4-, 40-, and 400-ft baselines (BL). Along with other signals, these three outputs are located on the record as follows:

Channel	Signal	
8	Old Combiner	
7	EW-520'	
6	400'	New Combiner
5	40'	New Combiner
4	4'	New Combiner
3	NS-1200	
2	EW-52	
1	AGC	
Edge	Time Marks	

READING THE PHASE DATA

Consider channels 4, 5, and 6 to be divided as shown in Fig. G1.

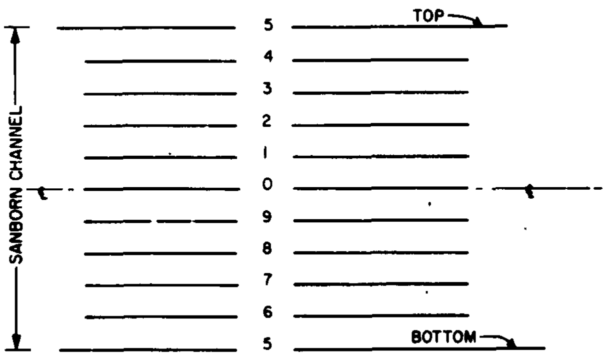


Fig. G1 - The 4-, 40-, and 400-ft channels (channels 4, 5, and 6), divided and numbered to facilitate angle readout

Example 1 (Fig. G2)

Log* the phase signal levels from channels 4, 5, and 6 to two decimal places and arrange this data as follows:

4' BL	-.32
40' BL	-.-17
400' BL	-.--83
Adding by inspection: (i.e., adjusting the last significant figure of each baseline from the reading below it) →	0.3183

Use the special table prepared for the long baseline combiner:

$$\arcsin(0.3183) = \underline{46.44^\circ} \text{ East.}$$

Note: This special table was compiled based on the 4-, 40-, and 400-ft baseline having their max.-min. cals. set on the edges of their respective channel recording.

If the special table is not available, a standard table of natural functions can be used after the phase reading is multiplied by 2.27647. Consider the case above.

$$(2.27647)(0.3183) = 0.724590401$$

$$\arcsin(0.72459) = \underline{46.44^\circ} \text{ East.}$$

The factor 2.27647 can be rounded off, at the sacrifice of accuracy of course; it comes from dividing the 4-ft baseline into the wavelength λ (in feet). Thus,

$$\frac{\lambda}{4} = \frac{9.10587}{4} = 2.27647$$

where

$$\lambda = \frac{v}{f} = \frac{2.99793 \times 10^{10}}{108.015 \text{ Mc}} \quad \frac{1}{(2.54)(12)} = 9.10587 \text{ ft}$$

and

v = velocity of light (cm)

f = frequency of system (cps).

Example 2 (Fig. G3)

In the case of a signal occurring west of zenith, the procedure for angle determination is the same as illustrated in Example 1, using the special table. However, when a

*Adjust readings for calibration, if necessary. Record was read at peak of the agc, channel 1.

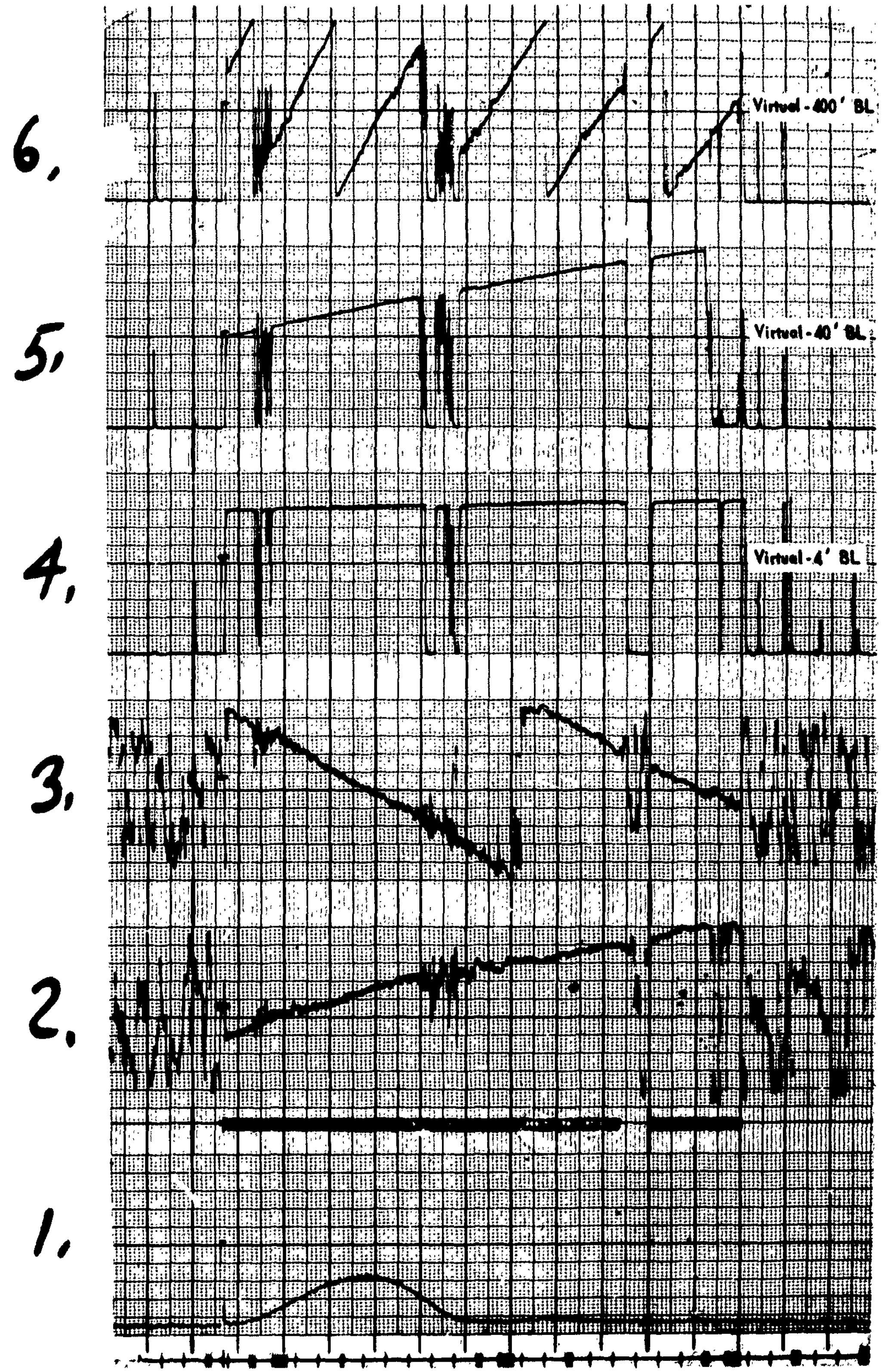


Fig. G2 - Example of signal occurring east of zenith standard table is used, an additional step must be included. The composite number determined from the three channels must be subtracted from 1.0000. This will be clear from the following. As in Example 1, log the signal levels from channels 3, 4, and 5 (Fig. G3).

4' BL	0.99
40' BL	-.-95
400' BL	-.--70
Adding: ⟶	0.9970

Using the special table 0.9970 gives 0.39° West. When using the standard table, proceed as follows:

	1.0000
	.9970
Subtr. ⟶	0.0030 .

Multiply by the factor 2.27647:

$$(2.27647)\ (0.003) = \underline{0.00682941};\ \text{so}$$

$$\arcsin\ (0.00682941) = \underline{0.39°}\ \text{West.}$$

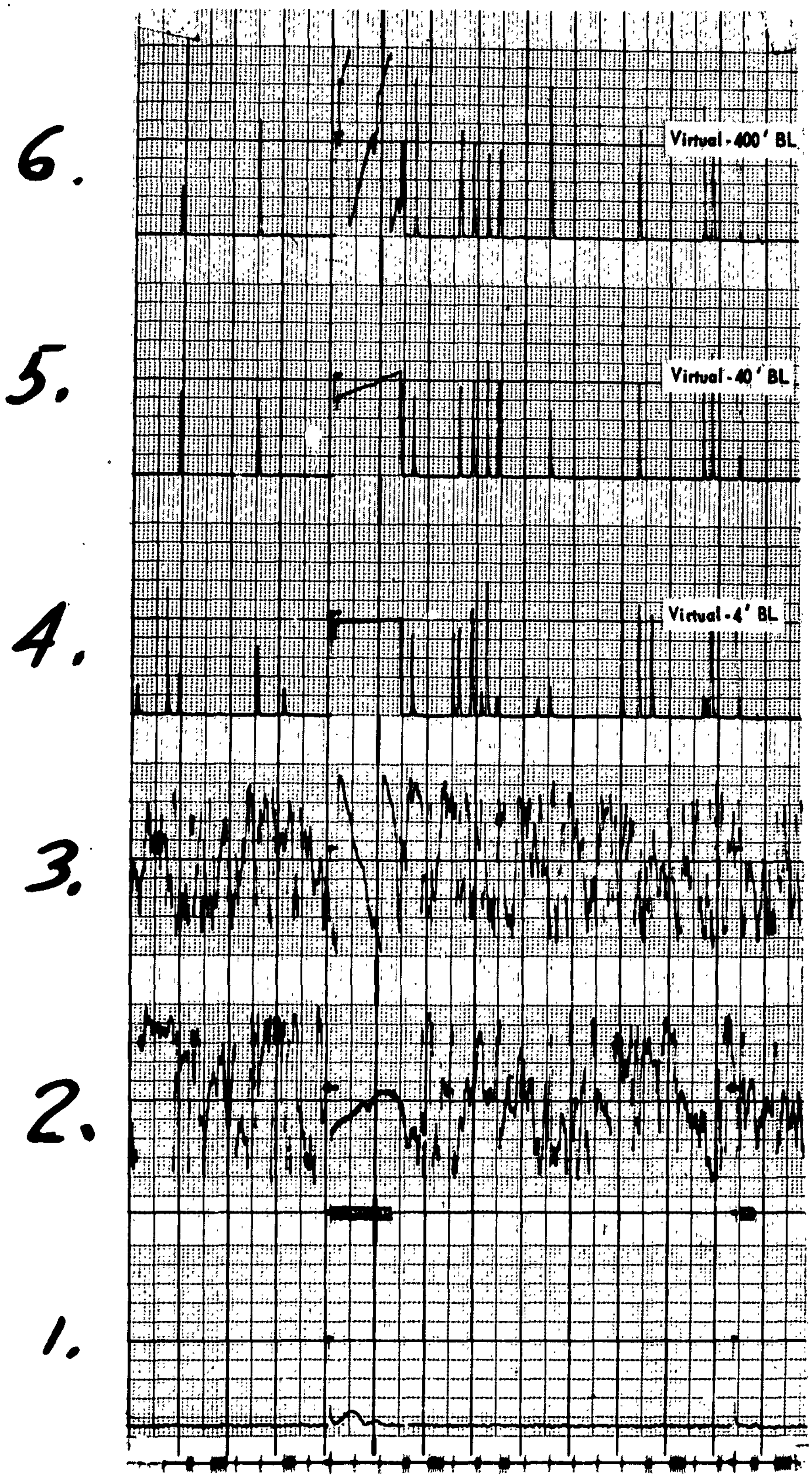


Fig. G3 - Example of signal occurring west of zenith

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U.S. Naval Research Laboratory. Report 5980.
RADIO-INTERFEROMETER ANALOG PHASE-CHANNEL COMBINER (MOD II) FOR UNAMBIGUOUS SPACE ANGLE MEASUREMENTS IN THE NAVY SPACE SURVEILLANCE SYSTEM, by M. G. Kaufman and C. H. Weaver. 62 pp. & figs, October 30, 1963.

The Navy Space Surveillance System, developed at the Naval Research Laboratory for the purpose of detecting nonradiating earth satellites, forms a radio fence along a great circle across the southern part of the United States. Four receiving sites alternate with three transmitting sites to form the fence. The transmitting stations illuminate satellites with radio energy as they cross the fence. The angle of arrival of the reflected signals is measured at each receiving station by a compound radio interferometer. These signals yield a multiplicity of channels of information which are normally recorded on paper, read, and resolved. Operationally, the resolution is done by a computer, but the angle of arrival can also be resolved by using slide rules and/or tables.

With the increasing satellite population, the number of fence crossings has increased considerably. Automation in the detection process is needed to facilitate the identification and sorting of satellites from each other (and from refuse) if a

UNCLASSIFIED (over)

1. Radio interferometers - Equip.
2. Space surveillance system - Data - Processing
I. Kaufman, M. G.
II. Weaver, C. H.

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The basic technique used in the Mod II phase-channel combiner is as follows. In the Space Surveillance System station electronics, the phase displacement for each channel is carried by a separate 1-kc signal. For combining purposes, each of these 1-kc signals is translated to a new frequency proportional to the interferometer baseline length, thus normalizing each of the phase channels. This is done by heterodyning the 1-kc signal with a set of reference frequencies derived from the precision oscillator in the station clock. The space angle solution is obtained by coincidence determination of the zero crossings of the above baseline frequencies. Pulses are generated at each zero crossing and monitored in an AND gate circuit. This circuit produces an output for the duration that the pulses from all the new baseline frequencies are in time coincidence. The time displacement of this coincidence pulse from a reference pulse is proportional to the sine of the space angle. This time displacement is detected and transformed into a dc voltage by an analog phase meter for presentation on a recorder, or it is digitalized and fed to a computer. The accuracy of this system is related to the longest baseline in the group.

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