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Signal-Simulator for the Navy Space Surveillance System Combiners

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ABSTRACT

In order to test the performance of an interferometer phase-channel combiner the phase of many signals must be varied in a coherent manner. The electro-mechanical signal-simulator used for combiner research is costly and considered too cumbersome for use in field installations. Consequently, using a basic principle of combiner operations, that of translating the incoming phase carriers to frequencies proportional to the antenna spacing, provides an indirect approach to the simulation of signals. Using a single signal source, a dynamic check of any or all channels may be rapidly made.

PROBLEM STATUS

This is an interim report on a continuing problem.

AUTHORIZATION

NRL Problem R02-35

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SIGNAL-SIMULATOR FOR THE NAVY SPACE SURVEILLANCE SYSTEM COMBINER

INTRODUCTION

In order to test or check on the performance of an interferometer phase-channel combiner* some means of varying the phase of many signals is required. The phase relationship among the signals must be varied continuously and coherently to simulate actual operating conditions.

In the past, signal simulation for combiner testing was instrumented by electro-mechanical means, namely: Several mechanical phase-resolvers were geared (with appropriate ratios) to a common motor-driven shaft, Fig. 1. The arrangement is exceedingly bulky for even as few as four signal channels. Although feasible for laboratory R&D on combiners, this mechanical assembly is not considered appropriate for field installations; hence, an all-electronic approach to signal-simulation is needed.

DESIGN CONSIDERATIONS

The simulation of signals into the combiner (Fig. 2) basically requires that the input phase rates be proportional to the length of the baselines. Under operational conditions the signal information from any baseline B_n appears as an input to the mixer of the form

$$E_{ns} = \sin\,(\omega_r t + \phi_n) \tag{1}$$

$$\phi_n = \frac{B_n}{B_o} f(\theta) \tag{2}$$

where

- E_{ns} = the signal information from the B_n baseline
- ω_r = reference frequency = $2\pi 1000$
- t = time
- ϕ_n = electrical phase from the B_n baseline
- B_n = baseline with length of n-ft.
- B_o = shortest unambiguous baseline ($< \lambda/2$)
- θ = space angle measured from zenith ($-\pi/2 \leq \theta \leq \pi/2$)

*A Phase-channel combiner is an electronic system used with multi-baseline radio interferometers to automatically resolve the angular direction cosine of a satellite in space (References 1 and 2).

$$f(\theta) = \alpha t \qquad (3)$$

where α = a constant proportional to the geometry of the situation. Inserting equation (2) and (3) in equation (1) gives:

$$E_{ns} = \sin\left(\omega_r + \frac{B_n}{B_o}\alpha\right)t \qquad (4)$$

E_{ns} is supplied to one input of a mixer circuit. The other input to the mixer, ignoring amplitude, is given by

$$E_{nHG} = \sin\left(1 + \frac{B_n}{10B_o}\right)\omega_r t, \qquad (5)$$

where the subscript HG signifies "harmonic generator".

These are multiplied in the mixer as follows:

$$E_{nMIX} = [E_{ns}][E_{nHG}] = [\sin\left(\omega_r + \frac{B_n}{B_o}\alpha\right)t][\sin\left(1 + \frac{B_n}{10B_o}\right)\omega_r t] \qquad (6)$$

$$E_{nMIX} = \tfrac{1}{2}\cos\left[\frac{B_n}{B_o}\alpha - \frac{B_n}{10B_o}\omega_r\right]t - \tfrac{1}{2}\cos\left[\text{sum of the angles}\right]t \qquad (7)$$

Note, the sum term is eliminated by filtering the output of the mixer, leaving:

$$E_{nF} = \tfrac{1}{2}\cos\frac{B_n}{B_o}\left[\frac{\omega_r}{10} - \alpha\right]t, \qquad (8)$$

where the subscript F indicates the filtered output of the mixer stage.

A schema to generate the electronic analog of equation (8) above, into a dynamic signal, is shown in Figure 3. Its algorithm follows. The 1-kc reference is passed through a resolver driven at a rate equal to minus 10α. Hence, the signal into each mixer is:

$$E_s = \sin(\omega_r - 10\alpha)t \qquad (9)$$

A ten to one frequency divider also operates on this signal (9) producing an output, $E_s/10$, to be fed to each harmonic generator.

$$E_s/10 = \sin \frac{(\omega_r - 10\alpha)t}{10} \qquad (10)$$

The harmonic generators perform a frequency multiplication by

$$(10 + \frac{B_n}{B_o})$$

giving:

$$E_{nHG} = \sin \left[\left(\frac{\omega_r}{10} - \alpha\right)\left(10 + \frac{B_n}{B_o}\right)\right]t$$

$$= \sin \left[\left(1 + \frac{B_n}{10B_o}\right)\omega_r - \left(10 + \frac{B_n}{B_o}\right)\alpha\right]t \qquad (11)$$

Finally, performing the multiplication of equation (9) by equation (11) in the mixer and eliminating the sum term yields:

$$E_{nF} = \tfrac{1}{2} \cos \left[\frac{B_n}{10B_o}\omega_r - \frac{B_n\alpha}{B_o}\right]t$$

$$= \tfrac{1}{2} \cos \frac{B_n}{B_o}\left(\frac{\omega_r}{10} - \alpha\right)t \qquad (12)$$

Note that the filtered output E_{nF} of each mixer is now identical in frequency to an operational signal given earlier by equation (8).

INSTRUMENTATION

The additional hardware required to instrument the signal-simulator are indicated by the shaded area in Fig. 3. This consists of:

1. An n-pole, double throw switch used to switch the input of the multi-channel combiner from operational status (from live data signals) to test condition (simulated signals).

2. A motor driven resolver.

3. A ten-to-one frequency divider.

An alternate and more flexible implementation is shown in Fig. 4 where the motor and resolver are replaced by an oscillator which may be off-set from its base frequency of 1 kc by an amount $\pm \Delta F$. Either means provides the proper phase-signal to the multiple mixer circuits which, in turn, produce a set of coherent phase varying signals to the corresponding zero-crossing detectors.

RESULTS

The validity of this method of signal-simulation was tested in the laboratory using seven channels of a current Space Surveillance System combiner as shown in Fig. 4. The combiner output recordings for four values of α are shown in Fig. 5. From these records it is seen that by off-setting the 1 kc signal generator from its center frequency by an amount $+ \Delta F$ a normal satellite pass from West to East is simulated; conversely, an off-set of $- \Delta F$ produces a simulated retrograde pass. The linearity of the recordings are within $\pm$ 1%.

By varying the magnitude of ΔF the time required for a complete horizon-to-horizon pan ranges from a minimum of 7 seconds to a theoretically unlimited maximum. The lower limit is primarily determined by filter inertia in the combiner circuits, while the upper limit depends upon the stability of the signal generator.

DISCUSSION

In practice, the combiner input will be switched (manually or automatically) away from the operational signal inputs to the signal-simulator inputs. In this mode the combiner will act as though it were receiving noise-free operational signals. The combiner output will sweep out a recorded trace covering all space angles from horizon to horizon, the sense of which (i.e. E-to-W or W-to-E) depends on the initial choice of the sign of ΔF.

Combiner operation can be checked by observing one or two simulated passes either by monitoring the combiner AND gate output pulse with an oscilloscope or viewing the combined-data trace on a paper recorder.

The use of this signal-simulator does not preclude or alleviate the usual periodic Space Surveillance System calibrations required to preserve "phase integrity", since these tests involve pre and post-detection components not included in the combiner. However, it does permit a check of combiner operation without disturbing the flow of uncombined data as well as providing an aid to off-line trouble-shooting.

The maximum amount of frequency shift, $\Delta F = (1/2\pi)(10\alpha)$, possible is limited by the ability of the harmonic generator corresponding to the longest baseline to maintain synchronization. For the combiner used this limit was reached at 1.5 cps off-set, which causes a frequency change of approximately 63 cps in the output of the 4.2 kc harmonic generator. These figures correspond to a simulated satellite pass from horizon to horizon requiring 7 seconds. This is well above present day satellite speeds as monitored from the earth.

CONCLUSIONS

A multi-channel signal-simulator for the phase channel combiner has been designed and implemented. Unlike its predecessors, this all-electronic unit has no mechanical moving parts, is fairly compact, and is flexible as to rate and direction of the simulated pass. It is now considered practical to incorporate such a unit in each combiner at the field installations.

Although the principles of operation are demonstrated with respect to existent baselines, the mathematical development is general. No modification need be made to the simulator to accommodate changes in baseline.

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REFERENCES

1. Easton, R. L. and Fleming, J. J. "The Navy Space Surveillance System", Proc. IRE Vol. 48 No. 4. pp. 663-669; April, 1960

2. Kaufman, M. G. and Weaver, C. H., "Radio-Interferometer Analog Phase-Channel Combiner (Mod. 2) for Unambiguous Space Angle Measurements in the Navy Space Surveillance System", NRL Report 5980, Oct. 1963.

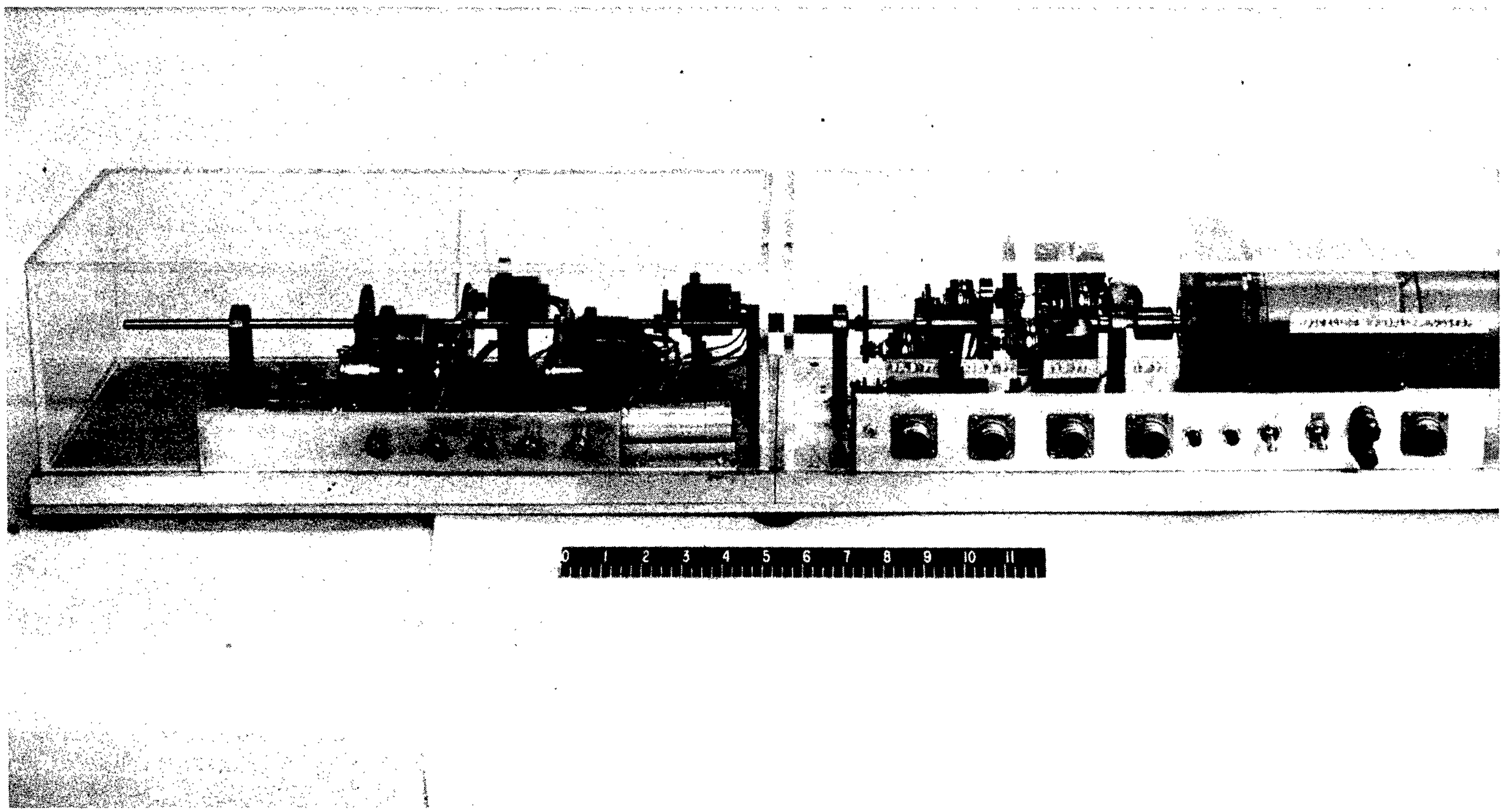

Fig. 1 - Signal-Simulator using Electromechanical Components

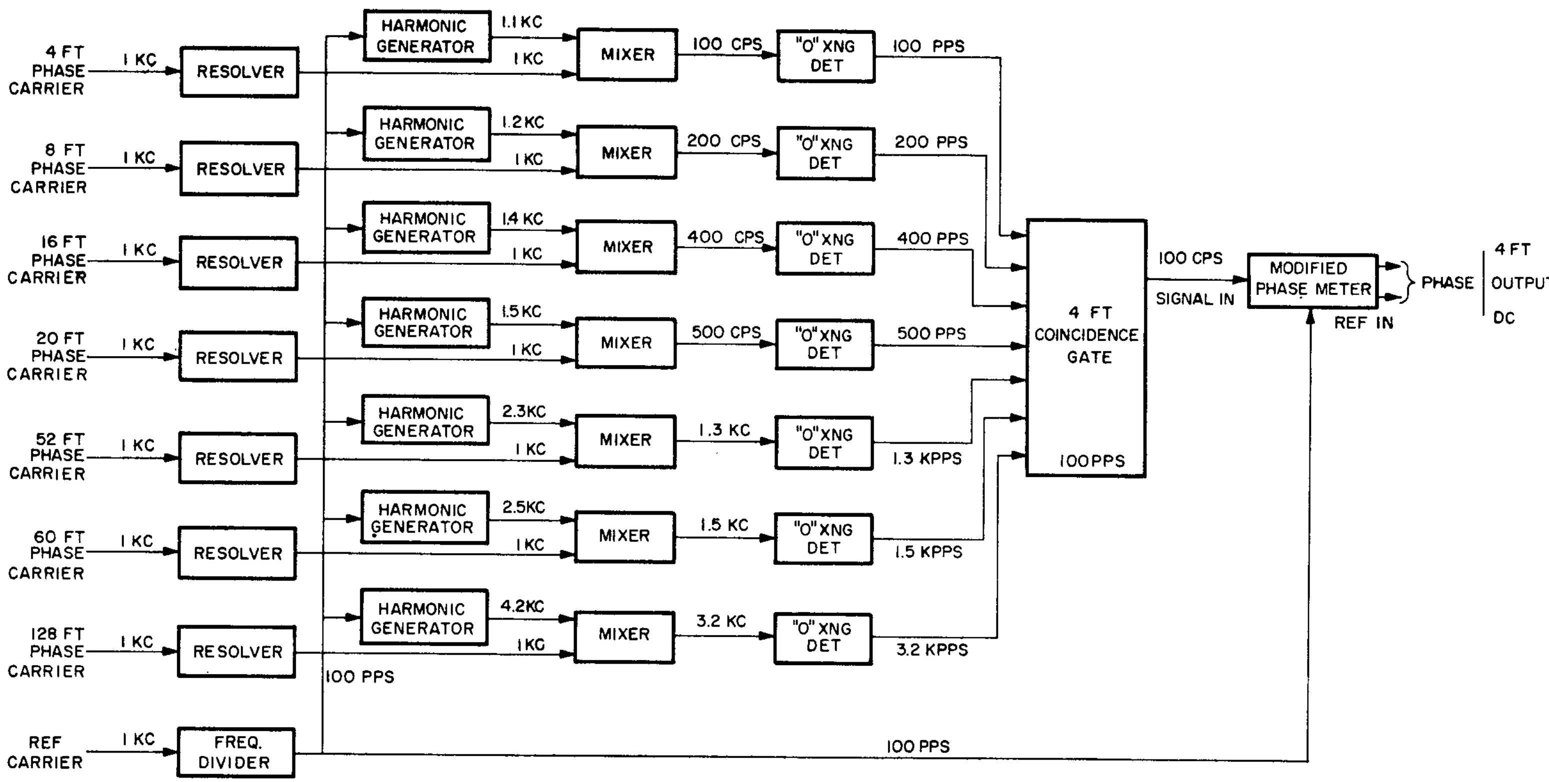

Fig. 2 - Phase-Channel Combiner (4 ft.)

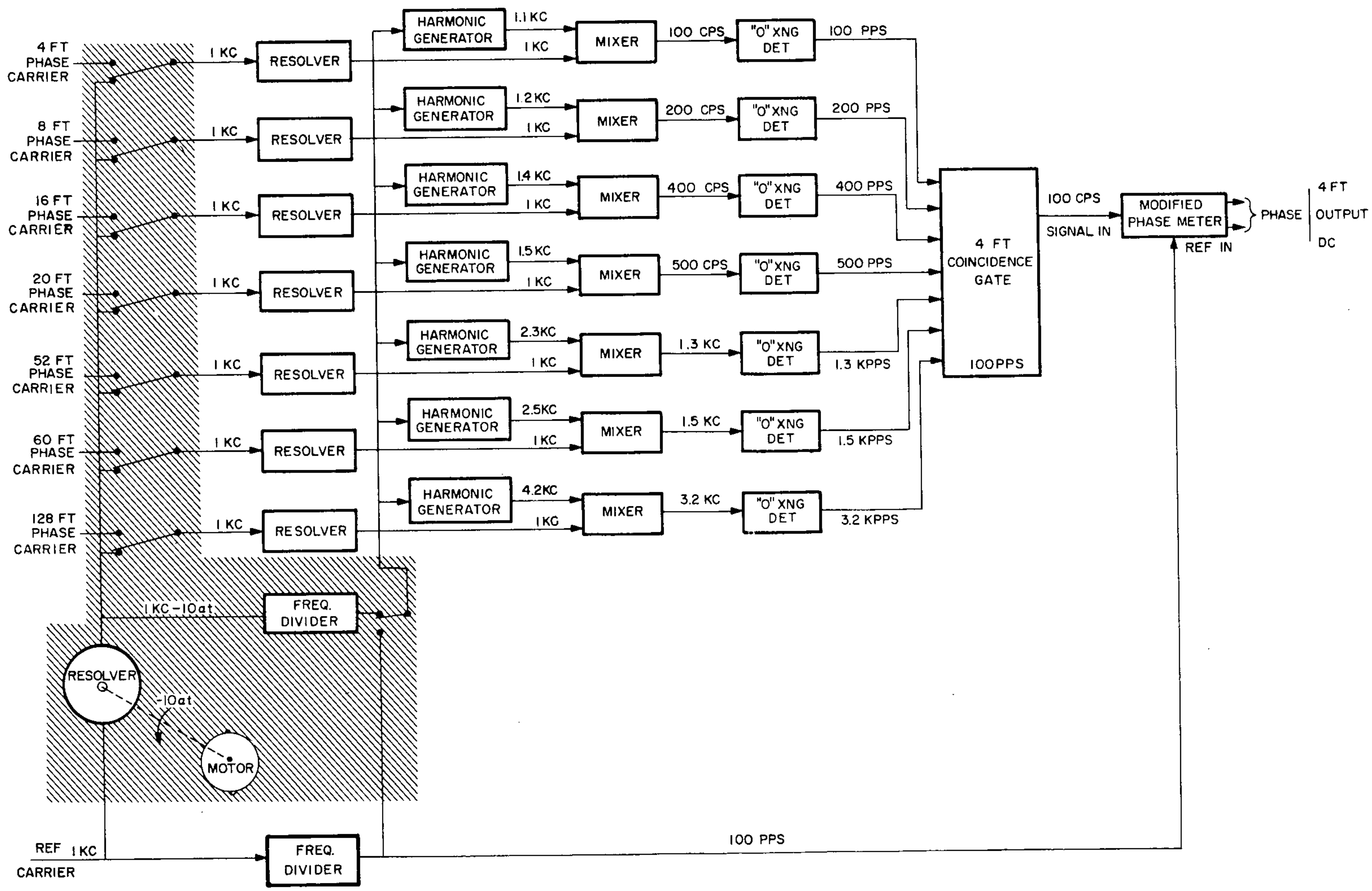

Fig. 3 - Signal-Simulator for the Phase-Channel Combiner (using one resolver)

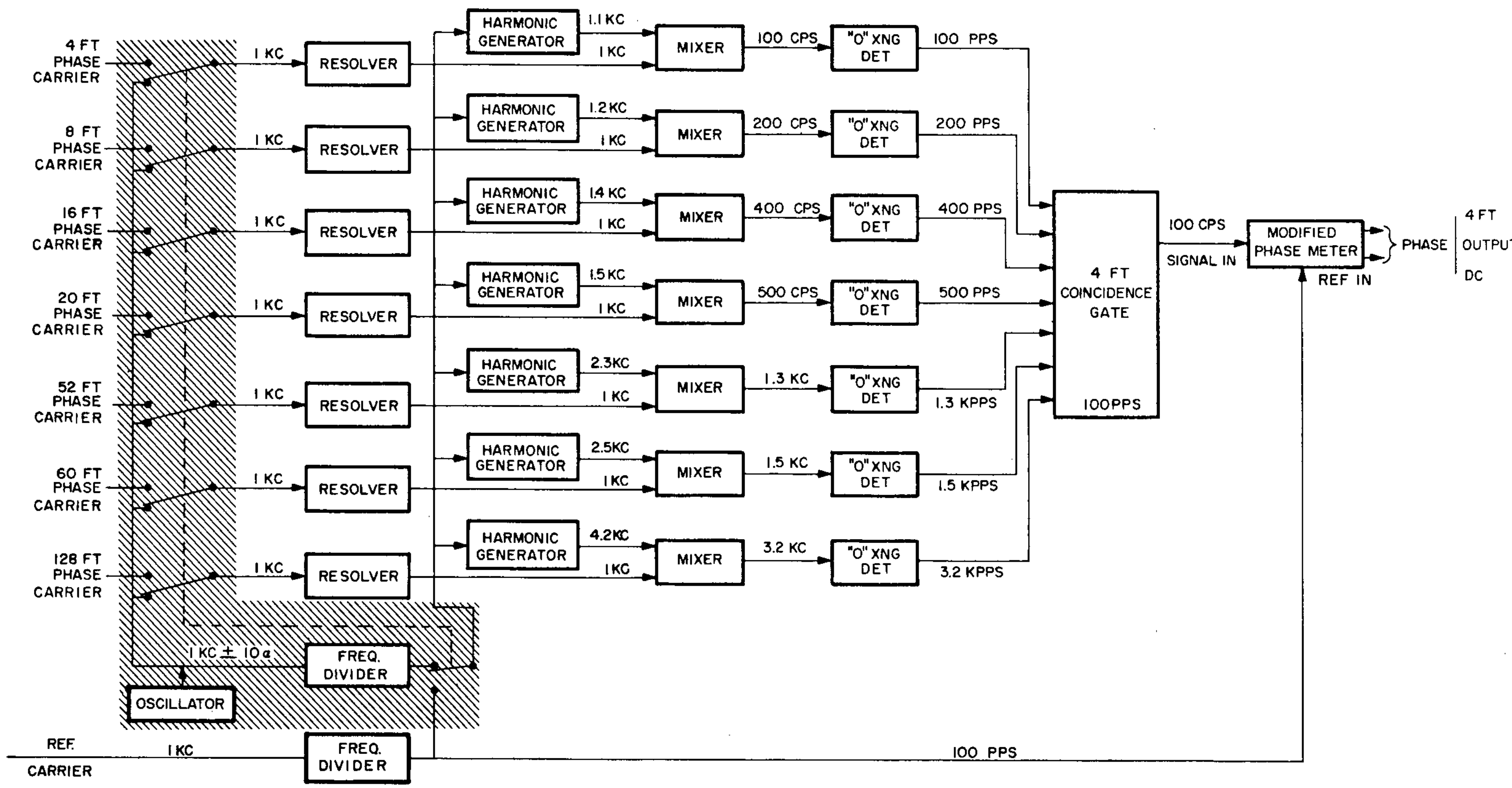

Fig. 4 - Alternate Signal-Simulator for the Phase Channel Combiner
(Resolver replaced by Off-Set Signal Generator)

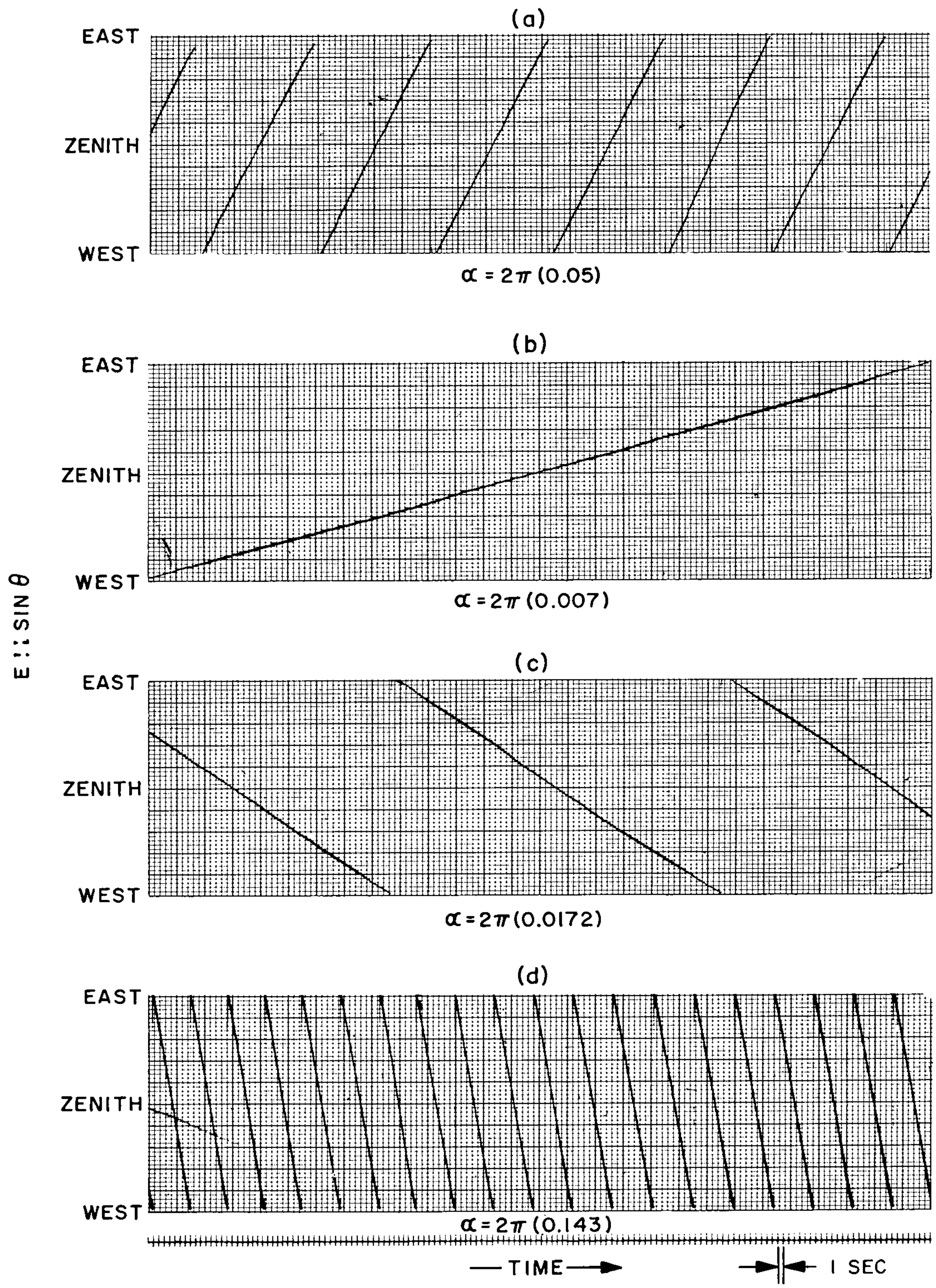

Fig. 5 - Recordings of the Combiner Output using the Electronic Signal Simulator

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