WHITE SANDS MISSILE RANGE (WSMR)
A PHASE - DIFFERENCE MEASURING TRACKING SYSTEM

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ABSTRACT

The Phase Difference Measuring (PDM) system is an RF interferometer object tracking system which utilizes the object's radiated telemetry power spectra for tracking purposes.

The PDM system is being developed in-house at White Sands Missile Range as a highly mobile electronic angle measuring system, to augument existing position measuring capability in range instrumentation systems. The system is comprised of two Remote Data Acquisition Stations (RDAS) and a Cosine Conversion Facility (CCF). Each RDAS is comprised of two antenna arrays configured as crossed baselines. The RDAS equipment utilizes high speed RF switching in a time sharing technique designed to reduce the amount of hardware required at the remote sites to produce direction cosines. The CCF collects two direction cosines from each RDAS, it then transforms the direction cosines to position data for subsequent transmission to a Range Control Center.

This paper will provide basic system theory, explain the proposed antenna PF switching techniques, and also the computer simulation analysis for a baseline consisting of two pair of antennas.

INTRODUCTION

The Interferometer Tracking Systems group of White Sands Missile Range is now developing a Phase-Difference Measuring (PDM) interferometer tracking system to use current technology, applying hardware and software to track airborne targets containing an S-band telemetry transmitter. The PDM system uses two antenna fields comprised of two orthogonal linear antenna arrays, called baselines (see Figure 1). Each baseline contains three antennas, spaced at 18.9 and 19.35 wavelengths at 2290 MHz. The PDM uses measured phase differences to compute a direction cosine for each baseline. Two baselines yield a line in space from the antenna field center: two antenna fields yield a point in space.

Each antenna field will be part of a Remote Data Acquisition Station (RDAS). The RDAS computes two direction cosines for each site. Figure 2 shows how two RDAS are connected to a central Cosine Conversion Facility (CCF), which uses the four direction cosines to compute an X, Y, Z position. This paper shall discuss the PDM's baseline configuration inherent errors, and possible corrections.

Hardware Phase Measurement

The PDM uses precisely located antenna arrays to measure the phase difference of an RF wavefront at antenna pairs within the array. Figure 3 illustrates the phase measurement principle. The direction cosine may be found by $\cos\theta = \frac{\Delta\phi}{D}$

where:

D = The distance between antennas (baseline length).
$\Delta\phi$ = The ray-path length difference from the object relative to each antenna, and
θ = The cosine - derived angle.

The PDM system uses a high-speed RF switch to time-multiplex the antenna pairs[1] (see Figure 4a) . The centrally located antenna is used as one input to the phasemeter: the radial antennas are multiplexed as the other phasemeter input. The processor/controller synchronizes the RF switch control and phase data collection. Currently operational interferometer systems do not time-multiplex antennas: if discrete components were used, five receivers and four phasemeters would be required (see Figure 4b). The phasemeter readings are the heart of the PDM system, since measured phase is related to ray-path length difference.

Given a single phase reading, it is impossible to obtain a unique solution, since only the fractional part of the phase difference can be measured: measured phase is between 0 and 1. With more than one phase measurement from antennas with different spacing, a unique (or unambiguous) direction cosine may be computed. Various mathematical algorithms have been developed for this so-called ambiguity resolution[2]. This paper will not discuss these methods specifically, but will use a simulated 2-antenna-pair ambiguity resolution method.

The actual point of this paper is to discuss the simulation of a baseline, the errors encountered, and the effects of error correction.

Measurement Errors

The errors inherent to any interferometer system are varied: some are purely geometrical, some are related to RF or computation phenomena. The baseline-related errors are:

1. RF and electrical noise,
2. Nearness error,
3. Parallax error,
4. Truncation error,
5. Survey error.

These errors will be explained as they are discussed. Error at the cosine level is measured in parts per million (ppm). Simulations will address errors for a single East-West baseline by moving the target from zero degrees (due East) in a counter-clockwise circular arc to 360 degrees around azimuth at a fixed range and elevation angle. A simulated cosine value was compared to the known actual cosine value to compute error. Figure 5 shows the result of a simulation with no noise, no nearness or parallax correction, ideal phasemeters, antennas ideally located, a target at a range of 6096 meters from the array center, at an elevation angle of 20 degrees (i.e., ideal conditions, no corrections). This simulation will serve as the departure point to discuss each error and correction.

Noise Errors

At low signal reception levels (below - 110 dm), receiver noise becomes an important consideration. Figure 6 shows the impact of noise on cosine accuracy, by injecting noise which is equivalent to five Bits of a phasemeter reading. Figure 7 shows the effect of noise when parallax and nearness corrections are made, i.e., the only error is due to noise.

Mote that noise still affects the solution.

Nearness Error

Nearness error is the error encountered when a target is radiating too close to the antenna field that the wavefront is no longer planar (i.e., the rays are not parallel). The phase measurement in this condition does not represent the actual ray-path length difference. The effect of nearness error may be seen when the nearness correction is used, by comparing Figure 8a to Figure 8b, Figure 8b illustrates the error under the same conditions as in Figure 8a with the exception of added nearness correction. The range has been decreased to illustrate the nearness error effect.

Parallax Error

Parallax error is encountered when an antenna pair center is not at the antenna field center. The PDM system's antenna pair centers are displaced from the antenna field center[3], so parallax is an important consideration. A comparison of Figures 9 and 5 shows the significance of parallax error: Figure 9 shows error under the same conditions (but with parallax corrections) as in Figure 5. Note that the error scale is now up to 60 ppm instead of 600 ppm.

Truncation Error

Because the PDMS phasemeters have a resolution to 11 Bits, truncation errors will occur. Figure 10 illustrates the effect of truncaiton on the cosine solution, in comparison to Figure 5.

Survey Error

Because the ray-path differences yield phase data, the antenna placement accuracy is crucial. Ideally, the antennas would he placed in their exact desired locations; in actual practice, this accuracy is impossible. The effect of antenna misplacement is shown in Figure 11, in which the antennas are placed to within 0.8 mm of the ideal location. Figure 12 shows the same situation as Figure 11, but to within Ø.1 mm. Note that the placement accuracy has a great effect on the solution: Ø.1mm is indeed the PDMS design tolerance.

Combined Errors and Corrections

Figure 13 illustrates the expected actual worst-case operational situation: all corrections are used, the noise content corresponds to 5 phasemeter Bits. The maximum error is approximately 300 ppm.

In actual operation, the expected noise content would be equivalent to at most 2 Bits. Figure 14 illustrates the error for an equivalent 2 Bits of noise: the maximum error is approximately 180 ppm.

CONCLUSION

The results of the simulation show that the most critical parameter in the system is survey error. Available technology can position the antennas to within 0.1 mm. With all the correcting factors properly handled and controlled, the final solution will be optimized.

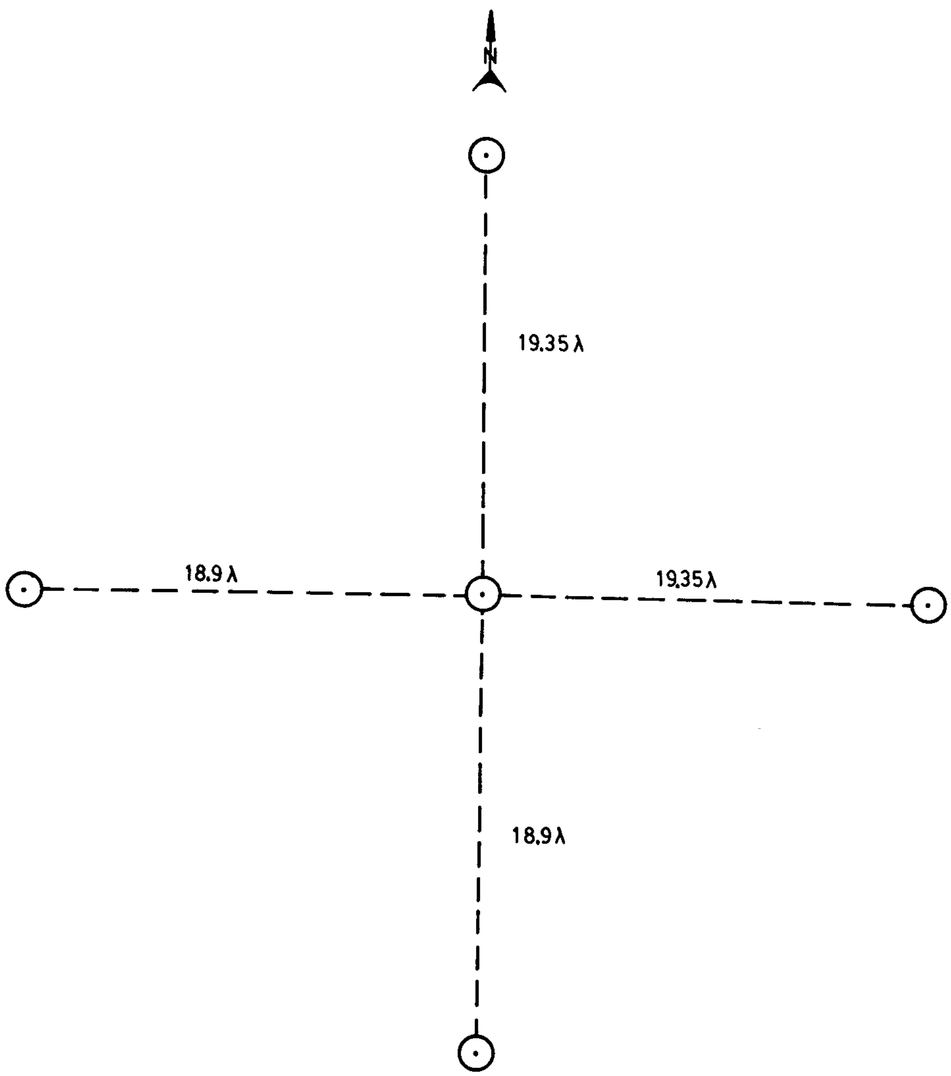
The PDM system can augument existing tracking systems in any test range. Some advantages derived from the PDM system are low cost, high mobility, high dynamic target tracking (the system is all electronic), and the capability to track a target under chaff and electronic countermeasures conditions.

References.

1. Mario Z. Parra, Applications of Switching Techniques to RF Interferometry, STEWS-NR-DE, White Sands Missile Range, New Mexico, November 1978.

2. William L. Shepherd, Ambiguity Resolution for Three-Antenna and Four-Antenna Baseline Angle Measuring Equipment, STEWS-ID-T, White Sands Missile Range, New Mexico, July 1979.

3. Forrest J. Dozier, Jr., Parallax Correction Investigation, STEWS-NR-DT, White Sands Missile Range, New Mexico, March 1982.



PDM ANTENNA FIELD CONFIGURATION AND SPACING CHARACTERISTICS

Figure 1

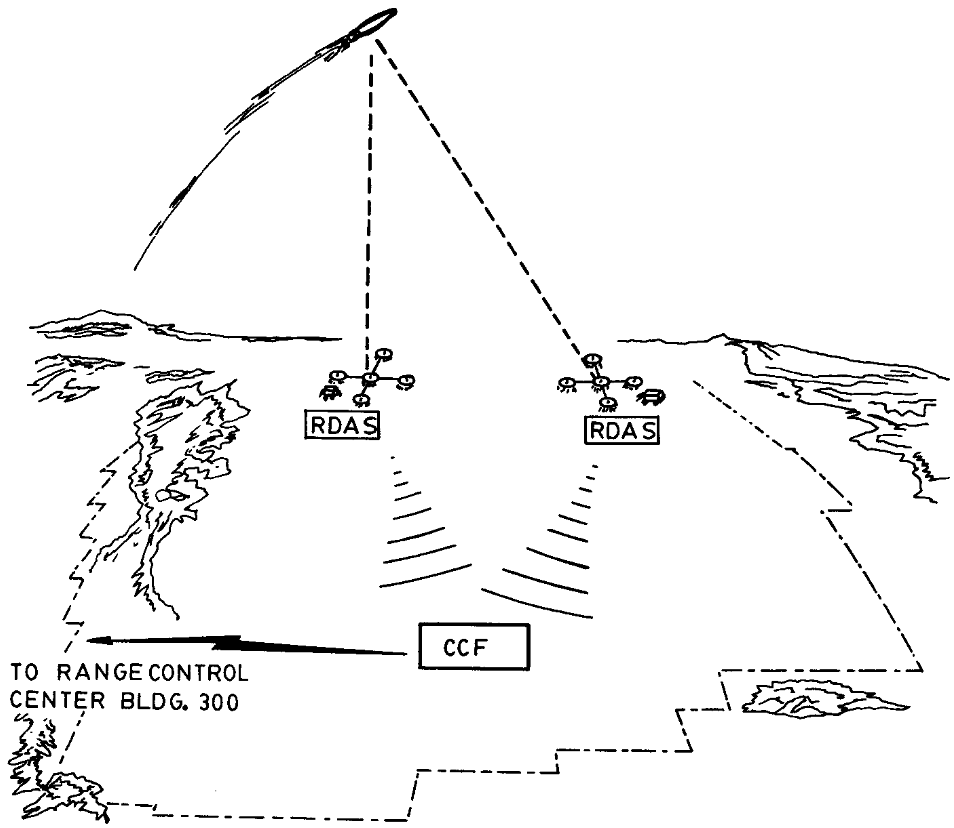


Figure 2

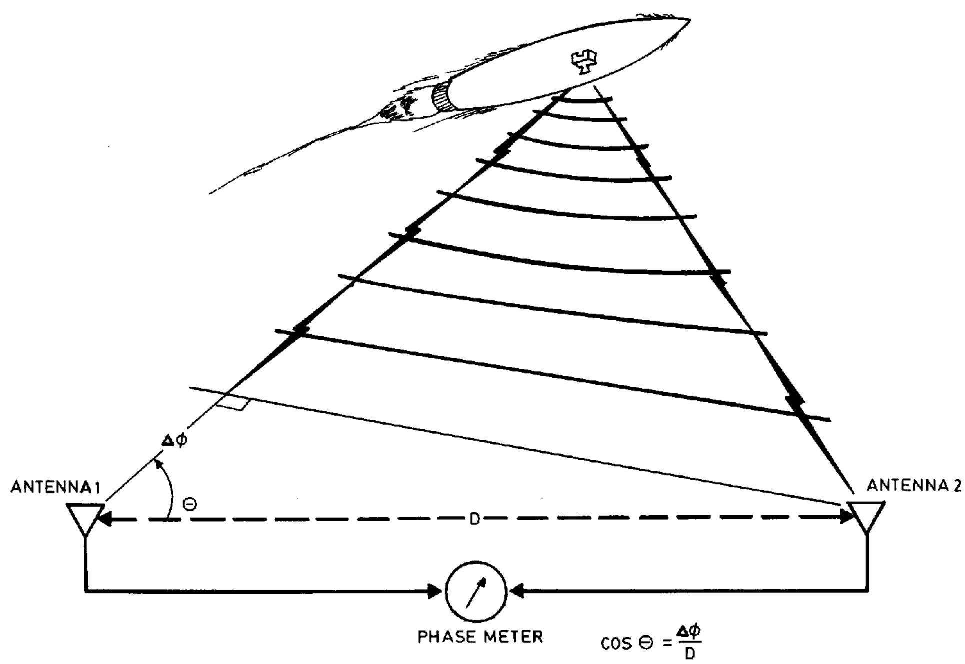


Figure 3

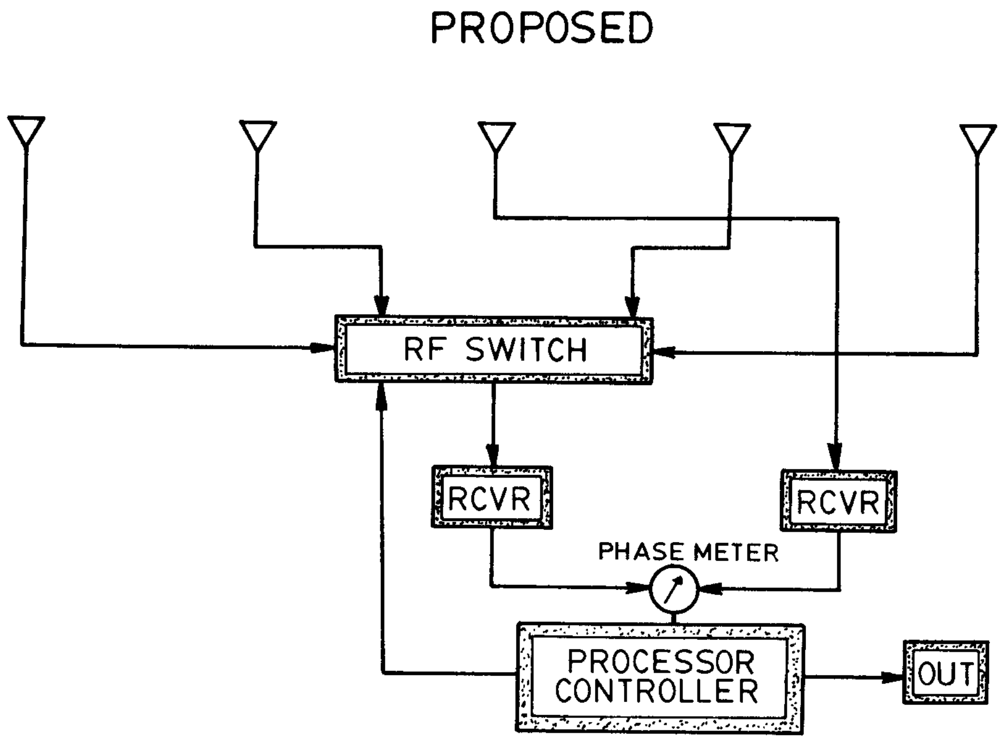


Figure 4a

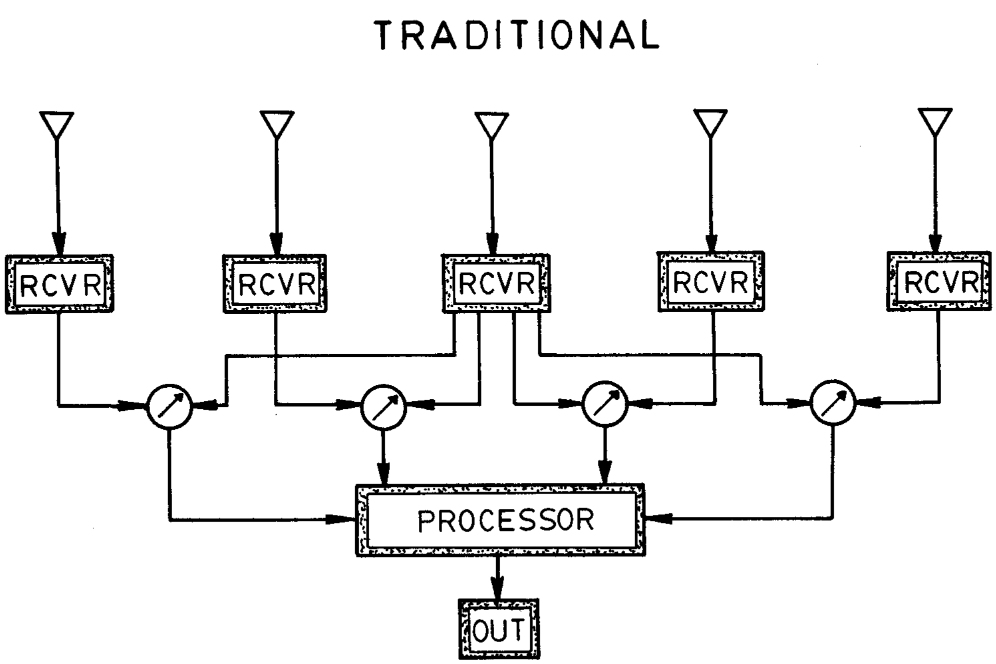
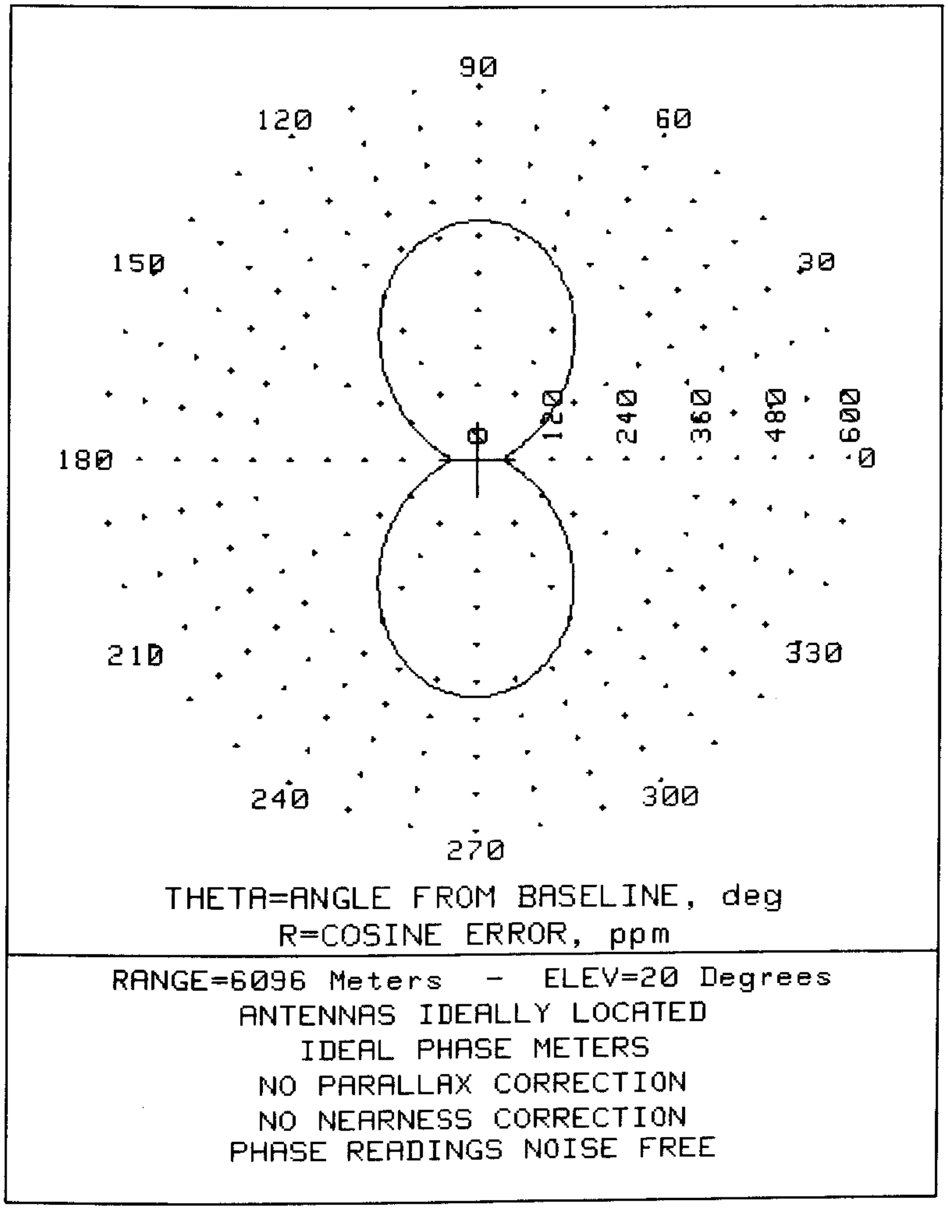


Figure 4b



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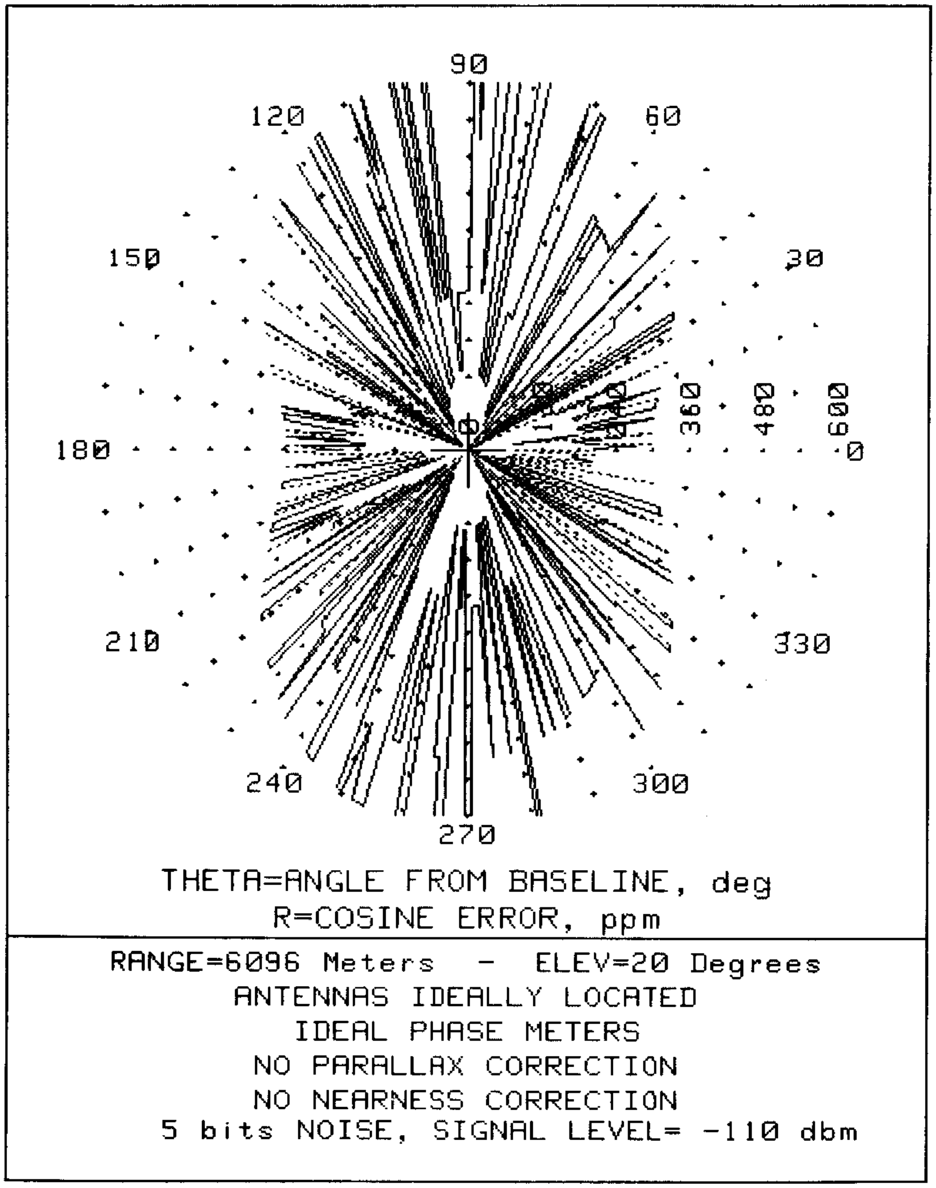
THETA=ANGLE FROM BASELINE, deg
R=COSINE ERROR, ppm
RANGE=6096 Meters - ELEV=20 Degrees
ANTENNAS IDEALLY LOCATED
IDEAL PHASE METERS
NO PARALLAX CORRECTION
NO NEARNESS CORRECTION
PHASE READINGS NOISE FREE

Figure 5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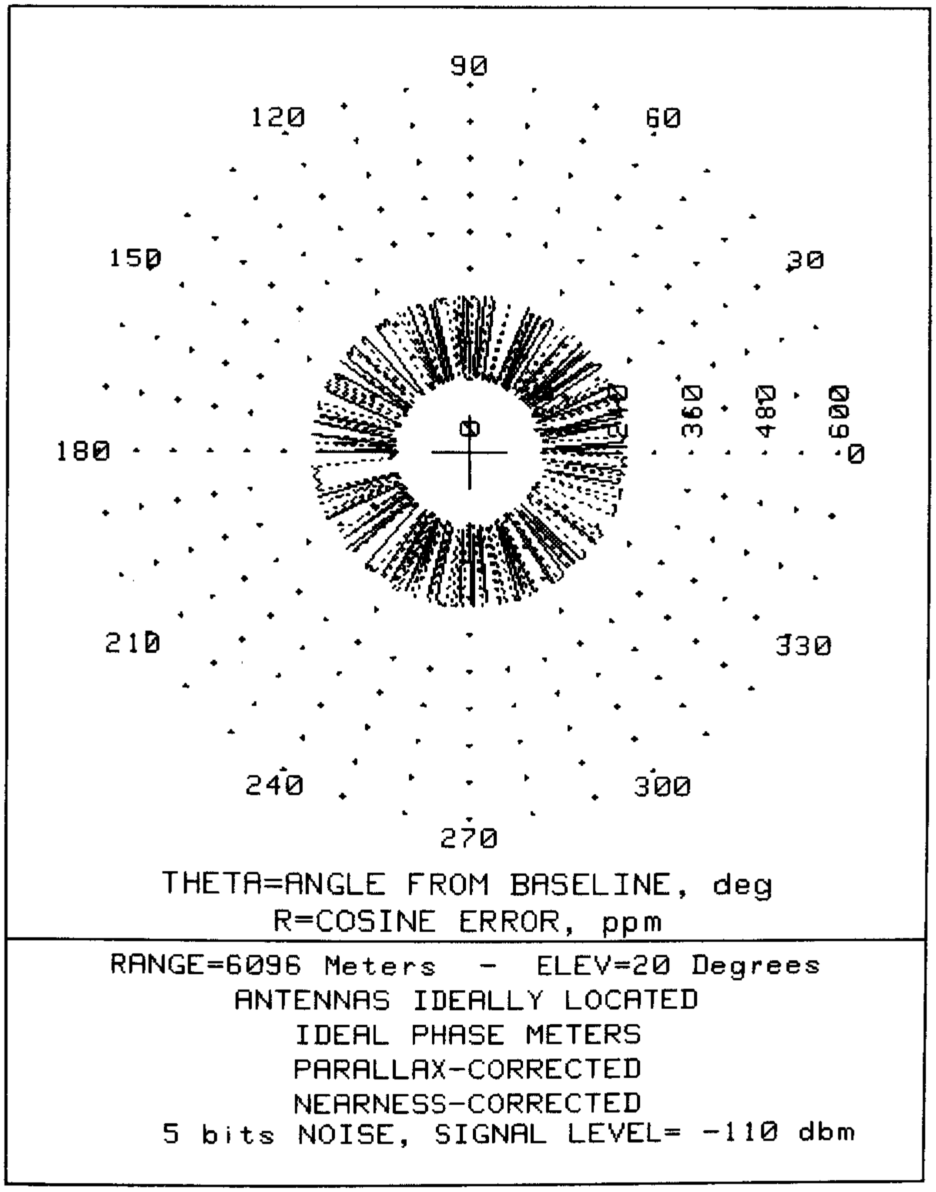
R=COSINE ERROR, ppm
RANGE=6096 Meters - ELEV=20 Degrees
ANTENNAS IDEALLY LOCATED
IDEAL PHASE METERS
NO PARALLAX CORRECTION
NO NEARNESS CORRECTION
5 bits NOISE, SIGNAL LEVEL= -110 dbm

Figure 6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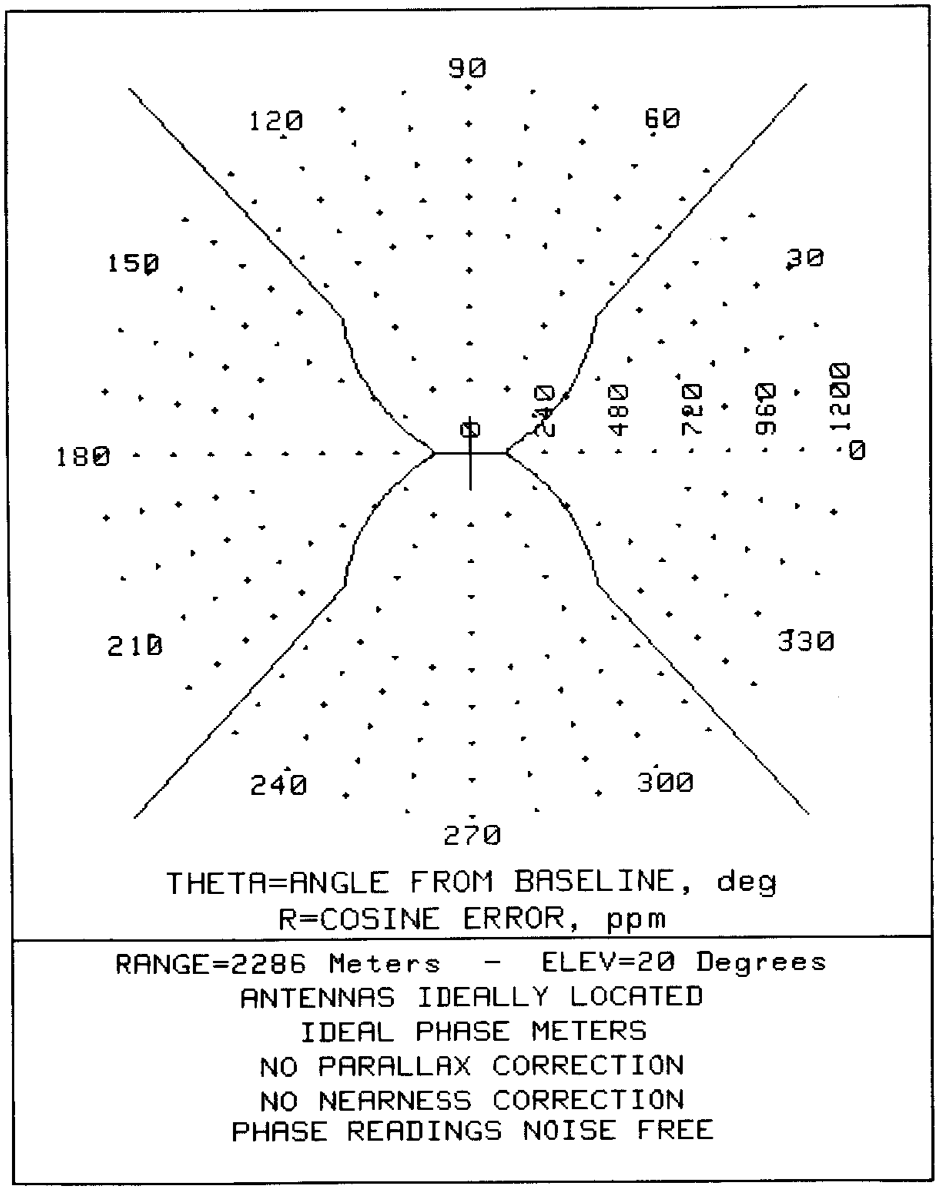
R=COSINE ERROR, ppm
RANGE=6096 Meters - ELEV=20 Degrees
ANTENNAS IDEALLY LOCATED
IDEAL PHASE METERS
PARALLAX-CORRECTED
NEARNESS-CORRECTED
5 bits NOISE, SIGNAL LEVEL= -110 dbm

Figure 7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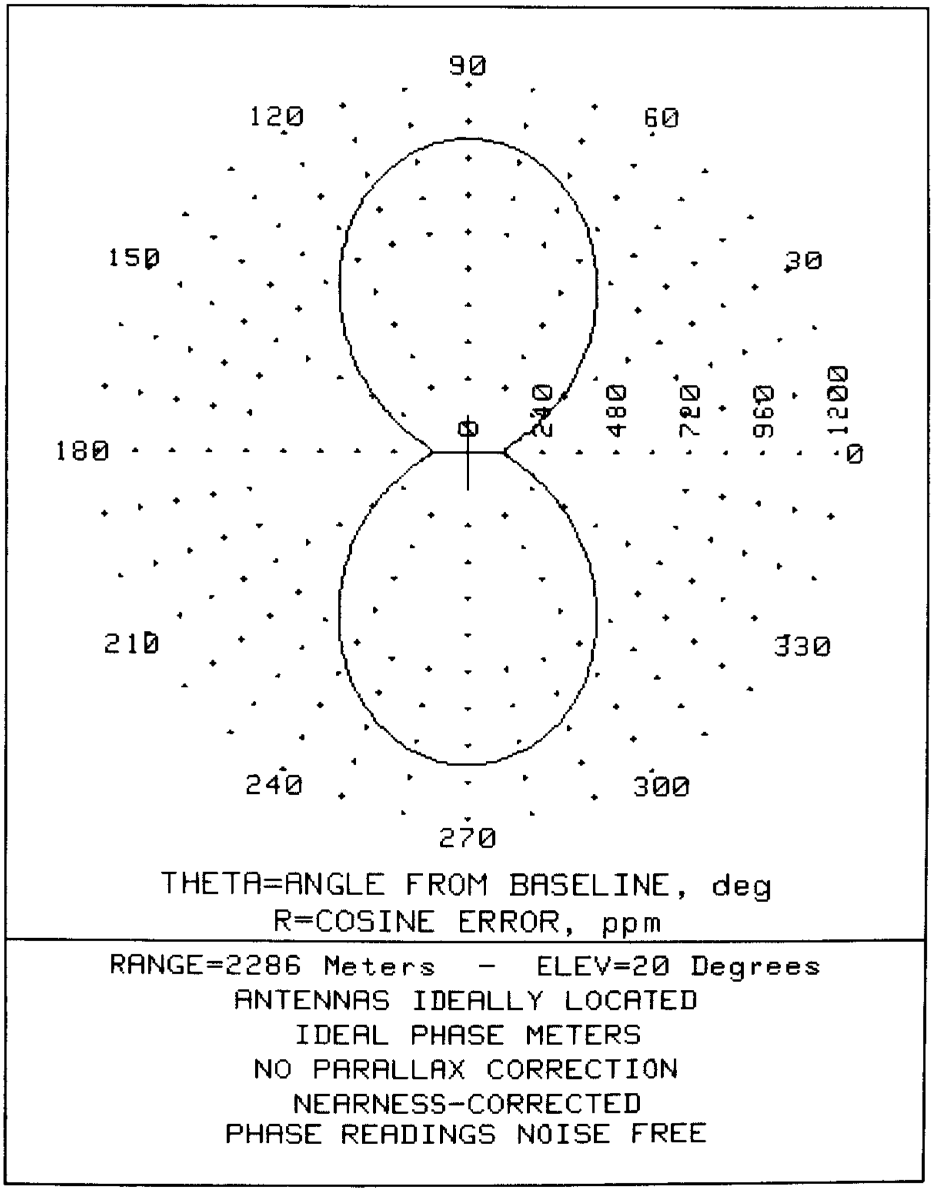
R=COSINE ERROR, ppm
RANGE=2286 Meters - ELEV=20 Degrees
ANTENNAS IDEALLY LOCATED
IDEAL PHASE METERS
NO PARALLAX CORRECTION
NO NEARNESS CORRECTION
PHASE READINGS NOISE FREE

Figure 8a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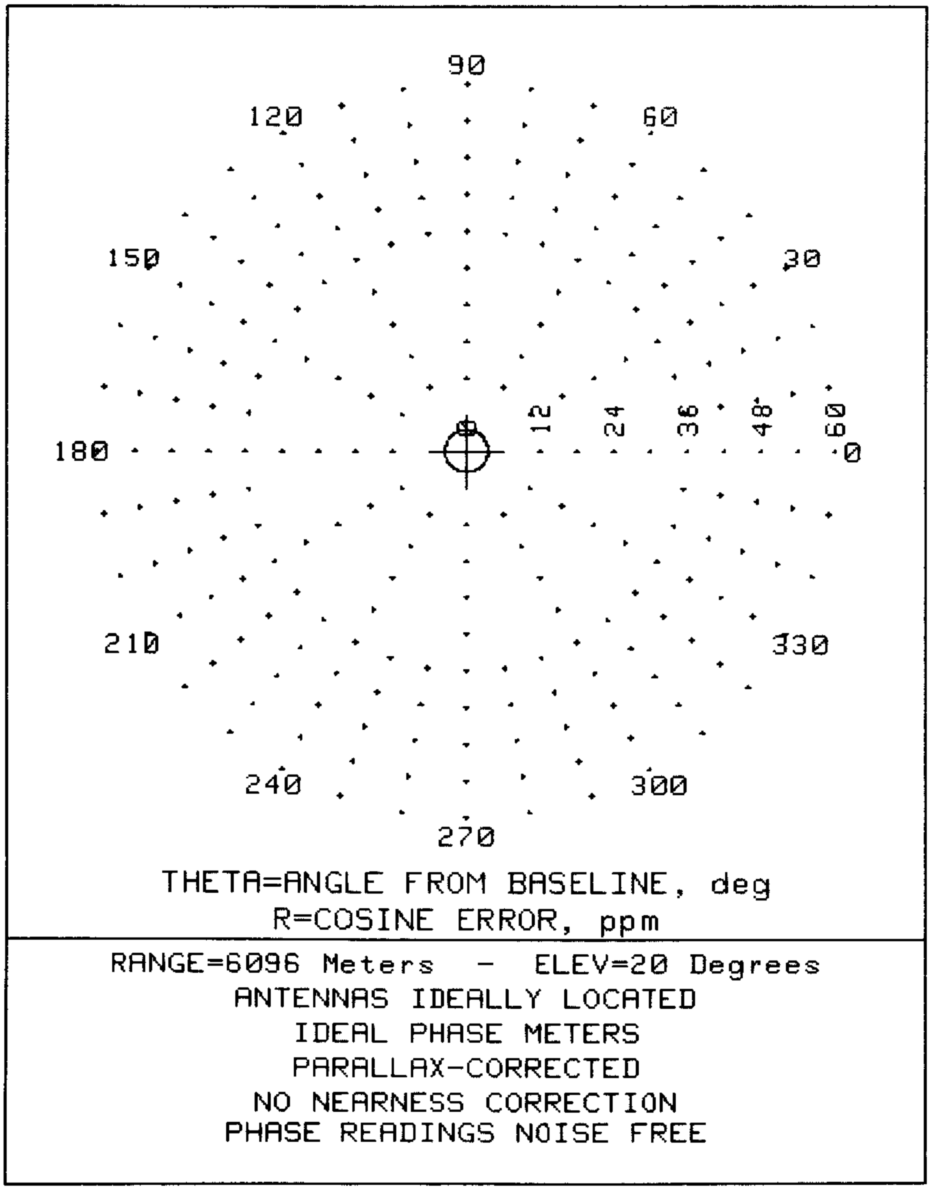
THETA=ANGLE FROM BASELINE, deg
R=COSINE ERROR, ppm
RANGE=2286 Meters - ELEV=20 Degrees
ANTENNAS IDEALLY LOCATED
IDEAL PHASE METERS
NO PARALLAX CORRECTION
NEARNESS-CORRECTED
PHASE READINGS NOISE FREE

Figure 8b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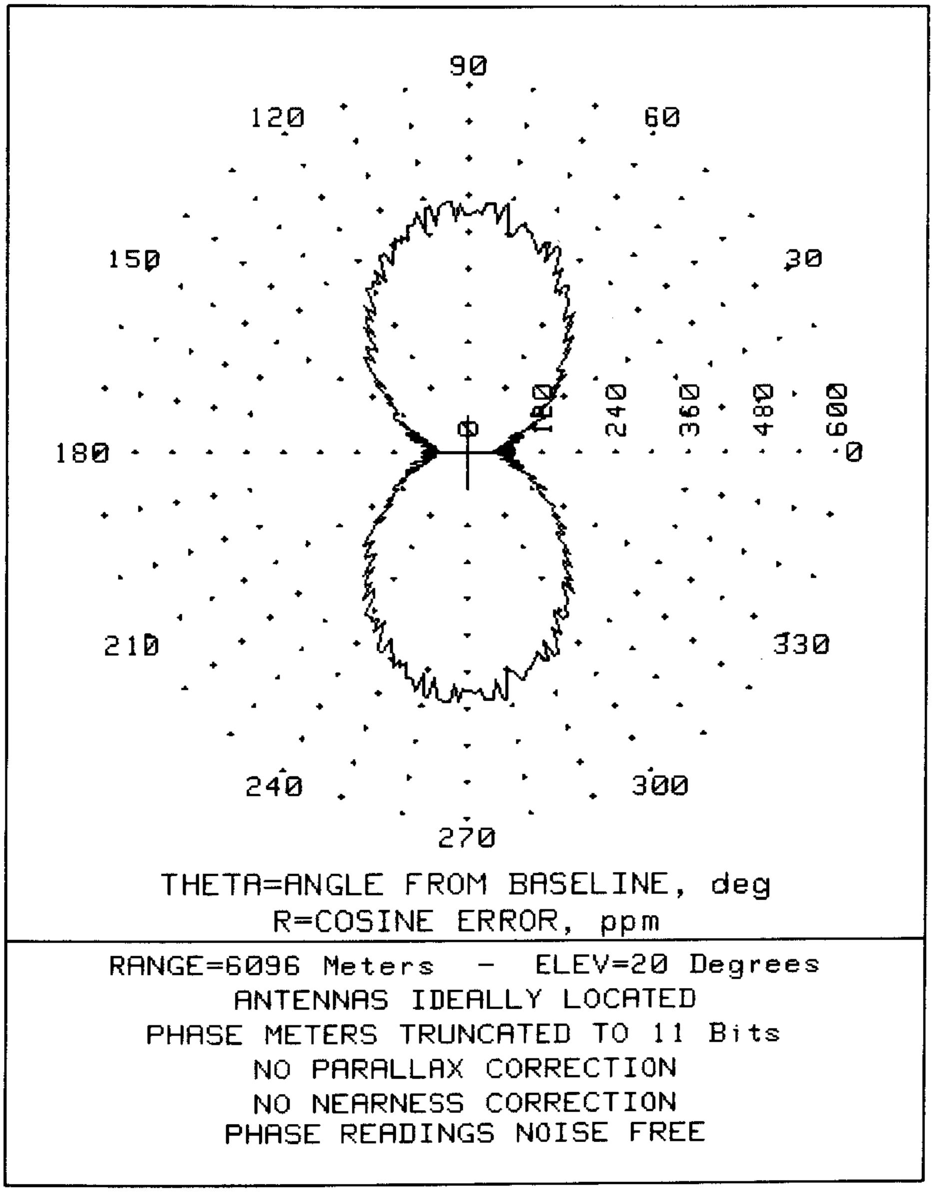
R=COSINE ERROR, ppm
RANGE=6096 Meters - ELEV=20 Degrees
ANTENNAS IDEALLY LOCATED
IDEAL PHASE METERS
PARALLAX-CORRECTED
NO NEARNESS CORRECTION
PHASE READINGS NOISE FREE

Figure 9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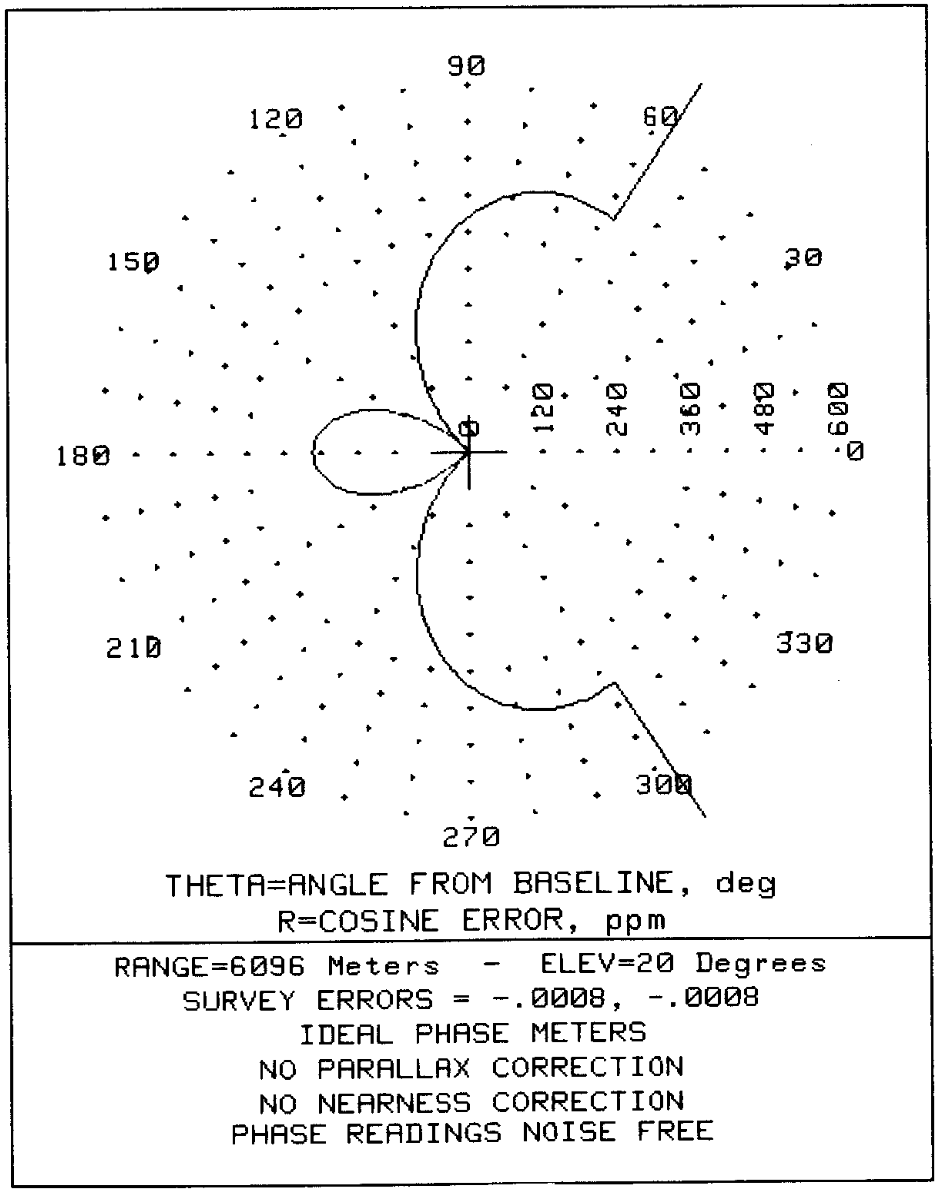
R=COSINE ERROR, ppm
RANGE=6096 Meters - ELEV=20 Degrees
ANTENNAS IDEALLY LOCATED
PHASE METERS TRUNCATED TO 11 Bits
NO PARALLAX CORRECTION
NO NEARNESS CORRECTION
PHASE READINGS NOISE FREE

Figure 10



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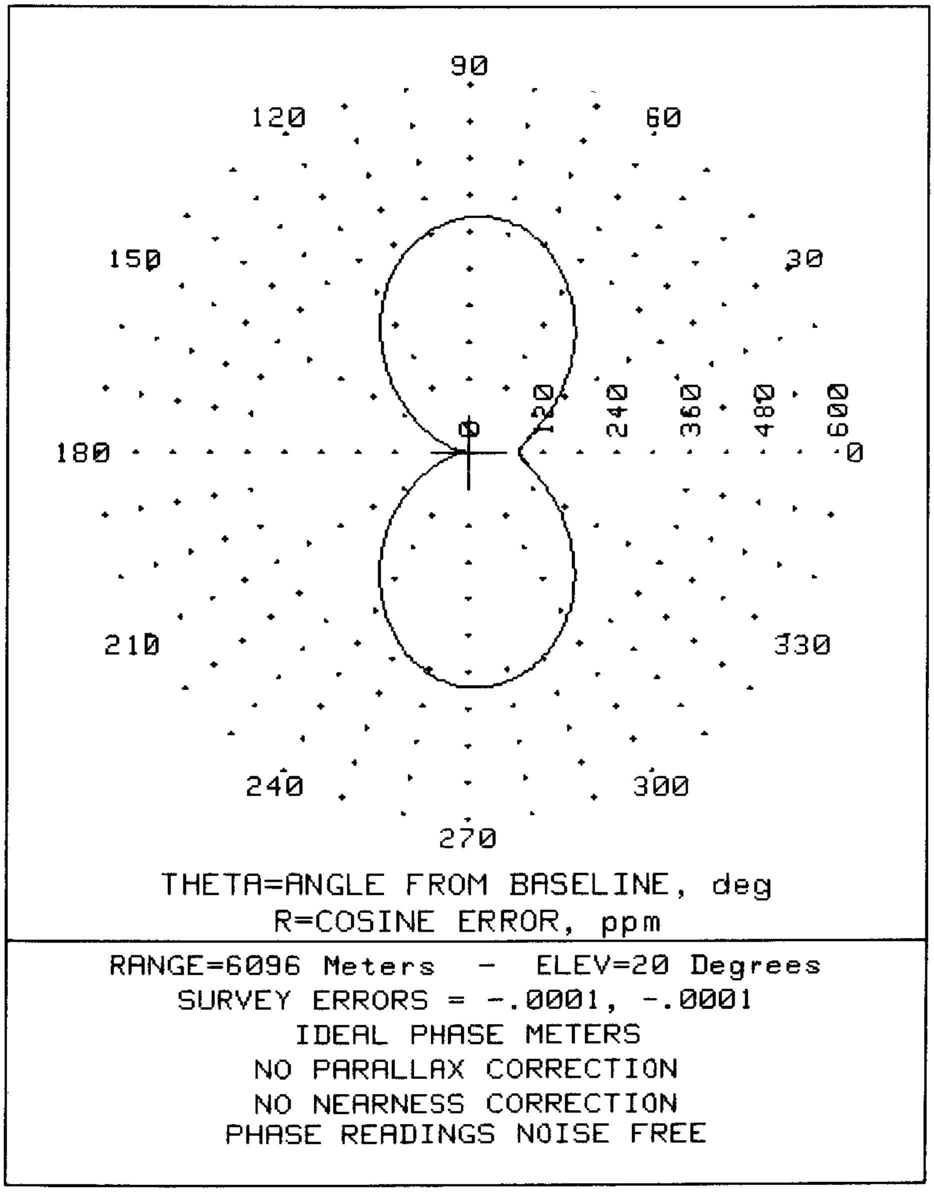
THETA=ANGLE FROM BASELINE, deg
R=COSINE ERROR, ppm
RANGE=6096 Meters - ELEV=20 Degrees
SURVEY ERRORS = -.0008, -.0008
IDEAL PHASE METERS
NO PARALLAX CORRECTION
NO NEARNESS CORRECTION
PHASE READINGS NOISE FREE

Figure 11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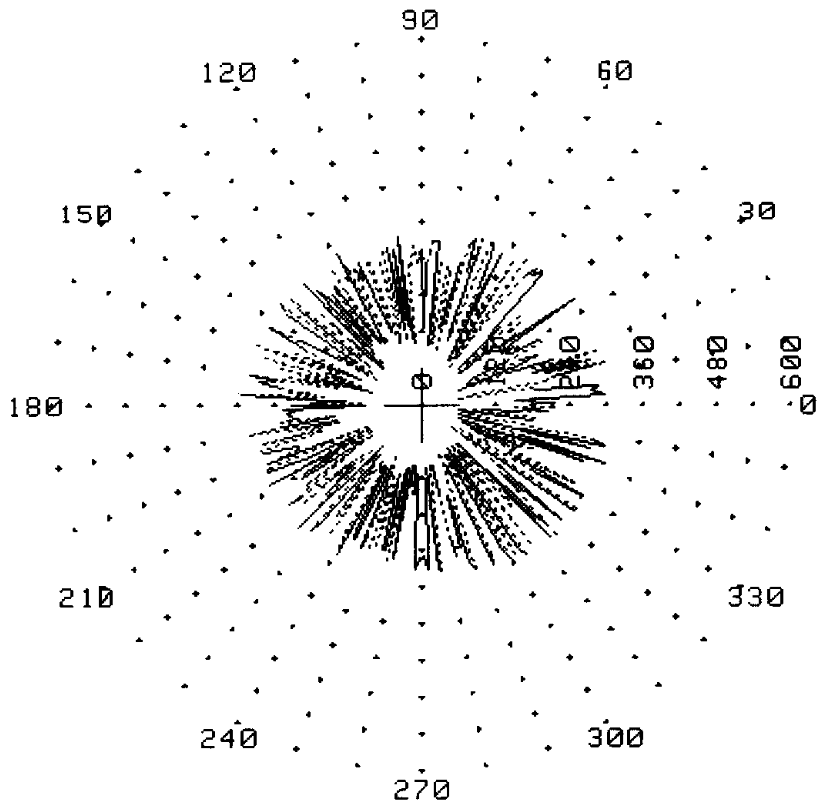
THETA=ANGLE FROM BASELINE, deg
R=COSINE ERROR, ppm
RANGE=6096 Meters - ELEV=20 Degrees
SURVEY ERRORS = -.0001, -.0001
IDEAL PHASE METERS
NO PARALLAX CORRECTION
NO NEARNESS CORRECTION
PHASE READINGS NOISE FREE

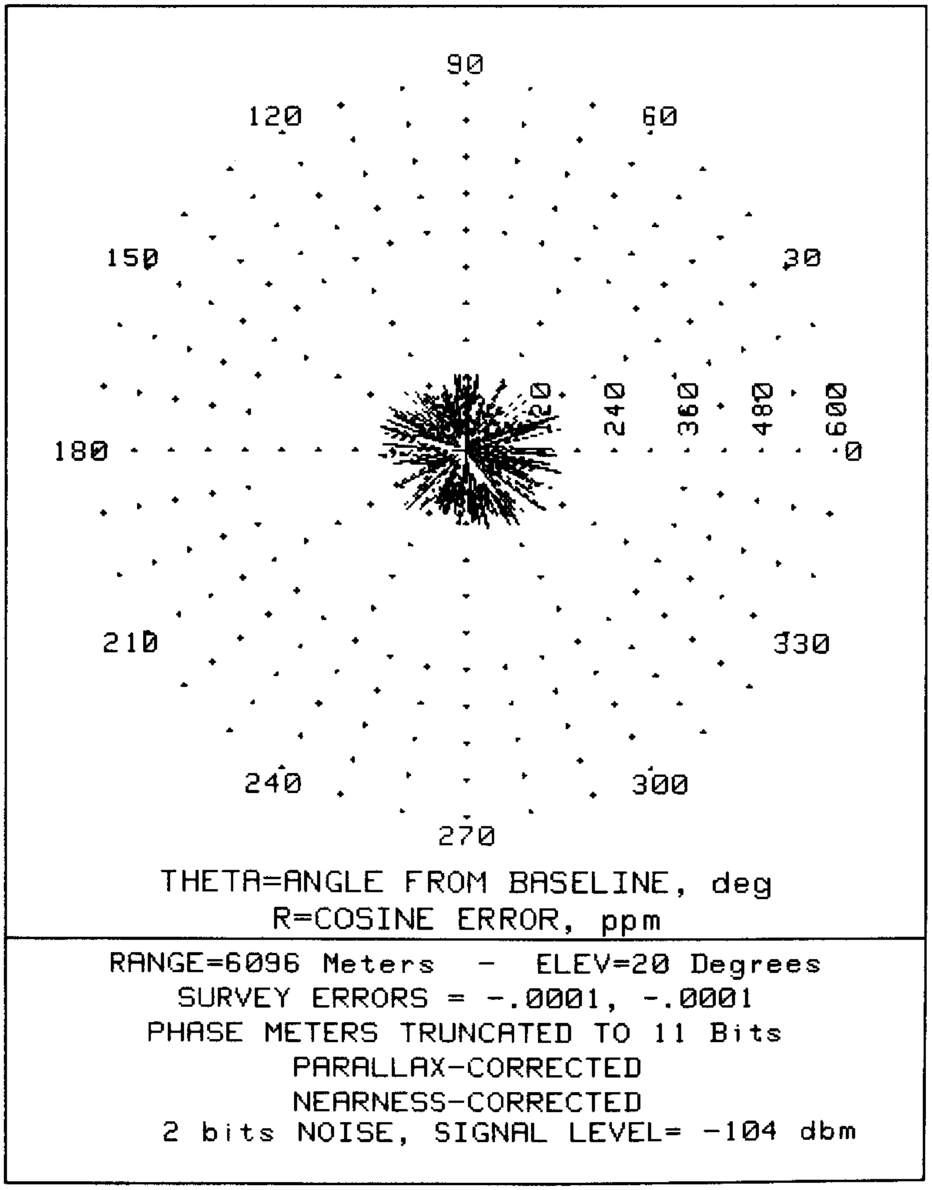
Figure 12



THETA=ANGLE FROM BASELINE, deg
R=COSINE ERROR, ppm

RANGE=6096 Meters - ELEV=20 Degrees
SURVEY ERRORS = -.0001, -.0001
PHASE METERS TRUNCATED TO 11 Bits
PARALLAX-CORRECTED
NEARNESS-CORRECTED
5 bits NOISE, SIGNAL LEVEL= -110 dbm

Figure 13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R=COSINE ERROR, ppm
RANGE=6096 Meters - ELEV=20 Degrees
SURVEY ERRORS = -.0001, -.0001
PHASE METERS TRUNCATED TO 11 Bits
PARALLAX-CORRECTED
NEARNESS-CORRECTED
2 bits NOISE, SIGNAL LEVEL= -104 dbm

Figure 14