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**MODELING A YAGI ARRAY ANTENNA
FOR VHF RADAR USE**

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13. ABSTRACT (Maximum 200 words)

This report details the results of modeling of an array of 4 Yagi antennas used with a 49.92 MHz radar. Each of the Yagi antennas has 6 elements and is optimized for narrow bandwidth and high gain. The model includes free space patterns and boresight patterns over uneven terrain.

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Introduction.

This paper contains results of modelling an array of 4 Yagi antennas to be used for VHF radar measurements at 49.92 MHz. The individual Yagi antennas are 6 element, gain optimized antennas designed for narrow bandwidth and maximum gain. The antenna dimensions are given in the Figure 1.

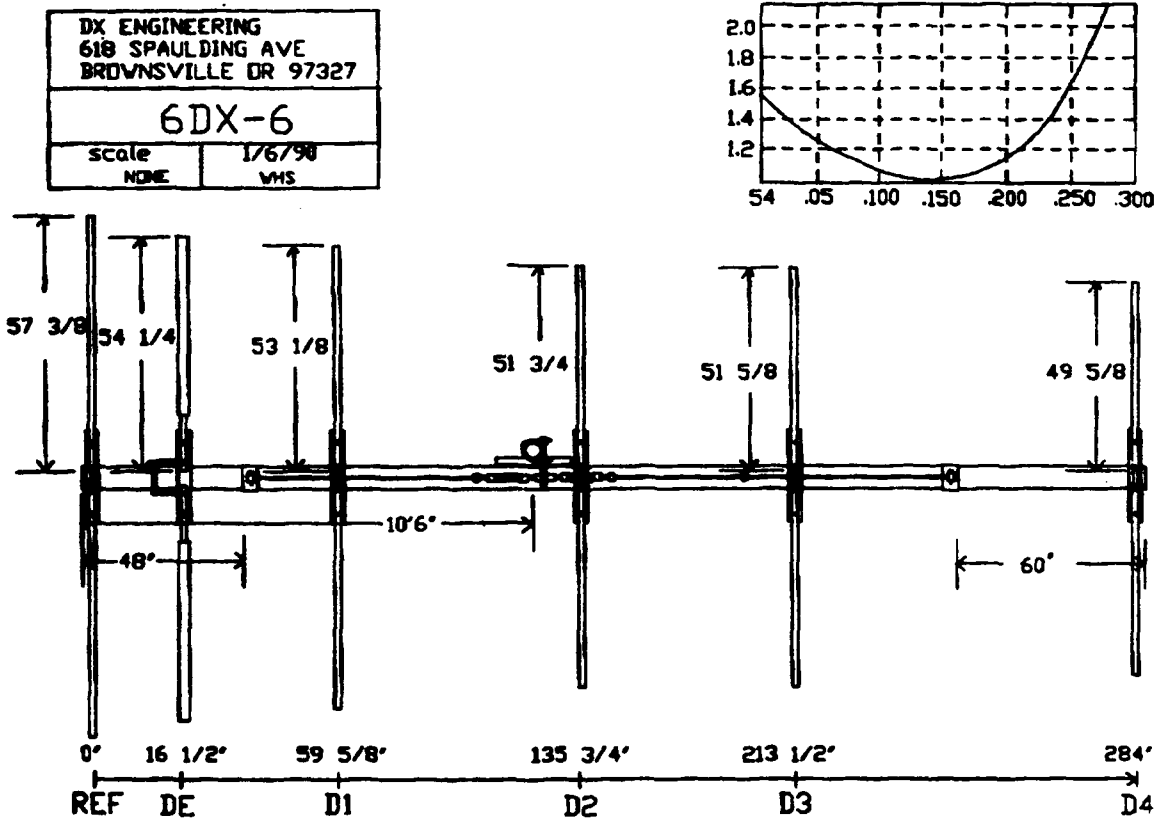


Figure 1. Six Element Yagi Antenna for VHF Radar Applications.

1. Radiation Pattern for One Antenna in Free Space.

The E-plane and H-plane radiation patterns of a single Yagi antenna have been computed with NEC2.2 at 49, 50, and 51 MHz. The results are shown in Figures 2, 3, and 4. The forward gain of a Yagi antenna is to a large extent a function of the boom length regardless of the number of elements, whereas the frequency range of available forward gain, gain bandwidth, is related to the number of elements for a given boom length. Most often, one reflector is used, so the number of elements are determined by the number of directors in addition to the fed element and the reflector. By inspection of the antenna configuration in Figure 1. it is seen that the boom is very long and the directors are wide spaced. From this, it was anticipated the gain bandwidth of the antenna would be quite narrow. This is supported by the computed radiation patterns. The design frequency of the antenna is 50.1 MHz. The radiation patterns at the design frequency, Figure 3, show a forward gain of 11.5 dBi and a front to back ratio of 20 dB. The H-plane pattern is not quite as elegant as the E-plane pattern, but this property is common to many Yagi antennas.

The radiation patterns for 49 MHz, Figure 2, show essentially the same forward gain, but the back lobe has increased considerably. At 51 MHz, Figure 4, the antenna is outside its' useful frequency range. The forward gain is -3 dBi, whereas the back lobe has a 8 dBi gain, so the antenna radiates backwards. This behavior is common to Yagi antennas with few elements on long booms. The forward gain decreases rather slowly for frequencies below the design frequency, but decreases very fast for frequencies above the design frequency. Such antennas must be used with some caution, as they are easily loaded by metallic structures in the close vicinity and also by other antennas in an array configuration. A more robust antenna can be obtained by adding two or three more directors on the same boom. Wider gain as well as impedance bandwidth will be obtainable, while retaining the forward gain, and the antenna will also be less vulnerable to ice and metallic object loading. The current antenna has operational requirements for a 250 kHz bandwidth and the selectivity of the antenna is specified to bandlimit the signal received by the radar. While it may be debatable if it is a good strategy to define the receiver bandwidth with the antenna, the design of a wider band antenna and other means of bandlimiting the received signals are outside the scope of this paper.

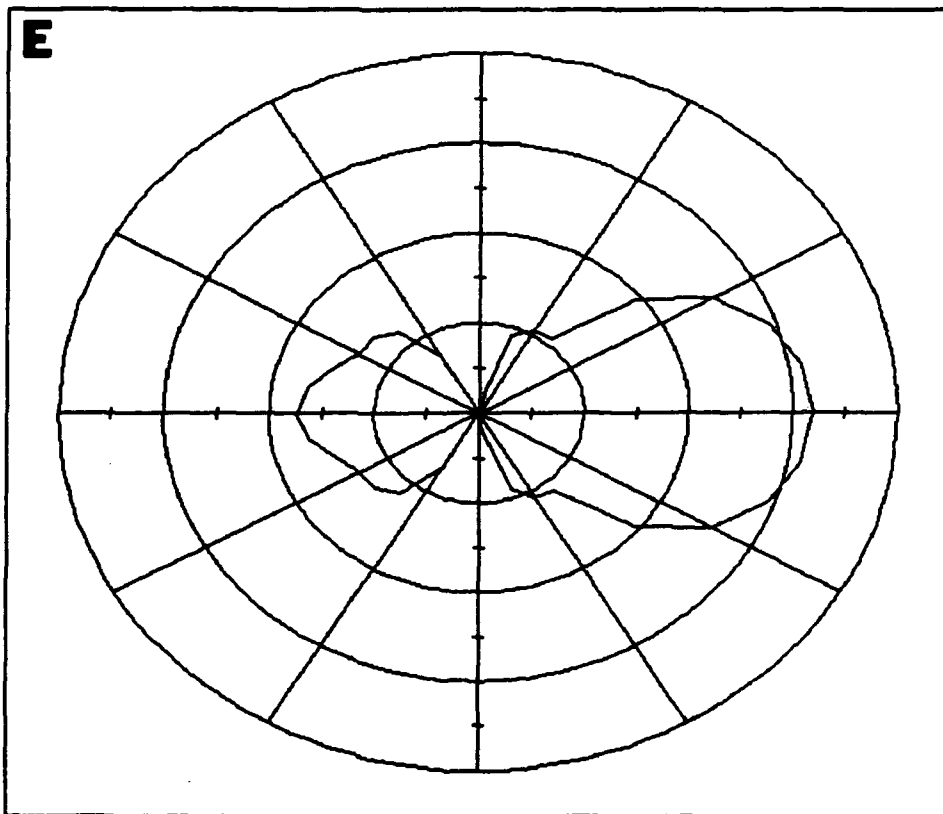
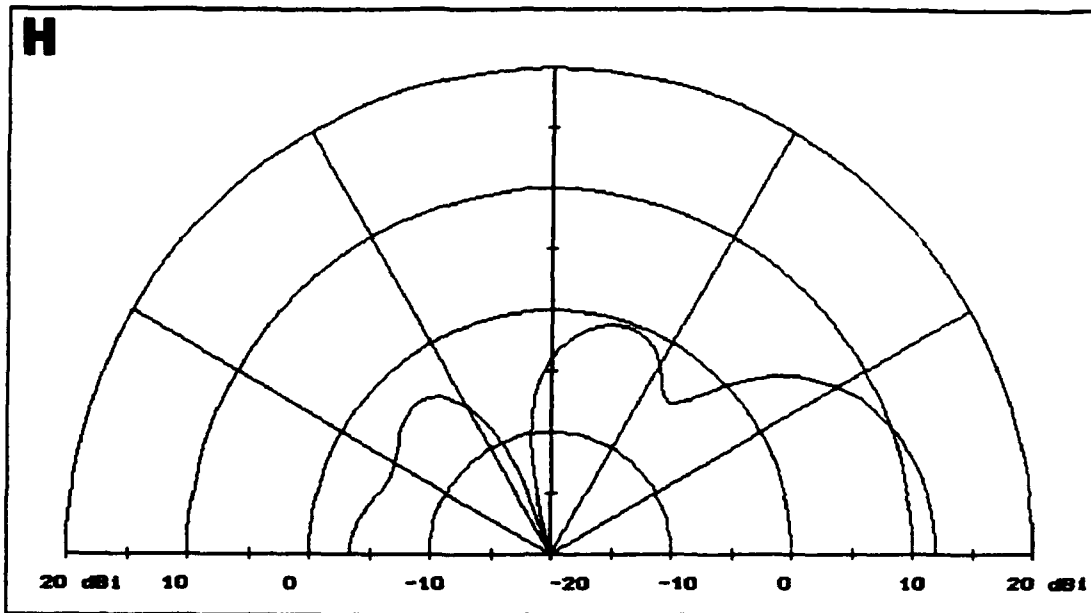


Figure 2. Radiation Patterns at 49 MHz for a Single Yagi Antenna in Free Space.

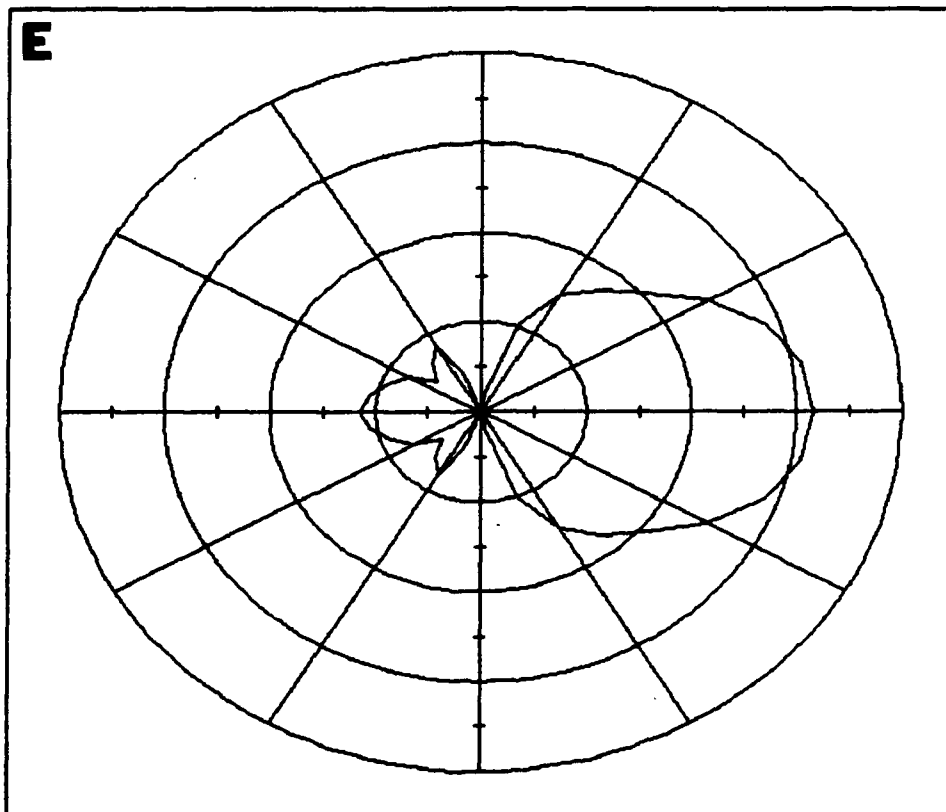
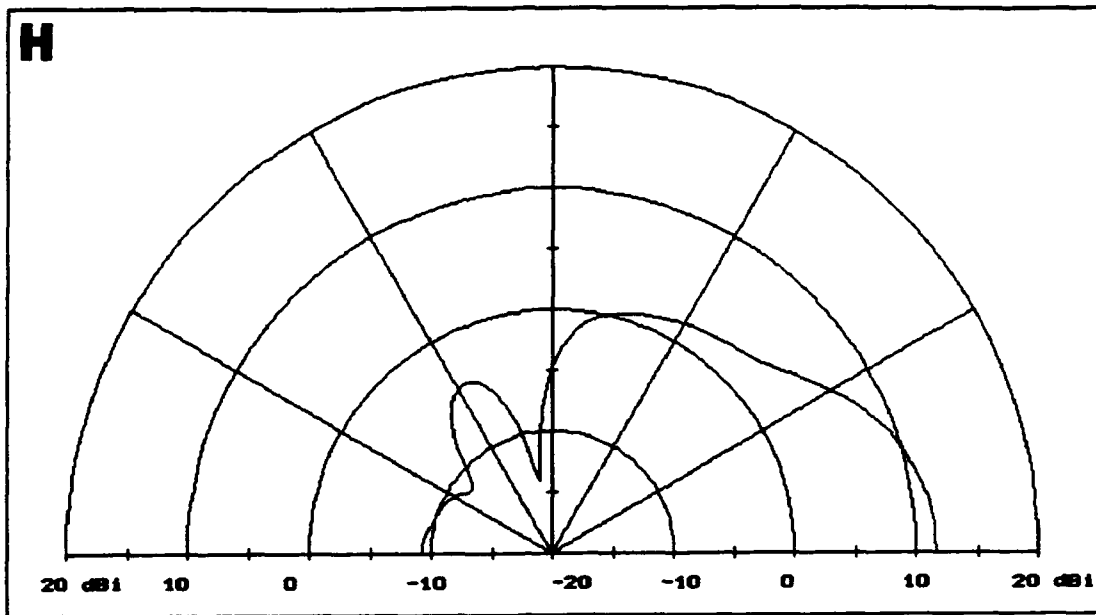


Figure 3. Radiation Patterns at 50 MHz for a Single Yagi Antenna in Free Space.

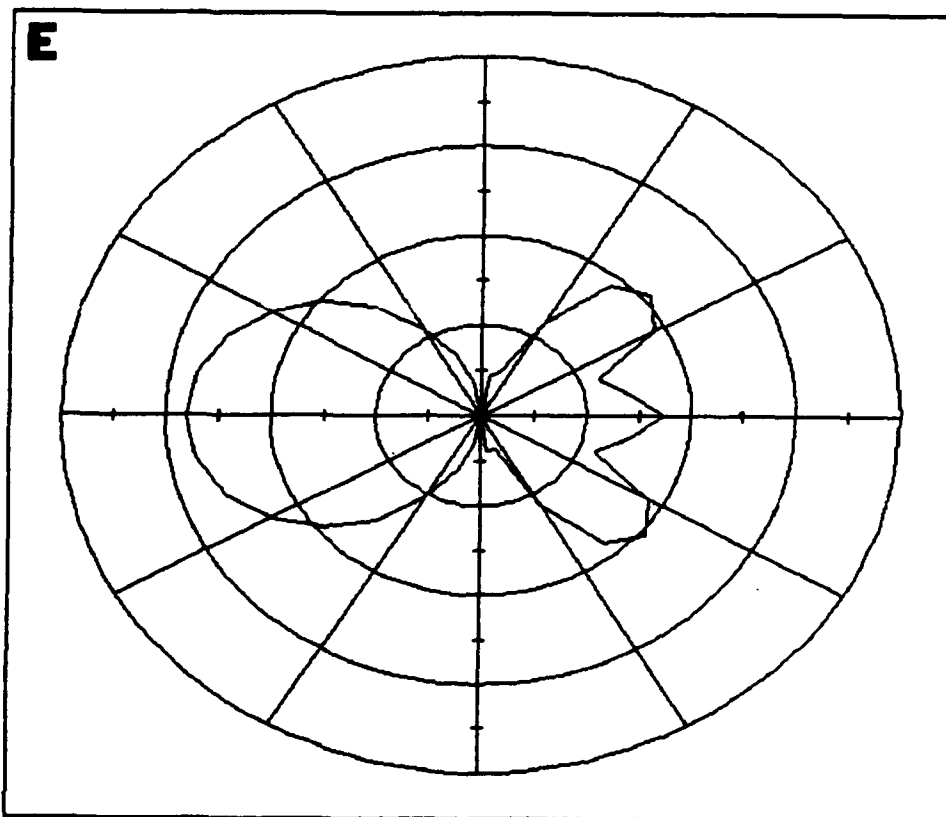
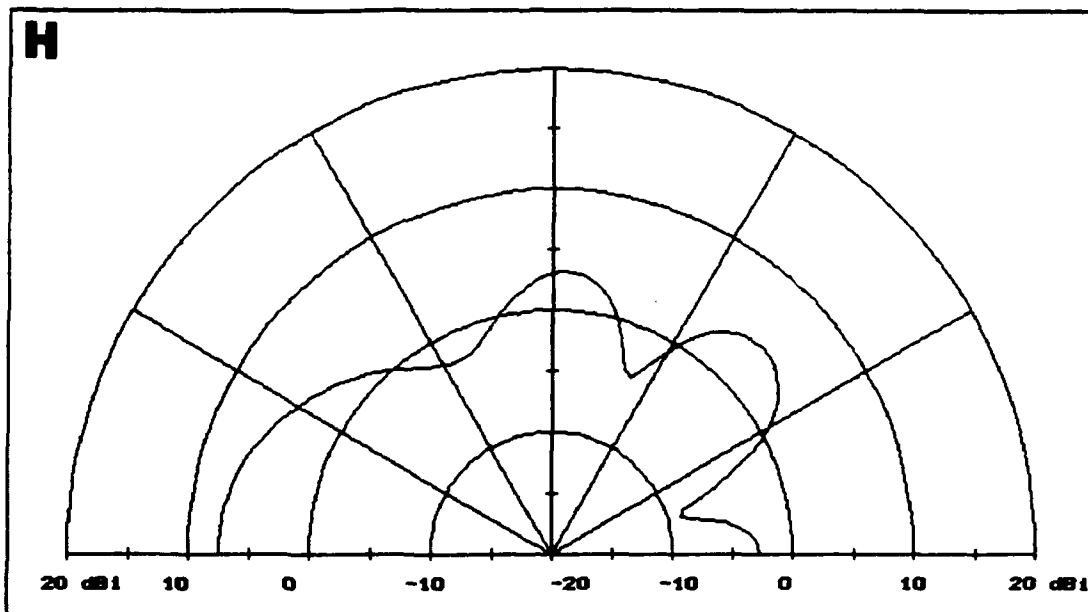


Figure 4. Radiation Patterns at 51 MHz for a Single Yagi Antenna in Free Space.

2. Radiation Patterns for a Four Antenna Array in Free Space.

The VHF radar requires a forward gain exceeding 17 dBi, and features a transmitter power of 50 kW. Four antennas are required to absorb the transmitter power and to obtain the required gain. The proposed configuration is a quad of two antennas over two antennas with 0.7 to 0.8 wavelength separation. The boresight gain is independent of the antenna separation, as the contributions from the individual antennas add up in phase in the far field, but the wider the separation, the more lobe splitting will occur around the main beam. The free space radiation patterns for quad arrays with 0.7 and 1.5 wavelength spacings, respectively, have been computed at 50 MHz, Figures 5 and 6.

The array spaced 0.7 wavelengths, Figure 5, exhibits a forward gain of 13 dBi and a substantial back lobe, so the front to back ratio is only 5 dB. The H-plane pattern shows a large sidelobe perpendicular to the front and back lobes. The occurrence of the large back lobe is most probably an effect of the mutual loading and the narrow bandwidth of the antennas. Wider spacing might remedy this.

Figure 6. shows the computed radiation patterns for an array spacing of 1.5 wavelengths. The forward gain is 18 dBi and the back lobe is greatly reduced. In addition, the uneven number of half wavelengths of spacing has reduced the radiation perpendicular to the forward beam. The E-plane pattern shows a narrower forward lobe and two side lobes at 30 degrees azimuth, but the front lobe is still wide enough, (15 - 20 degrees), to cover the needs for this antenna. Thus the wider spaced array provides the expected forward gain, 6 dB more than the forward gain of the individual Yagi antennas, while retaining a respectable side lobe level and front to back ratio. Better side lobe suppression may result from further fine tuning of the configuration, including changes to the individual antennas.

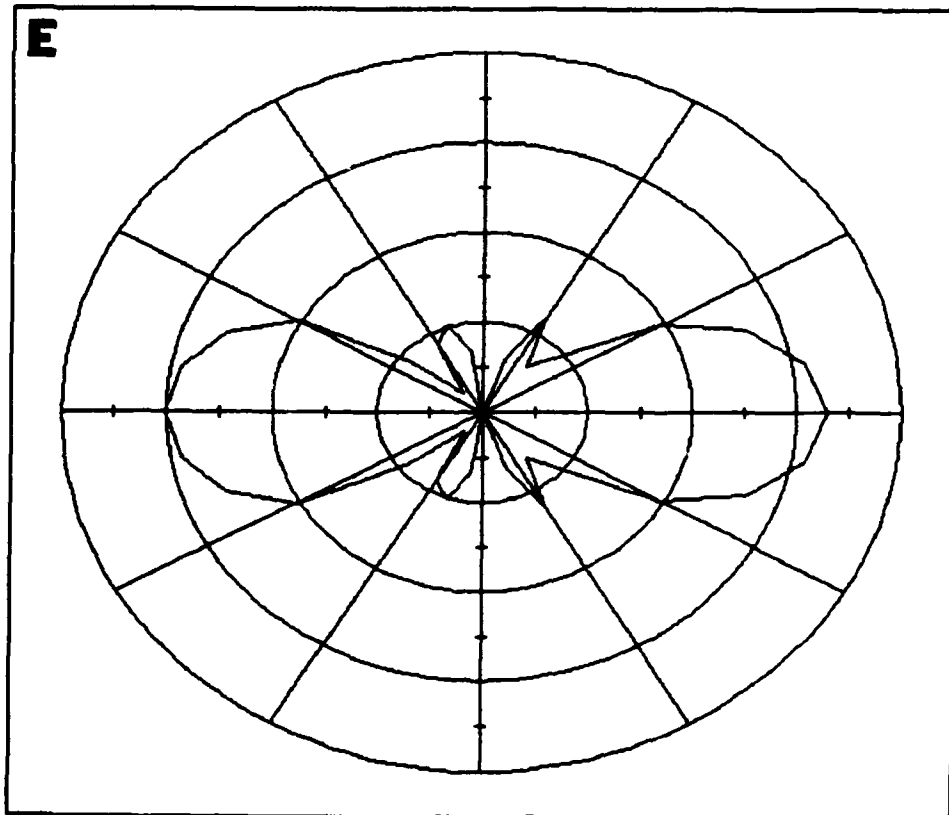
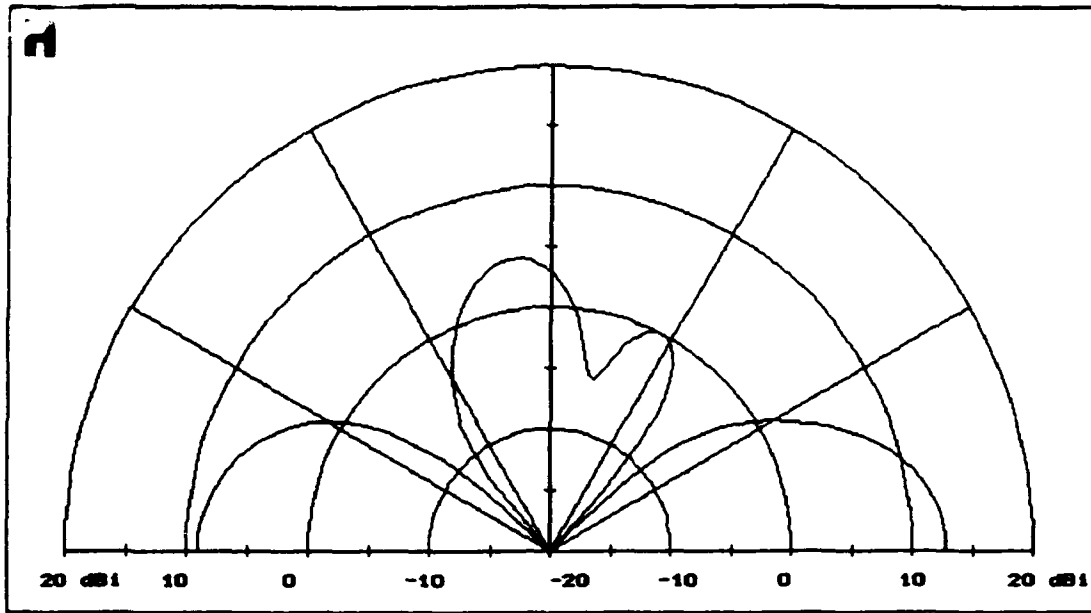


Figure 5. Radiation Patterns at 50 MHz for an Array of Four, Six Element Yagi Antennas Spaced 0.7 Wavelengths in Free Space.

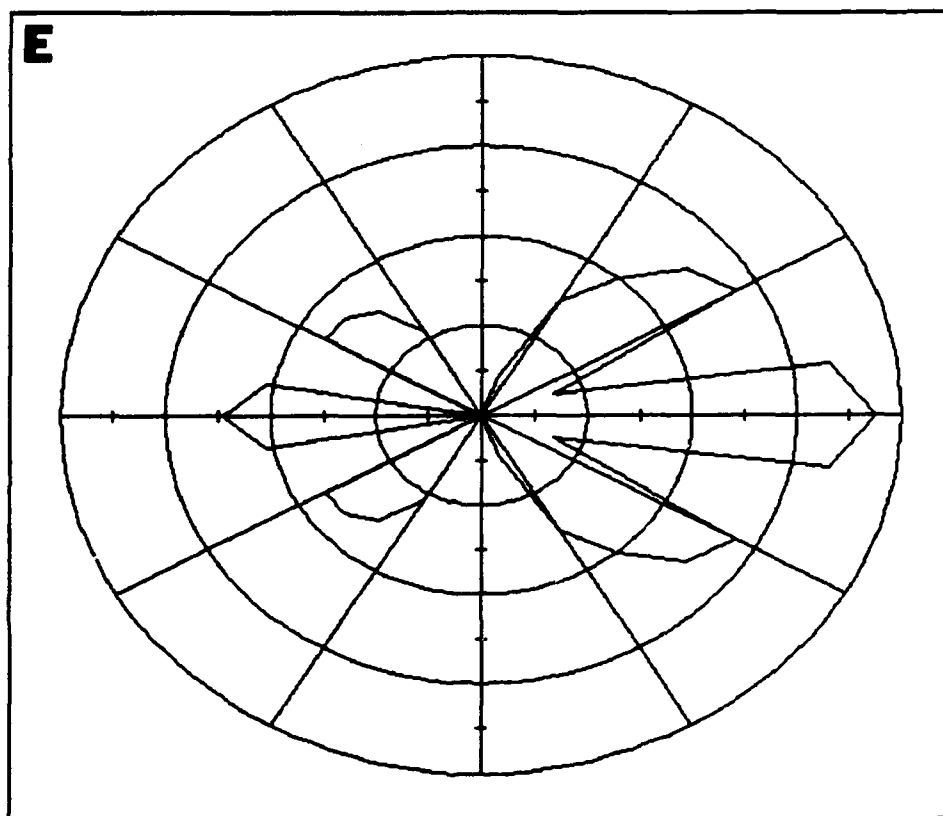
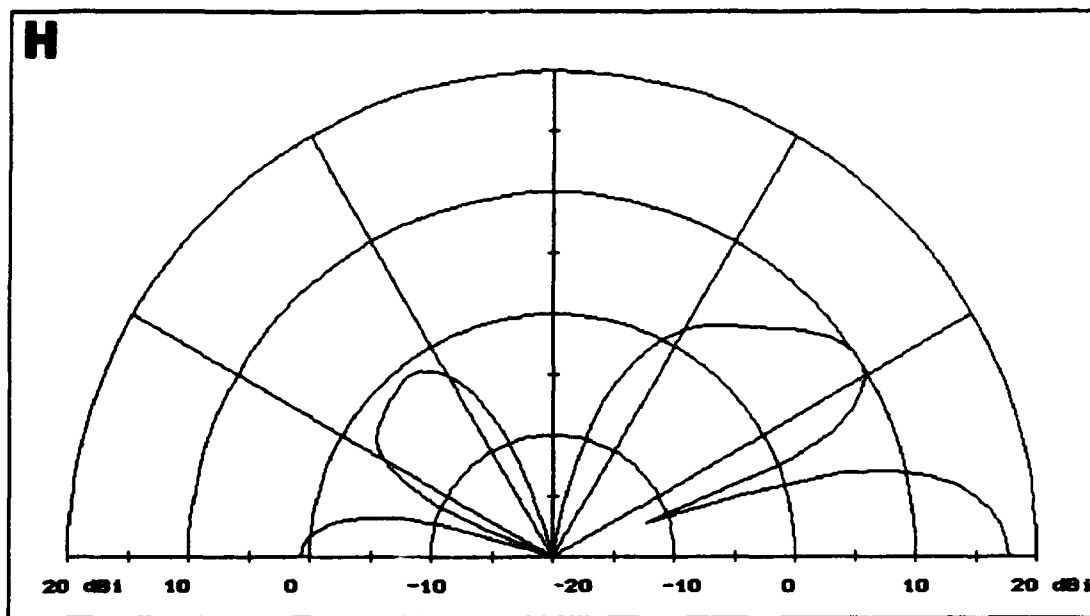


Figure 6. Radiation Patterns at 50 MHz for an Array of Four, Six Element Yagi Antennas Spaced 1.5 Wavelengths in Free Space.

3. Array of Four Antennas Over Uneven Terrain with Finite Conductivity.

The antenna array is to be deployed over uneven terrain in New Mexico, looking at a radar target at approximately -2 to $+10$ degrees elevation in the boresight direction of 190 degrees true. The terrain blocking angle is approximately -2.5 degrees.

Reflections from the terrain under the antenna will change the radiation pattern relative to the free space pattern. Notably, a null in the radiation pattern may appear close to ground, and up to 6 dB enhancement of the forward gain may be obtained at some elevation angle where the direct and reflected rays add in phase. In addition to the properties of the antenna array itself, the deployment height and the terrain features will determine the radiation pattern.

Antennas intended for line of sight links are usually deployed as high above the ground as possible. This ensures a maximum forward gain at low elevation, but also creates severe lobing of the main beam vs. elevation. The current antenna must illuminate the elevation range -2 to $+10$ degrees as uniformly as possible, while maintaining as much gain as possible at an elevation of -2 degrees.

The NEC program can only handle very simple flat or stepped horizontal surface ground planes. A specially developed program that can compute radiation patterns for antennas over uneven terrain has been used to evaluate the height of deployment of a quad array with 1.5 wavelength spacing. The program uses a piecewise linear ground profile to describe the terrain in sectors originating vertically under the antenna. It is presumed the terrain gradients perpendicular to the azimuth direction under computation are flat, making the reflection geometry two dimensional. A better, three dimensional solution is possible, but very computation intensive. Such a solution has not yet been attempted at PL. The reflective properties of the ground are computed from the Fresnel reflection coefficients for horizontal and vertically polarized waves. The reflection coefficients are functions of wave frequency, angle of incidence and conductivity and permittivity of the ground. It should be remembered that ground with small conductivity is still a good, but not perfect reflector, due to the dielectric properties of the ground material. The dry desert cliffs in New Mexico have been assigned a conductivity of 0.001 and a permittivity of 2.5 for the calculations.

Uniform illumination at low elevation angles may be obtained over an uneven terrain even if a small hill is situated in the antenna foreground. In such cases, the antenna is mounted at a relatively low height and given a small angular elevation. At very low elevation angles, reflections from the foreground can be either diminished or eliminated. The boresight terrain profile in New Mexico is found in Figure 7. A small hill is present at a distance

of 1200 meters from the antenna and the prior mentioned strategy can be applied. Computed radiation patterns for the quad array with 1.5 wavelength spacing mounted with the lowest pair of antennas 3 and 6 meters above ground respectively, are found in Figures 8 and 9. Antenna elevations angles of 0, 5, 10, and 15 degrees were used.

The free space radiation pattern is included as a reference. Both figures show that an elevation of 0 degrees yields the same forward gain at negative elevations as the free space radiation patterns. The hill suppresses the ground reflections in this range. However reflections create nulls in the radiation patterns at 1 and 10 degrees respectively, and no gain enhancements relative to the free space pattern are seen at all. At an antenna elevation of 5 degrees, a four dB gain enhancement is seen in the elevation range of 1 to 10 degrees, yielding a uniform 20 dBi gain when the lowest antennas are mounted 6 meters above ground. The gain at negative elevations is also relatively uniform at 15-17 dBi.

The configuration with the lowest antennas mounted 3 meters above ground yields a uniform gain of 15 to 17 dB throughout the -2 to +10 degree elevation range. The gain is rather uniform, but less than desirable by 2 dB. The maximum gain enhancements for elevation angles in the interval 1 to 10 degrees are obtained at antenna elevations of 10 degrees. However, the gain at elevation angles less than 1 degree, range from 10 dBi at -2 degrees to 15 dBi at 0 degrees. This is not acceptable for the intended purpose. At antenna elevations of 15 degrees, even less gain is obtained at elevation angles less than 1 degree, although a uniform gain enhancement is obtained in the range from 1 to 15 degrees when the lowest antennas are mounted 3 meters above the ground.

The most suitable configuration for the current purpose is to mount the antenna array with the lowest antennas 6 meters above the ground and an antenna elevation of 5 degrees.

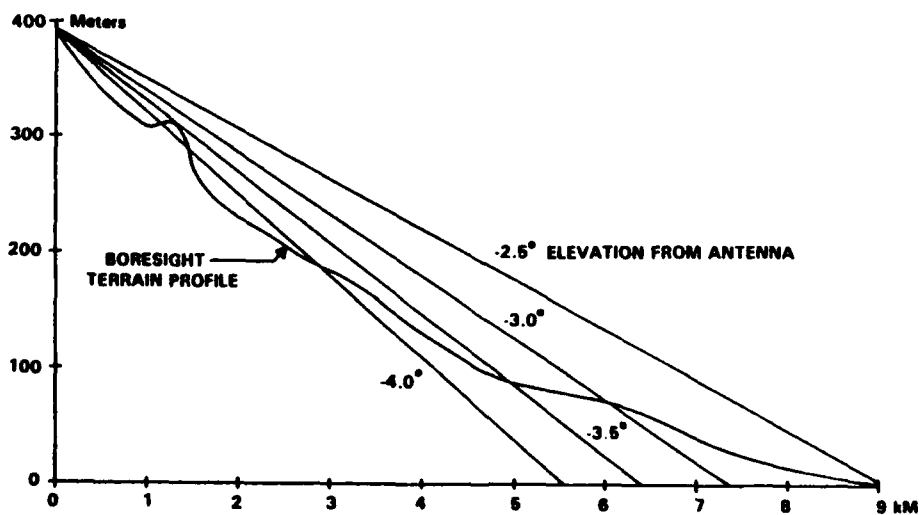


Figure 7. Boresight Profile for New Mexico Radar Range.

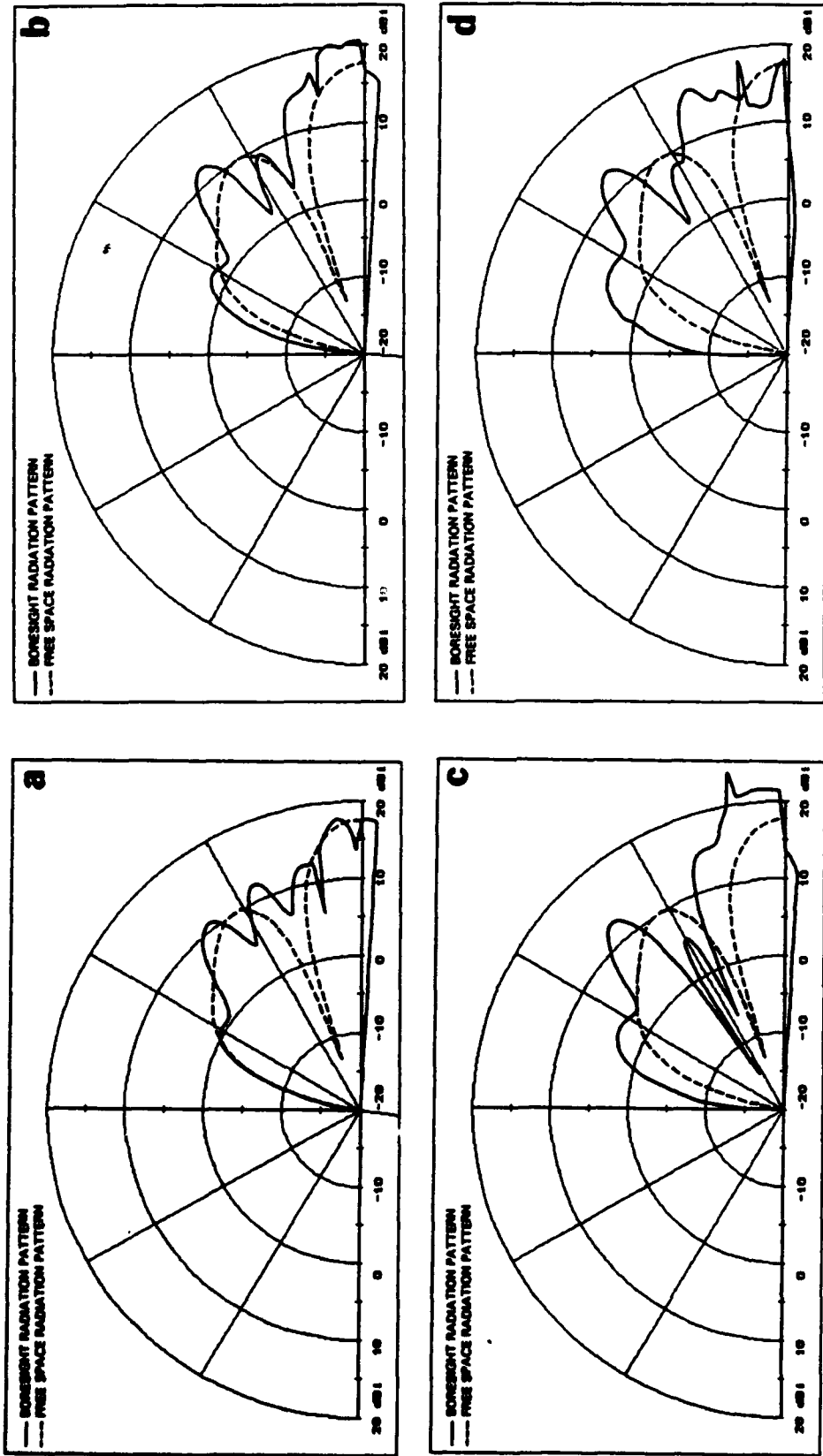


Figure 8. Boresight Radiation Patterns at 50 MHz for Quad Yagi Array Mounted with the Lowest Antennas 3 Meters Above the Profile in Figure 7.
 Antenna Elevation Angle:
 a. 0 Degrees
 b. 5 Degrees
 c. 10 Degrees
 d. 15 Degrees

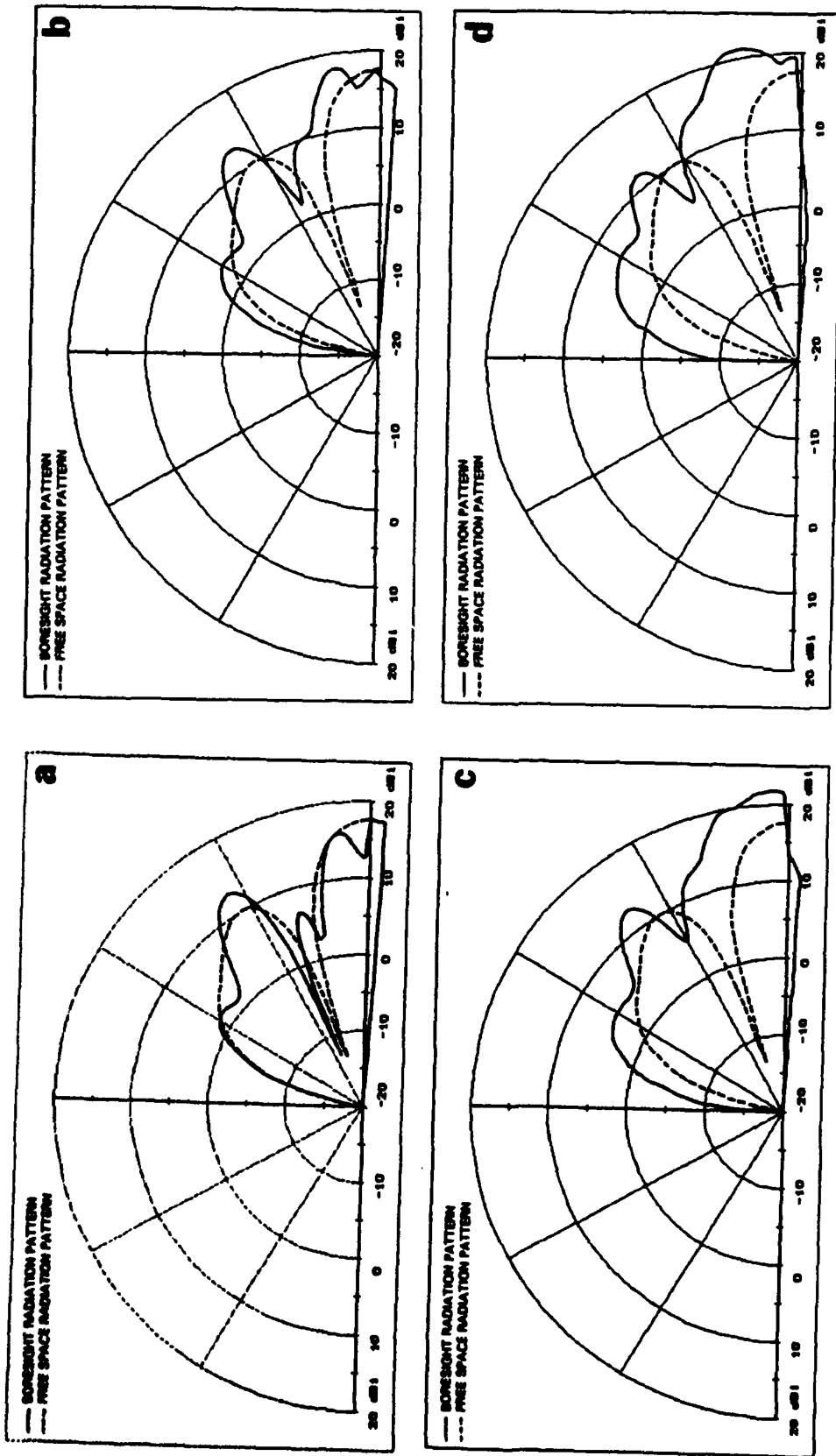


Figure 9. Boresight Radiation Patterns at 50 MHz for Quad Yagi Array Mounted with the Lowest Antennas 6 Meters Above the Profile in Figure 7.
 Antenna Elevation Angle:
 a. 0 Degrees
 b. 5 Degrees
 c. 10 Degrees
 d. 15 Degrees

4. Prediction of the Diurnal Galactic Noise Variation.

The diurnal variation of the galactic noise at a given frequency can be predicted when the radiation pattern of the receiving antenna and the distribution of galactic noise sources are known. The distribution of galactic noise sources at 136 MHz, presented by Taylor¹ was used for the predictions in this report. The galactic noise power is presented as equivalent temperature in Kelvin (K). The noise power at other frequencies and in a given bandwidth can be obtained as:

$$P_n(\text{freq}) = (136/\text{freq}) T_n^{2.3} P T k B \text{ (Watts)}$$

where freq is the frequency in MHz, k is Boltzmanns constant: $(1.38 \cdot 10^{-23})$ and B is the receiver noise bandwidth in Hz.

The quantity T_n is the noise temperature present at the antenna terminal. T_n is computed from:

$$T_n = \frac{\int T(\psi, \phi) G(\psi, \phi) \sin(\phi) d\phi d\psi}{\int G(\psi, \phi) \sin(\phi) d\phi d\psi}$$

where ϕ is the elevation, ψ is true azimuth, $G(\psi, \phi)$ is the antenna gain in the direction ψ, ϕ and $T(\psi, \phi)$ is the galactic noise temperature in the direction ψ, ϕ .

ψ and ϕ must be computed to orient the galactic noise map correctly with respect to the antenna aperture. This is done by computing the projection of the antenna aperture on the galactic noise map in right ascension and declination for the time of day and date. A computer program has been written to perform such calculations.

The computed diurnal variation of the galactic noise power in a 10 kHz bandwidth as seen by the quad Yagi antenna array situated in New Mexico is presented in Figure 10. The date is April 1. The diurnal variation, especially the passage of the cluster of strong noise sources situated on the ecliptic through the main beam at 1500 UT is seen.

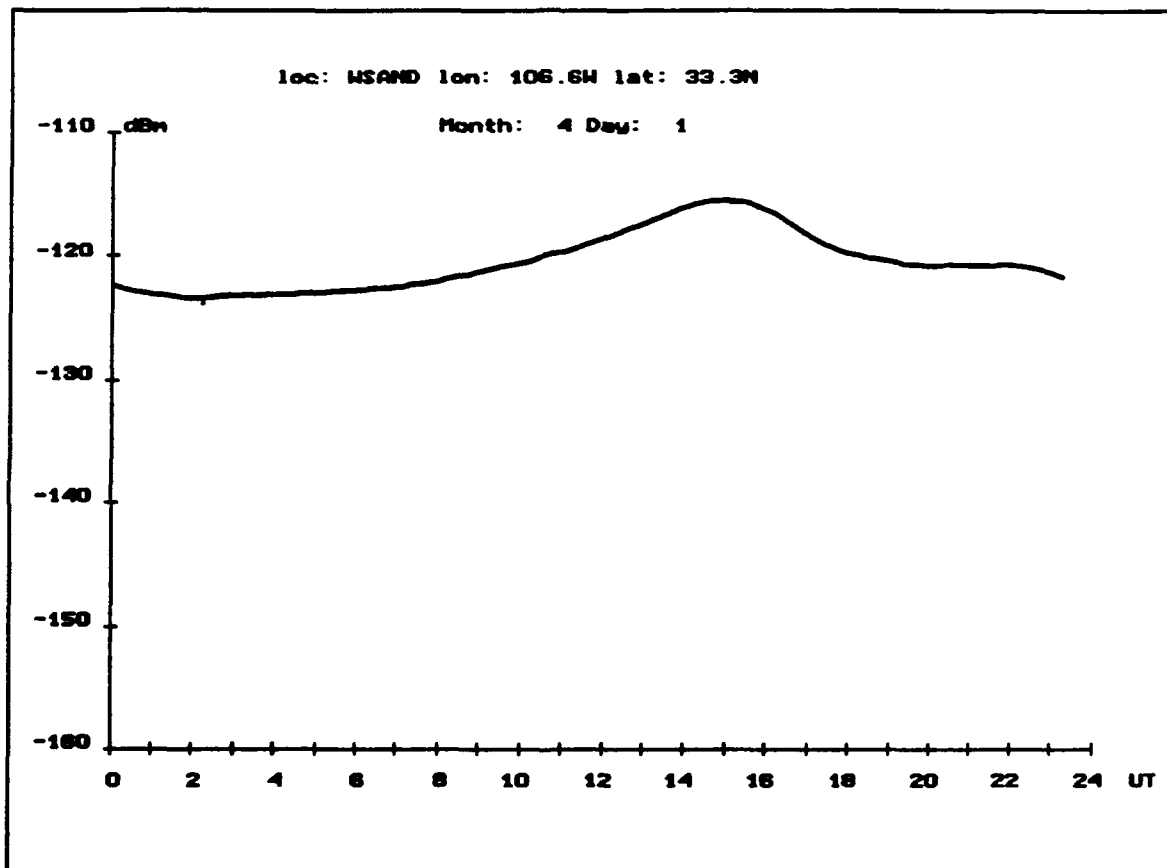


Figure 10. Diurnal Variation of the Galactic Background Noise at the Radar Range in New Mexico on 1 April, bandwidth of 10 kHz.

REFERENCES

1. R.F. Taylor, (April 1973) 136MHz/400MHz Radio-Sky Maps, *Proceedings of the IEEE*, vol 61, no. 4, pp 469-472.