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TECHNICAL NOTE R-50

OVER-THE-HORIZON TRANSMISSION AT 136 Mc/s

Prepared By

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June, 1963

BROWN ENGINEERING COMPANY INC.
HUNTSVILLE, ALABAMA

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OVER-THE-HORIZON TRANSMISSION AT 136 Mc/s

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Prepared For

INSTRUMENTATION BRANCH
ASTRIONICS DIVISION
GEORGE C. MARSHALL SPACE FLIGHT CENTER

By

SCIENTIFIC RESEARCH LABORATORIES
BROWN ENGINEERING COMPANY, INC.
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ABSTRACT

The degree of over-the-horizon propagation that may be reasonably expected at a frequency of 136 Mc/s is considered for vehicle altitudes ranging from 10,000 feet to 200 kilometers. It is shown that over-the-horizon transmission due to ionospheric and lower atmospheric refraction results in a "look angle" below the horizon of less than 0.2°.

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INTRODUCTION

This study was initiated because of the concern over the warm-up time of the AROD transponder. The earliest possible turn-on time of the data-link transponder depends on the degree of over-the-horizon transmission that may be reliably expected at the VHF frequency. This technical note arrives at an estimate of the magnitude of the total bending caused by the ionosphere and the lower atmosphere for vehicles at altitudes of 3.048 (10,000 feet), 6.096 (20,000 feet), 100, 150 and 200 kilometers and for a command frequency of 136 Mc/s.

ANALYSIS AND DISCUSSION

The electromagnetic radiation propagated from a satellite to a ground station experiences bending in the ionosphere and in the lower atmosphere. The refractive index of the lower atmosphere varies with the partial pressures of dry air and water vapor, and with the temperature; thus, the degree of bending is greatest in the lowest levels of the troposphere. At radio frequencies below 10,000 Mc/s, refraction in the lower atmosphere is substantially independent of frequency.

An electromagnetic signal passing through a plane stratified, ionized medium is bent away from the normal on ingress and toward the normal on egress. The incident and emerging signal paths are parallel and displaced. The planar approximation of the ionosphere must be abandoned when the elevation angle of the source is less than a few degrees. A spherical ionosphere produces a prism-effect resulting in a net bending of the signal path. The degree of bending decreases with the square of the transmitted frequency. Figure 1 shows how ionospheric refraction, which occurs mainly in the F-region, can produce bending around the horizon. The effect is exaggerated in the diagram.

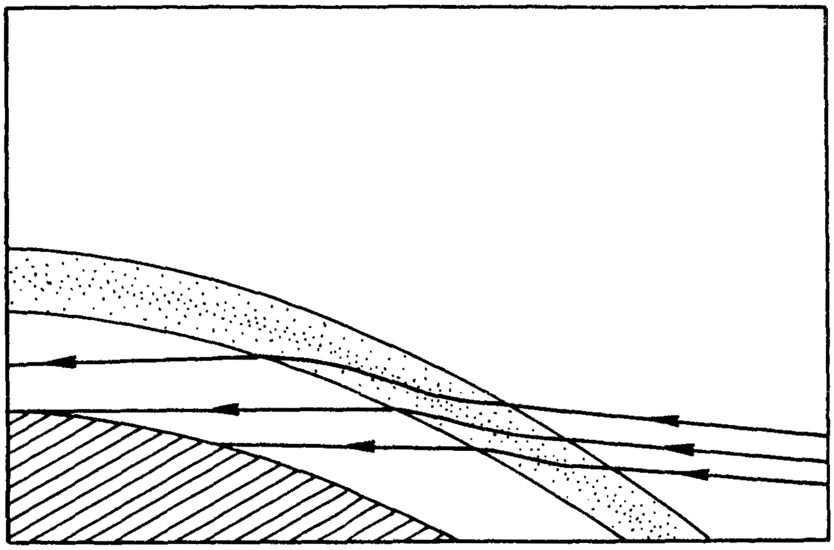

Figure 1. Ionospheric Refraction Resulting in Bending Around the Horizon

V. A. Counter (1) has studied the variation in tropospheric and ionospheric bending as functions of elevation angle and the satellite altitude. Figure 2 shows the geometry involved.

In Figure 2, G is the ground station; S is the satellite; the curved line from S to G is the transmission path; E_o is the observed elevation angle, i. e., the angle between the horizon and the tangent to the transmission path at G; E_t is the true elevation angle; h is the altitude of the satellite; and δ is the angle between the straight line from G to S and the tangent to the transmission path at S.

To answer the question, "How far over the horizon can the satellite be detected?", we need to know the angle $E_o - E_t$. Figure 3 illustrates the geometry for reception on the horizon, i. e., $E_o = 0°$.

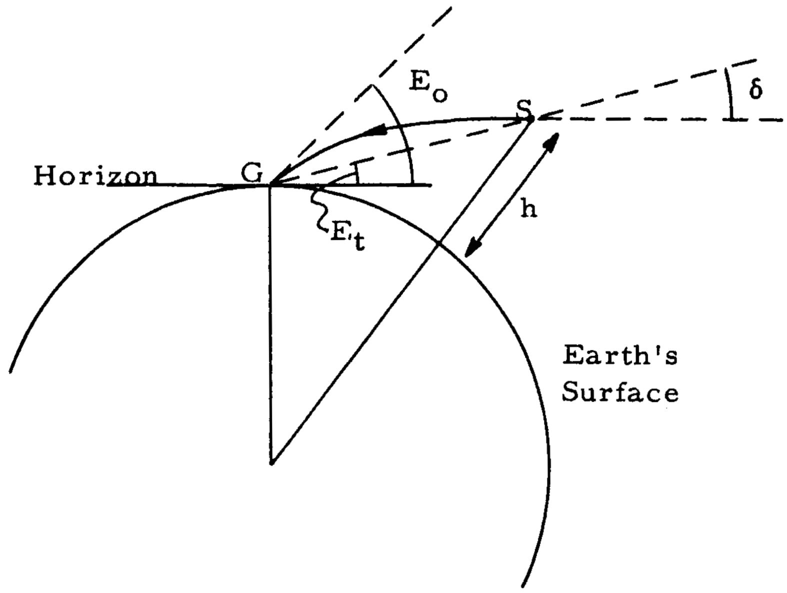

Figure 2. Transmission Path Geometry

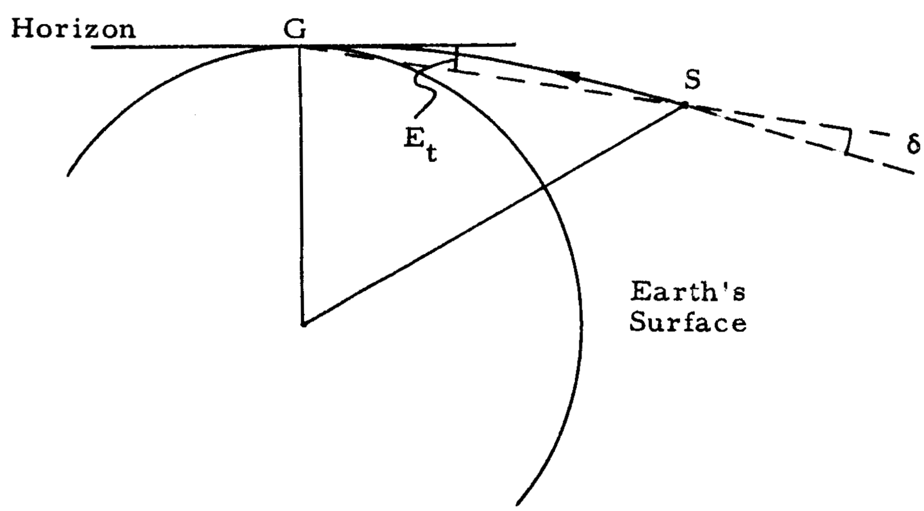

Figure 3. Geometry of Reception on the Horizon

In Figure 3, the angle of interest is E_t. Since the radius of curvature of the transmission path decreases as the altitude decreases, it is obvious that $E_t \neq \delta$. (In Figure 2, $E_o - E_t \neq \delta$.) If, however, we assume that the transmission path has a constant radius of curvature equal to the curvature at G, then $E_t = \delta$ in Figure 3, $E_o - E_t = \delta$ in Figure 2, and the transmission path is now the arc of a circle. Estimations of δ will be over-estimations of the net bending, because in actuality, the radius of curvature increases with altitude. This is Counter's procedure. He has plotted the tropospheric and the ionospheric contributions to the angle δ for various satellite altitudes and true elevation angles down to 1°. Since our interest is in over-the-horizon transmission, we shall concentrate on Counter's values for 1° elevation. There will be slightly more bending of the signal from a vehicle below the horizon (the tangent plane to the earth through the observer's feet) because of the greater path length through the ionosphere and lower atmosphere; however, Counter's values will provide a close approximation of the over-the-horizon transmission.

Figure 4 shows the variation in tropospheric bending at a true elevation angle of 1° as a function of satellite altitude. The curve has been extrapolated to altitudes below 10 kilometers.

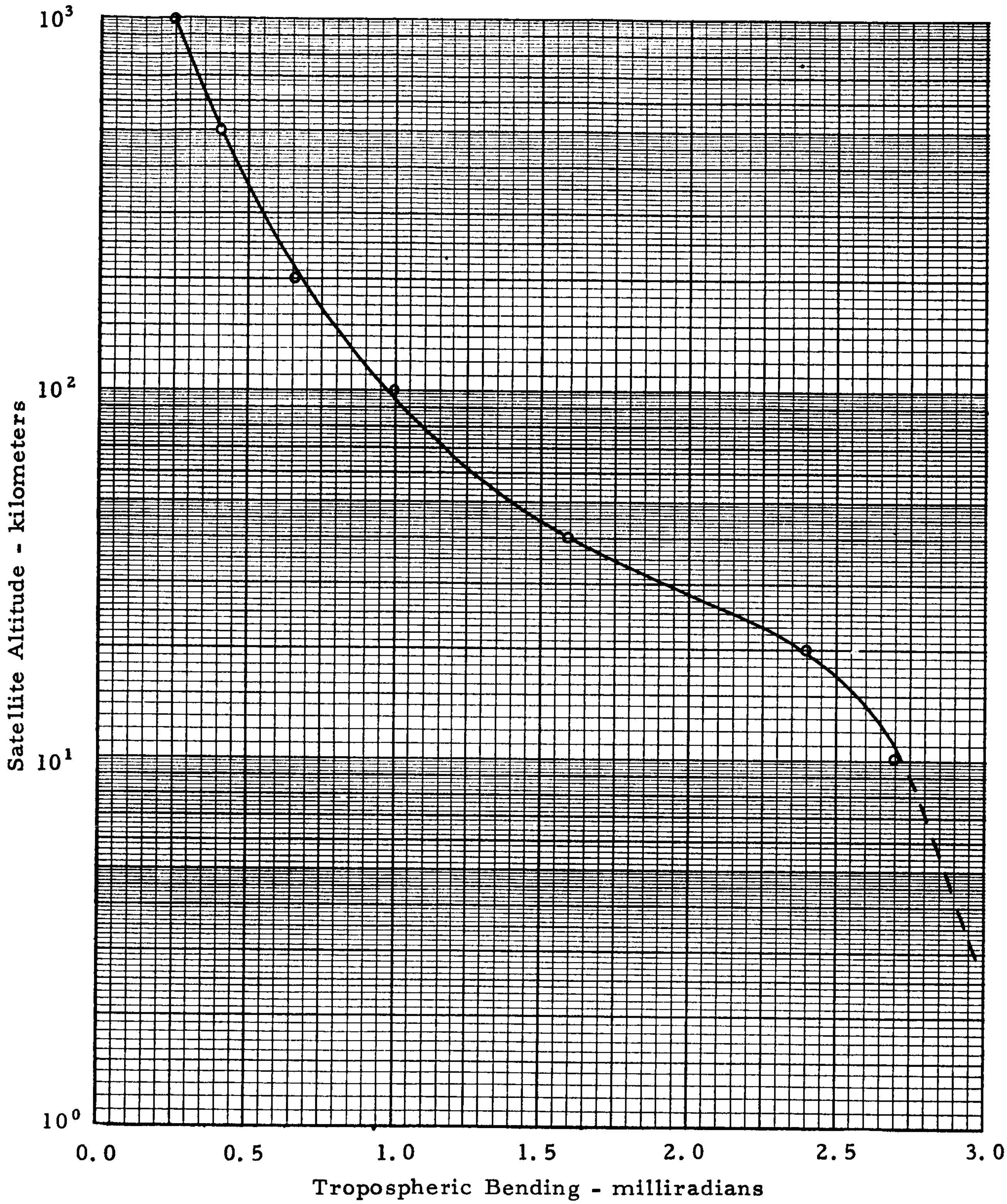

Figure 4. Lower Atmospheric Refraction of the Radio-Frequency Transmission from a Satellite at a True Elevation Angle of 1°

Under normal conditions, ionospheric bending contributes to δ only at the highest altitude considered in this study, i.e., 200 kilometers. This is the height of the F1 region. Counter's investigation of ionospheric bending was based on an analysis of ionospheric data for Washington, D. C. Although ionospheric conditions vary with time of day, season, phase of the sunspot cycle, etc., Counter's values will be sufficient, since the scope of this report is to obtain merely an estimate of the expected angular deviation of over-the-horizon transmission. He has plotted the ionospheric bending of 100 Mc/s transmission versus elevation angle for selected satellite altitudes. The magnitude of the ionospheric bending contribution to δ for 1° true elevation angle and a satellite altitude of 200 km was scaled to 136 Mc/s by multiplying by the factor $(100/136)^2$.

Table I contains the results of this study. The altitudes were specified to the author. (3.048 km = 10,000 feet; 6.096 km = 20,000 feet.)

Table I

Estimated Angular Deviation of Over-The-Horizon Transmission at 136 Mc/s

Satellite Altitude (kilometers)	Lower Atmospheric Bending (milliradians)	Ionospheric Bending (milliradians)	Total Bending δ (milliradians)	(degrees)
3.048	2.96	----	2.96	0.17
6.096	2.82	----	2.82	0.16
100.	1.00	----	1.00	0.06
150.	0.78	----	0.78	0.05
200.	0.66	2.48	3.14	0.18

Under certain conditions, e.g., daylight side ground stations and a high number density of electrons in the ionosphere, produced by enhanced solar ionizing radiations, there will be significant contributions to δ from ionospheric bending in the D-region (altitude $\sim$ 60 km) and in the sporadic E-region (altitude $\sim$ 100 km). These circumstances are temporal and, to a large extent, unpredictable. Under normal conditions, the F-region plays the major role in ionospheric refraction.

CONCLUSION

The small magnitude of the angular deviation of the 136 Mc/s signal due to refraction implies that very little time can be gained by relying upon over-the-horizon transmission for turn-on of the AROD tracking equipment.

REFERENCE

1. The graphs of V. A. Counter that pertain to this investigation are contained in: A. Valakos, "Airborne Ranging and Orbit Determination Design Feasibility Report, Volume 2," IBM Document No. TR-023-022, March 20, 1963.

REFERENCES OF GENERAL INTEREST

1. K. Rawer, "Propagation Problems With Space Radio Communications", Journal of Research NBS - D. Radio Propagation, Volume 66 D, No. 4, July - August 1962.

2. J. L. Pawsey and R. N. Bracewell, Radio Astronomy, Oxford University Press, 1955.