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UHF Radio Propagation Data for Low Antenna Heights Volume I

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F. G. KIMMETT

J. M. HARMAN

BOULDER, COLORADO
November 1969

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UHF RADIO PROPAGATION DATA FOR LOW ANTENNA HEIGHTS

VOLUME I

L. G. Hause, F. G. Kimmett, and J. M. Harman

This report is a presentation in two volumes of measurement techniques, data, comparisons, and conclusions obtained from a UHF propagation measurement program at 230 and 415.9 MHz. Antenna heights were 3 m or less above ground. Vertical polarization was used, and the antennas were omnidirectional in the horizontal plane. The terrain was generally rocky, hilly, and relatively free of trees. Path lengths varied from 2 to 45 km. Volume 1 describes the equipment, techniques, and results and presents data from the Wyoming area, including some buried antenna tests. Volume II presents data obtained in Idaho and Washington.

Key words: Buried antennas, low antennas, path loss measurements, UHF propagation, vertical polarization.

1. INTRODUCTION

This report has been prepared to:

(1) Explain the potential usefulness of UHF radio propagation data from low antennas for analyzing communications problems.

(2) Describe the methods and equipment used in gathering the data.

(3) Discuss the UHF measurements as a function of various parameters such as frequency, antenna heights, and path geometry.

Most land-mobile communication systems operate with low antennas. Man-made noise sources are often located very near the ground. Examples of such sources are automobile ignitions, arc welding units, and small electrical appliances. The information obtained from investigation of UHF radio propagation from low and buried antennas can be applied in analyzing problems dealing with communications signal strength and electromagnetic interference.

On smooth terrain an important characteristic of the UHF band is the natural isolation for beyond line-of-sight locations. The size of the useful propagation area may be adjusted with antenna height. For this reason and the convenient antenna sizes, UHF is ideal for certain mobile communication systems in that the same frequencies can be reassigned to other areas at smaller spacings than are required at lower frequencies. For rough terrain, however, much of the isolation advantage is lost, as will be seen from the body of data.

Measurements were made from vertically polarized antennas less than 3 m above ground. More than 145 paths were involved, which varied from 2 to 45 Km. Two frequencies were used, 230 and 415.9 MHz. The terrain where the measurements were made in parts of Wyoming, Idaho, and Washington was hilly and rocky (see figs. 1, 2, 3, 4, and 5). The measurements were made between June and November 1968. Another large body of data from low antennas 230 to 9200 MHz is found in McQuate, et al. (1968).

The main purpose of the UHF tests was to reduce propagation uncertainties encountered in matching a communication system to the radio environment. Communication system parameters and component specifications are determined from a knowledge of the uncertainties and their statistics. The performance of a UHF system is dependent upon both terrain and antenna locations. By determining the location dependence, it is possible to identify a reasonable value of system gain.

The data are presented in graphic form with basic transmission loss plotted versus receiving antenna height. In addition to the path loss measurements over 145 propagation paths, buried antenna measurements were also conducted in the Wyoming area.

2. SITE SELECTION

U.S. Geological Survey maps with the largest scale available of the areas in Wyoming, Idaho, and Washington were obtained to encompass the proposed test areas. After careful study of the maps, the potential sites were visited and selections were made mainly on the basis of the following criteria:

(1) The ability to locate the sites accurately on available U.S. Geological Survey maps.

(2) Accessibility of the test units, based on road conditions and terrain.

(3) Highest ground within 100 m of the point selected from the map study (in most instances).

An effort was made in all three states to have uniform coverage. The boundaries of the test areas were selected on the basis of geological nature and factors other than communication requirements.

3. EQUIPMENT AND OPERATIONS

3.1 Antennas

Antennas used were quarter-wave monopoles over a ground plane. All antennas were constructed in such a way that they could be calibrated at the feed point (see figs. 6, 7, and 8). Radiation patterns for these antennas are shown in figures 9 and 10. For zero elevation angle the gain of the antennas is 1.8 dB above isotropic for both frequencies. In air, the VSWR values were less than 1.2 at the operating frequencies.

3.2 Receiving Unit

The unit provided for measuring power at the receiving antenna terminals was designed to incorporate both mobility and accuracy. A block diagram of the receiver is shown in figure 11. Some of the receiving unit features are described below.

(1) Preamplifier, local oscillator, and mixer units were usually housed within the antenna (except for the buried tests). This arrangement eliminated lossy r-f transmission lines.

(2) Sensitivity, gain stability, dynamic range, and recording voltage linearity, with respect to the logarithm of the received power level, were the essential characteristics of the 70-MHz IF amplifier (see figs. 12 and 13). The narrow passband with a compatible local oscillator stability provided more than adequate sensitivity in the 40-dB linear range of the IF amplifier.

(3) Telescoping fiberglass tubing was used to construct the tripod support for the receiving antenna. The height of this structure could be varied from 3 to 6 m. Because wind velocities from 10 to 40 mph are almost always present in the Wyoming area, nylon guide cords were used to stabilize the antenna. To record antenna height above ground, a signal from a Nichrome wire potentiometer was utilized as a height sensing input to an X-Y recorder.

(4) Primary power requirements for the receiver were all low power and low voltage direct current that allowed sustained performance up to 14 hours without battery recharging.

(5) Receiver calibration was obtained by means of a signal generator providing a known substitution signal. The block diagram for the signal generator is shown in figure 14. A temperature compensated power meter was used to check the calibration of the signal generator prior to each path loss measurement.

3.3 Transmitting Unit

A block diagram of the transmitter is presented in figure 15. Maximum power output was 20 W for each frequency. These transmitters were also powered from storage batteries; again advantages in mobility were achieved. The transmitter was often placed directly under the antenna support, minimizing the transmission line length (see fig. 8). Precision, power attenuators, and a temperature compensated power meter measured r-f power output prior to each path loss measurement.

3.4 Operations

Two vehicles were required: one for receiving equipment and the other for transmitting equipment. Normal operation required the attention of three people; however, the equipment could be operated by two more slowly. The receiver vehicle was normally stationary, while the transmitter van moved from site to site. Before daily measurements were made, sites for possible measurements were chosen from map locations and path loss calculations were made. The receiver and transmitter vans were located on site, equipment was set up, and signal level values were recorded as a function of antenna height. Voice communications were necessary for coordination of measurements. Signal generator and oscillator frequency measurements were made daily on the equipment to insure maintenance of stability. A weekly equipment check was performed by making repeated measurements over a short line-of-sight path. As measurements were being recorded, a comparison of the 230 and 415.9 MHz path loss measurement charts provided a quick check, which could indicate possible calibration error or an equipment malfunction. If the data indicated a variation from the expected values, a second run would be made on each frequency to recheck operations while both vans were "on site".

Upon completion of the measurements for a particular path, black and white photographs of the path were taken from each terminal to show terrain features that might have a bearing on the test data.

4. AREA TEST RESULTS

Data and supporting information for each path for the areas tested are presented following the figures, with Wyoming first, Idaho second, and Washington third. The data for each path are presented in numerical order in a standard format. Generally, down-path pictures were obtained at each site. Path profiles were plotted from U.S. Geological Survey maps. Basic transmission loss was derived for each frequency and for each of the transmitting antenna heights, 0.75 m and 3 m above ground. Basic transmission loss is defined as the loss over any particular path between the terminals of two impedance-matched, lossless, isotropic antennas. To calibrate the recorder at the receiver output, a calibrated substitution signal was supplied to the receiving antenna terminals. The value of this power level was corrected for power level to the transmitting antenna terminals and known power gains of both antennas.

5. COMPARISONS AND CONCLUSIONS

In order to view particular sets of data for intercomparison and comparison with other sets, the graphical presentations shown in figures 16 through 26 were produced. In these plots the points representing the individual paths were always selected from the values on the height-gain curves, representing equal heights of the transmitting and receiving antennas (either both atnennas at 3 m or both antennas at 0.75 m).

Between 230 and 416 MHz the difference between median values of transmission loss at the same antenna heights and distances for each frequency is essentially the same as for free space. For these two frequencies, the variability of transmission loss caused by changes in radio path locations for fixed length paths in rough terrain is essentially independent of path length and frequency for the path distances covered by these tests (see fig. 25). Observed values in the three states show that variations from path to path (paths of the same length) may be as great as 60 dB.

Line-of-sight path loss values differ from free-space path loss by approximately the same amount for a given set of antenna heights and a given frequency. This is demonstrated by comparing figures 24 and 25 for identification of such paths.

The variation of path loss with antenna height (for vertical polarization) is relatively independent of frequency or path length for the range of frequencies and lengths investigated here. Lowering both antennas from 3 m to 0.75 m produces a median increase in path loss of approximately 20 dB (see figs. 20 and 21). Lowering an antenna from 0.75 m to the surface increases the median path loss by 8 dB (see fig. 47).

Figure 26 is a graph showing only Washington data; the Soap Lake area paths show approximately 8 dB less loss on the average than those for Ritzville. Observing the profiles, we can see that sites selected in the Soap Lake area were more favorable for communications because of the type of terrain. Accessibility and terrain roughness, the two major siting criteria, greatly influenced the outcome; the person selecting these sites was not concerned with communications. The Soap Lake area (fig. 4) is very rough terrain cut up by the very large canyons or coulees. The Ritzville area on the lower right of figure 4 is rolling wheat land. Data from the Ritzville area exhibit approximately 20 dB more path loss than that from the Soap Lake region. If the data from the Soap Lake area are compared with the main body of data, then a difference of approximately 15 dB is observed. For further analysis see Barsis et al. (1969).

We have compared path loss statistics for the parameters of distance, antenna height, frequency, terrain type, and profile geometry. An additional comparison can be made on the basis of paths having a common terminal. Because some of the sites were selected on open high ground, it is probable that the bias introduced by these sites can be determined from our body of data; however the methods used to treat this topic would be more complex than those employed in this preliminary analysis.

6. RECOMMENDATIONS

Because the path loss increases sharply as antennas are lowered from 3 m, the probability that the dominant mode of propagation is by means of off-path terrain reflection rapidly increases as the antennas are lowered. The effect also rises rapidly with terrain roughness. In order to obtain greater insight into the prevalence and character of this mechanism, we recommend that for future measurements in rough terrain path loss data be obtained for various azimuths using an omnidirectional, as well as a directional antenna at low antenna heights. The down-path elevation angles to the horizon should also be measured for paths having obstructions in the near forground.

7. UHF BURIED ANTENNA TESTS

These tests were performed at 415.9 MHz in the Wyoming area, as shown in figures 27 and 28. The antennas used for these tests were vertically polarized and omnidirectional in the horizontal plane. Forward and reflected power to buried antennas was measured and recorded. The difference between forward and reflected power was assumed to be radiated. Reflected power was never found to be greater than 25 percent of forward power at the antenna terminals.

The principal site was a large Sherman granite slab designated site A (see figs. 29 and 30). Seven tests were made from site A to site B, which is located on a knoll 670 m west of site A (see figs. 31 and 32). Site B is made up of broken weathered rock, not Sherman granite. Remaining tests were made from site 9 to site A. Eight tests were made; briefly they are as follows:

(1) One height gain measurement run was made from 0.25 m within the hole at site A to 2 m above ground. This test was done with the transmitting antenna at site B at a height of 0.75 m.

(2) One height gain measurement run was made from 0.7 m within the hole at site B to 2 m above ground. This test was done with the transmitting antenna at site A, 0.75 m above ground.

(3) One height gain measurement run was made from 0.7 m within the hole at site B to 2 m above ground. This test was made with the transmitting antenna 1 m deep in the hole at site A.

(4) One height gain measurement run was made from 0.7 m within the hole at site B to 2 m above ground. This test was made with the transmitting antenna 1 m deep in the hole at site A and covered with broken rock.

(5) Two height gain measurement runs were made at site 9 with the transmitter at site A. The antenna at site A was 3 m above ground for the first run and buried 1 m below the surface for the second run. The receiving antenna height range was 0.75 m to 3 m above ground.

(6) One path loss measurement was made from site A to site B with both antennas 1 m deep, and both covered with broken rock.

(7) Height gain measurement runs were made at site B with the site A transmitting antenna at ground level and covered with a 0.2, 0.4, 0.6, and 1 m layer of broken rock. The receiving antenna height range was 0.75 m to 3 m above ground.

(8) One height gain measurement run was made at site B with the antenna at site A at ground level and covered with a 1 m layer of broken rock, which was thoroughly soaked with approximately 15 gal of water. The receiving antenna height range was 0.75 m to 3 m above ground.

All heights were measured from ground level to the feed point of the antenna. For the tests in which the antenna was buried below ground level,a protective cavity was provided (see fig. 33). With this protection, reflected power at the antenna terminals never exceeded 10 percent of forward power. During tests 7 and 8, no protective cavity was used but the feed point was carefully waterproofed. When the antennas were buried the holes were filled level with the surrounding ground.

The path from site A to site B is line-of-sight,as shown by the terrain profile in figure 35. The path from site A to site 9 is not line-of-sight (see fig. 36). Site A is on the brow of a small hill with a small part of the hill mass between site A and site 9.

Figures 31 and 32 show the flat area at site B. This area is approximately 7 m wide in the north-south direction and 12 m in the east-west direction. Figure 30 shows a section of the granite slab with the transmitting system in operation. Figures 37 and 38 show the holes at site A and B. In figure 37 the meter stick extends down to the feed point, although it does not appear to do so. In figure 39, a pile of rock and several bags of small rock fragments may be seen; these were removed prior to the tests. The plywood reinforcement and the receiving antenna at site B are shown in figure 40. Figures 41 and 42 show the holes in site A and B as they appeared when filled with broken rock. Tests 7 and 8 were performed at site A approximately 20 m south of the hole at site A. Figure 34 and figures 43 through 46 show this antenna location at various stages of coverage with broken rock.

8. UHF BURIED ANTENNA TEST RESULTS

Test results are shown in figure 47 through 50 with the curves, or points, numbered to correspond to the test description in the previous section. The transmission loss value (basic transmission loss cannot be measured without antenna gains) from test 2 at the position where the receiving and transmitting antenna heights are 0.75 m is 80.5 dB (see fig. 47). The transmission loss value from test 6 for which both the transmitting and receiving antennas are buried 1 m below ground level is 161.5 dB. Therefore, the difference in path loss in going from the 0.75 m height above ground to the buried condition is 81 dB. The difference between the curves representing the results of tests 3 and 4 indicate that the loss difference between an open and covered hole, like the one at site A, is 4 dB.

The difference between moving an antenna from 0.75 m above ground to 1 m inside an open hole is approximately 30 dB. For the holes at sites A and B, the 30 dB value is confirmed by the difference between the test 2 and 3 curves as well as the differences on these height gain curves between the 0.75 and -0.7 m values.

The results shown in figure 48 indicate a loss of approximately 34 dB for the condition of moving the antenna from 0.75 m above ground to the condition of being buried 1 m below ground. The assumption has been made on the basis of the discussion in section 5 that lowering the antenna from 3 m to 0.75 m will increase the path loss by 10 dB. Results from the tests with a vertically polarized antenna at ground level covered with an incrementally increasing depth of rock indicates that for this type of pile there is little loss in signal level but a decided change in pattern from that of the antenna to that of the antenna and pile combination (see fig. 49). Wetting the pile increased the loss by 4 or 5 dB (see fig. 50).

9. ACKNOWLEDGMENT

This work was sponsored by the Air Force Systems Command, Space and Missile Systems Organization (SMQHN), Norton Air Force Base, California.

We wish to thank Mr. George Evers for his efforts in preparing and operating many items of equipment used in these tests.

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Barsis, A.P., M. E. Johnson, and M. J. Miles (1969), Analysis of propagation measurements over irregular terrain in the 76- to 9200-MHZ Range, ESSA Tech Rept ERL 114-ITS 82 (U.S. Government Printing Office, Washington D.C. 20401).

McQuate, P. L., J. M. Harman, and A. P. Barsis (1968), Tabu- to 9200-MHZ range- Part 1: Gunbarrel Hill receiver site, ESSA Tech Rept. ERL 65-ITS 58 (U.S. Government Printing Office Washington D. C. 20401

11. FIGURES

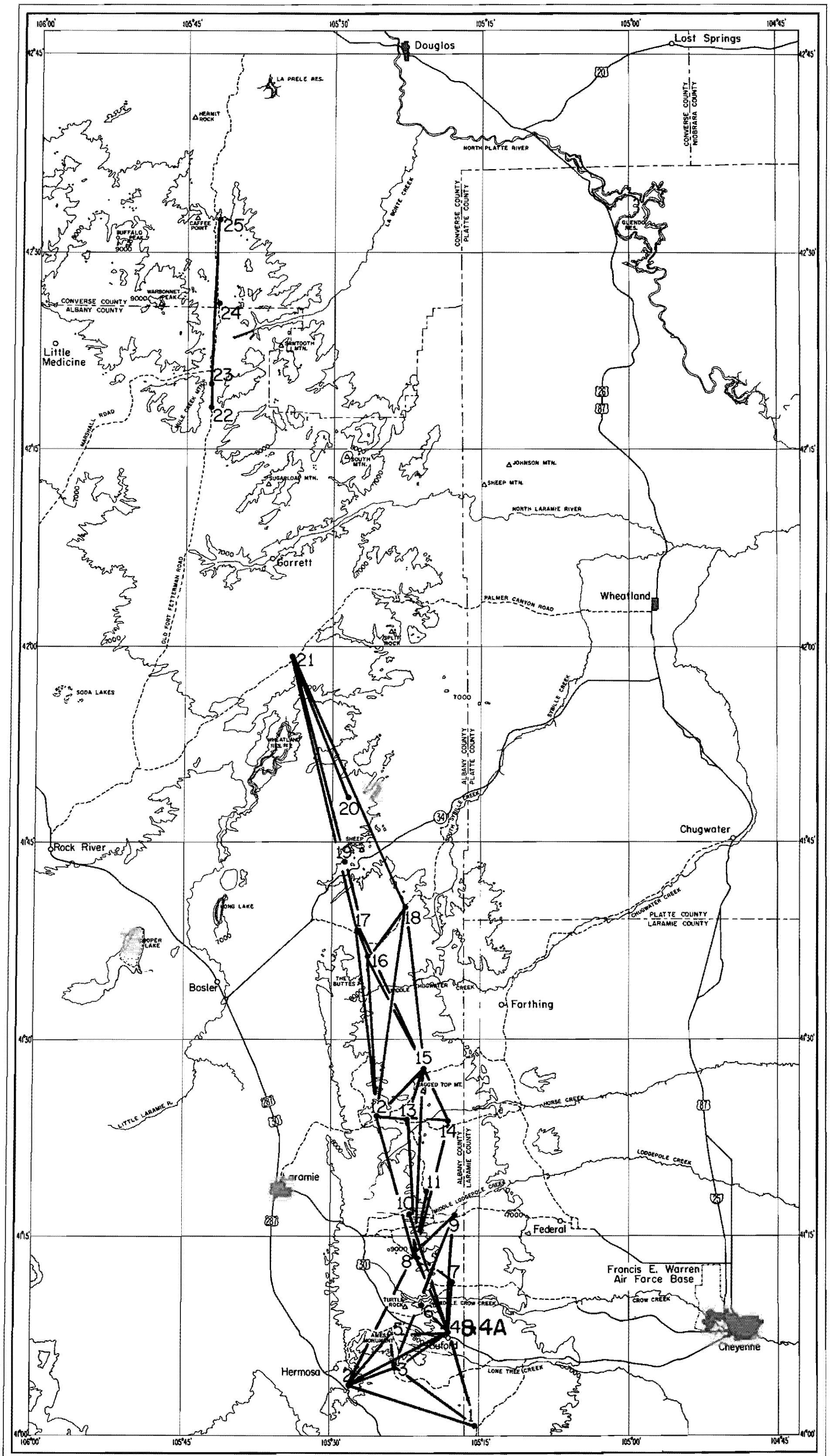


Figure 1. Wyoming test area sites and paths

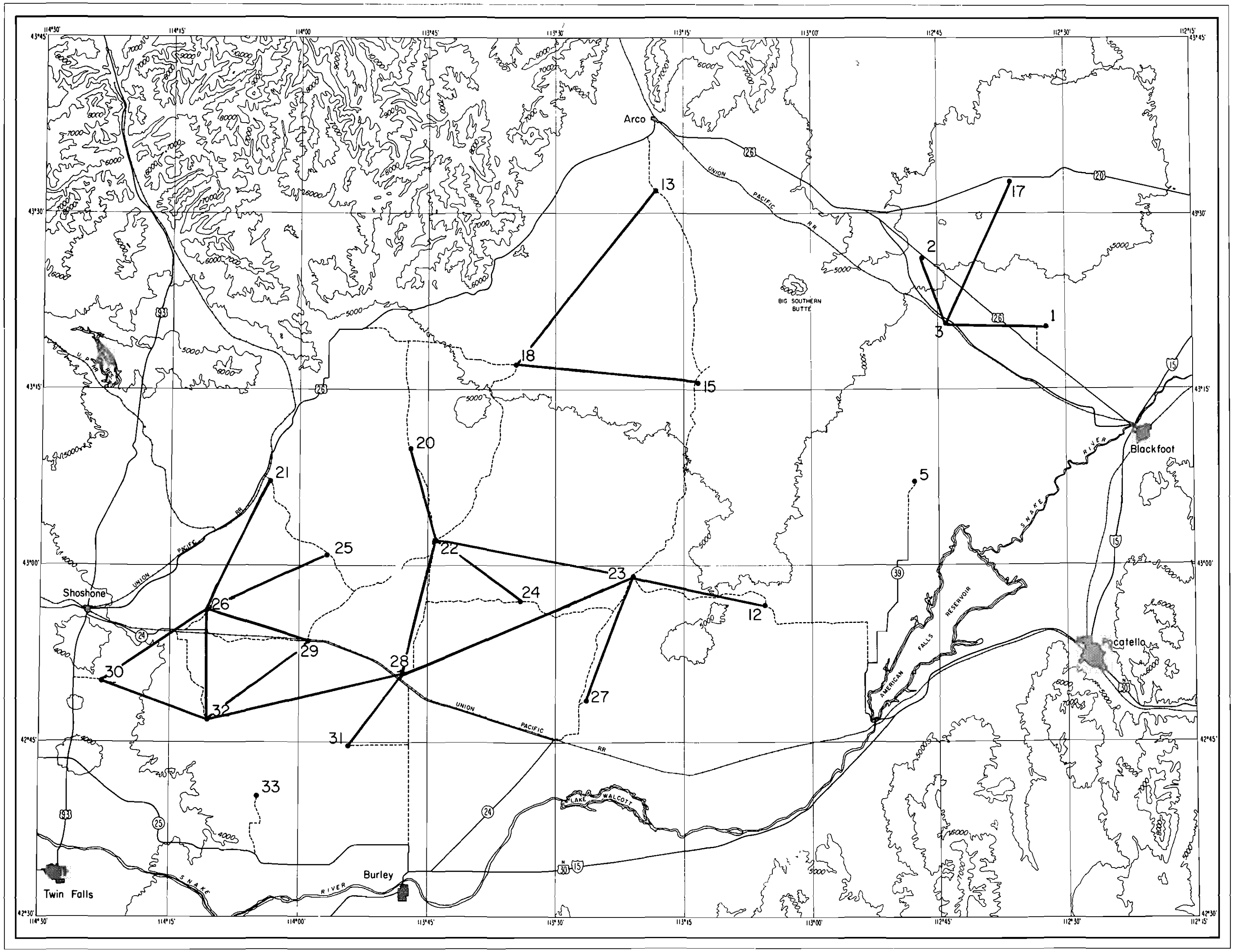


Figure 2. Idaho, eastern test area

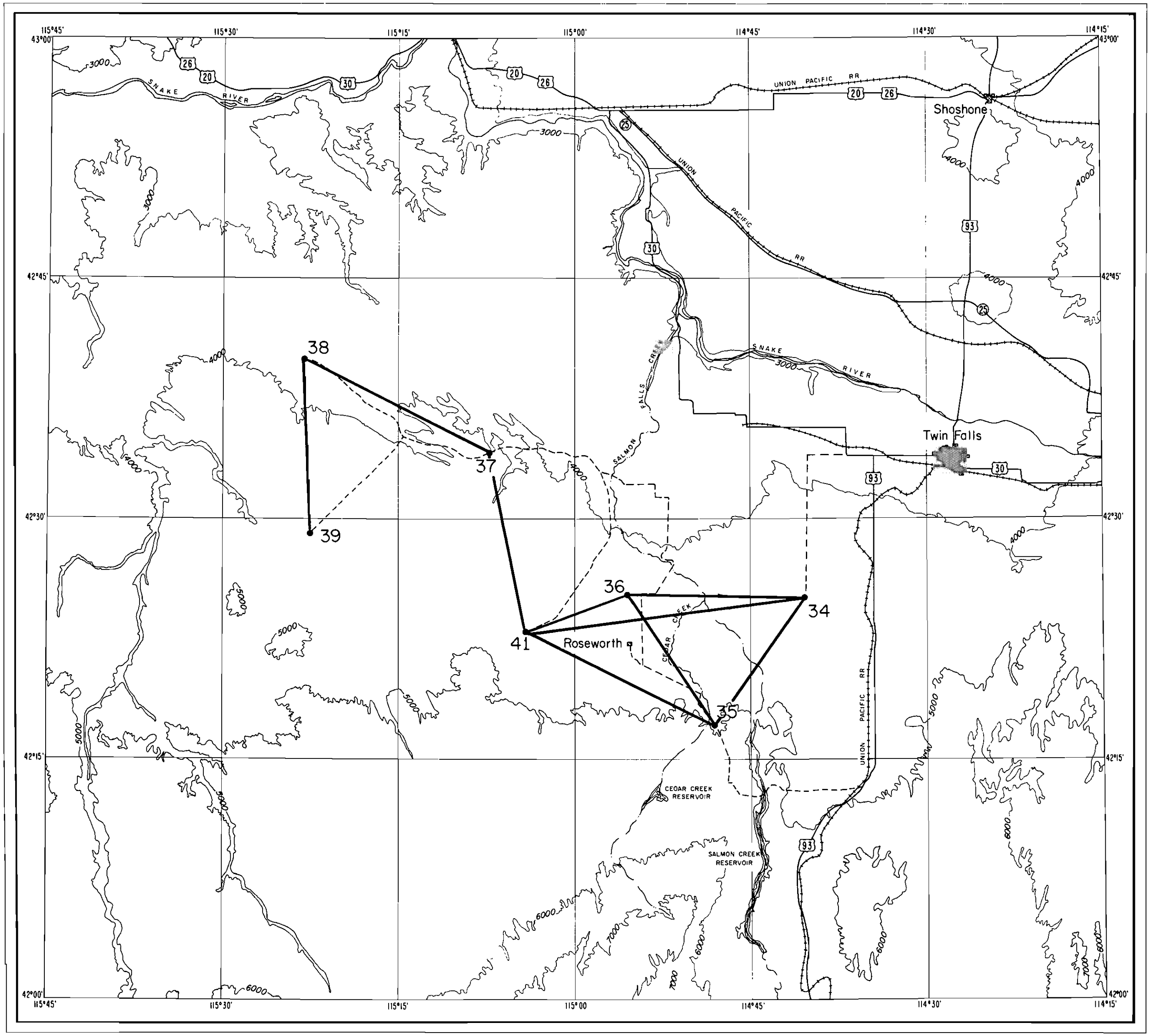


Figure 3. Idaho, western test area

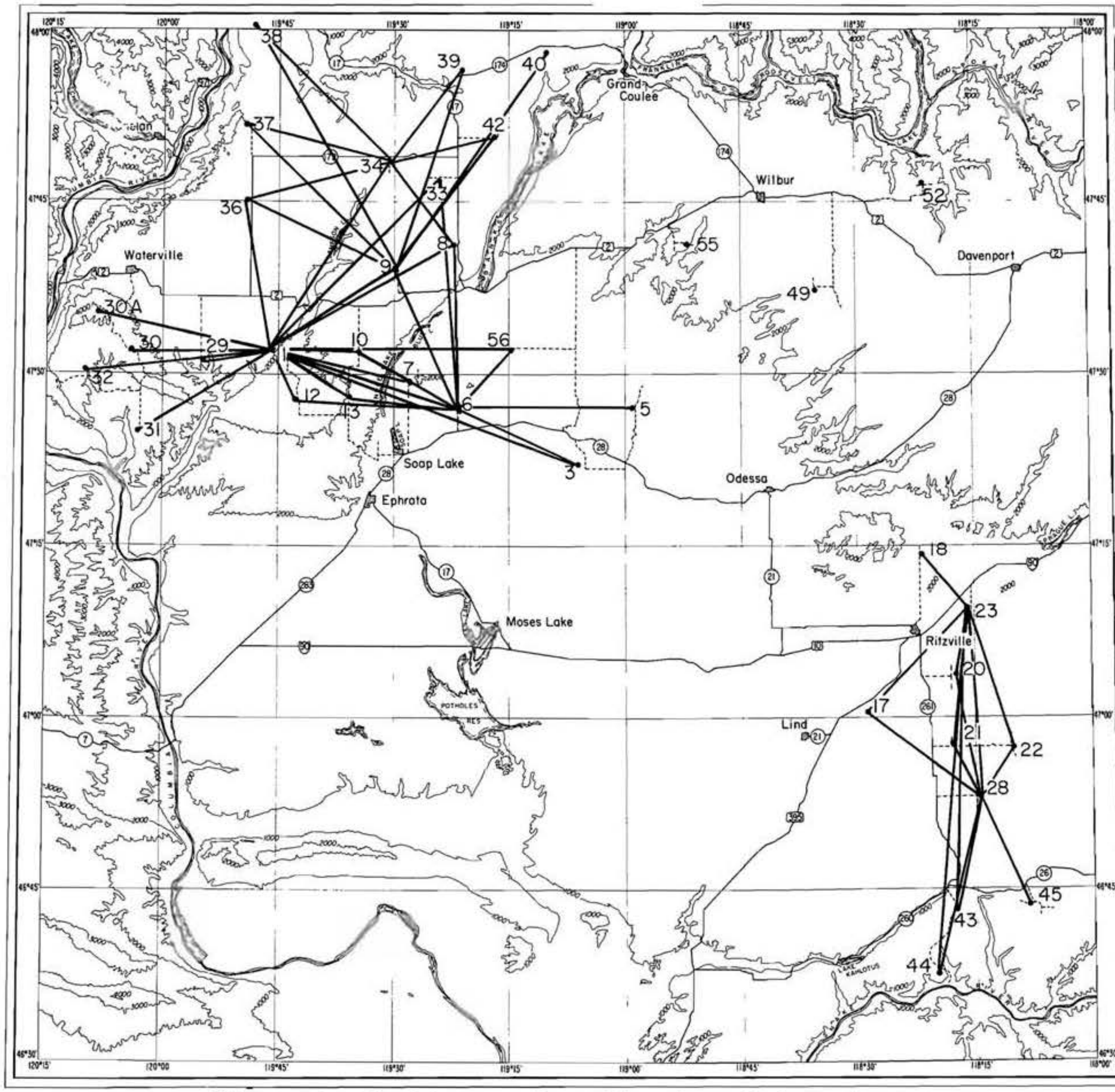


Figure 4. Washington, Ritzville - Soap Lake test area

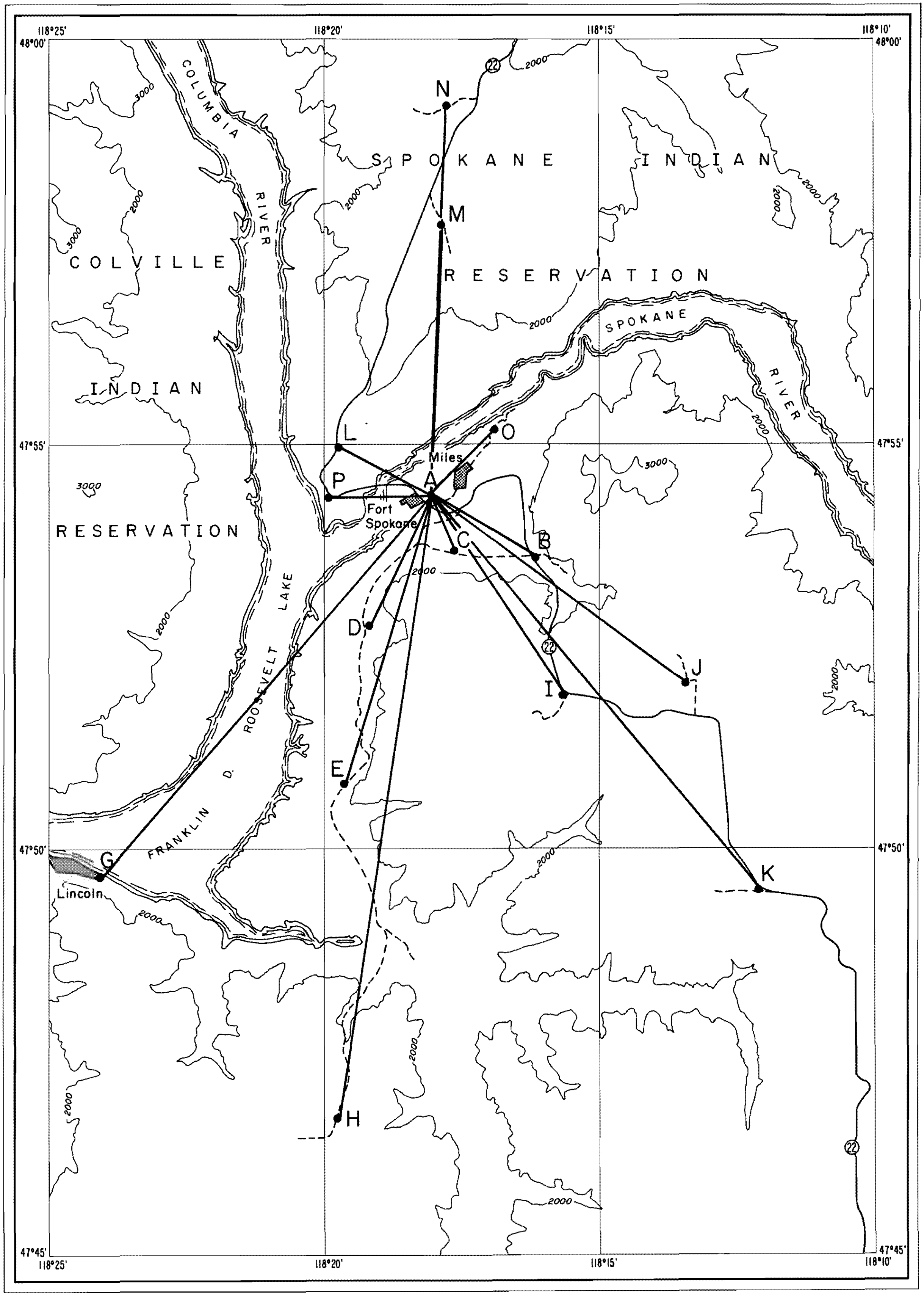


Figure 5. Washington, Fort Spokane test area

Figure 6. Receiver calibration position

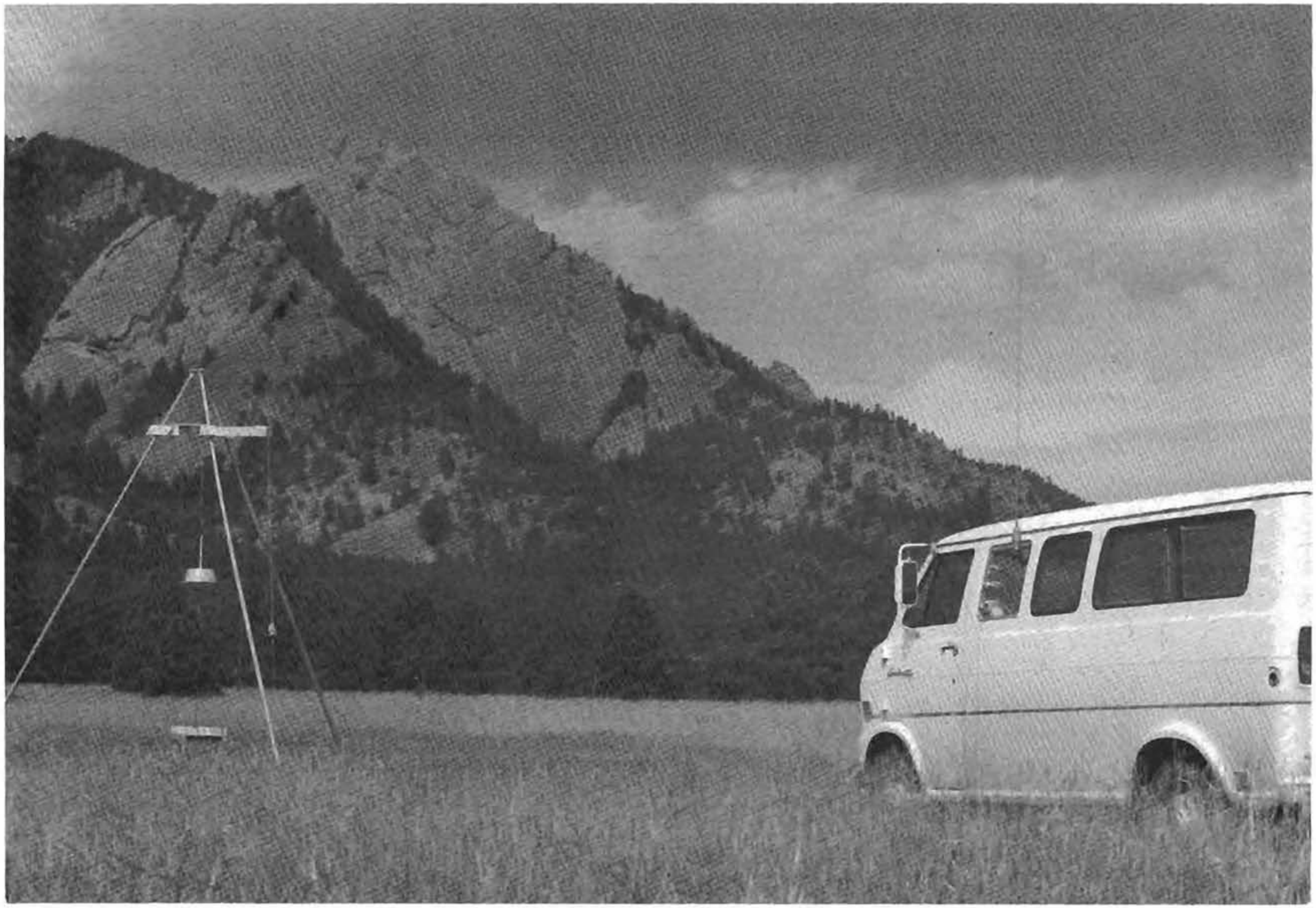


Figure 7. Receiver in operation

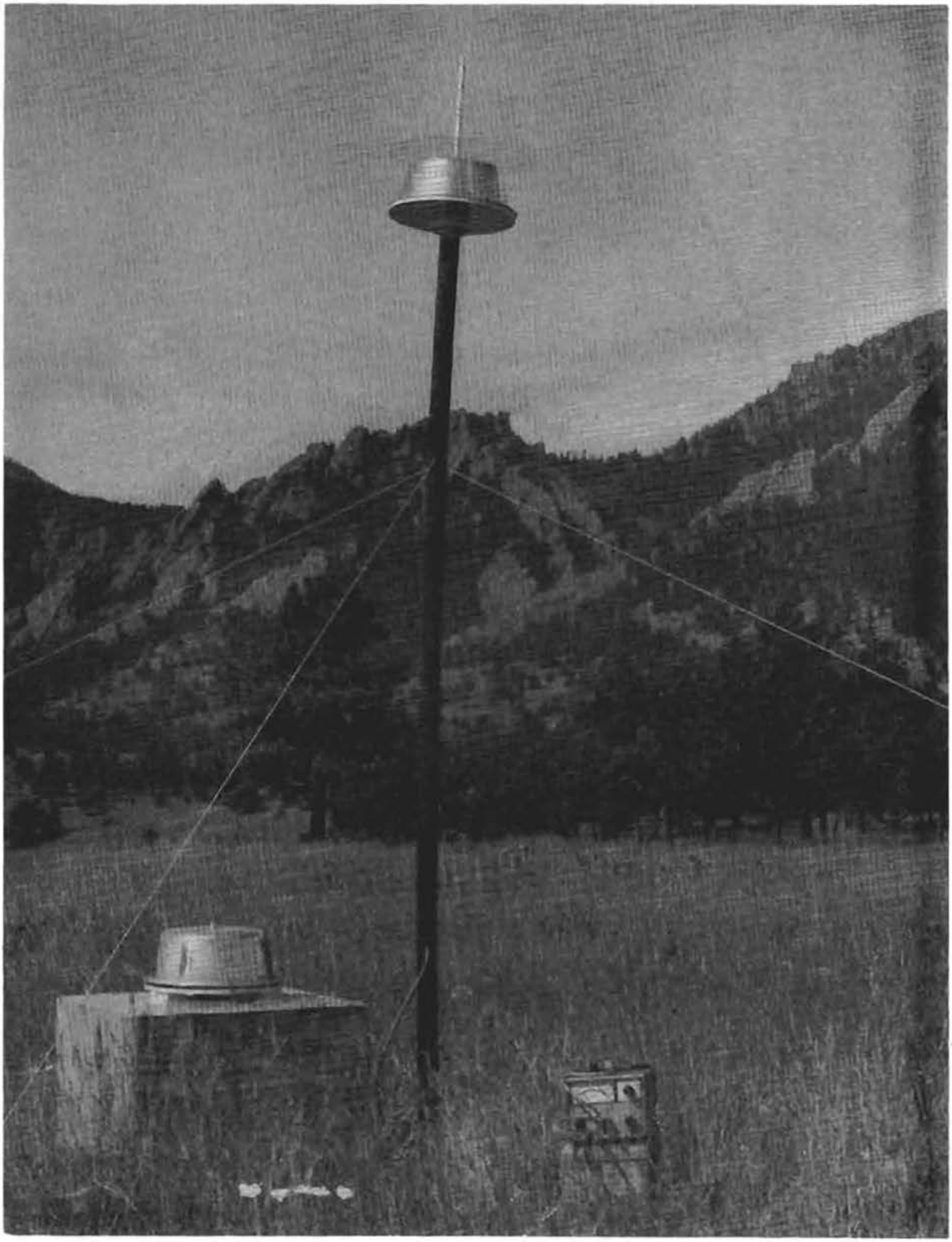


Figure 8. Transmitting antenna at 3.0 m height

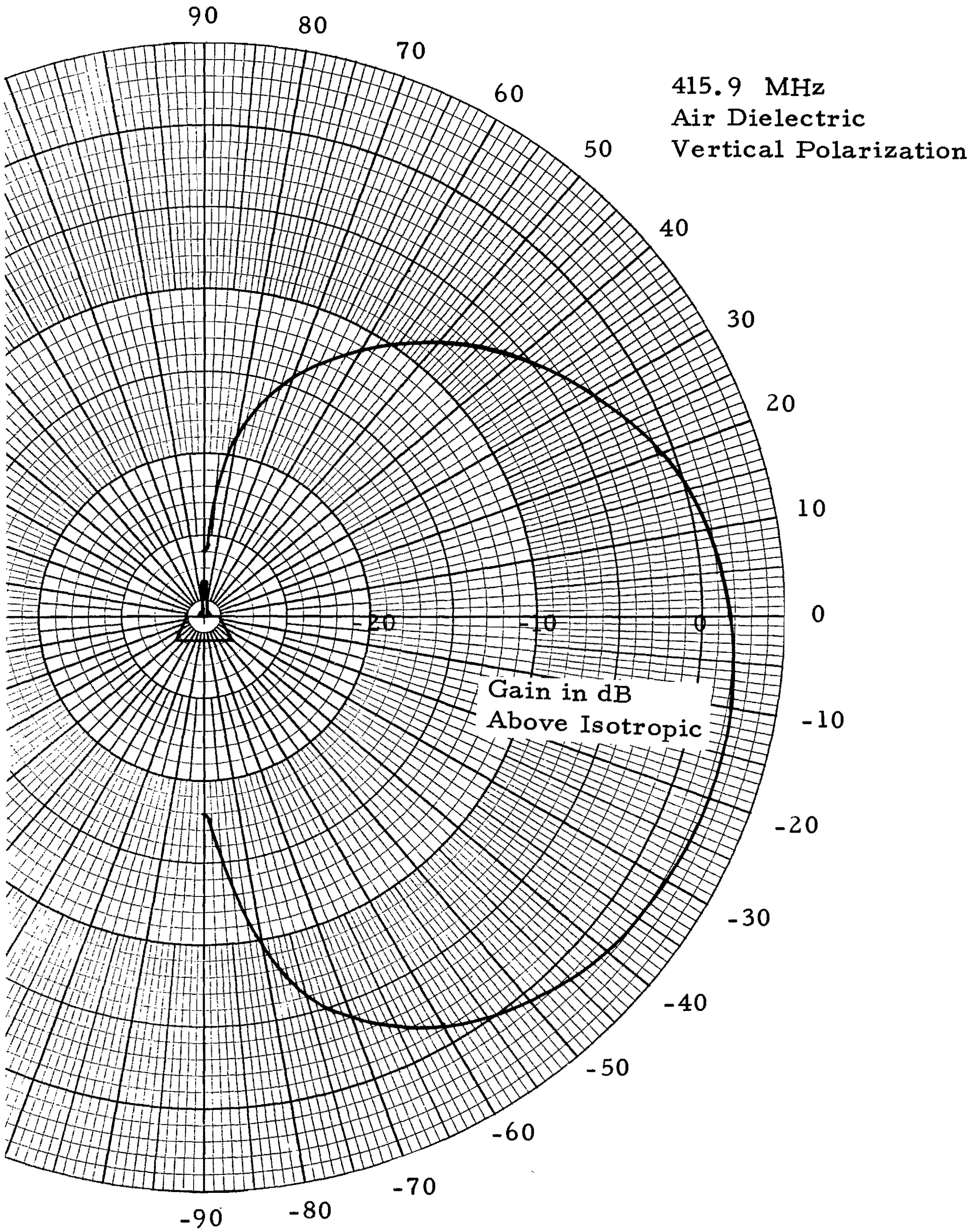


Figure 9. Stub antenna vertical pattern for 415.9 MHz

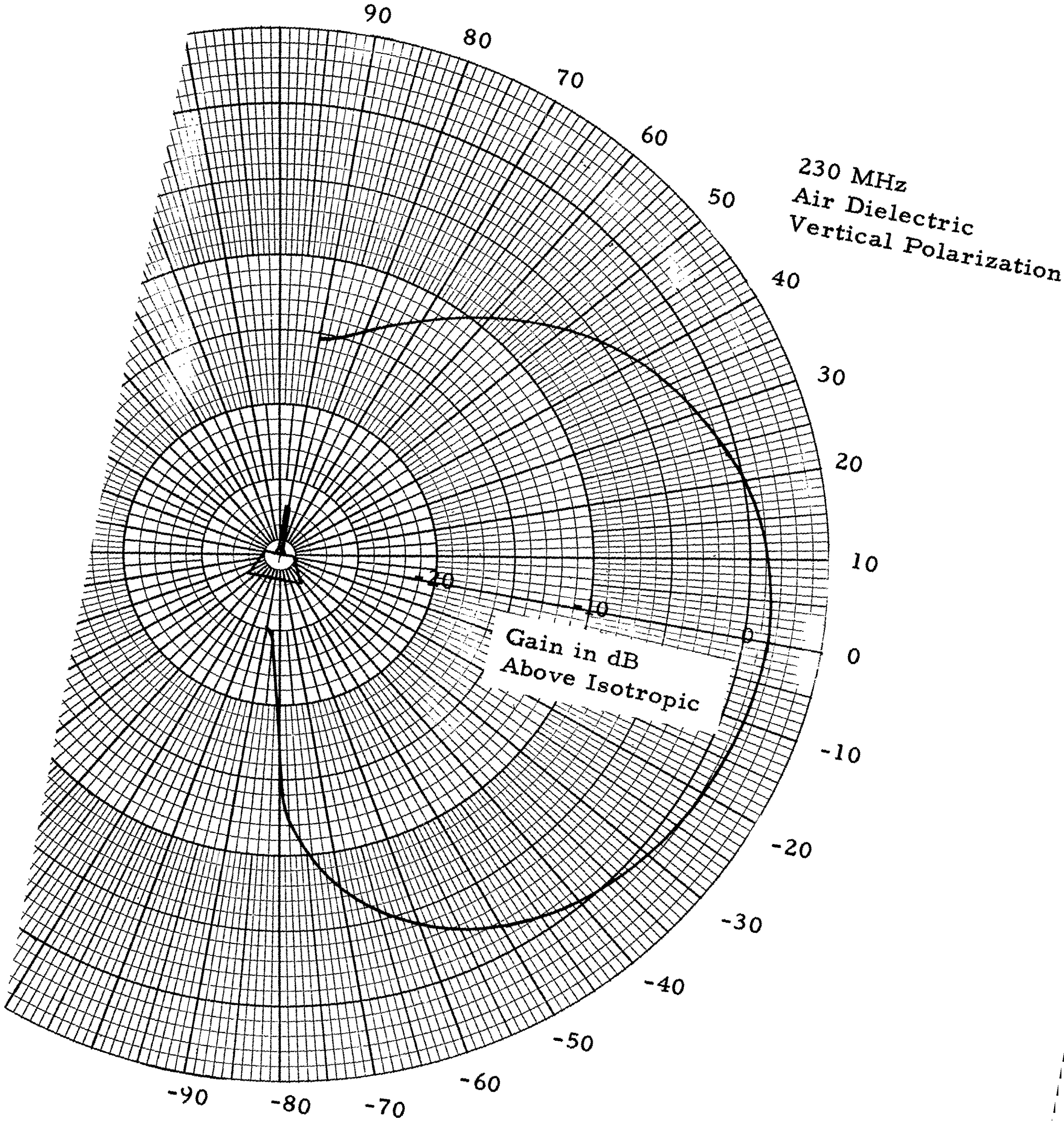


Figure 10. Stub antenna vertical pattern for 230 MHz

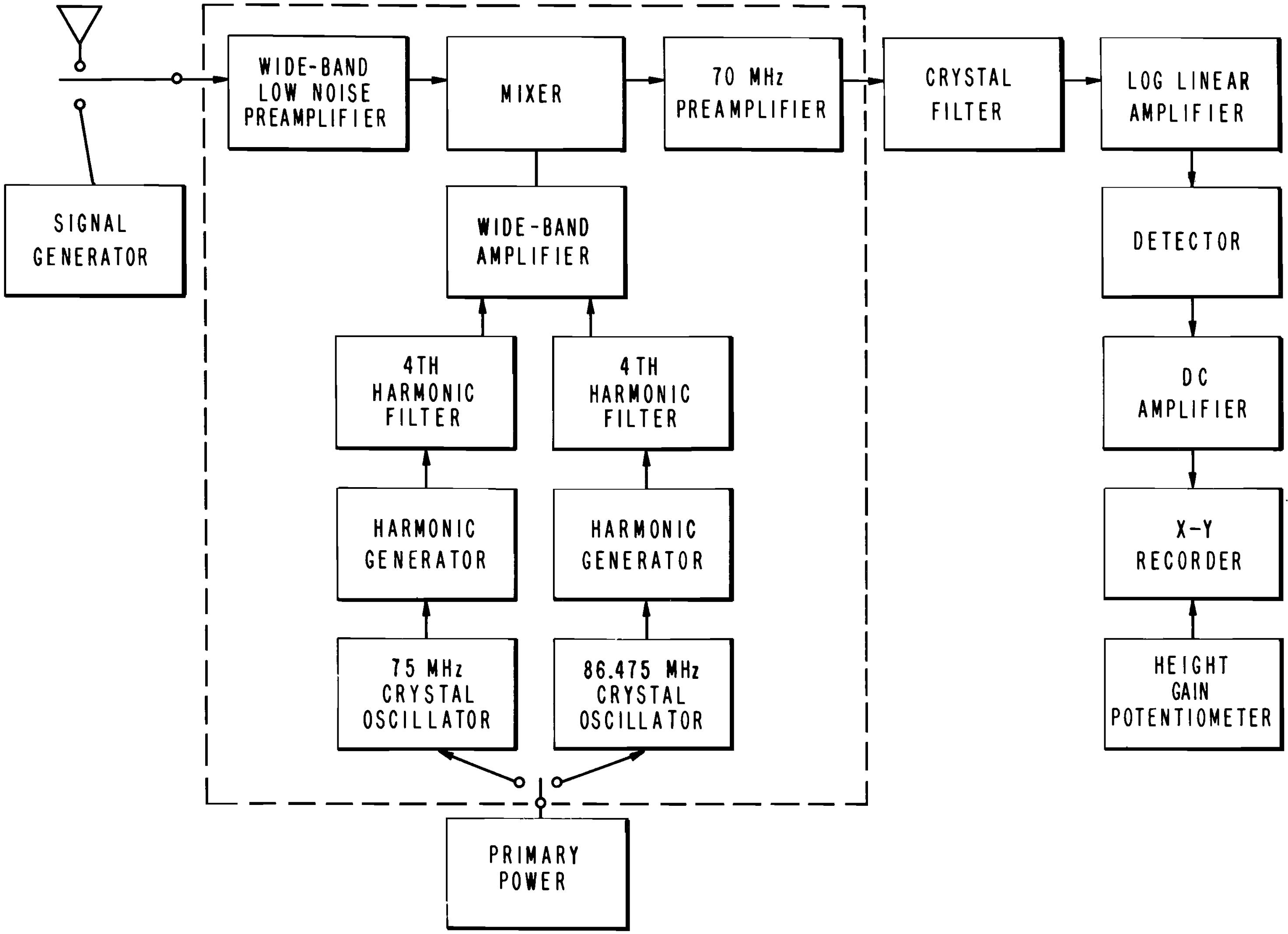


Figure 11. Receiver block diagram.

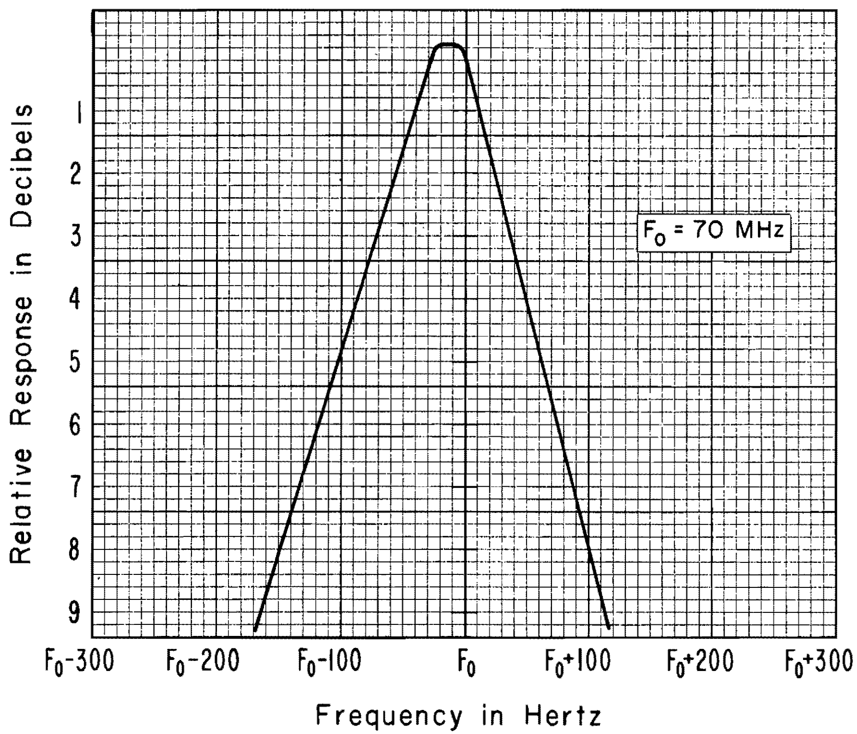


Figure 12. IF filter characteristic

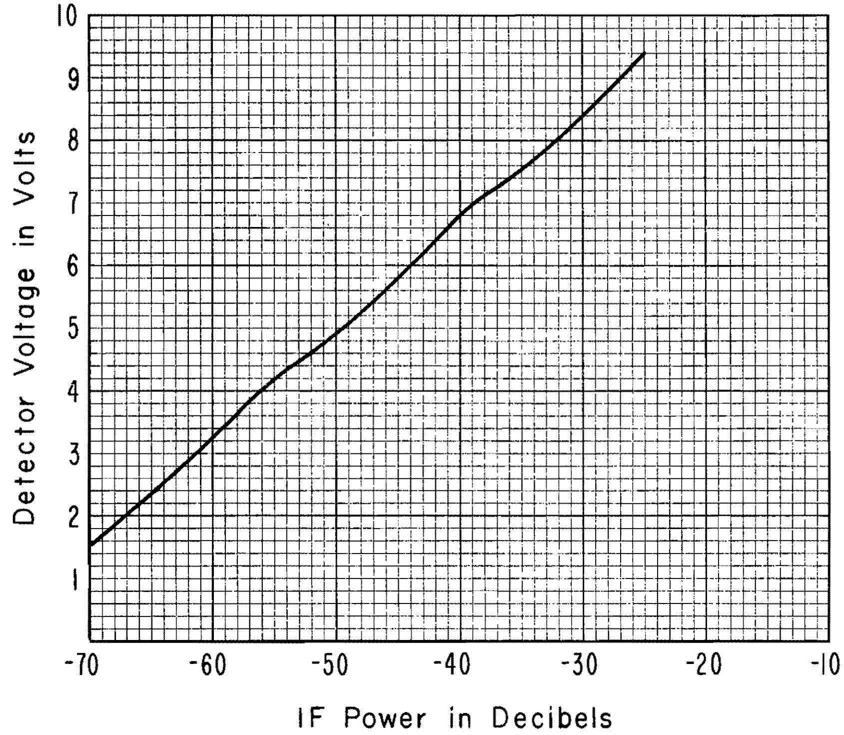


Figure 13. Log linear IF amplifier (70 MHz) dynamic range

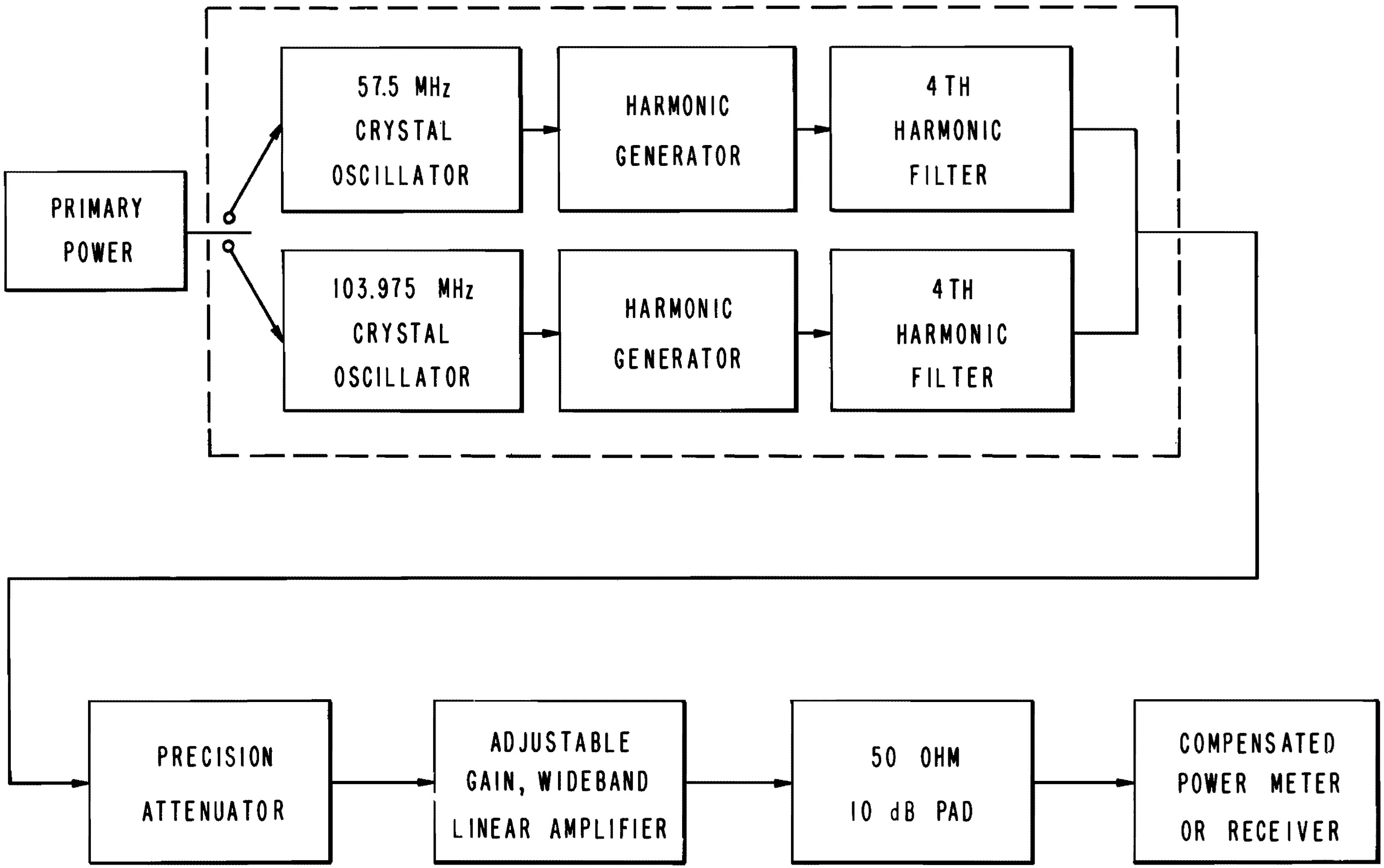


Figure 14. Signal generator block diagram

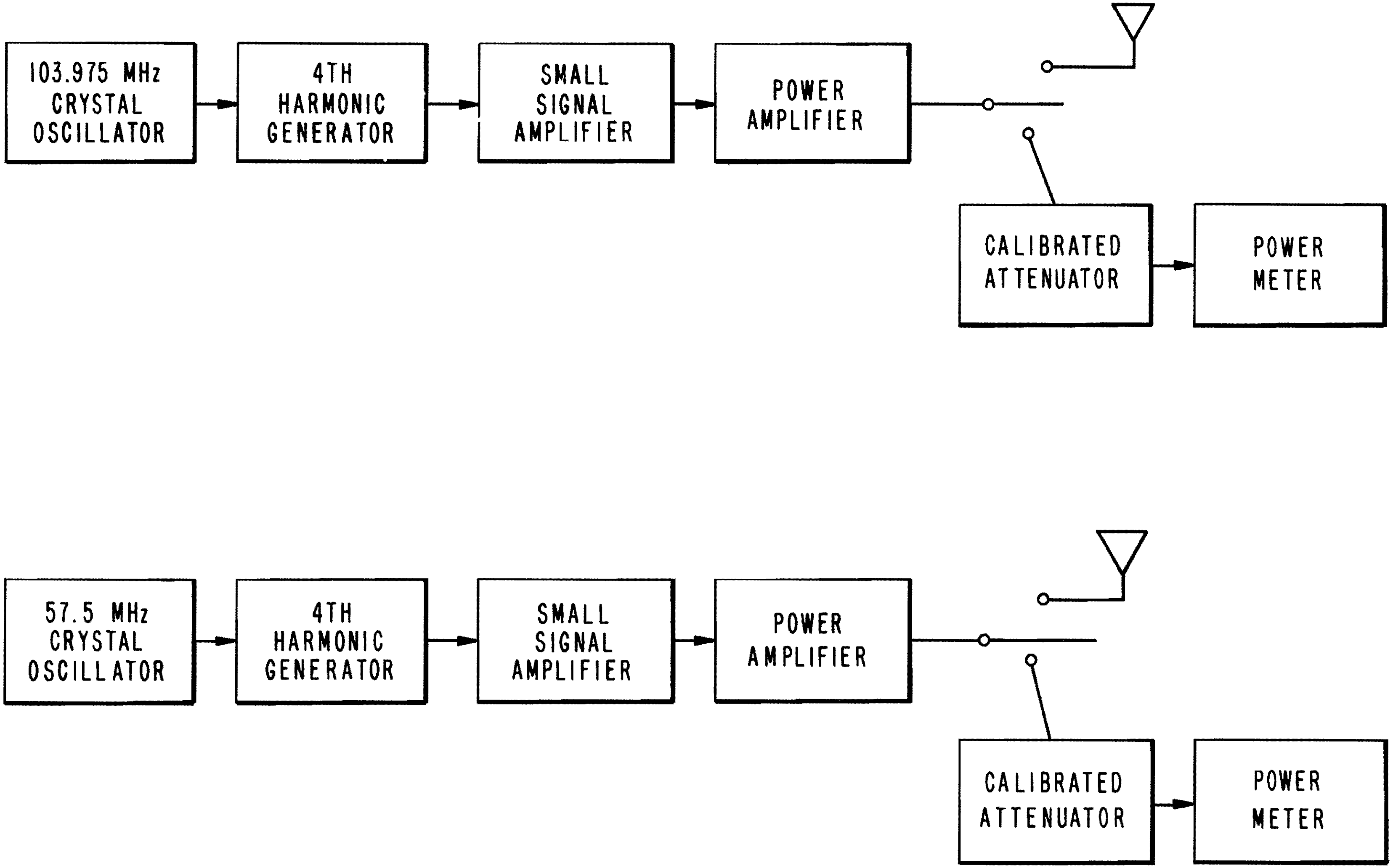
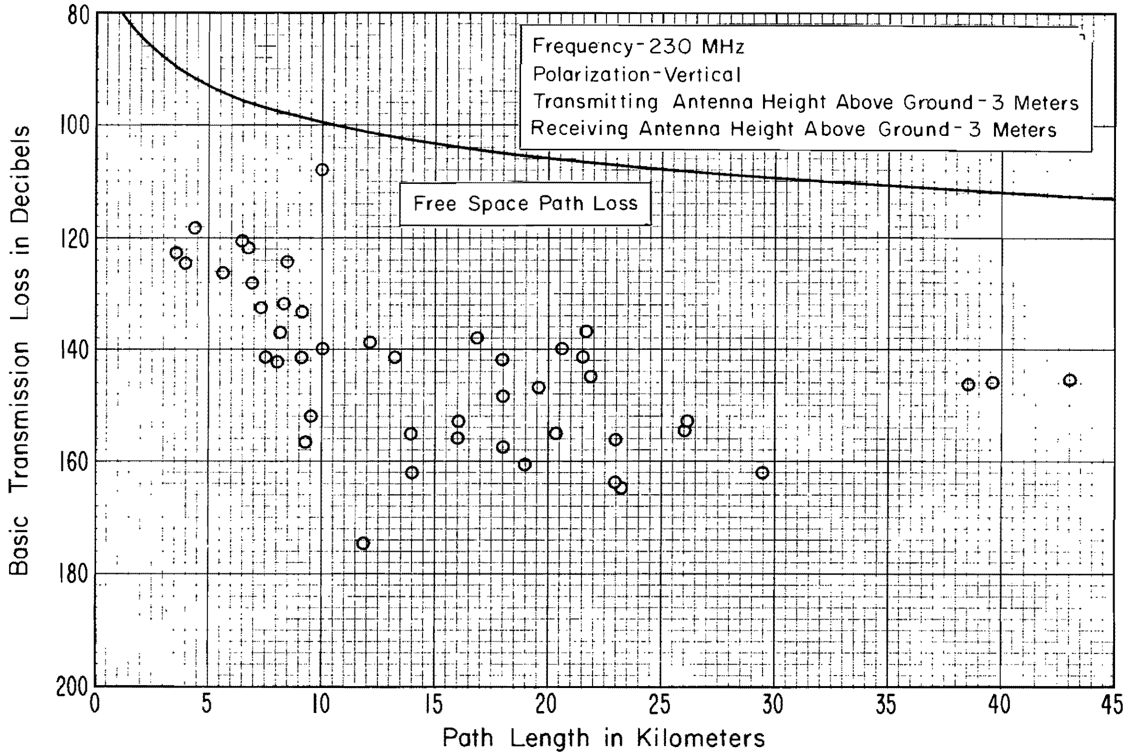


Figure 15. Transmitter block diagram



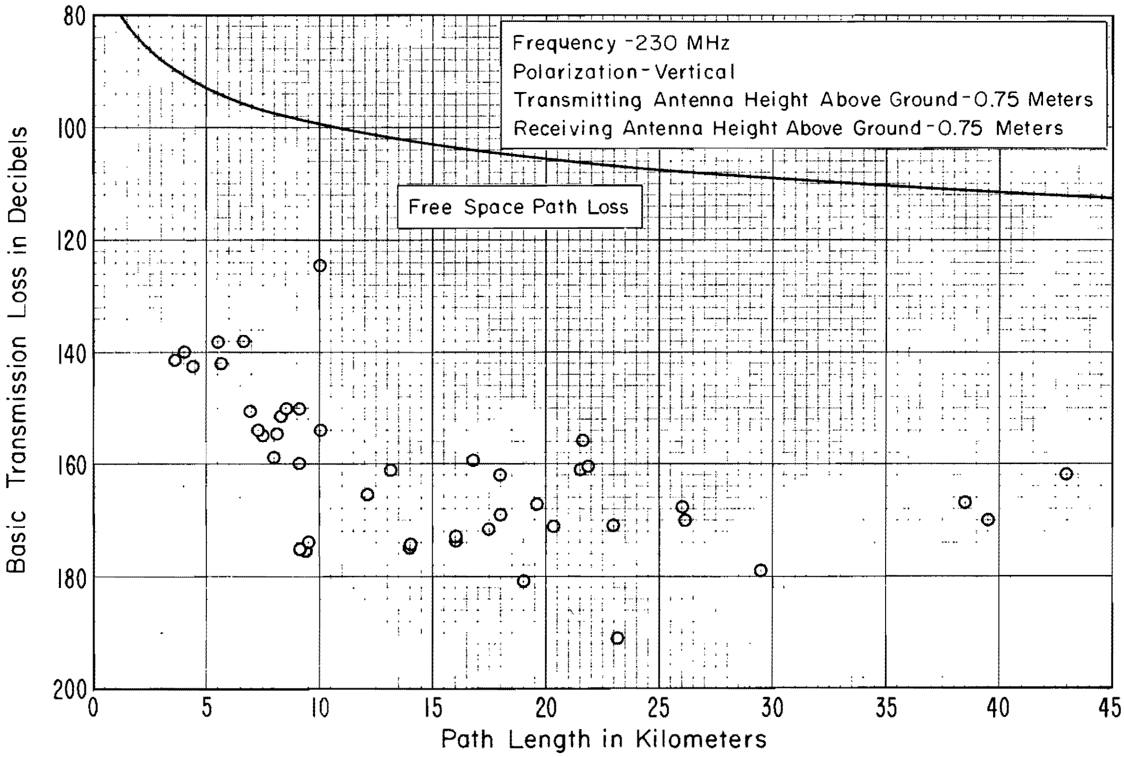
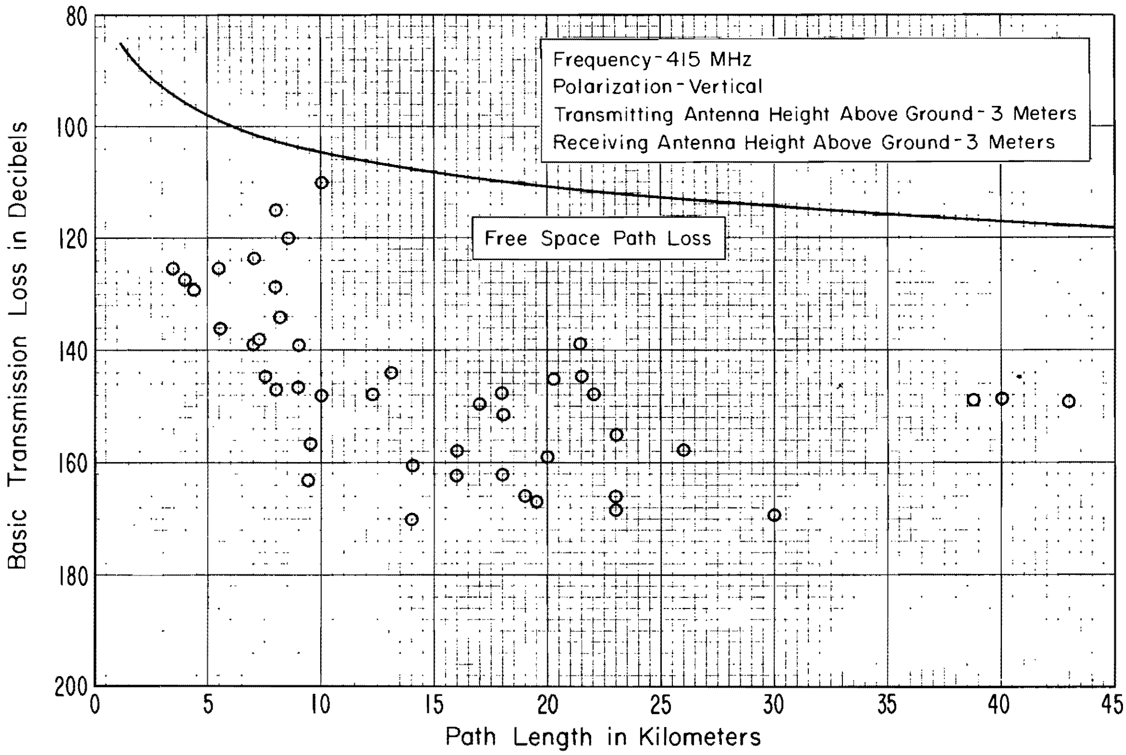


Figure 16. Wyoming area radio path loss at 230 MHz



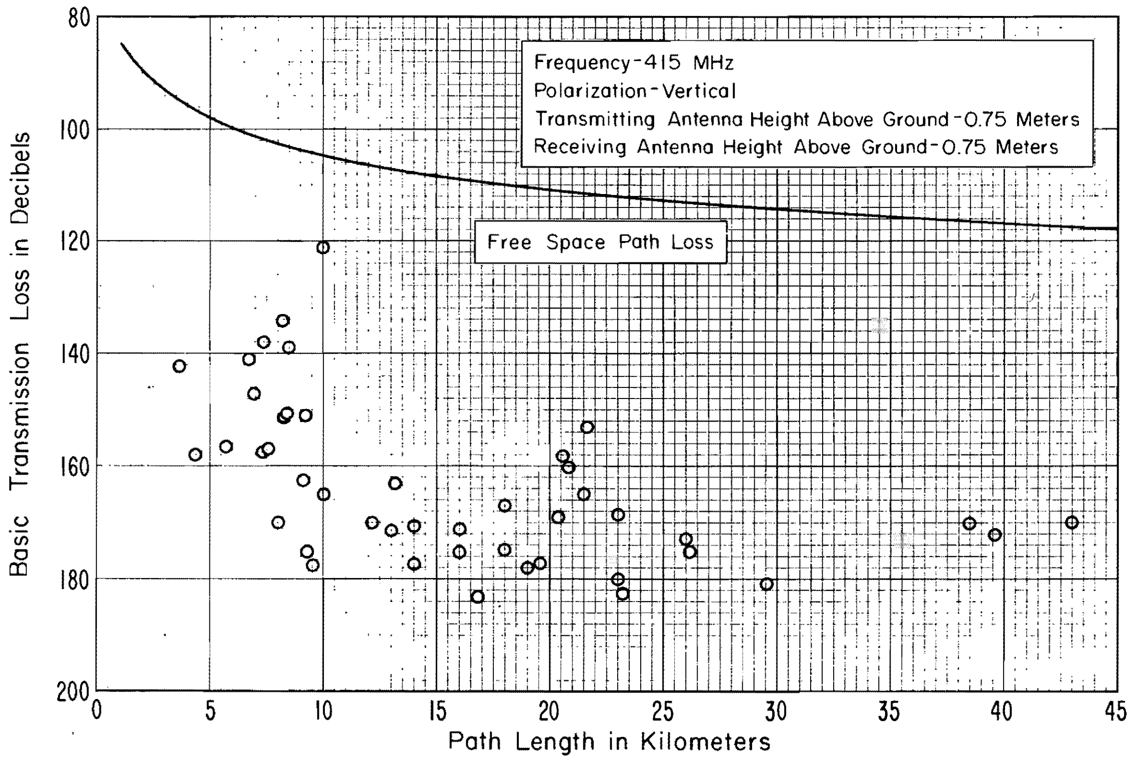
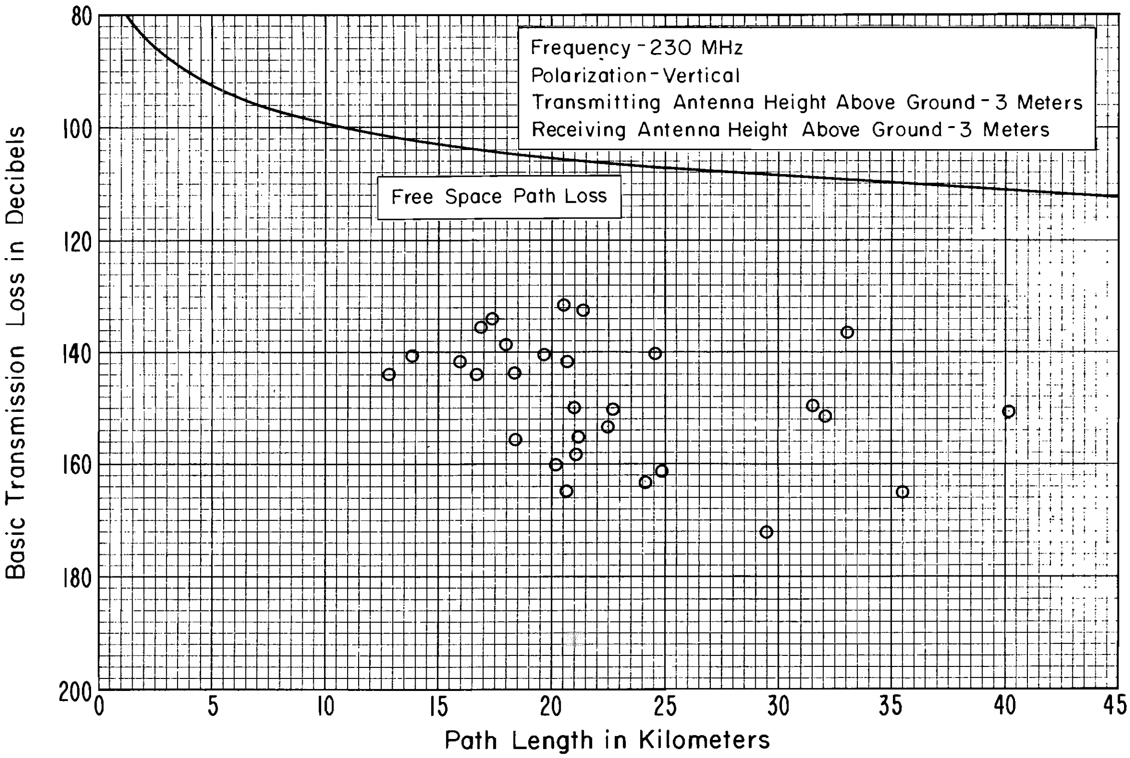


Figure 17. Wyoming area radio path loss at 415.9 MHz



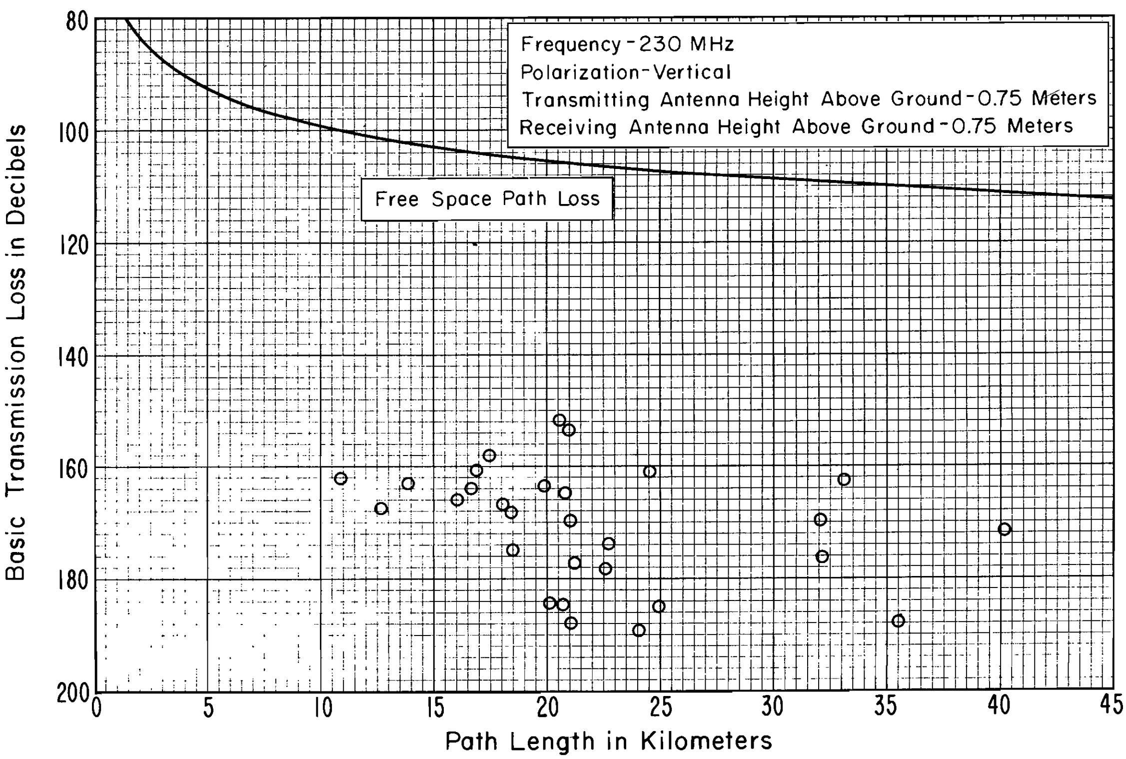
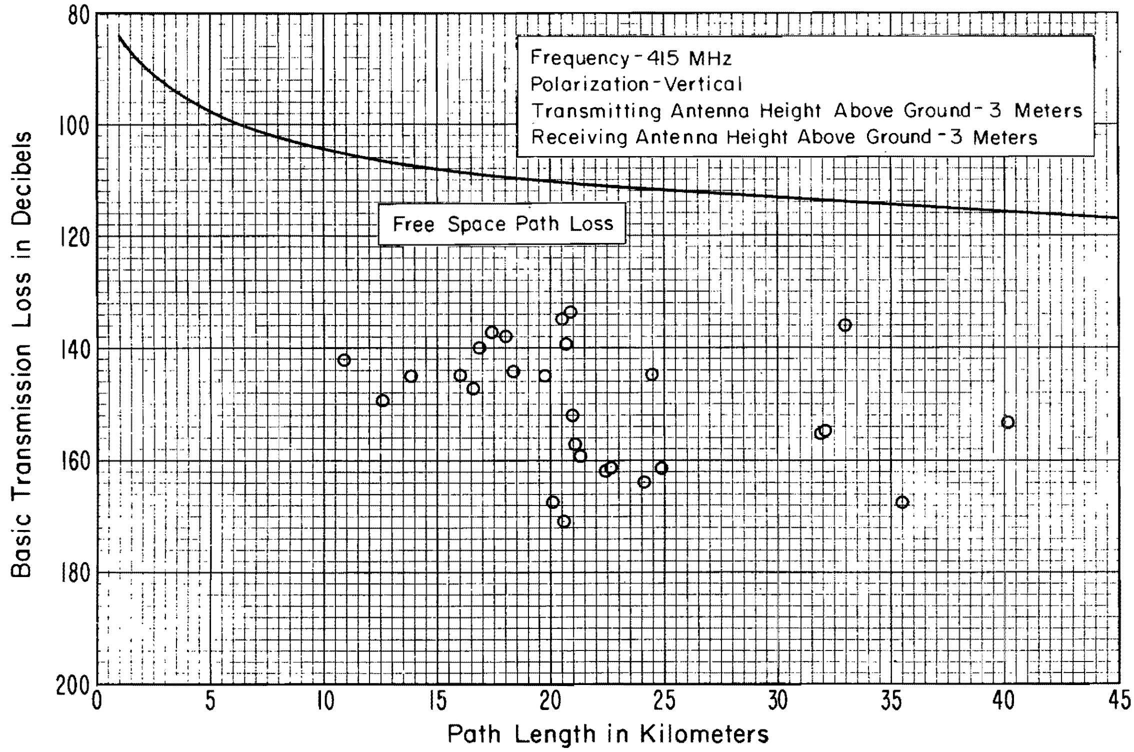


Figure 18. Idaho area radio path loss at 230 MHz



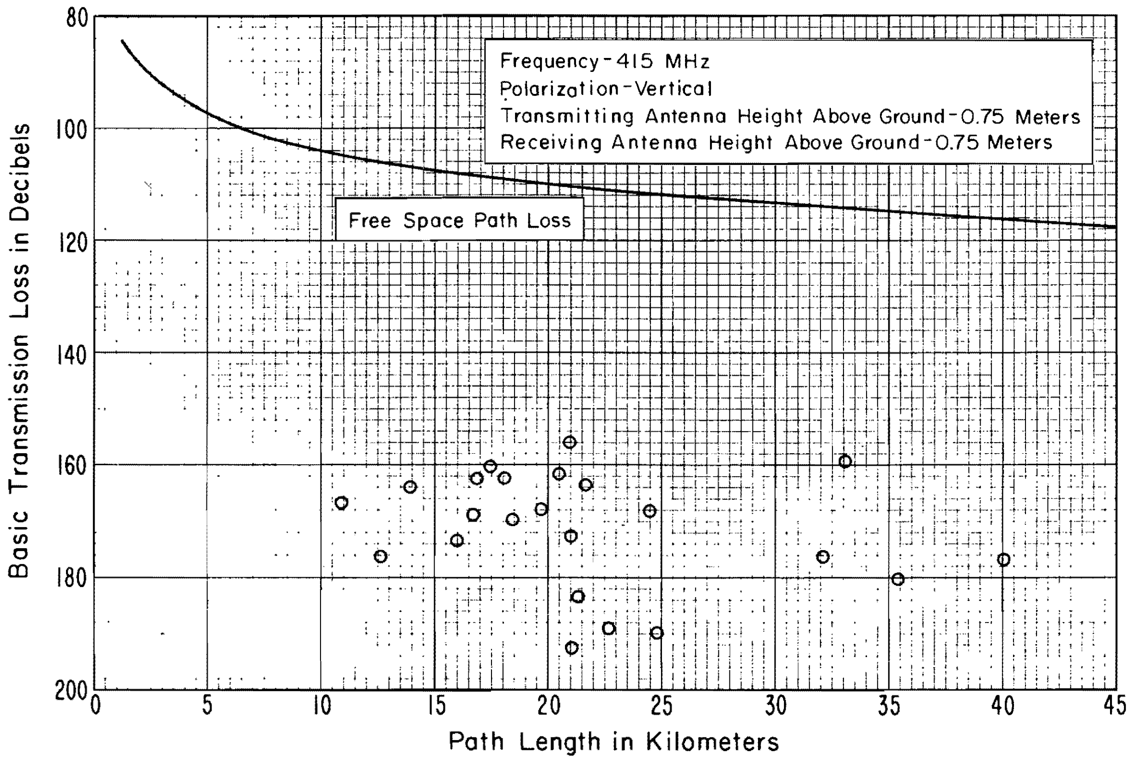
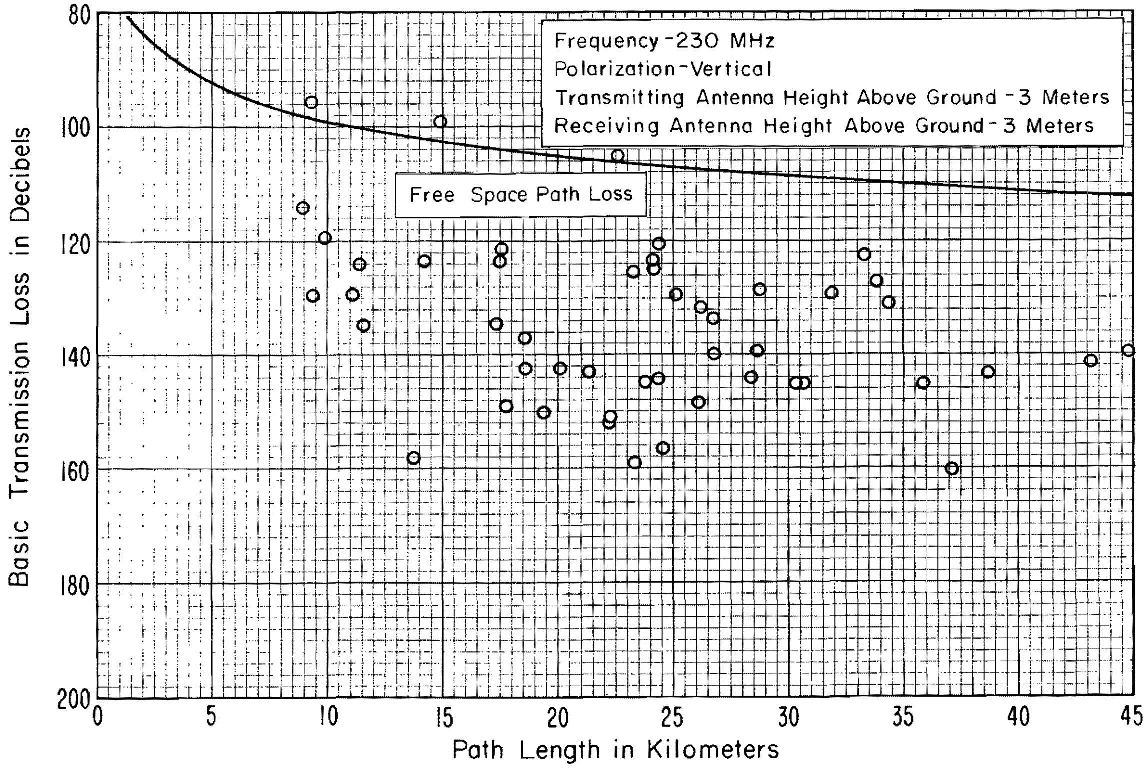


Figure 19. Idaho area radio path loss at 415.9 MHz



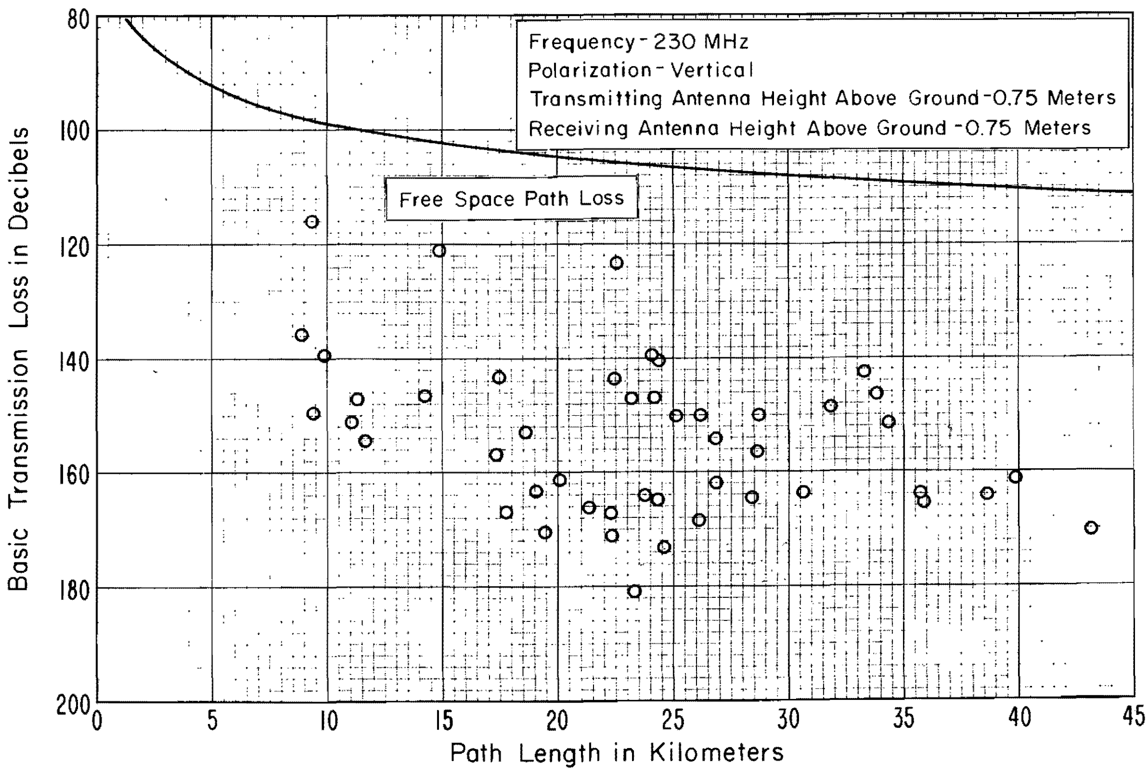
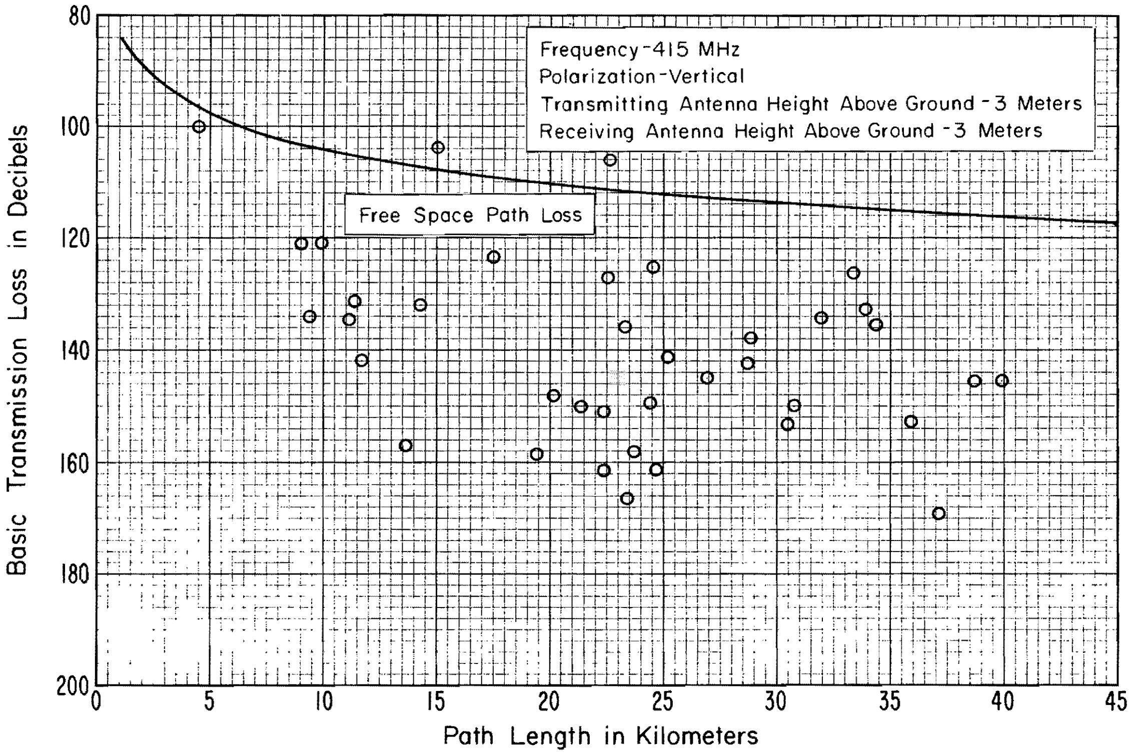


Figure 20. Washington area (Ritzville and Soap Lake) radio path loss at 230 MHz



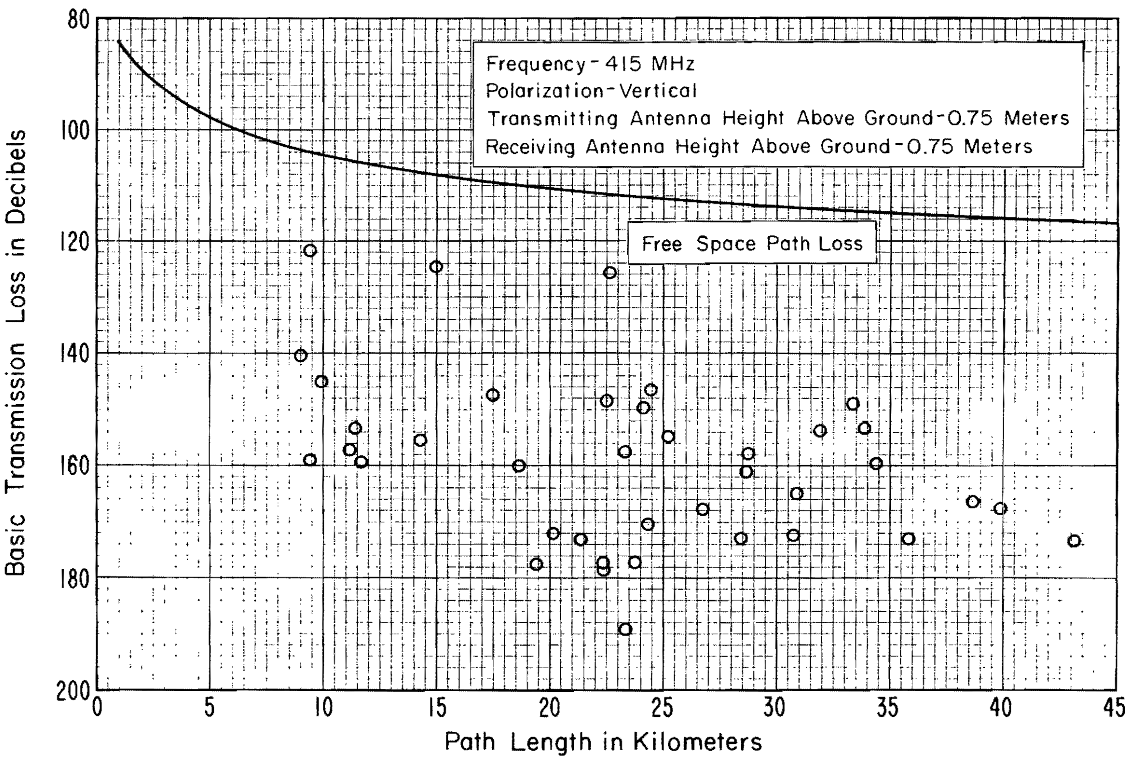
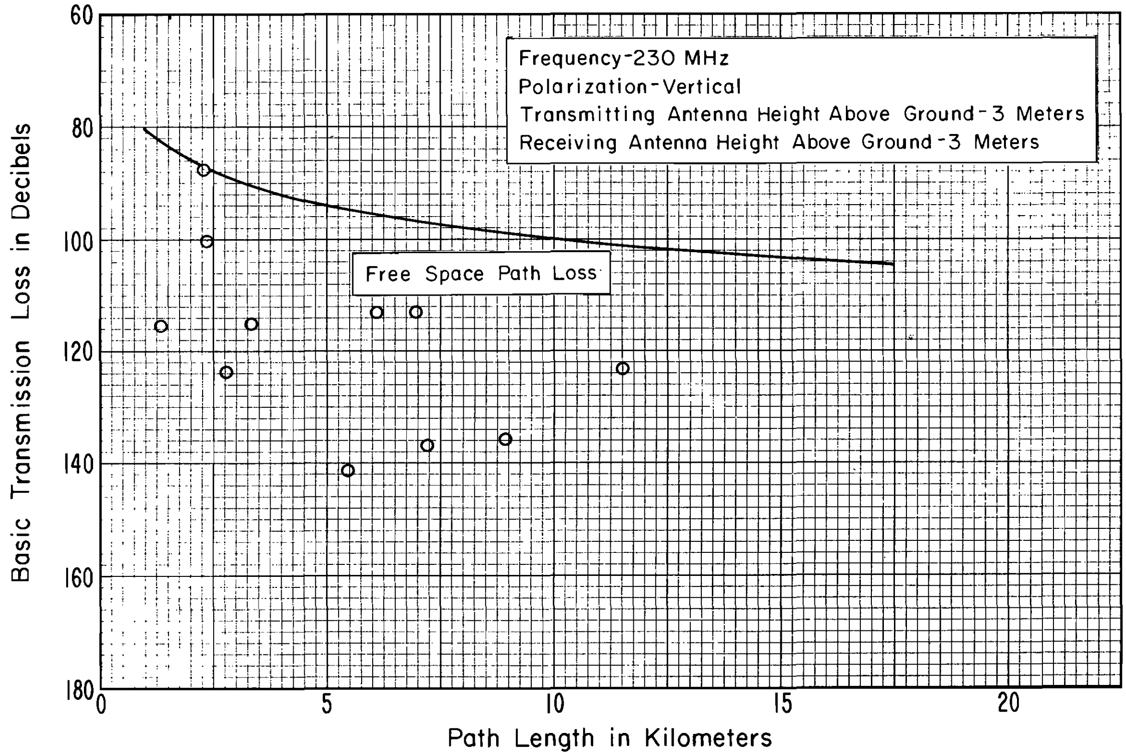


Figure 21. Washington area (Ritzville and Soap Lake) radio path loss at 415.9 MHz



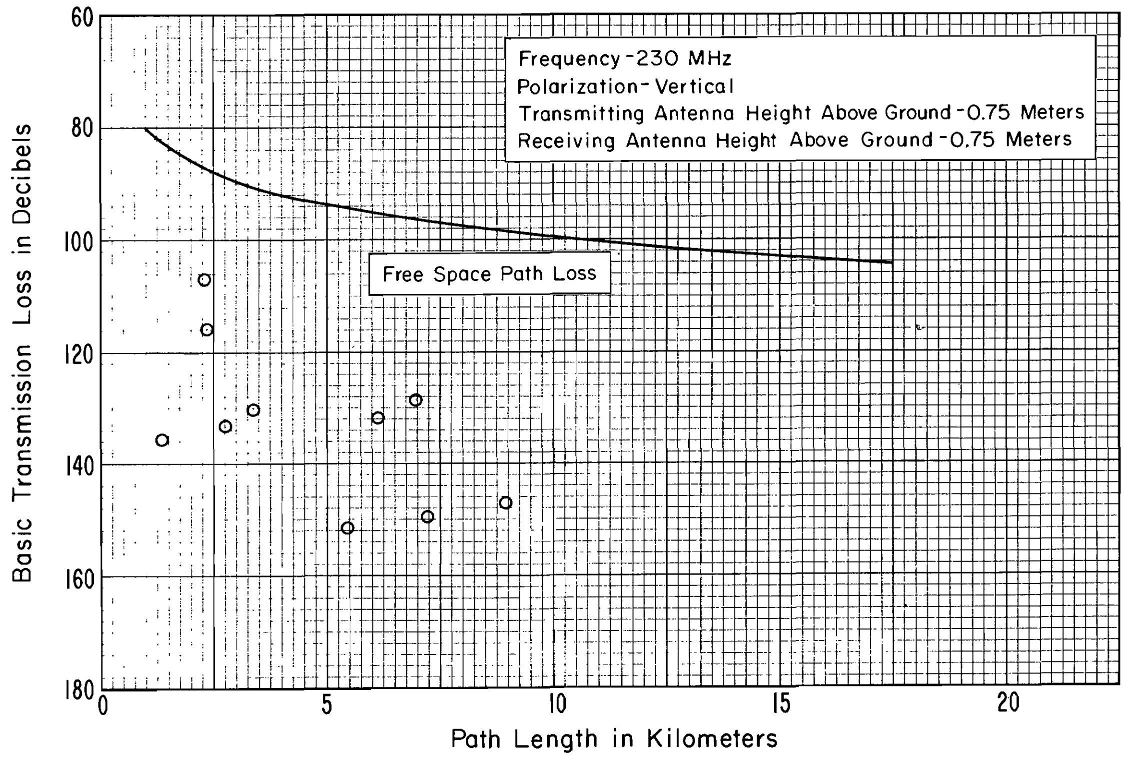
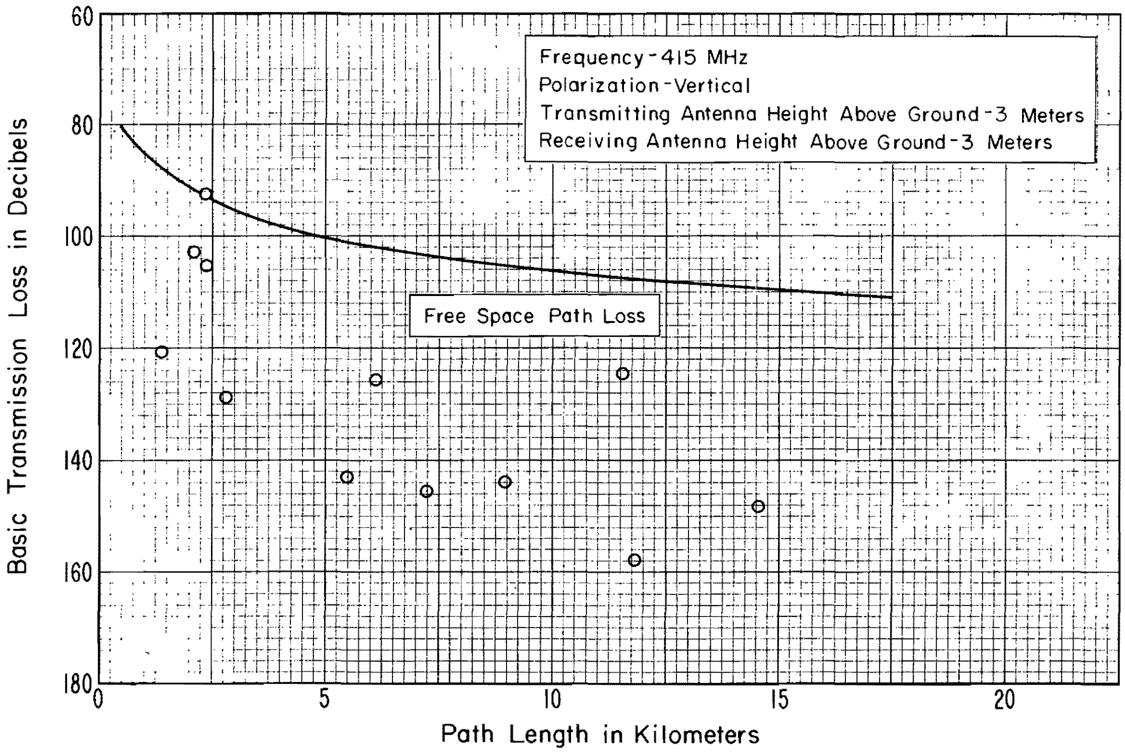


Figure 22. Washington area (Fort Spokane) radio path loss at 230 MHz



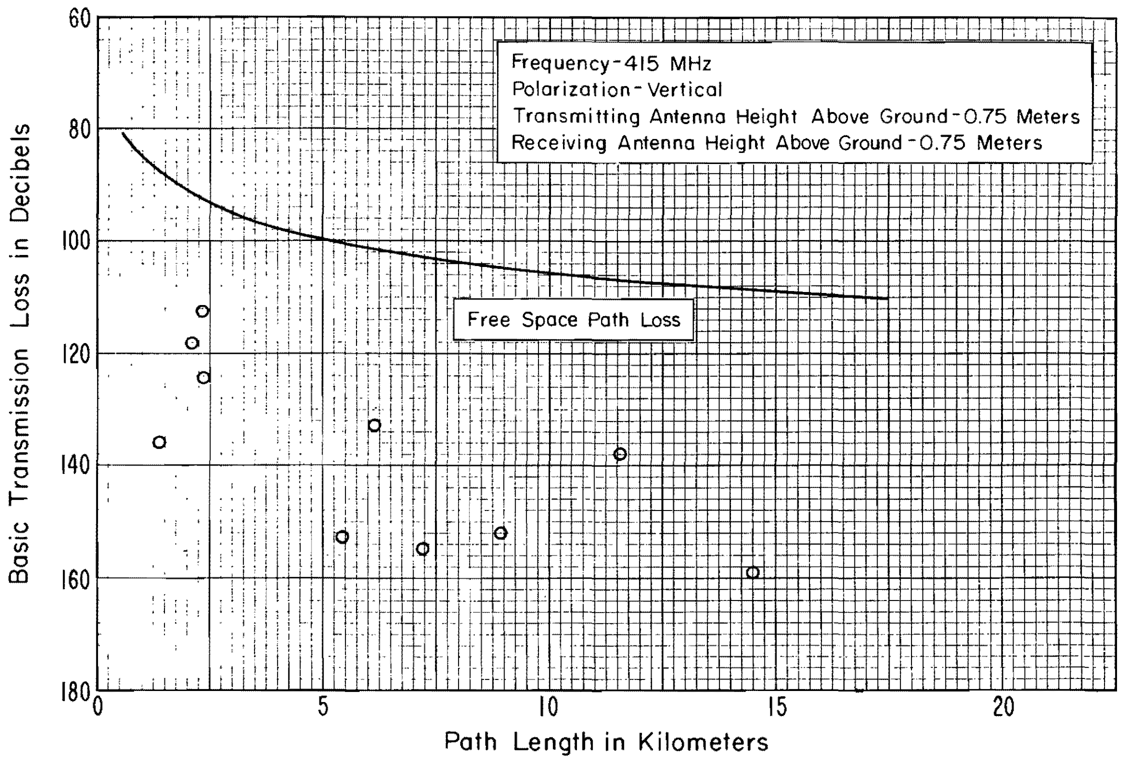


Figure 23. Washington area (Fort Spokane) radio path loss at 415.9 MHz

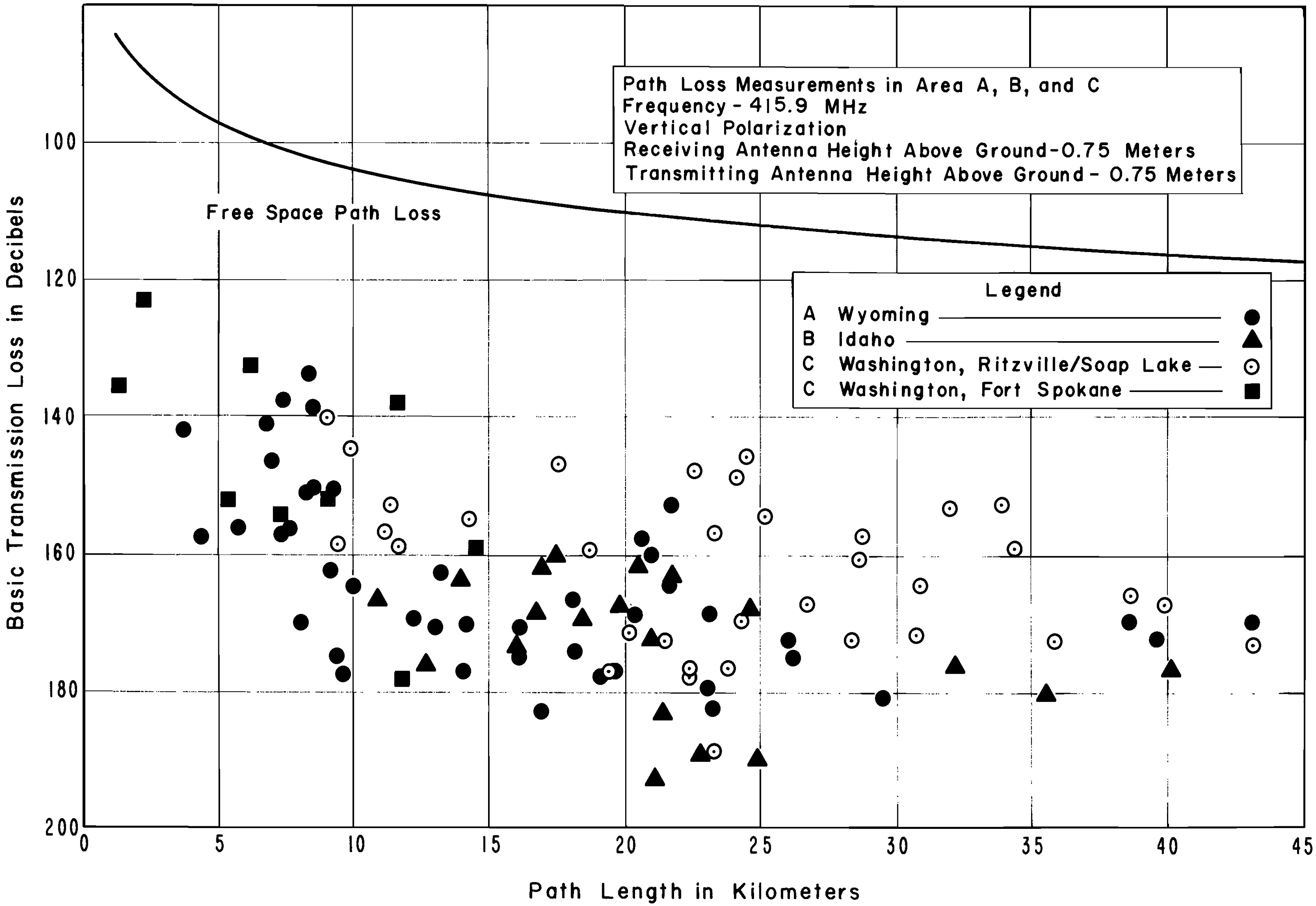


Figure 24. Basic transmission loss for all non line-of-site paths.

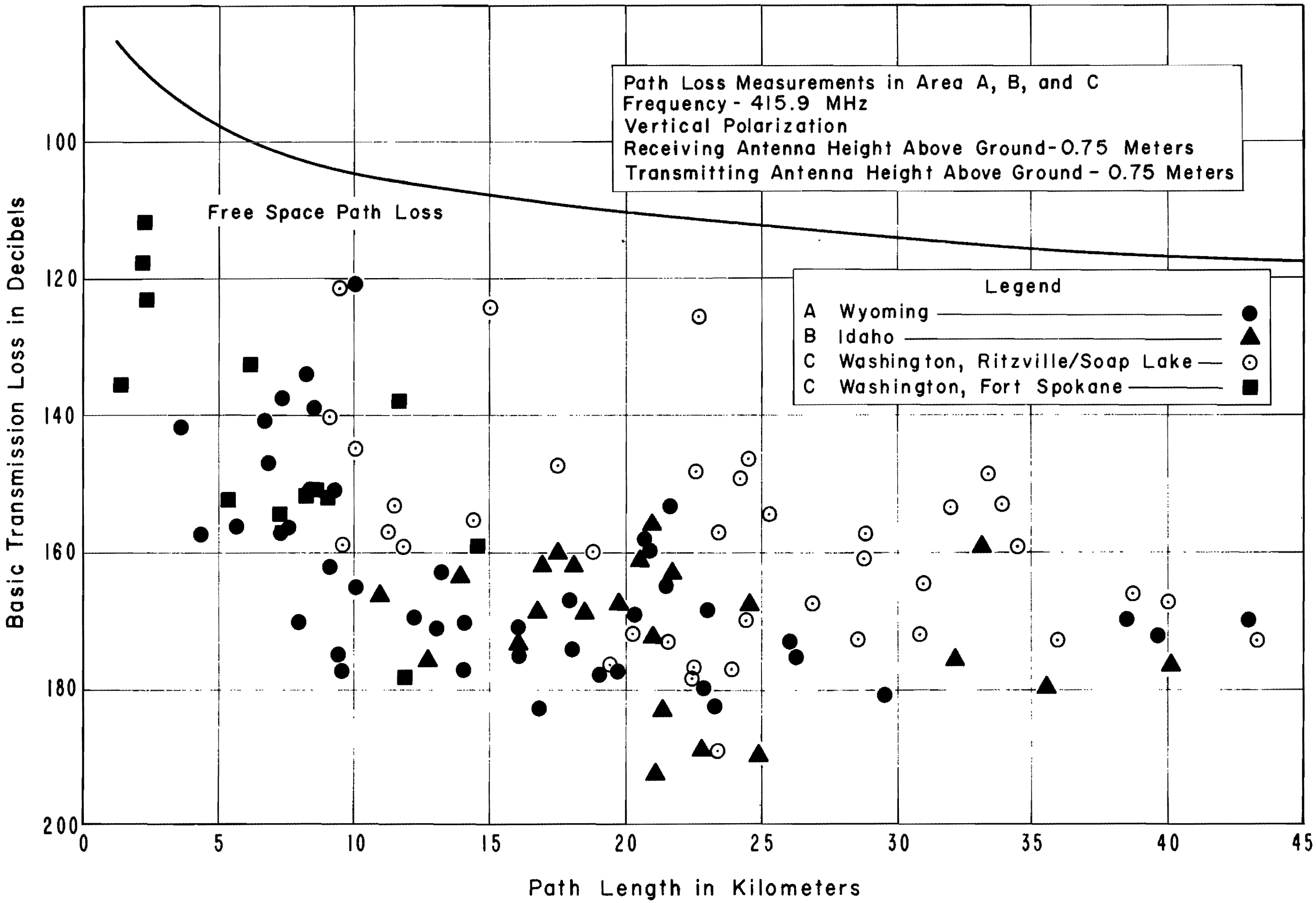


Figure 25. Basic transmission loss for all paths.

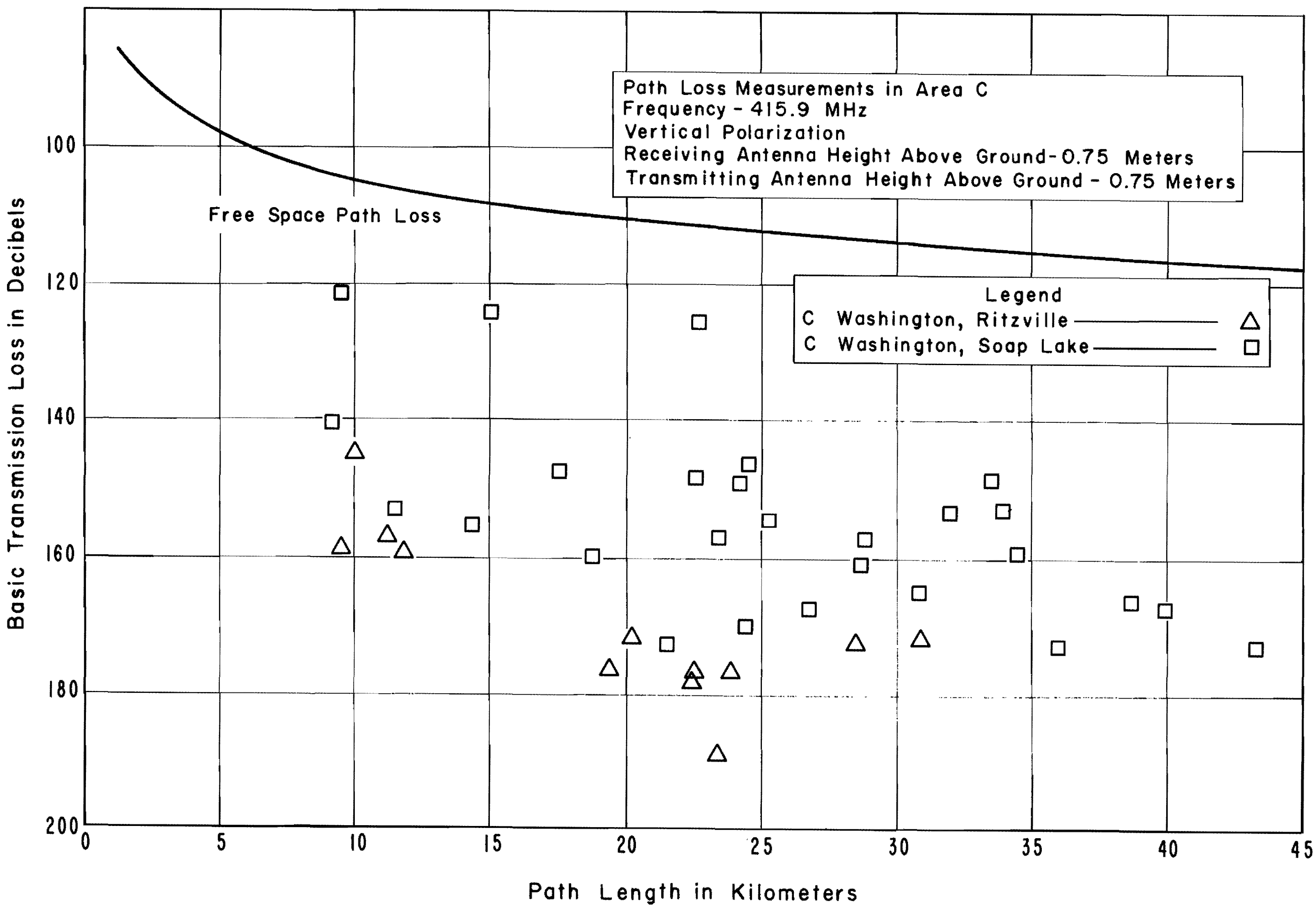


Figure 26. Basic transmission loss Washington intra-area comparison

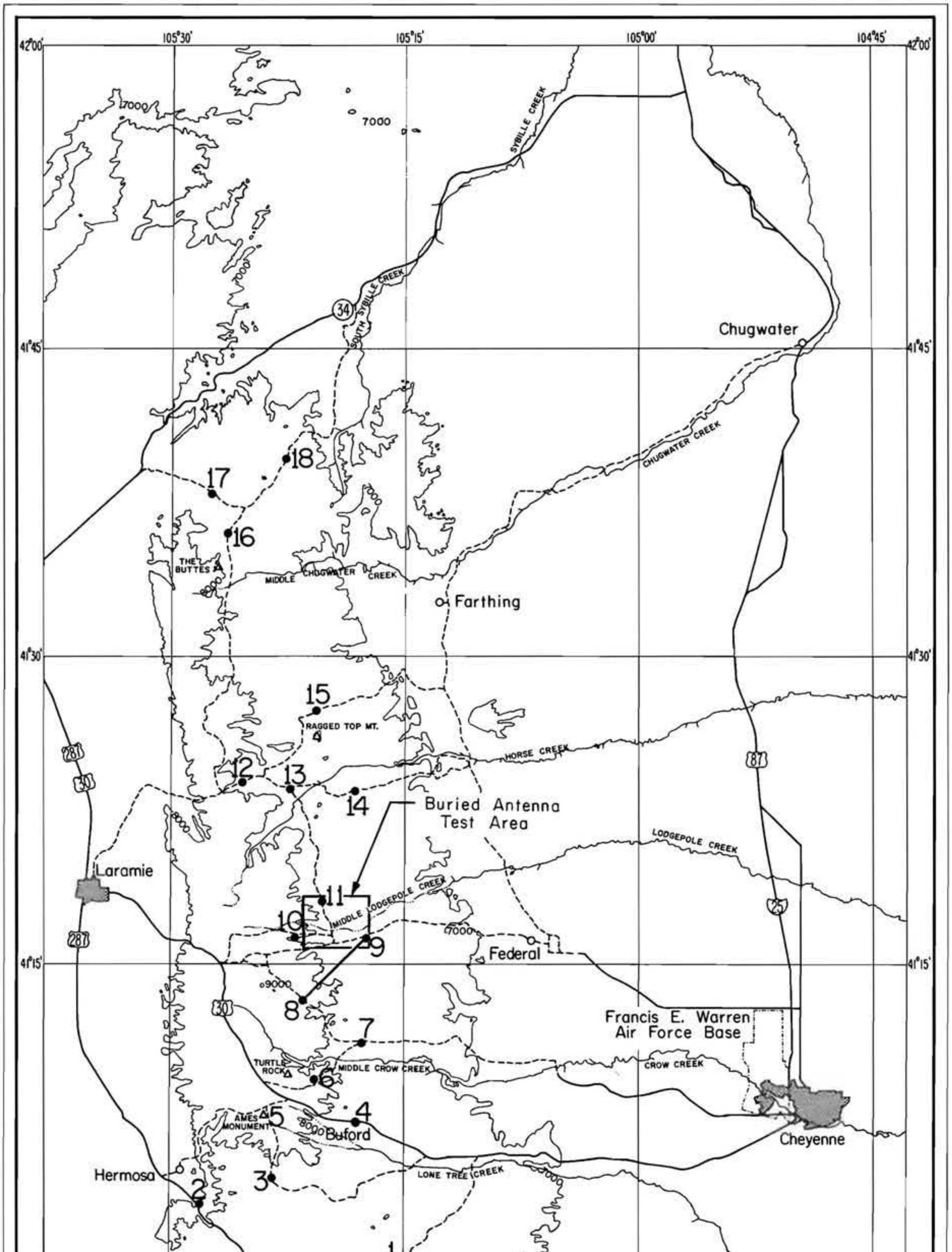
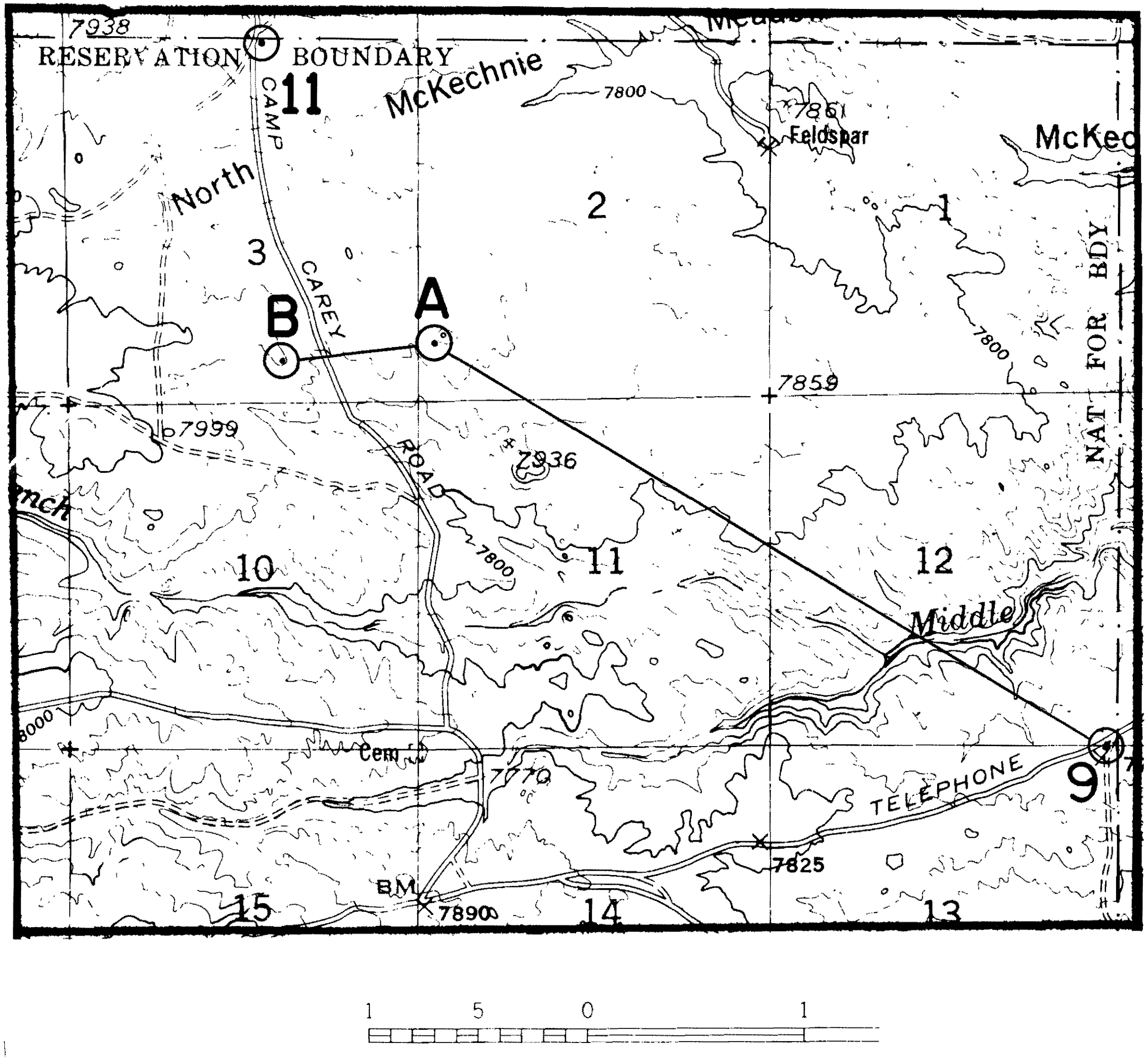


Figure 27. Southern Wyoming area.



Kilometers

Figure 28. Buried antenna test area.

Figure 29. Site B with site A in the background.

Figure 30. Site A during test 2.

Figure 31. Site B as observed from site A.

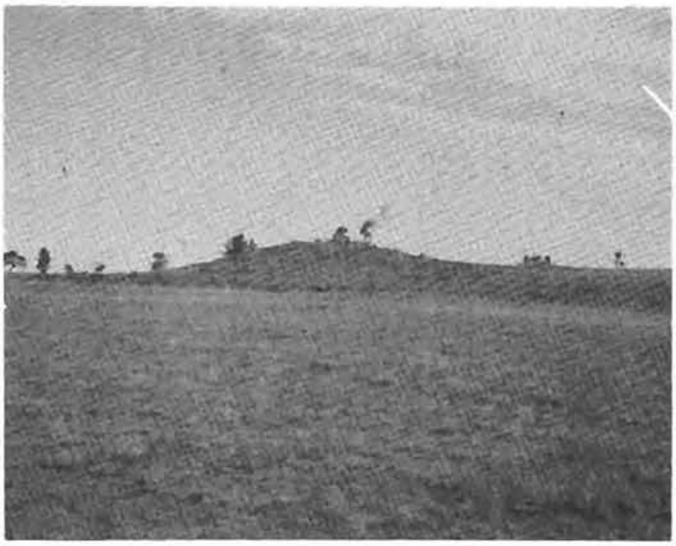


Figure 32. Site B with the camera pointing North.

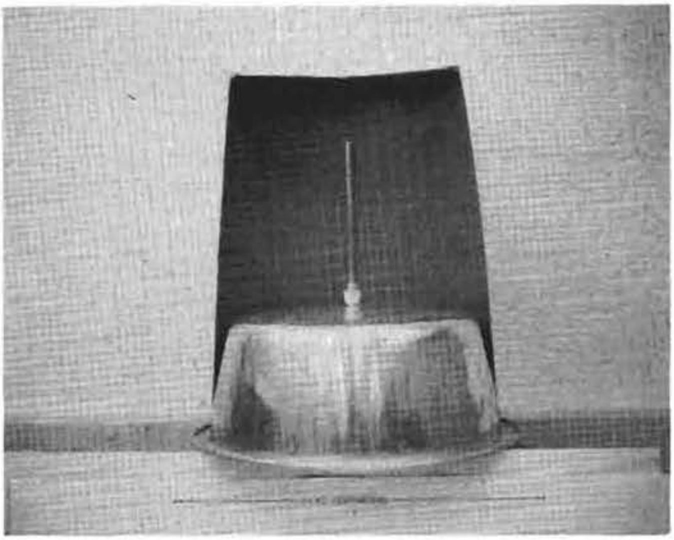


Figure 33. Protective cavity used during tests 4, 5, and 6.

Figure 34. Site A prepared for test 7 with the antenna at ground level.

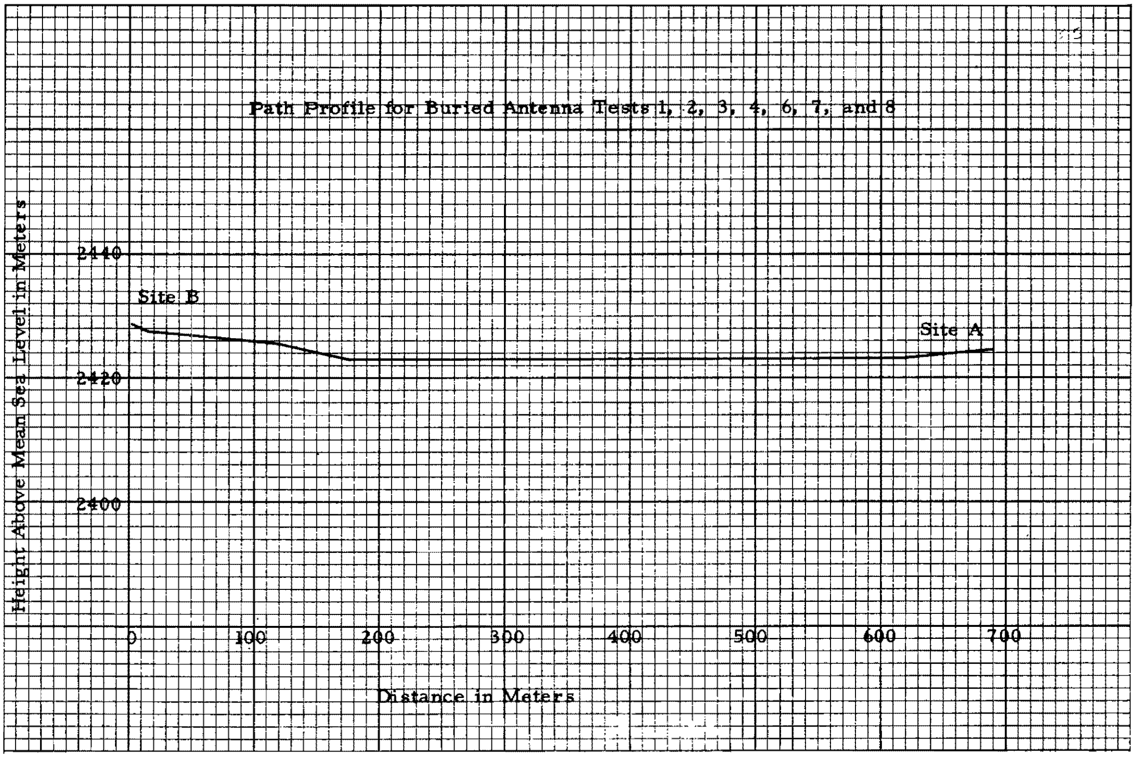


Figure 35. Path profile for buried antenna tests 1, 2, 3, 4, 6, 7, and 8.

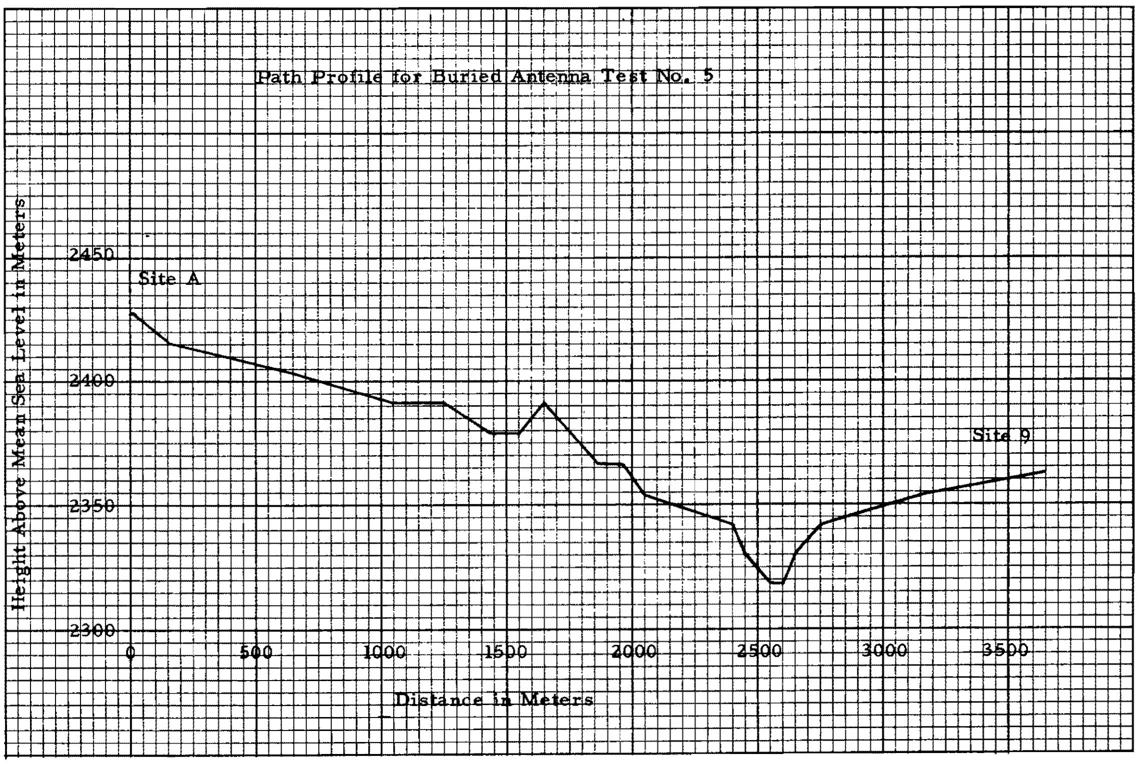


Figure 36. Path profile for buried antenna test 5.

Figure 37. Site A UHF test hole.

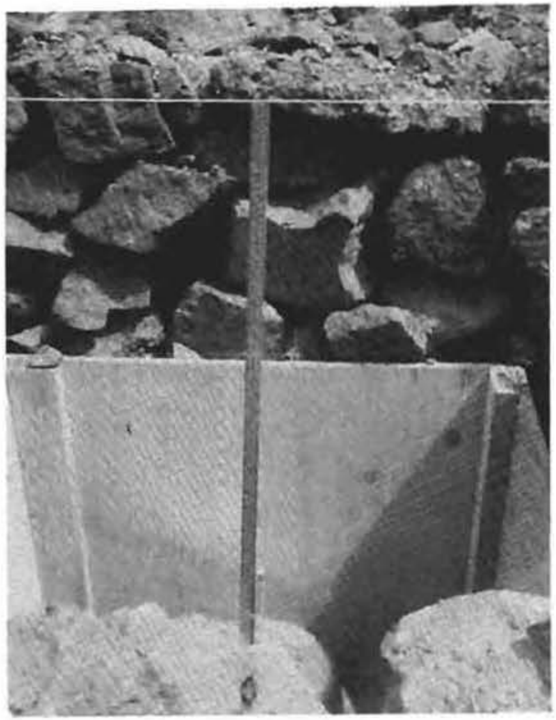


Figure 38. Site B UHF test hole.

Figure 39. Site A prepared for test 1.

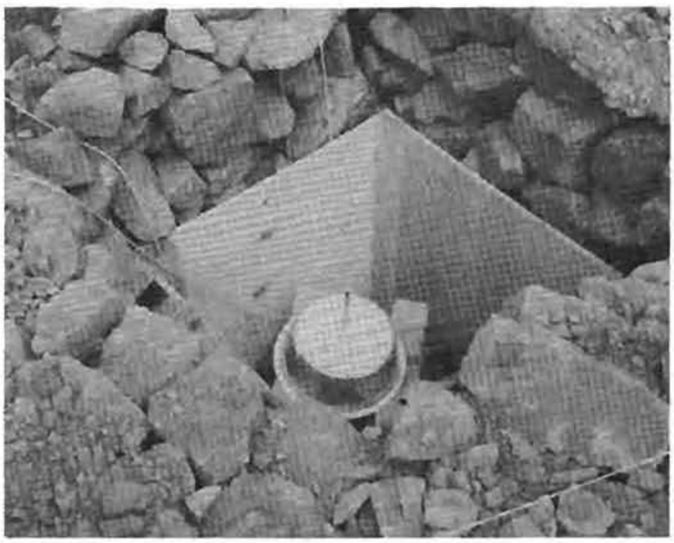


Figure 40. Site B prepared for test 3.

Figure 41. Site A prepared for tests 4, 5, and 6.

Figure 42. Site B prepared for test 6.

Figure 43. Site A, test 7. The antenna is covered by 0.2 m of broken rock.

Figure 44. Site A, test 7. The antenna is covered by 0.4 m of broken rock.

Figure 45. Site A, test 7. The antenna is covered by 0.6 m of broken rock.

Figure 46. Site A, test 7. The antenna is covered by 1.0 m of broken rock.

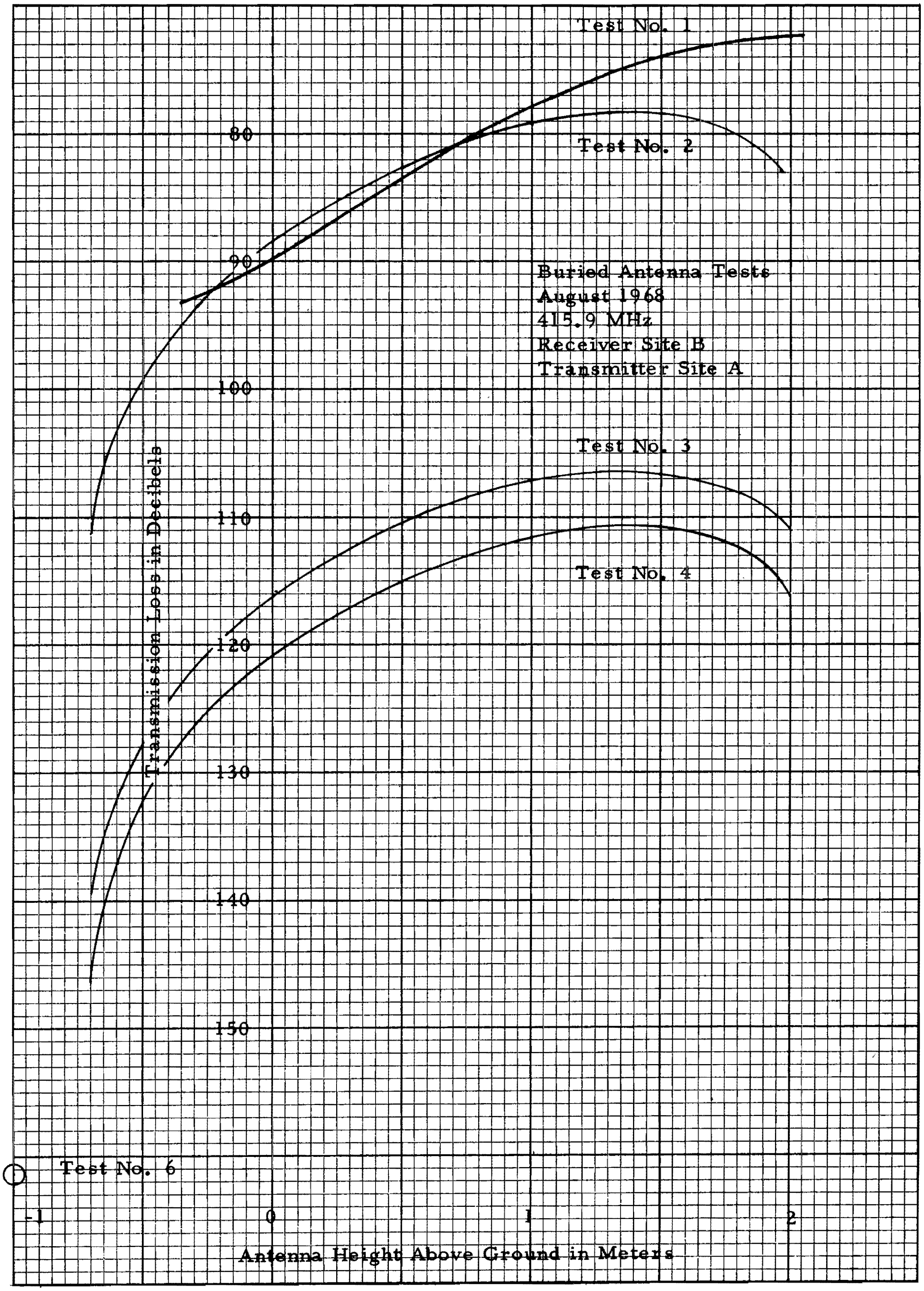


Figure 47. Buried antenna test results for tests 1, 2, 3, 4, and 6.

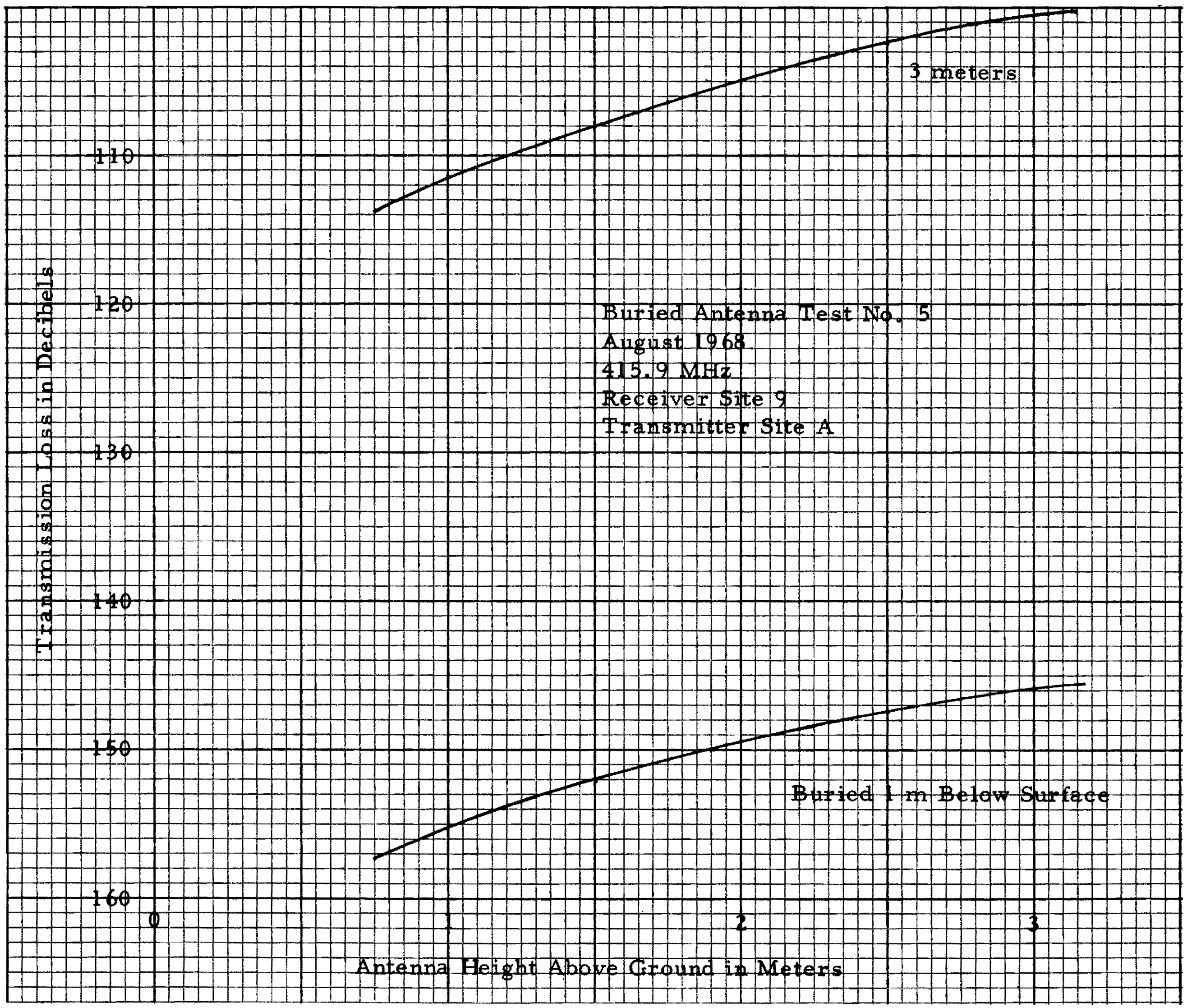


Figure 48. Buried antenna test results for test 5.

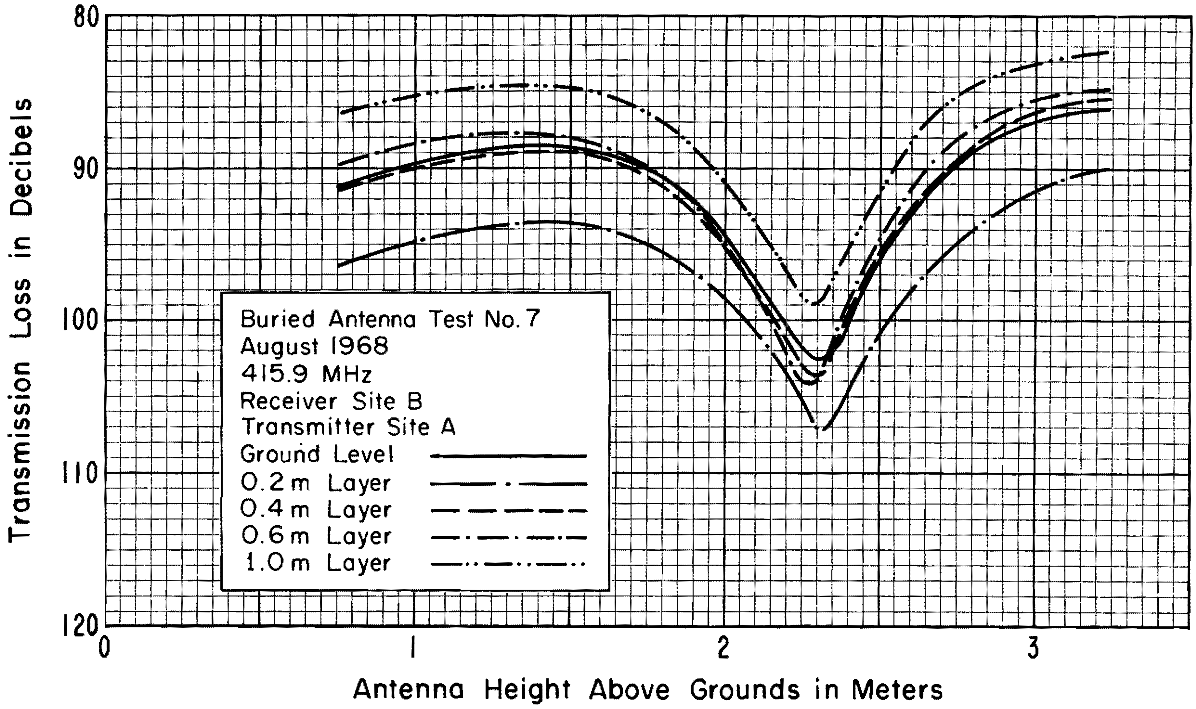


Figure 49. Buried antenna test results for test no. 7.

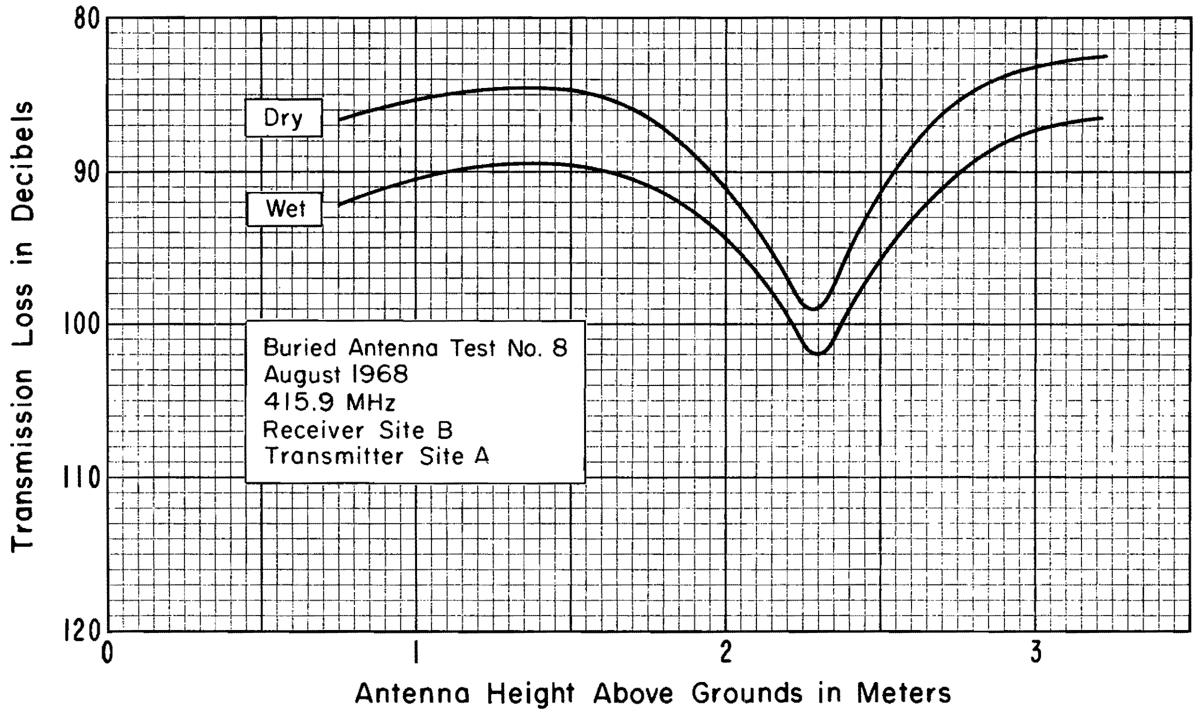


Figure 50. Buried antenna test results for test no. 8.

12. PATH PICTURES AND DATA

12. PATH PICTURES AND DATA

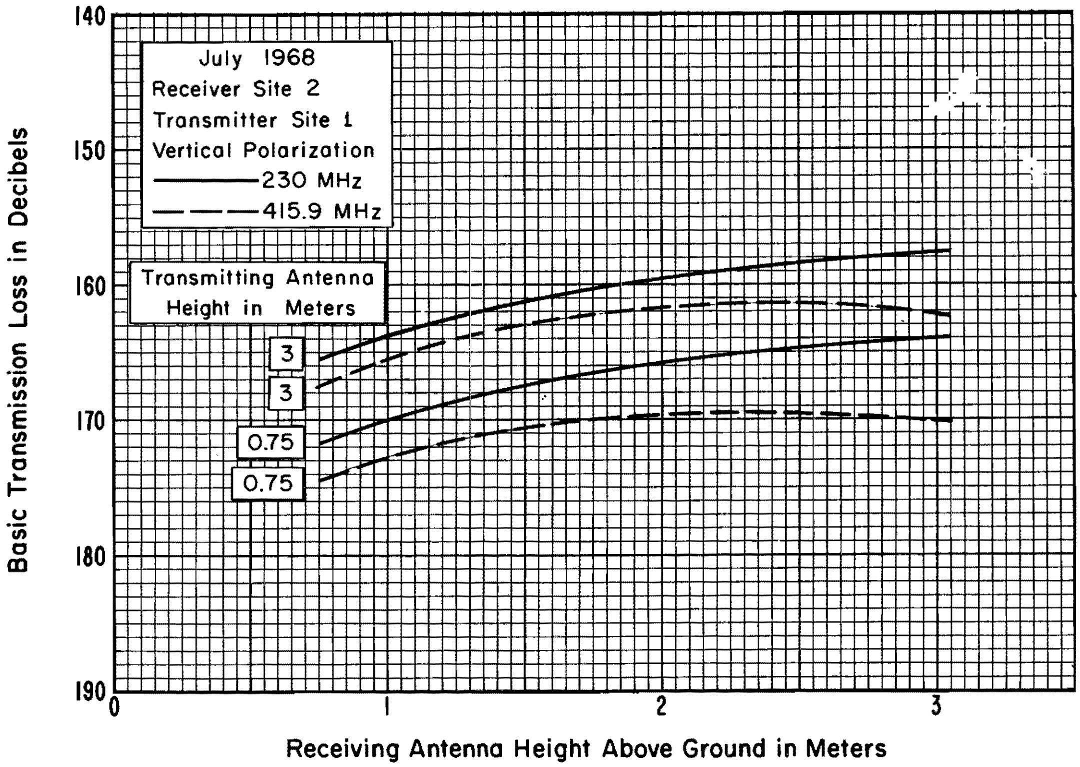
Wyoming PATH 1 - 2

From site 1 toward site 2

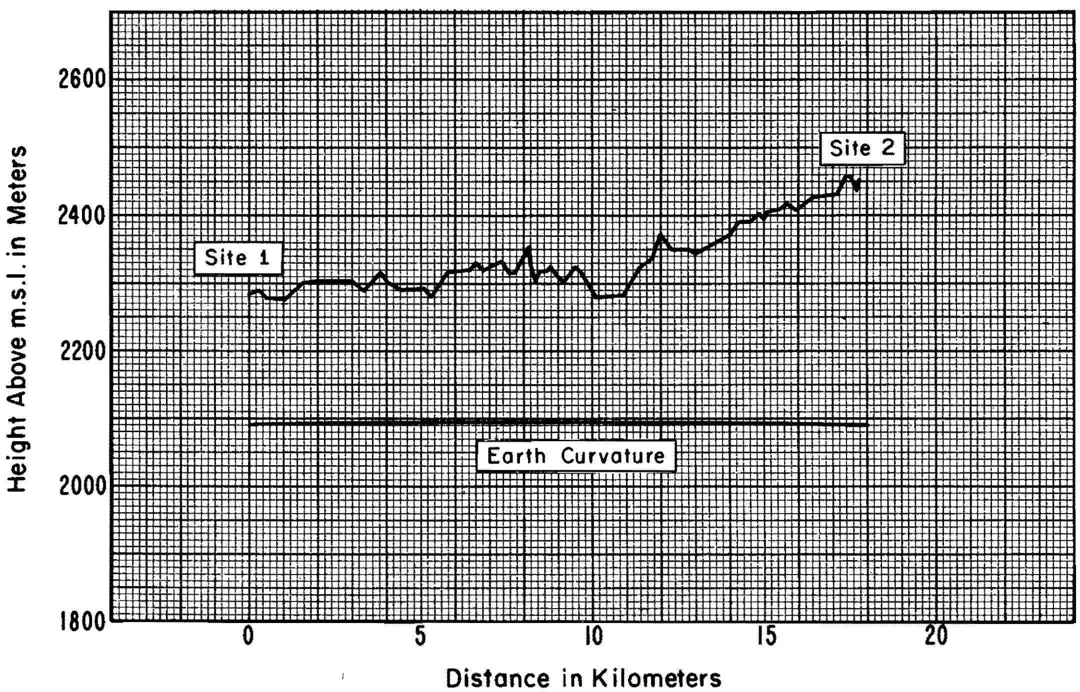
From site 2 toward site 1

WYOMING PATH 1—2

PATH LOSS MEASUREMENTS



TERRAIN PROFILE

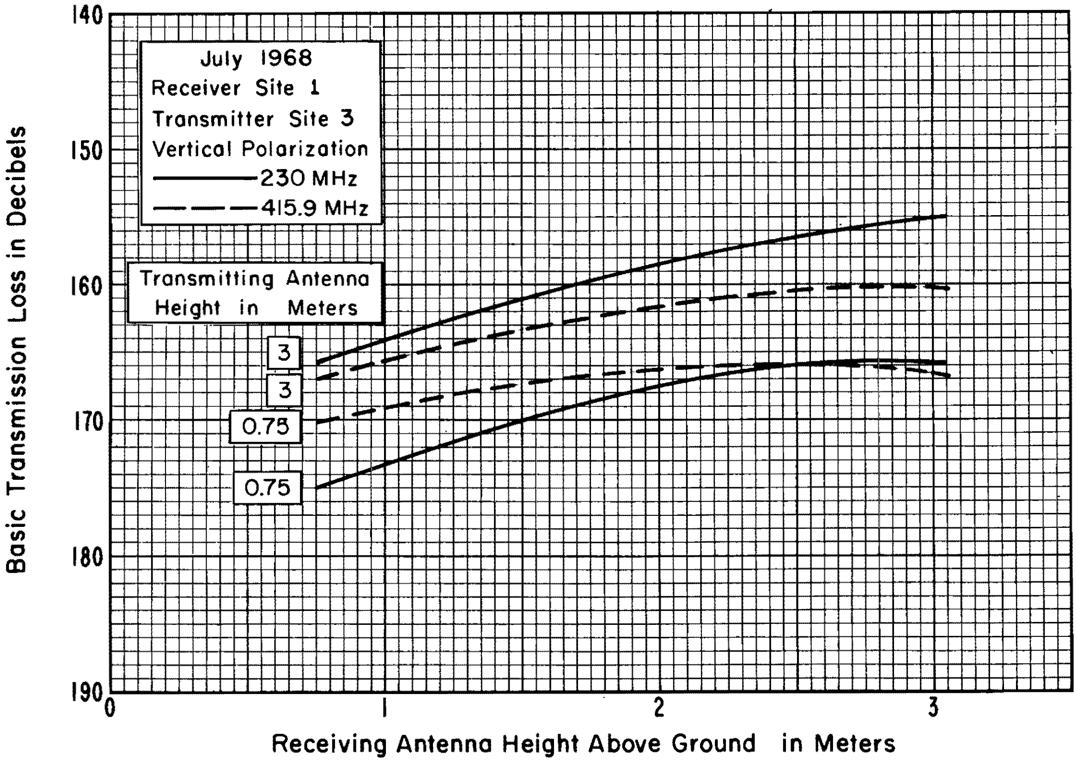


Wyoming PATH 1 - 3

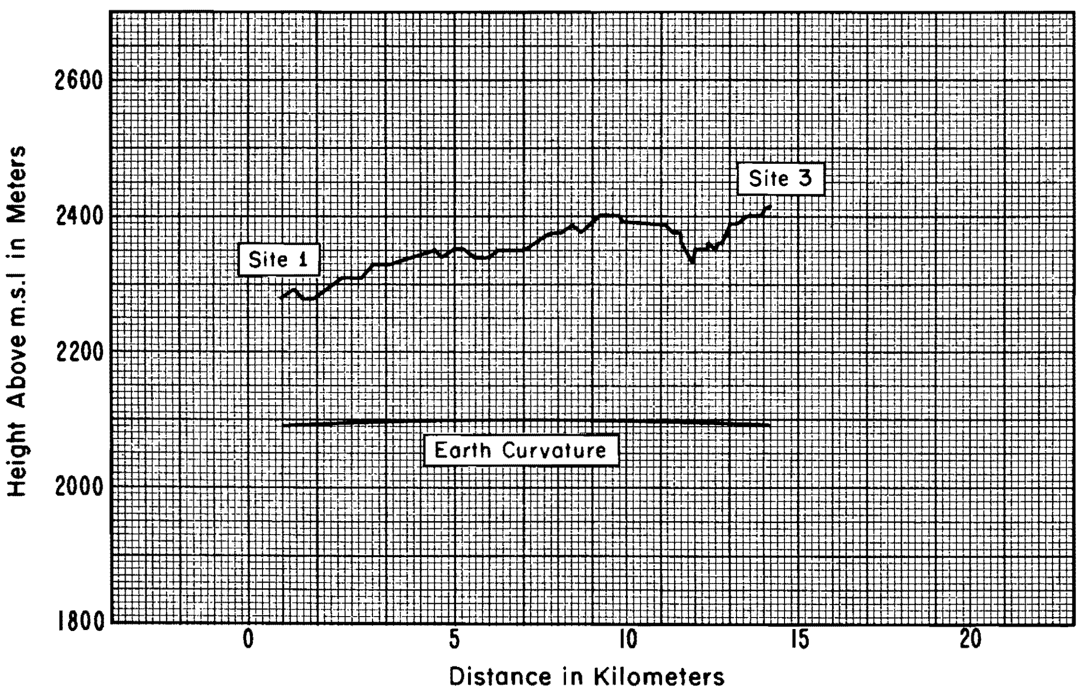
From site 1 toward site 3

From site 3 toward site 1

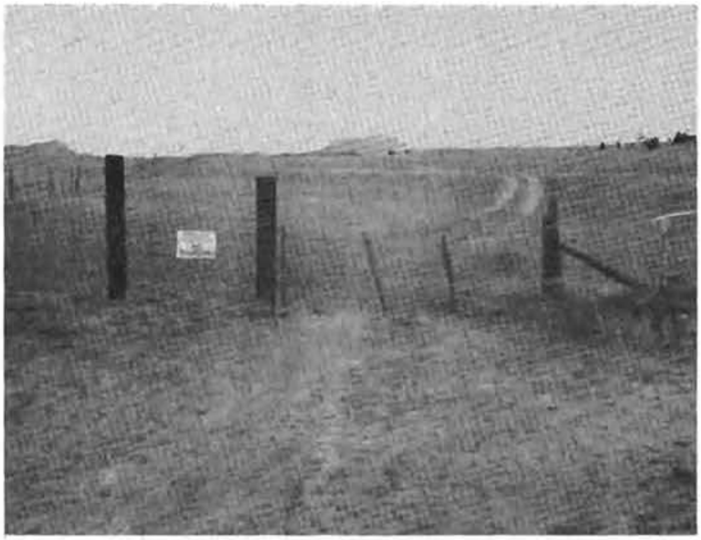
PATH LOSS MEASUREMENTS



TERRAIN PROFILE



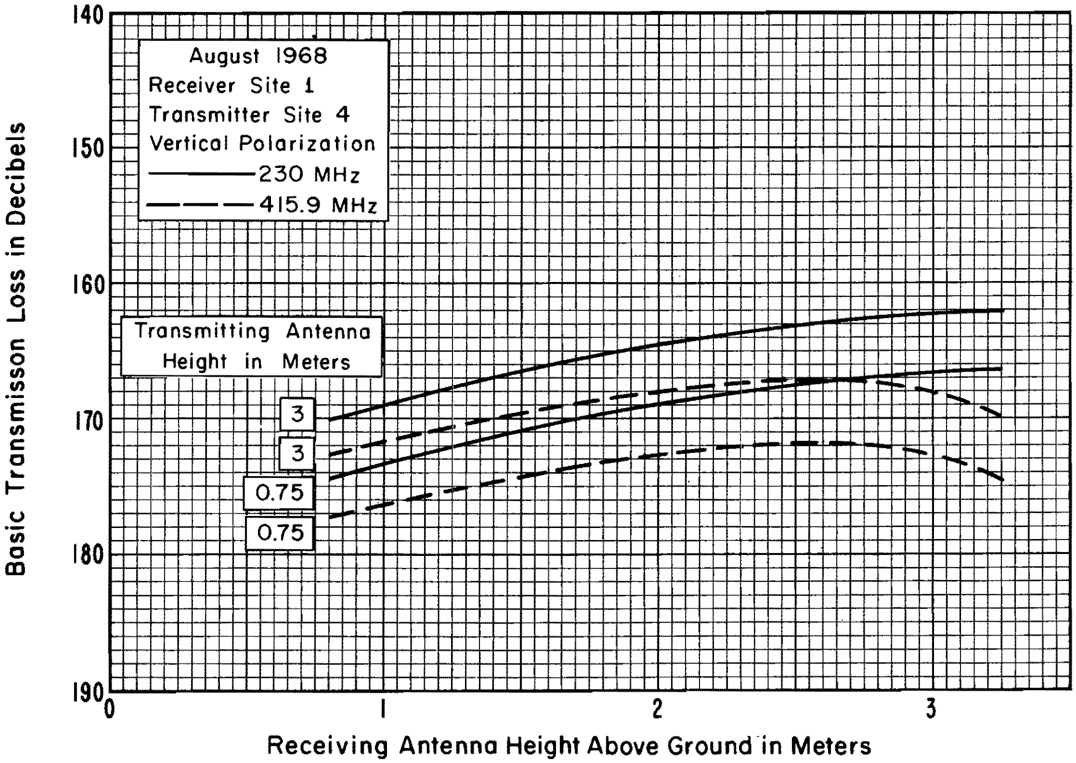
Wyoming PATH 1 - 4



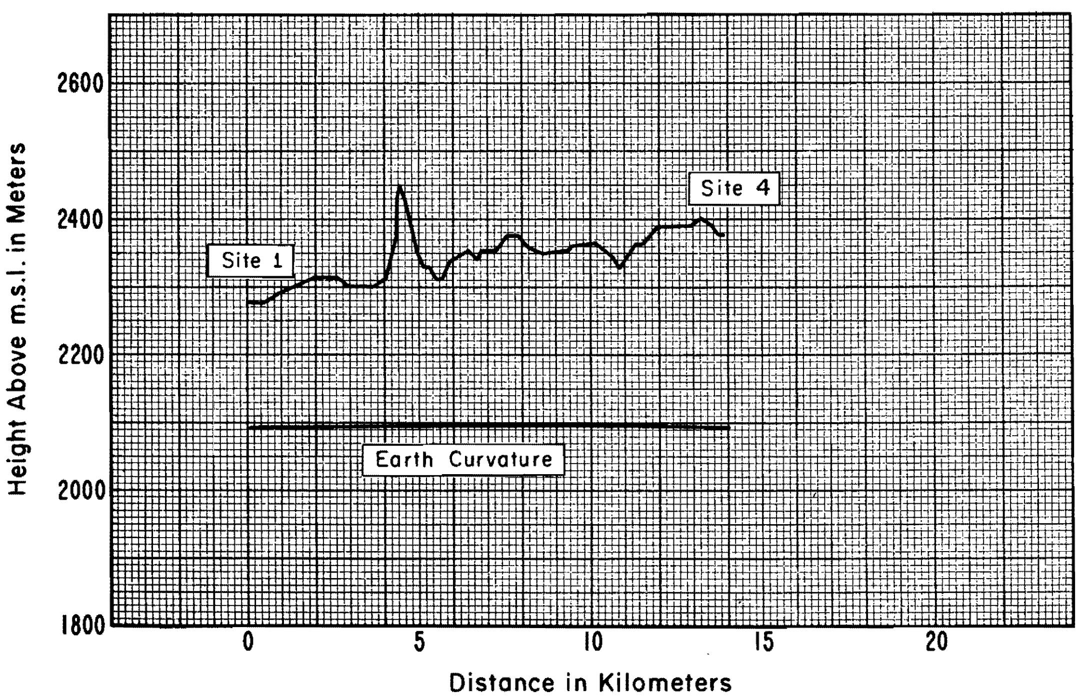
From site 1 toward site 4

From site 4 toward site 1

PATH LOSS MEASUREMENTS

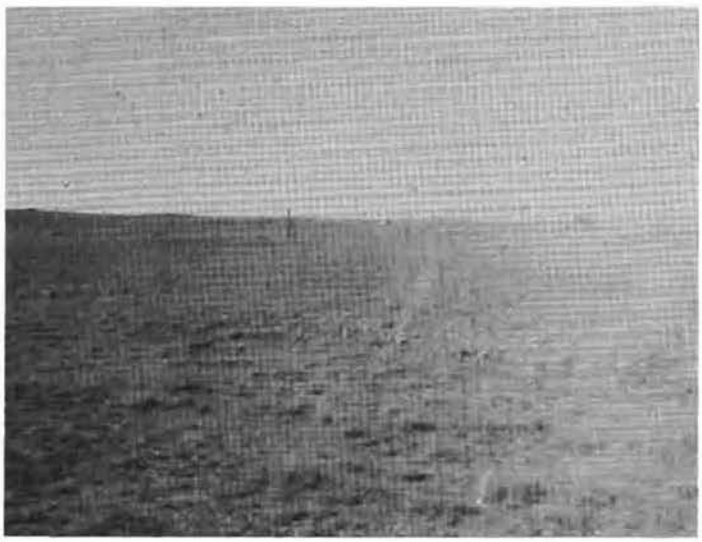


TERRAIN PROFILE



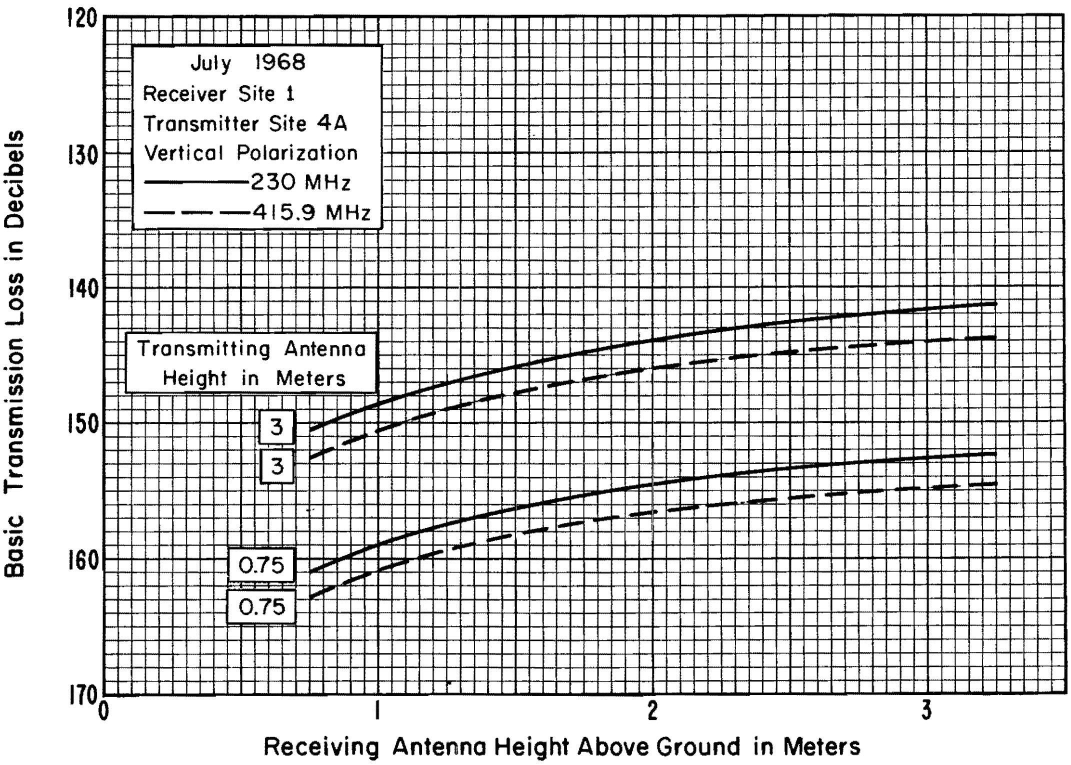
Wyoming PATH 1 - 4A

From site 1 toward site 4A

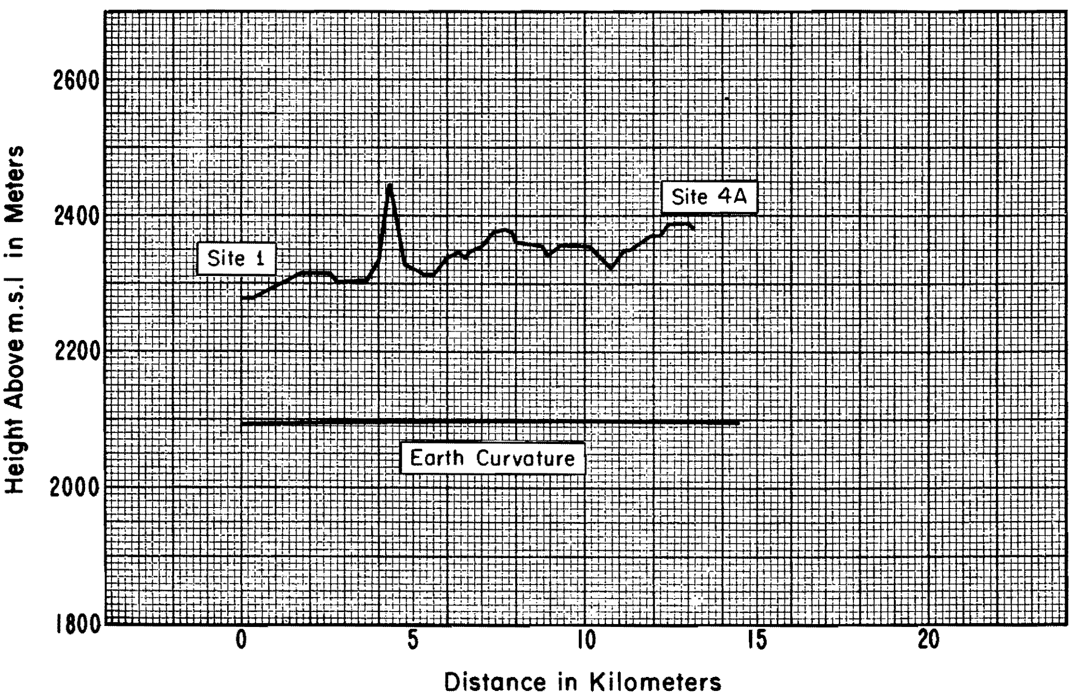


From site 4A toward site 1

PATH LOSS MEASUREMENTS



TERRAIN PROFILE

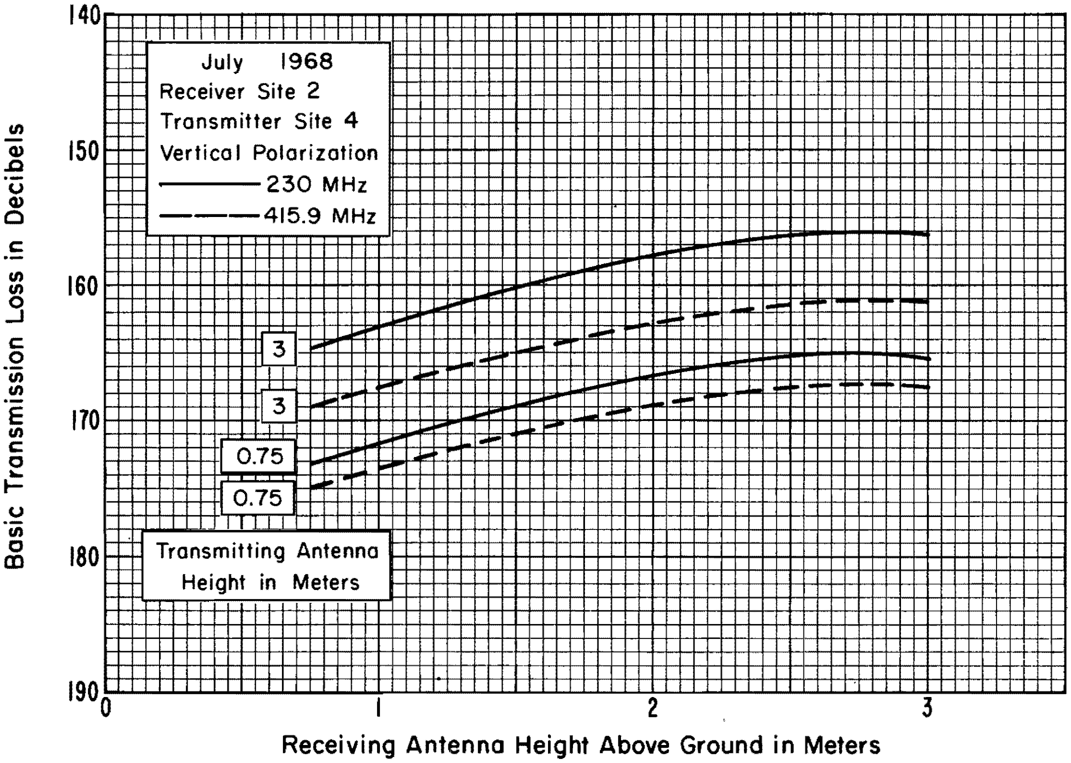


Wyoming PATH 2 - 4

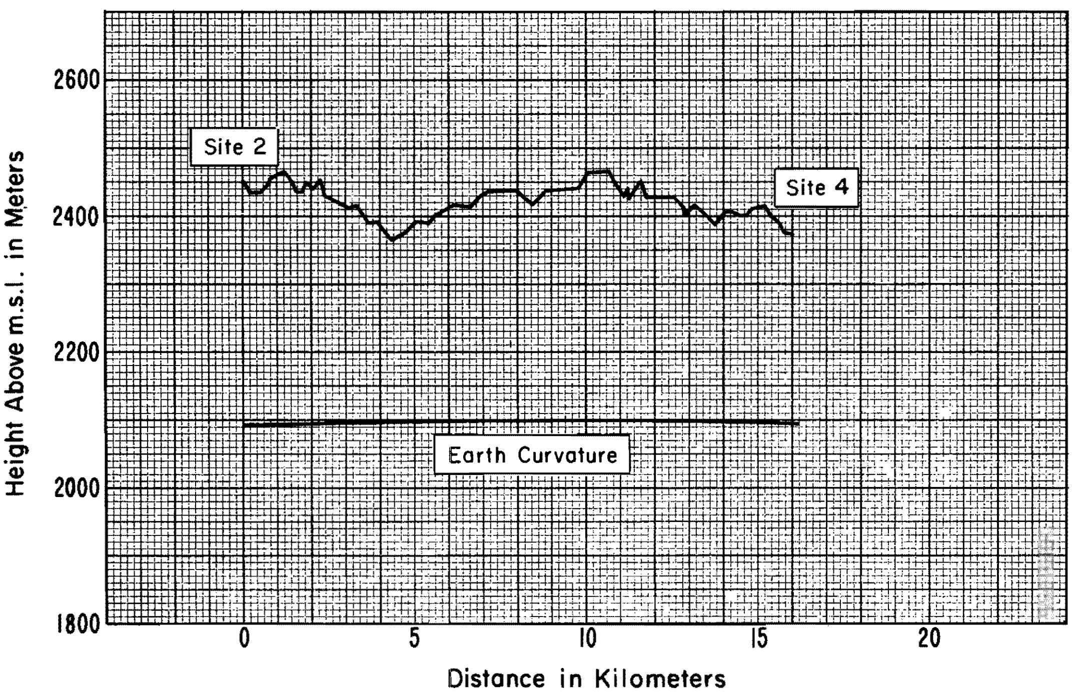
From site 2 toward site 4

From site 4 toward site 2

PATH LOSS MEASUREMENTS

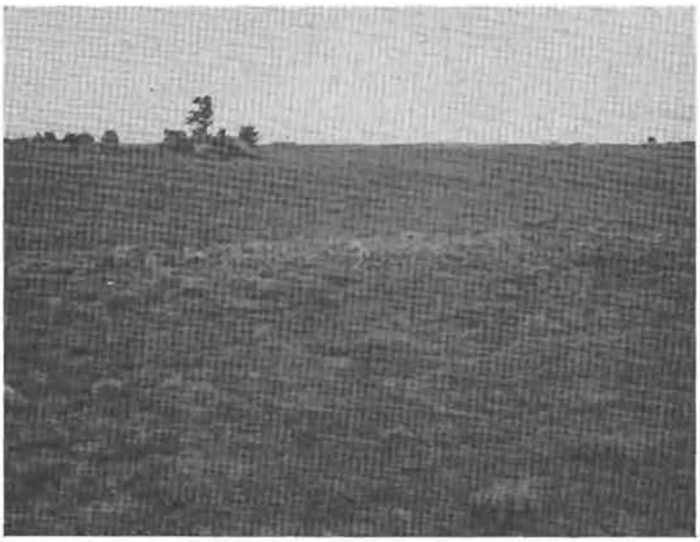


TERRAIN PROFILE



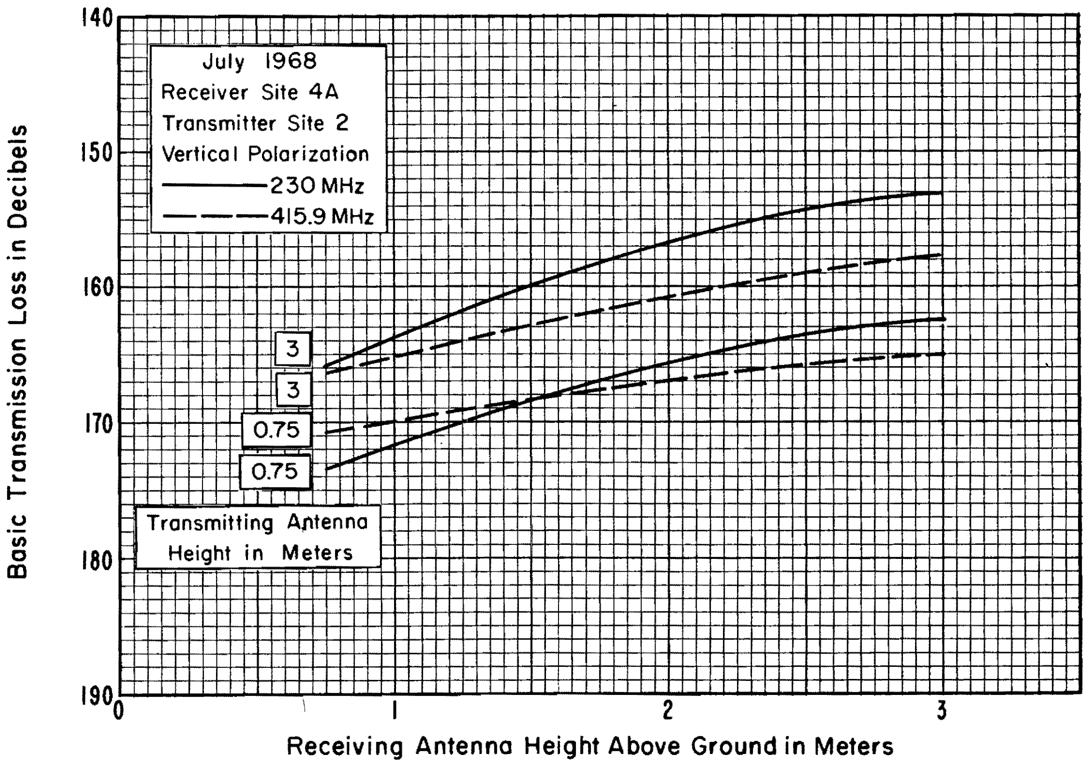
Wyoming PATH 2 - 4A

From site 2 toward site 4A

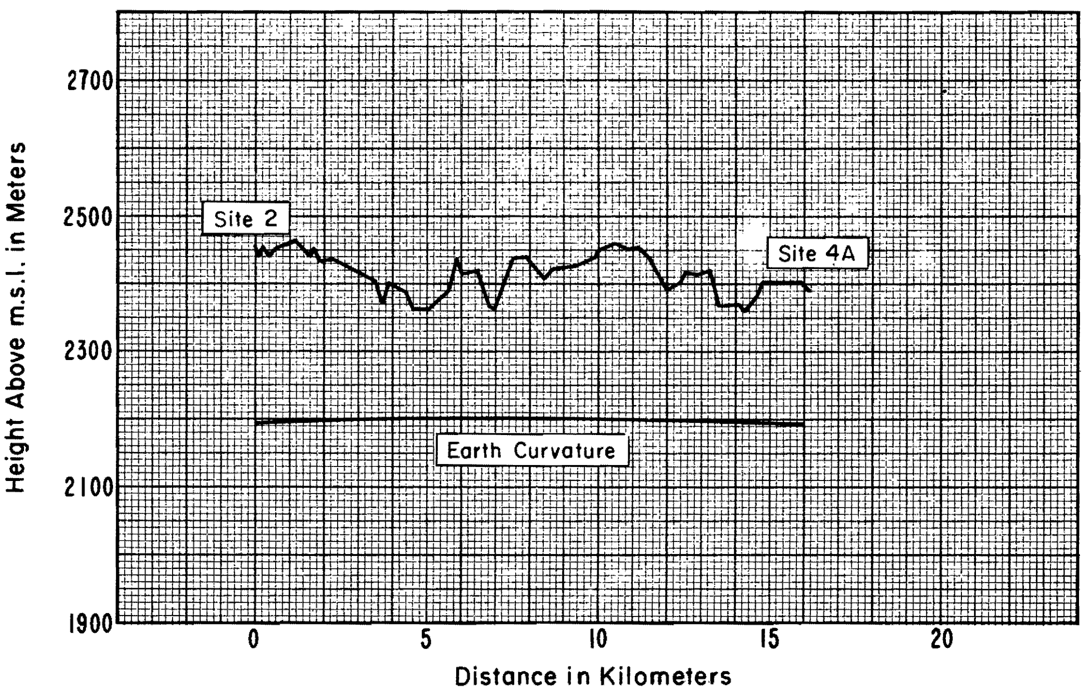


From site 4A toward site 2

PATH LOSS MEASUREMENTS



TERRAIN PROFILE

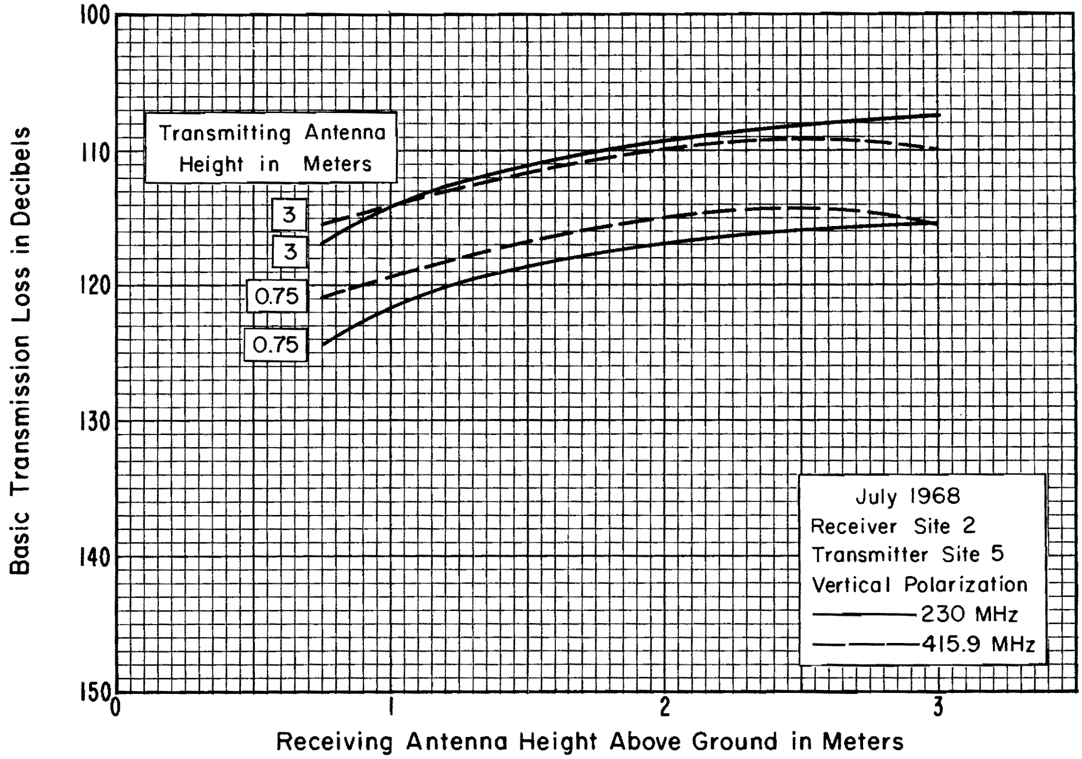


Wyoming PATH 2 - 5

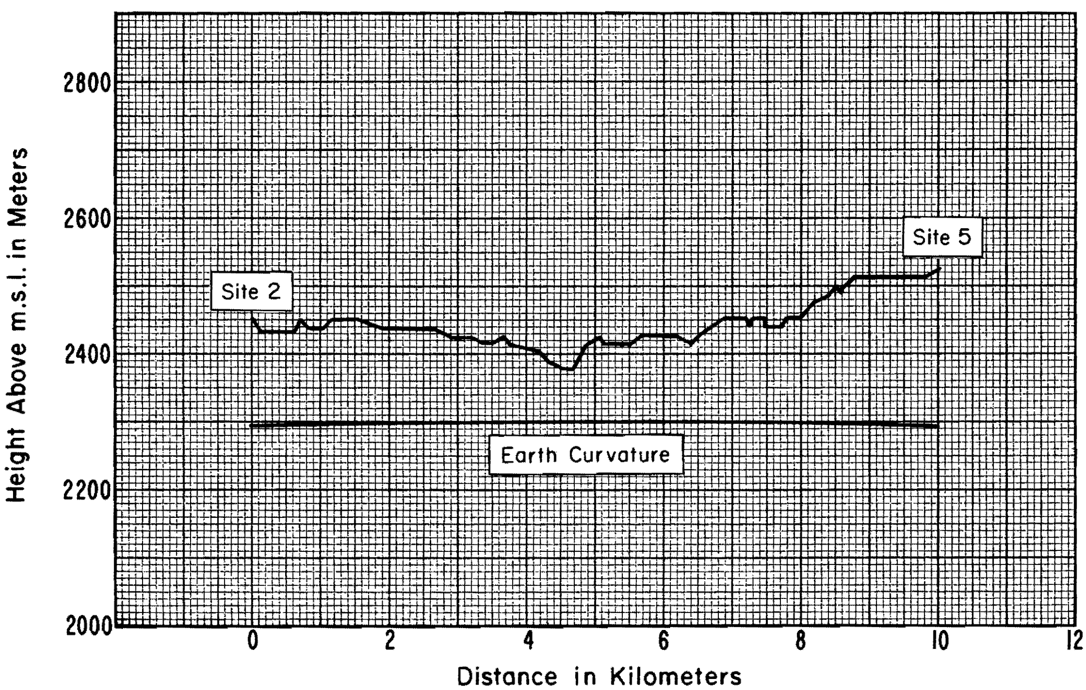
From site 2 toward site 5

From site 5 toward site 2

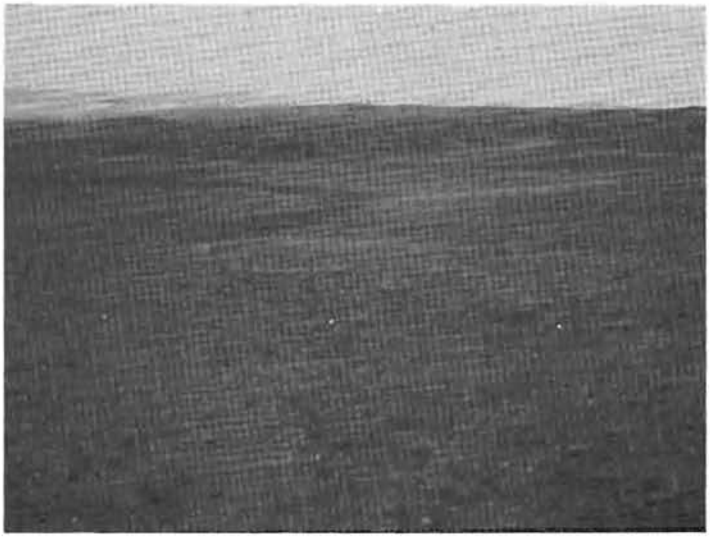
PATH LOSS MEASUREMENTS



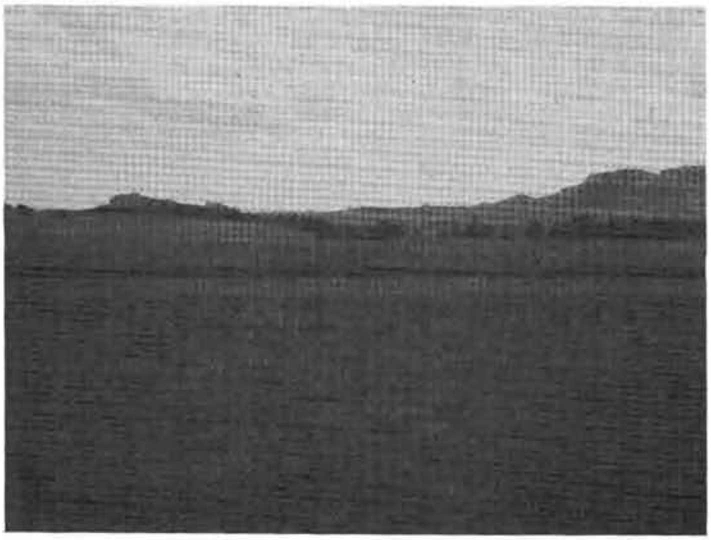
TERRAIN PROFILE



Wyoming PATH 2 - 8

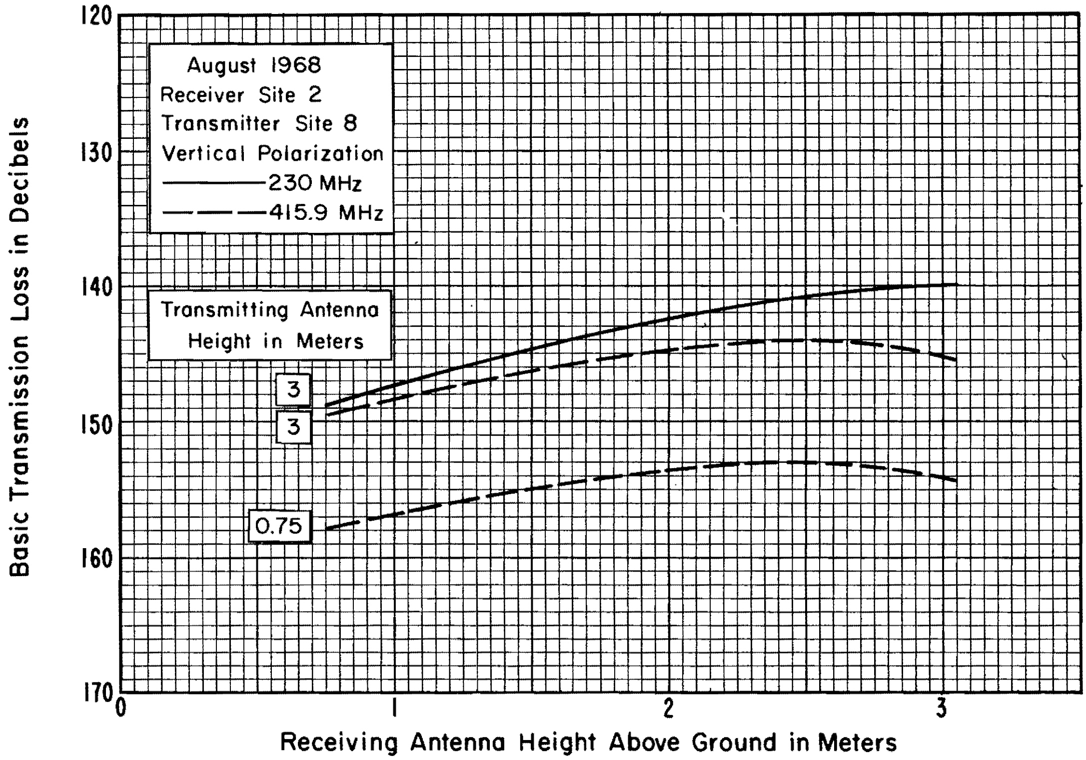


From site 2 toward site 8

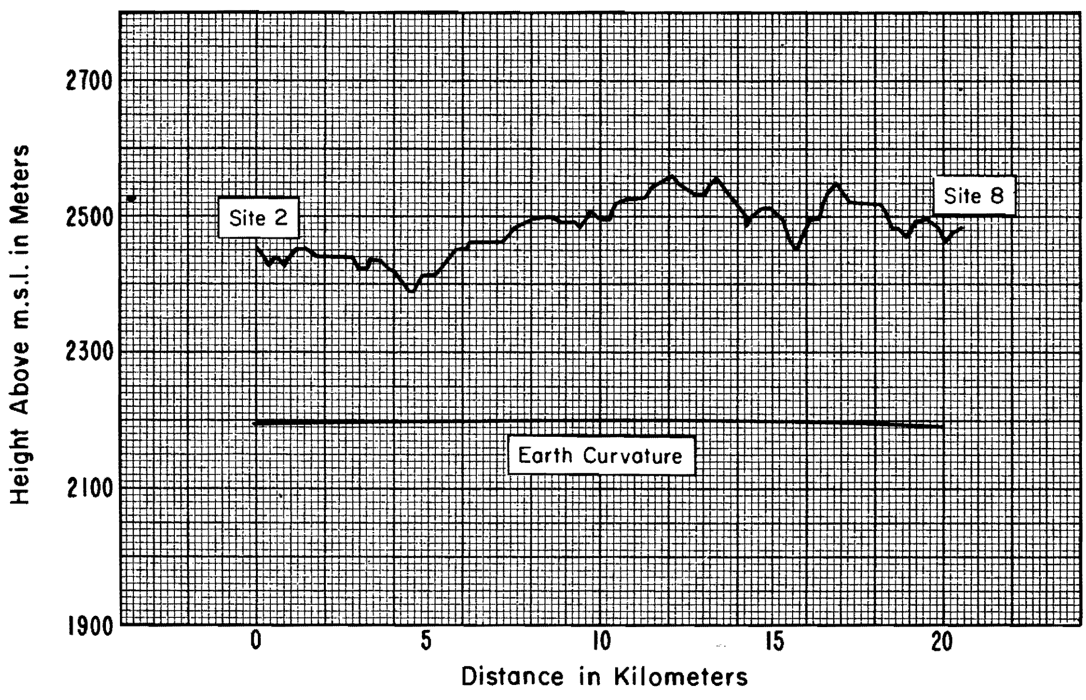


From site 8 toward site 2

PATH LOSS MEASUREMENTS



TERRAIN PROFILE



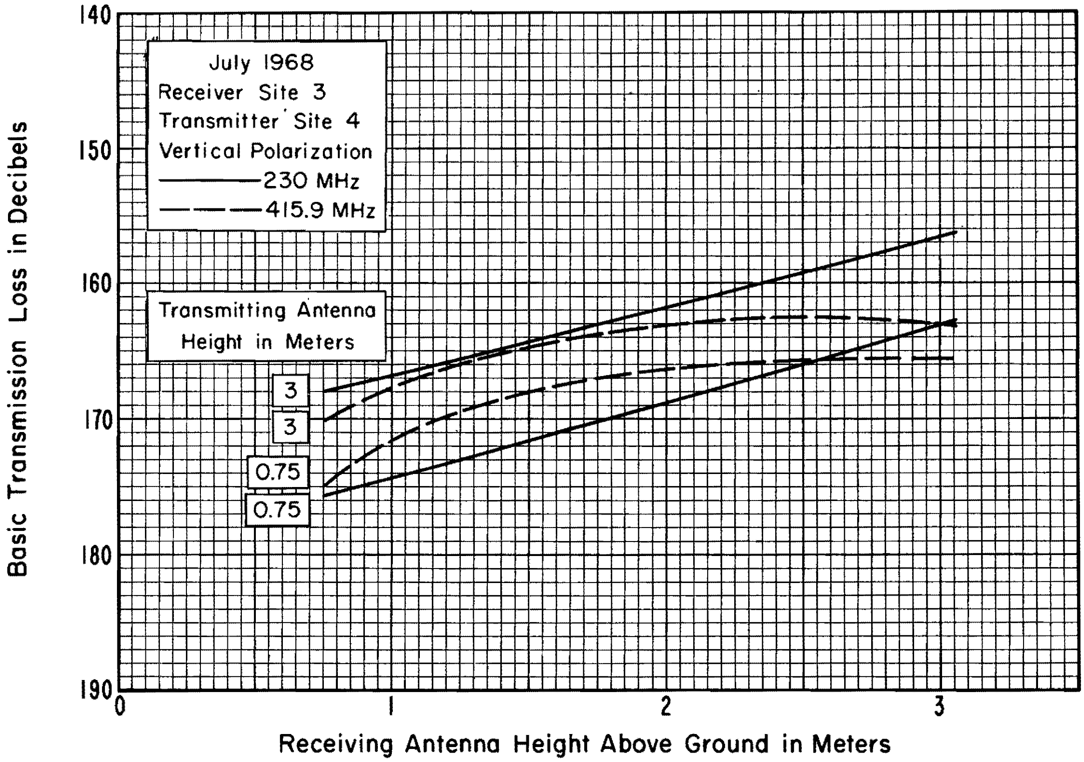
Wyoming PATH 3 - 4

From site 3 toward site 4

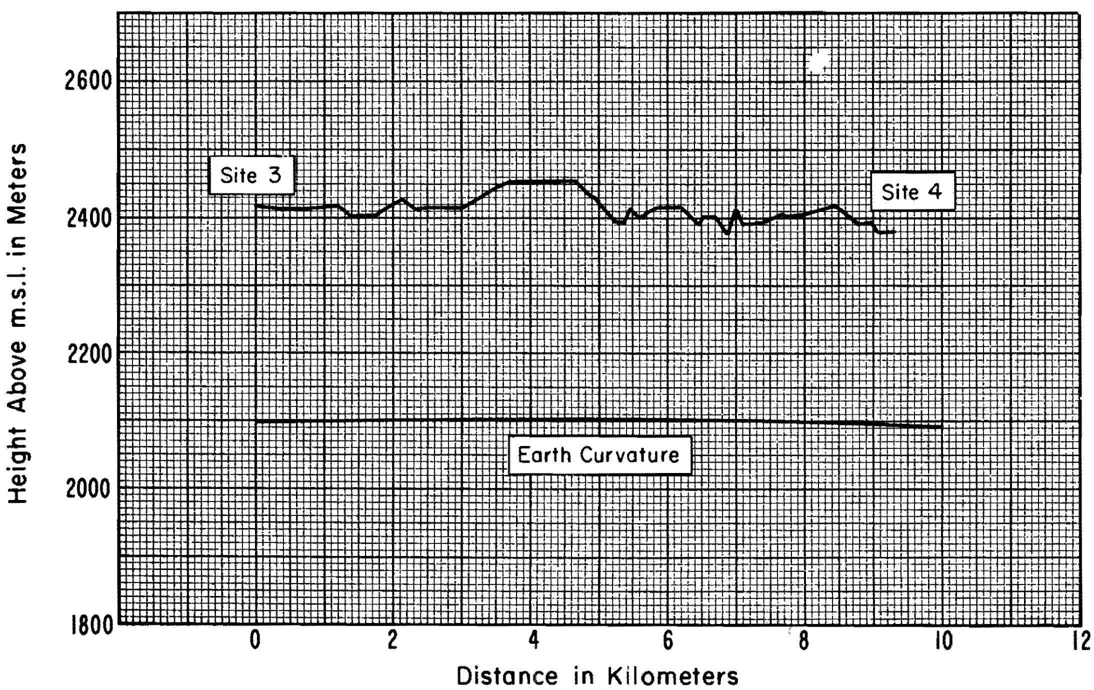
From site 4 toward site 3

WYOMING PATH 3 —— 4

PATH LOSS MEASUREMENTS

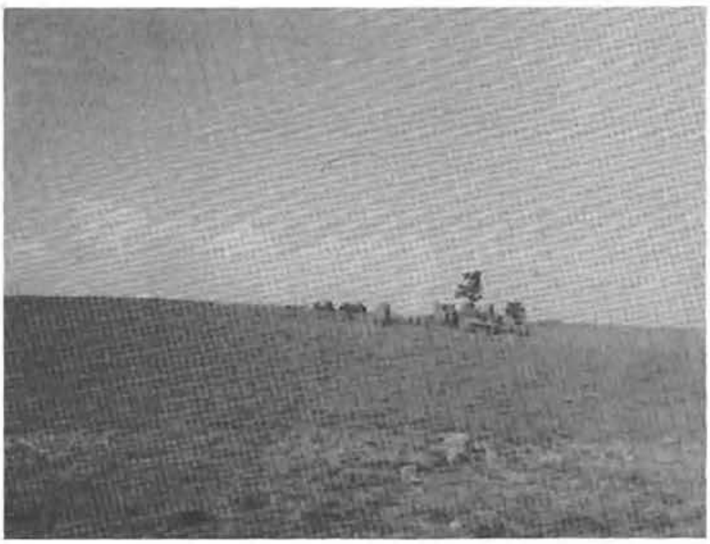


TERRAIN PROFILE



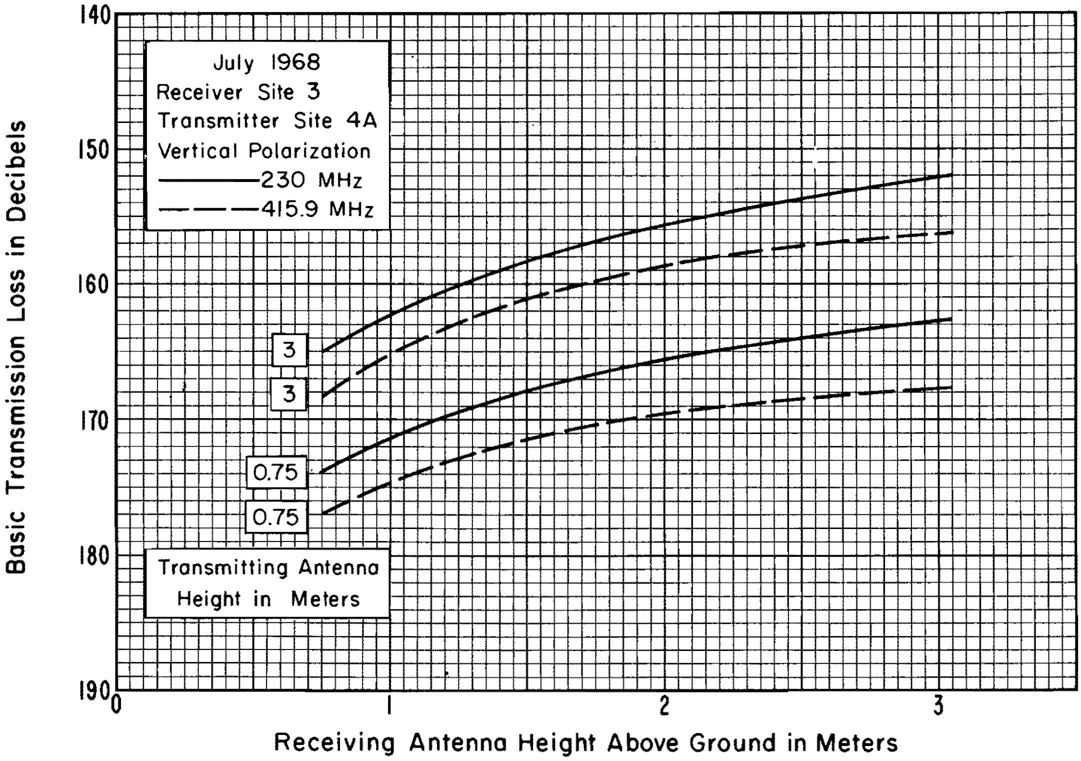
Wyoming PATH 3 - 4A

From site 3 toward site 4A

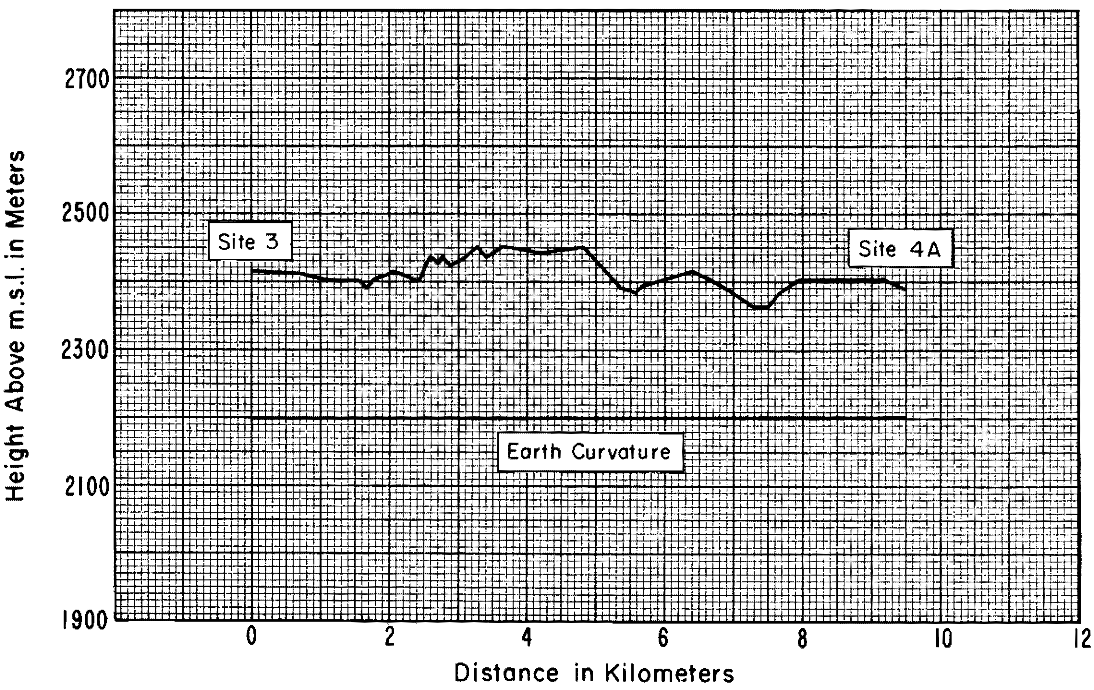


From site 4A toward site 3

PATH LOSS MEASUREMENTS

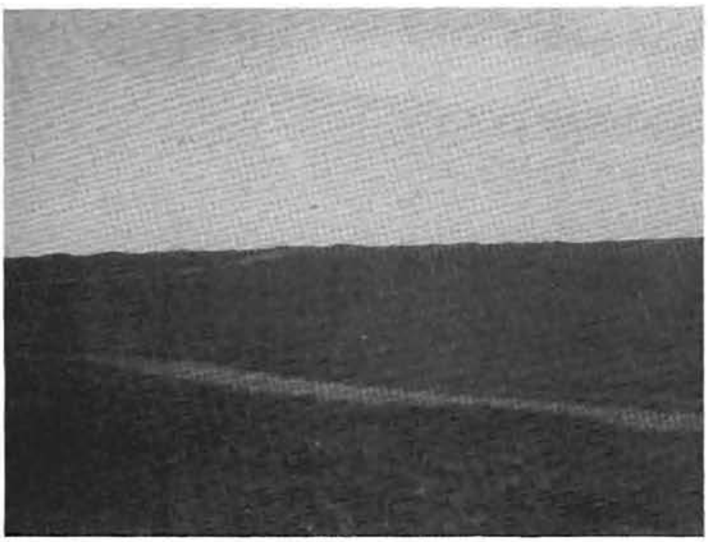


TERRAIN PROFILE



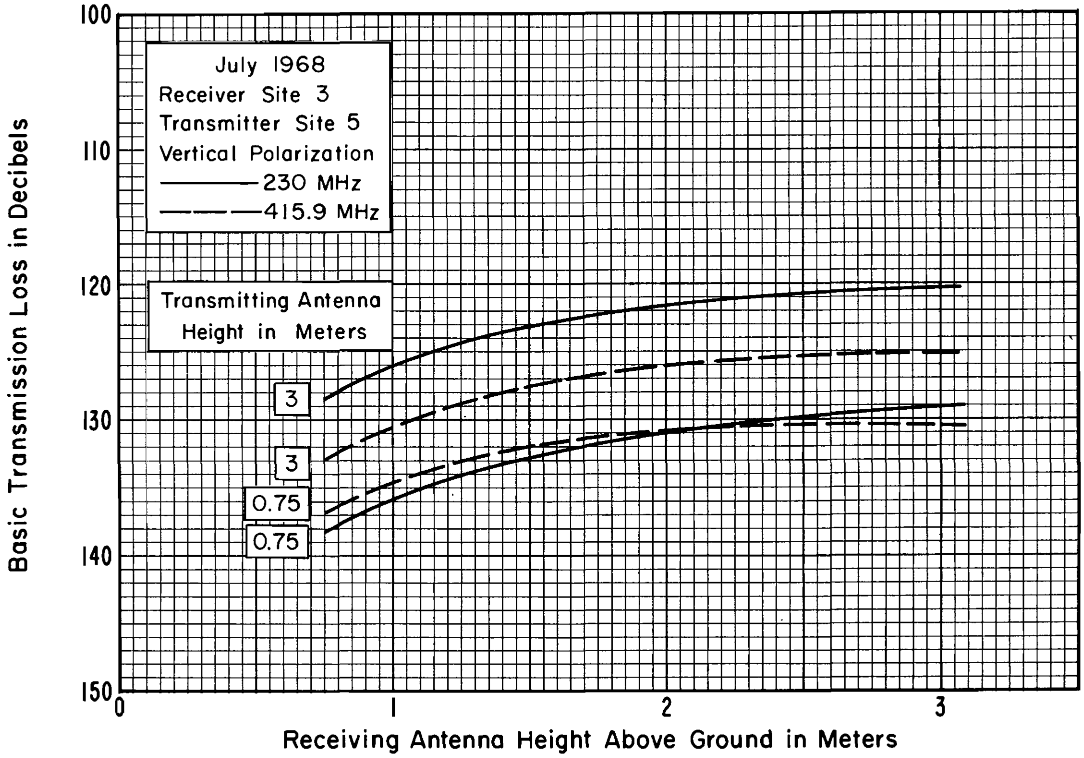
Wyoming PATH 3 - 5

From site 3 toward site 5

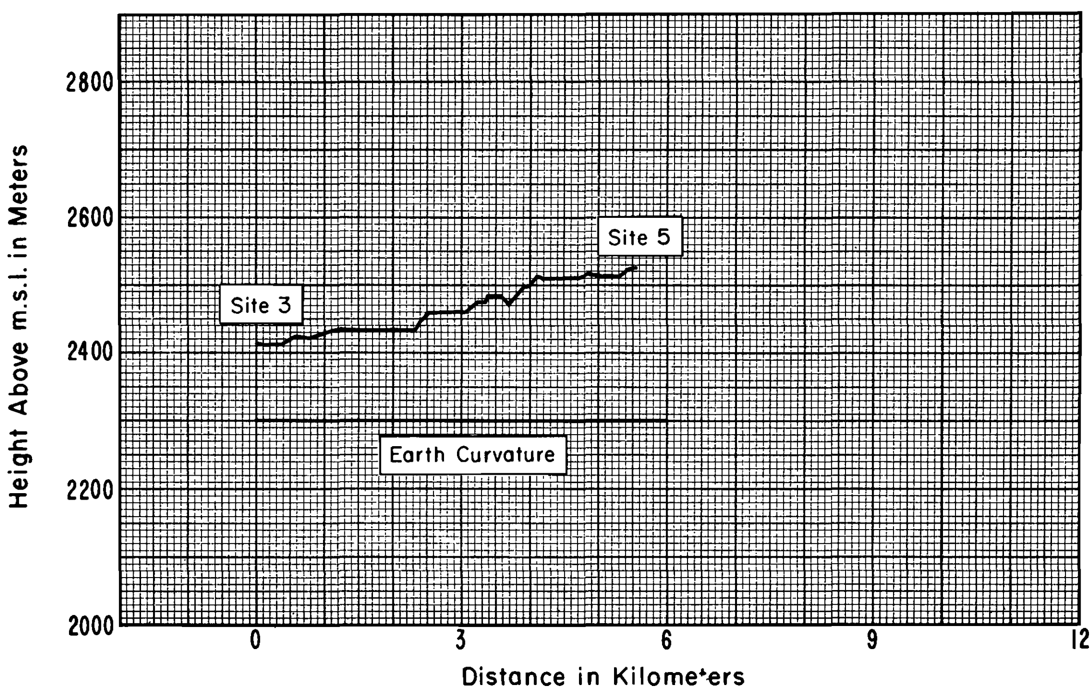


From site 5 toward site 3

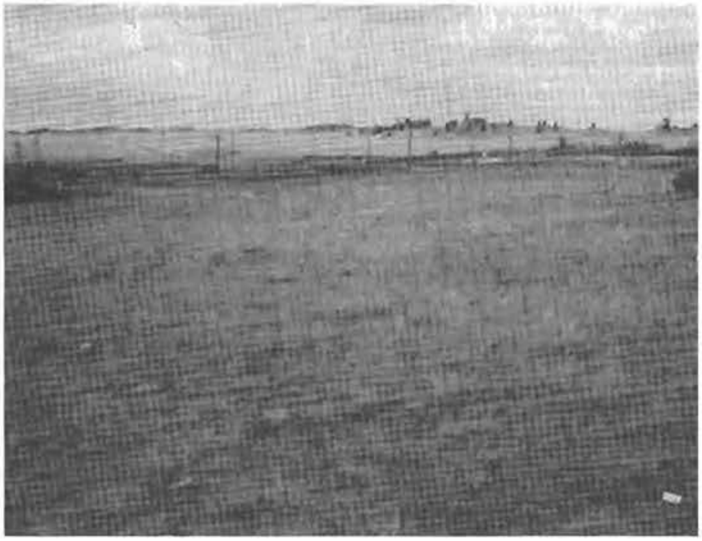
PATH LOSS MEASUREMENTS



TERRAIN PROFILE



Wyoming PATH 3 - 9

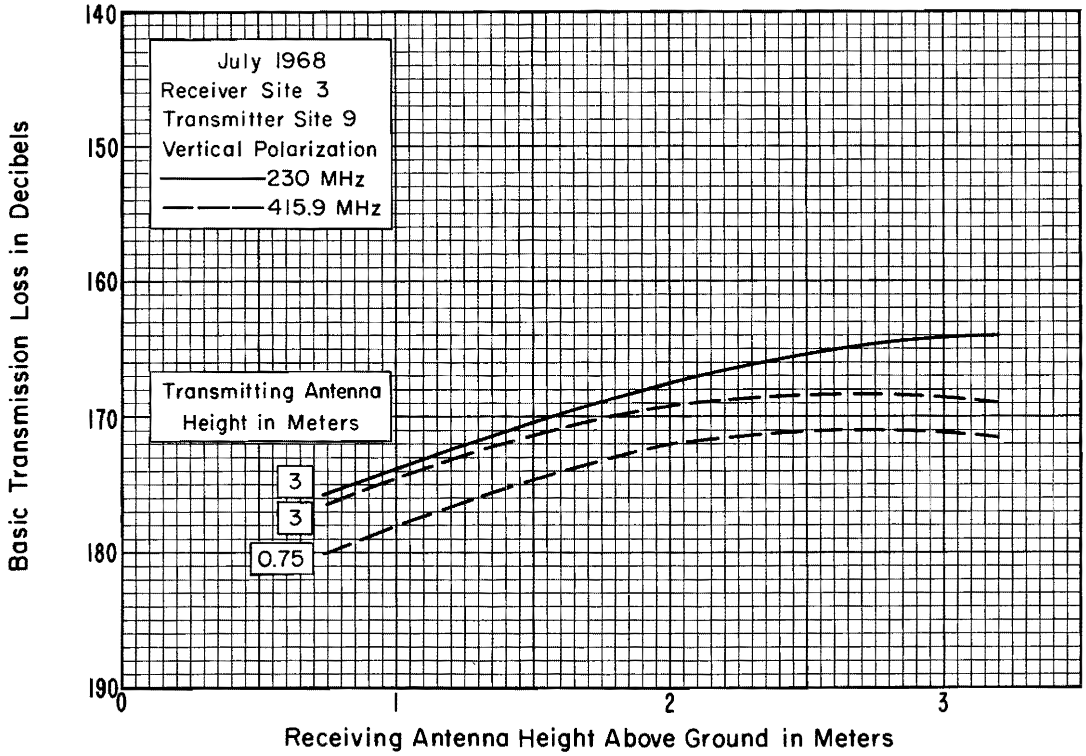


From site 3 toward site 9

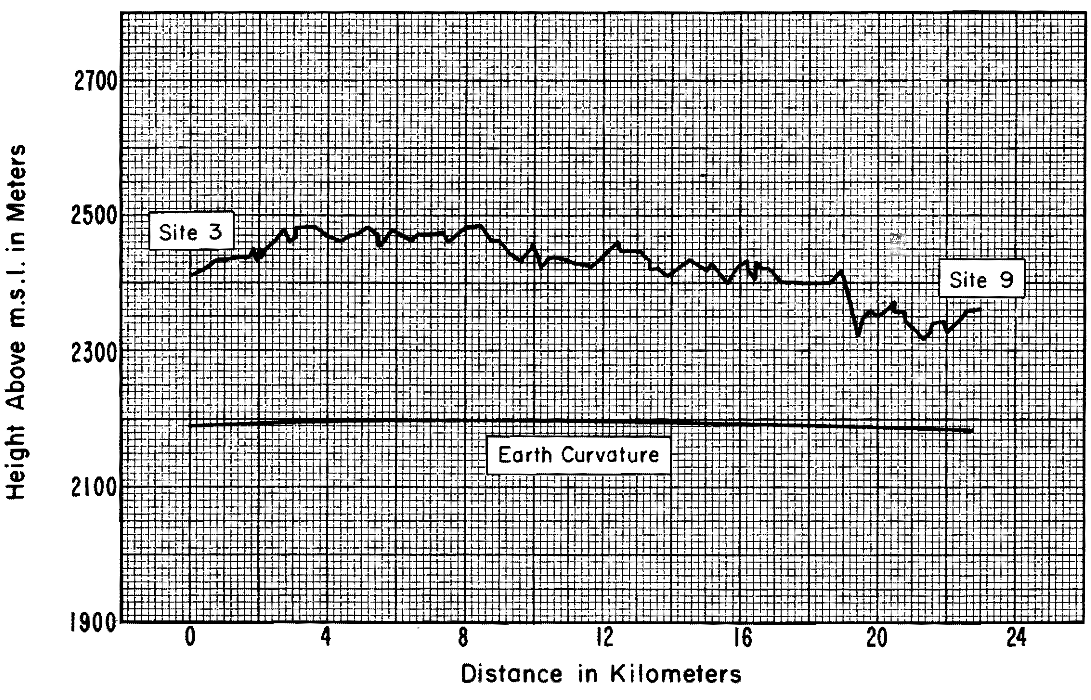
From site 9 toward site 3

WYOMING PATH 3——9

PATH LOSS MEASUREMENTS



TERRAIN PROFILE

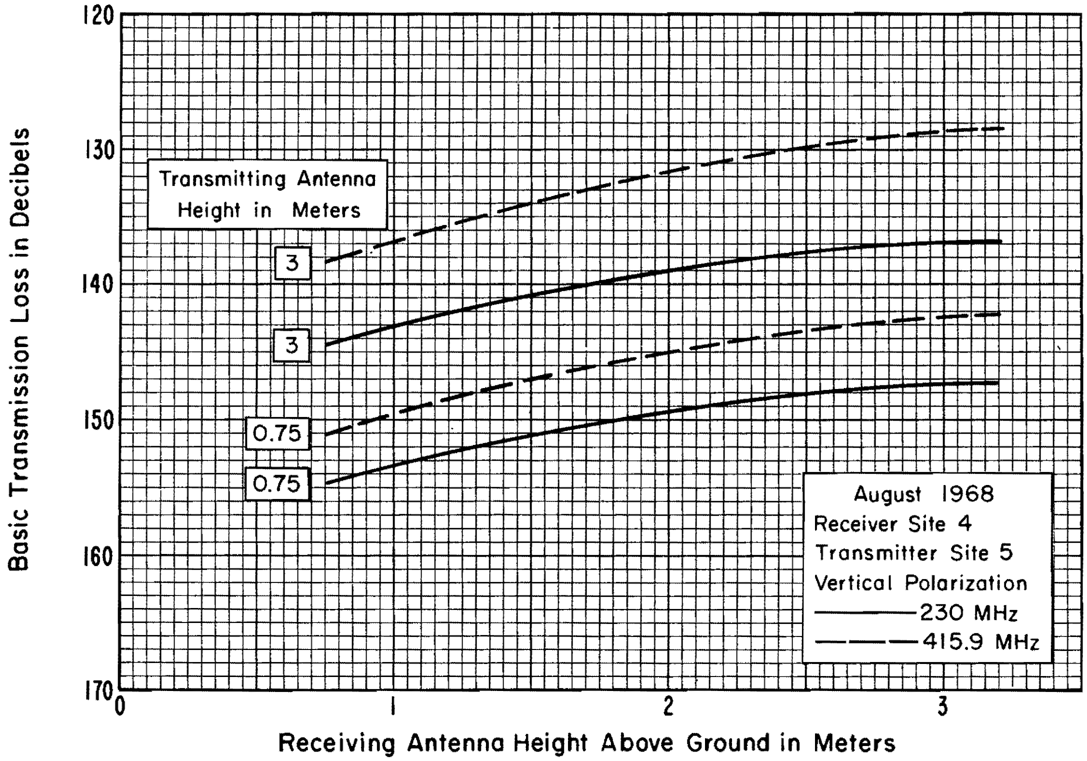


Wyoming PATH 4 - 5

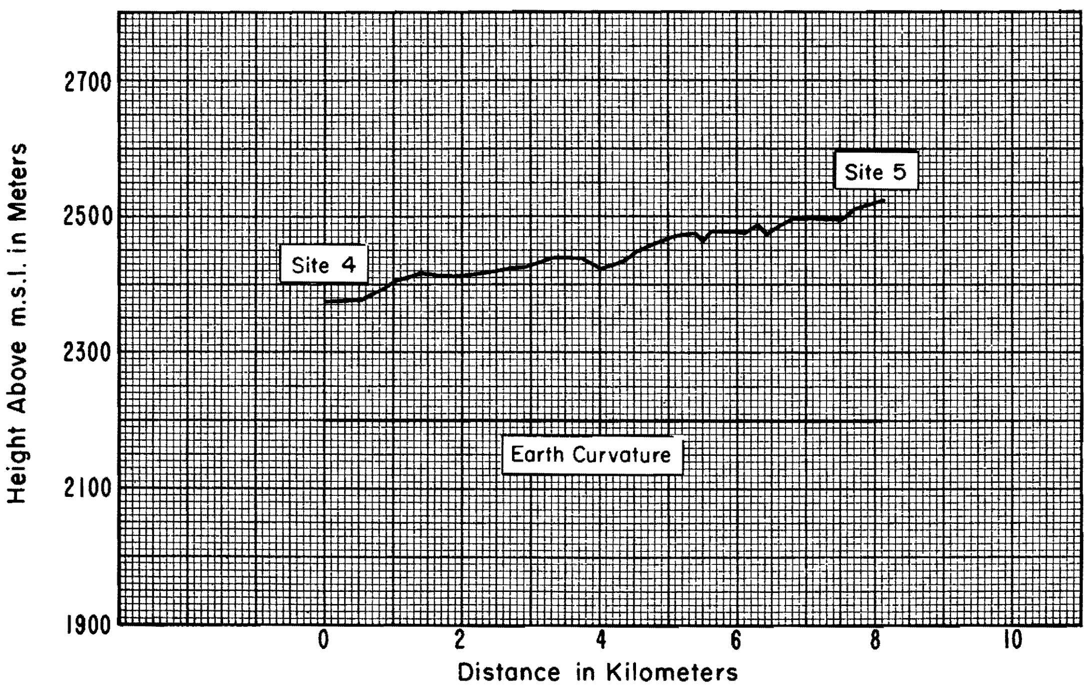
From site 4 toward site 5

WYOMING PATH 4——5

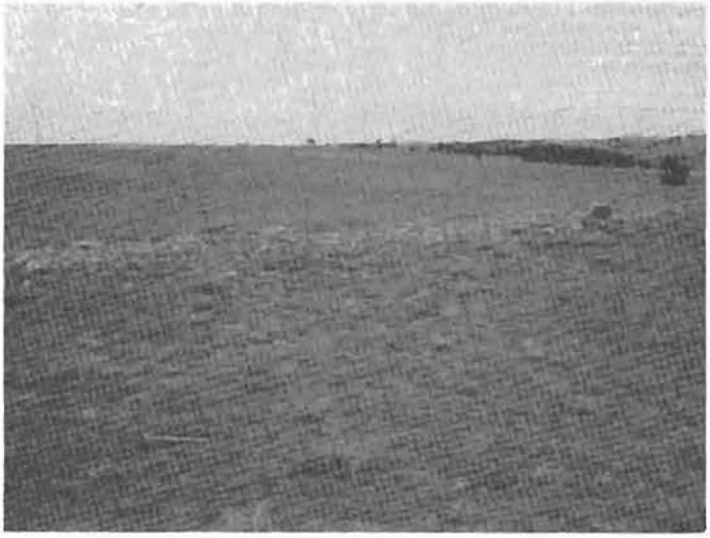
PATH LOSS MEASUREMENTS



TERRAIN PROFILE



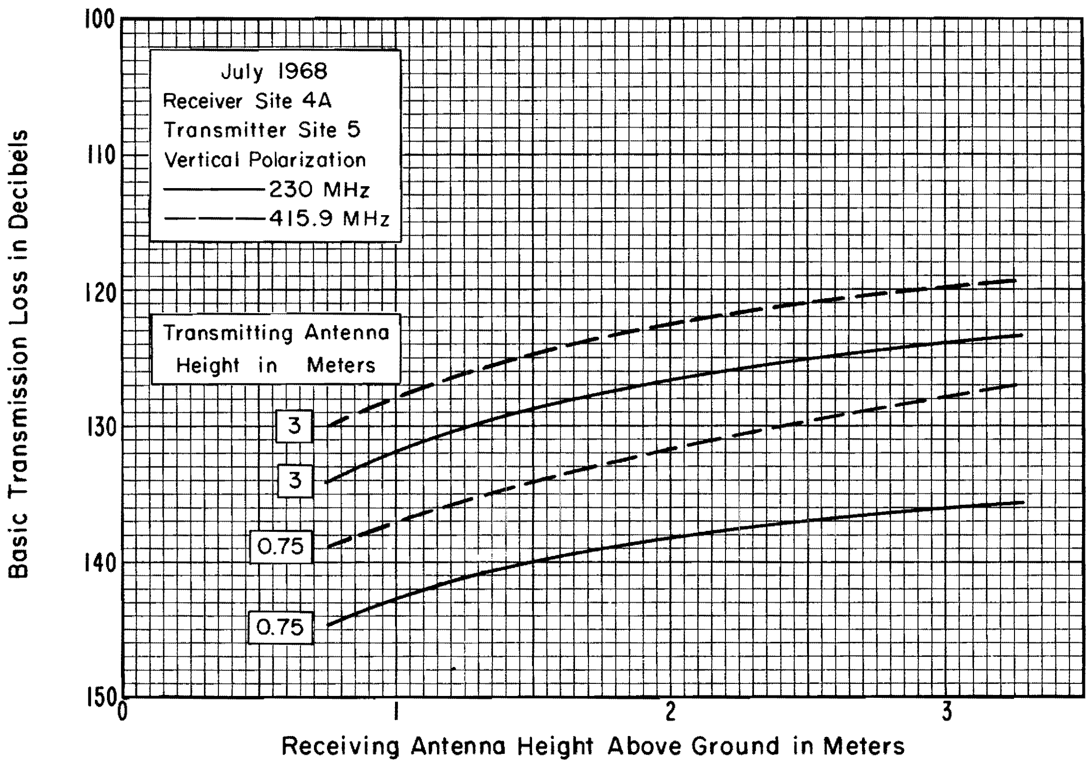
Wyoming PATH 4A - 5



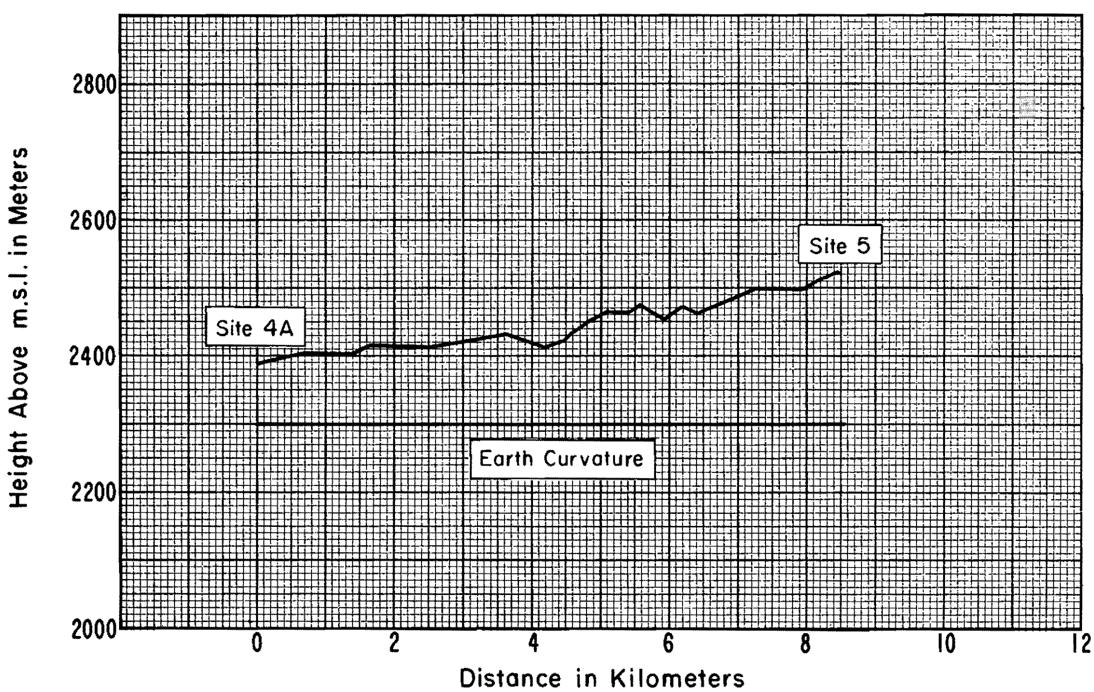
From site 4A toward site 5

From site 5 toward site 4A

PATH LOSS MEASUREMENTS



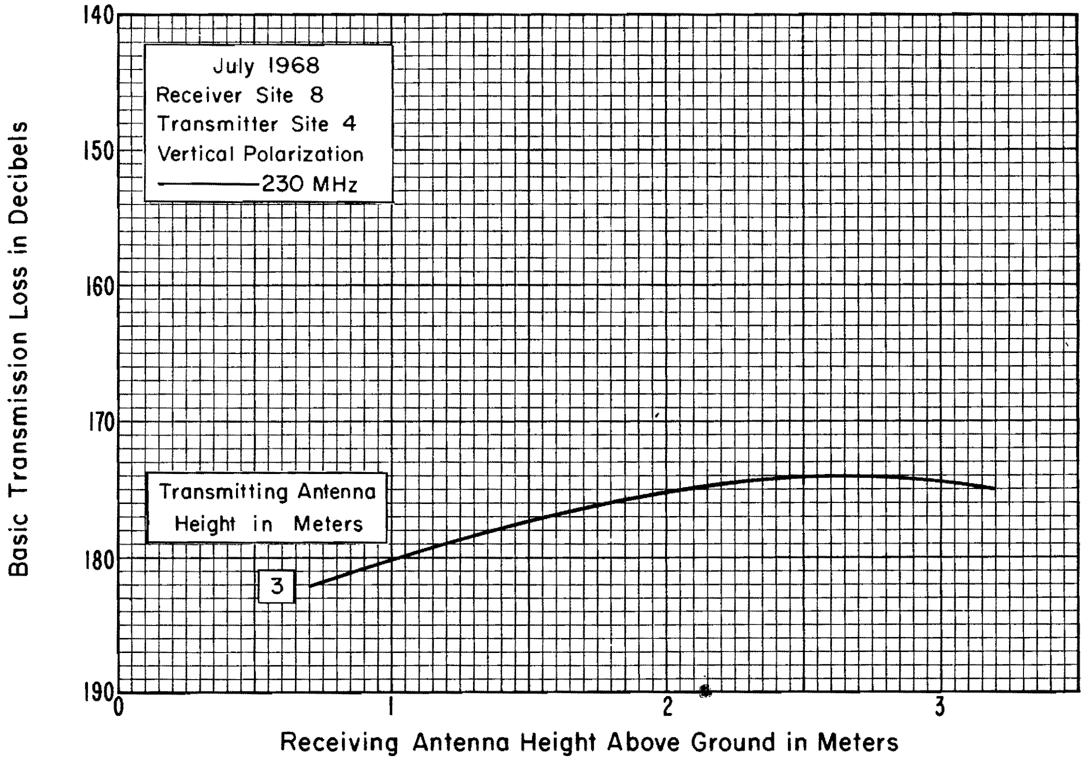
TERRAIN PROFILE



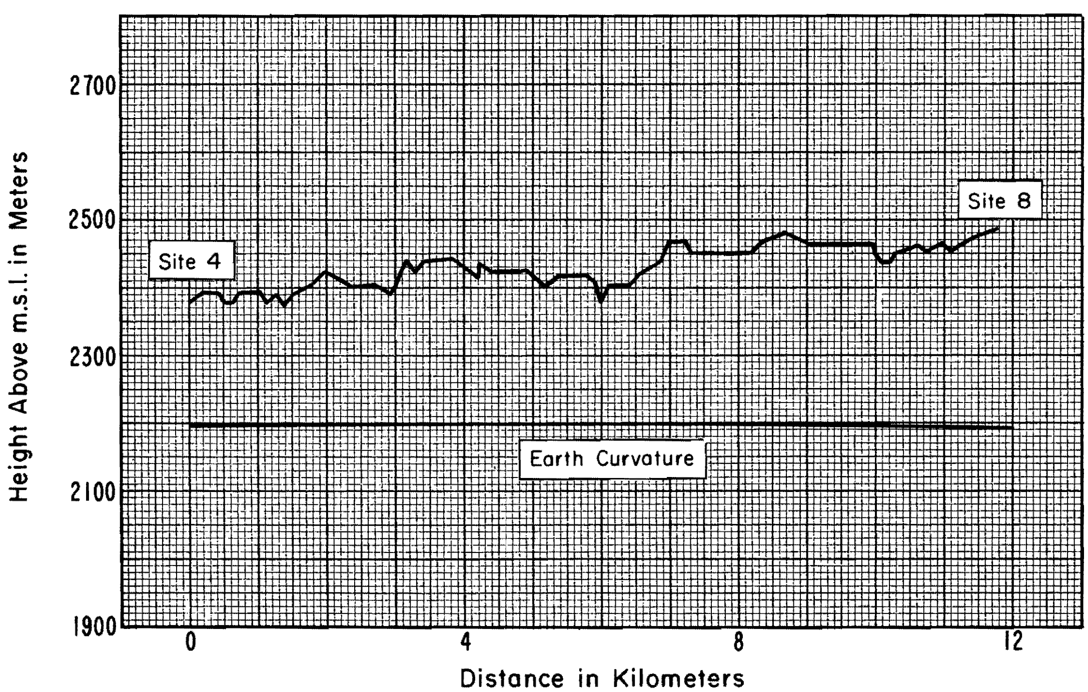
Wyoming PATH 4 - 8

From site 4 toward site 8

PATH LOSS MEASUREMENTS



TERRAIN PROFILE

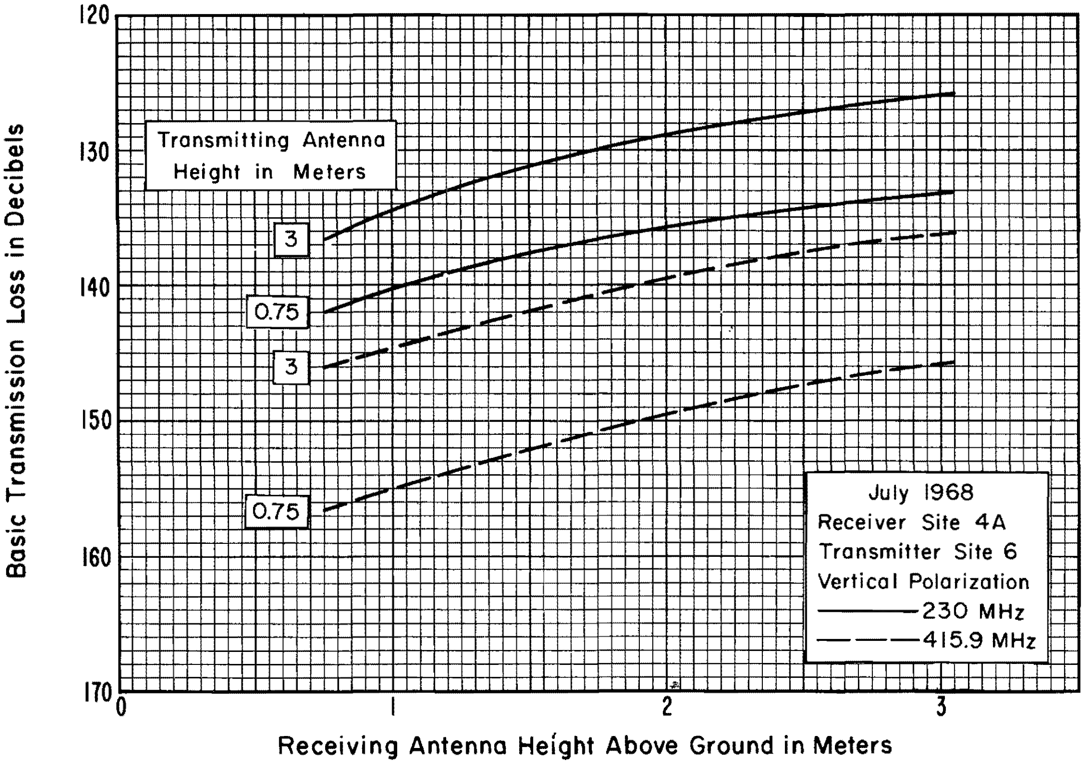


Wyoming PATH 4A - 6

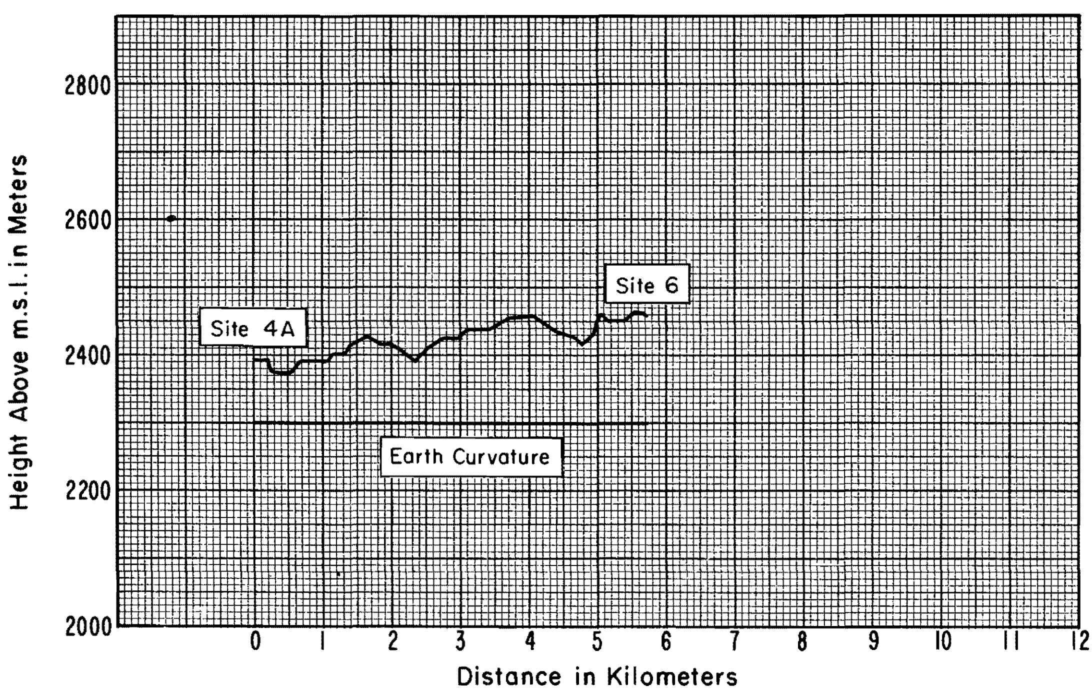
From site 4A toward site 6

From site 6 toward site 4A

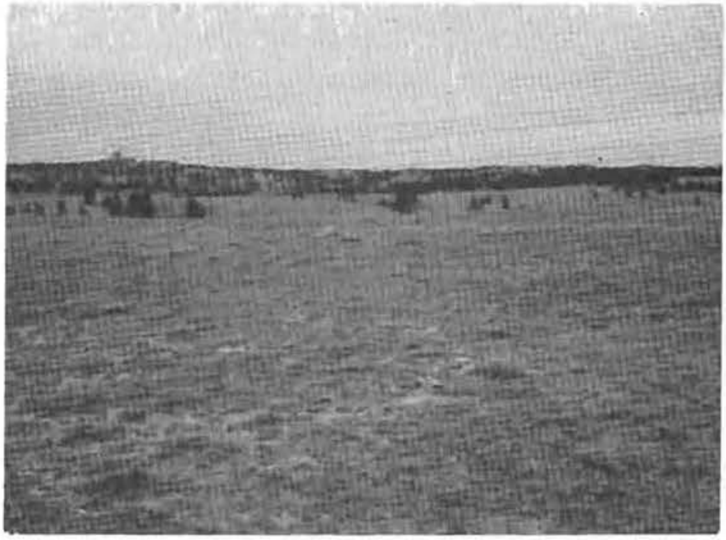
PATH LOSS MEASUREMENTS



TERRAIN PROFILE



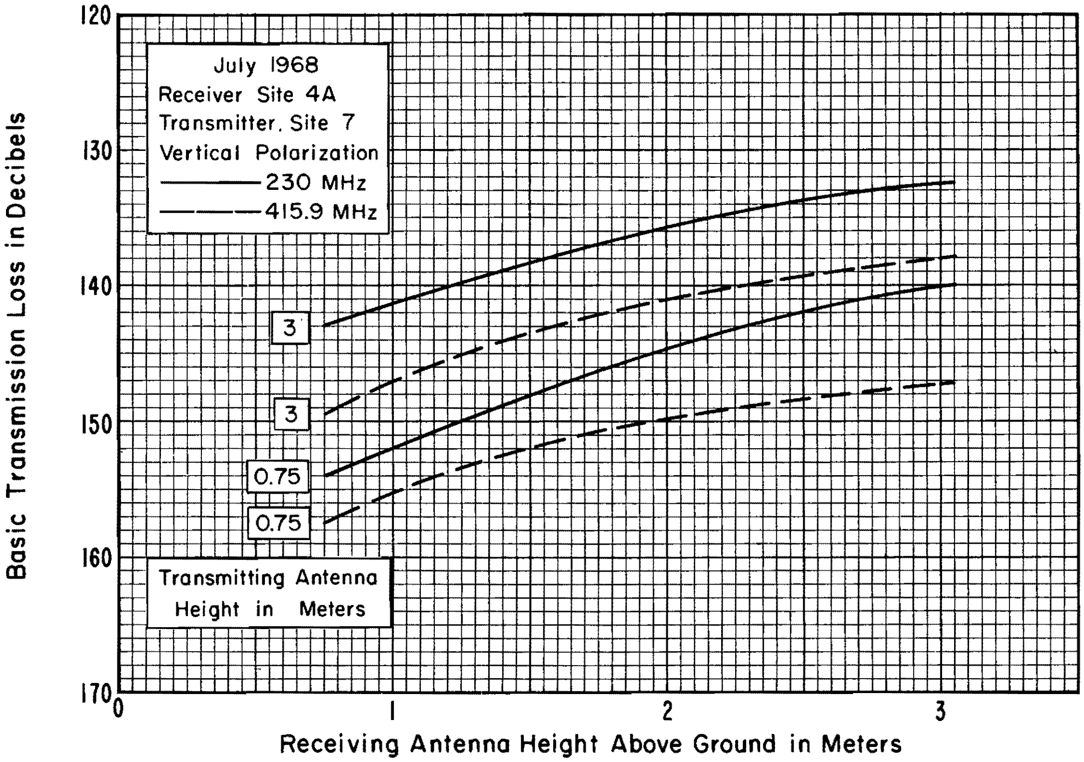
Wyoming PATH 4A - 7



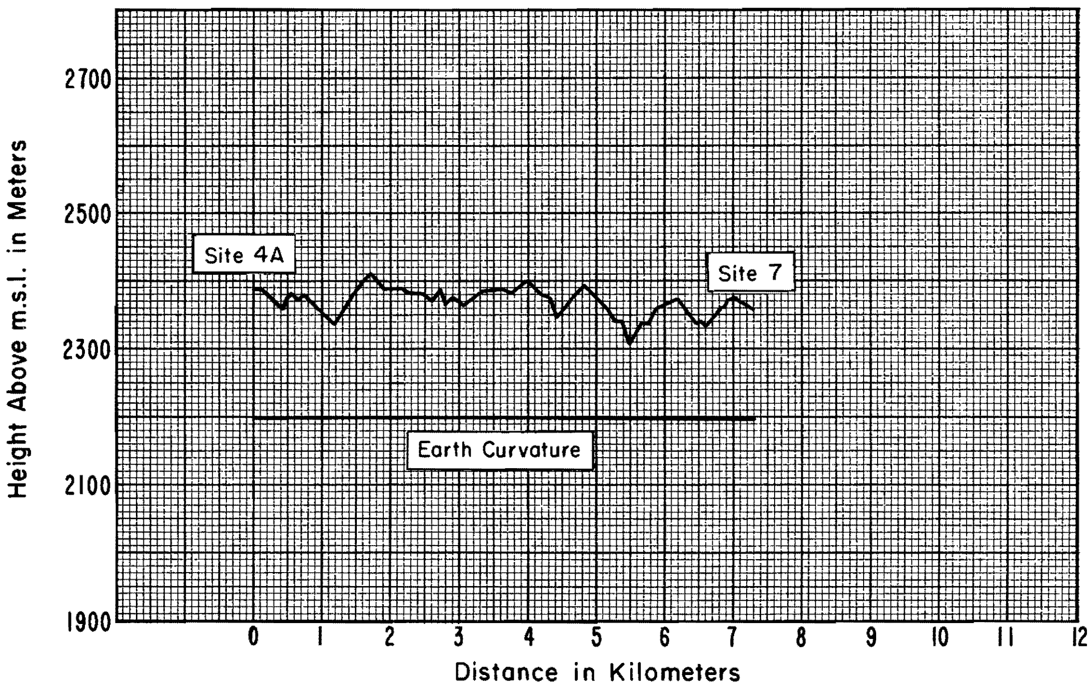
From site 4A toward site 7

From site 7 toward site 4A

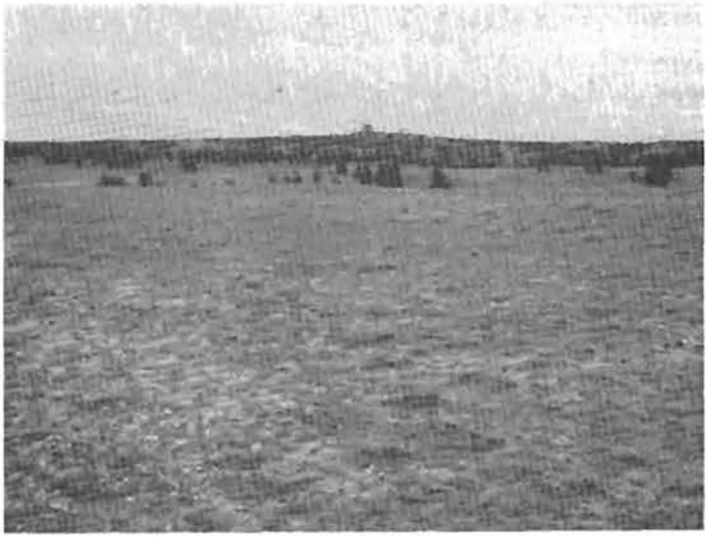
PATH LOSS MEASUREMENTS



TERRAIN PROFILE



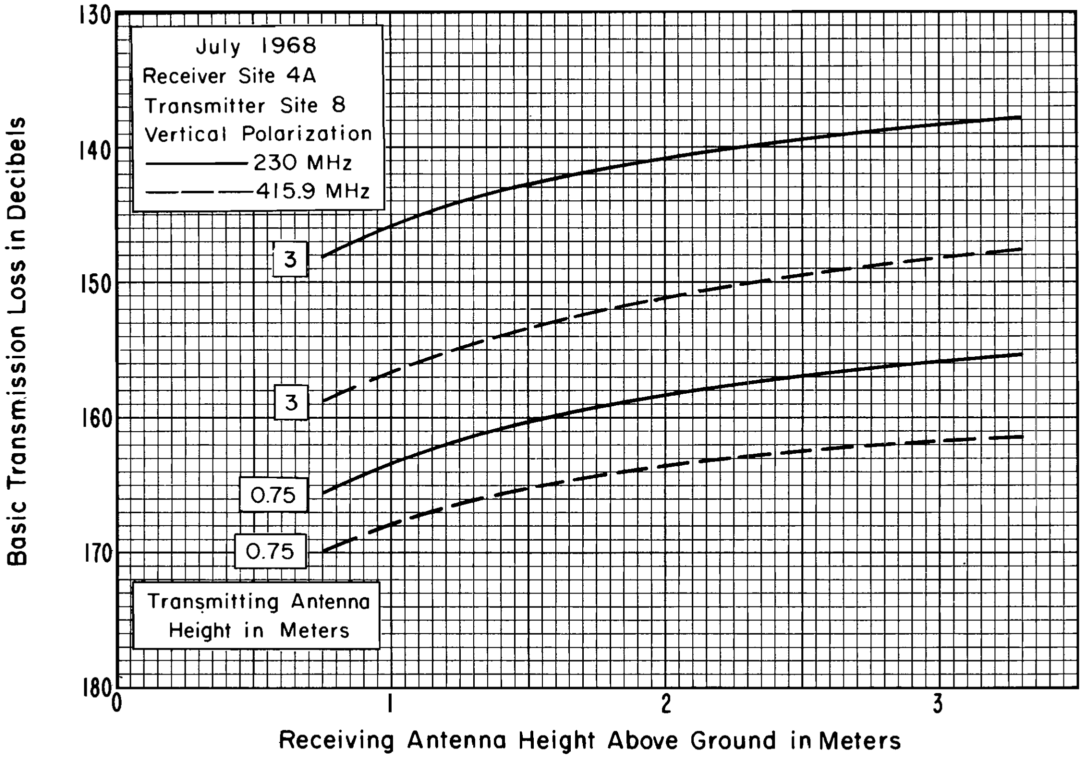
Wyoming PATH 4A - 8



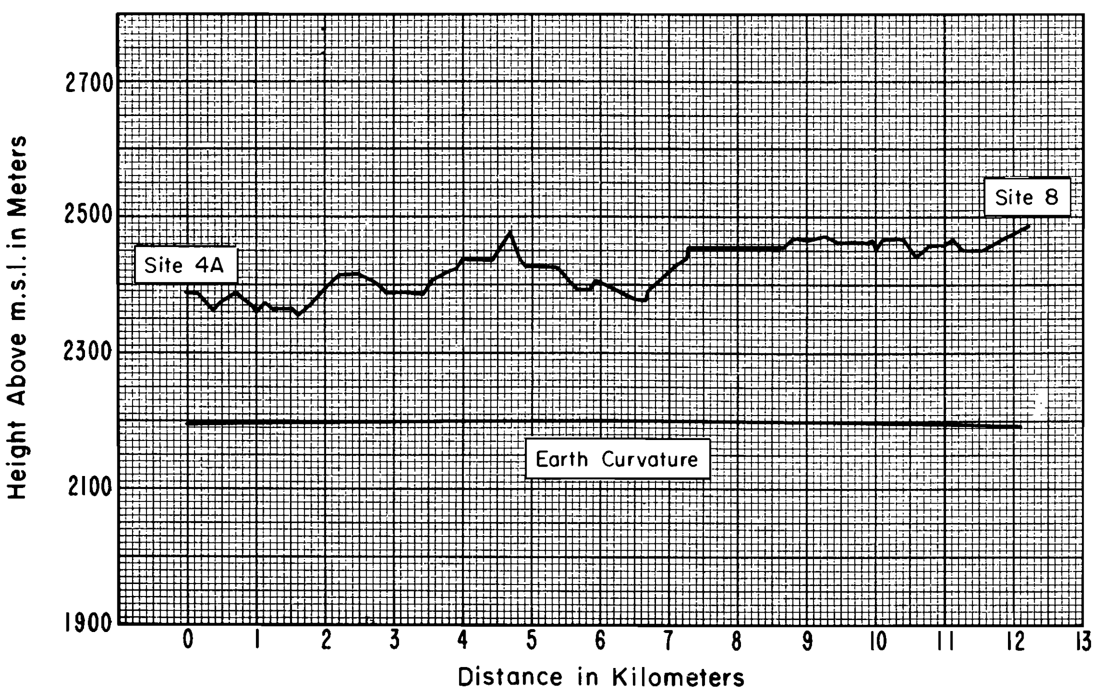
From site 4A toward site 8

From site 8 toward site 4A

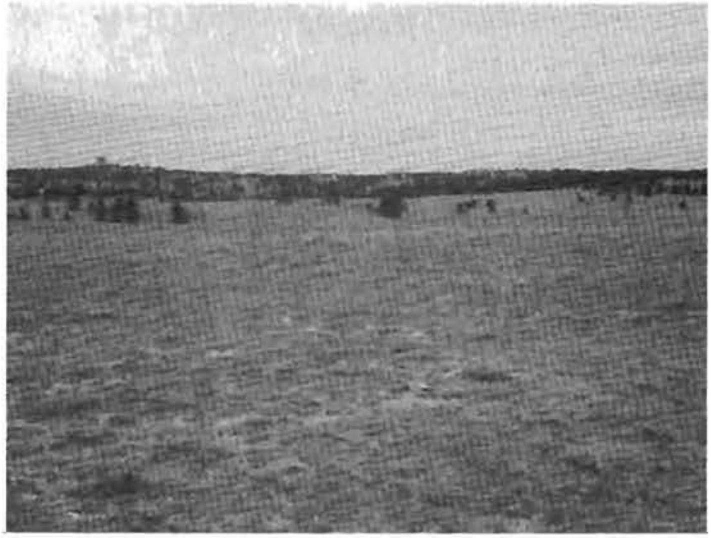
PATH LOSS MEASUREMENTS



TERRAIN PROFILE



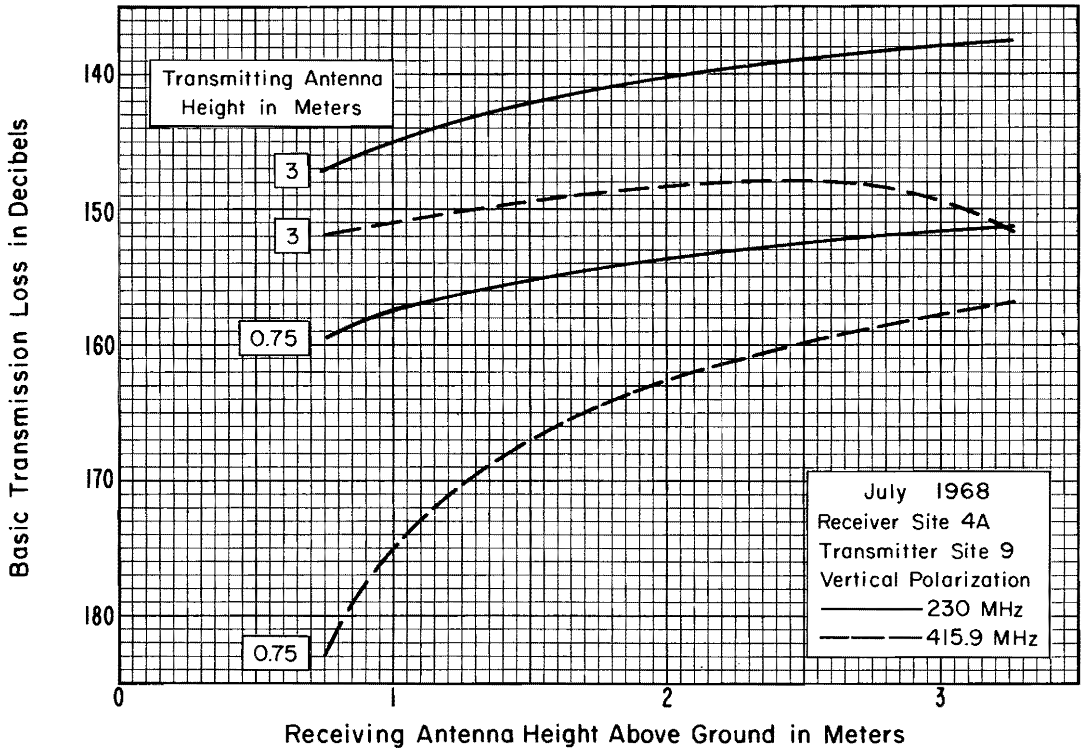
Wyoming PATH 4A - 9



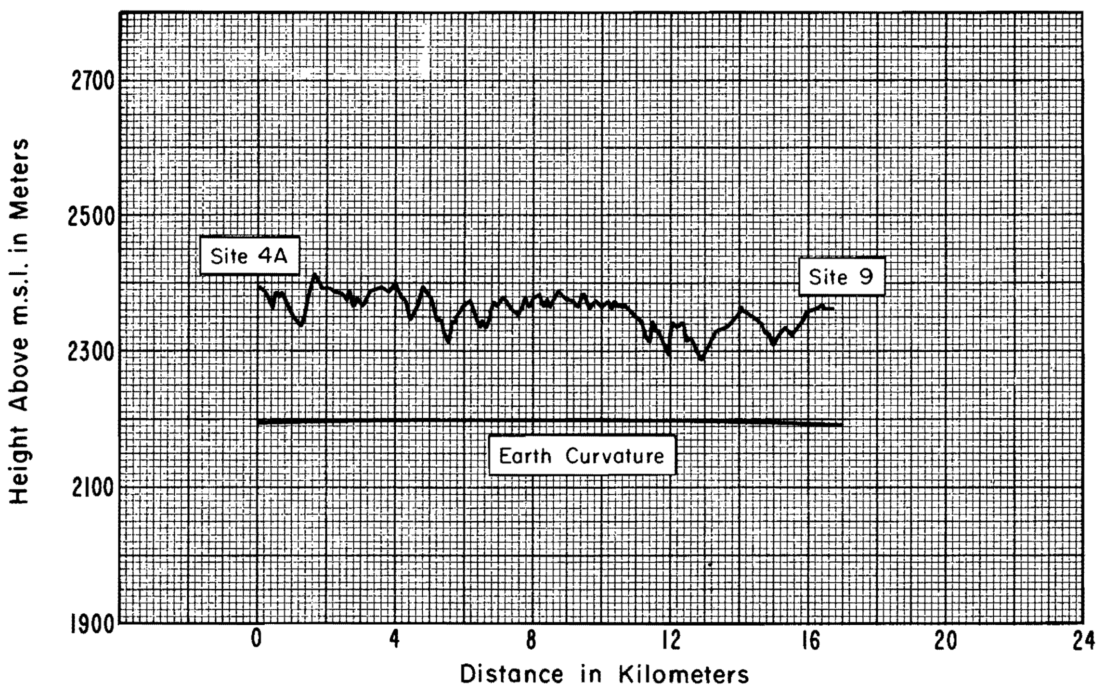
From site 4A toward site 9

From site 9 toward site 4A

PATH LOSS MEASUREMENTS



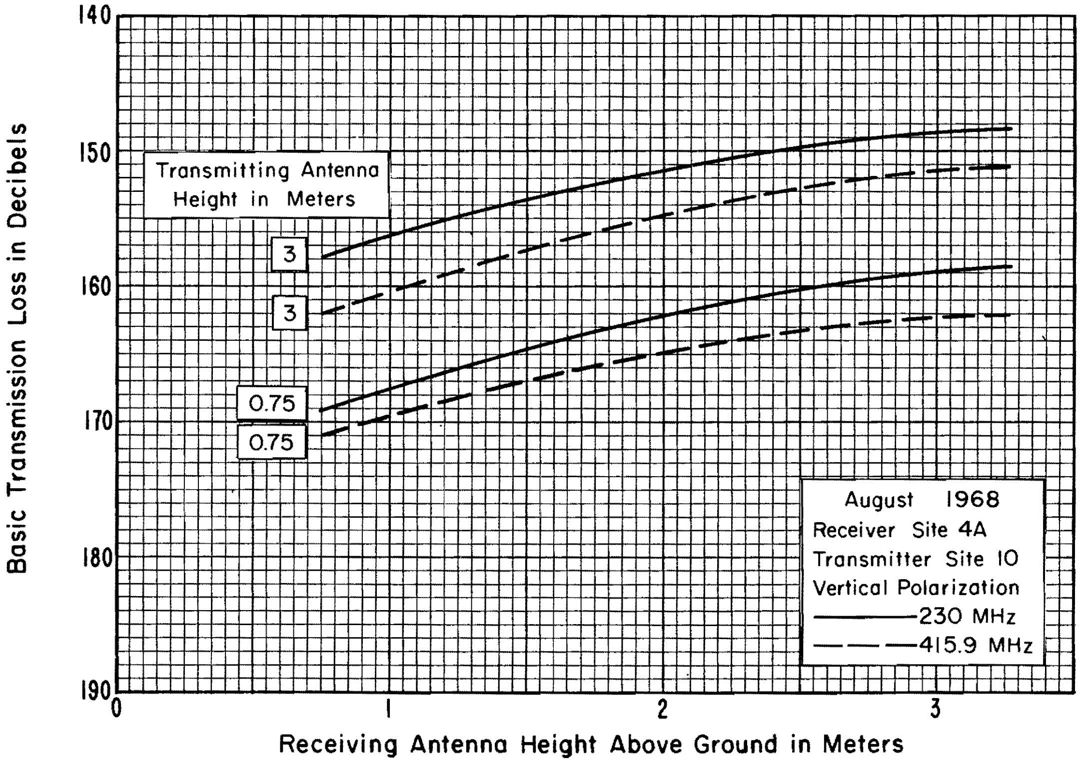
TERRAIN PROFILE



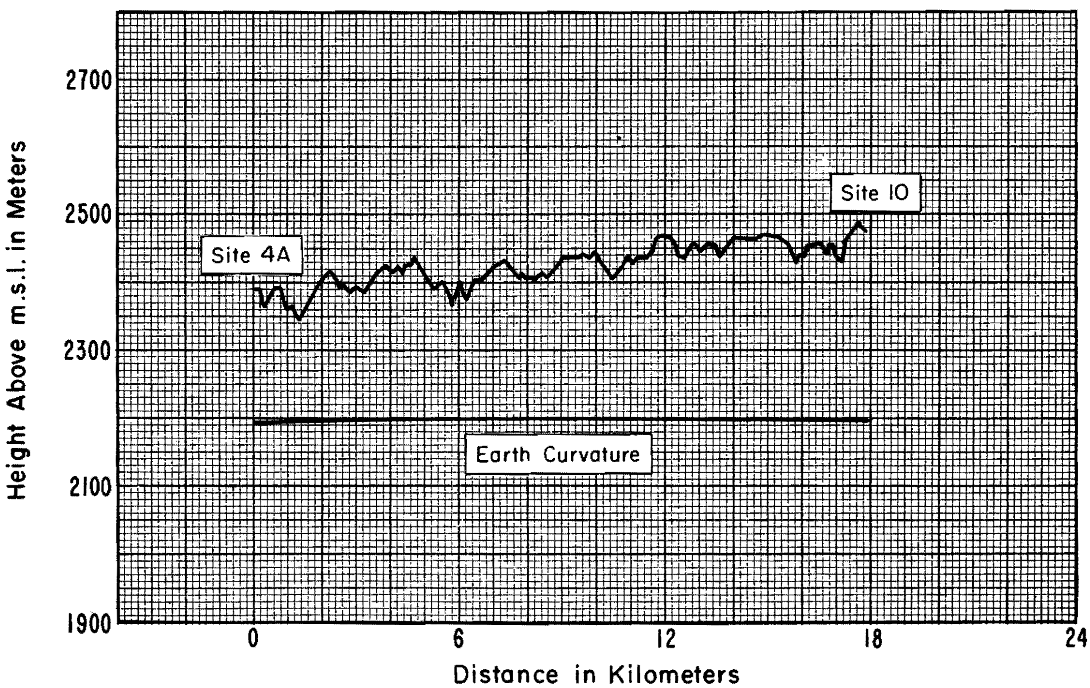
Wyoming PATH 4A - 10

From site 4A toward site 10

PATH LOSS MEASUREMENTS

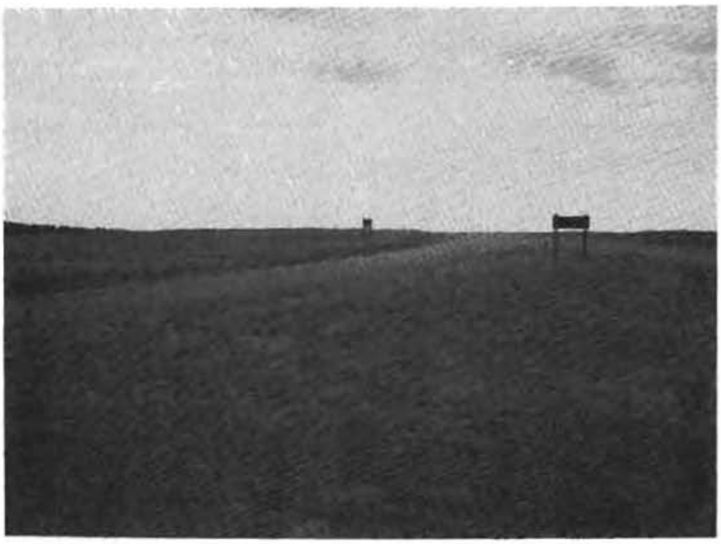


TERRAIN PROFILE



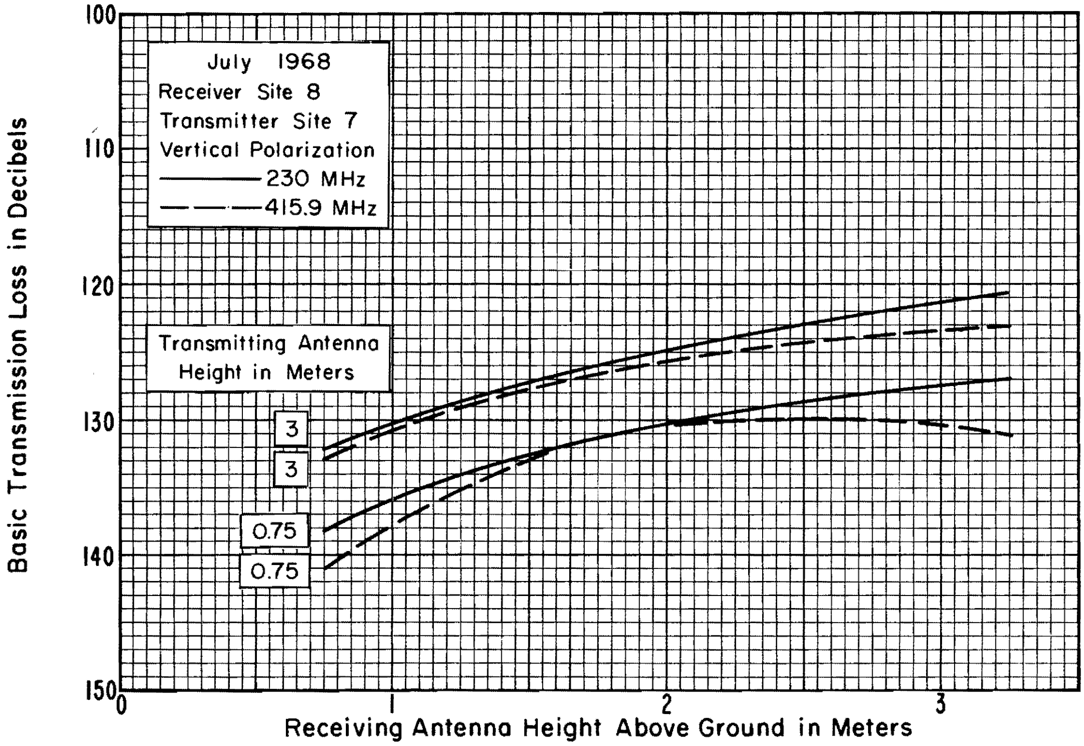
Wyoming PATH 7 - 8

From site 7 toward site 8

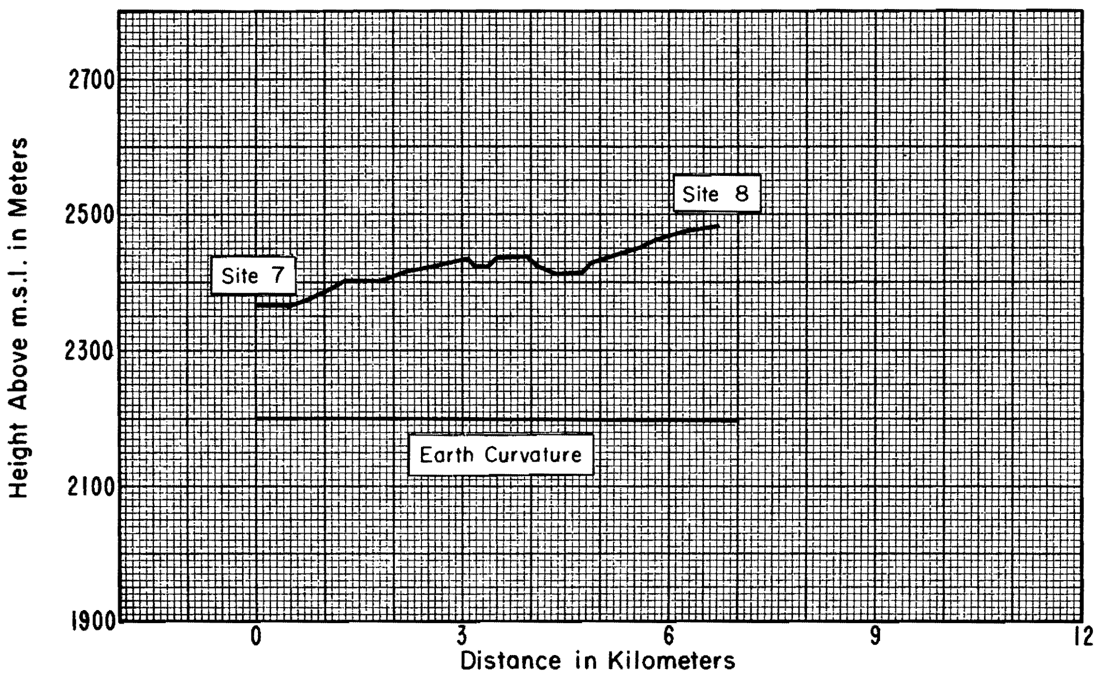


From site 8 toward site 7

PATH LOSS MEASUREMENTS



TERRAIN PROFILE

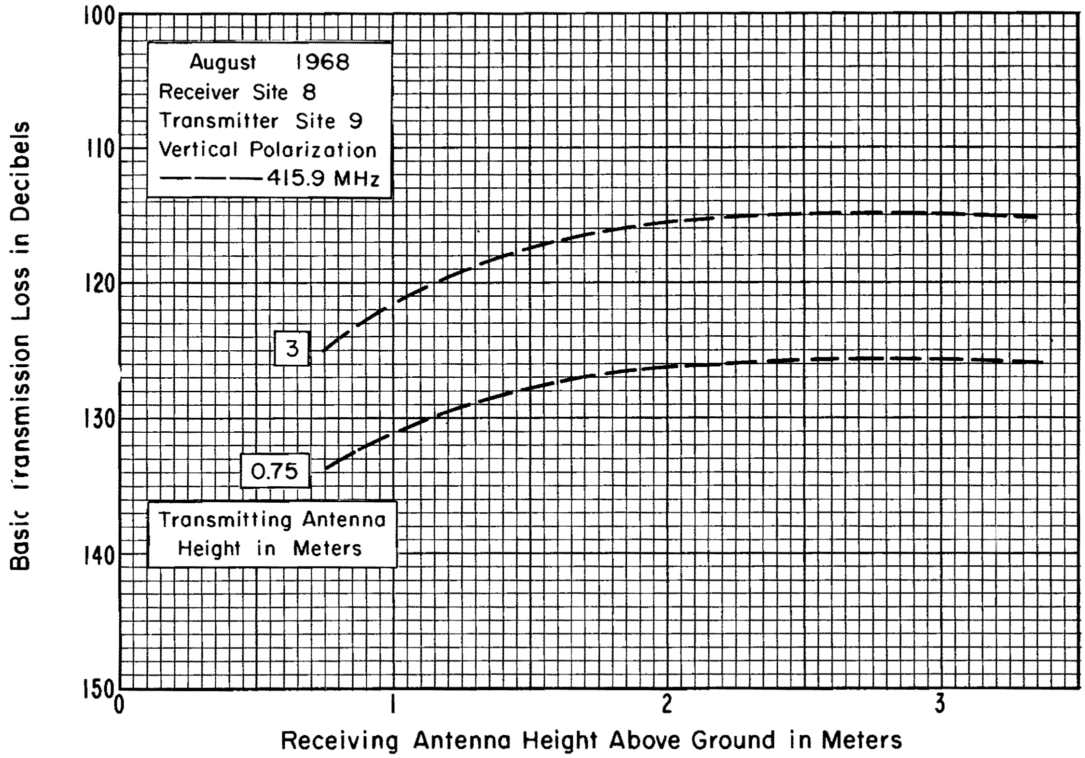


Wyoming PATH 8 - 9

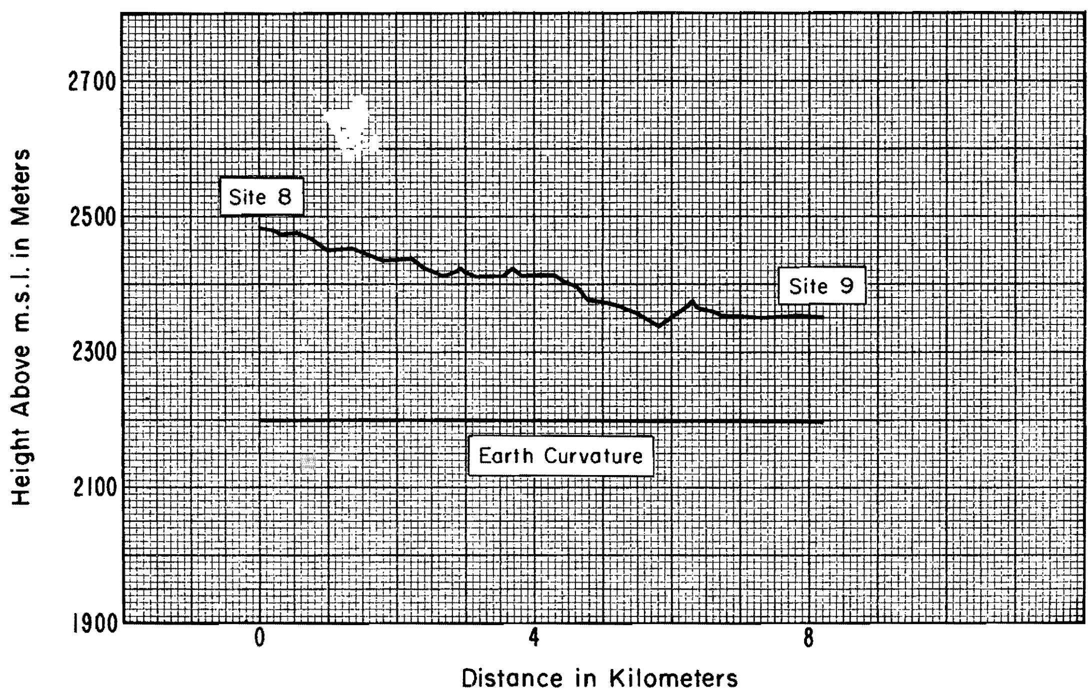
From site 8 toward site 9

From site 9 toward site 8

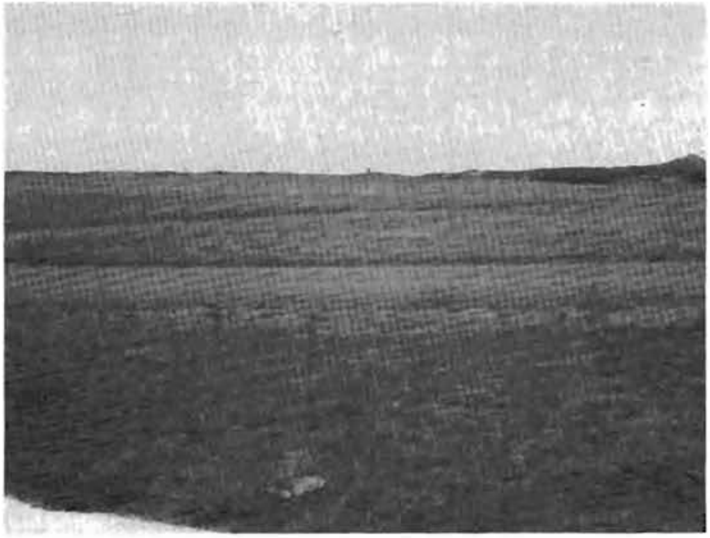
PATH LOSS MEASUREMENTS



TERRAIN PROFILE



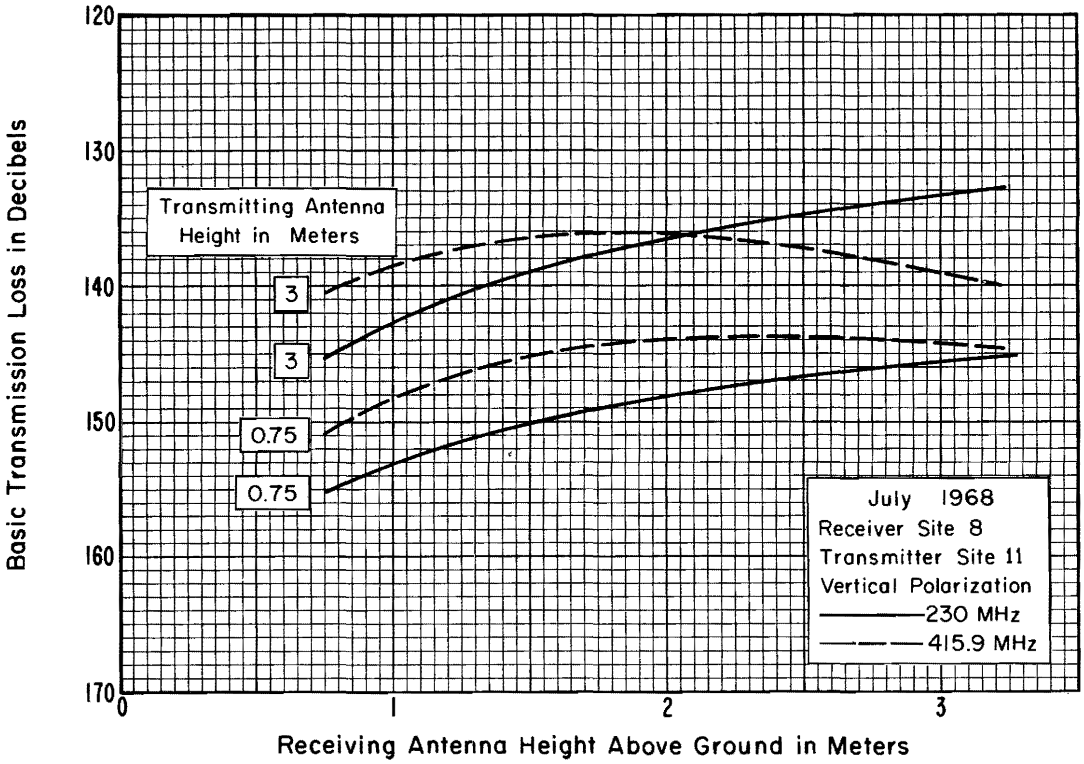
Wyoming PATH 8 - 11



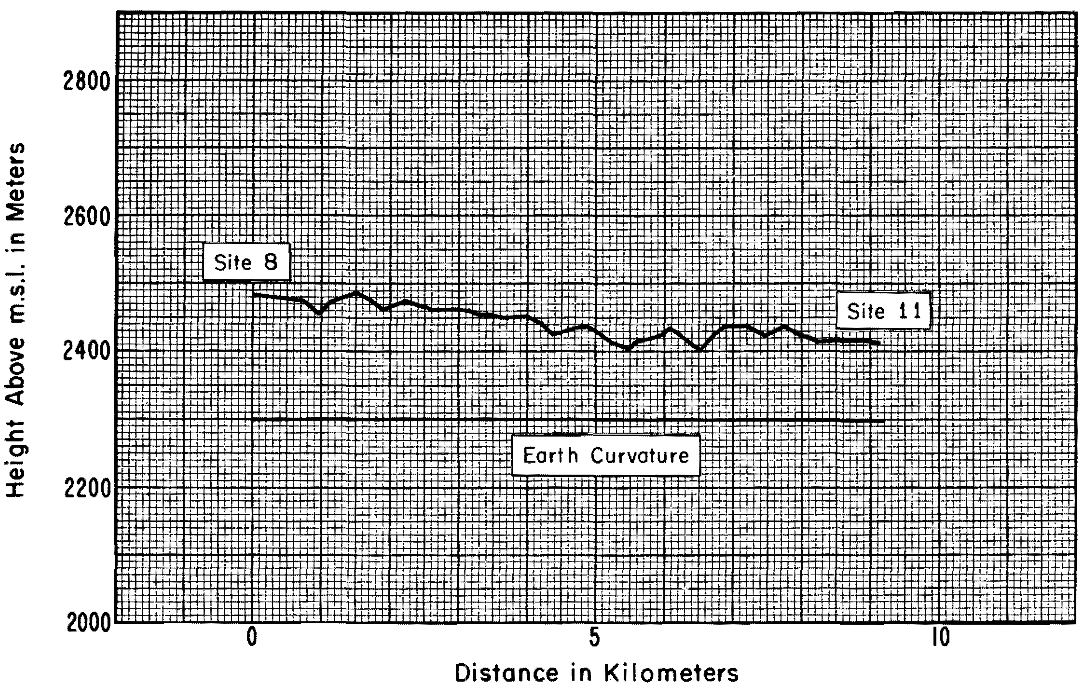
From site 8 toward site 11

From site 11 toward site 8

PATH LOSS MEASUREMENTS



TERRAIN PROFILE



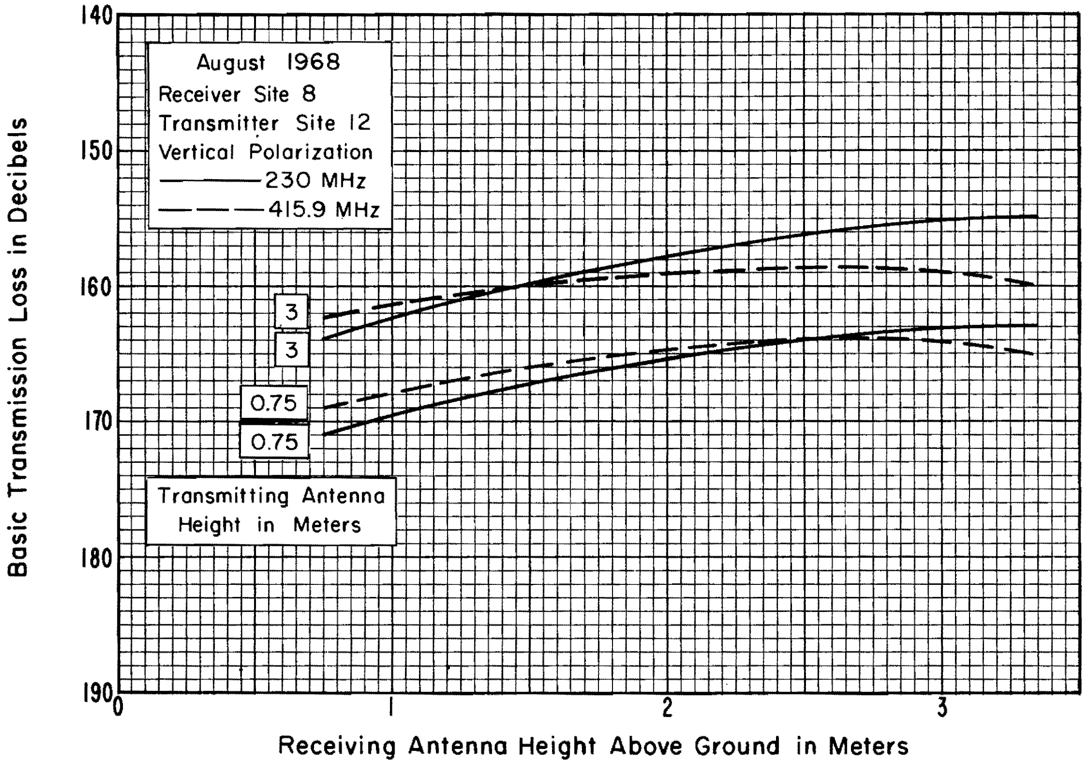
Wyoming PATH 8 - 12

From site 8 toward site 12

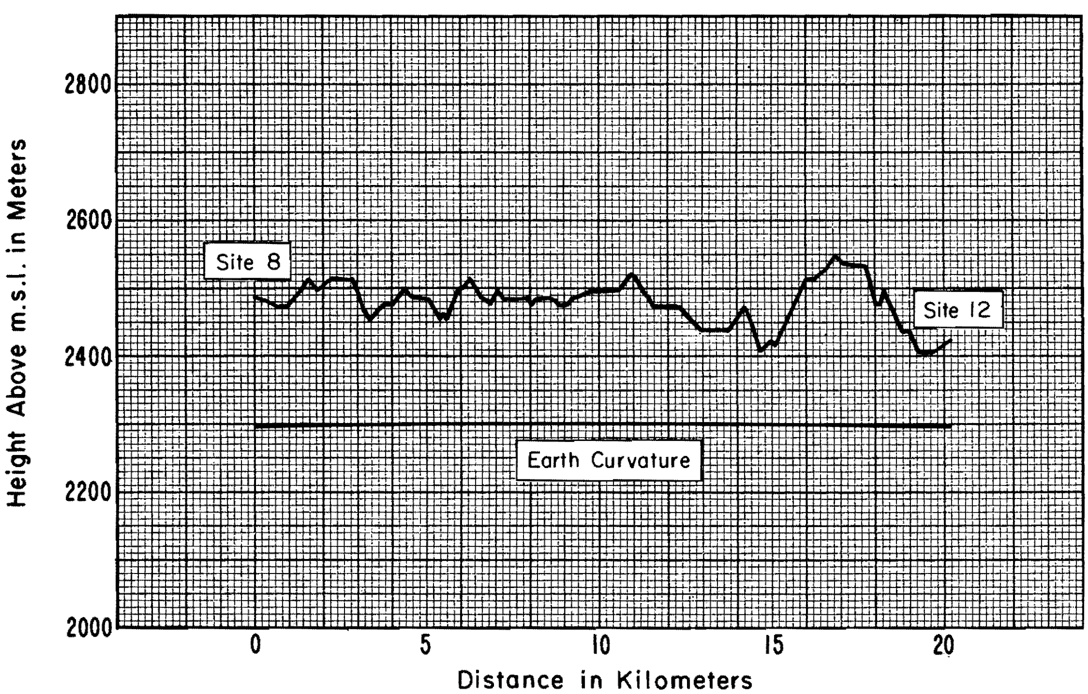
From site 12 toward site 8

WYOMING PATH 8 — 12

PATH LOSS MEASUREMENTS



TERRAIN PROFILE

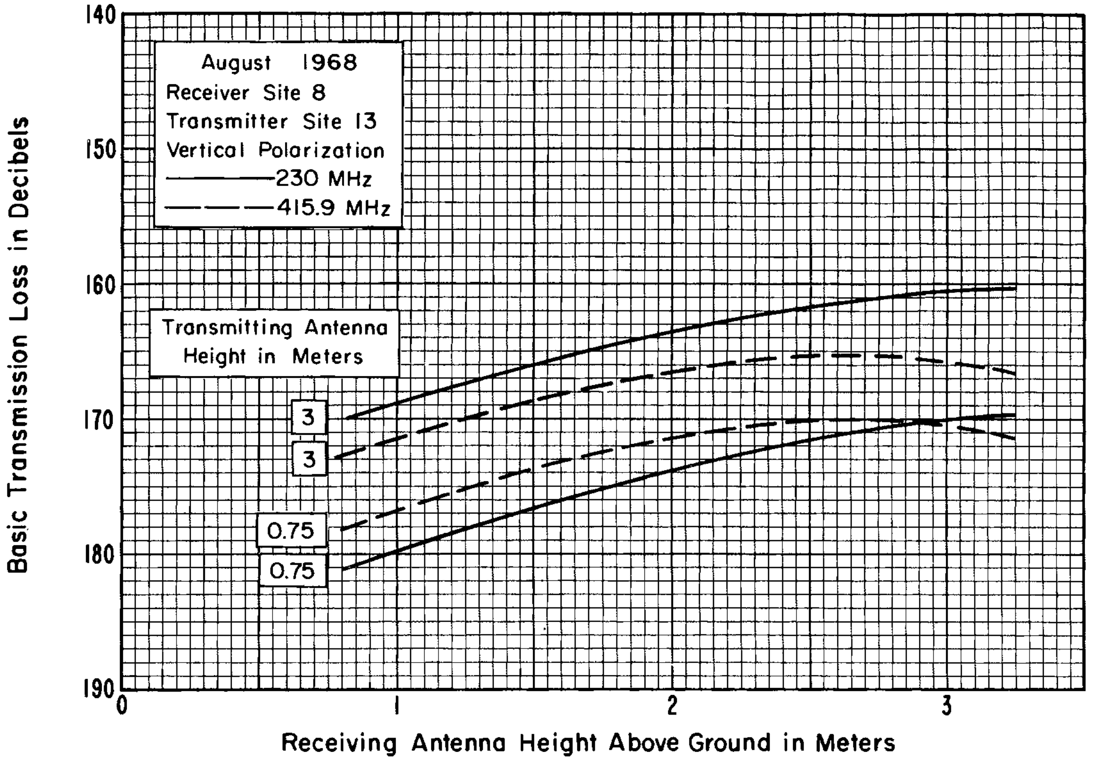


Wyoming PATH 8 - 13

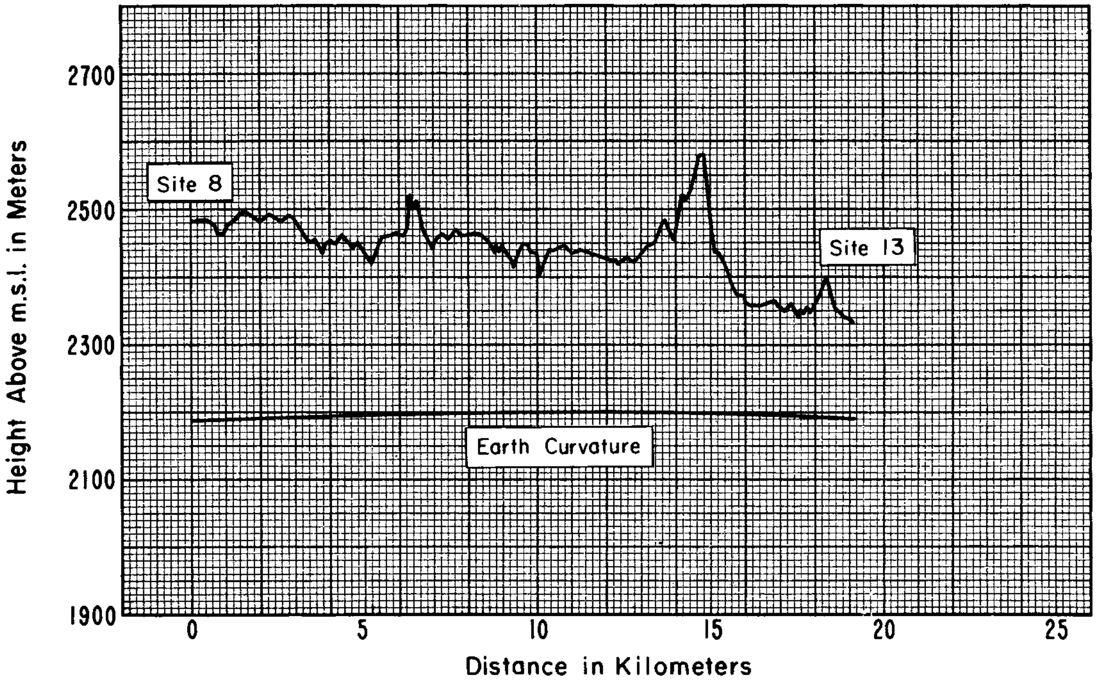
From site 8 toward site 13

From site 13 toward site 8

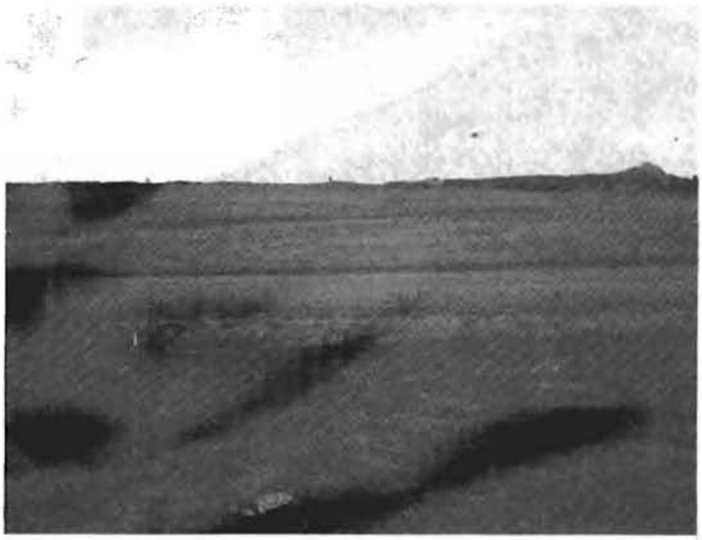
PATH LOSS MEASUREMENTS



TERRAIN PROFILE



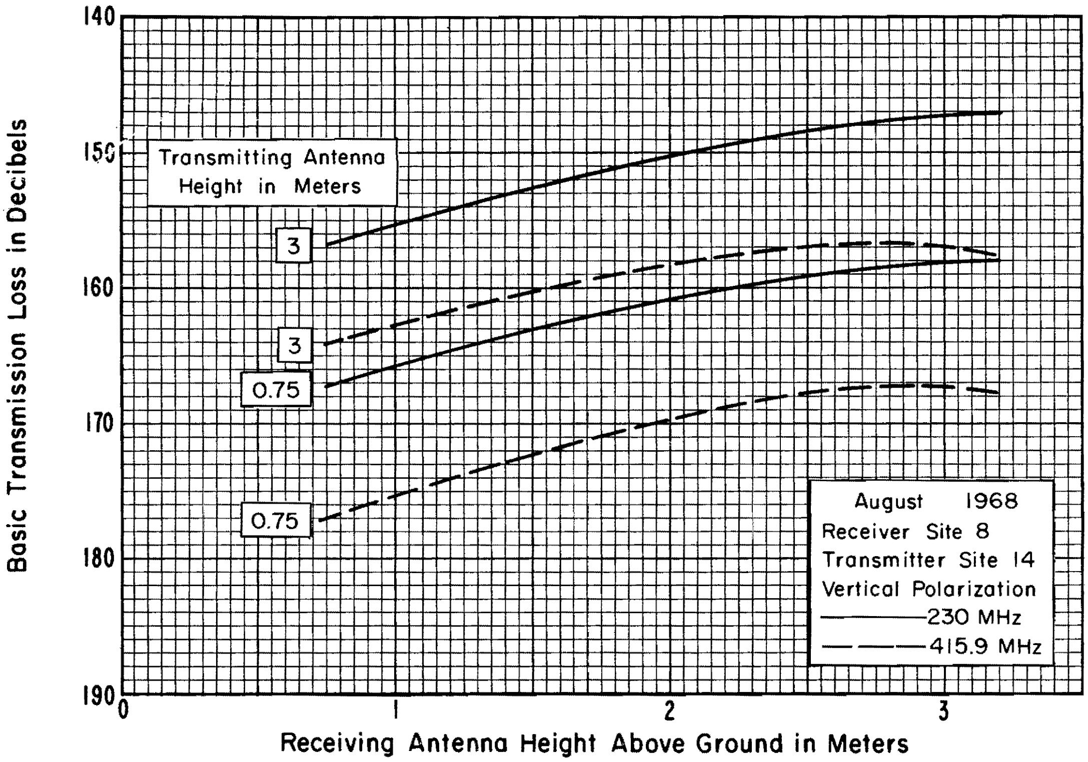
Wyoming PATH 8 - 14



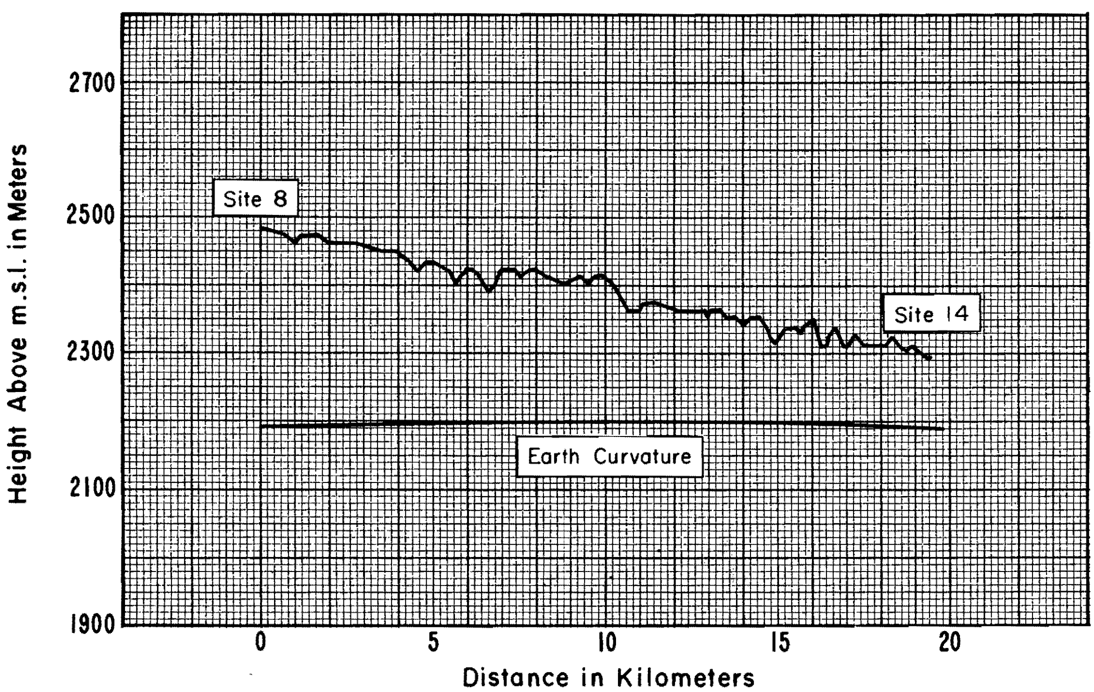
From site 8 toward site 14

From site 14 toward site 8

PATH LOSS MEASUREMENTS



TERRAIN PROFILE

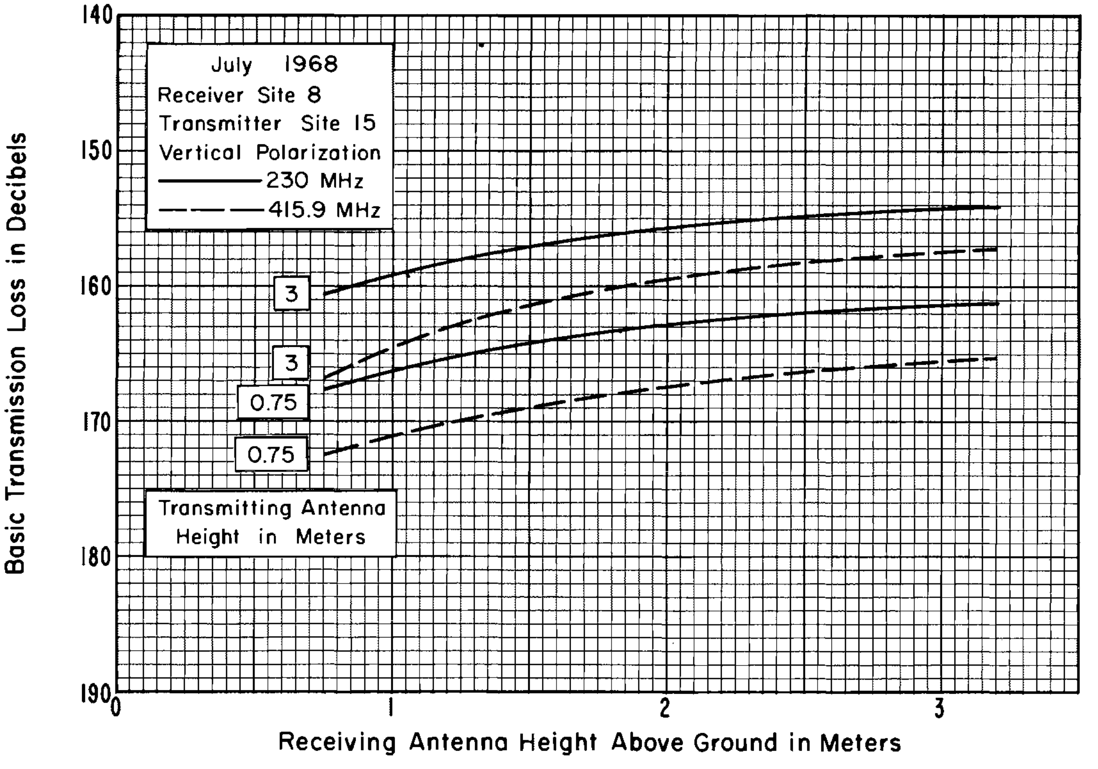


Wyoming PATH 8 - 15

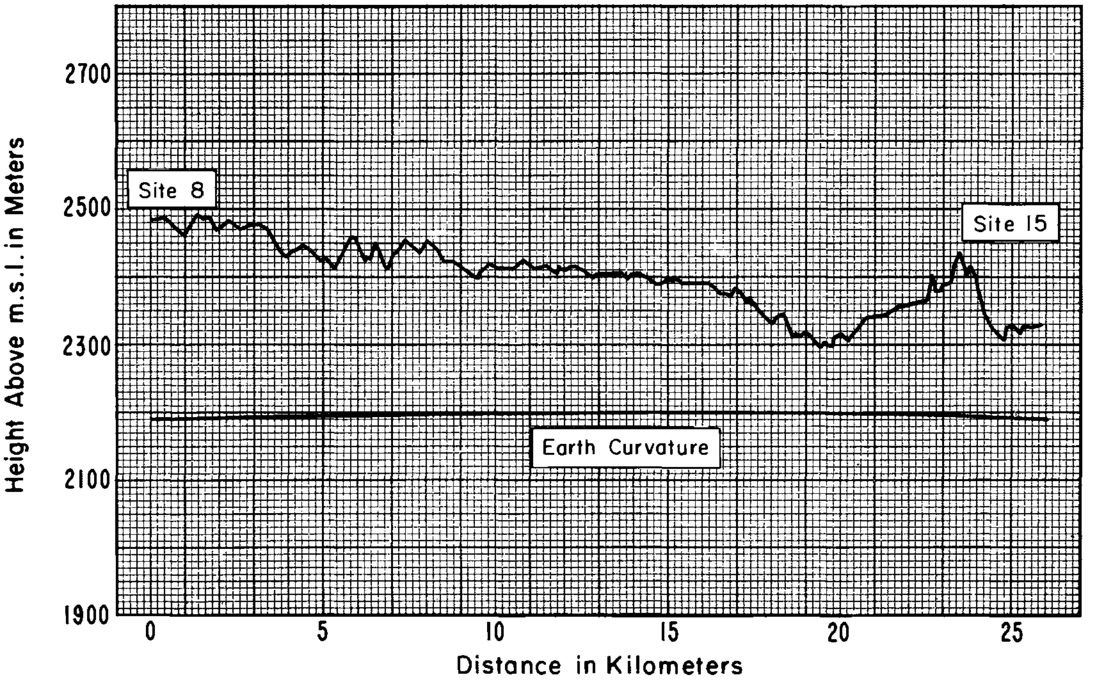
From site 15 toward site 8

From site 8 toward site 15

PATH LOSS MEASUREMENTS

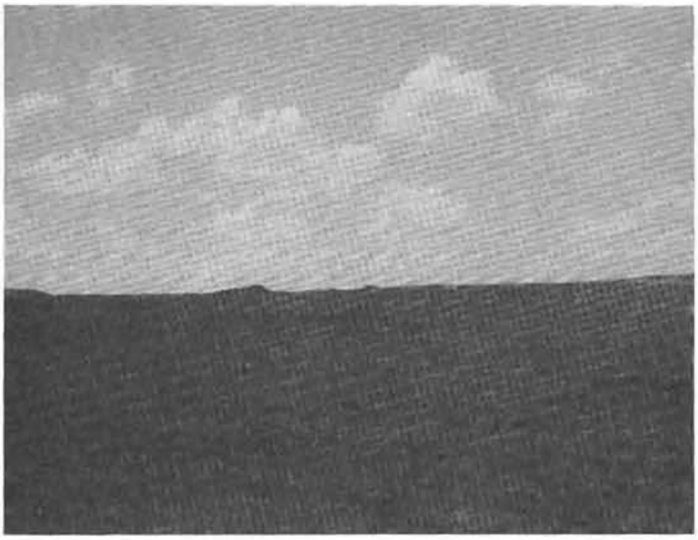


TERRAIN PROFILE



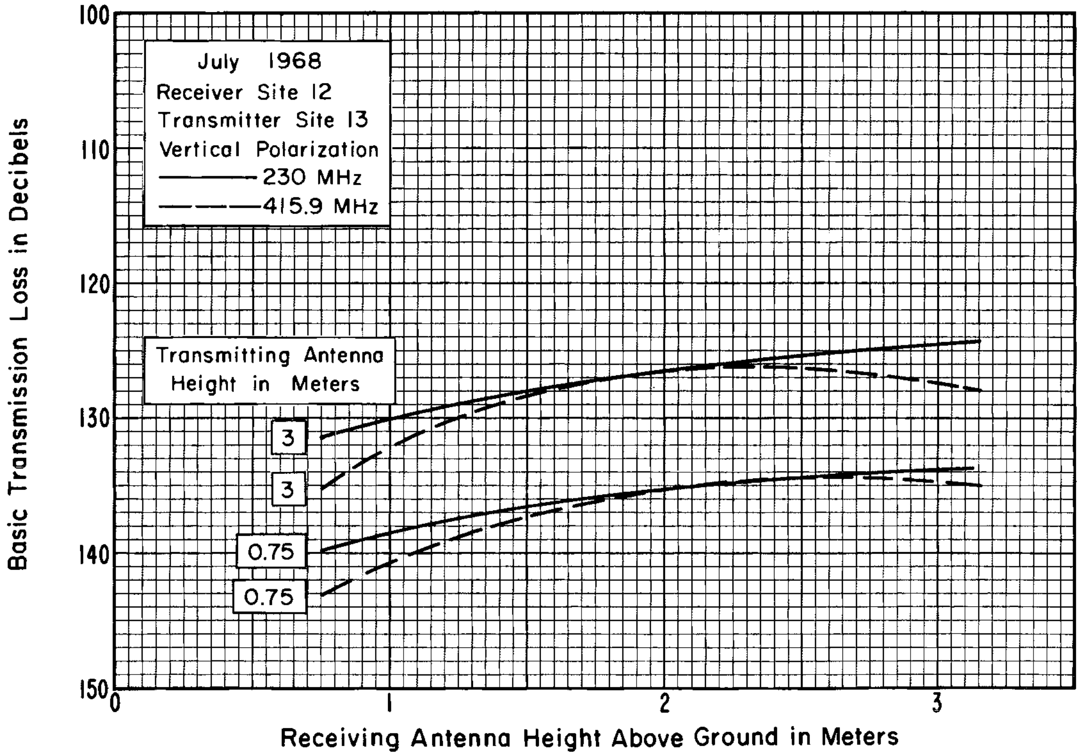
Wyoming PATH 12 - 13

From site 12 toward site 13

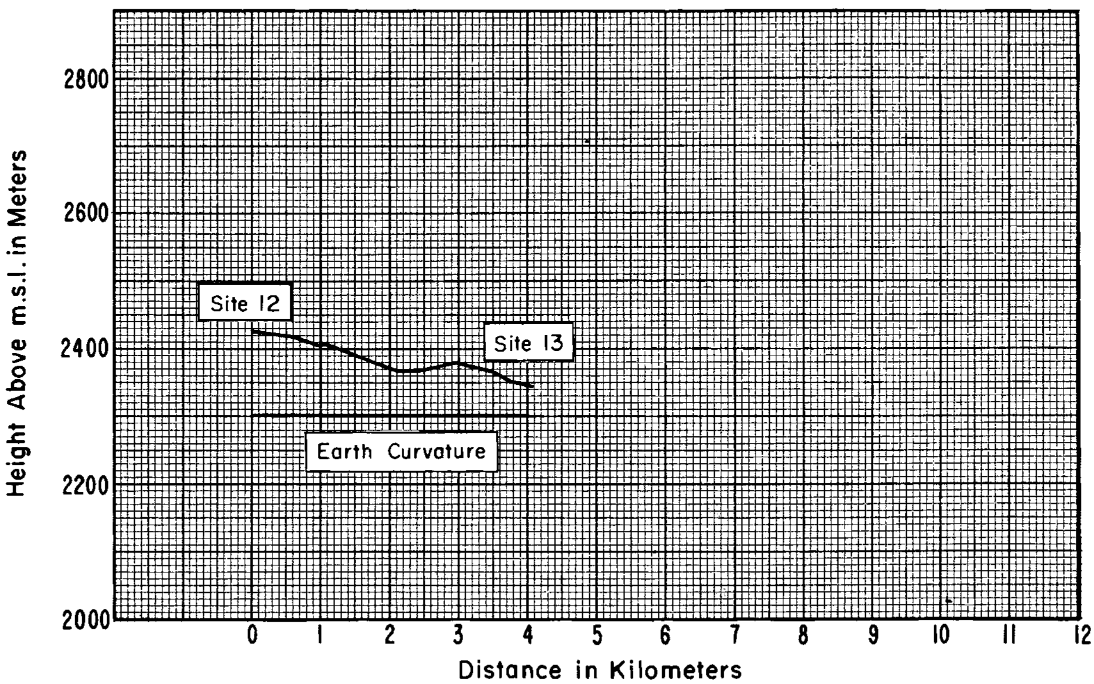


From site 13 toward site 12

PATH LOSS MEASUREMENTS

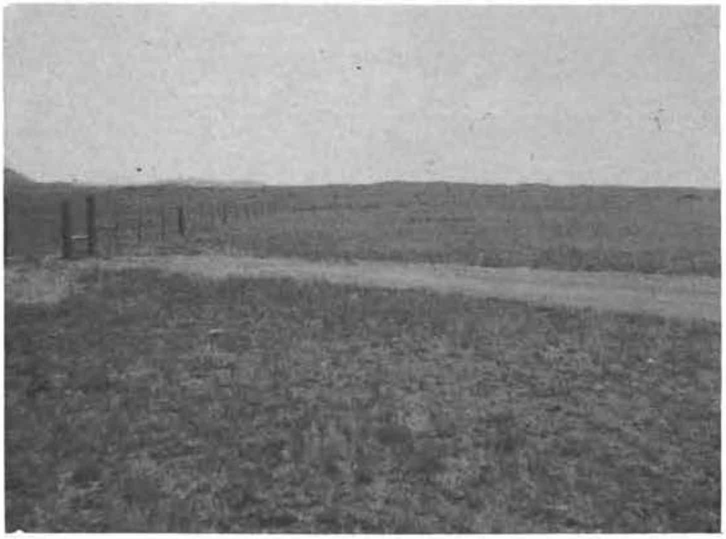


TERRAIN PROFILE



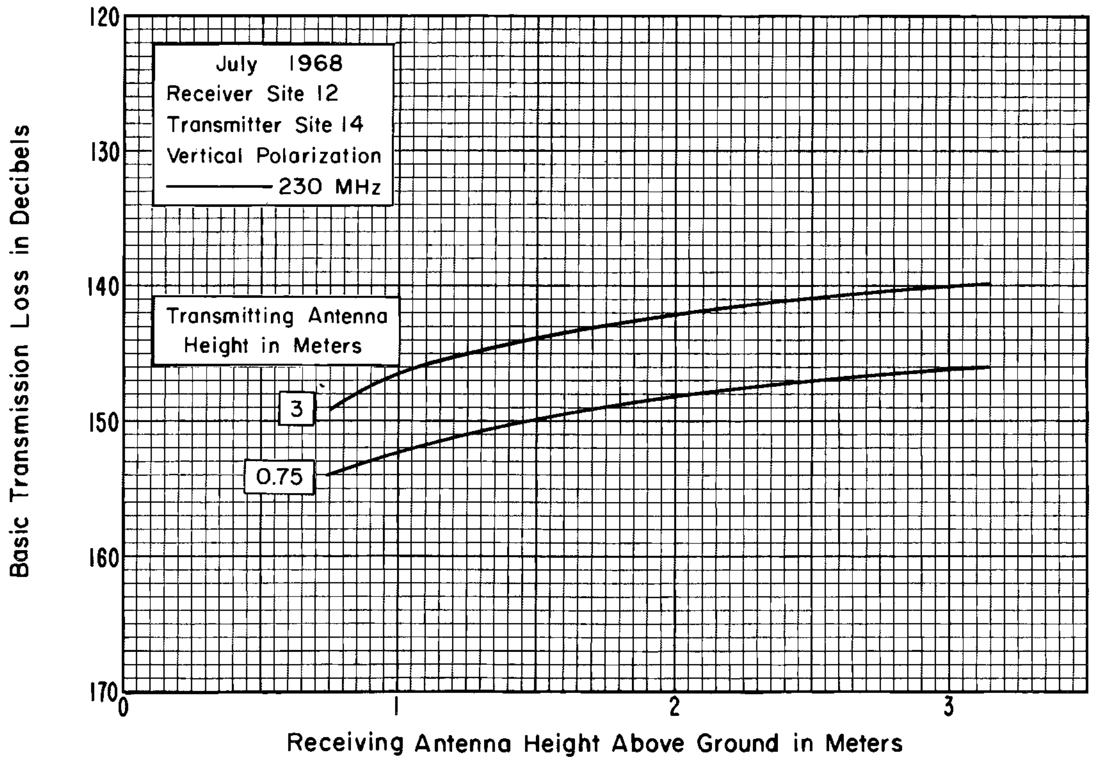
Wyoming PATH 12 - 14

From site 12 toward site 14

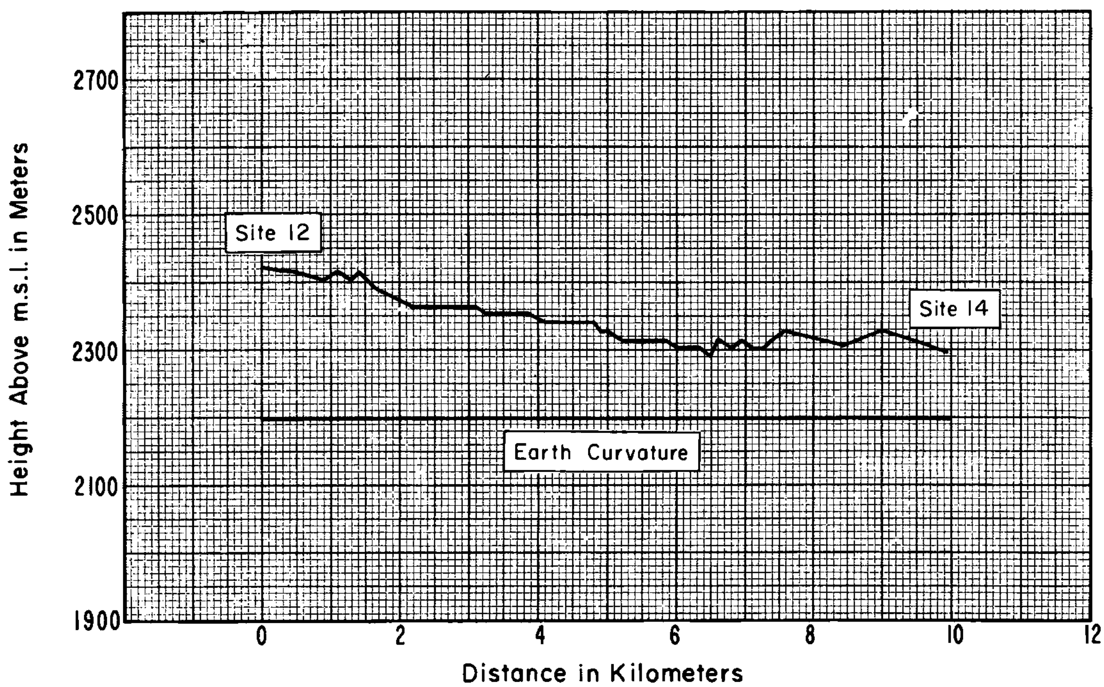


From site 14 toward site 12

PATH LOSS MEASUREMENTS

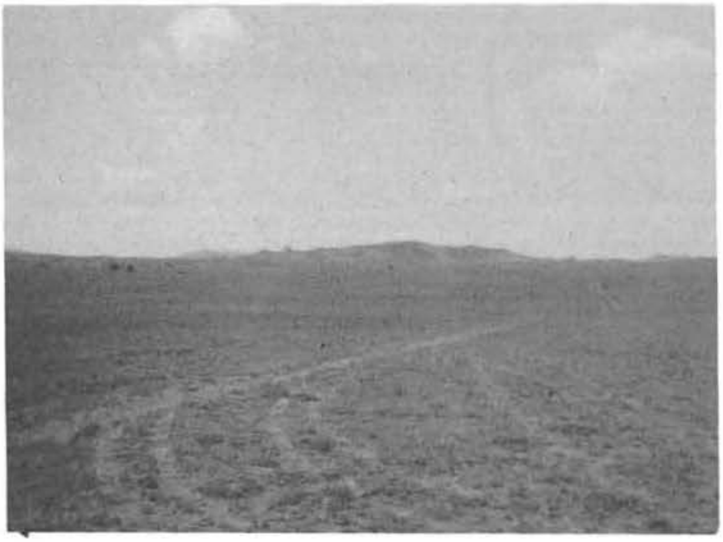


TERRAIN PROFILE



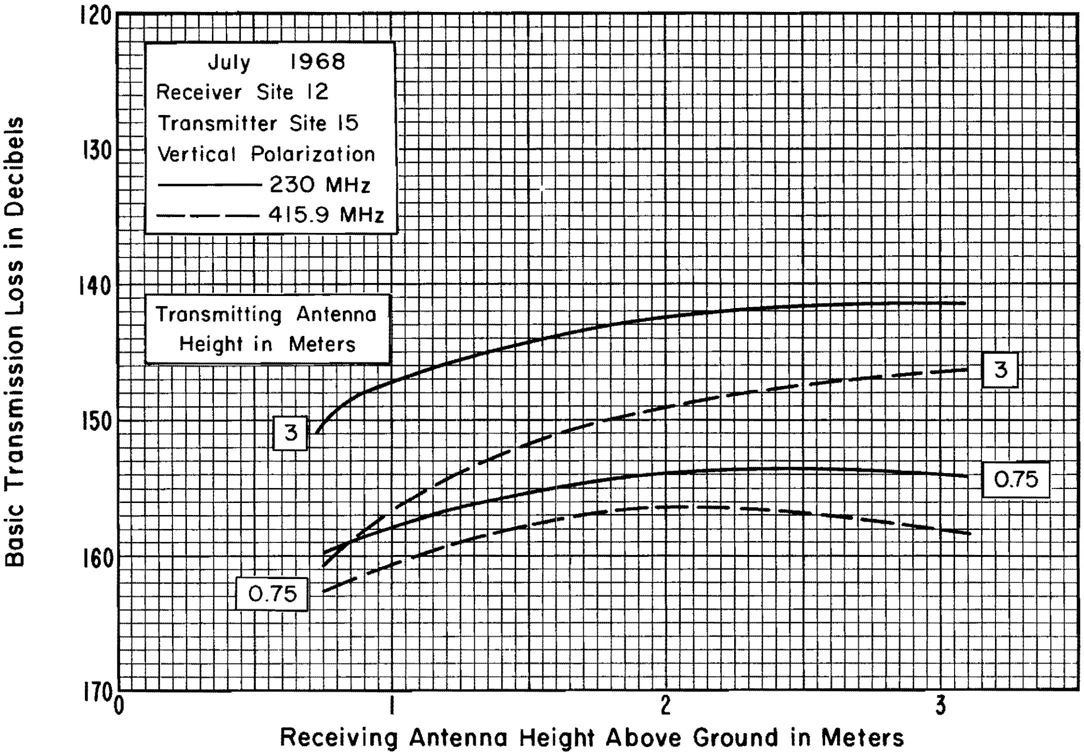
Wyoming PATH 12 - 15

From site 12 toward site 15

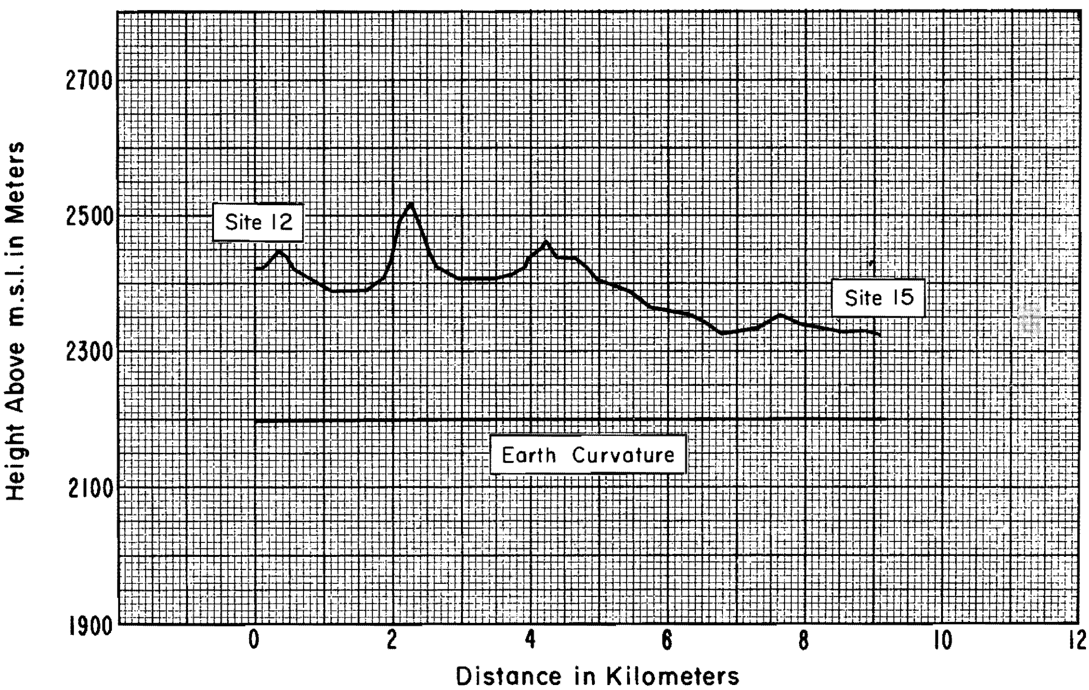


From site 15 toward site 12

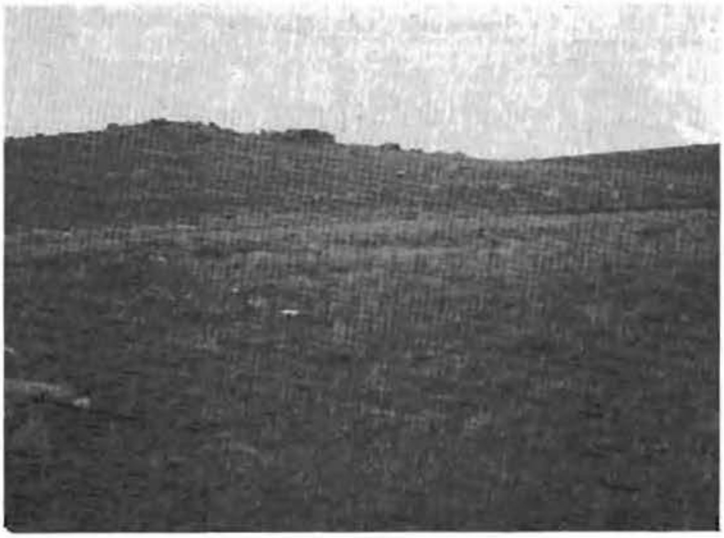
PATH LOSS MEASUREMENTS



TERRAIN PROFILE



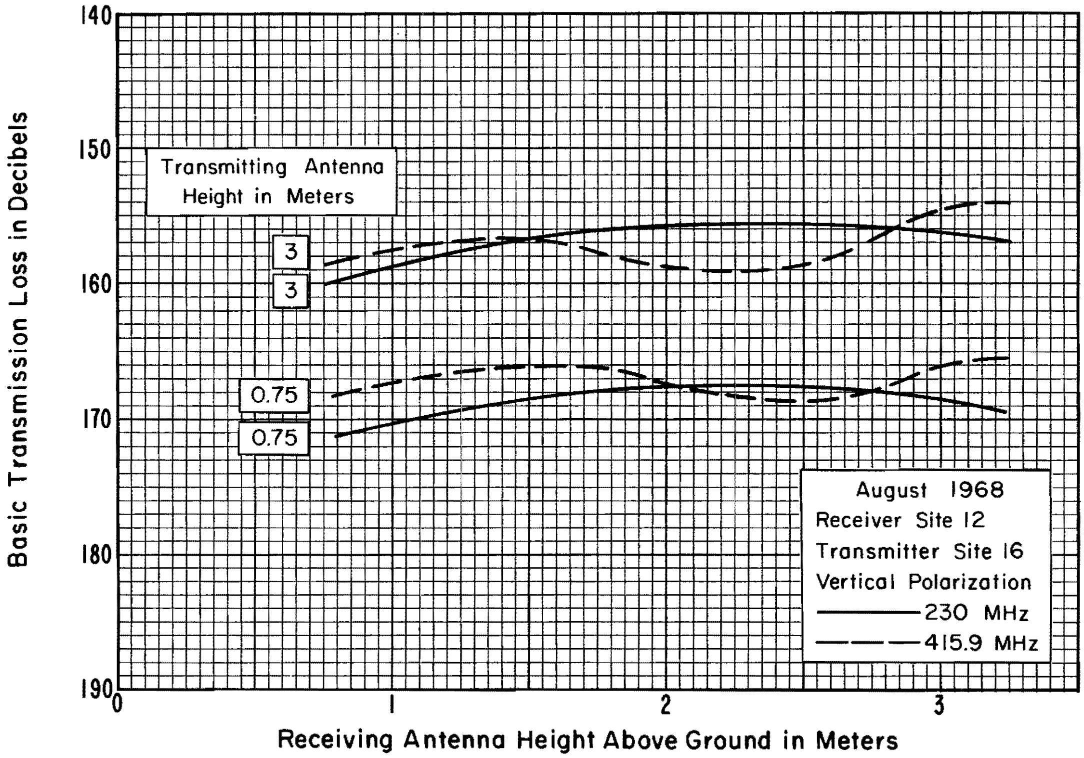
Wyoming PATH 12 - 16



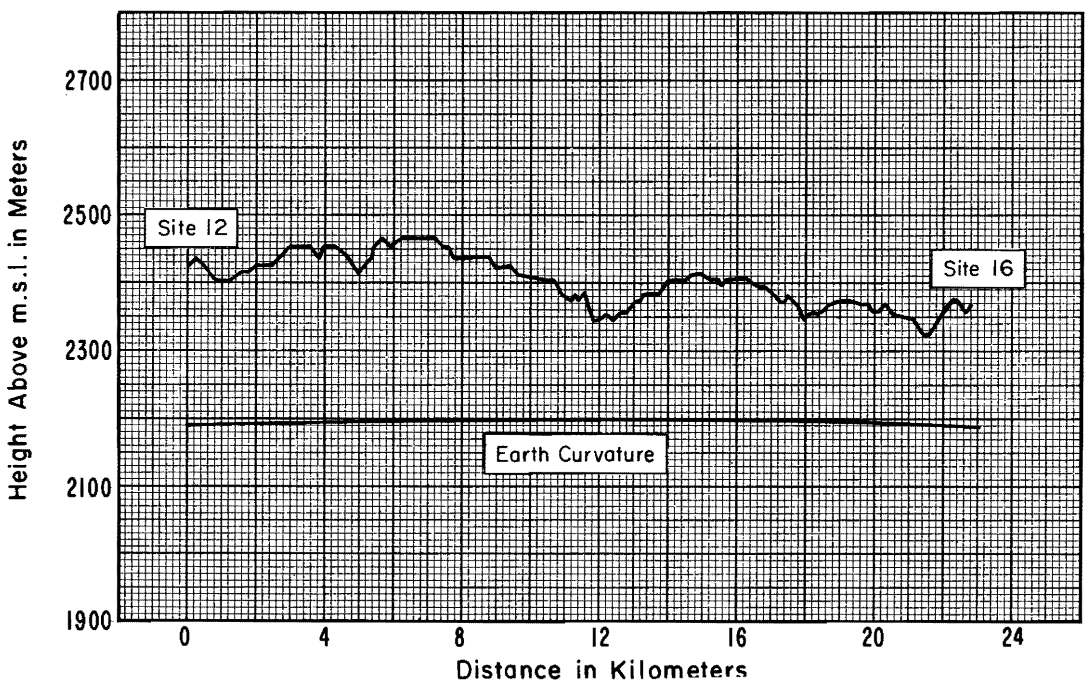
From site 12 toward site 16

From site 16 toward site 12

PATH LOSS MEASUREMENTS

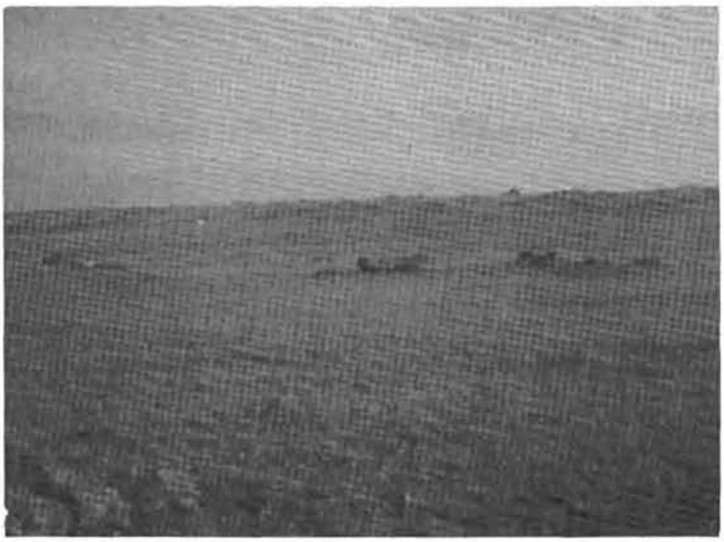


TERRAIN PROFILE



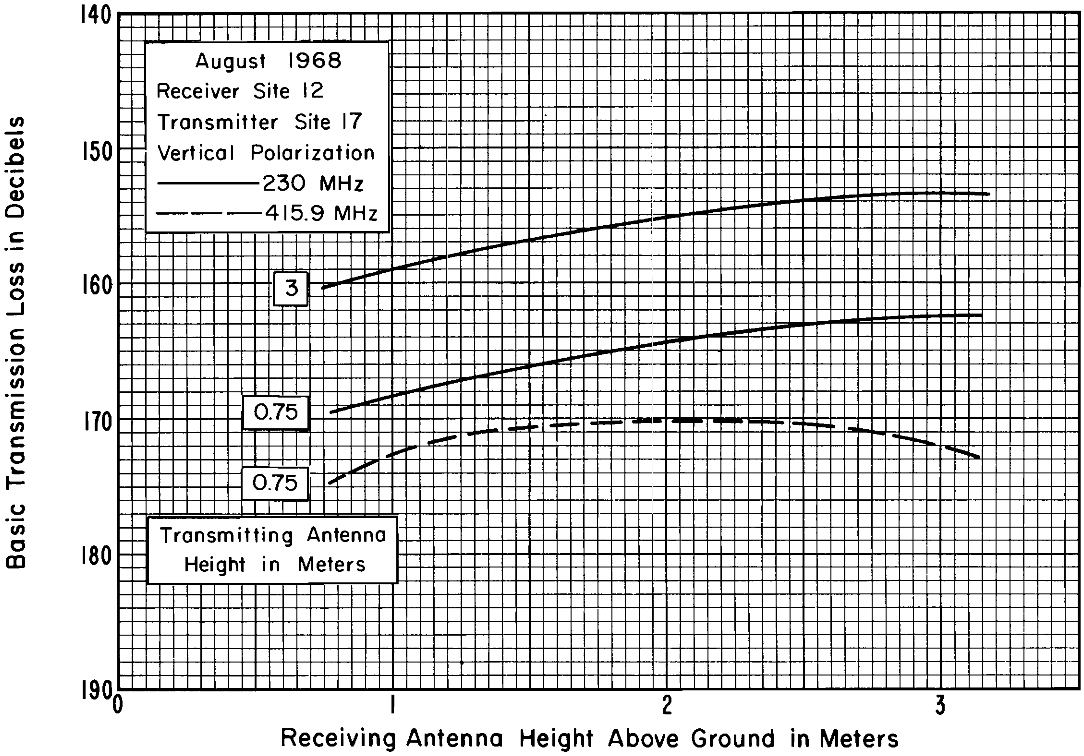
Wyoming PATH 12 - 17

From site 12 toward site 17

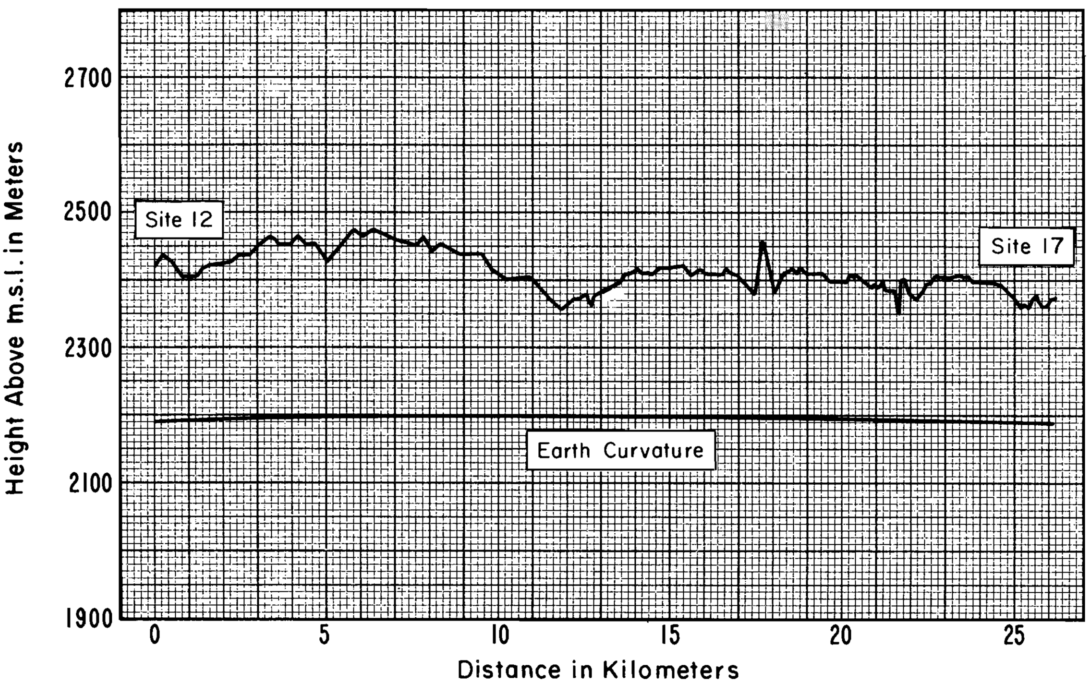


From site 17 toward site 12

PATH LOSS MEASUREMENTS



TERRAIN PROFILE



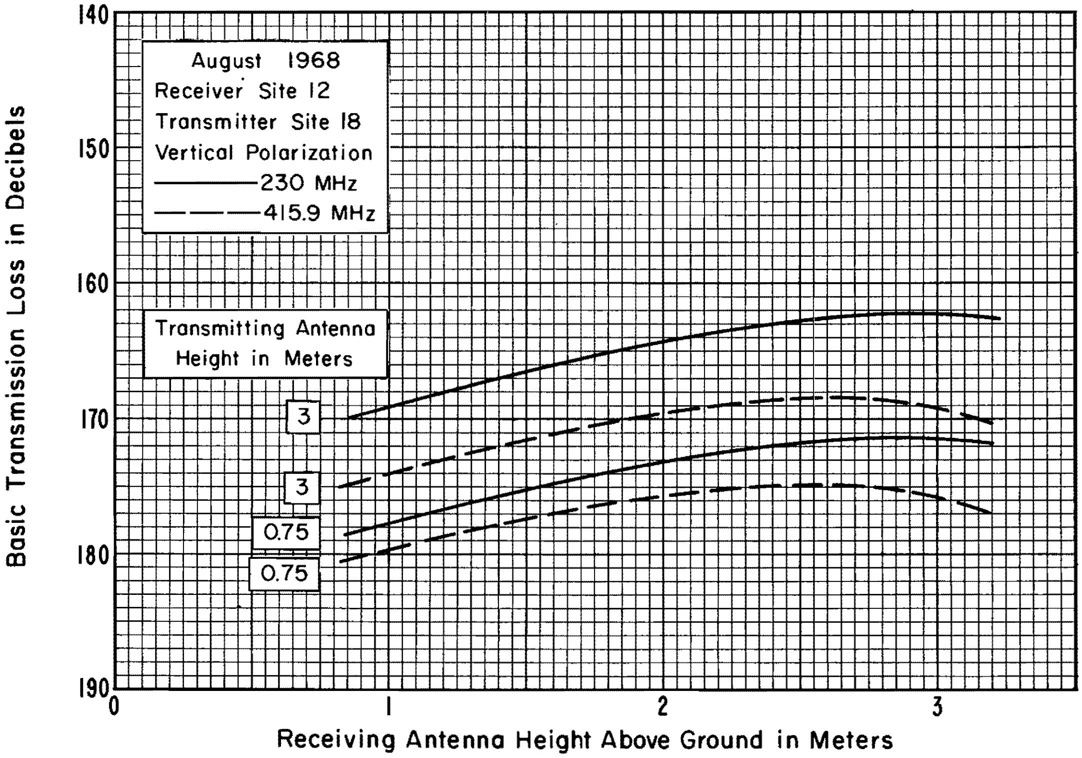
Wyoming PATH 12 - 18

From site 12 toward site 18

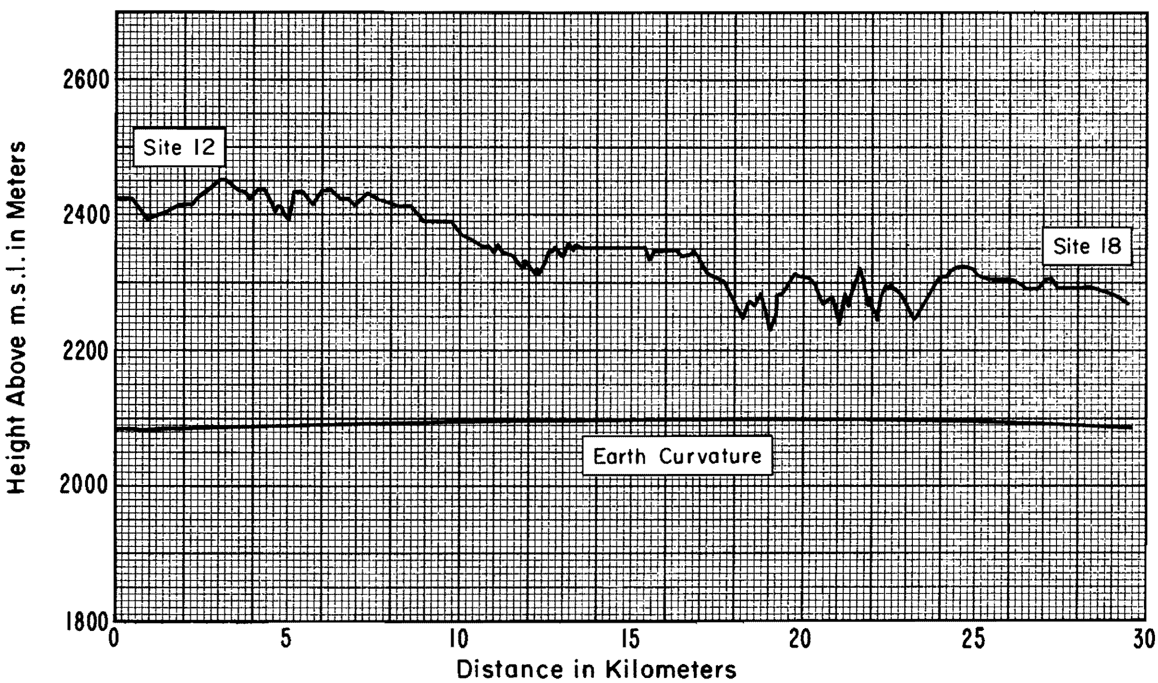
From site 18 toward site 12

WYOMING PATH 12 — 18

PATH LOSS MEASUREMENTS

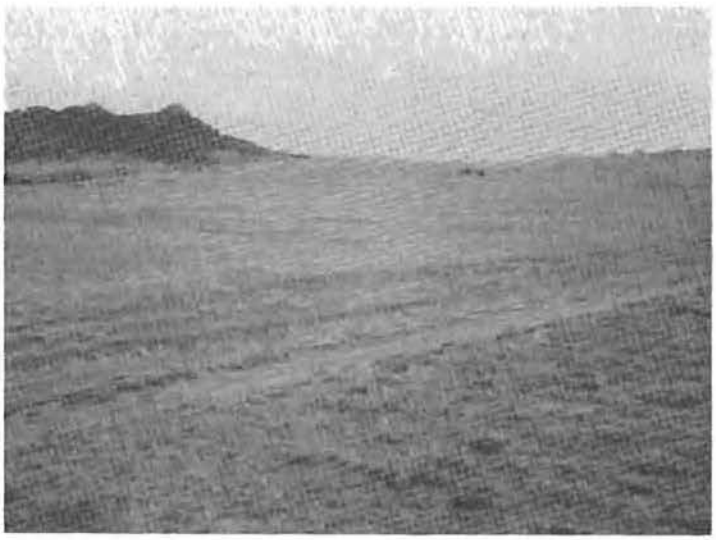


TERRAIN PROFILE



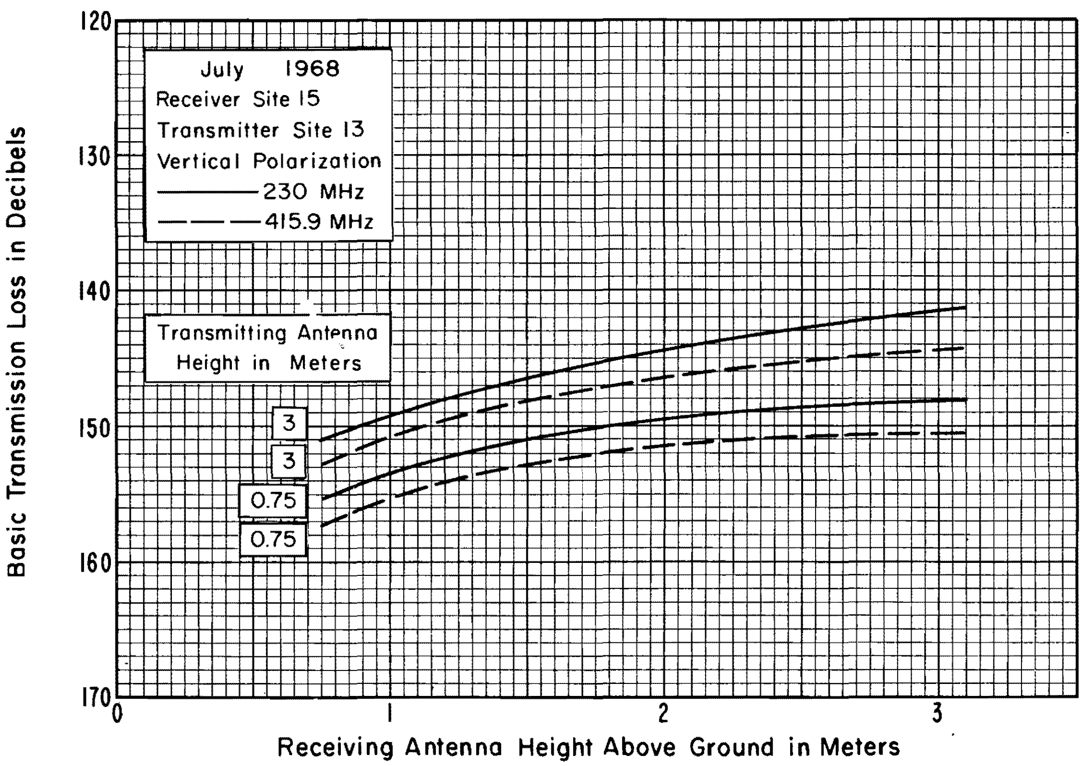
Wyoming PATH 13 - 15

From site 13 toward site 15

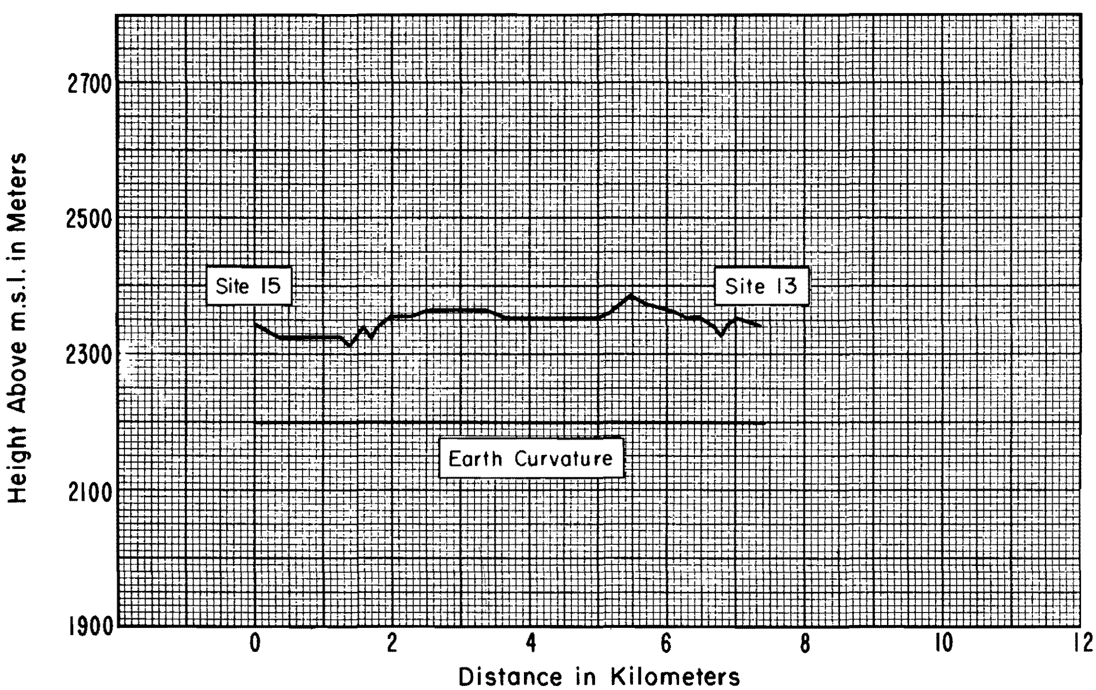


From site 15 toward site 13

PATH LOSS MEASUREMENTS

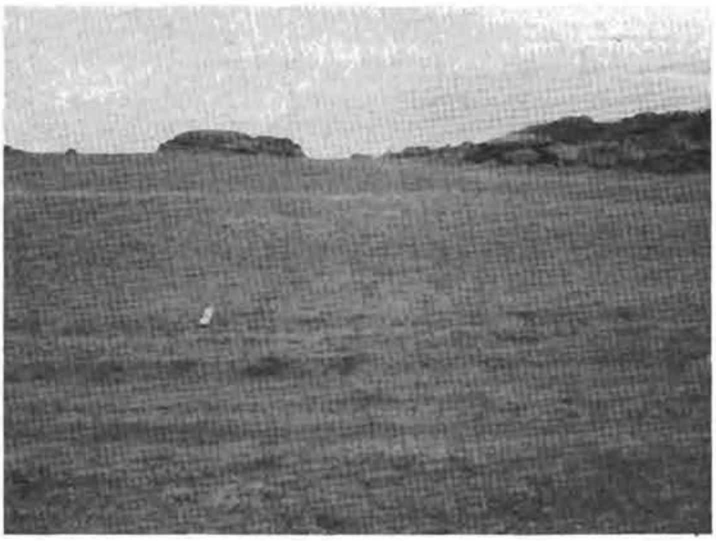


TERRAIN PROFILE



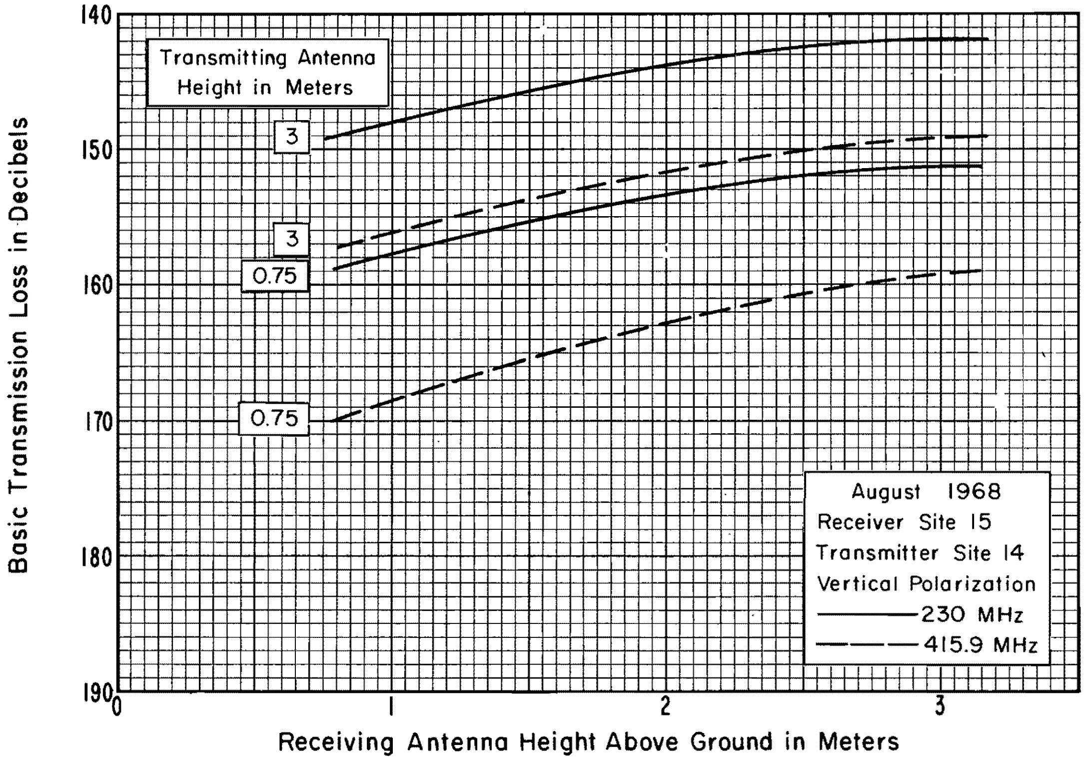
Wyoming PATH 14 - 15

From site 14 toward site 15

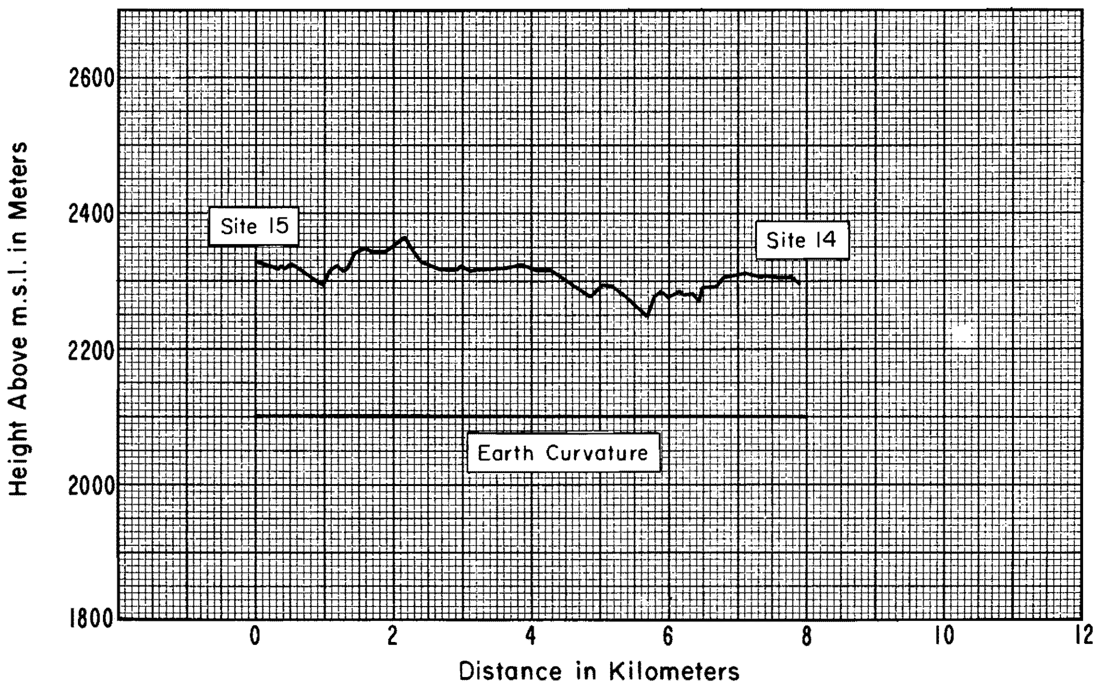


From site 15 toward site 14

PATH LOSS MEASUREMENTS

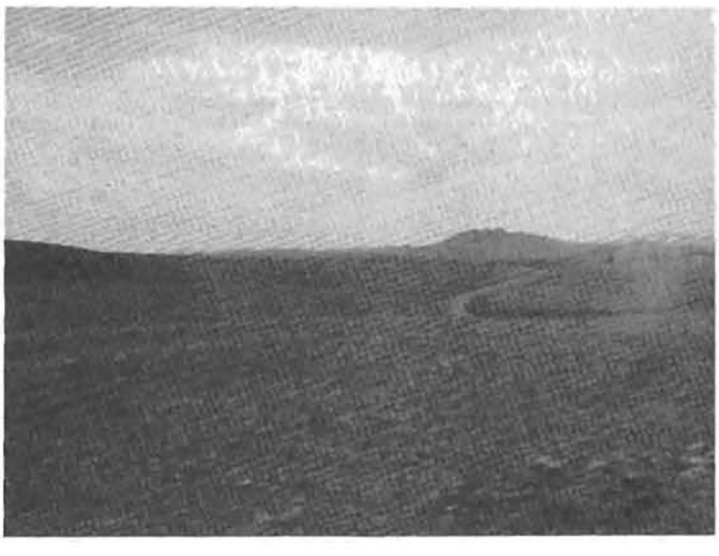


TERRAIN PROFILE



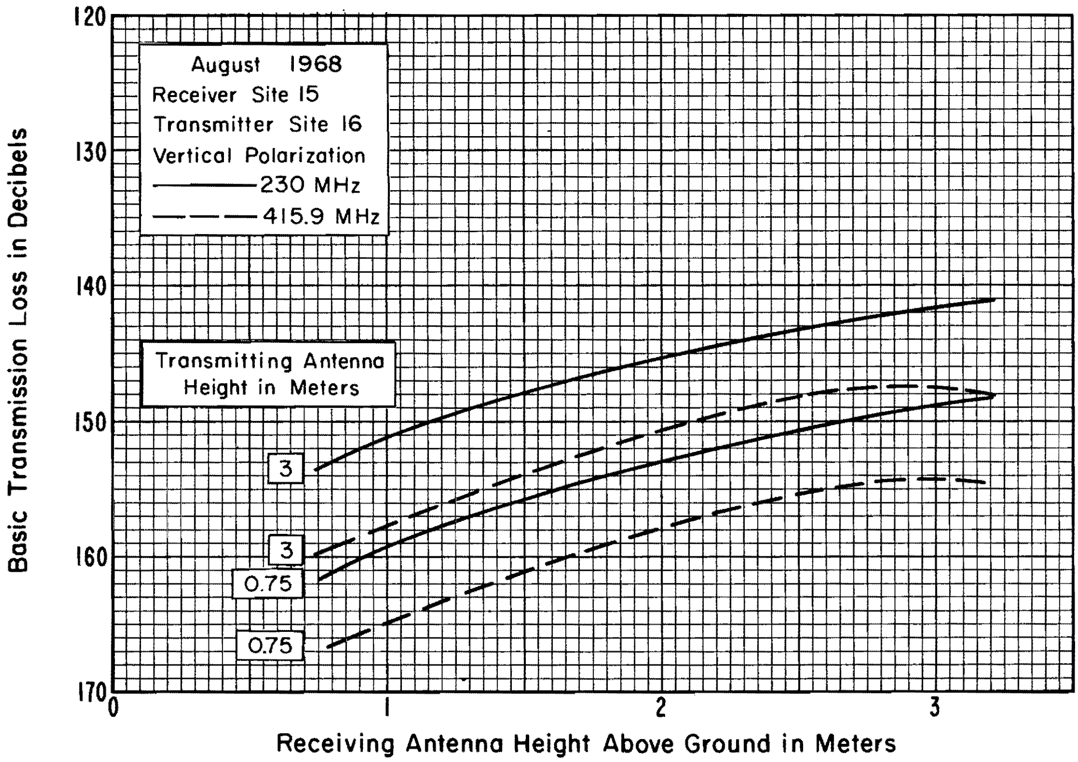
Wyoming PATH 15 - 16

From site 15 toward site 16

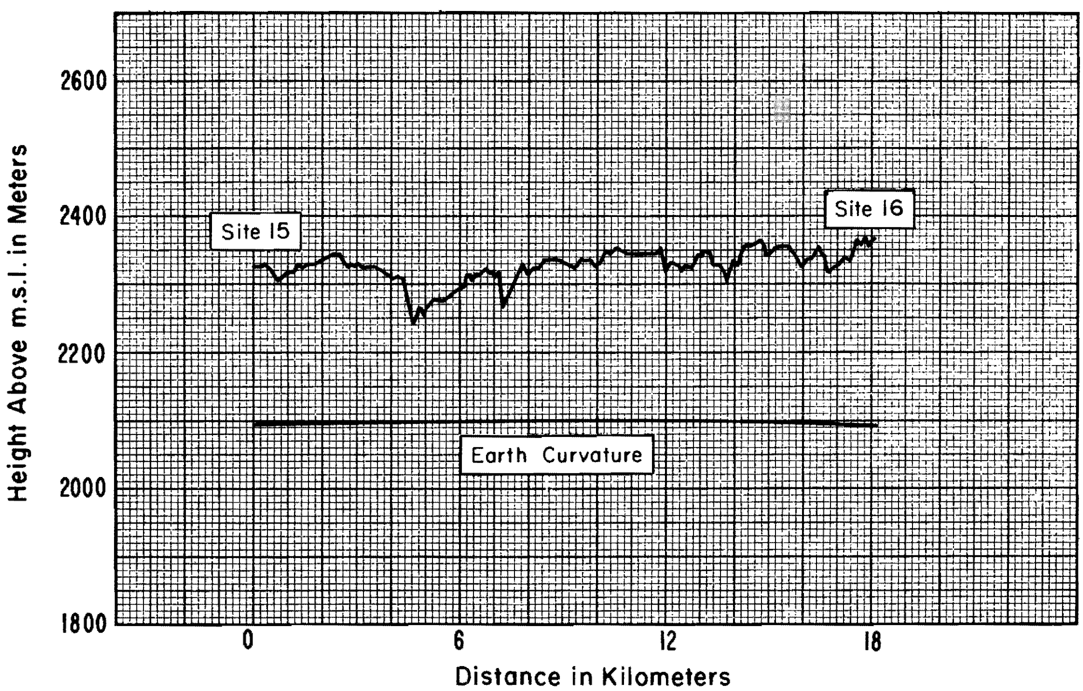


From site 16 toward site 15

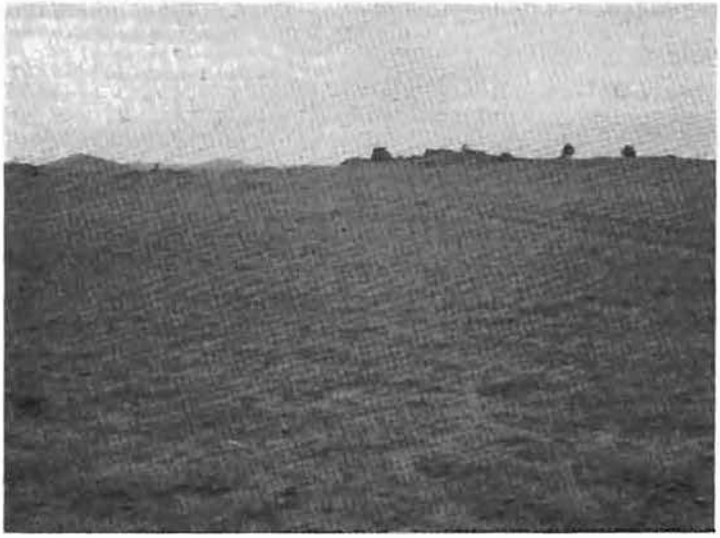
PATH LOSS MEASUREMENTS



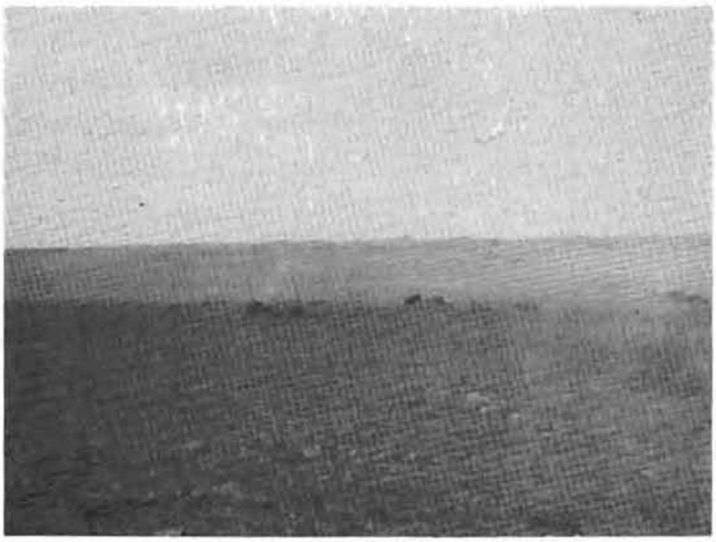
TERRAIN PROFILE



Wyoming PATH 15 - 17

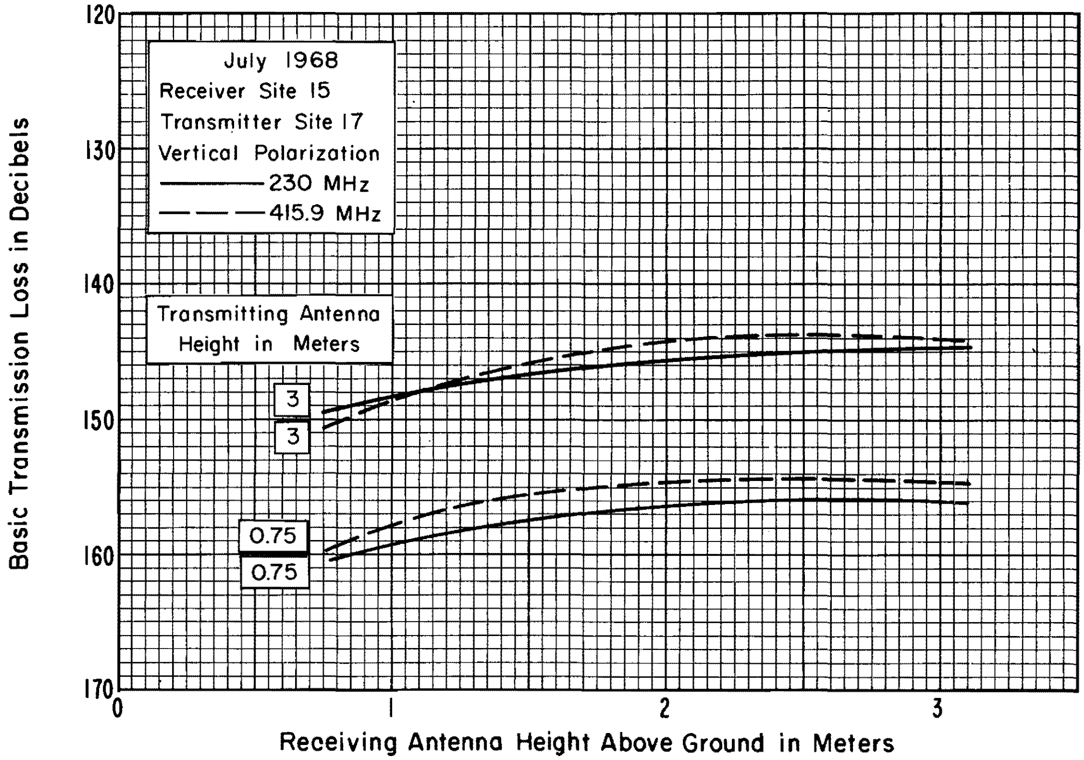


From site 15 toward site 17

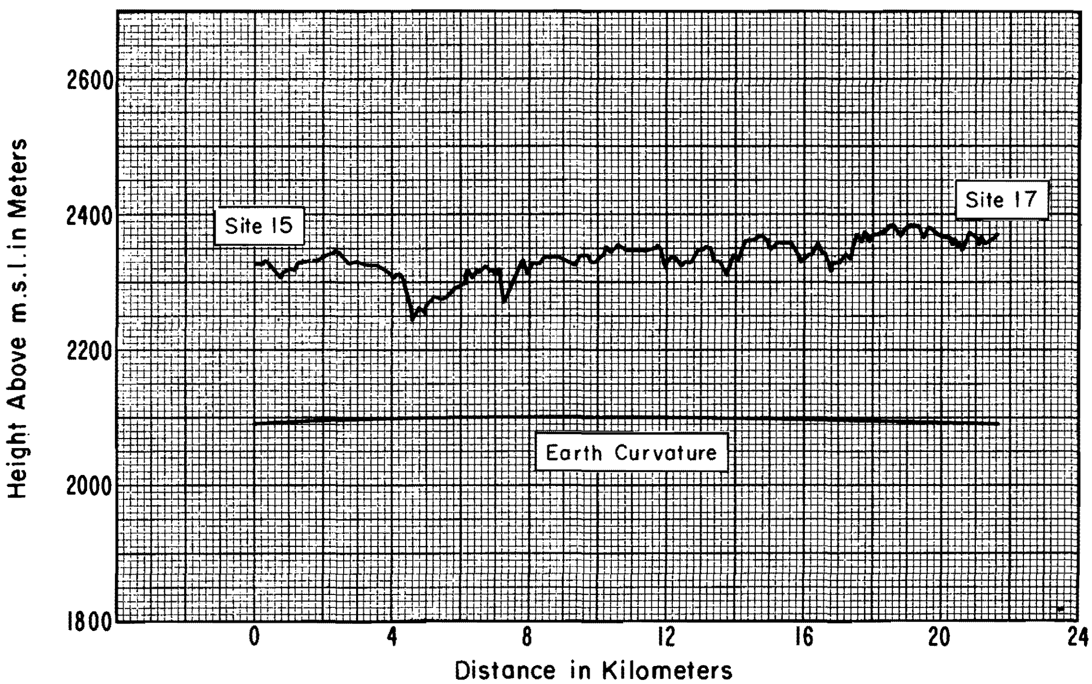


From site 17 toward site 15

PATH LOSS MEASUREMENTS

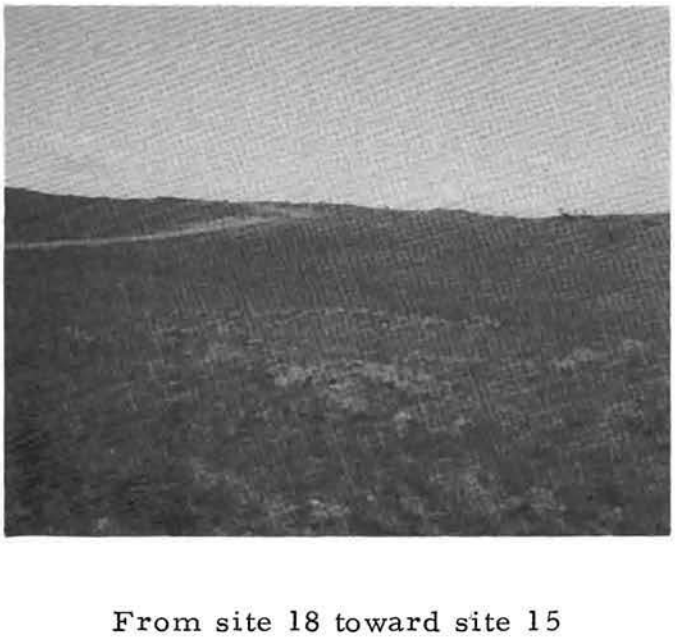


TERRAIN PROFILE



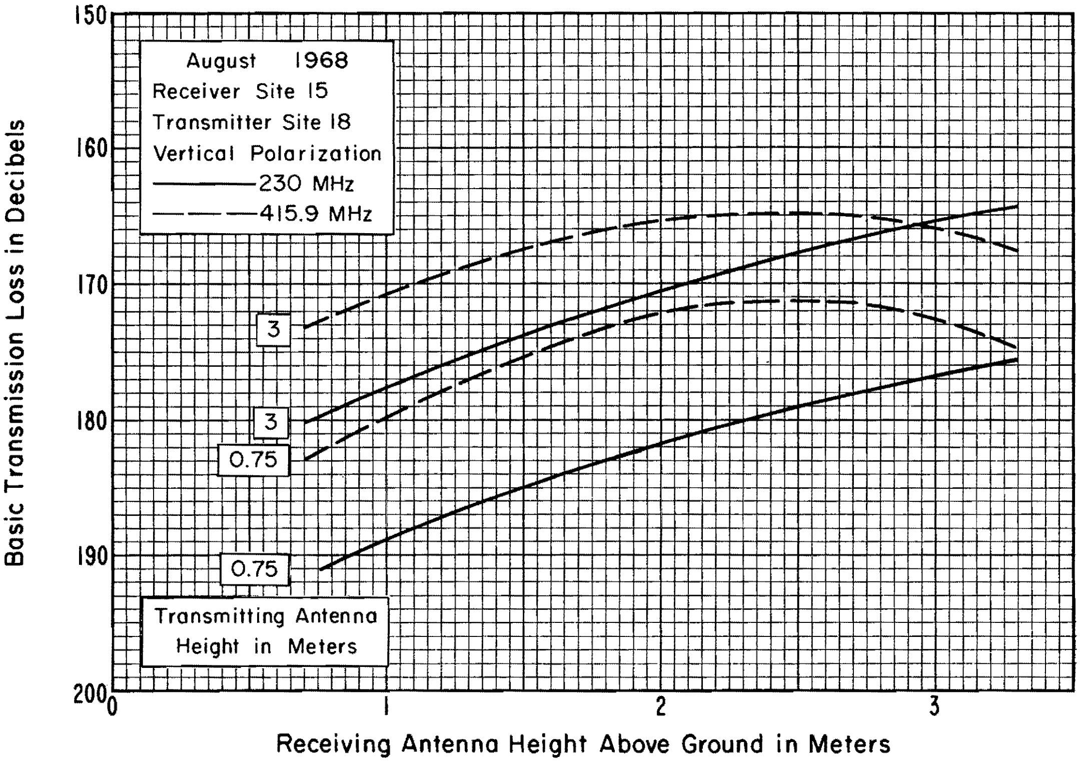
Wyoming PATH 15 - 18

From site 15 toward site 18

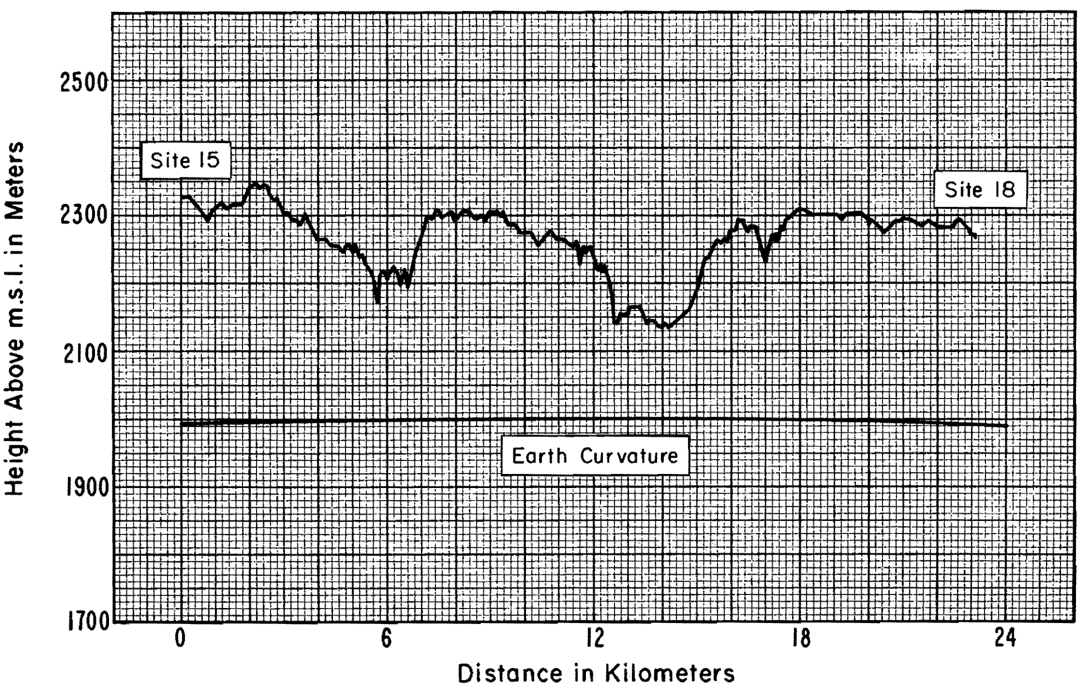


From site 18 toward site 15

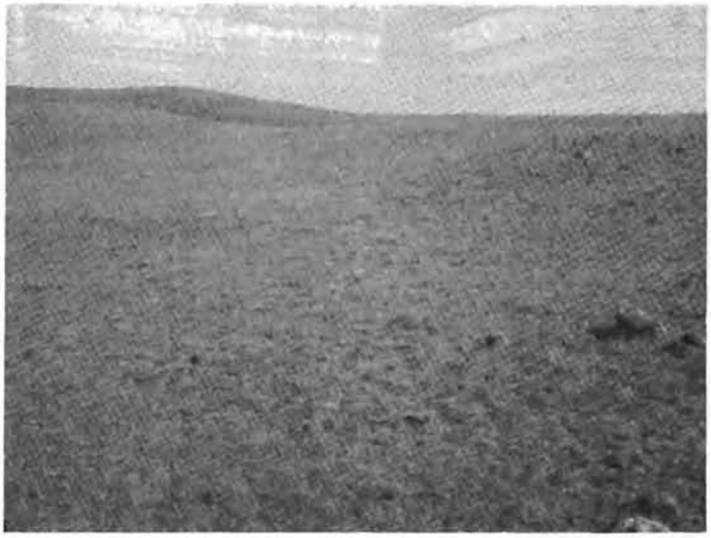
PATH LOSS MEASUREMENTS



TERRAIN PROFILE



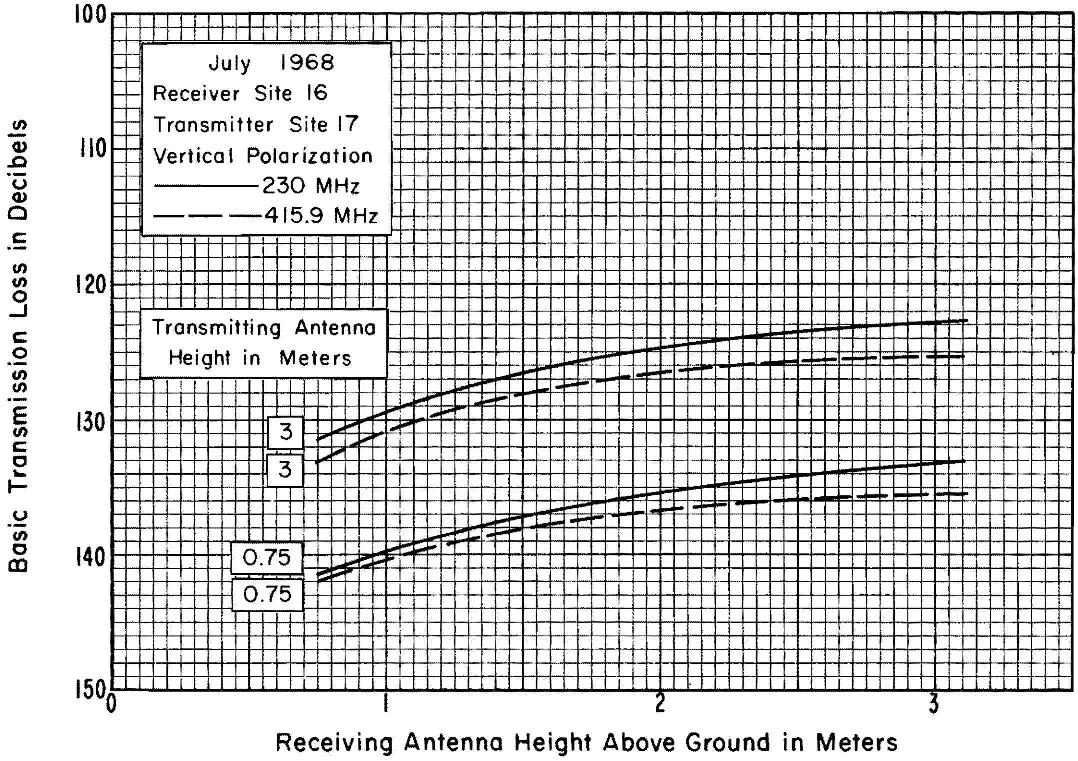
Wyoming PATH 16 - 17



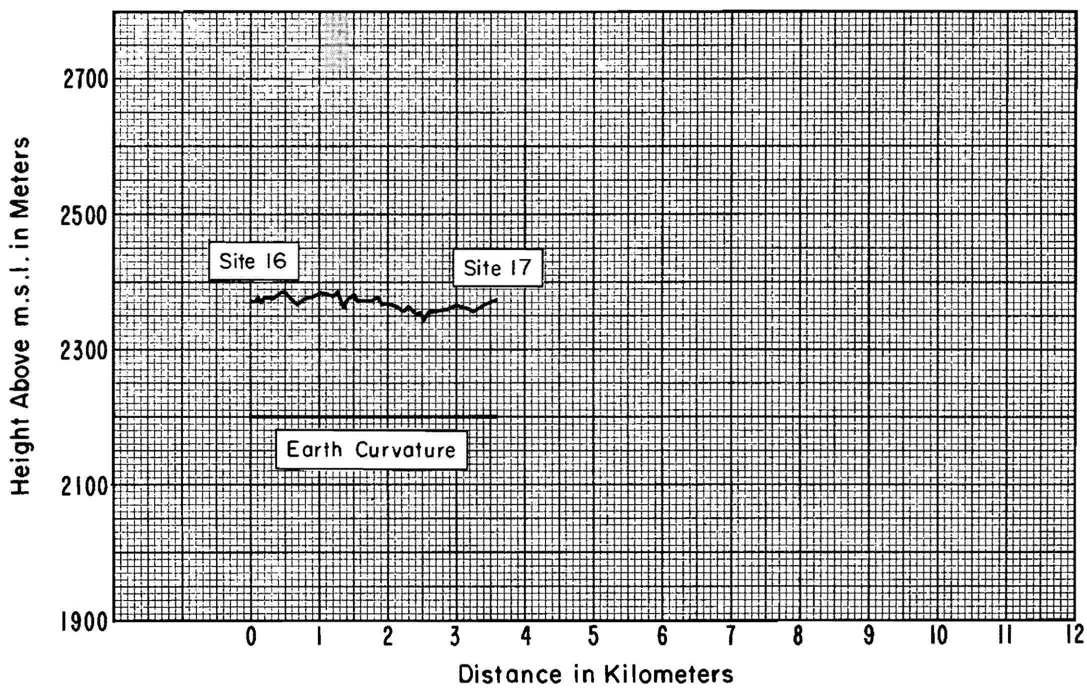
From site 16 toward site 17

From site 17 toward site 16

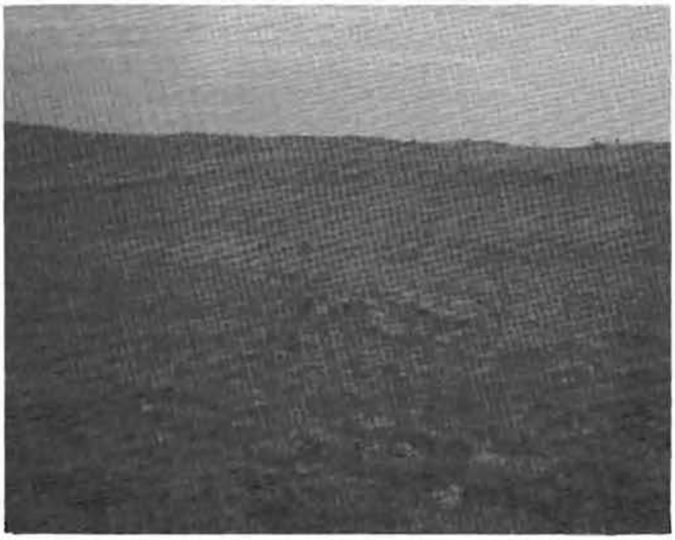
PATH LOSS MEASUREMENTS



TERRAIN PROFILE

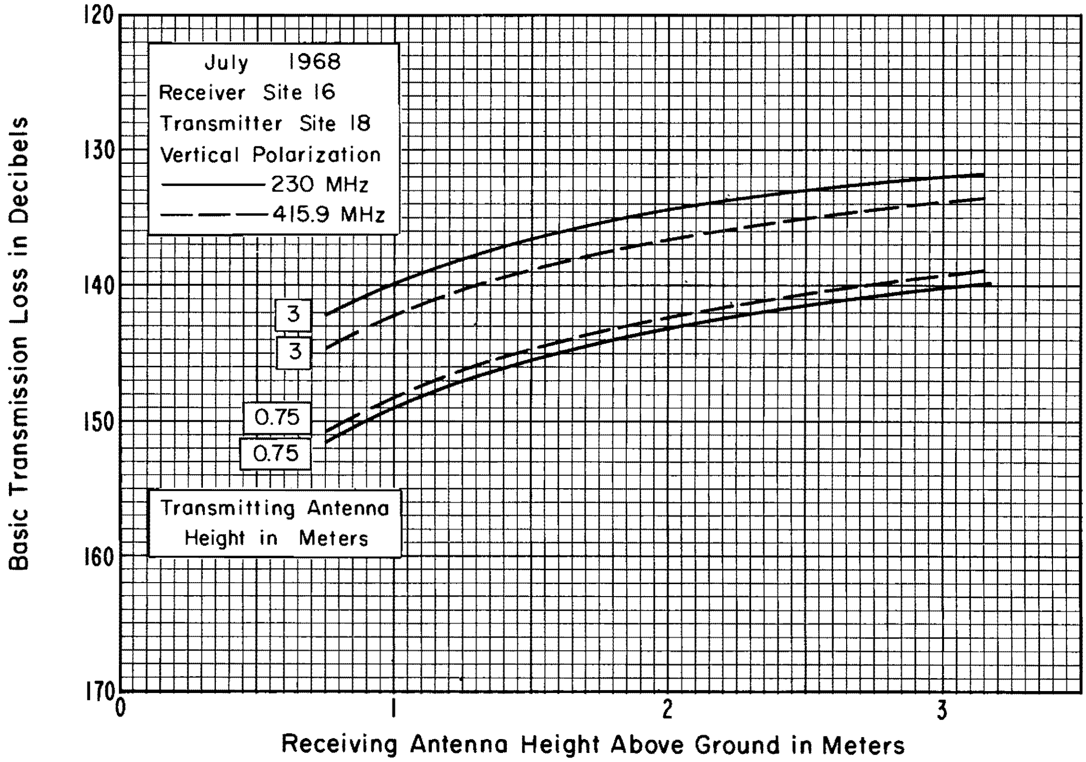


Wyoming PATH 16 - 18

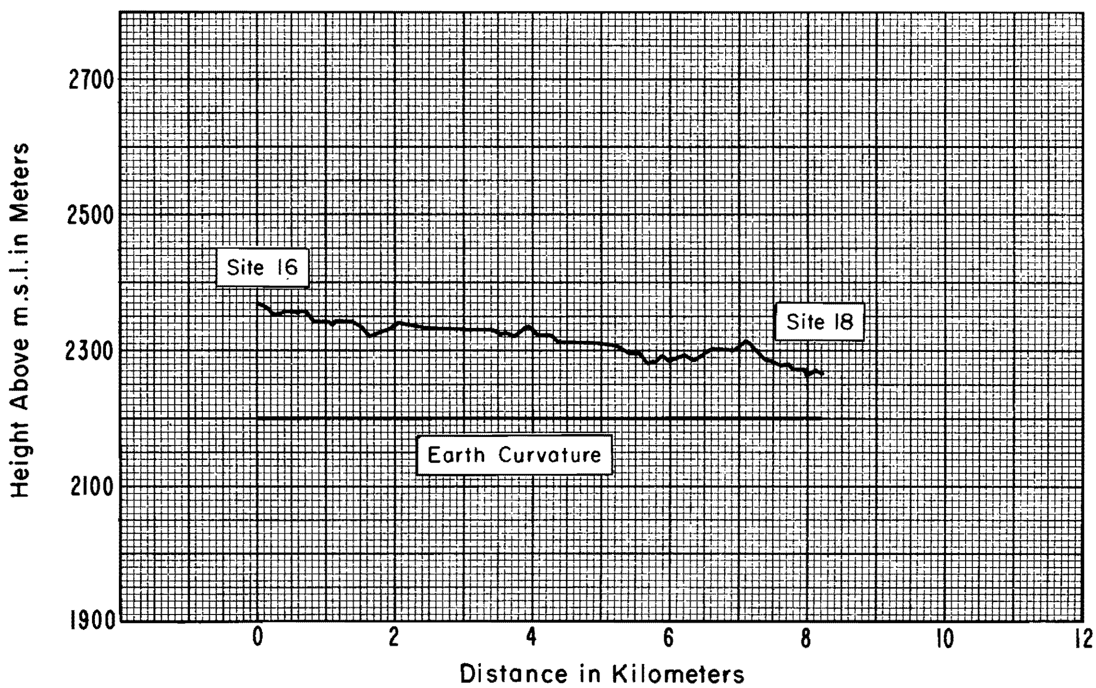


From site 16 toward site 18

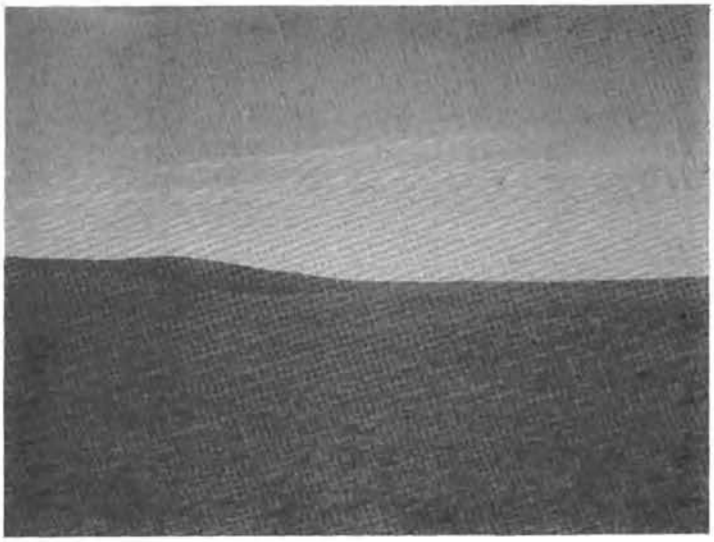
PATH LOSS MEASUREMENTS



TERRAIN PROFILE



Wyoming PATH 16 - 21

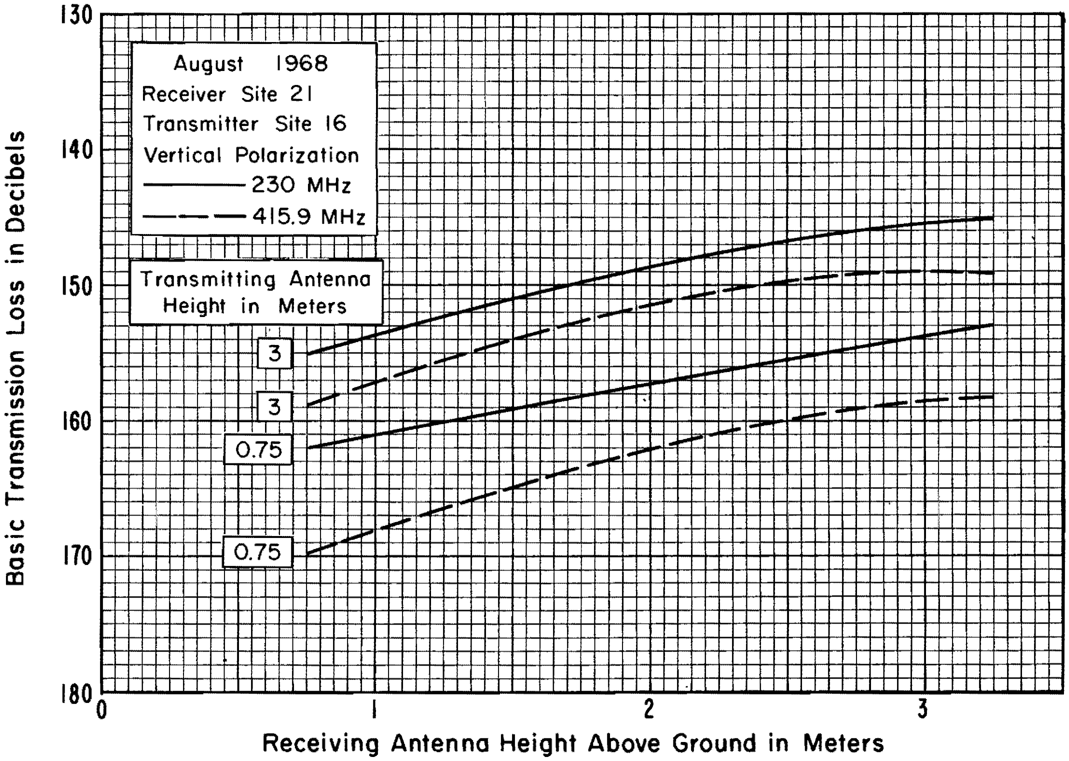


From site 16 toward site 21

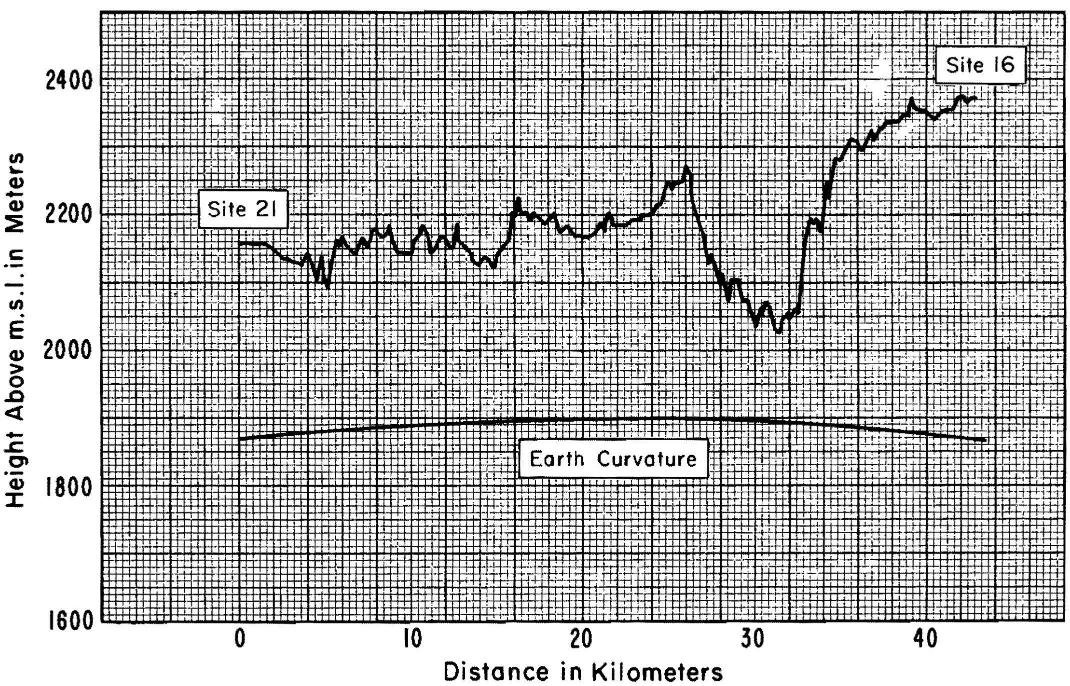
From site 21 toward site 16

WYOMING PATH 16—21

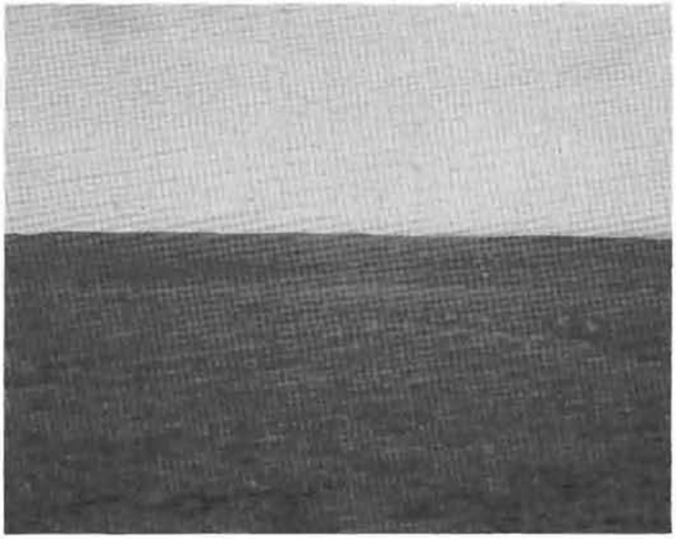
PATH LOSS MEASUREMENTS



TERRAIN PROFILE



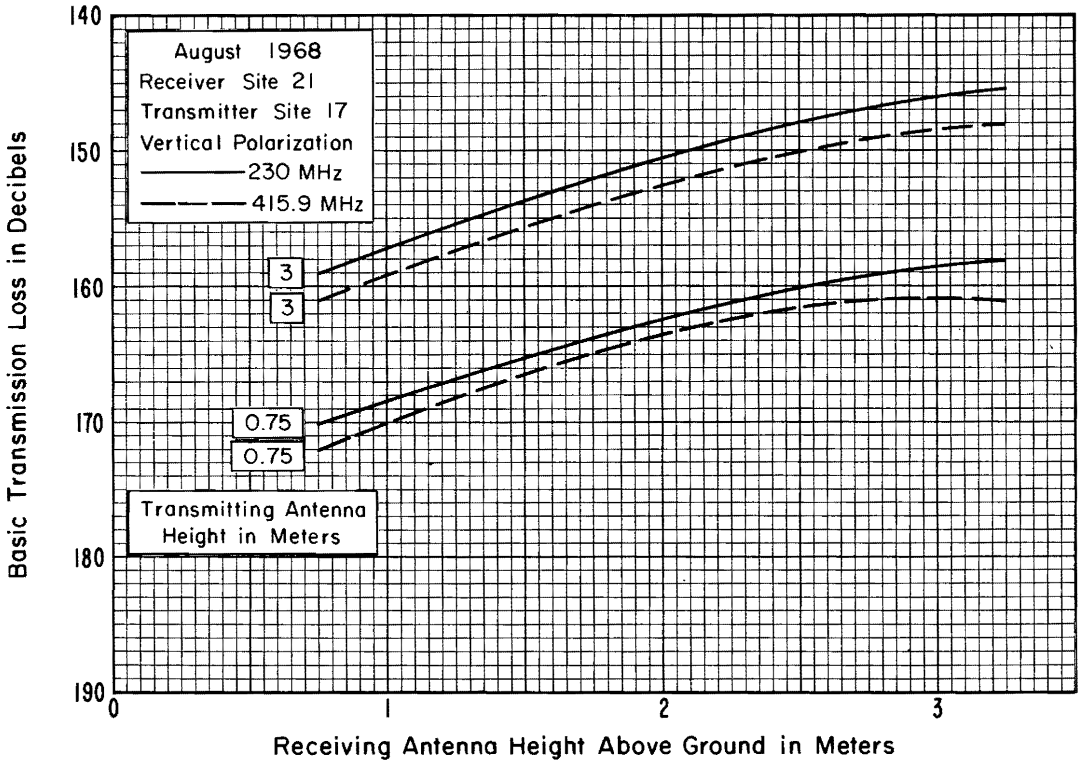
Wyoming PATH 17 - 21



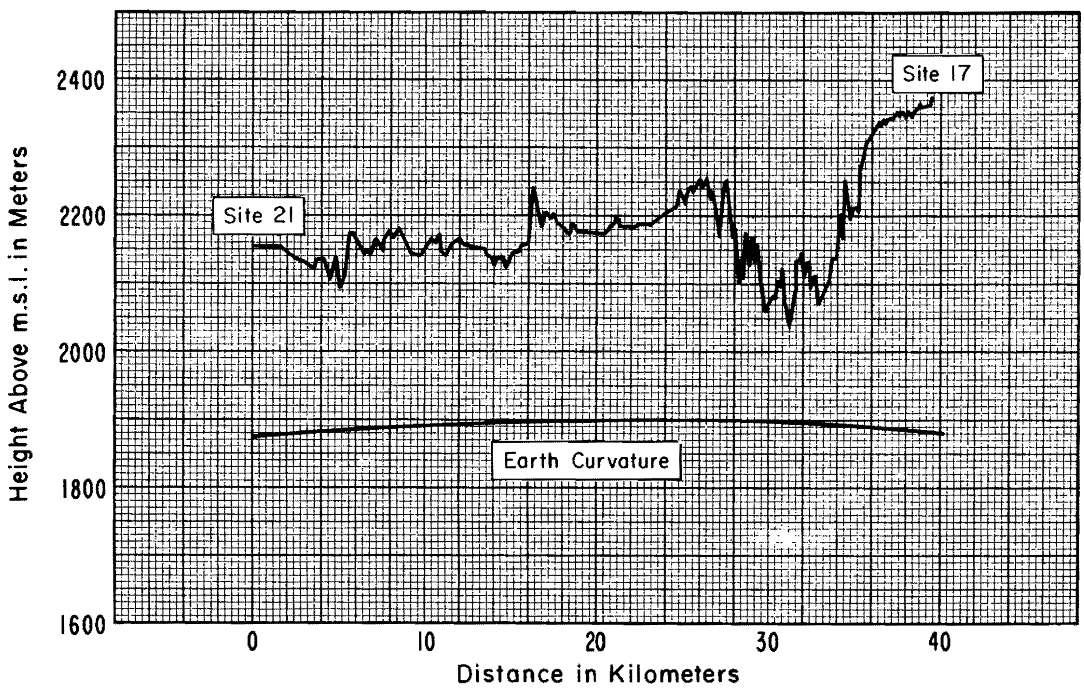
From site 17 toward site 21

From site 21 toward site 17

PATH LOSS MEASUREMENTS



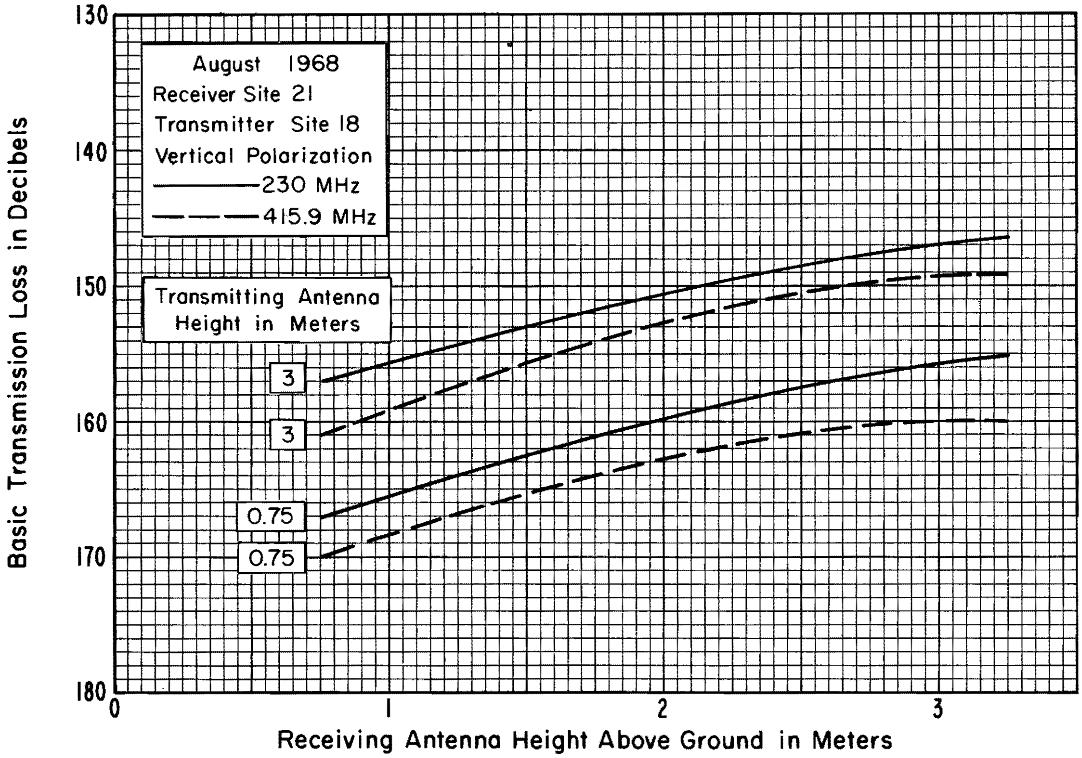
TERRAIN PROFILE



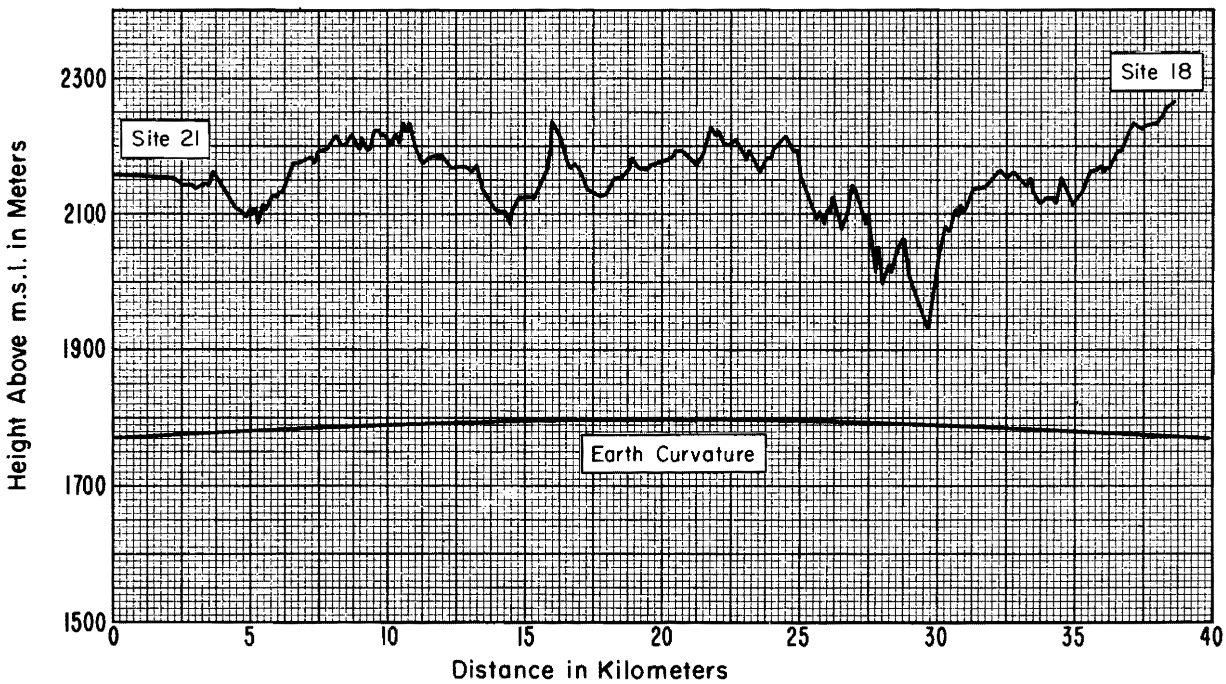
Wyoming PATH 18 - 21

From site 21 toward site 18

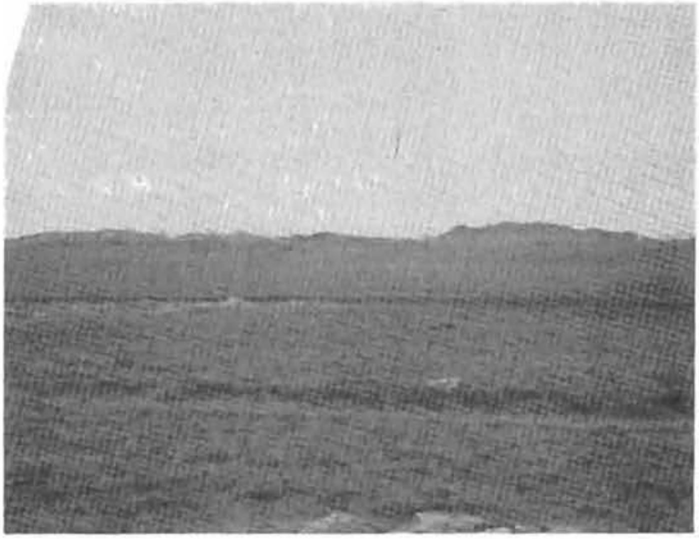
PATH LOSS MEASREMENTS



TERRAIN PROFILE



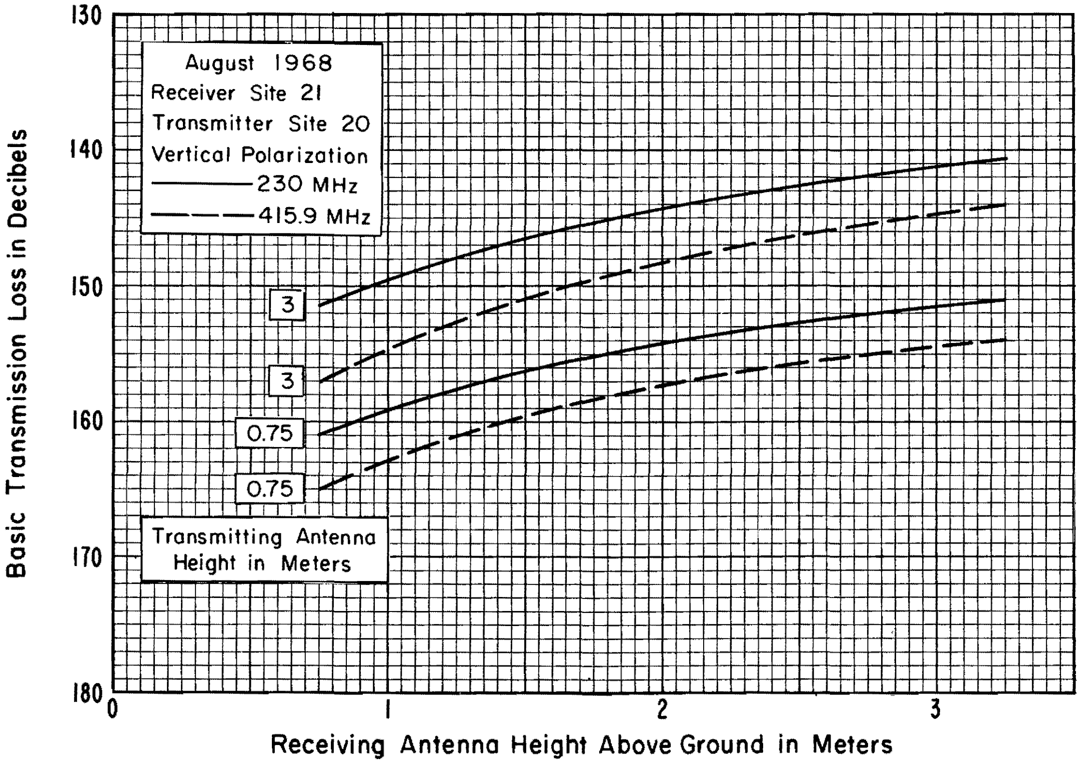
Wyoming PATH 20 - 21



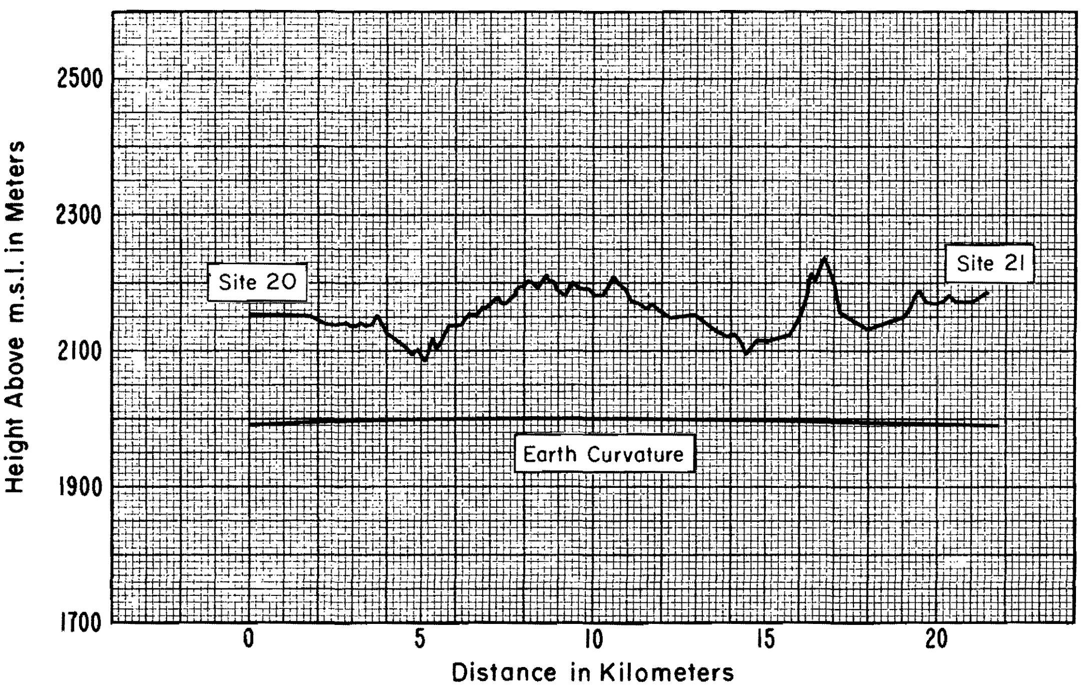
From site 20 toward site 21

From site 21 toward site 20

PATH LOSS MEASUREMENTS



TERRAIN PROFILE

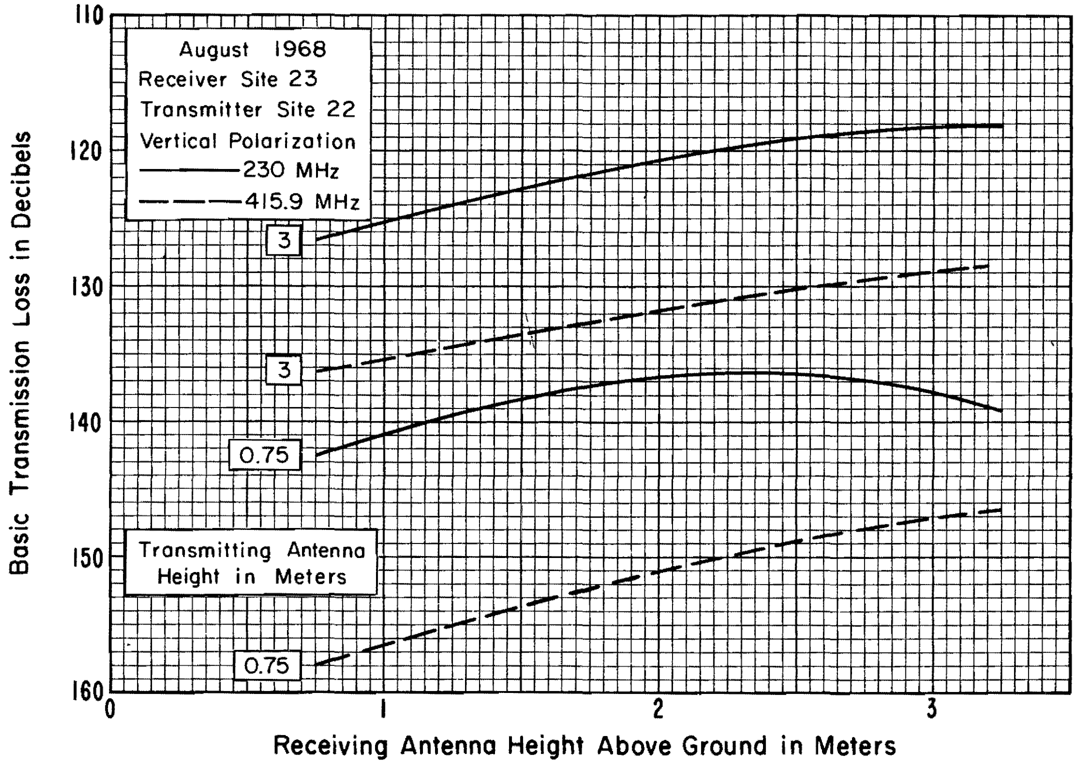


Wyoming PATH 22 - 23

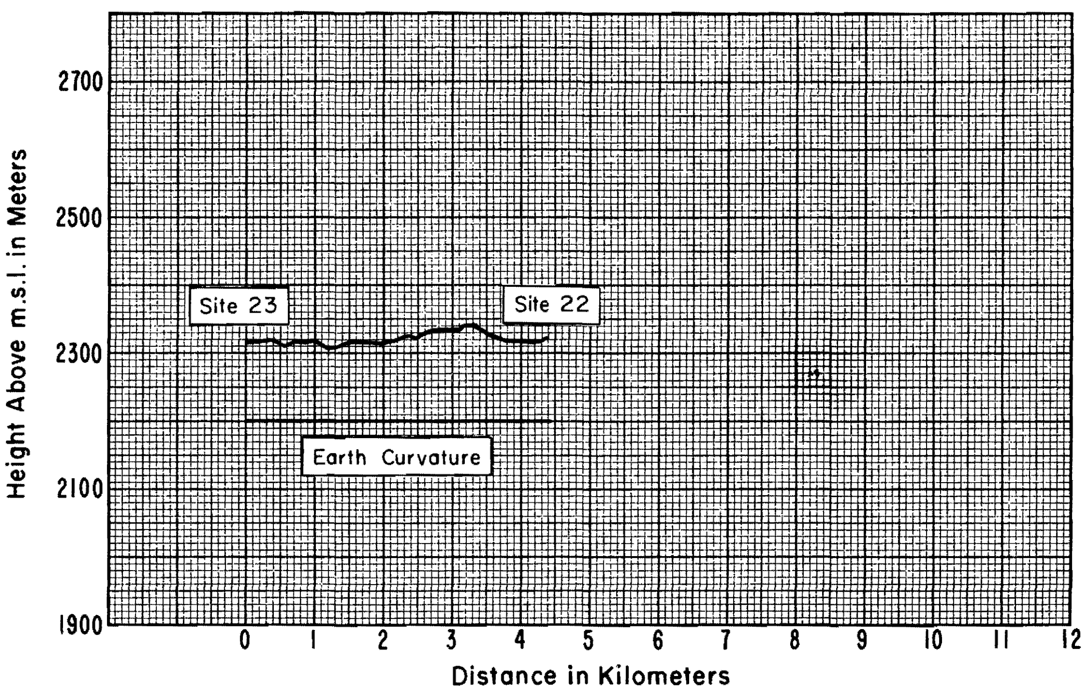
From site 22 toward site 23

From site 23 toward site 22

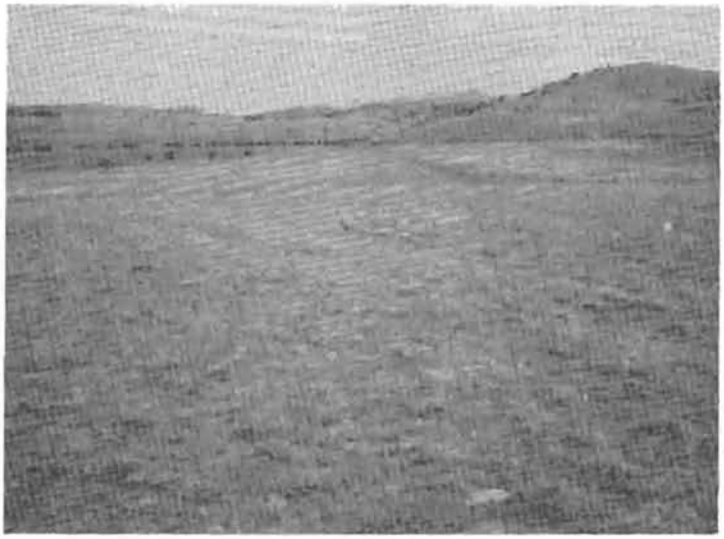
PATH LOSS MEASUREMENTS



TERRAIN PROFILE



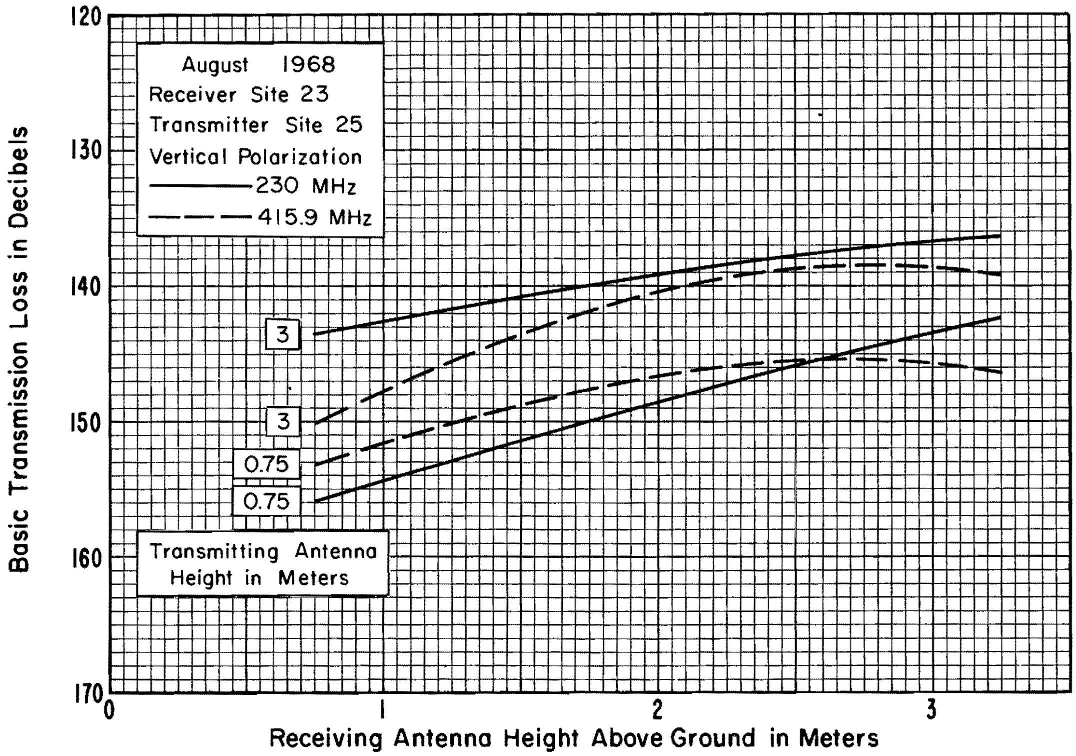
Wyoming PATH 23 - 25



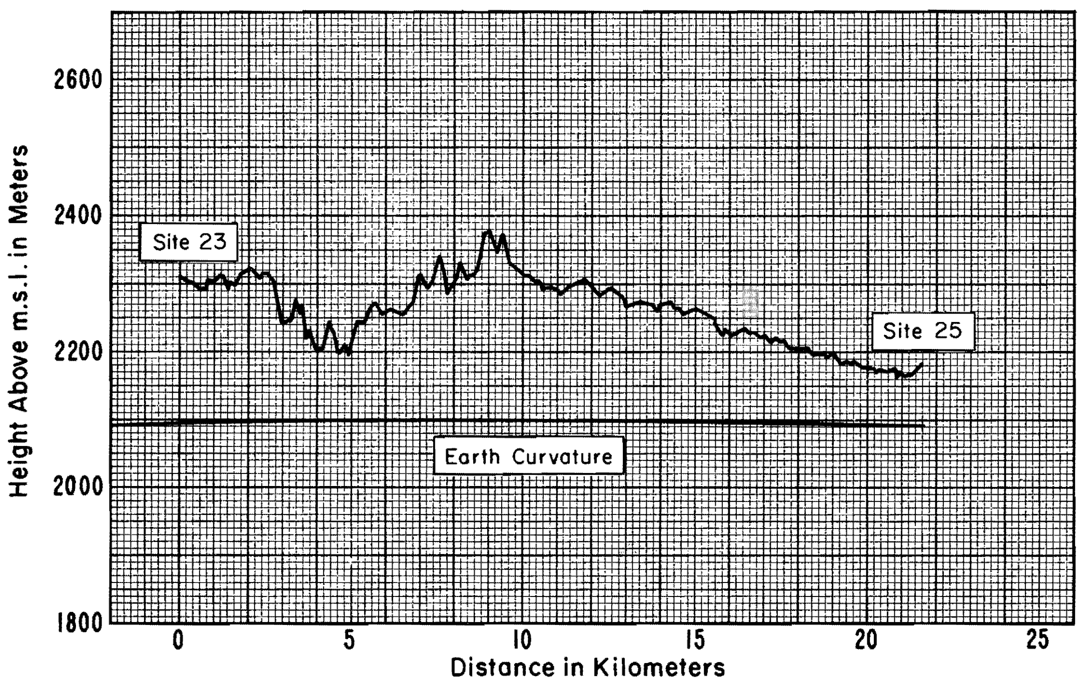
From site 23 toward site 25

From site 25 toward site 23

PATH LOSS MEASUREMENTS



TERRAIN PROFILE



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