ORBITING MULTI-BEAM MICROWAVE RADIOMETER FOR SOIL MOISTURE REMOTE SENSING

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Large Space Antenna Systems Technology - 1984
December 4-6, 1984

INTRODUCTION

Knowledge of soil moisture is useful to many scientific disciplines. For example, in atmospheric circulation modeling for meteorology and climatology, soil moisture is an important boundary condition which affects the evapotranspiration process, which in turn influences humidity, cloud formation and precipitation. In hydrology, knowledge of soil moisture is needed for reservoir management, drought survey, and flood prediction. In agriculture applications, timely moisture information can be used to aid preplanting and irrigation scheduling, and routine soil moisture survey can help determine crop stress and increase the crop yield forecast accuracy.

The presence of water molecules, which are highly polar, increases the dielectric constant of the soil, which, in turn, causes a reduction in soil surface emissivity. Microwave emissivity can be ascertained by measuring the microwave brightness temperature and physical (thermal) temperature of the soil surface. Microwave radiometers are used to measure the brightness temperature whereas physical temperature is frequently obtained from an infrared radiometer such as the Multi-Spectral Scanner (MSS) or Thematic Mapper aboard the Landsats.

The "sensing depth" of passive microwave (defined here as the depth below the surface such that 63 percent of the power received by the radiometer emanated from the volume between this depth and the top surface) decreases with increasing sensing frequency. Consequently, in order to penetrate deep into the soil, low frequencies are preferred. However, because the resolution of passive microwave is determined by the real aperture antenna, low frequency implies large antenna aperture, especially from satellites. Moreover, at frequencies below L-band, there are radio frequency interferences (RFIs), both man-made and extra-terrestrial in nature. As a good compromise, the 21 cm hydrogen band (1.413 HGz), protected for radio astronomy purposes, is the prime frequency for radiometric remote sensing of soil moisture from space.

THE EFFECT OF SOIL MOISTURE ON EMISSIVITY

Figure 1 shows, for the uppermost 25 cm of soil, some experimental data of measured soil surface emissivity at 1.4 GHz vs soil moisture together with two linear regression lines. The bare surface (solid line) has more "sensitivity" to soil moisture change. For one percent change in soil moisture (by dry weight), the corresponding change in emissivity is about 1.3 percent. The dashed line is from the combination of several types of vegetation covered surface and its sensitivity is greatly reduced.

In terms of microwave brightness temperature, the dynamic range of bare surface is about 90 K, and that of the mixed vegetation as shown in Fig. 1 is about 20 K. As we shall see later, a large spaceborne microwave radiometer has a typical measurement accuracy of about 3 K; hence, one can ascertain several levels of soil moisture from passive microwave, even in the vegetation covered areas.

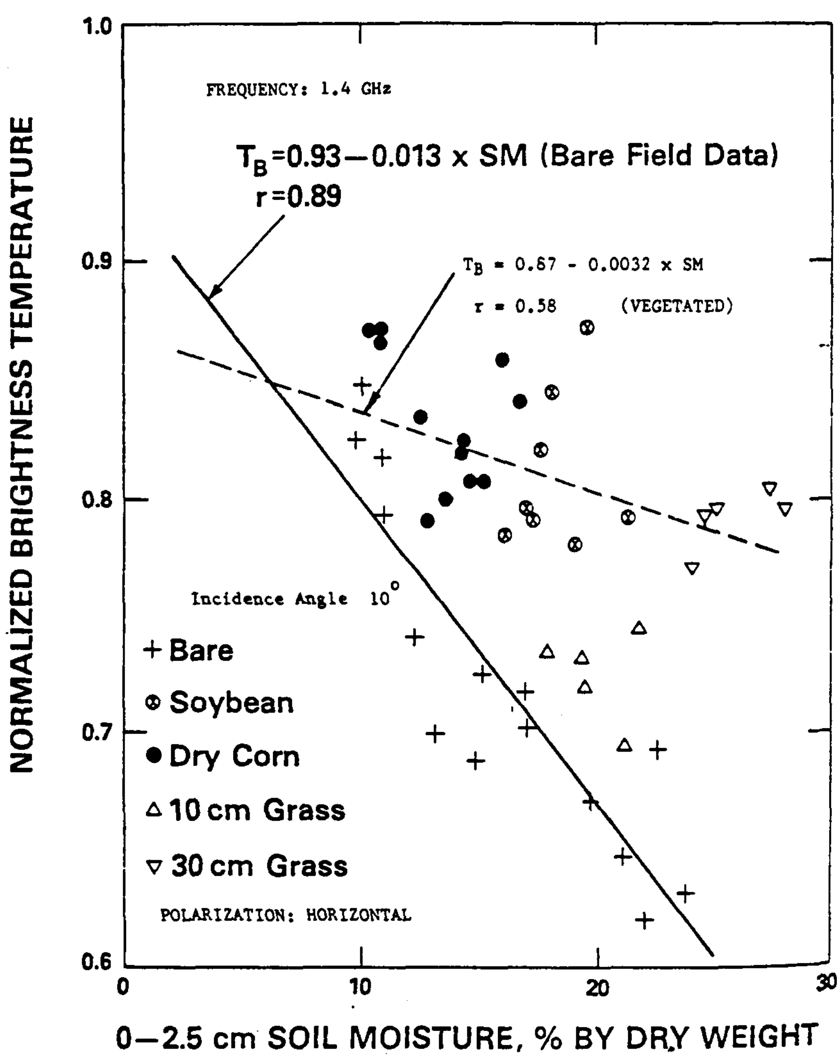


Figure 1 (Adapted from ref. 1)

OTHER FACTORS INFLUENCING EMISSIVITY

However, microwave emissivity alone is not enough for soil moisture determination, because there are other factors that tend to complicate the interpretation of the soil moisture. Therefore, other ancillary data are also needed to help improve soil moisture retrieval. Surface geometric characteristics, such as vegetation canopy and surface roughness, will reduce the sensitivity of emissivity to soil moisture change. Of the two factors, vegetation canopy is the more serious one. This effect must be removed before meaningful interpretation from vegetated areas can be made, because vegetation can reduce the sensitivity by up to 50 percent. By using measurements from visible and near IR wavelengths, one can differentiate bare from vegetated areas, and also ascertain the biomass of the vegetation. The roughness effect can be estimated with either dual polarization or multiple frequency techniques. In general, this effect is not as severe as that of vegetation canopy.

The microwave emissivity is also different for different soil texture, due to the different binding force of host soil particles. However, since the primary interest from most scientific or application points of view is the available water from the soil, this effect becomes unimportant. It turns out that the emissivity as a function of "available water" (field capacity) is nearly independent of soil texture.

Figure 2 depicts the theoretical sensing depth vs frequency for several soil moisture contents and vertical profiles.

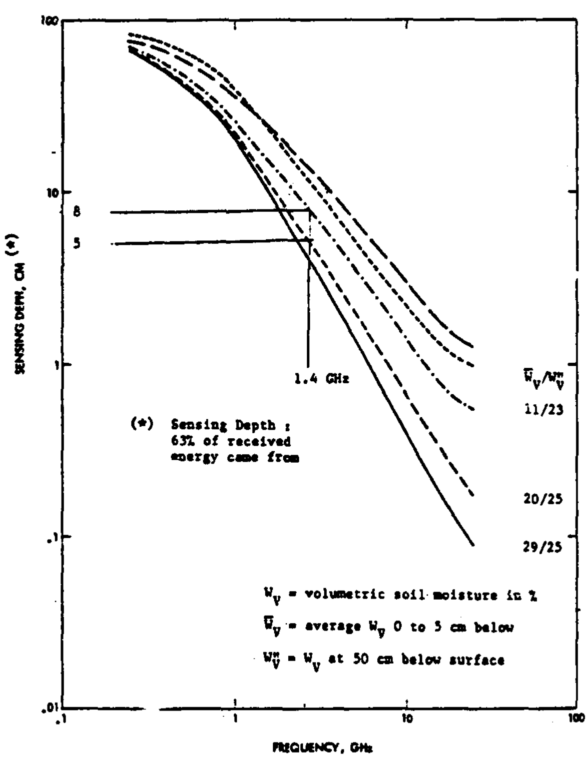


Figure 2 (From ref. 2)

A MULTI-BEAM MICROWAVE RADIOMETER WITH 15-M ANTENNA

For soil moisture sensing, both high spatial resolution and large swath width are desirable system parameters. It is also important that the radiometer map a given area continuously. However, at times not all three conditions can be fully achieved and trade-offs must be made. Since mechanical scanning is impractical for such a large antenna, a multiple-feed design is used to achieve the large swath width.

Figure 3 shows the side and front views of the current quad aperture design 15-meter hoop/column antenna, as currently designed. The front view shows the four 6.09-meter sub-apertures.

The current design is a multiple beam/multiple quadrant offset reflector system. Four separate areas of illumination (sub-apertures) on the parent reflector are shown. The surface is shaped as if it were four offsets; thus, the parent reflector is cusped.

As a result of the large physical size of the feed arrays needed, only two six-meter sub-apertures of the 15-meter parent aperture are planned. Feed arrays then are able to produce a total of 29 beams across the ground track of the sensor platform. The reflector shape will include two sub-apertures rather than the four currently under construction. The resulting arrangement is called a "pushbroom" configuration.

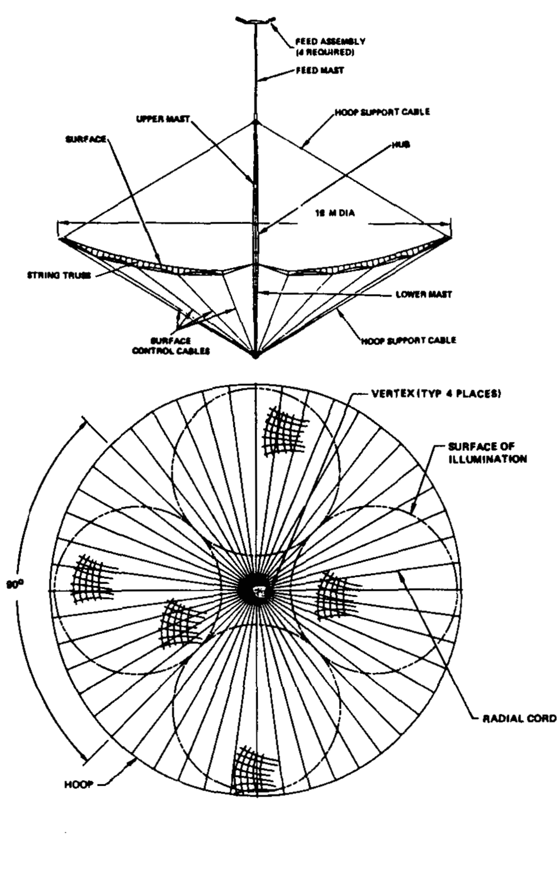


Figure 3

BEAM FORMATION

Only two sub-apertures are used for the radiometer mission, as shown in Figure 4. The feed arrays are located between the two sub-apertures so as to minimize the blockage. The top array contains 14 separate feeds and illuminates sub-aperture #1. Similarly, the bottom feed array contains 15 separate feeds and illuminates sub-aperture #3.

The center of the bottom feed array generates beam #15 which is pointed at nadir. The two feeds at the end of this feed array yield the two edge beams, #1 and #29. The remaining 12 feeds of this array produce the other odd numbered beams. The top feed array produces 14 even numbered beams, #2 through #28, whose positions are interspersed among the 15 beams produced by the bottom feed array.

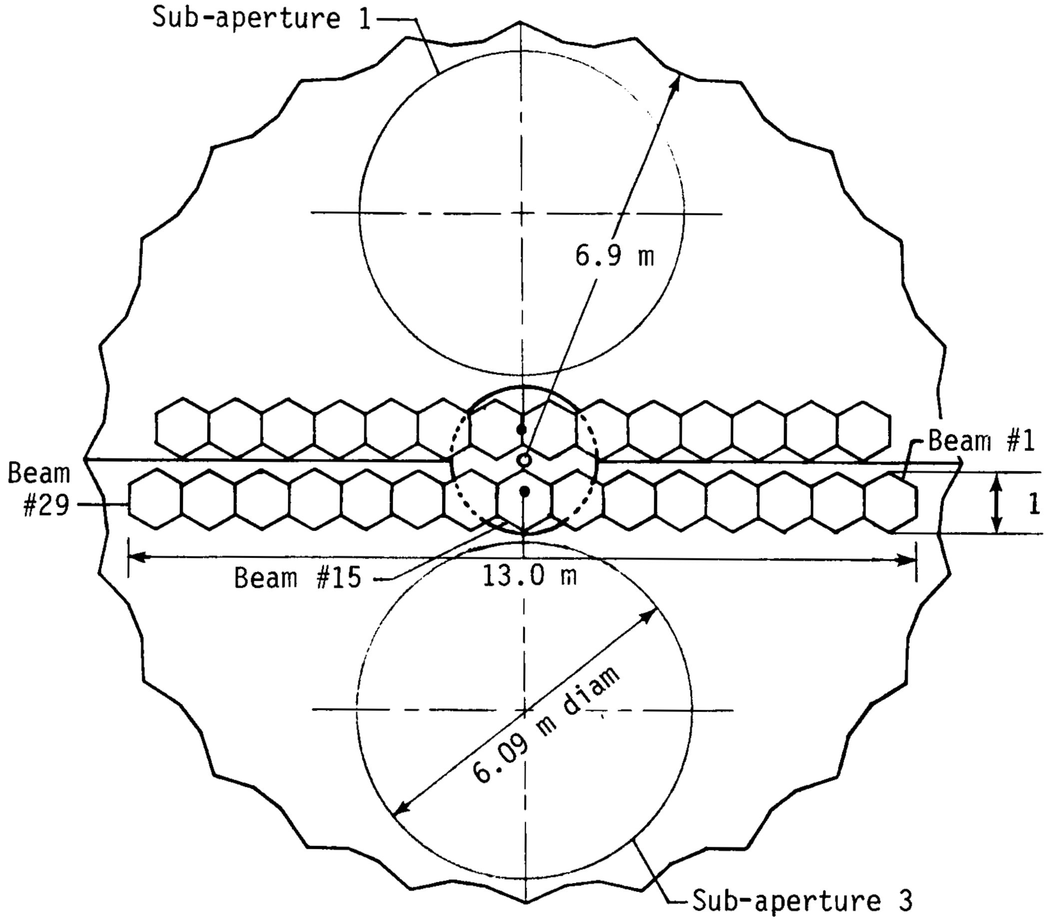


Figure 4

FOOTPRINT LOCATION FOR THE 15-M HOOP-COLUMN PUSHBROOM RADIOMETER

Figure 5 shows one-half of the interspersed beams, from #15 (nadir) to #29. The remaining beams #1 to #14 are the mirror image of Figure 5, symmetrical about the vertical 90 degree line.

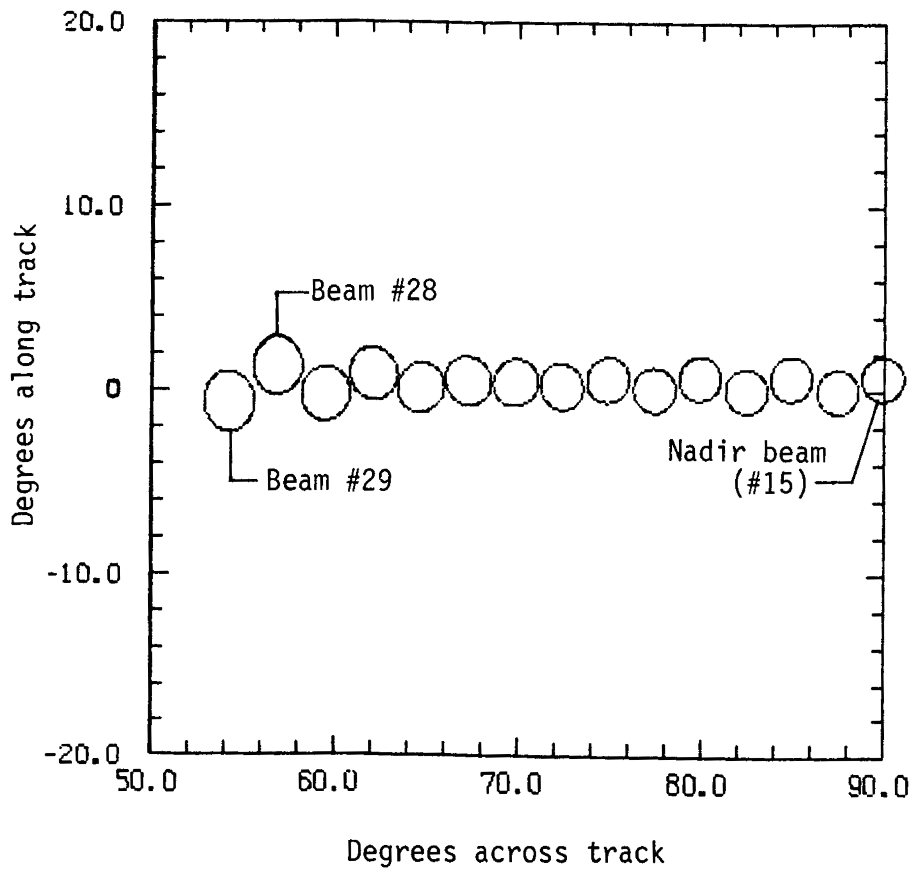
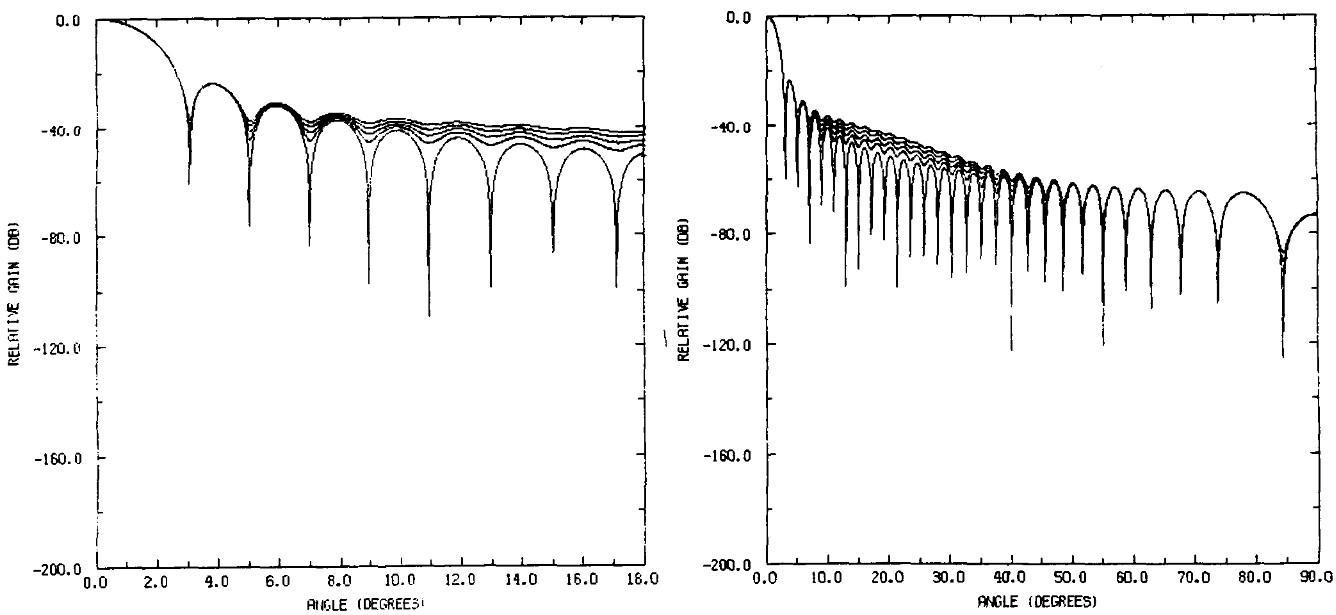


Figure 5

ANTENNA GAIN PATTERN OF THE CENTER BEAM

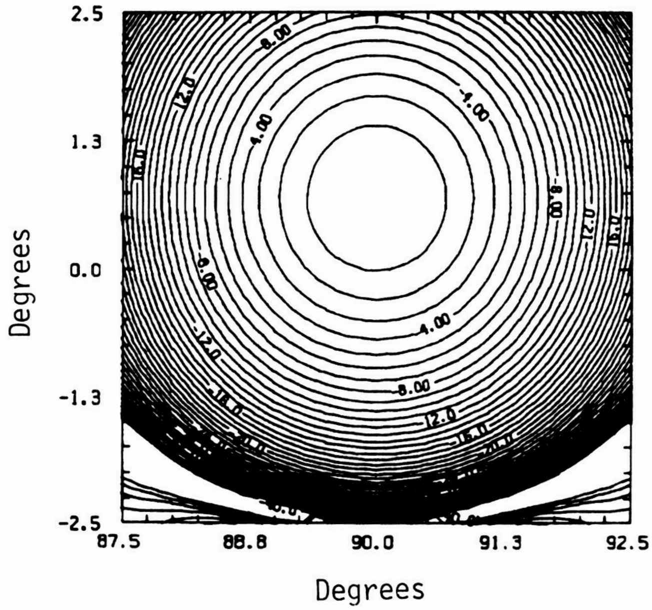
The secondary radiation (antenna gain) pattern of the nadir beam (#15) is shown in Figure 6a. The primary radiation pattern of the feed is assumed to have a shape of "cosine θ" raised to 1.5, where θ is the angle from the center of the 6.09 m sub-aperture. The five separate patterns correspond to the different reflector surface roughness sizes of 0, 50, 69, 90, and 110 mils (RMS). The correlation length C is assumed to be 10 inches. It is seen that the phase errors due to random surface roughness tend to fill the space between the far outside lobes; the main lobe pattern is hardly changed. Figure 6b is also the secondary radiation pattern of the nadir beam, with the angle extended to 90 degrees.



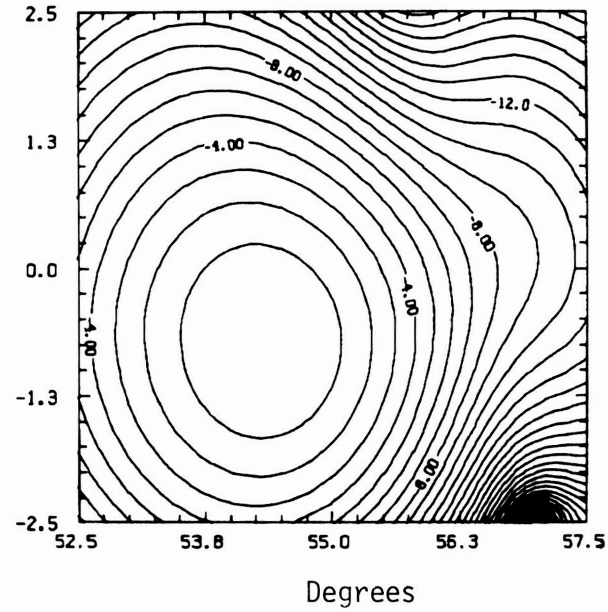
(a) (b)

Figure 6

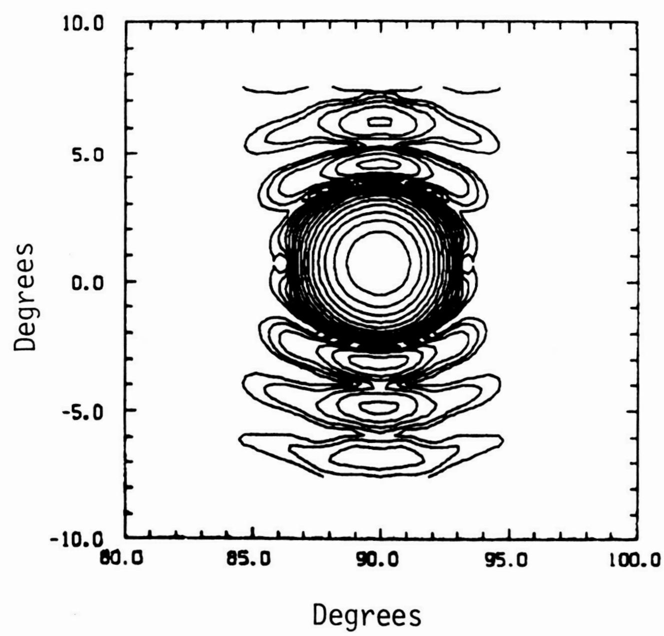
Figure 7a is a plot of the contour of the secondary radiation pattern of the nadir beam (#15) within 2.5 degrees of nadir. Figure 7b is a similar plot for the main lobe of Beam #29. Figure 7c is a plot of Beam #15's radiation pattern out to 10 degrees. The contour interval is 1 dB.



(a)



(b)



(c)

Figure 7

LOSS DUE TO REFLECTOR ROUGHNESS

Figure 8 shows the effect of reflector surface roughness on beam efficiency. For a 100 mil RMS, the resulting reduction in beam efficiency due to surface roughness will be about 2 percent, if one starts with an ideally smooth reflector surface with a beam efficiency of 90 percent.

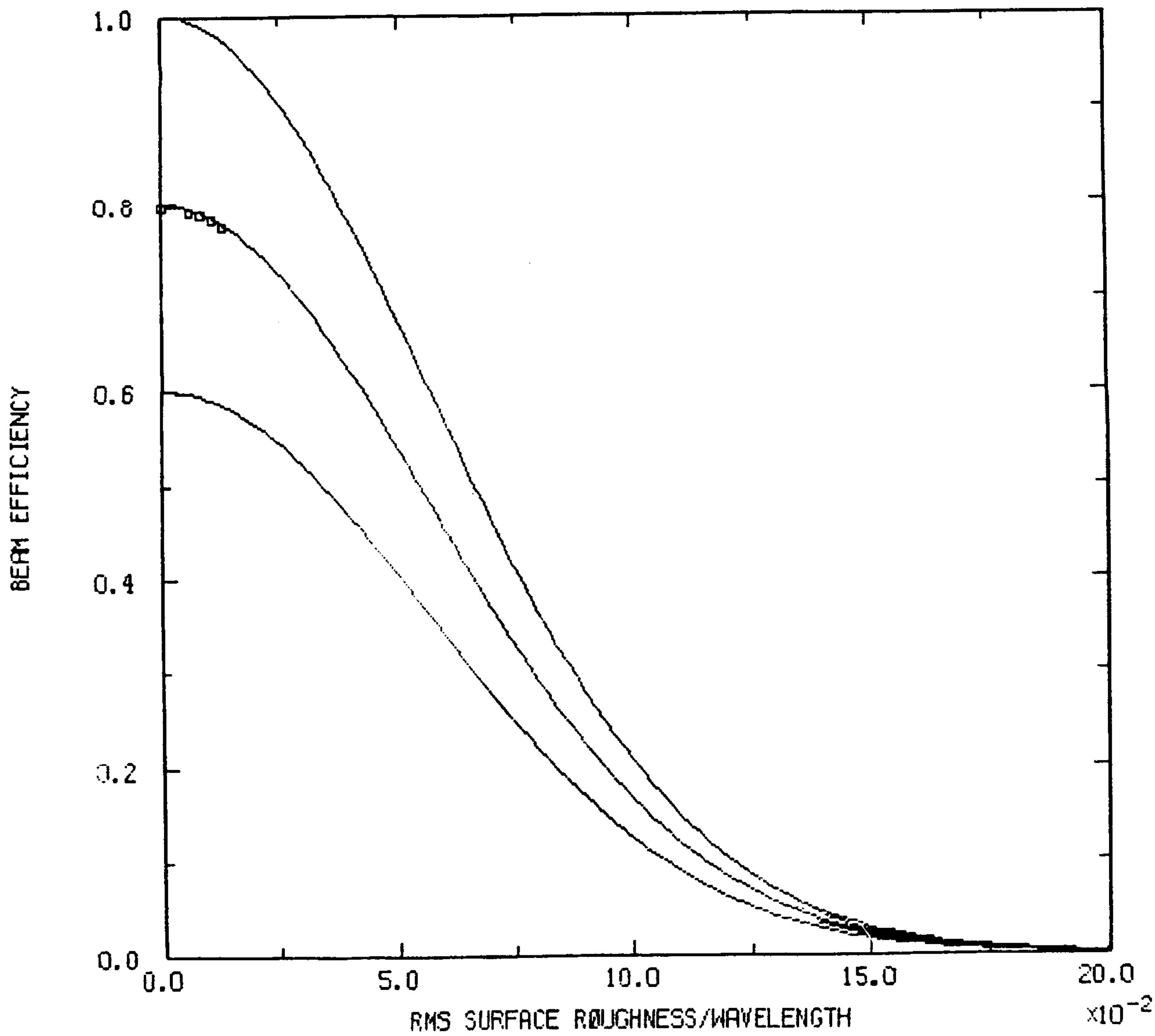


Figure 8

SUMMARY OF SYSTEM PARAMETERS OF THE RADIOMETER

From a 300 km orbit, the 2.25 degree beam width would yield a nadir spatial resolution of 13.1 km at nadir. For the swath edge beams (#1 and #29), the footprint size is degraded to 18.7 km x 14.7 km. The radiometer will yield a swath of 458.4 km. The nadir angle at the edge of the swath is about 37 degrees, and the corresponding incidence angle is 39 degrees. The time it takes for the sub-satellite point to move a footprint diameter is 1.77 sec. From a 300 km orbit, the equatorial drift is about 2500 km per orbit. With the 458 km swath width, the radiometer can produce a global soil moisture map in 6 days.

The system parameters and accuracy budget of the microwave radiometer are as given in Table 1.

Frequency:	1.413 GHz
Bandwidth	27 MHz
Effective Antenna Aperture Diameter:	6.09 m
Number of Beams:	29
Polarization:	Horizontal
Beam Efficiency:	85 to 90%
Temperature Sensitivity:	0.36 K*
Integration Time:	1 sec. (assumed)
I.F. Bandwidth:	13.5 MHz
System Noise Figure:	2 dB (dsb)
Antenna Temperature:	280 K
Feed Loss:	1.5 dB
Mesh Loss:	0.17 dB
Calibration Accuracy Estimate:	
Antenna Mesh (emissivity/transmissivity)	2.3 to 2.8 K
Feed Loss	0.3 to 0.6 K
Receiver Calibration Error	2.0 K
RSS	3.1 to 3.5 K

*Does not include spatial antenna effects such as the inversion from antenna brightness temperature or the defined resolution cell.

Table 1

SUMMARY OF RADIOMETER SYSTEM REQUIREMENTS

The power, weight, and communications requirements of the 29 channel microwave radiometer are given in Table 2.

POWER REQUIREMENTS

Assembly	Power Per Radiometer
Front-end	1.8 W
Video	2.7 W
Signal Processing	3.5 W
Total Power Per Channel	8.0 W
DC/DC Converter Efficiency	80%
Total Power for 29 Channels	290 W
Misc. Power	10 W
Total Power	300 W*

WEIGHT REQUIREMENTS

Feed Panel:	150 oz	
Radiometer		
Front-end	16 oz	
Thermal	16 oz	
Video	10 oz	
Signal Proc.	18 oz	
Enclosure	80 oz	
Total wt Per Channel:	290 oz	
Total wt for 29 Channels		525 lb
Interconnecting Structure		75 lb
Total Weight		600 lb*

DATA RATE REQUIREMENT

Radiometer Duty Cycle	64 BPS
Reference Temperature	16 BPS
Multiplexed Physical Temperature	16 BPS
Total Per Channel	96 BPS
Coding Overhead:	28 Coded 8 Bit Word/Sec
Total Bit Rate: (29 Beams)	6496 BPS

*Does not include requirements for thermal control system.

Table 2

REFERENCES

1. Wang, J. R., J. C. Shiue, and J. E. McMurtrey III, Microwave remote sensing of of soil moisture content over bare and vegetated fields, Geophys. Res. Lett., 7, 801-804, 1980.

2. Njoku, E. G., J. P. Scheilde, and A. B. Kahle, Joint microwave and infrared studies for soil moisture determination, Rept. SM-YO-00495, Jet Propulsion Laboratory, Sept. 1980.