Reflector Antenna, its Mount and Microwave Absorbers for IIP Radiometer Experiments

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1 Introduction

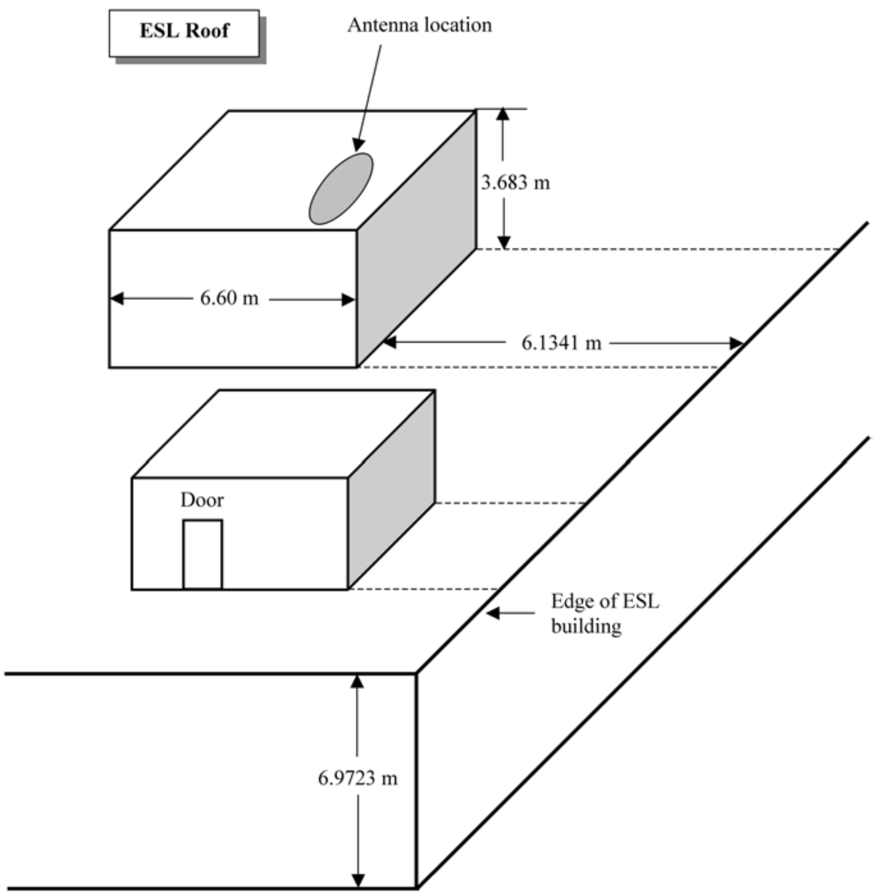
As mentioned in [1], measurements are required for the IIP radiometer to demonstrate successful ground-based observations of natural media. In this report, details for experimental setup are described including the reflector antenna chosen, its feed, mount and microwave absorbers which are used as calibration targets.

2 Reflector Antenna

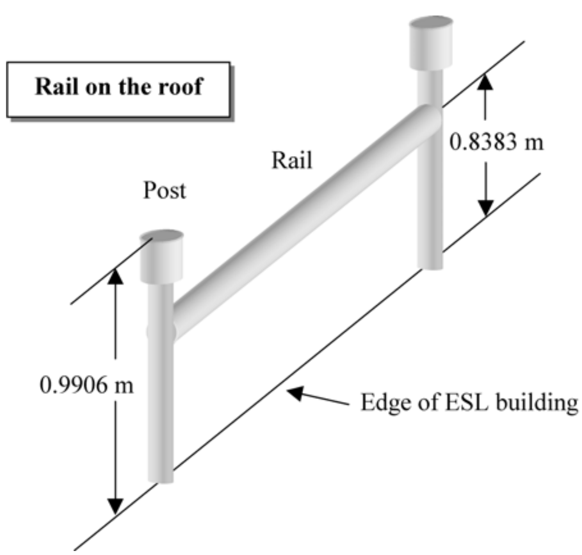
In this section, details for setting up a reflector antenna for testing the IIP radiometer are presented. Most of the ideas are based on work in [1]. The antenna setup for measurements is first explained. Second, the antenna and its mounting structure chosen is shown.

Antenna Setup for Measurements

It is important that targets of interest are in the far zone of the antenna, so the reflector antenna (it will be referred to as the dish) is placed on the ESL 2nd-level roof and adjusted to be in a downward observation configuration. Before setting up the antenna, it is necessary to know that dimensions of the building. Figure 1 illustrates the structure on ESL roof with dimensions in meters.



(a)



(b)

Figure 1: Dimensions of the structure on ESL roof. (a) Building dimensions. (b) Rails dimensions.

Although it is desirable to use a large antenna to obtain a narrow beam, or in other words, a small spot size, the largest dimension is limited due to the fact that the antenna must be operated in the far zone. Since the frequency range of the IIP radiometer is from 1330-1427 MHz (wavelengths from 0.210-0.226 m) and the dish diameter was chosen to be 1.2 m (refer to [1]), the far zone range is equal to $r_{far} = 2D^2/\lambda_{\min} = 13.7$ m. By assuming that the antenna efficiency (Q) is 0.8, the beamwidth can be approximated by $2\psi = 2\lambda_{\max}/(DQ) = 0.245$ rad = 14 degrees ($\psi = 7$ degrees). The geometry of this setup is shown in Figure 2. Here, h is the antenna height from the ESL 2nd-level roof, H is the antenna height from the ground, r is the distance from the dish to the center of the spot size, θ is the observation angle from nadir and θ_0 is the smallest θ such that the downward looking path does not intersect the building.

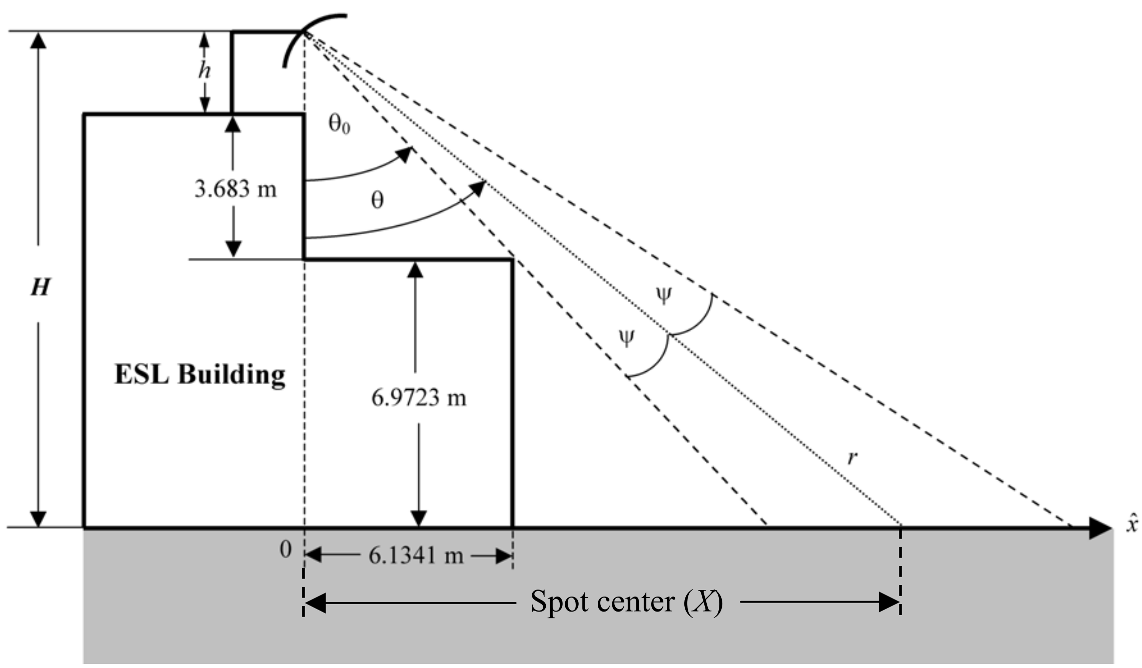


Figure 2: Geometry of the measurement setup.

It is obvious in Figure 2 that the effect of the building structure can be reduced by setting the angle θ (from nadir) of the dish to be larger than $\theta_0+\psi$. Here, $\theta_0 = \tan^{-1}(6.1341/(h+3.683))$. Changing the antenna height h not only affects the minimum angle θ, but also affects the spot center (X), and spot size (Along range (AR)× Cross range (CR)). Table 1 summarizes examples for target centers and sizes for several values of h. Note that from [1], $X = H \tan\theta$, $AR = H[\tan(\theta + \psi) - \tan(\theta - \psi)]$, and $CR = 2H \tan\theta \sin\psi$.

Table 1: Spot centers and sizes as a function of antenna height.

h (m)	Minimum θ (degrees)	Spot center at minimum θ (m)	Target size at minimum θ (m^2) ($AR \times CR$) (3 dB)
1.0	60	20.18	12 × 4.93
1.5	57	18.72	10.452 × 4.569
2.0	55	17.36	9.76 × 4.41
2.5	52	15.55	8.75 × 4.11

It can be observed that as the antenna height increases, the target size is smaller. Although a smaller target size is desired, dealing with the antenna height above 2 m is inconvenient. As a result, the antenna height of 1.5 m is chosen which corresponds to the spot center of 18.72 m from the antenna and target size with dimensions 10.452 × 4.569 m^2.

Assembling a Reflector Antenna and its mount

At this point, a centered fed parabolic antenna with 1.2 m diameter is chosen. An antenna mount is also required so that the dish can be attached to a post. In this work, both of them were selected from "DH Satellite" company with the total price of $162. Note that this company also provides struts for attaching a feed to the antenna. The details for installation instruction are given in [2]. Figure 3 shows the antenna and its mount after assembling them together. Figure 4 illustrates the base can which is the part connected to a post. It is obvious that by removing two sets of nuts and bolts shown in Figure 4 at Points A and B, the whole antenna structure can be detached from the post. The look angle of the antenna can be changed by adjusting the locations of two nuts (Points C and D) on the long bolt.

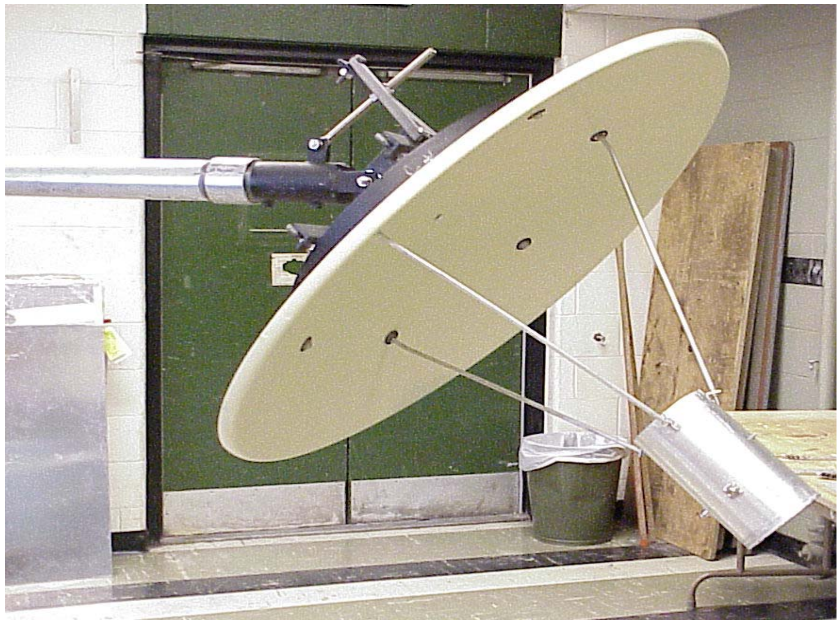


Figure 3: Antenna structure and its mount.

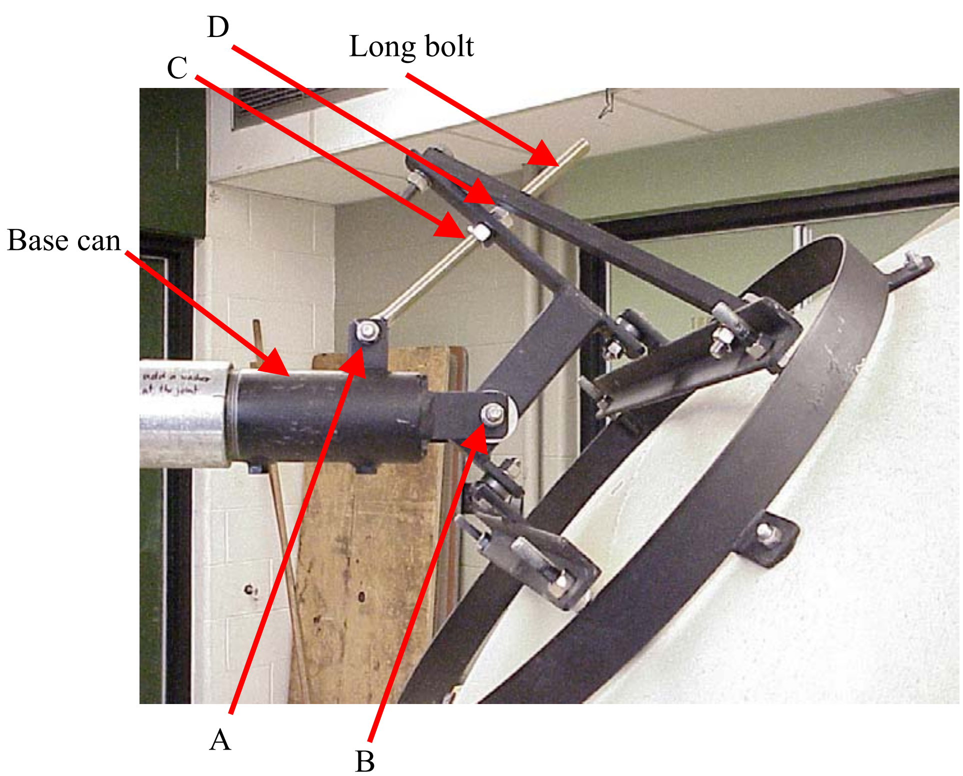


Figure 4: Base can (The part of the antenna mount which connects to a post).

3 Feed Antenna

In this section, the feed antenna chosen for our application is explained. Here, an open-ended circular waveguide was selected. The details include how to choose the size of this waveguide, the length of dipoles for feeding the waveguide, and its pattern.

Choosing a Feed Antenna

For this work, an open-ended circular waveguide is chosen as a feed antenna for the dish. Since it is common to use only one mode in this waveguide, its diameter cannot be any arbitrary size. The geometry of the feed chosen is shown in Figure 3.1. It is made of aluminium with thickness 0.15 cm. Note that the feed figure is shown in wire frame format so that the three dimensional structure of the feed including the shorted end at the back can be seen.

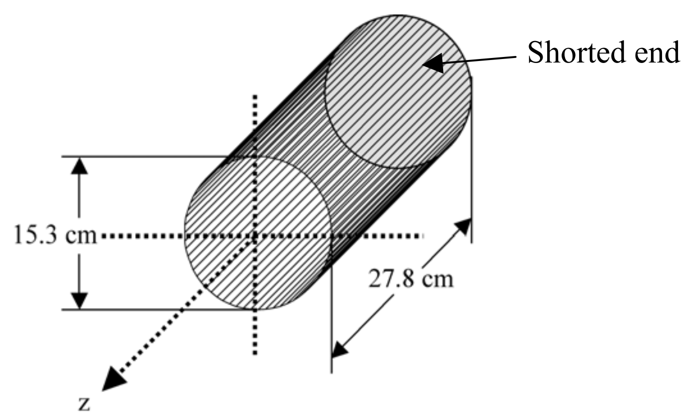


Figure 3.1: Feed antenna and its dimensions.

For this feed, only electromagnetic waves in TE_z mode is of interest, so only the cut off frequency $f_{c,mn}$ in this mode is considered. From [3],

$$f_{c,mn} = \frac{\chi'_{mn}}{\pi d \sqrt{\mu_0 \varepsilon_0}} \quad (1)$$

where χ'_{mn} is zero of derivative $J'_{mn}(\chi'_{mn})$ (n=1,2,3,…) of the Bessel function $J_m(x)$ and d is the inner diameter of this feed. It is possible to find that the two lowest cutoff frequencies are 1.149 (TE_{11}) and 1.906 GHz (TE_{21}), respectively. Since the operating frequency of the IIP radiometer is less than 1.5 GHz. Only one mode exists in this circular waveguide.

Feeds of the Open-Ended Circular Waveguide

In the tests for IIP radiometer, both vertical and horizontal polarizations are needed, therefore, two-perpendicular dipoles are selected as the feeds of the circular waveguide. Two issues related to these dipoles are worth mentioning which are their locations and lengths.

To find the appropriate locations of the feeds, it is necessary to know the guided wavelengths of the operating frequencies. For a frequency of 1.4 GHz, the guided wavelength can be computed from

$$\lambda_{11} = \frac{2\pi}{\sqrt{k^2 - \left(\frac{\chi'_{11}}{a}\right)^2}} \tag{2}$$

where $k^2 = (2\pi f)^2 \mu_0 \varepsilon_0$ and a is the inner radius of the circular waveguide. It is found that $\lambda_{11} = 0.37$ m. From the concept of "quarter-wavelength transformer", the feed dipoles are placed at the distance of $\lambda_{11}/4$ from the shorted end of the waveguide, so each dipole "sees" the shorted end as an open which reflects all of the energy back to the open-ended side. Note that two dipoles are placed perpendicular to each other.

Next, we have to find the optimum length of dipoles such that the reflection from both feeds are as low as possible. Here, brass rods with a diameter of 0.05 inches are used. To fine tune this, a cut and try process was employed. The procedure can be explained as follows.

1) Attach only one dipole to the circular waveguide.
2) Measure the scattering parameter S_{11} and record the data.
3) Cut the brass rod by 2 mm.
4) Repeat Steps 2 and 3 many times and collect the data.

Figure 3.3 shows the change in S_{11} as the brass rod is shorter. From this, it can be observed that the bandwidth of a dipole is not so large. The dipole length was chosen such that minimum S_{11} occurs at the center of the band of interest. Here, the center frequency of 1.38 GHz was selected for both dipoles which corresponds to the dipole length of 4.8 cm. After both dipoles were attached to the circular waveguide, the whole feed was mounted on the reflector and all scattering parameters were measured (S_{11}, S_{22}, S_{12}, S_{21}). The results are shown in Figure 3.4 from the frequency of 0.5 to 3 GHz. Figure

3.5 is the same as Figure 3.4 only the frequency band of interest (1.33 to 1.43 GHz) is zoomed in.

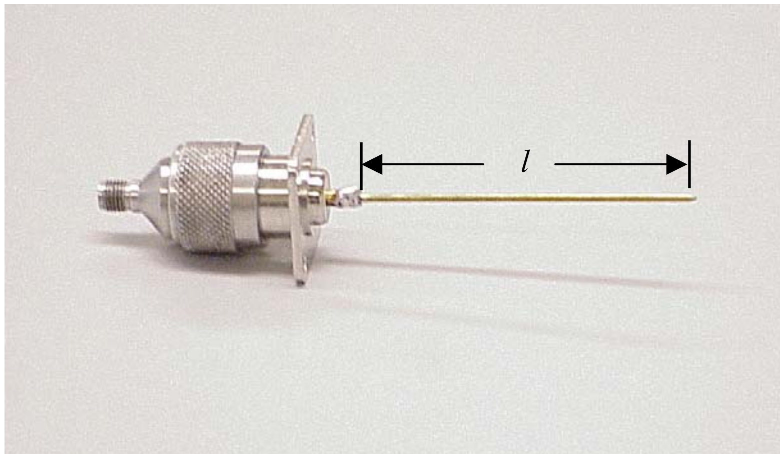


Figure 3.2: A dipole used as a waveguide feed. *l* is defined length of dipole.

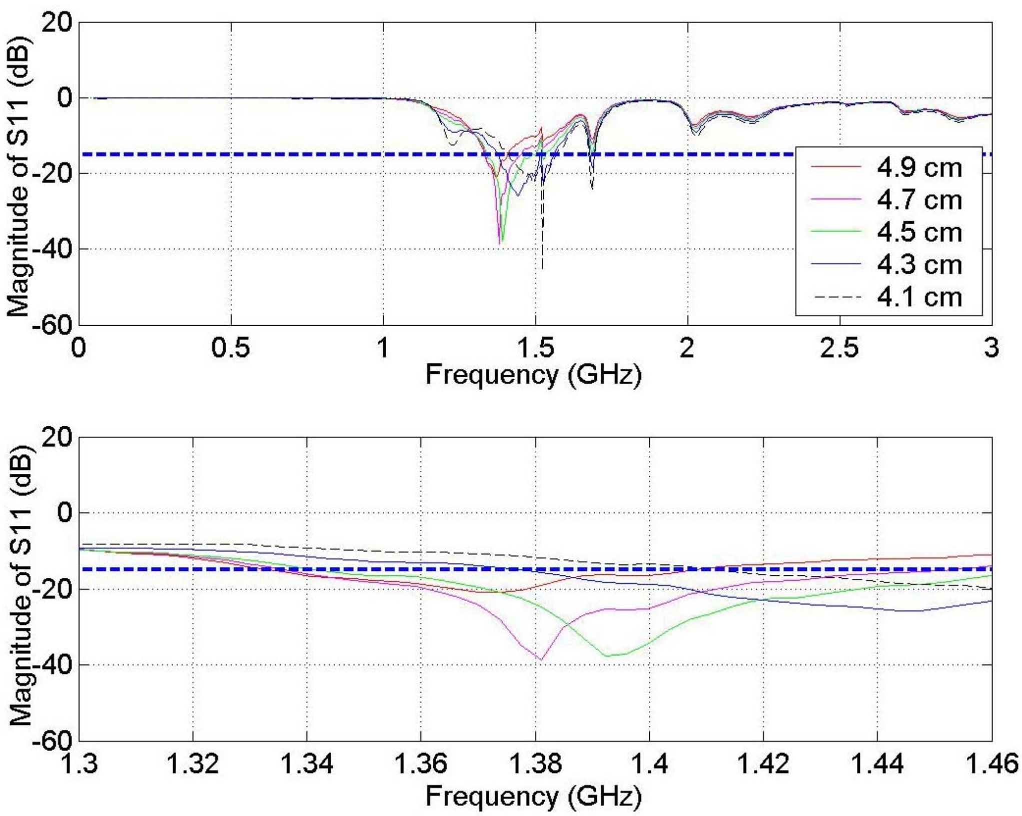


Figure 3.3: Changes in S_{11} as the brass rod length decreases.

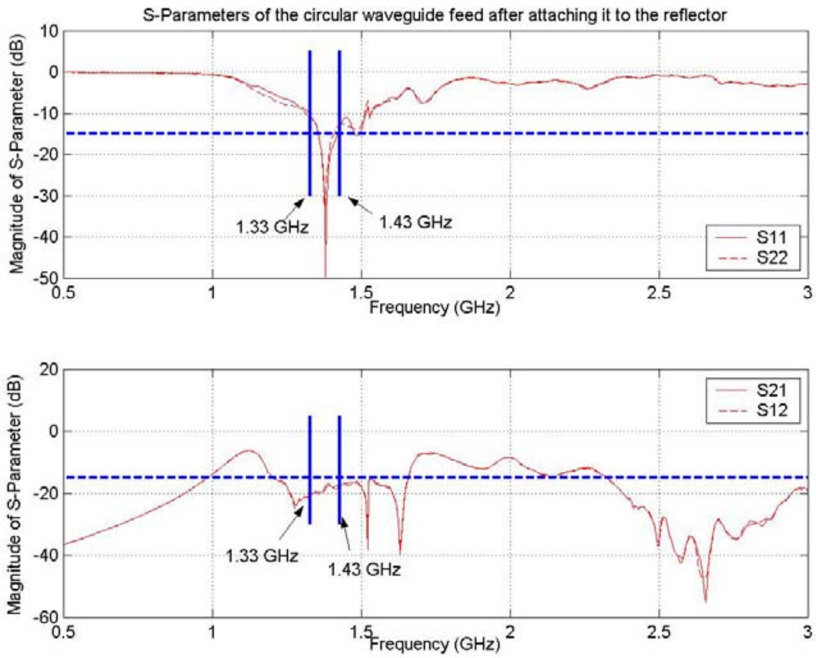


Figure 3.4: Scattering paramters measured at the waveguide feed with optimum dipole length a function of frequency (0.5 to 3.0 GHz).

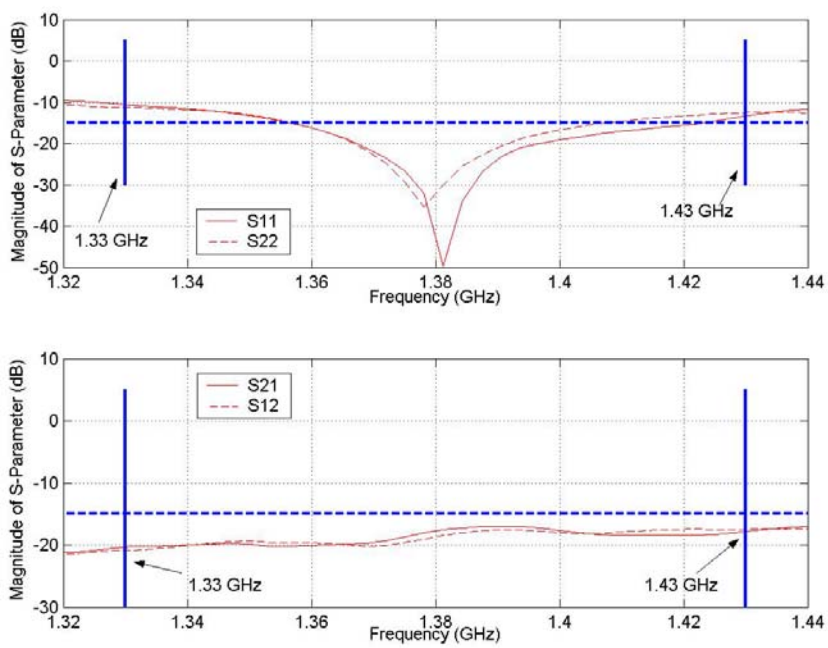


Figure 3.5: Scattering paramters measured at the waveguide feed with optimum dipole length as a function of frequency (1.32 to 1.44 GHz).

From Figure 3.5, it is observed that the magnitudes of S_{11} and S_{22} vary from –50 to –10 dB in frequency range 1.33 to 1.43 GHz with the minimum value at 1.38 GHz. S_{12} and S_{21} vary from –21 to –17 dB.

Antenna Feed Pattern

In the radiometer application, it is better to under-illuminate the dish because over-illumination can cause sidelobes in the radiation pattern of the dish. With sidelobes, the reflector can pick up unwanted power from other directions which can reduce the accuracy of the measurements. As a result, the feed pattern is of interest. To obtain the radiation pattern, the OSU's Reflector code was employed to compute the pattern. This code assumes that only TE_{11} mode exists in the feed. The coordinate of the open-ended circular waveguide is specified as shown in Figure 3.6. The radiation pattern in yz plane is illustrated in Figure 3.7 as a function of angle θ.

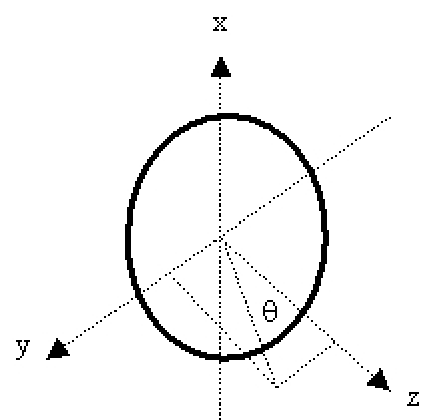


Figure 3.6: Coordinate of the open-ended circular waveguide for computing radiation pattern.

For the reflector mentioned in Section 2, it has the ratio of the focal length to diameter (f/D) equal to 0.45 which means the focal length $f = 0.45\times1.2 = 0.54$ m. The illumination angle which is defined as the angle between the lines FA and FO (indicated in Figure 3.8) is $\phi = \tan^{-1}((D/2)/f) = 48°$. From Figure 3.7, it can be seen that most of the energy (5 dB beamwidth) radiated from the feed is in the dish.

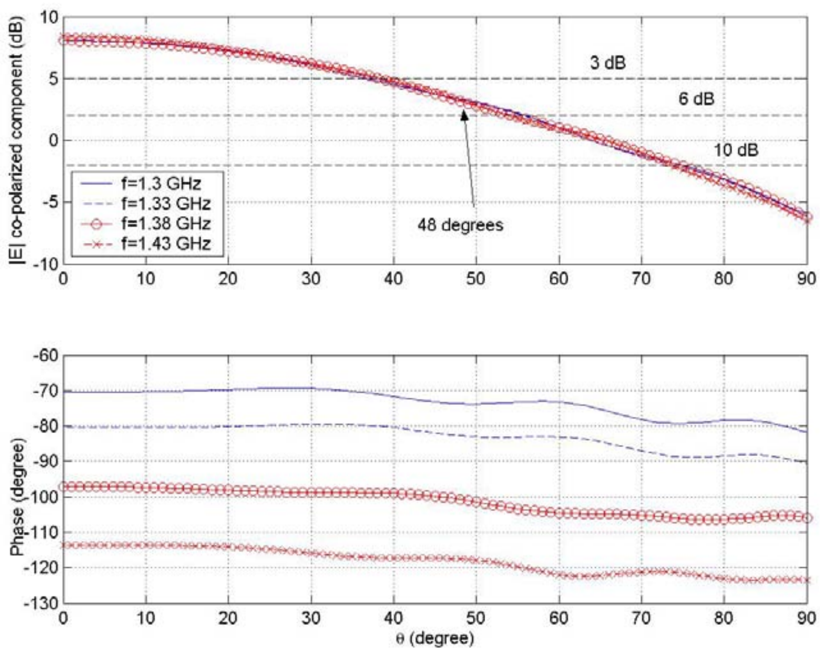


Figure 3.7: Radiation pattern from an open-ended circular waveguide.

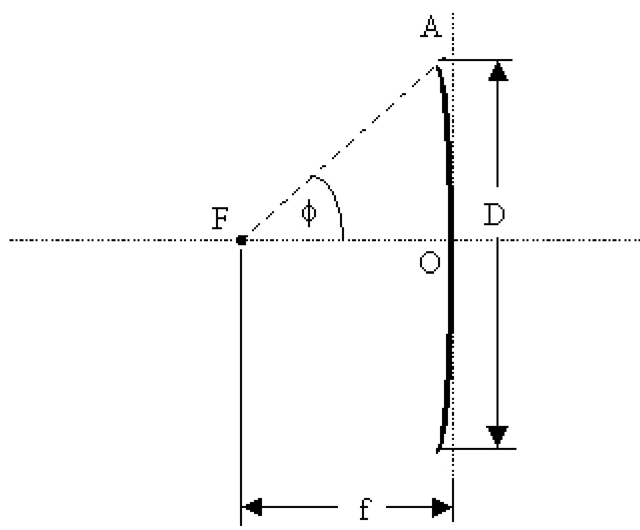


Figure 3.8: Diagram of the parabolic dish.

4 Antenna Mount

At this point, the reflector antenna and its feed are ready for the measurements. As stated in [1], the antenna will be placed on the 2nd-level of ESL roof. Therefore, it is necessary to build a stable supporting structure for the antenna. In this section, details for the antenna mount will be discussed and the finished structure will be shown.

Antenna Mount Structure

It is important that the antenna mount structure is strong and stable because it will be placed on the roof where it is windy. Although there are various kinds of antenna mount available in the market, non-penetrating roof mount (NPRM) from Channel Master seems to be the best candidate for this application ($99 each) because it is designed specifically to handle high wind load and easily modified. Figure 4.1 illustrates this NPRM. It can be observed that the cage of NPRM which extends to the back of the post allows us to use a large number of concrete blocks to weigh down this structure. This makes the NPRM more stable. The instruction, assembly manual and its dimensions are described in [4]. Despite the fact that this NPRM is designed for a dish that looks up in the sky, it is relatively easy to modify this structure so that it can support an antenna with downward observation.

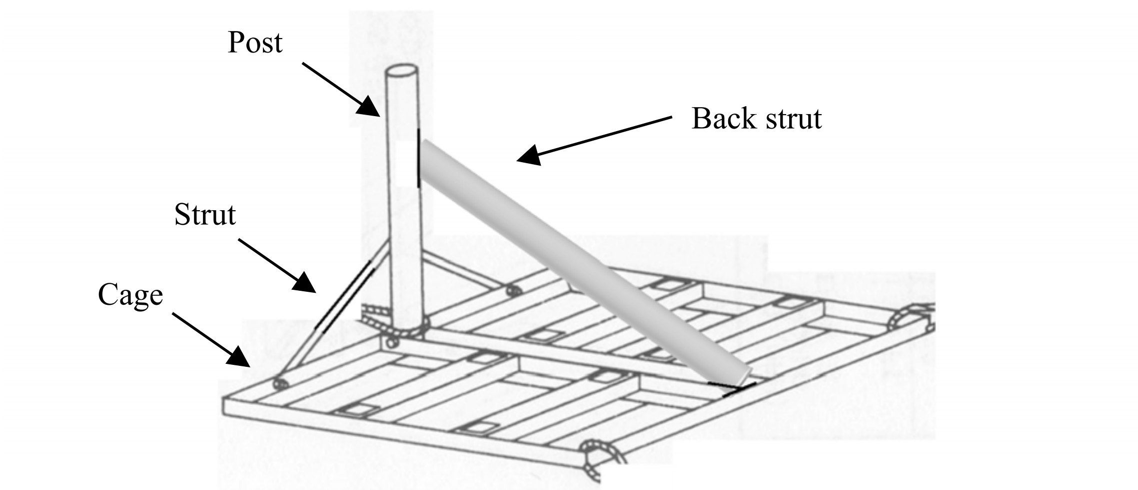


Figure 4.1: Non-penetrating roof mount.

Modification of Non-penetrating Roof Mount

To arrange the antenna such that it observes in downward directions, the base can (indicated in Section 2) must be connected to a horizontal post. Therefore, additional structure must be built to make this possible. In this work, 3-inch galvanized pipes with thickness of 3 millimeters and their compatible fitting are used to modify NPRM structure. Note again that the antenna height is chosen to be 1.5 m. The design of the modified structure is shown in Figure 4.2. Table 4.1 lists additional parts which were purchased from “Pipe & Valves” company with the total price of approximately $300. Figure 4.3 illustrates the finished structure with the reflector antenna attached. It is worth mentioning that a few concrete blocks are used to weigh down the structure. Numbers in circles in this figure correspond to the part numbers listed in Table 4.1.

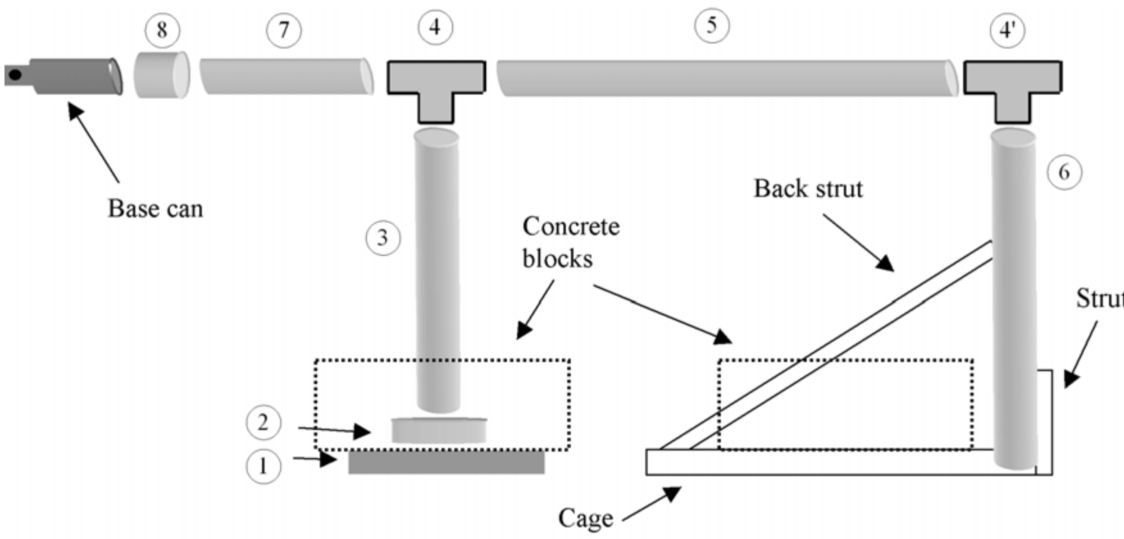


Figure 4.2: Design of the modified non-penetrating roof mount.

Table 4.1: Additional parts for the modified structure.

No.	Part	Quantity
1	Metal plate (12” × 26” with thickness of 0.5”)	1
2	3” Galvanized flange	1
3	3” Galvanized pipe (59” long, threaded both ends)	1
4	3” Galvanized tee (threaded inside)	2
5	3” Galvanized pipe (64” long, threaded both ends)	1
6	3” Galvanized pipe (63” long, threaded both ends)	1
7	3” Galvanized pipe (30” long, threaded one end)	1
8	3” Galvanized coupling	1

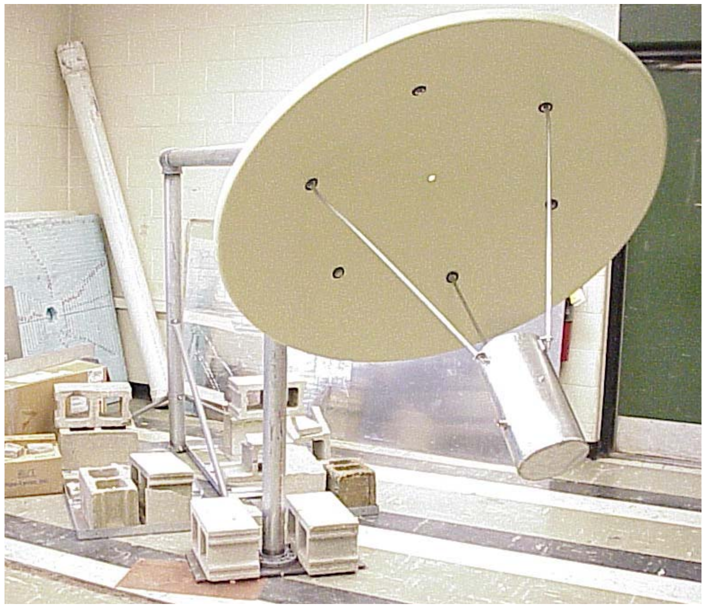


Figure 4.3: Finished structure.

Assembling the Antenna Mount

Although only a few pieces of pipes and fitting are used to build this antenna mount, it is necessary to assemble everything by following the correct procedure. Failing to do so makes this job very difficult (each pipe is heavy). The procedure is described below:

1) First, attach the flange to the metal plate in the middle with nuts and bolts. Countersinks must be made under the plate such that its bottom surface is flat after connecting the flange.
2) Screw Pipe 3 to the flange.
3) Screw Tee 4 on top Pipe 3 and lie down the whole structure.
4) Screw Pipe 5 in one side of the tee.
5) Screw Tee 4' to the other end of Pipe 5.
6) Screw Pipe 6 in the bottom of Tee 4'
7) At this step, two persons are needed to stand up the whole structure. One person hold the structure still while the other one attaches Pipe 6 to the cage in the position as shown in Figure 4.2.
8) Attach two struts and back strut to Pipe 6. The whole structure should be able to stand by itself. Then, place a few concrete blocks on the cage and the metal plate.

9) Screw in Pipe 7 into Tee 4.
10) Screw in Coupling 8 to Pipe 7.
11) Screw in the base can.
12) Attach the antenna mount to the base can with nuts and bolts. Make sure that the number of concrete blocks on the cage is enough to stabilize the structure.

5 Microwave Absorbers

As mentioned in [5], converting measured radiometer voltage into brightness temperature needs at least two calibration targets with known brightnesses. One of the targets is microwave absorber. To make the assumption that an absorber is a blackbody, the absorber reflectivity must be minimal. In this section, criteria for selecting absorbers will be described. Since absorbers are usually expensive, financial issues will be discussed also.

Type of Absorbers

There are two major types of absorbers that can be used as targets for the radiometer: planar and pyramidal absorbers. Table 5.1 summarizes the advantages and disadvantages of each type.

Table 5.1: Summary of advantages and disadvantages of each absorber type.

Type	Advantages	Disadvantages
Planar absorber	- Easy to handle - easier to store a large quantity in a building	- more expensive to obtain the same low reflectivity as pyramidal absorbers
Pyramidal absorber	- less expensive compared to planar absorbers	- difficult to store a large number because care must be taken to keep the pyramidal shape in a good condition

Both kinds of absorbers can be purchased from "ETS-Lindgren" company (used to be Rantec). Table 5.2 summarizes characteristics of each absorber type and the model numbers that are relevant to this application. Table 5.3 summarizes the prices and lead time. It is known that as the thickness of a planar absorber or the height of a pyramidal absorber increases, the reflectivity will decrease, but the price will be more expensive and difficult to handle. Therefore, only models with thickness up to 12 inches are shown.

Table 5.2: Summary of characteristics and model number of each absorber type. Each model has a footprint of 61 cm × 61 cm. (*R* = Reflectivity)

Type	Model number	Operating frequency	Test frequency (*R* = -20 dB at this frequency)	Guaranteed Reflectivity at 1-2 GHz (Normal Incidence)	Thickness or height (inch)
Planar absorber	FL-4500CL	> 455 MHz	> 0.8 GHz	-	4.5
Pyramidal absorber	EHP-8PCL	1 GHz-40 GHz	-	-30 dB	8.5
	EHP-12PCL	1 GHz-40 GHz	-	-35 dB	12.25

Table 5.3: Summary of prices and lead time of each absorber type.

Type	Model number	Price	Lead time (week)	Total price (119 pieces)
Planar absorber	FL-4500CL	$ 95	4-6	$ 11,305
Pyramidal absorber	EHP-8PCL	$ 47	3-4	$ 5,593
	EHP-12PCL	$ 57	3-4	$ 6,783

All types of the absorbers mentioned above have been purchased for further testing and they arrived at ESL already. The test of absorbers will be described in a future document. From Tables 5.2 and 5.3, it is obvious that the performance of pyramidal absorbers are much better and the prices are half of the planar one. Therefore, pyramidal absorber seems be a good candidate for the calibration target of the radiometer.

Absorbers as Targets for the IIP Radiometer

In Section 2, it is found that the area of a target that covers 3 dB beamwidth is 10.452 × 4.569 m^2. Since the footprint of 1 piece of absorber is 61 cm × 61 cm, 119 pieces are required to cover this area. Table 5.3 lists the prices for 119 pieces of each absorber type. It was found that there are some absorbers which can be used available at ESL and they are listed in Table 5.4.

Table 5.4: Absorbers available at ESL.

Type	Height (inch)	Number of Pieces	Number of Pyramids on 1 piece
EHP-12CL	12	39	6×6
EHP-18CL	18	20	4×4
Pyramidal absorber	23	5	4×4
Pyramid absorber	30	5	6×6

By using combinations of absorbers we have and some new ones, it is possible to reduce the total price. Table 5.5 lists the cost of extra pyramidal absorbers (both 8” and 12”) required for various combinations of ones we already have. Tables 5.6 and 5.7 are the same as Table 5.5 only the target length is reduced by 1.2 m (discard two end rows of absorbers) and a factor of 2/3, respectively. To choose what combinations to use, it is suggested that the performance of each absorber type be tested first by measuring the reflectivity.

Table 5.5: Combinations of absorbers available at ESL and prices of extra pyramidal absorbers required.

Absorbers available at ESL		Number of extra absorbers required	Price of extra absorbers needed for 8 and 12 inch pyramidal absorbers	
Combinations of various types	Number of pieces for each combination		8”	12”
12”	39	80	3,760	4,560
12”+18”	59	60	2,820	3,420
12”+18”+23”+30”	69	50	2,350	2,850

Table 5.6: Combinations of absorbers available at ESL and prices of extra pyramidal absorbers required if the target length is reduced by two rows of absorber.

Absorbers available at ESL		Number of extra absorbers required	Price of extra absorbers needed for 8 and 12 inch pyramidal absorbers ($)	
Combinations of various types	Number of pieces for each combination		8”	12”
12”	39	66	3,120	3,762
12”+18”	59	46	2,162	2,622
12”+18”+23”+30”	69	36	1,692	2,052

Table 5.7: Combinations of absorbers available at ESL and prices of extra pyramidal absorbers required if the target length is reduced by a factor of 2/3.

Absorbers available at ESL		Number of extra absorbers required	Price of extra absorbers needed for 8 and 12 inch pyramidal absorbers ($)	
Combinations of various types	Number of pieces for each combination		8”	12”
12”	39	80	3,760	4,560
12”+18”	59	60	2,820	3,420
12”+18”+23”+30”	69	50	2,350	2,850

6 References

[1] J. T. Johnson, “Initial External Experiment Plan for IIP Radiometer,” March 15, 2002. http://esl.eng.ohio-state.edu/~swe/iip/expsetup.pdf.

[2] “B Mount Installation Instructions” provided by DH Satellite company. The document is in the file “Antenna_mount_instruction.pdf”.

[3] C. A. Balanis, *Advanced Engineering Electromagnetics*. New York: Wiley, 1989.

[4] “Instruction and Assembly Manual” provided by Channel Master. The document is in the file “Non_penetrating_roof_mount.pdf”.

[5] J. T. Johnson, “Continued External Experiment Plan for IIP Radiometer,” April 10,2002. http://esl.eng.ohio-state.edu/~swe/iip/expsetup2.pdf.