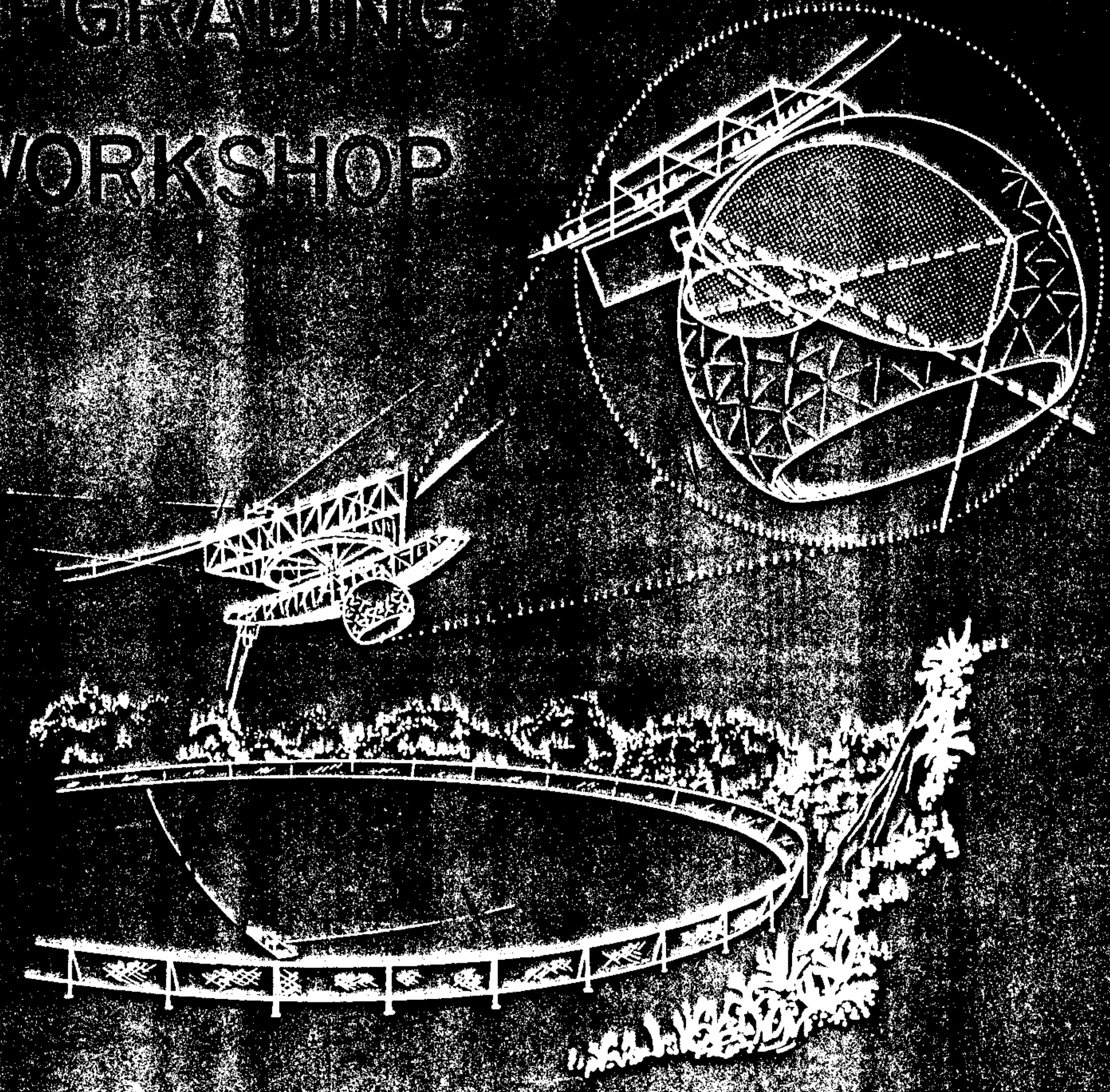
PROCEEDINGS
OF THE ARECIBO UPGRADING WORKSHOP



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THE IMPACT OF THE PROPOSED ARECIBO OBSERVATORY UPGRADE ON MIDDLE ATMOSPHERE RESEARCH

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The Arecibo Observatory has made important contributions and has great potential in the study of the dynamics of the neutral atmosphere including the troposphere, the stratosphere and the mesosphere.

There are at present three radar frequencies that are being exploited: 50, 430 and 2380 MHz. (In addition, there is a range of HF frequencies in a bi-static mode, using the Heating Facility to illuminate, but which we will not discuss here, since there would be no benefits to be derived from the upgrading.)

The proposed upgrading of the Arecibo 300 meter antenna will benefit the research work in the three regions of the atmosphere we have mentioned above through improved performance in the three existing radars, including multifrequency operation.

The improved performance is derived from three of the system improvements that have been mentioned in the upgrading proposal, and one additional advantage discussed in the appendix, namely:

a) The shielding of ground, ocean, ships and air craft radar returns (clutter) and shielding from interference at the operating frequencies (e.g. military radars, radio communication) by the conducting radome around the feed.
b) By providing a second radar feed for the 430 MHz radar (and possibly for the 50 MHz radar)
c) By improving the receiver sensitivity and antenna performance, specially at large zenith angles, as a consequence of the asymmetric illumination and the shielding of the surrounding ground.
d) By providing a focusing possibility, allowing focusing the antenna in the near field to the altitudes wider observation.

Figure 1 shows the expected scientific benefits of the upgrading in a matrix form, in terms of the three different frequencies and three different regions of the atmosphere. We will discuss here the most important benefits.

The reduction of ground clutter and interference by means of a radome around the feed will produce one of the most important benefits to middle atmospheric science. Figure 2 show a typical instrumental output of the 430 MHz radar, showing the spectra of backscatter signals from turbulent fluctuations in index of refraction from clear-air at tropo-and stratospheric heights. Notice the large peak at center produced by ground clutter. The spectral width of this line is comparable, and the intensity is much larger, than that of the desired signal. When the radar is pointed in the vertical direction to get the vertical component (only techniques radar can measure vertical velocities), the Doppler shift are reduced, making discrimination of signal and clutter signatures impossible at times. The smaller the velocity, the more difficult to discriminate. Figure 2 also shows weak ocean clutter echoes (responsible for the asymmetric shape of spectrum at high altitudes) which get confused with weak high altitude signals with same Doppler shift. In addition, ships going by the Arecibo harbor produce echoes with similar characteristics to those of the desired signals.

Mesospheric measurements are also contaminated with echoes from ships and aircraft at comparable distances (S. Juan airport is at 75 km from Arecibo).

The Gregorian will provide the Observatory with dual beam capabilities at 430 MHz (also possible at 50 MHz) permitting simultaneous measurements of vertical, V_z, and horizontal velocities, V_x. It should be mentioned that the reduction of feed illumination from 300 to 200 meters will not reduce its sensitivity when one considers improved performance at 15° zenith angle, and the fact that the middle atmosphere is in the near field of a 300 meter aperture (see Appendix).

The average power and bandwidth of the S-band transmitter, combined with the processing power of the new correlator and the array processor, make the S-band radar the highest resolution radar in the world and the most sensitive at its frequency. Figure 3 shows recent results showing full spectral characteristics of the radar returns at 256 simultaneous altitudes, at 15 meter separation. At present, the radar is operated in a bi-static mode, since the transmitter lacks pulse modulation capabilities and an electronic transmit-receive switch. As a consequence, only a small fraction of the illuminated stratosphere can be observed and the large aperture of the radar is not used for reception. Pulsing the radar, alone, would not remove this limitation since the stratosphere is in the near

CLUTTER + GROUND SCREEN

	MESOSPHERE	STRATOSPHERE	TROPOSPHERE
50 MHz		*V_z free of clutter *Partial reflection	*Clear air V_z free of clutter
430 MHz	*Improved N_e, $\underline{V}$, ν	*V_z free of clutter	*V_z free of clutter
2380 MHz			
Mult Freq			*Clear air V_z versus precipitation

DUAL BEAM

	MESOSPHERE	STRATOSPHERE	TROPOSPHERE
50 MHz	*Momentum deposition		
430 MHz	*V_z, $V_{x,y}$	*V_z, $V_{x,y}$ *Momentum deposition	
2380 MHz			
Mult Freq			

IMPROVED SENSITIVITY

	MESOSPHERE	STRATOSPHERE	TROPOSPHERE
50 MHz			
430 MHz	*Lower altitudes (near field) *Better $V_{x,y}$ at 15°		
2380 MHz			
Mult Freq	*D V_x / D z versus turbulence		

FOCUSING POSSIBILITIES

	MESOSPHERE	STRATOSPHERE	TROPOSPHERE
50 MHz			
430 MHz			
2380 MHz		*Highest resolution measurements 15m x 15m (assumes monostatic radar)	*Low power precipitation radar
Mult Freq			

Figure 1. Matrix showing scientific benefits in the three radar frequencies at three middle atmospheric heights as a consequence of the technical improvements a) to d) mentioned in the text, made possible with the installation of the Gregorian feed.

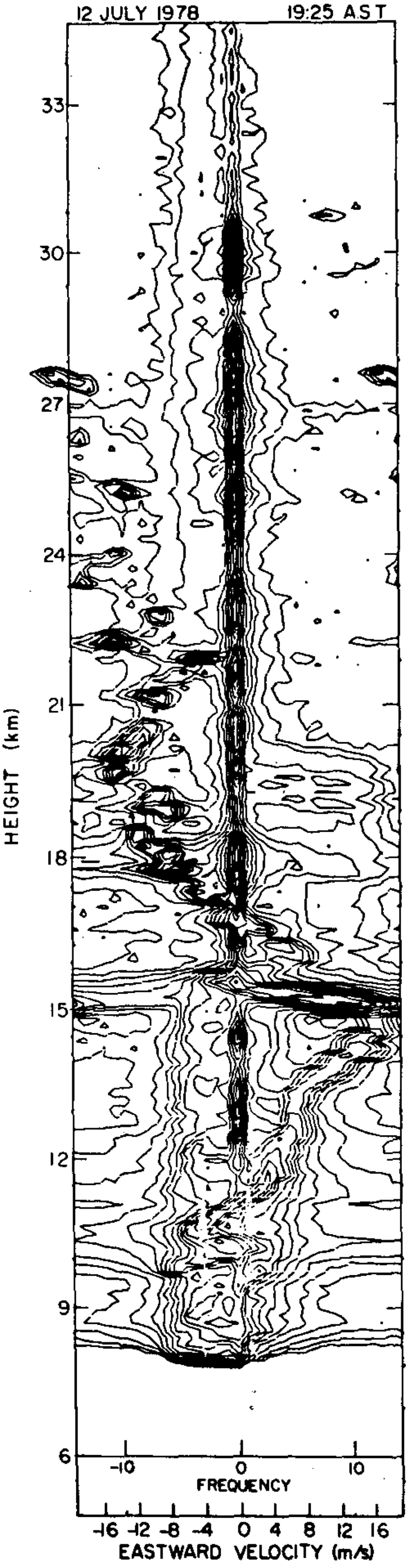
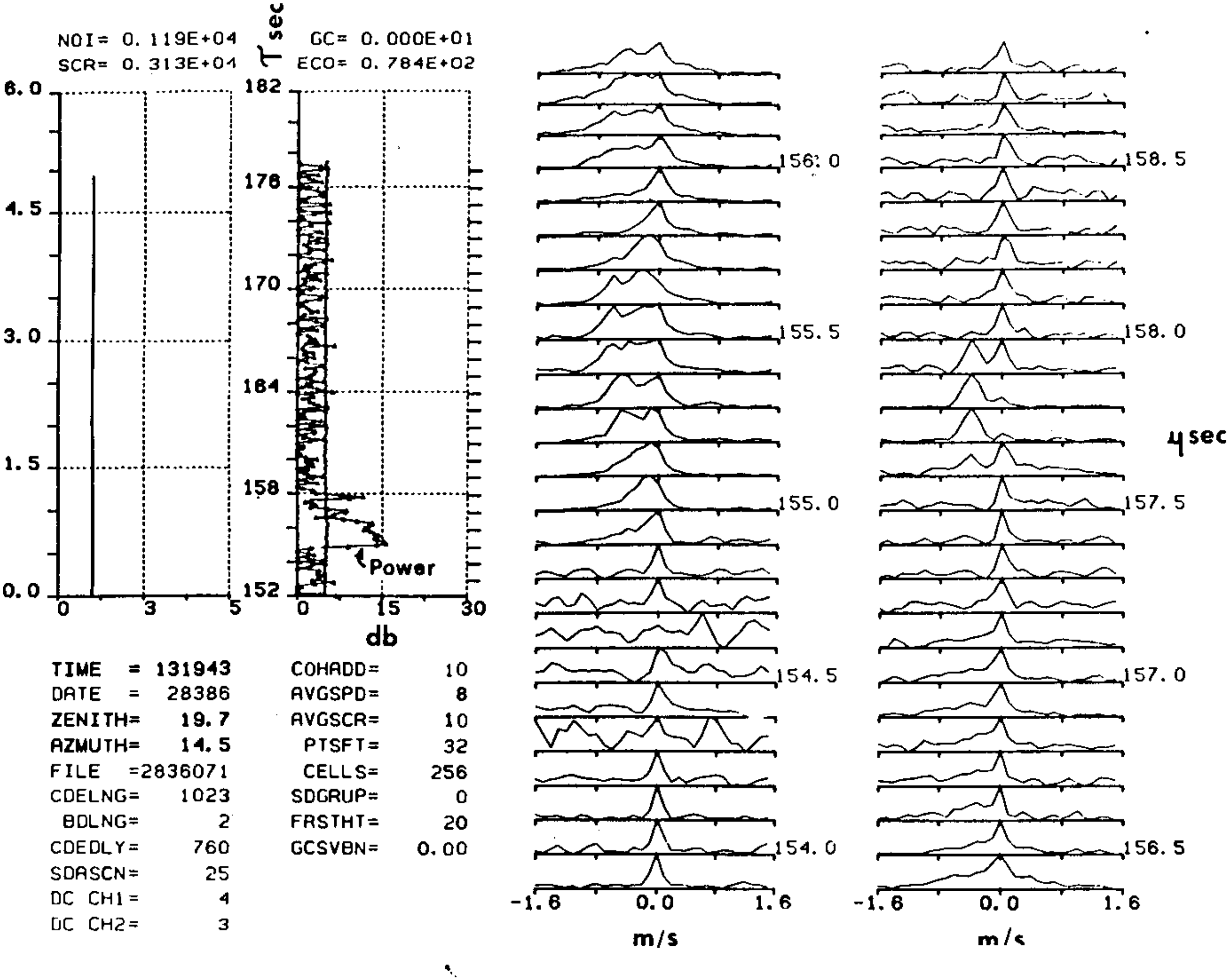


Figure 2. Contour plots of frequency power spectra of backscatter signals from clear air turbulent fluctuations in index of refraction. Total power is a measure of turbulence intensity, Doppler shift a measure of velocity and Doppler width of the turbulent kinetic energy. The feature at the center is ground clutter, the one at-4m/sec between 27 and 35 kms is ocean clutter. Ground clutter makes it almost impossible to measure vertical velocities, since they are of the order of ± 1m/sec. (Woodman, 1980).



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DC CH2= 3

COHADD= 10
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AVGSCR= 10
PTSFT= 32
CELLS= 256
SDGRUP= 0
FRSTHT= 20
GCSVBN= 0.00

Figure 3. Sample on-line plot of S-band stratospheric observations. The jagged profile in the center is power as a function of delay (152 to 177 μsec). Frequency spectra for a few selected delays (154 to 150 μsec) as a function of vertical velocity (-1.6 to 1.6 m/sec) are shown on the right half of the picture, normalized to maximum amplitude. DC contamination has not been subtracted. Resolution is 15 meters. Notice sharp layer at 158 μsec delay. (Woodman, Ierkic and Perrilat, personal communication).

field and the large aperture of the radar is not taken advantage of (see Appendix). The Gregorian feed should allow focusing of the antenna at stratospheric heights by (hopefully) simply moving the horn up about a 1.3 meters or by providing it with appropriate diverging lenses. Focusing should recover about 25 db of sensitivity. In addition, focusing would concentrate the illumination (and field of view on reception) to an area of the order of 10 meters in diameter (!) at lower stratospheric heights. This horizontal resolution would match very nicely the 15 meter vertical resolution already achieved, converting the radar in a unique and very powerful tool to study the morphology of turbulence in the stratosphere. At present other radars are limited to 150 meter resolution, where as the structure of turbulence is known to be as small as 30 meters or less.

Focusing should also improve the performance of the 430 MHz radar at stratospheric heights.

Although the Gregorian is not expected to respond at 50 MHz. It should be possible to install an easily removable 50 MHz feed (Yagis of arrays) inside the radome to benefit from its ground shielding. A 50 MHz feed inside the radome would allow multifrequency observations in the troposphere and allow precipitation observations with a relatively low power 2350 transmitter at the same time the clear-air dynamics is being observed with the 50 MHz system. It would also allow momentum deposition studies using Vincent's technique.

Figure 4 shows some typical Incoherent Scatter spectral measurements at mesospheric heights. The potential of the instrument to measure electron density and neutral velocities at this altitudes is noise limited. The improvements in system noise temperature and reduced vignetting at 15° will benefit these measurements. Reduction of the illuminated area from 300 to 200 meter diameter should not affect the sensitivity since the mesosphere is in the near field.

Concluding Remarks

The proposed upgrading definitively brings system improvements which would allow users to do new and better science in the field of Middle Atmospheric Physics. The benefits will be enhanced even more, if we can use the S-band radar in a monostatic mode and if we can focus the radar at the altitudes being observed.

We recommend a feasibility and cost study of the focusing possibilities of the radar feeds and of the necessary modification of the S-band transmitter to permit pulsed, monostatic operations. If feasible, its implementation should be included in the upgrading proposal.

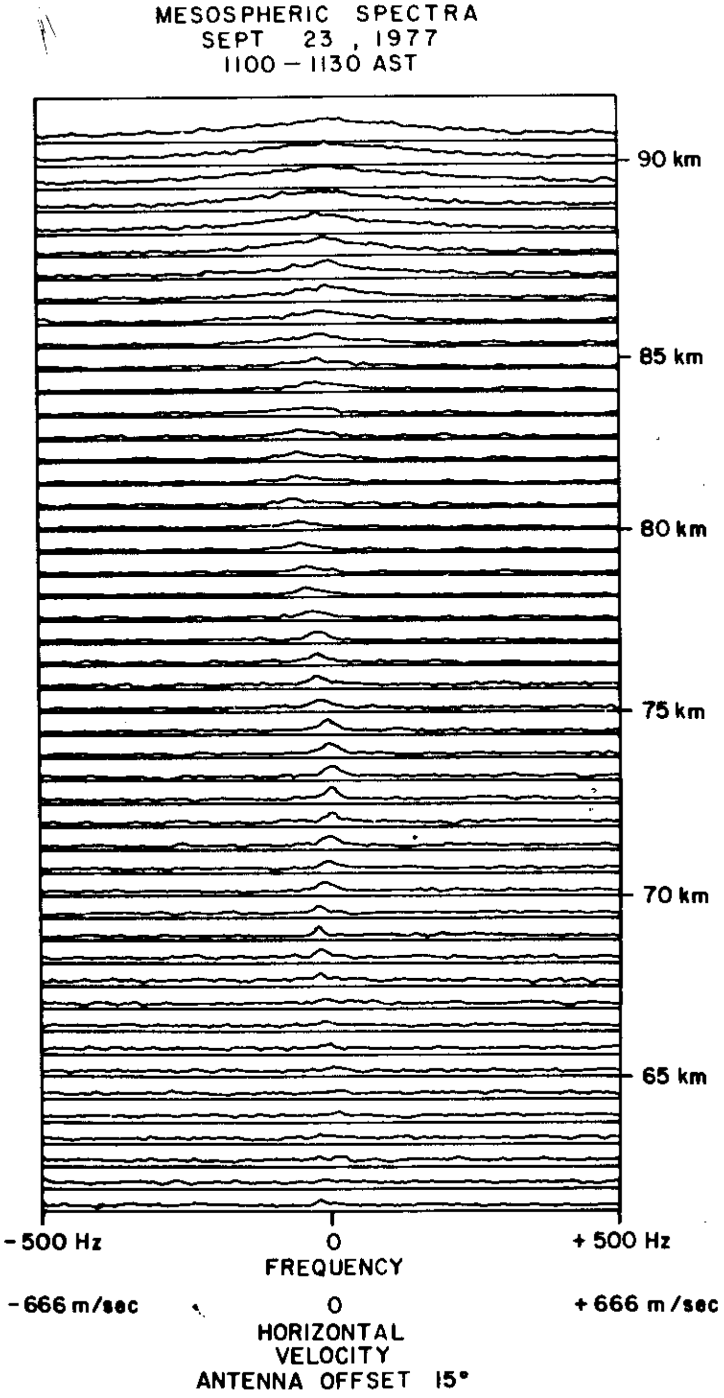

Figure 4. Frequency power spectra profile of incoherently scattered signals from free electrons at mesospheric heights. Power is a measure of electron density, Doppler shift of background velocity and width is mainly due to ion neutral collisions. Altitude on the lower end is signal-to-noise limited. These altitudes are often contaminated with aircraft returns from the San Juan airport. (Harper, 1978).

Appendix. - Near field and focusing effects affecting middle atmosphere radar observation.

As it has been shown by Farley (1), the radar equation for an homogeneous soft target can be written in terms of an effective area, A_{eff}, as

$$\frac{P_r}{P_t} \sim \frac{\sigma \Delta r}{R^2} A_{eff}$$

In this form the formula is valid in the far and near field. Here, σ is the scattering cross-section per unit volume, Δr is the pulse length and R the distance to the scattering volume.

The receiving effective area in the far field is equal to the physical area collecting the backscatter energy, i.e. $A_{eff} = A_{ph}$. In the near field, for an antenna focussed at infinity, the effective area is reduced to

$$A_{eff} = A_{ph} \left(\frac{\lambda R}{A_{ph}}\right)^2 = \frac{\lambda^2 R^2}{A_{ph}}$$

due to the lack of phase coherence for the signals arriving outside a Fresnel region of area $\lambda R = A_{ph}$.

Figure 5 shows the dependence of A_{eff} on R for different antenna sizes. Notice that in the near field a smaller antenna has more effective area than a larger one. This has important consequences in the Arecibo radars for middle atmospheric research. At Arecibo the transition from the far to the near field occurs at around 100 and 250 Kms. for 430 and 2380 MHz, respectively. This means that a Gregorian feed illuminating 200 meters diameter area would not be a disadvantage for mesospheric over the present 430 MHz linear feed which illuminates 300 meters: especially at a 65 Kms., where the maximum sensitivity is desired. Furthermore, at 2380 MHz, the effective area for scatters at 15 kms of altitude is 0.0037 of the potential physical area. This loss in sensitivity (25 db) is recovered if the antenna is focussed to the altitude being observed. Here the Gregorian would be of advantage since focusing (hopefully) would involve moving the horn up and down approximately 1.3 meters, or an appropriate diverging lens at the mouth of the feed horn. Focusing would have the additional advantage of reducing the scattering volume to a "point" 10 meters in diameter, matching the range resolution of the S-band radar.

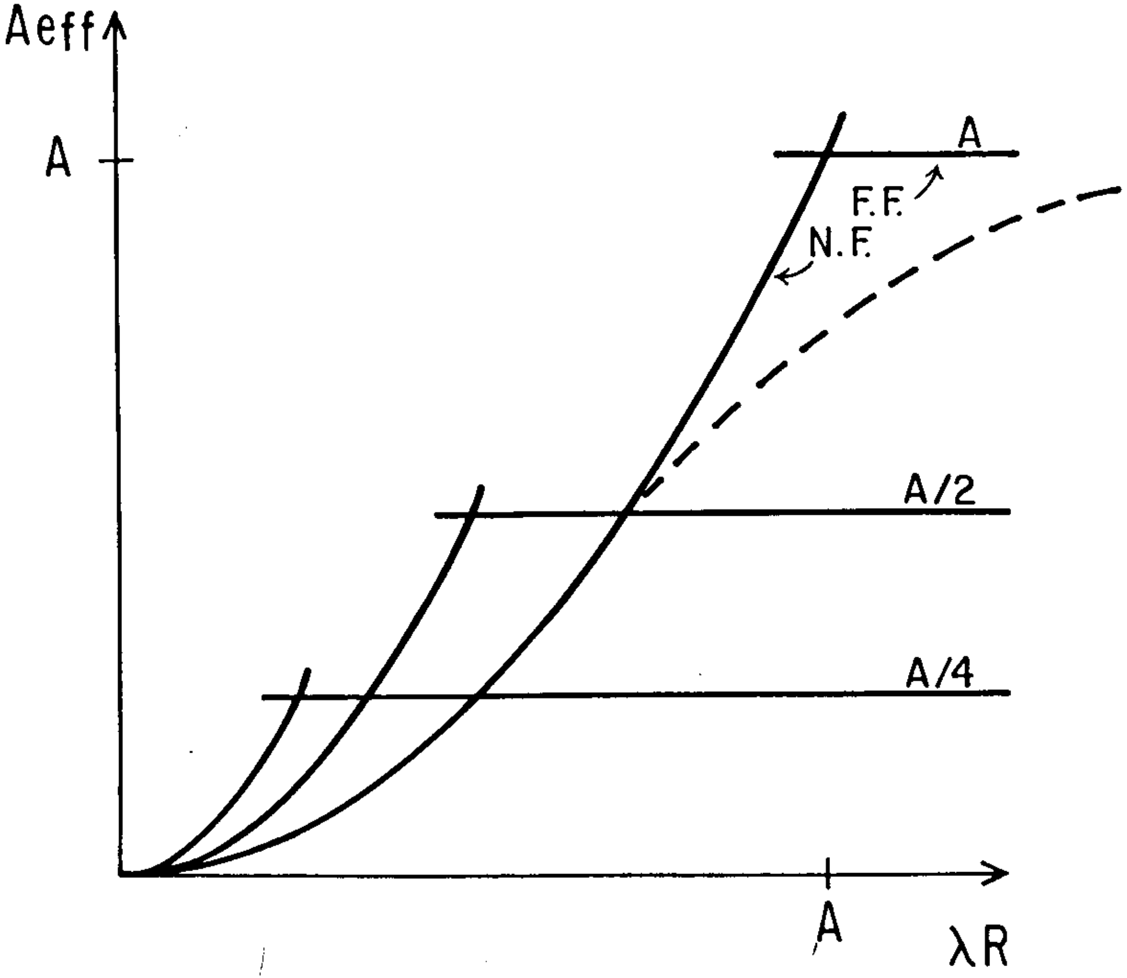

Figure 5. Sketch of behavior of effective area of an antenna of size A, $A/_2$ and $A/_4$ in terms of distance R (normalized as λR), valid for far (FF) and near (NR) field. Notice that in the near field smaller antennas have better performance.

References

1. Farley, D.T. (1984). Antenna size for MST radars, Middle Atmosphere Program Handbooks, Vol. 9, Edited by S.A. Bowhill and B. Edwards. SCOSTEP Secretariat, University of Illinois, Urban-Champaign, Ill.

Discussion following Ron Woodman's talk:

Hagfors: Thank you very much, Ron. The focusing of the beam in the lower part of the atmosphere is a fascinating idea. I think we'll be able to investigate this possibility, because we are conducting studies of polar diagrams and antenna performance as a function of feed position. It would not be very difficult to include focusing in the calculations.

Closing comments by Tor Hagfors:

I certainly appreciate all the advice we have gotten during this meeting. At the beginning I indicated that we had called you all together to seek additional advice, and to make last minute modifications in the proposal which I hope to submit to the Foundation within the next few months. I thought our ideas were pretty much close to perfection - that we had thought through all the possibilities - and I had not quite counted on the amount of advice that we have received here. There are many more suggestions before us than I had ever expected to come out at this meeting.

I will go through a few of these, and I will, in the cases where we have discussed them prior to this meeting, tell you what our opinions were. Maybe I should start with the most outrageous suggestions first: the requirements that were placed before us yesterday of importance for Zeeman splitting observations: the complete absence of beam squint, the absence of cross-polarization and the increase by at least five degrees of declination coverage. As you remember, I turned to the proponent of those yesterday, and asked him to come up with a suggestion for their solution. Is it forthcoming? (laughter)

Heiles: Do you want it now or later?

Hagfors: The squint problem we're certainly aware of and we are making computations and an assessment. We have all the necessary ingredients built into our computer models of the antenna. We shall, therefore, be able to make quantitative statements of the performance once the computations have been carried out. The increased declination coverage I quite frankly have no solution for. I don't think we can hope to get even a fraction of a degree more than we are proposing. Now about the cross-polarization. I believe - 40 db or some such number was mentioned for the main beam.

Heiles: All I was talking about was squint.

Hagfors: You did also talk about cross-polarization, at least at the cocktail party.

Heiles: I don't remember that! (laughter)

Hagfors: All I can say is that we will do our best, and in the proposal we will certainly specify what we expect to be able to achieve.

The other item which I thought was very interesting and worthwhile contemplating, was the possibility of obtaining observations simultaneously at a number of different frequencies. This request came during the meeting particularly from George Dulk, who wanted to observe from 100 MHz to 8 GHz in one go. I am certain that is not possible, but we have discussed the possibility of having nested horns, two, or possibly as many as three. But the center frequencies of these different channels will have to be relatively far apart. We have considered nested horns in relation to pulsar research, where it is highly desirable to observe at widely different frequencies, simultaneously on the same pulse. We are indeed planning to propose to have feed systems of this nature, and maybe they can serve several purposes.

The ability to suppress interference and clutter was discussed in several contexts during the meeting. It is very hard to assess this ability theoretically. All we can do at the moment is to do some handwaving. But we are planning to use the mini-Gregorian for tests. You may remember that this antenna has an open space frame around it, and that we plan extensive tests on an antenna range. What we clearly must do, to satisfy the atmospheric science community, and others, is to make experiments where this open space frame is covered with aluminum foil or some similar material and actually measure the polar diagrams of the feed with the foil in place. That will not add much to the labor and should provide quantitative information on the amount of interference suppression to be expected on the large Gregorian antenna. I believe this is the only way it can be done. We cannot hope for a theoretical assessment because the structure is just too complicated.

The question of elliptical beams came up. This is something which has been of rather major concern to us, for several reasons. We have had several discussions of this problem in ASAC meetings. Many users are extremely concerned about the beam ellipticity and the complexity of deconvolving and making maps with such a beam. We also have other concerns about the ellipticity. That is, we do not yet know what the polarization properties of the system will be when we have an elliptical beam. The mapping from a circular horn to an elliptical illumination pattern is a very complicated one. It appears as if one inevitably builds in an extra cross-polarization term into that mapping. We don't know for sure, and are in the process of investigating it.

We have considered the possibility of using a different type of horn when extreme polarization purity is required. This means that, if we do build the elliptical option into the system geometry, as we are currently planning, then we imagine that a small set of elliptical horns could be constructed in order to squash the elliptical illumination pattern into a circular one. I believe this is an option. It has not been well investigated yet, but I hope it will, before the final proposal submission to the Foundation.

The other question which has come up is the question of having multiple feeds and multiple beams. We have discussed this option also, but do not yet know the answer as to how many feeds can be placed in the focal plane. Remember that the final geometry has not yet been settled, because we are still investigating what will happen if we raise the platform to obtain another ten feet of separation between the paraxial focus and the reflector. When we've completed these calculations, it will be possible to determine how much room there is for a cluster of feeds.

We do have computer programs to investigate the effect of moving the feed horn both laterally and axially. We have developed these programs for the main purpose of determining the sensitivity to exactness in mechanical design. This in turn has an impact on the price of the mechanical construction. There is no reason why we cannot extend this analysis to find out what happens to the beams as we move the feed horn away from its optimal position. My guess is that we can form a cluster of beams above a certain frequency to be determined simply because there will not be enough room for several low frequency horns.

I was somewhat disappointed in the acceptance of our plans by the atmospheric science community, because I had thought it was more attractive than what appeared during the presentations. In particular, I had placed considerable emphasis on the fact that one would have wider bandwidths available than at present, and I had hoped that this would appeal to observers of the plasma lines. In order to gain the interest of the atmospheric scientists, we may have to include some extra items in the proposal, in addition to the feed itself and the ground screen, such as an extra transmitter, a wider bandwidth transmitter to transmit at multiple frequencies. I had thought we should submit proposals for such added items independently of the major Gregorian proposal, but maybe it should all be combined into one. This is a question of politics. I'm not sure which way to go, and will probably seek advice from the AAB (Arecibo Advisory Board) and the ASAC (Arecibo Scientific Advisory Committee) during their meetings which are coming up shortly.

I also sense from this meeting that it is important to include a number of add-ons such as receivers, data-processing equipment, etc. which have been pushed aside because they are relatively minor items compared to the ones we have been considering so far.

So these are some of the things we have learned, which we shall try to fold into the ultimate proposal. I should maybe say a few words about the work we have done. We have expended approximately half a million dollars in these plans, in computations, hiring extra people etc. We have not received any extra support from the National Science Foundation for the work and have had to make considerable sacrifices in our operations. I wanted to include some of these extra expenses in the proposal for the ground screen, but I was advised against it by many, and did not include it. By now we are running out of funds to expend on further work. So I'm afraid the proposal will <u>not</u> be perfect - you need not be worried about that, Ed. It will have gaps here and there, unfortunately but I sincerely hope that it will provide convincing evidence that the Gregorian project is an extremely cost-effective way to buy great new scientific information.

Thank you very much.