RADIO FREQUENCY SCIENCE CONSIDERATIONS

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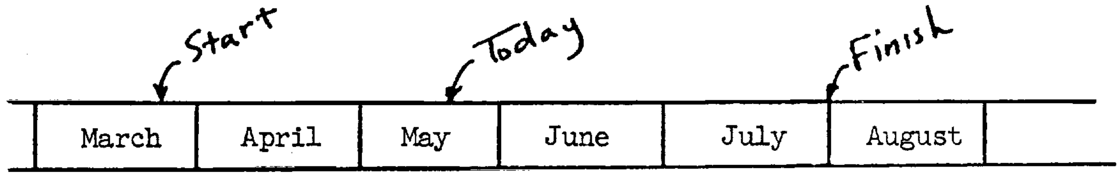
DR. CROFT: Many scientists have been waiting a long time to get access to a radio link that is completely outside the atmosphere, and I would like to talk about how we might use the 400 MHz link to do some scientific research at the same time we use it for telecommunications. There hasn't been much mention of this subject thus far in this meeting and in part, that lack is due to our tendency to think in terms of just the sensible atmosphere, the lower part. However, the ionosphere and the magnetosphere form the top of the atmosphere; and one can't hope to understand the atmosphere without knowledge of the exosphere. As a result, I like to include the ionosphere when I speak of the "atmosphere."

Figure 7-36 is an outline of my activities relevant to this subject. One of my objectives is to compose a consensus, not just my views, so if any of you have suggestions to be included in the final report, please contact me.

There are three areas of investigation listed in Figure 7-36. First, what can we do to get new scientific information by using the 400 MHz link by itself; second, what can we do to back up the experiments that are flown and, third, how can we help in the design of follow-on probes? We are going to be designing more probes in the future and, eventually, we will want to know what happened on this set for the purpose of engineering the next set. So what should we be looking for to meet these three areas?

A study previously conducted by Coombs of Ames led to a list of recommended objectives which are summarized on Figure 7-37 and present some very good ideas. One of the most straight forward goals is the measurement of the strength of the signal and serves to get both the measurement of absorption as a form of scientific information about the atmosphere and to provide

FIGURE 7-36



to consider 3 adjunct uses of the 400 MHz telecommunications system:

1. obtain new scientific information
2. provide backup information for the experiments flown
3. obtain measurements which aid in designing future probes

FIGURE 7-37

Coombs' suggested starter list:

1. Measure 400 MHz amplitude to determine absorption and perhaps scintillation (if data rate permits)
2. Measure noise strength near 400 MHz to reexamine 400 MHz choice and to observe thermal, cosmic and local synchrotron noise trends
3. Probe VSWR sensing to monitor integrity of system, icing, and possibly plasma effects
4. After probe is finished, have the bus radio occultation in the same region where the probe fell - primarily to evaluate the occultation

Other ideas briefly mentioned

-dual frequency from the probe
-high-gain tracking antenna on the bus
-two-way communication, bus to probe and back
-more than one probe, or an auxiliary space-deployed unit
-sensor antennas on the probe
-additional DSN facilities

data which will aid us in the design of future systems. Scintillation could be observed by this same means if we incorporate sufficiently rapid sampling of the amplitude.

This is a good time to bring up a point concerning the telemetrv system; it has a "soft decision" feature, that is we won't get on-off decisions from it, but rather we are going to get a bit (i.e., a decision) and some measure of the confidence in that bit. The coding engineers who are trying to optimize this system should keep in mind the scientists' need for a good quantitative measurement of the amplitude variations. It might be possible to kill two birds with one stone in this case. That is, if we measure atmospheric scintillation as an adjunct to the telemetry code, we would come out with good scientific understanding of the planet's atmosphere and with a good set of data for designing future probes. We would get our confidence measure for this telemetry string at the same time, provided that we do the coding right. I haven't seen any mention of this kind of reasoning in the literature.

The second suggestion of Coombs which is also very natural is that we should measure the noise. I will have more to say about that in connection with subsequent figures.

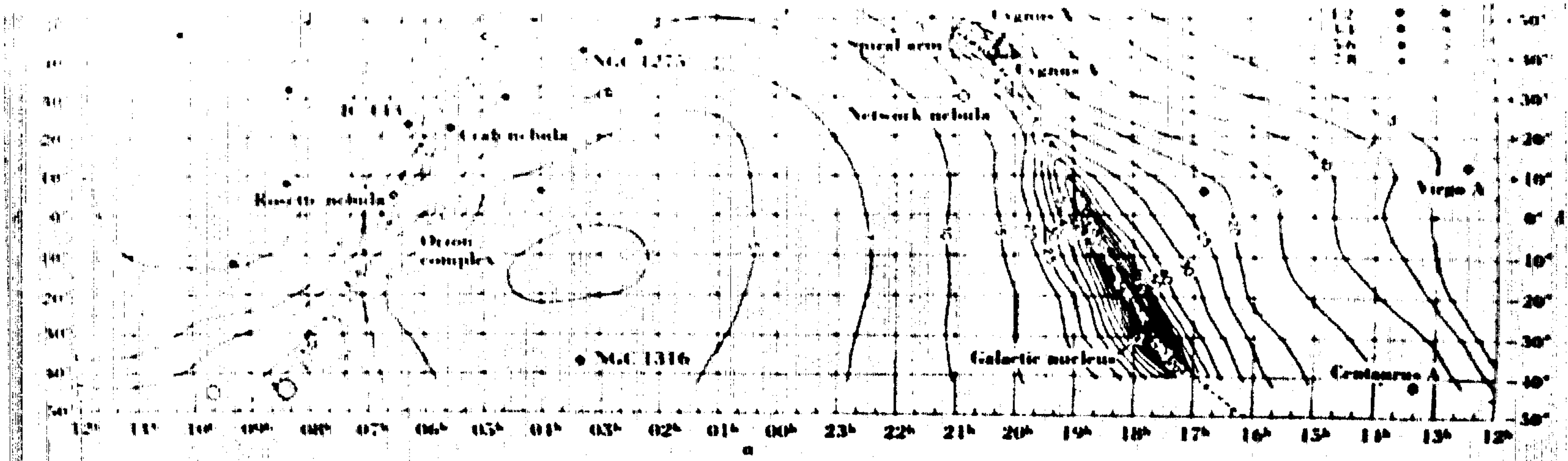
The third suggestion was to measure the standing wave ratio on the antenna. He points out that we are going to have these probes descending into some extremely unearthly atmospheres, and for example, the antenna elements might ice up; some kind of material might be physically deposited on the antenna that would cause a loss of telemetry. If the telemetry fades out, we would want to know the cause. It would be very illuminating to know the standing wave ratio, for that purpose alone. If something breaks, the standing wave ratio is a good diagnostic indication. If the telemetry weakens and the standing wave ratio goes bad, you would have a good clue as to why it went bad.

If we do telemeter the VSWR, while the probe is in the ionosphere, we could measure the ionospheric plasma effect. In this case, the effect is somewhat masked by the local ionization induced by the vehicle itself, but nevertheless, this idea merits further consideration.

Coombs suggested that after probe descent the bus perform an S-band Occultation in the same region of the planet where entry occurred. His objective was to shed some more light on the occultation method itself.

I won't go into those last items on Figure 7-37 because of time. With regard to measuring noise; because we have selected 400 MHz, we are in a frequency regime where, for the various missions, the cosmic noise, the planet disc temperature and the synchrotron emissions are of comparable magnitude. We inherently measure their sum. (This isn't true, however, at Jupiter, where the synchrotron radiation overwhelms everything else, but on the other missions we are going to be measuring the sum of several comparable sources.) I think it would not be productive to measure the noise unless we can somehow identify the relative strength of the components.

I have included Figure 7-38, a radio map of the sky, because it shows the distribution of cosmic noise at 250 MHz. The situation at 400 MHz is similar. The lower portion of this figure is a representation of the same data in shades of gray. The white dots are the radio star sources and the light-band is the spatially diffuse emission; it is probably synthrotron emission from electrons in our own galazy. You can see there are large areas of comparative quiet. If we can manage it, we might enter the planetary atmosphere on a side that faces a quiet area and thereby eliminate a lot of this source of noise. That should be one of the things considered in entry-point selections, albeit, a minor point.



In the plot above, to get temperature in °K at 250MHz, multiply by 6 and add 80°K.

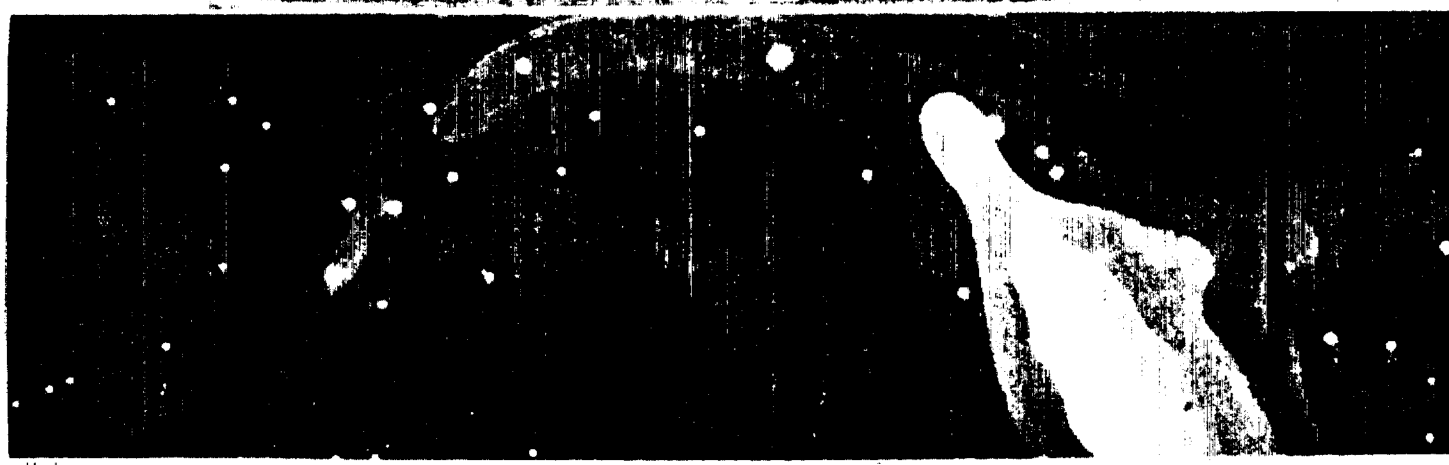


Fig. 8-2. Radio-sky panorama obtained by converting the contour map of Fig. 8-1 to shades of black and white. The figure gives an impression of how the sky would appear if our eyes were sensitive to radio waves instead of to light.

Figure 7-38

Microwave absorption spectroscopy is often used to identify molecules but examination of the frequency axis of Figure 7-39 reveals that most of the identifiable absorption bands are in the 10 GHz region or higher. Ammonia has a 23.5 GHz absorption band, but it is pressure-broadened to such an extent that it is a major absorber even down at 400 MHz. This figure indicates that there is not much hope of measuring individual absorption lines and thereby doing any kind of molecular species identification unless we venture into the S, X and K bands.

Ammonia is an unusual molecule in that the three hydrogens lie in a triangle and the nitrogen atom forms the peak of a pyramid shape as shown in Figure 7-40. Classical mechanics

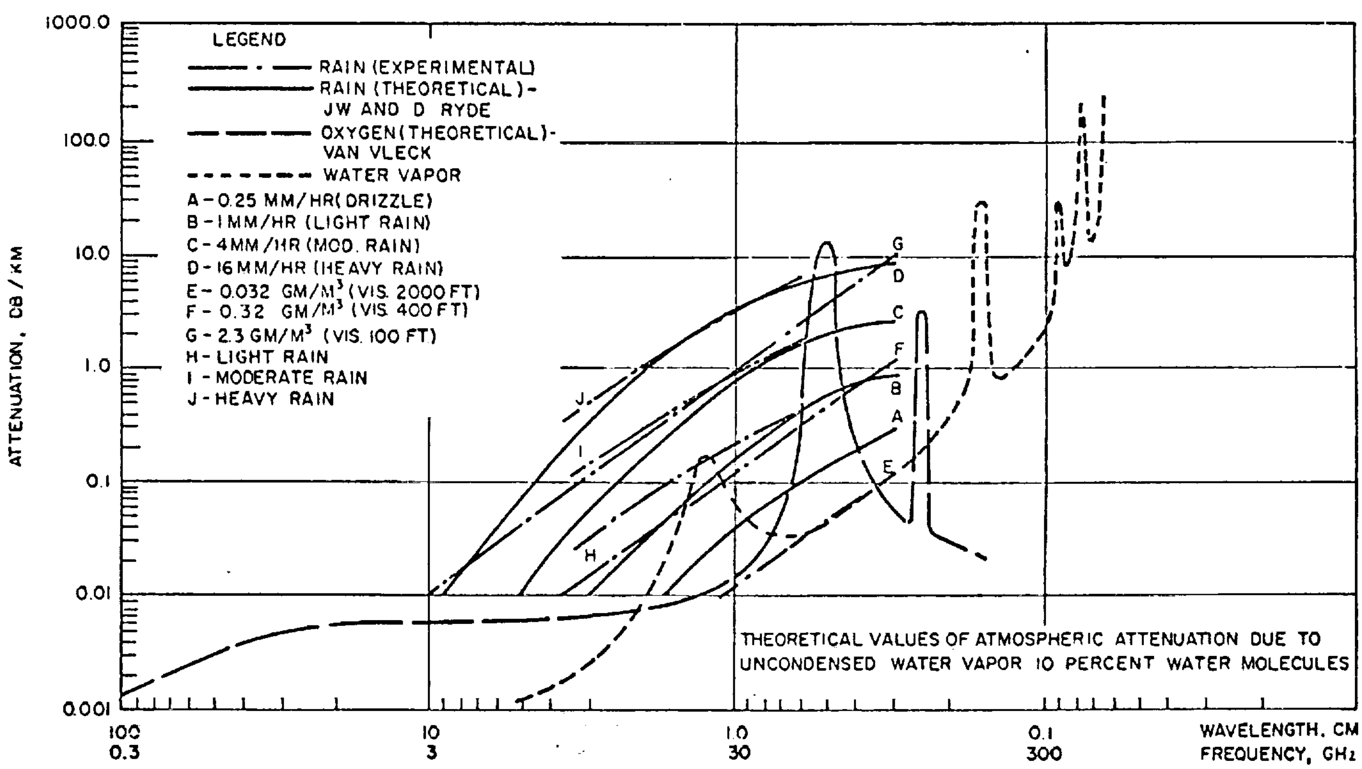


Figure 7-39. Atmospheric Attenuation Summary

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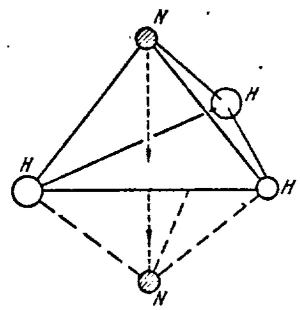

Figure 7-40

leads you to conclude that the nitrogen must remain on the top, but quantum-mechanically it is found that the atom can tunnel through that potential barrier at the center of the triangular base and get down to the bottom position. That oscillation from the top to the bottom is called "inversion" and the fact that it has to tunnel makes it "hindered inversion;" this slows the natural frequency somewhat. As a result of tunnelling, the nitrogen atom oscillates at 23.5 GHz but pressure broadening causes it to be effective even at 400 MHz. At Jupiter, absorption by ammonia is a major factor but this doesn't appear to be the case at the other planets of interest.

There is a mention in the literature that water droplets with ammonia in solution in the droplets might be a major absorber even down at 400 MHz, at least in Jupiter's atmosphere. I don't know how serious this problem is, but it may be the limiting item determining how deep we can go in the Jupiter atmosphere.

Figure 7-41 is calculated for Earth, but it shows the general trend that ionospheric absorption is not a problem on Earth and my calculations to date indicate that similar absorption (or less) occurs on the outer planets considered. The absorption is on the order of a tenth of a db. The measurement of absorption would not reveal anything about the ionosphere nor would it be a problem. I don't see anything of significance here for us.

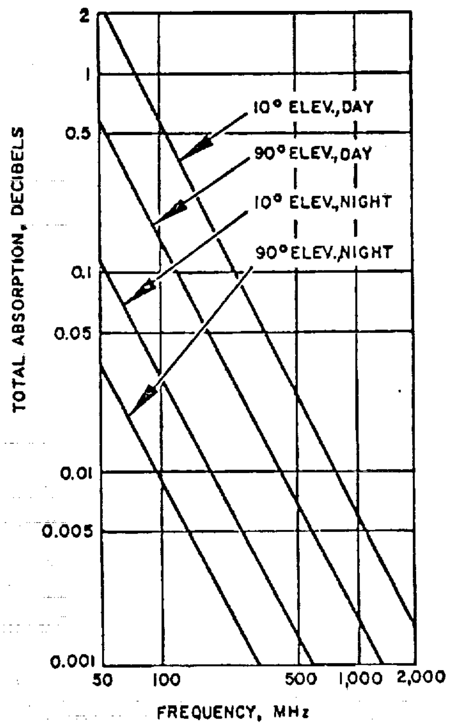

Figure 7-41. Ionospheric Attenuation for a Source at 1,000-km Height

There is some possibility of equipping the probe with a sensor for measuring capacitance; with this, we might determine the ionospheric density. By using the 400 MHz antenna standing wave ratio, we might get the same kind of data. Such a measurement would be scientifically interesting and also useful to the engineers who design future probes.

Figure 7-42 is a photograph of Saturn and I have indicated the probe approaching along the inner white line and the bus on the outer white line. I am trying to show that the bus could observe the direct signal from the probe to get the telemetry, and it could also simultaneously observe the Doppler-shifted echo reflected off the ring. I can assure you that if that could be received, this signal could be very informative to scientists. Right now, this concept isn't in the baseline design because the 400 MHz transmitter doesn't operate until the probe descends into the atmosphere. I do not yet know if the reflected signal would be strong enough for such an obser-

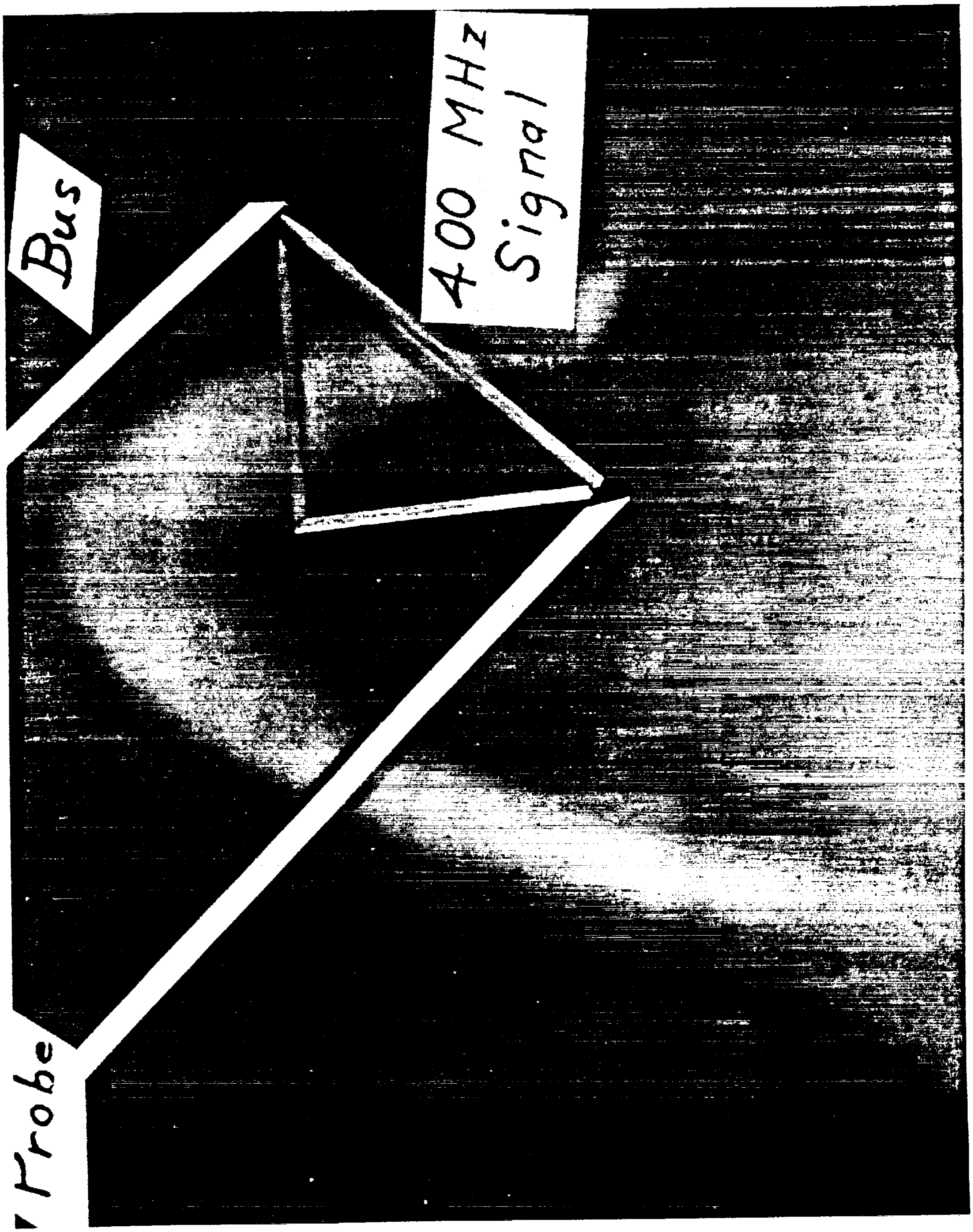

Figure 7-42

vation with the baseline design, and I will do some more study on this. There is a debate concerning the cause of the observed radio scattering off the rings, and different models explain it in different ways. Some models lead to the prediction that scattering as shown in Figure 7-42 would be very weak; others indicate this would be a strong echo. It would be very informative if we could see it.

Figure 7-43 shows an exciting concept I haven't heard mentioned earlier. If we operate this radio system before entry, then it is feasible to orient the bus and probe so that there is a brief period during which the 400 MHz signal goes through the rings of Saturn. A ring occultation at this low frequency would provide additional data about the structure and composition. (Prior S-band occultations will have occurred.) It appears possible to perform and complete this occultation experiment before probe entry (Figure 7-44). Therefore, it appears this experiment wouldn't conflict with the other requirements of the 400 MHz system.

For Saturn, Jupiter, and probably Uranus, there is virtually no chance of seeing the reflection off the surface as shown in Figure 7-45. For Titan, however, this is a reasonable possibility. If we build the capability into the bus receiver of looking for Doppler shifted echos well away from the direct signal, then we should look for this reflection from Titan. It could tell us a great deal about the atmosphere and the surface.

For Uranus, at the time of these probe missions, the planet's spin axis will be within about 10° of the direction to the sun. In Figure 7-46 the sun is to the left and the probe and bus are approaching Uranus. If we have two-way Doppler, as Paul Parsons mentioned, we could measure the Doppler shift and perhaps obtain an indication of the north-south winds. Because of the near-alignment of sun, spacecraft and planet, there is comparatively

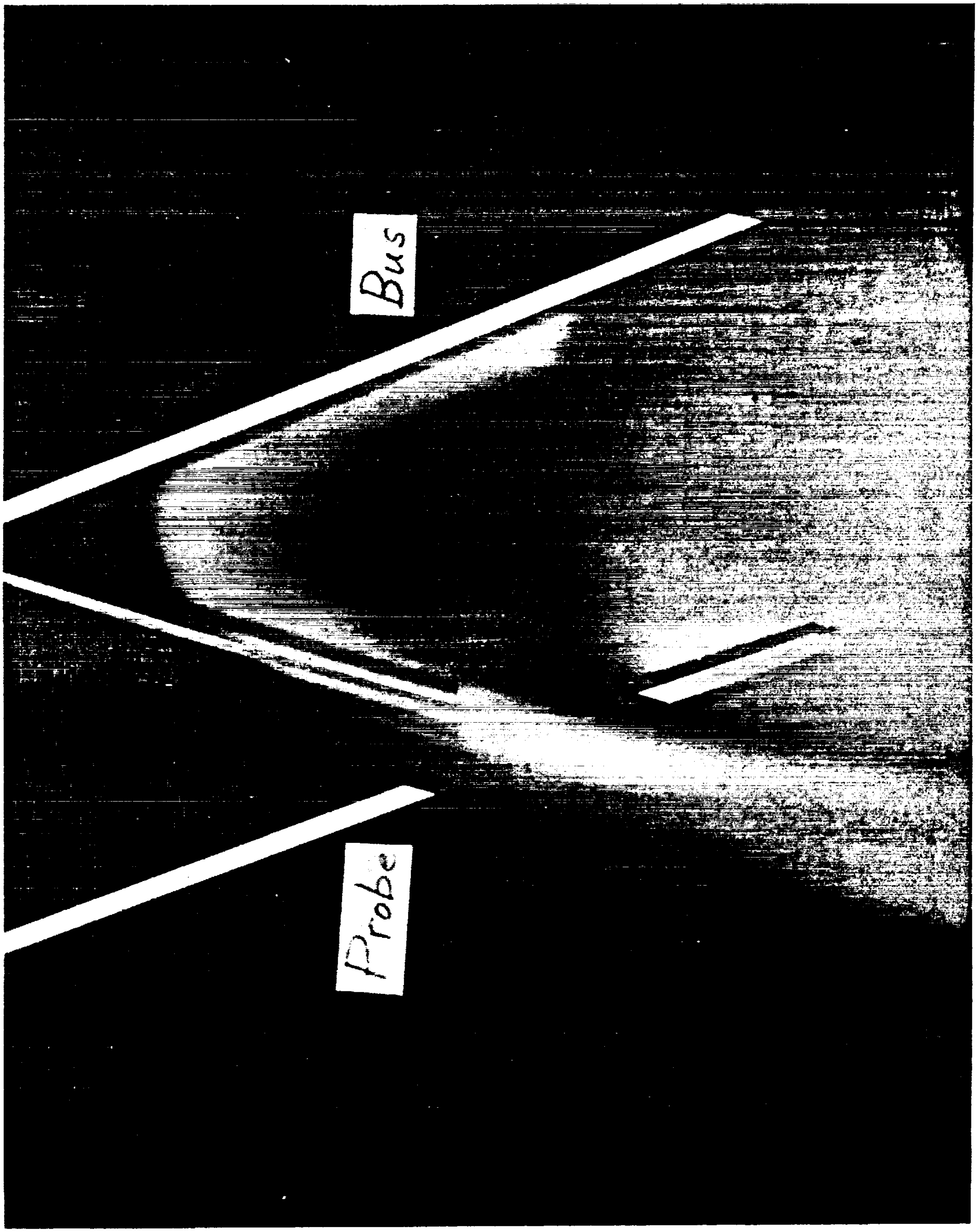

Figure 7-43

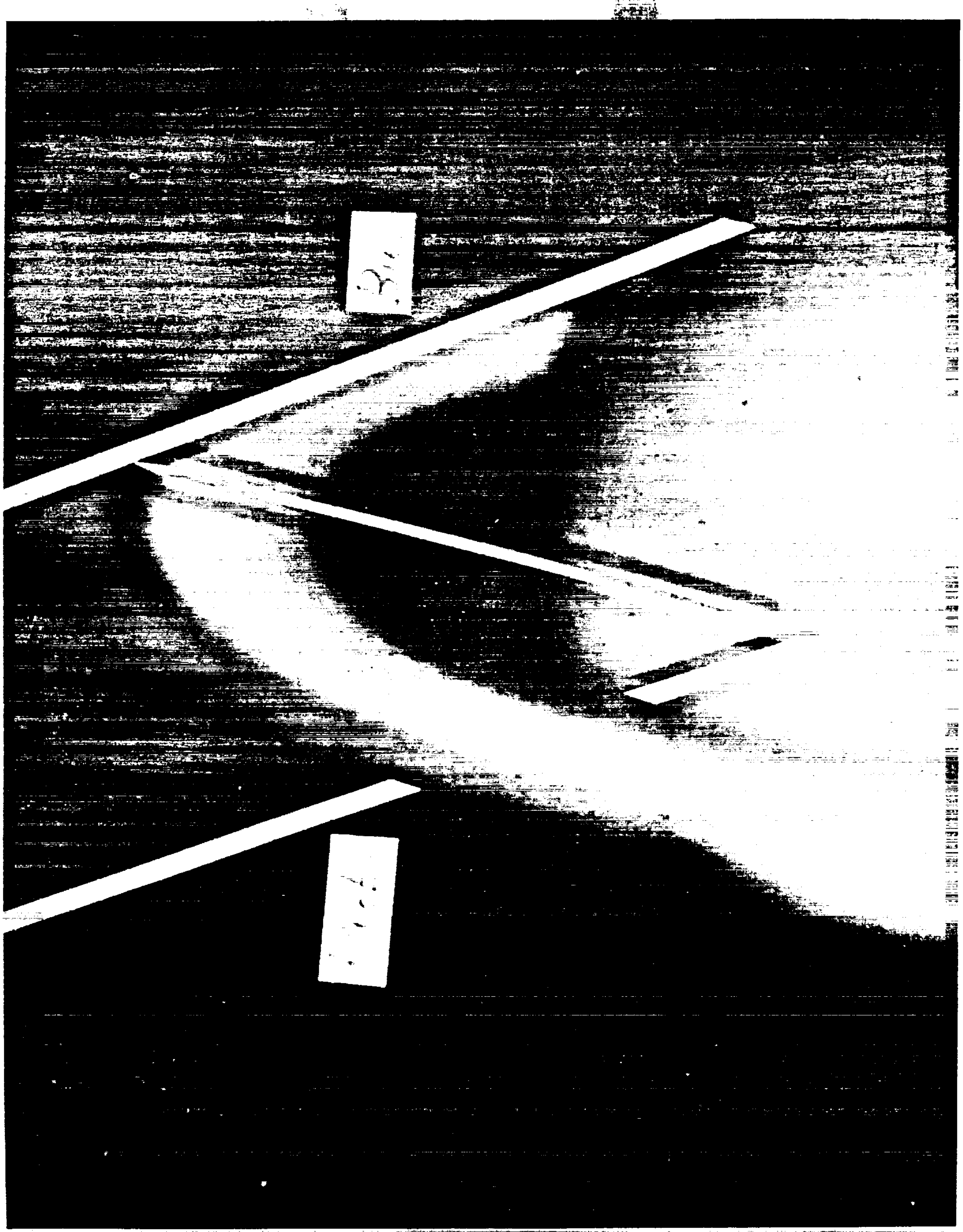

Figure 7-44

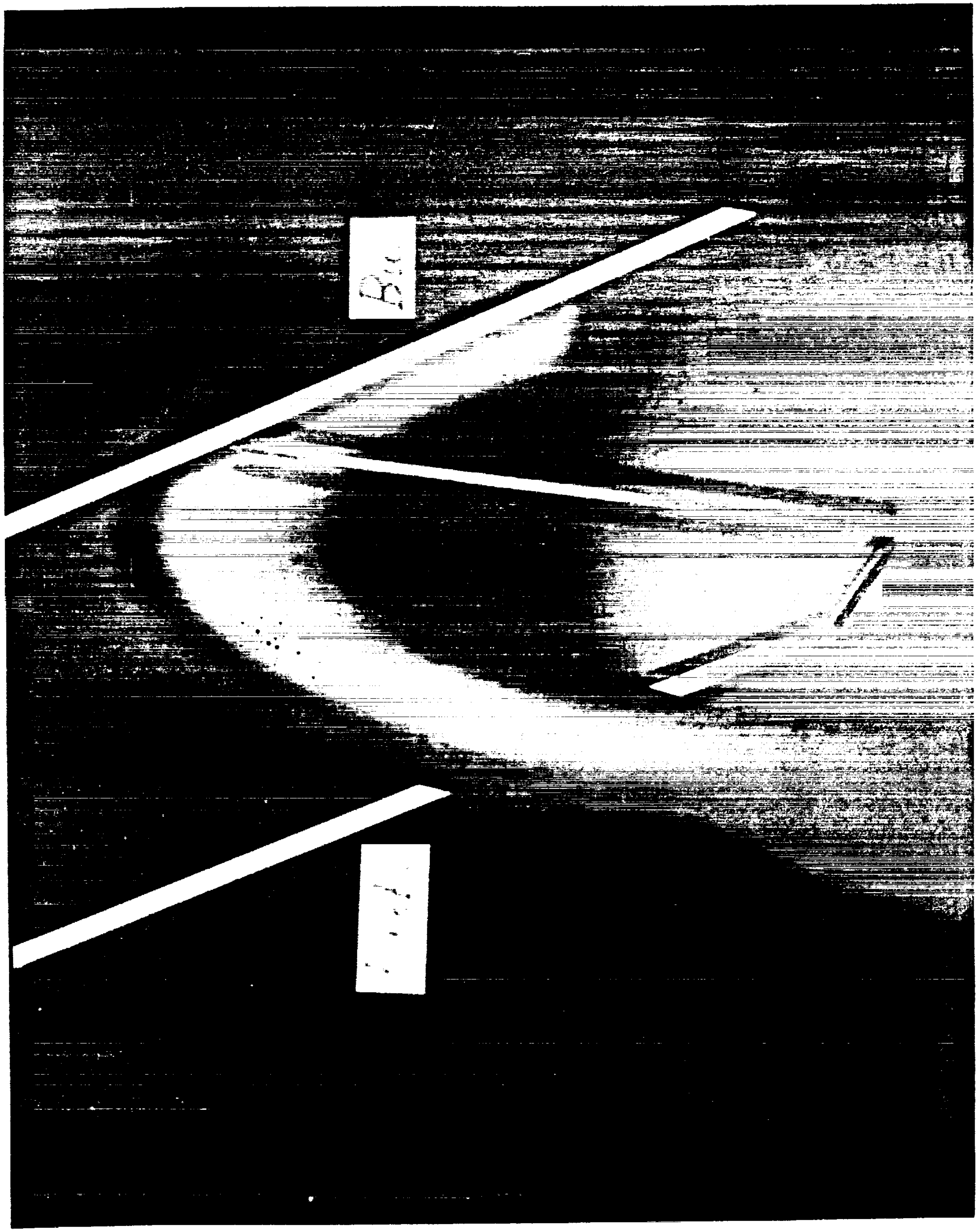

Figure 7-45

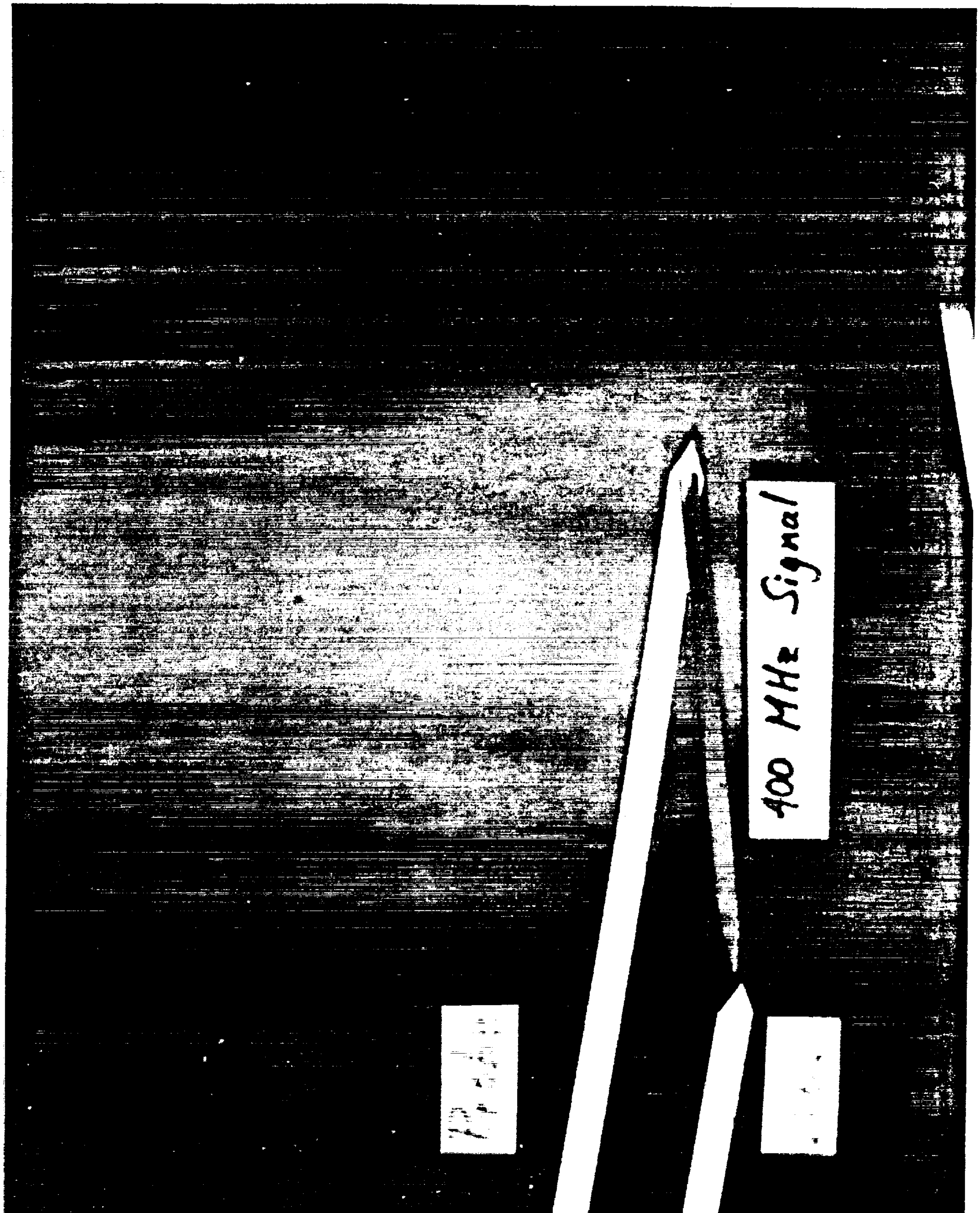

Figure 7-46

little parallax involved. All vectors are almost in a straight line, and we may be able to resolve the north-south wind by measuring the motion of the probe's terminal descent.

Before entry, the measurement of Doppler would permit accurate tracking and would solve one of the problems that the entry people are worried about; namely, where did the probe actually go in. With Doppler measurements at 400 MHz, we could reconstruct the final pre-entry track and find out where it went. That would be a very valuable adjunct to other experiments.

I had planned to carry you through a dual-frequency calculation, but for lack of time I'll only show the result, in Figure 7-47. If we transmit two frequencies and measure differential group delay, we can determine the electron content, I, which is the electron density averaged along the path multiplied by the length of the path. If the frequencies differ by two to one, we obtain a total effect three-quarters as large as would be obtained if the highest frequency were infinite. The message here is that if you had two frequencies which differ by 2:1 or even $\sqrt{2}$:1; we would get a measurable delay difference from which we could infer the electron concentration along the path. In turn, this would provide the electron content of the ionosphere and possibly the magnetosphere if one exists. So here is still another valuable radio measurement prior to entry.

If we operate the radio system prior to entry, it may be possible to occult a satellite as depicted in Figure 7-48. The occultation at the satellite would be interesting to scientists and it would also give trackers an accurate measurement of the probe location. As with the Doppler tracking, this helps determine where the probe entered the planet. I think a satellite occultation experiment would benefit navigation and science. It would be of particular interest to navigators if two-way doppler cannot be incorporated.

FIXED-FREQUENCY $\frac{\text{PHASE}}{\text{GROUP}}$ DELAY

$$T_1 \cong \int_D \frac{ds}{C} \mu^{\pm 1} \cong \frac{1}{C} \int_D \left(1 \mp \frac{40.3\ N_e}{f_1^{\ 2}}\right) ds = \frac{D}{C} \mp \frac{40.3}{cf_1^{\ 2}} \underbrace{\int_D N_e\ ds}_{I}$$

DUAL FREQUENCY DELAY DIFFERENCE

$$\Delta T = T_1 - T_2 \cong \mp \frac{40.3\ I}{cf_1^2} \pm \frac{40.3\ I}{cf_2^2}$$

$$\Delta T = \mp \frac{40.3\ I}{C} \left(\frac{1}{f_1^{\ 2}} - \frac{1}{f_2^{\ 2}}\right)$$

Figure 7-47

If we operate the 400 MHz transmitter during entry, we could determine the radio blackout point. With a dual frequency link in operation, we would get the blackout at two different frequencies and that ought to be useful to the physcists for identifying species. Different atoms ionize at different vehicle speeds or mach numbers.

I have mentioned several experiments that would be possible if we operate at 400 MHz system before entry, although that is not presently in the baseline design. Figure 7-49 summarizes and emphasizes this area of consideration. I feel that these observations would be very valuable to all scientists; not just radio scientists and, therefore, I recommend pre-entry transmissions from the probe be considered. I would summarize this partially completed study as follows: the idea of transmitting 400 MHz (perhaps two-way transmission, perhaps dual frequency

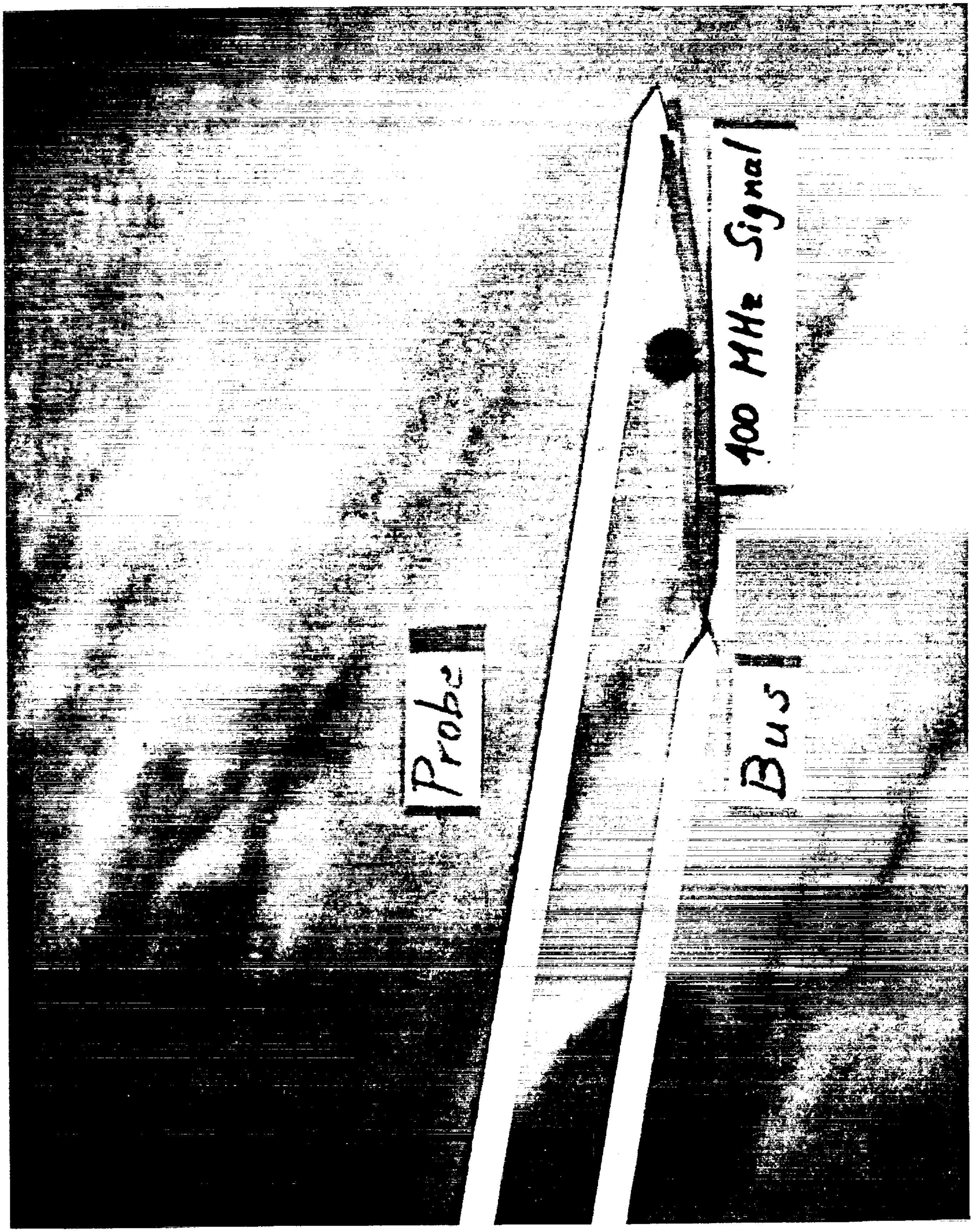

Figure 7-48

transmission) before entry has many striking advantages and yet presently is not being considered. I think the reason is because it is so costly to put items inside the probe's heat shield and protect them during entry. However, it seems to me that there are a number of seemingly unconventional ways to circumvent this cost. For one example, portions of the equipment could be ejected from the probe in the last minute before the entry. There is no need for two-way tracking or dual frequency tracking during final descent so that part of the aparatus, including a battery to run it, could be kicked off before entry. (At Uranus, we might wish to retain two-way tracking.) This is the concept I would like to suggest; an innovative approach to permit productive 400 MHz transmission outside the dense atmosphere.

Thank you.

FIGURE 7-49

Possible 400 MHz Observations BEFORE Entry

A grazing reflection from the rings of Saturn, and perhaps an occultation

Monitor electron concentration during approach by the dual-frequency method

Occult a satellite

Look for reflections from the planet (unlikely to be seen, but very informative if they are measured.)

Monitor the radio blackout at the entry

Observe ionospheric and possibly magnetospheric scintillation

Measure Faraday rotation to determine magnetic field strength

Doppler tracking to determine entry point accurately

UNIDENTIFIED SPEAKER: I think what you mentioned represents a viewpoint that we have not heard very much about in our science advisory committee on J/U, and I would suggest that in the interest of representing the radio science desires, that it would be appropriate for you to discuss this problem somewhat with John Lewis, so that we can get some inputs into the Van Allen Committee and have a better opportunity to evaluate it. We have been operating this committee for about four months and we have not talked about many of the things that you have proposed. We are going to have this continuing interaction with the science team and we would like very much for you to bring this to their attention.

DR. CROFT: I will definitely do that.

MR. SEIFF: I want to make sure I understood this suggestion for a Doppler tracking of the entry probe. You are talking about tracking it during the period prior to entry from the bus vehicle, whose position can then be established after flyby by the perturbation of the trajectory due to the planet.

DR. CROFT: Yes, just like they do the normal trajectory.

MR. SEIFF: That sounds like an extremely valuable idea to me.

MR. GRANT: I don't know what the cost of it is. Of course, everything always has its cost. But the return from it is certainly beneficial.

DR. CROFT: Each pound within the probe body costs you so much, but what would it cost if we kicked off part of that probe? That ejected part would be the cheapest element of the whole bus-probe combination. You don't have to pay for decelerating that mass on the bus, so it is cheaper than a pound of bus equipment. And it is certainly cheaper than a pound of gear inside the probe.

MR. SEIFF: There is another possibility in this same class. You are able to track the probe very accurately by inertial instruments, as a perturbation to the bus trajectory as a result of the Delta V impulse that is applied to it. All of this requires accuracy now, but if that could be done accurately, then I guess the same scheme could be applied; namely, of using post-flyby knowledge of the bus trajectory plus the perturbation that has been applied directing the bus away from the trajectory that the probe is following.

UNIDENTIFIED SPEAKER. The trajectory is going to be known after the fact.

MR. SEIFF: The bus trajectory will be known.

UNIDENTIFIED SPEAKER: What you have to do is somehow get that tied back to the probe.

MR. SEIFF: I am just suggesting that it could be done inertially as well as by radio.

UNIDENTIFIED SPEAKER: In the mission analysis splinter group yesterday, we also wanted to strongly suggest this idea of having communications on the way in because certainly at Jupiter and Saturn, this will be the only data we can get from the probe.

You pointed out in the very first figure that such operation is ruled out; in the baseline there are no communications on the planetary approach prior to entry.

DR. CROFT: I pointed that out specifically for contrast because I also said that we are looking for new views with regard to the baseline. One of the main topics I would like to question in the splinter session is the possible removal of this restriction against pre-entry transmission.

UNIDENTIFIED SPEAKER: Was that brought out because of the power limitation or an antenna problem?

MR. GRANT: I think the question is more broad than that. There is the problem of determining the position of a probe which is always moving relative to the planet. There is going to be an extremely large desire on the part of the science community to have pre-entry transmission for the particles and fields kind of experiments at Jupiter and that requirement ought to be on the table and looked at to see just what the problems are going to be.

We appreciate your comments about it here. But let's be careful because we are talking already about fairly extensive missions and fairly expensive probes. When we start talking about dual frequencies and a two-way Doppler link between the spacecraft and the probe, you are talking about some pretty tough problems. They won't come cheap.

DR. CROFT: I was going to read, as a closing point, a quotation from Admiral Rickover* in 1953 about the gap between an engineers' view and an academic outlook as to the practicality of what could be done by advanced technological systems. It was closely relevant to your point, with which I concur.

UNIDENTIFIED SPEAKER: We certainly want your ideas brought into the discussion we are going to be having in the next couple of years, and we can consider the problems.

UNIDENTIFIED SPEAKER: I think there are a number of interesting concepts that he proposes can be achieved from an analysis of a one-way, noncoherent signal. I would be a little concerned, though, that some of them may be too subtle to appear to have the kind of frequency stability that we expect on a probe, particularly with a transmitter that is going to be on for an hour as its whole life. I think you have to look at that to see if it is going to rule out some of these fairly subtle effects.

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* From journal "Nature", volume 243, June 1, 1973

DR. CROFT: If we had a signal going to this spacecraft for the purpose of tracking, then we have the ability to command the probe. Is there any need for this?

UNIDENTIFIED SPEAKER: That is not in the baseline. There is no commandlink capability on the bus, neither the Pioneer nor the Mariner.

DR. CROFT: I realize it is not in the baseline but the baseline is something that you people have to work to. If we had two-way for the purpose of tracking, then commanding the probe is relatively straightforward.

SESSION VIII - SCIENCE INSTRUMENTS

Chairman: Mr. Joel Sperans
NASA Ames Research Center

Because this session was beginning later than planned, Mr. Sperans deleted his planned introductory remarks and introduced the first speaker, Professor A. Nier of the University of Minnesota.