# MICROWAVE PROPAGATION IN THE ATMOSPHERES OF THE OUTER PLANETS

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MR. R. E. COMPTON: First of all I will discuss the atmosphere absorption that exists in the atmospheres of the three major outer planets, Jupiter, Saturn, and Uranus; then I will discuss system noise temperature problems at Jupiter.

As we know, the atmospheres of the outer planets are very similar in content, being comprised mainly of hydrogen and helium. There are three principle sources of microwave absorption: the ammonia and water content, and ammonia clouds, if present. Microwave absorption; therefore, is proportional to several factors: the elevation or depth that we go into the atmosphere; the probe aspect angle at which we transmit from the probe to the spacecraft; the operating frequency at which we operate the RF link; and also the models that describe the various atmospheres for the three planets.

Figure 7- 7 shows, for instance, the calculated zenith absorption for the Jupiter cool/dense atmosphere which is the worst-case model. It has the highest ammonia mass fraction of the three atmosphere models. The position of the ammonia/water solution cloud is shown and you see from the curves the variation in absorption as frequency and depth are increased. Shown are the values for propagation directly up through the atmosphere, normal to the surface sphere.

Figure 7- 8 shows how the absorption varies with the atmosphere models, the dotted line being the nominal model and the solid line the cool/dense. As seen, there is a large difference between the models at higher frequencies. But as we lower the frequency to the UHF region below 1 GHz, the curves converge. The atmosphere effects are not as significant as they could be at higher frequencies and greater depths.

ZENITH ABSORPTION FOR THE JUPITER COOL/DENSE ATMOSPHERE

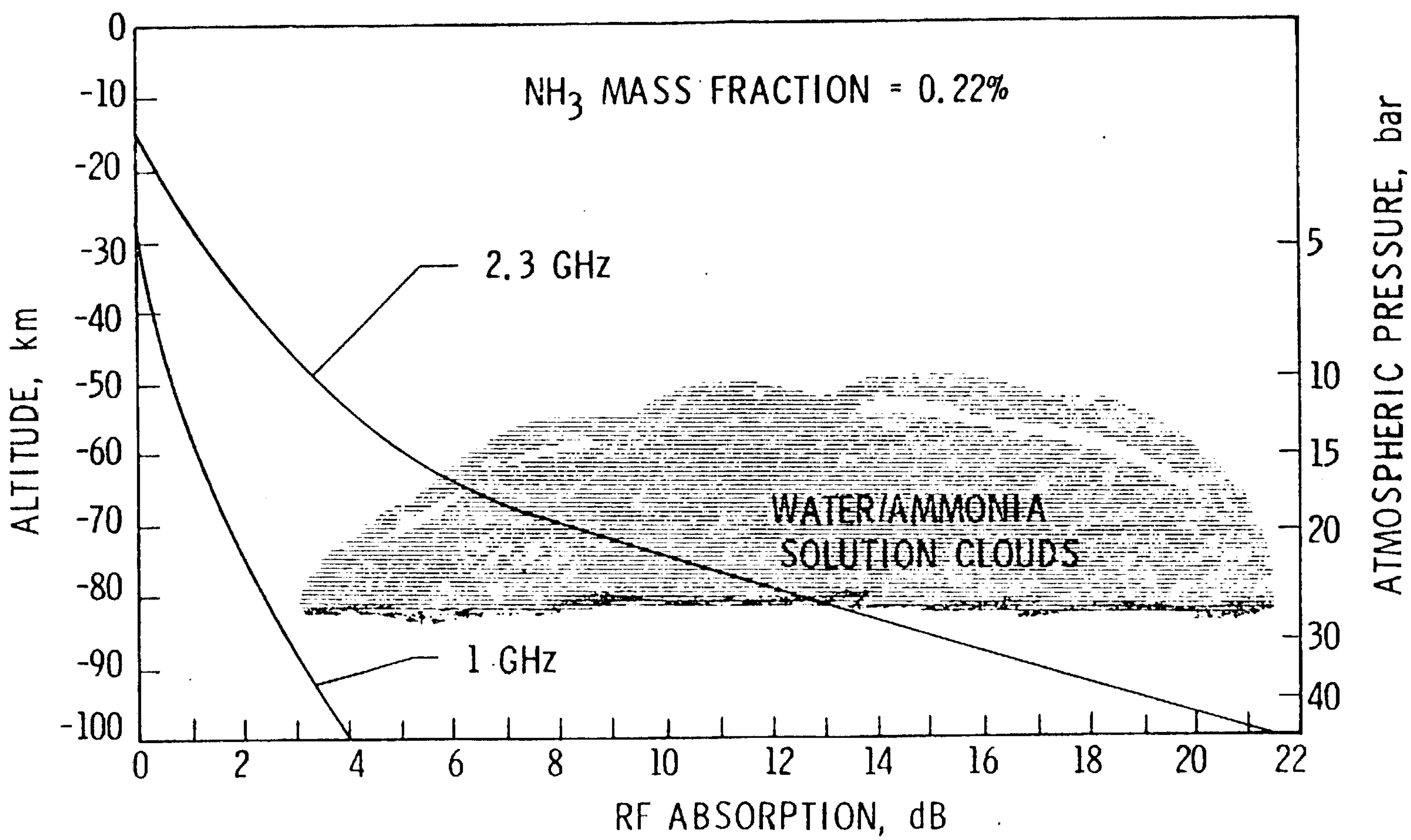



FIGURE 7- 7

## ZENITH JOVIAN ATMOSPHERE ABSORPTION

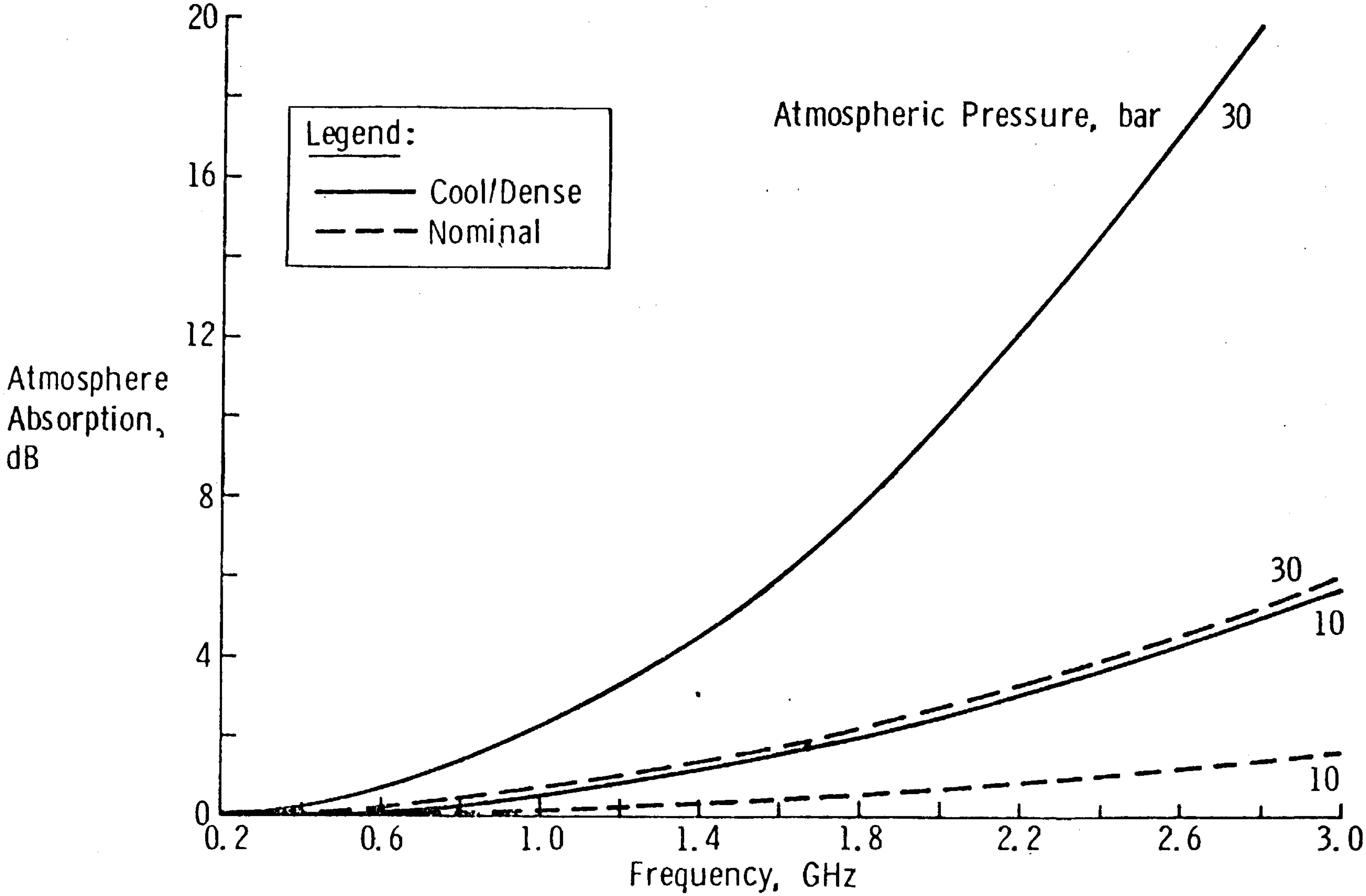



Figure 7-8

Moving to Saturn, Figure 7-9 shows the zenith absorption that is calculated from the worst-case atmosphere, which is the cool model. Again, we are below the ammonia ice cloud and the effects of propagation to the clouds enhances the curves by increasing their slopes. Again, for operating frequencies on the order of 400 MHz and for a depth of 10 bars, we are only talking about 0.5 dB of absorption due to the atmosphere.

A similar condition exists at Uranus, as seen in Figure 7- 10 The worst case is the nominal atmosphere because for the cool model the cloud level is well below 50 bars. Therefore, for a 10-bar probe mission, we have the nominal case and we have also penetrated through the ammonia ice cloud. The RF absorption is less than 0.5 dB for 400 MHz.

Figure 7-11 shows what happens as the probe aspect angle increases. This is strictly the refraction effect that occurs in the atmosphere, and does become quite severe for a probe aspect angle approaching 90 degrees - in other words, if we were propagating out towards the local horizon. For probe aspect angles on the order of 45 degrees or less, refraction losses can be approximated very well by the secant of the angle.

UNIDENTIFIED SPEAKER: Is this a function of frequency?

MR. COMPTON: The defraction effect is not a function of frequency. It is only a function of the probe depth and the probe aspect angle.

Moving on to the next subject of the system noise temperature, Figure 7-12 shows the various thermal noise components of the receiver system that is on the flyby spacecraft. The system noise temperature is a value that is used in the link analysis, and it determines the threshold noise level in the receiver. It is comprised of three components: (1) the antenna noise temperature ($T_A$), (2) the feed line ($T_F$), and (3) the front end of the receiver ($T_R$).

ZENITH ABSORPTION FOR THE SATURN COOL ATMOSPHERE

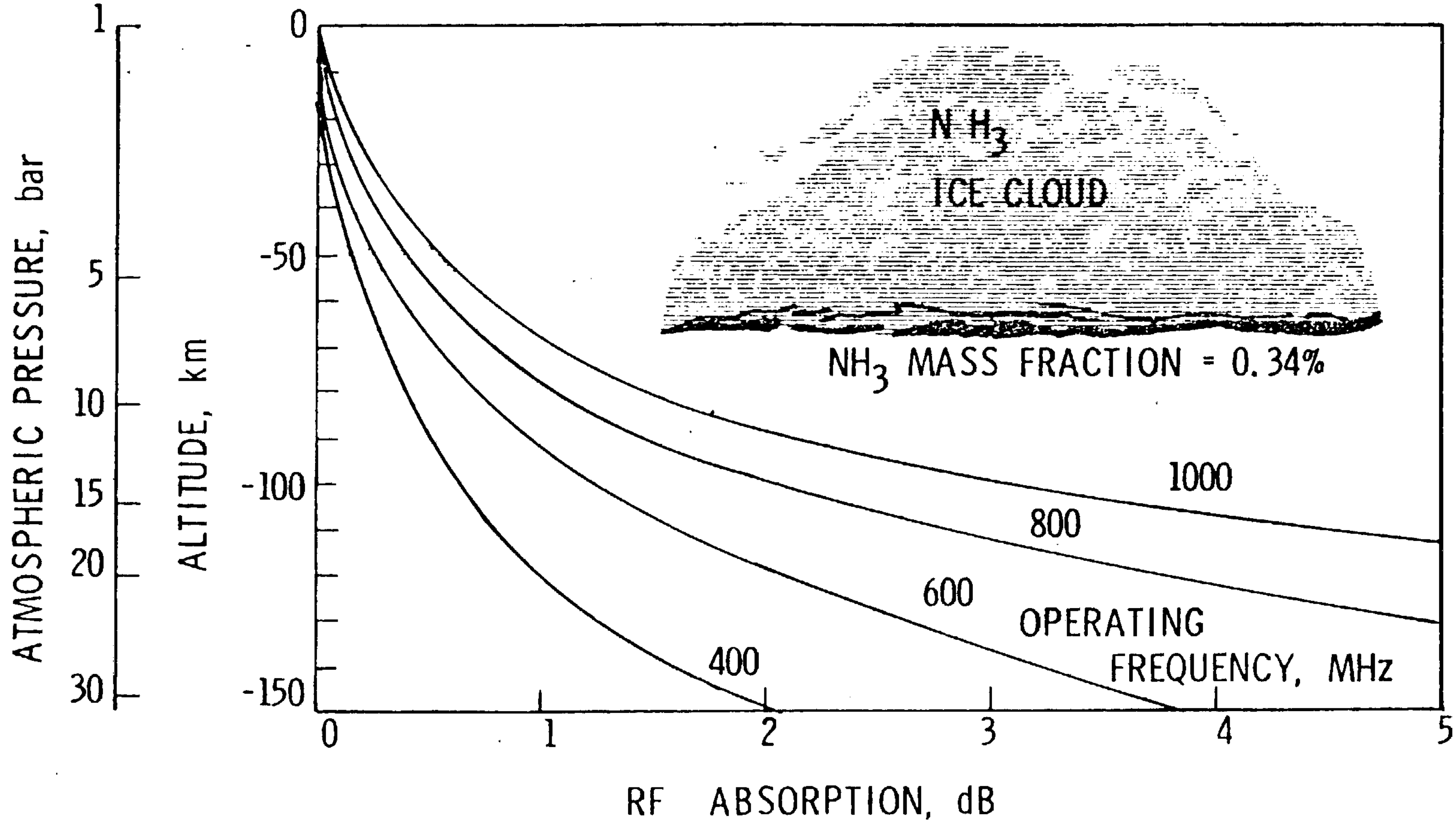



Figure 7-9

## ZENITH ABSORPTION FOR THE URANUS NOMINAL ATMOSPHERE

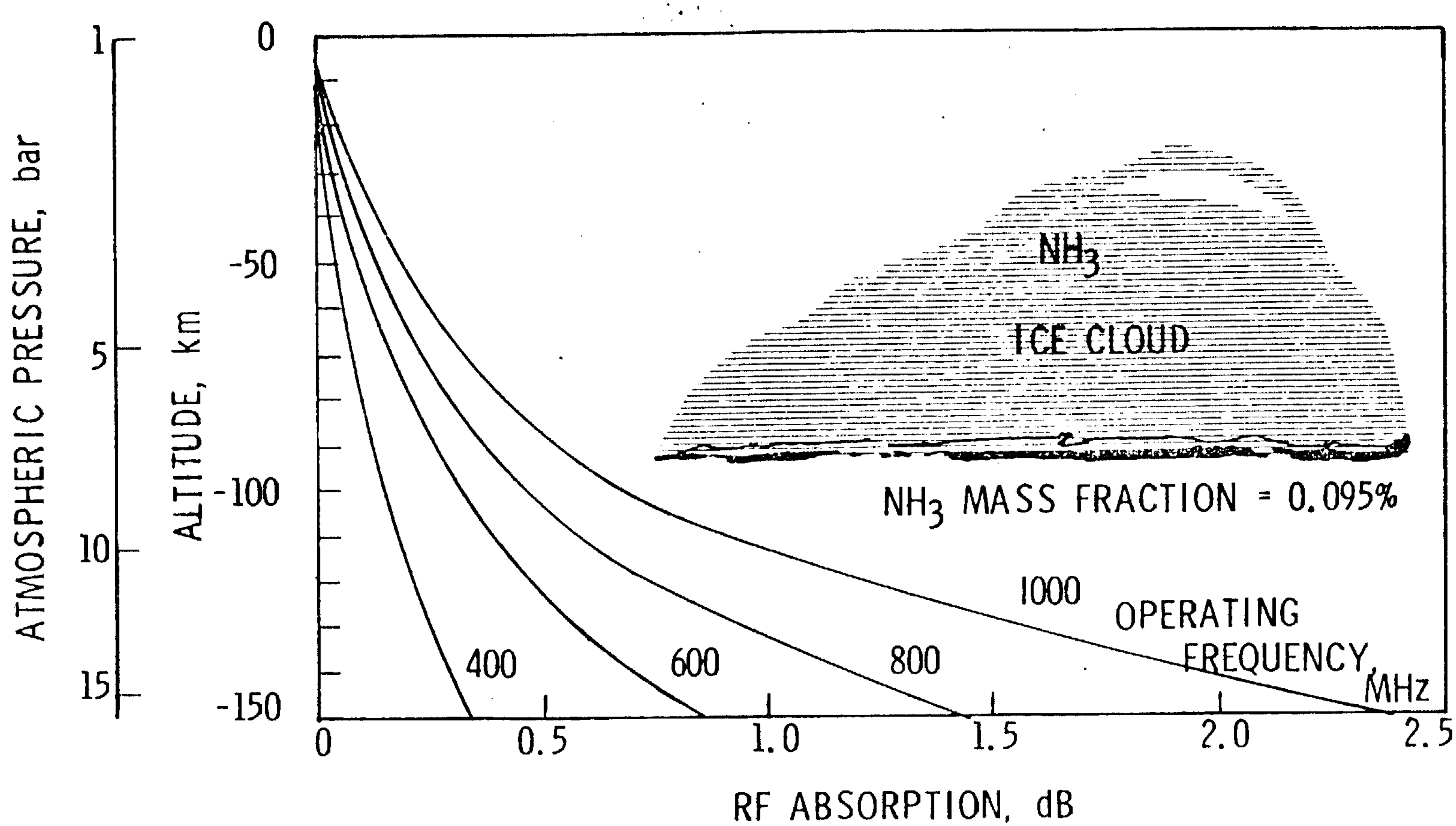



Figure 7-10

## DEFOCUSING LOSS FOR JUPITER COOL/DENSE ATMOSPHERE

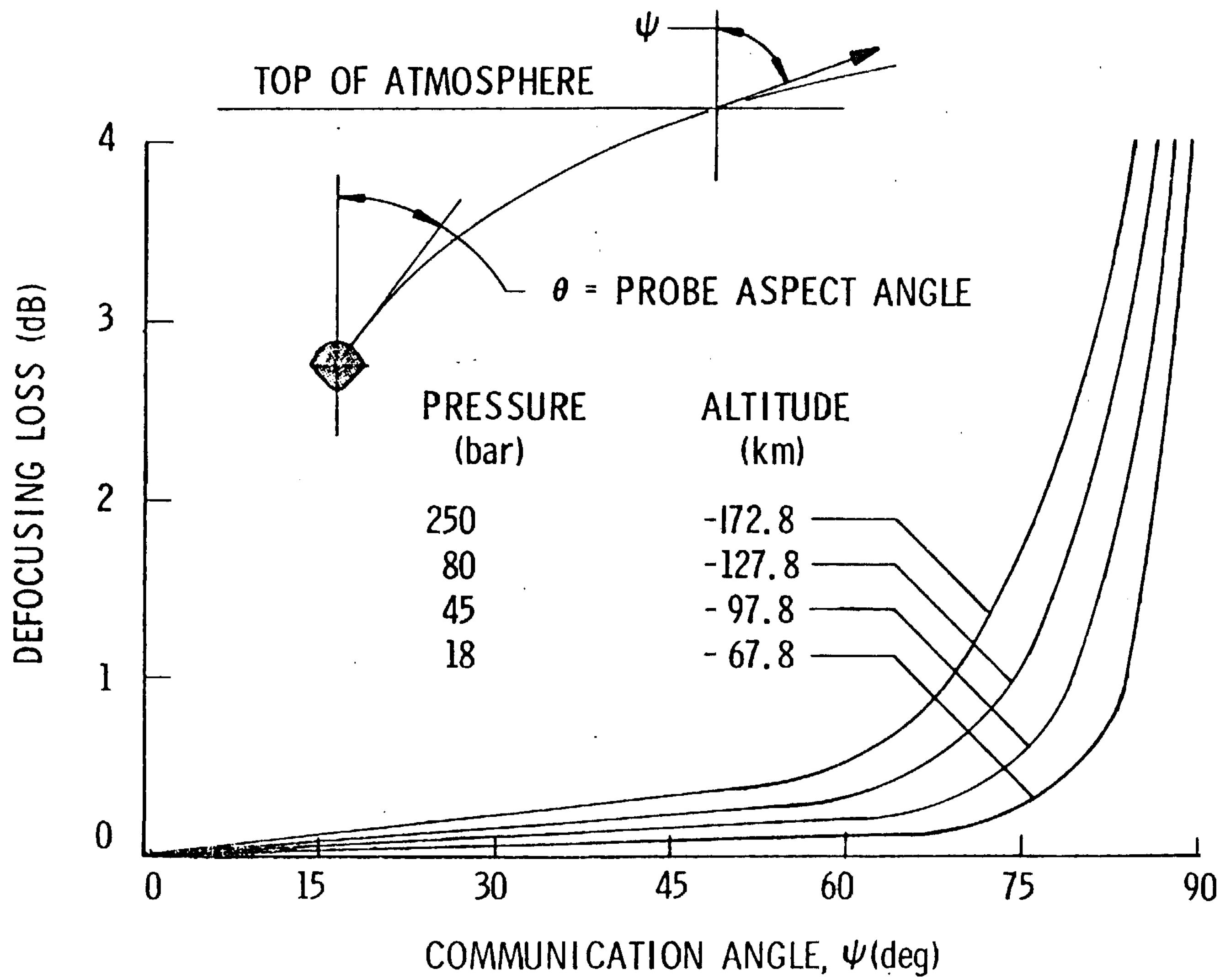
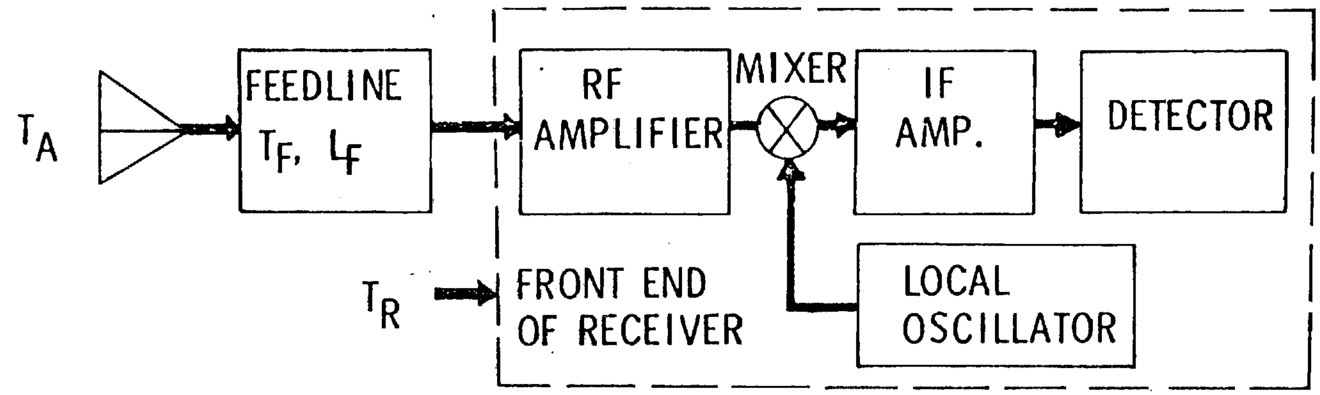



Figure 7-11

## THERMAL NOISE COMPONENTS OF THE RELAY RECEIVER




$T_A = T_G + T_{BS} + T_{BD}$ as applicable

$T_S = T_A + T_F + L_F T_R$

$T_F = 290^0 (L_F - 1)$

Figure 7-12

The antenna noise temperature ($T_A$) is comprised mainly of three parts, depending upon the type of pattern we have chosen for the antenna that is on the spacecraft. Galactic noise ($T_G$) is always present in the background of the antenna pattern. We also have the synchrotron brightness temperature ($T_{BS}$) from the magnetosphere, if one is present at the planet. Jupiter and Saturn have magnetospheres; Uranus does not. We also have the disc brightness temperature ($T_{BD}$), which is present for all of the planets. So the system noise temperature is the sum of the noise temperatures of the antenna, the feed line, and the front end of the receiver itself.

Figure 7-13 shows typical solid state microwave receivers and their noise figures, which can also be converted to noise temperatures as shown on the right. I averaged the various noise figures for three different types of solid state receivers and the average ranges from 2.5 to 3.0 dB. This corresponds to the receivers noise temperatures shown on the right of the curve that would typically be used for the relay link receiver.

Figure 7-14 shows the synchrotron noise model for Jupiter that is in the present monograph. Also given in the monograph is an equation to calculate the synchrotron noise temperature as a function of the wavelength and distance in the model penetrated by a ray vector. Since this model is a function of the amount of the model that we intercept, it is very dependent upon the type of antenna that is used on the flyby spacecraft and whether or not all the antenna pattern is directed at the planet. If we had an axisymmetric (butterfly) pattern on a Pioneer spacecraft, only a portion of the magnetosphere would be in the antenna beam. So the magnetosphere's influence is different, depending upon the geometry and the antenna pattern shape. The amount of beam which intercepts the model determines how much brightness temperature we have from the magnetosphere. As the mission progresses and we have the probe descending towards the planet, we have primarily the noise coming from the planet disk itself with a small contribution from the magnetosphere. So we can see that the synchrotron

## NOISE FIGURE FOR MICROWAVE RECEIVERS

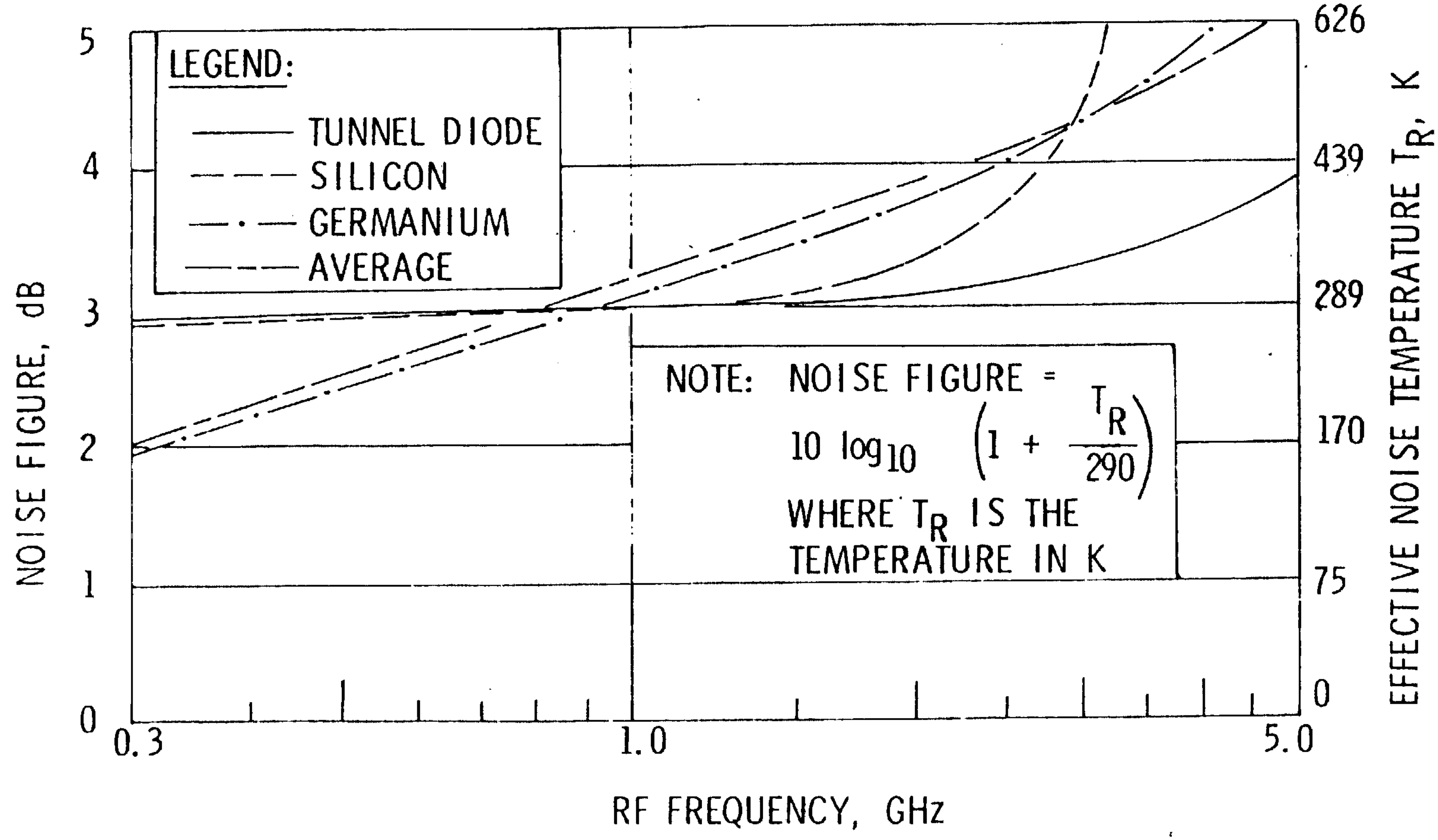



Figure 7-13

## JOVIAN SYNCHROTRON EMISSION MODEL

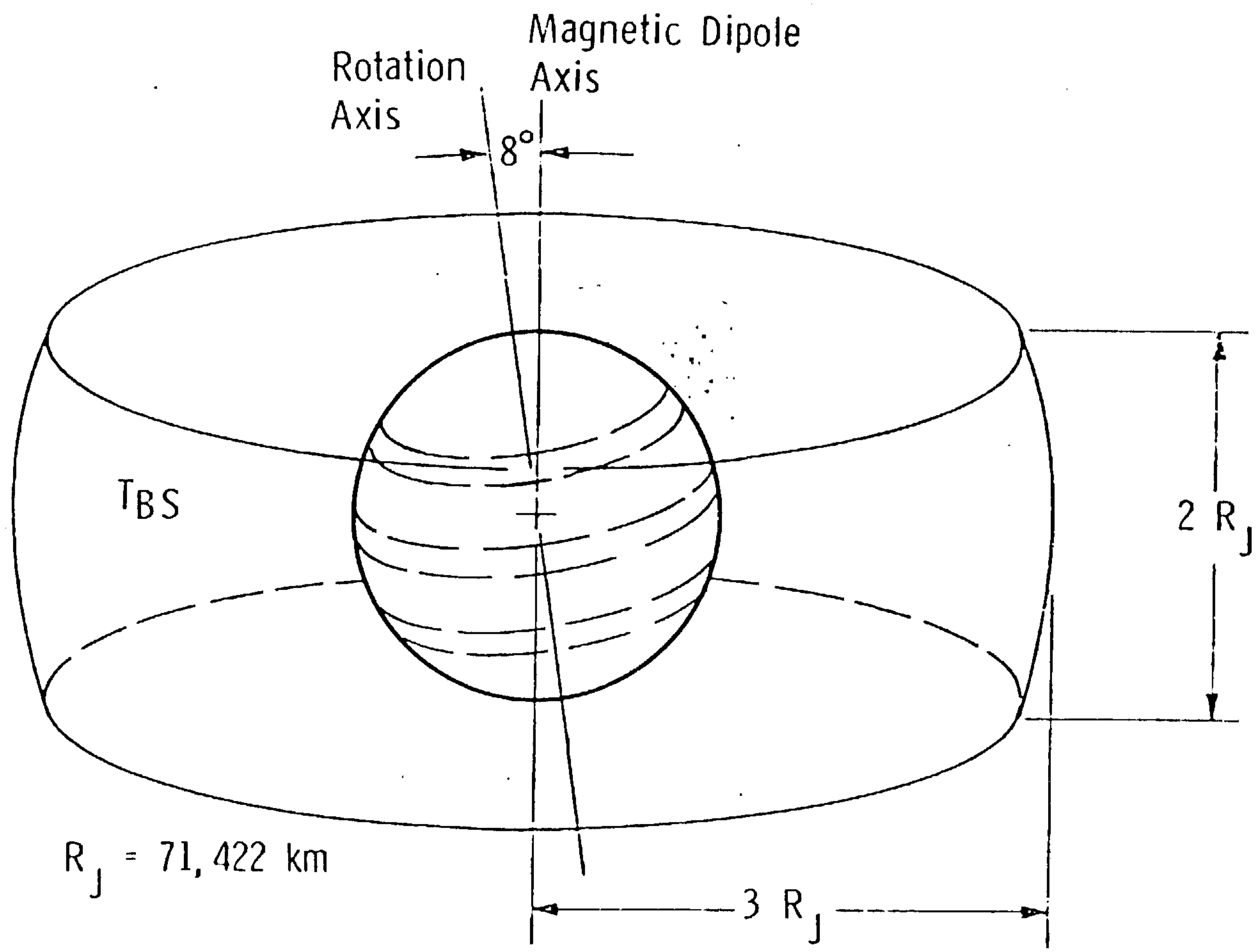



Figure 7-14

noise temperature varies as we progress through the mission from entry to the end of the mission. For Saturn, the noise synchrotron temperature is only a function of the wavelength and we do not have a model like Jupiters. Figure 7-15 shows the disk brightness temperature taken from the Jupiter monograph. The grey areas are the ranges of observed brightness temperatures that have been measured on Earth and the upper limit below 1 GHz is less than 500 kelvin. The upper limit curve was used for the disk temperature in the calculations.

The next three figures are the calculated antenna and system noise temperatures for the three planets of interest. Figure 7-16 shows the noise temperatures for Jupiter. The lower curves show the antenna noise temperatures for two types of antenna patterns, the solid curve being for a dish antenna on a Mariner 3-axis stabilized spacecraft and the dotted curve for a split antenna beam as required by a Pioneer spin-stabilized spacecraft. As seen by the curves, the antenna noise temperature, which is the major contributor to the system noise temperature, and the total system noise temperatures can range above 1,000 kelvin. As seen, the temperatures increase as the frequency is lowered. So this is one parameter that does get worse when lowering the operating frequency. The noise temperature of the system does tend to increase as a result of the planet's influence within the antenna pattern.

Figure 7-17 shows the same calculations for Saturn. The effects are very similar, but they are more pronounced due to the arbitrary equation given in the monograph for Saturn's synchrotron noise. The difference between the antenna noise temperature and the total system temperature is about 1,000 kelvin at 1 GHz.

Figure 7-18 shows Uranus which does not have a synchrotron source of noise. We only have the background galactic noise and the planet disc noise present plus the feedline and receiver noise temperature. All of the temperatures lie below 1,000 kelvin, so

RANGES OF OBSERVED JOVIAN DISK BRIGHTNESS TEMPERATURES

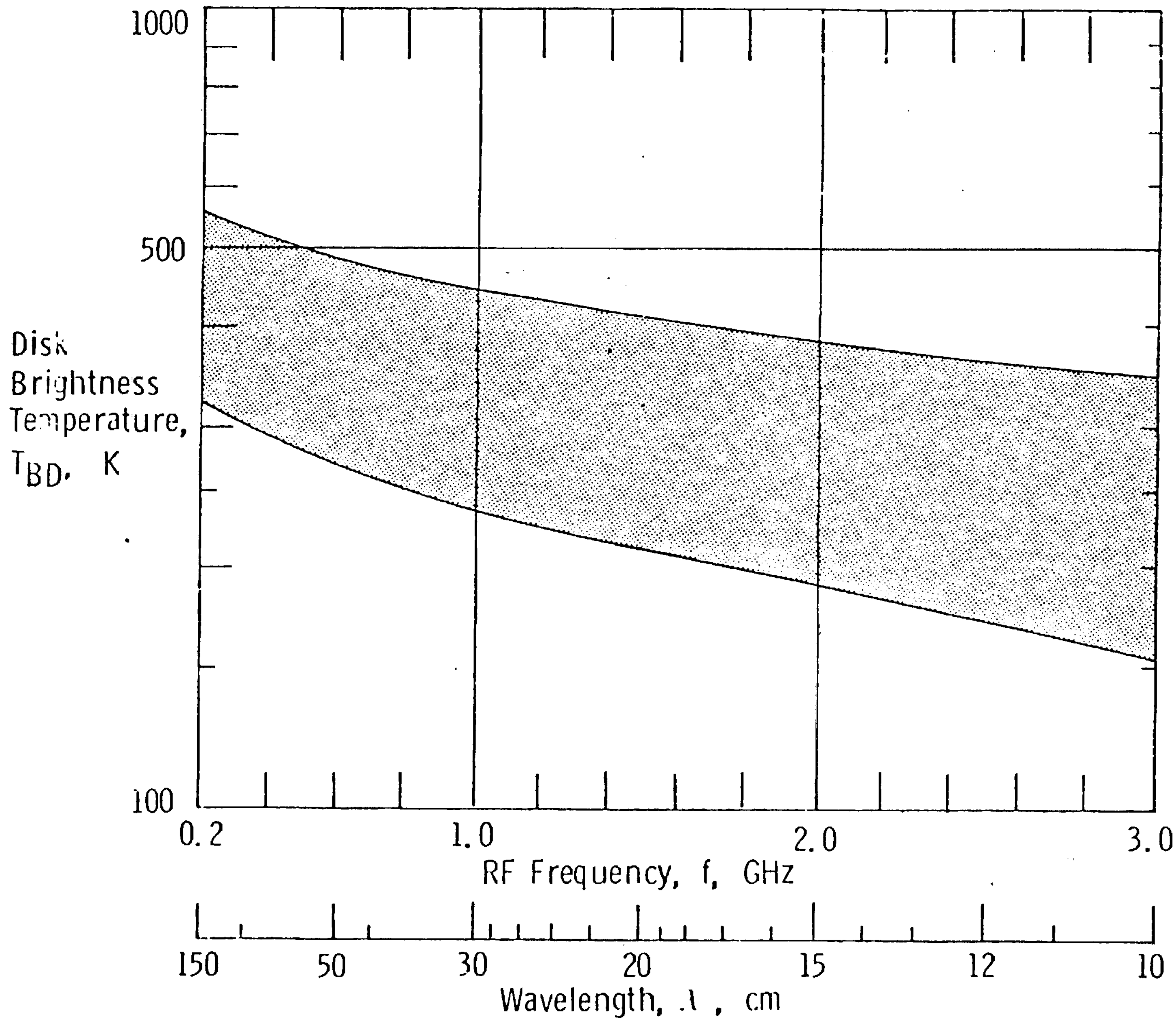



Figure 7-15

NOISE TEMPERATURE FOR JUPITER

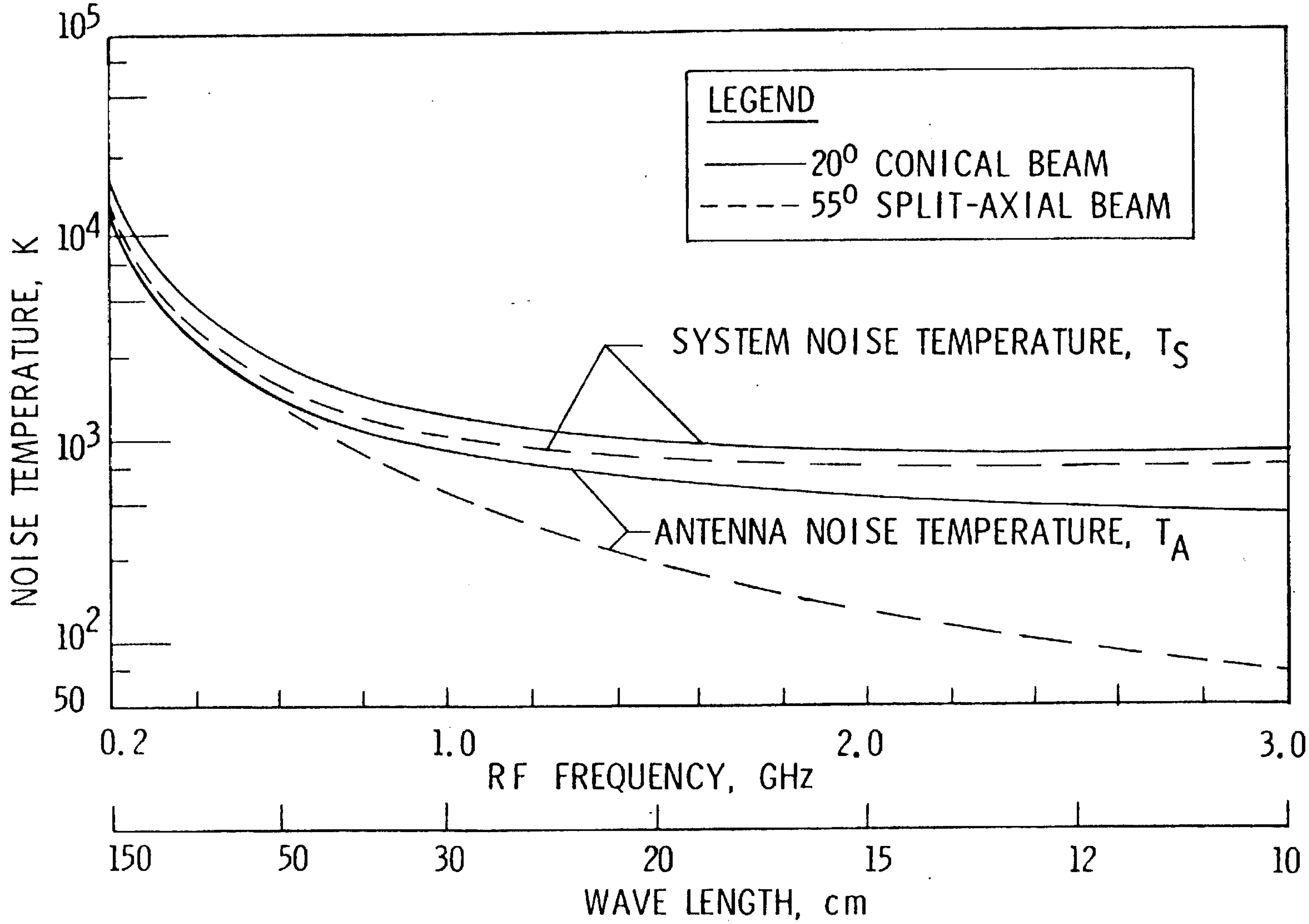



Figure 7-16

## NOISE TEMPERATURE FOR SATURN

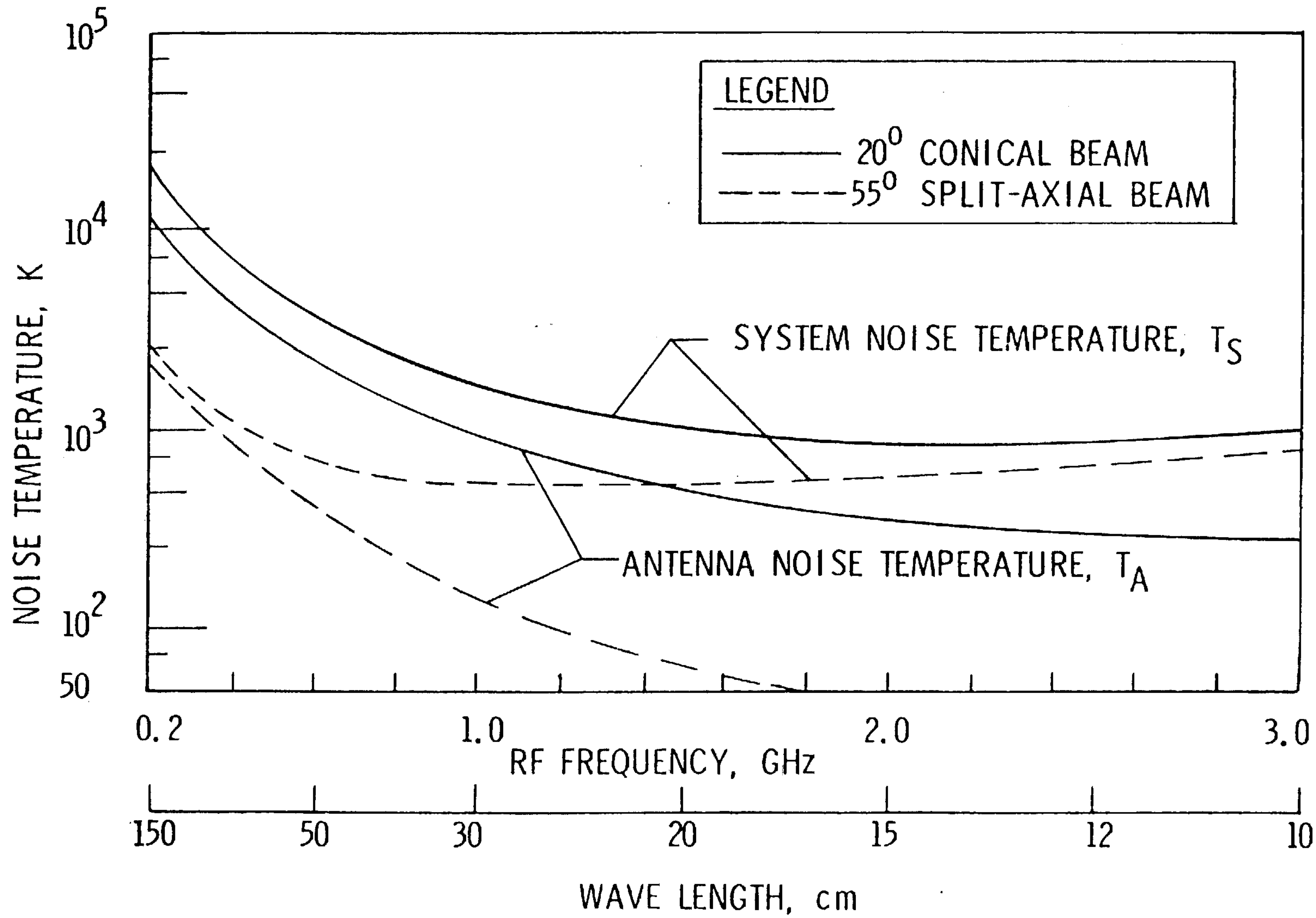



Figure 7-17

NOISE TEMPERATURE FOR URANUS

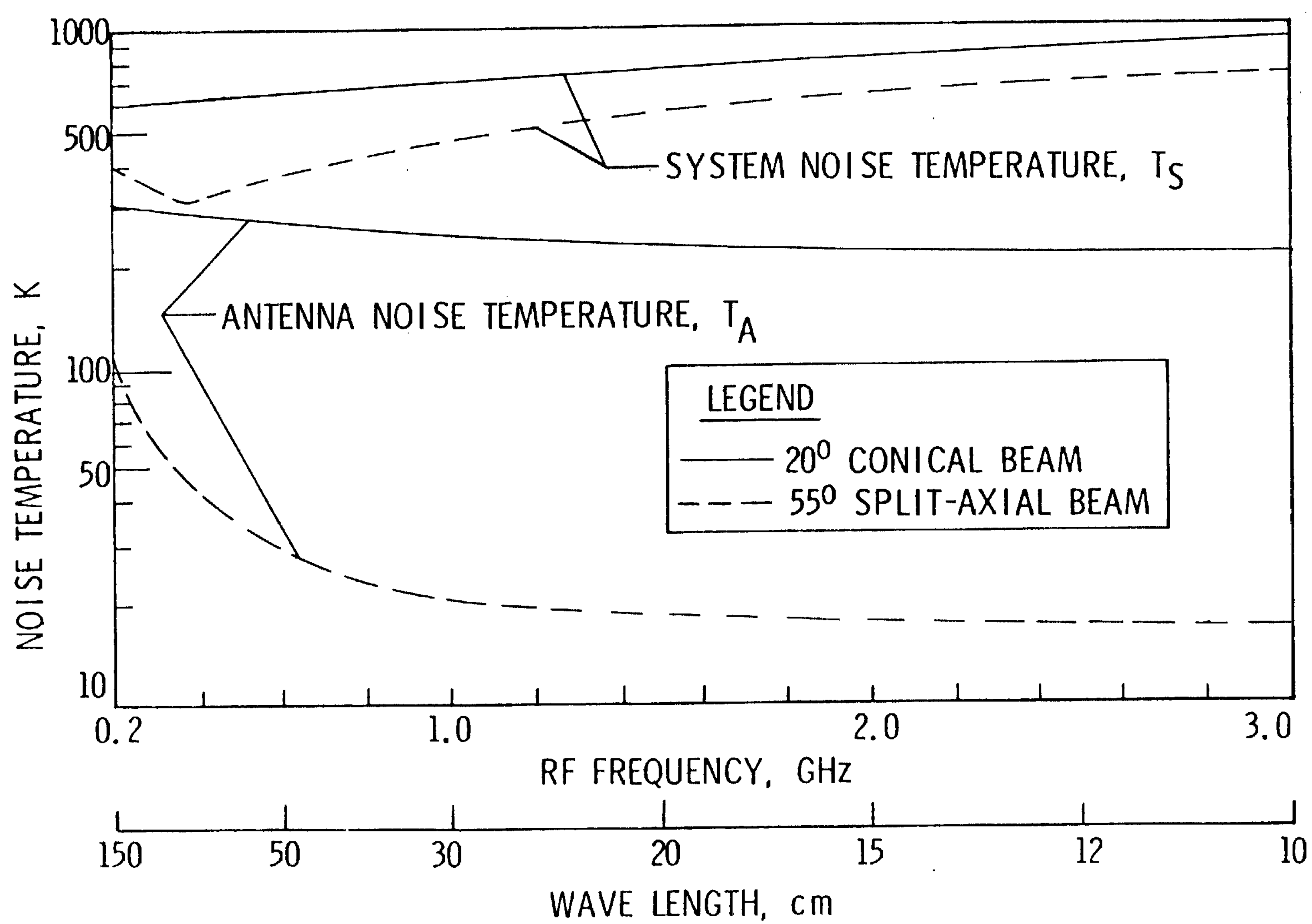



Figure 7-18

the effect is not as predominant as it is for the other two planets. For Uranus the system temperatures generally increase with increasing frequency, in contrast to the curves with negative or zero slope for the other two planets.

Figure 7-19 has some conclusions to outer planet atmosphere propagation. As shown previously, the Jupiter cool/dense atmosphere is the worst-case model and atmosphere absorption can become quite significant and must be considered in determining the effects of propagating through the atmosphere. In order to minimize the atmosphere effects, one should be concerned with keeping the probe aspect angle as small as possible during the mission, the RF frequency as low as practical, and the depth of descent less than 20 bars. The atmosphere losses for Saturn and Uranus are not significant for a typical 10-bar mission using UHF transmission.

Thermal noise in the communication system places a limit on the minimim detectable signal present in the receiver to operate with and the noise effects change as the mission progresses from entry to the end of the mission. Jupiter is the worst of the three planets with its very noisy synchrotron source.

MR. L. FRIEDMAN: I would like to make a comment. I think this analysis shows how a lot of effects vary with the frequency of the transmission; but it assumes antennas of fixed beam width. Actually, your antennas are generally space limited; so I think, if you let the beam width also be a function of frequency and put the whole RF link together, you might get a more realistic picture of how the whole system performance varies with frequency.

MR. COMPTON: Yes, I agree with you. The problem in letting the beam widths vary is that in doing so, you are assuming as the beam widths become more that you are going to somehow track the aspect angle changes.

MR. FRIEDMAN: The beam width can only vary subject to the mission requirements. But you showed 55 and 20 degrees.

## OUTER PLANET ATMOSPHERE PROPAGATION RESULTS

- THE JUPITER COOL/DENSE ATMOSPHERE MODEL IS WORST CASE.
- MINIMIZE THE DEPTH, ASPECT ANGLE, AND RF FREQUENCY TO MINIMIZE THE ATMOSPHERE EFFECTS.
- ATMOSPHERE LOSSES AT SATURN OR URANUS ARE LESS THAN 2 dB AT UHF FOR A 10-BAR PROBE MISSION.

- THERMAL NOISE IN THE COMMUNICATION SUBSYSTEM PLACES A LIMIT ON THE MINIMUM DETECTABLE SIGNAL.
- PLANET NOISE EFFECTS CHANGE DURING A PROBE MISSION WITH GEOMETRY AND ANTENNA BEAMWIDTH.
- JUPITER HAS THE LARGEST THERMAL NOISE EFFECT.

Figure 7-19

MR. COMPTON: Right, they were for two entirely different types of antennas and flyby geometries.

MR. GRANT: One question I had, Revis, was that a 20 degree half angle or beam width?

MR. COMPTON: It was a 20 degree beam width antenna.

MR. GRANT: I agree that you might get more insight than we have here, especially for the Mariner, to see how, if you change the beam width, you could come up with a more optimum operating point.

MR. FRIEDMAN: I think that this ultimately ties into battery weight on the probe and the variation of the transmitter efficiency is very small.

MR. COMPTON: That particular trade-off was included in the Saturn Uranus studies that McDonnell covered. Actually, I am not sure if the antenna beam widths were ever factored in as a variable directly with everything else, but, except for Jupiter, the net effect of the noise and the atmospheric attenuation tended to be small over the frequency range that we are considering.

MR. GRANT: Our next speaker is Paul Parsons who is an engineer in the applied communications research group at JPL. He has been working on advance studies related to the Mariner project, and he will speak about data relay design.