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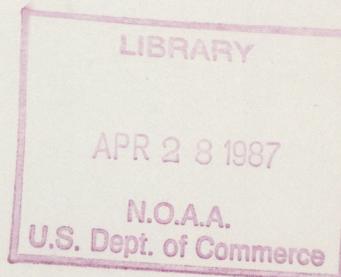
NOAA Technical Memorandum ERL ESG-24



PROFILER/SATELLITE INTERFERENCE ANALYSIS

Russell B. Chadwick

Environmental Sciences Group
Boulder, Colorado
February 1987



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PROFILER/SATELLITE INTERFERENCE ANALYSIS

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Abstract. An engineering analysis of potential radio interference between the Wind Profiler Demonstration Network and three NOAA satellite-based systems is presented. These three systems are: Geostationary Operational Environmental Satellite (GOES) system, the Search and Rescue Satellite (SARSAT) system, and the TIROS series Data Collection System (TDCS). The Profiler considered in this analysis is the UHF wind Profiler to be supplied by Sperry Corporation under a contract awarded June 1986. This analysis is based on the interference-to-noise ratio at the satellite receiver. Several engineering changes have been made to the original contract to reduce potential interference. The effects of these changes are presented.

1. Introduction

This report gives an engineering analysis of potential radio frequency interference between the Profiler and the Geostationary Operational Environmental Satellite (GOES) system, the Search and Rescue Satellite (SARSAT) system, and the TIROS series Data Collection System (TDCS).

The wind Profiler is a sensitive ground-based pulsed radar capable of detecting return signals from omnipresent radio refractive-index irregularities in the clear atmosphere. By measuring the Doppler shift associated with these returns the winds can be determined. The Profiler necessarily transmits high power pulses upward and has the potential to interfere with sensitive satellite-borne receivers, especially those in low Earth orbit. Some interference between an experimental 405.25 MHz Profiler and a SARSAT receiver at 406.05 MHz has been reported. Recommendations for eliminating this interference potential for a network of 31 Profilers to be deployed in the central United States starting in 1989 are given in this report. These recommendations are based on estimated interference-to-noise ratios.

Since the Profiler will find wide application in weather forecasting and aircraft route planning, it is important that its frequency be located in a band where an operational frequency allocation can be obtained. The present choice is the 403-406 Meteorological Aids band. However, the 403-406 MHz band is bracketed on both sides by services that transmit Earth-to-space. The GOES system uses the 401.7-402 MHz band. Since the satellites are above the Equator only a Profiler near the Equator (which none of them are) would pose a problem. The SARSAT system occupies the 406-406.1 MHz band and uses low polar orbiter satellites that are designed to cover the entire Earth, creating a significant potential for interference. The TDCS receiver is carried on the same polar orbiter satellite as SARSAT but occupies a bandwidth of about 30 kHz centered at 401.65 MHz, so it is less of a problem.

The approach used here to quantify interference potential is to find the interference-to-noise ratio (INR) at the satellite receiver. The first step is to find the total incident power P_I at the satellite receiver when the satellite is located over the network and is receiving the maximum interference power. Then the in-band receiver noise P_n is determined and the ratio P_I/P_n formed. This is a worst case situation that does not include frequency rejection effects. Frequency rejection of the receiver is accounted for by multiplying P_I/P_n by a value less than unity, which is the portion of the incident power in the receiver bandwidth. This product yields the INR. Conclusions and recommendations are based on values of INR for different cases.

The radar parameters used in this analysis are similar to those to be used by Sperry Corporation in the construction of wind Profilers for the 31-station demonstration network.

2. Incident Power Analysis

2.1 Main Beam Case

As shown in Appendix A the incident power from one Profiler at a satellite receiver is

$$P_I(\text{dBm}) = P_T(\text{dBm}) + G_T(\text{dBi}) + G_R(\text{dBi}) + L_R(\text{dB})$$

where P_I is total average power at satellite receiver,
 P_T is Profiler transmitted average power (+61.8 dBm High mode, +55.8 dBm Low mode),
 G_T is Profiler antenna gain toward satellite,
 G_R is satellite antenna gain,
 and L_R is path loss.

For GOES $G_R = +9.4$ dBi and $L_R = -175.7$ dB, and for SARSAT and TDCS $G_R = -6$ dBi and $L_R = -143.2$ dB as shown in Appendix A. If the satellite is in the main beam of the Profiler antenna, the on-axis antenna gain of 32 dB given in Appendix B is used for G_T . The incident power, P_I , is seen to be -72.5 dBm for the GOES case and -55.4 dBm for the SARSAT and TDCS cases in the Profiler High mode. These values are reduced by 6 dB for the Low mode.

For the GOES and Profiler demonstration network this is a hypothetical case because the geostationary orbit does not intercept any of the Profiler main beam pointing positions.

2.2 Sidelobe Case

In this case there is an active network of N Profilers, but the satellite is not in the main beam of any one of them. Appendix A shows the incident power from N Profilers at a satellite receiver is:

$$P_I(\text{dBm}) = P_T(\text{dBm}) + G_R(\text{dBm}) + L_R(\text{dB}) + 10 \log \sum_{i=1}^N G_{Ti}$$

where the terms are as above except that G_{Ti} is the i^{th} Profiler antenna gain toward the satellite.

Appendix B shows that the average gain of the proposed Sperry Profiler antenna can be represented as a constant value over the elevation angles in Table 1.

Table 1. Average gain of Sperry Profiler antenna

Angle from beam-pointing direction	G_{T1} (dBi)
0° - 2.5° (main beam)	+32
2.5° - 30°	+4.5
30° - 60°	-8.8
60° - 90°	-18.7

Appendix C shows that for the Profiler demonstration network the maximum elevation angles to GOES from each site are between 38° and 55° from the horizon. Thus, by choosing to orient the Profiler so the two off-vertical beams point away from the GOES satellites, all the sites will be, at worst, in the same gain region of Table 1, i.e., 30°-60° where the average gain is -8.8 dBi. Then the incident power equation simplifies to

$$P_I(\text{dBm}) = P_T(\text{dBm}) + G_R(\text{dBi}) + L_R(\text{dB}) + 10 \log N + G_{T1}(\text{dBi})$$

where $G_{T1} = -8.8$ dBi as in Table 1. The demonstration network is planned to be 31 sites so that $N = 31$. Then

$$P_I(\text{dBm}) = 61.8 + 9.4 - 175.7 + 14.9 - 8.8 = -98.4 \text{ dBm}$$

is the total incident power at the GOES satellite receiver for the Profiler High mode, and the Low mode incident power is reduced from this by 6 dB.

Next consider the analysis for SARSAT and TDCS. Appendix D covers the case in which the satellite passes over the center of the demonstration network. The worst interference case excluding main beam passage has 14 Profilers with elevation angles between 87.5° and 60° and 17 Profilers with elevation angles between 60° and 30°. If P_{I2} denotes the interference power at angles from 87.5° to 60° and P_{I3} denotes the interference power at angles from 60° to 30°, the total interference power will be the sum of these two.

$$P_{I2}(\text{dBm}) = P_T(\text{dBm}) + G_R(\text{dBi}) + L_R(\text{dB}) + 10 \log 14 + G_{T1}(\text{dBi})$$

$$P_{I2}(\text{dBm}) = 61.8 - 6 - 143.2 + 11.5 + 4.5 = -71.4 \text{ dBm}$$

$$P_{I3}(\text{dBm}) = 61.8 - 6 - 143.2 + 12.3 - 8.8 = -83.9 \text{ dBm}$$

$$P = P_{I2} + P_{I3} = -71.2 \text{ dBm}$$

Note that this is about 16 dB less than the incident power when the satellite passes through the main beam of a Profiler.

2.3 Transmitter Blanking Case

For this analysis it is assumed that N Profilers are active, but that any Profiler has the transmitter blanked whenever the zenith angle to a satellite is less than 30° . This will be termed a $\pm 30^\circ$ blanking cone. The case of Section 2.1 is a 0° blanking cone, and the case of Section 2.2 above is a $\pm 2.5^\circ$ blanking cone. The incident power to GOES is as Section 2.2.

The incident power for SARSAT and TDCS in the transmitter blanking case has been found (Section 2). Since P_{I2} denotes the incident power from Profilers that see the satellite in the angular region with zenith angle less than 30° , P_{I2} will be zero when the appropriate transmitters are blanked. So the total incident power will then be P_{I3} which is -83.9 dBm.

This discussion relates to the vertical beam, but the same reasoning applies to the two oblique beam cases. The worst case has about 14 Profilers in the ± 4.5 dBi gain region and about 17 Profilers in the -8.8 dBi gain region.

3. Incident Power-to-Receiver Noise Ratios

To find incident power to receiver noise ratios, it is necessary to find the in-band receiver noise for GOES, SARSAT, and TDCS. The in-band receiver noise in each case can be determined by finding the effective noise temperature and combining it with the receiver bandwidth. The system noise is made up of three components: 1) receiver electronic noise, 2) radiation from the Earth, and 3) cosmic noise reflected from the Earth. To simplify the situation the Earth is assumed to be a beam-filling, perfect absorber at a physical temperature of 300° K in each case. This means that the system effective noise temperature is the receiver noise temperature plus 300° K.

The GOES band is 401.7-402.0 MHz, and the noise figure of the receiver is 3 dB. This becomes an effective receiver noise of 284° K and the added noise from the Earth will increase this by 300° K so the resulting 584° K over the 300 kHz of bandwidth results in -116.1 dBm of in-band noise.

The SARSAT band extends from 406.0 to 406.1 MHz and the SARSAT receiver has an effective noise temperature of 320° K for a system noise temperature of 620° K and thus the in-band noise power is -120.6 dBm.

The TDCS receiver has a noise figure of 2 dB for a noise temperature of 170° K. The system noise temperature becomes 470° K and over the 30 KHz bandwidth the system in-band noise is -127.1 dBm.

Now it is straightforward to calculate the ratio of incident power to in-band receiver noise for each of the three cases discussed in Section 2. For Case 1 (satellite in the main beam) the P_I/P_n ratio is given in Table 2.

Table 2. P_I/P_n ratio (dB) when satellite is in the main beam of a Profiler

	High mode		Low mode
GOES	43.6	(hypothetical)	37.6
SARSAT	65.2		59.2
TDCS	71.7		65.7

For Case 2 (satellite at overhead center of 31-station network but not in any main beam) the P_I/P_n ratio is given in Table 3. This case is nearly equivalent to blanking Profiler transmitters whenever a satellite is in the main beam.

Table 3. P_I/P_n ratio (dB) when satellite is not in main beam ($\pm 2.5^\circ$ blanking cone)

	High mode		Low mode
GOES	17.7		11.7
SARSAT	49.4		43.4
TDCS	55.9		49.9

For Case 3 (31-station Profiler network where a transmitter is blanked whenever the zenith angle to a satellite is less than 30°) the P_I/P_n ratio is given in Table 4. This is the same as having a blanking cone of $\pm 30^\circ$ about the Profiler.

Table 4. P_I/P_n ratio (dB) with transmitter inhibited whenever satellite is inside a $\pm 30^\circ$ blanking cone

	High mode		Low mode
GOES	17.7		11.7
SARSAT	36.7		30.7
TDCS	43.2		37.2

The main conclusion from these intermediate results is that because of geometrical considerations there is a greater chance for interference with SARSAT and TDCS than with GOES.

4. Frequency Rejection Effects

Appendix E presents frequency rejection data derived from frequency spectra of transmitted signals provided by Sperry. These frequency spectra are based on the measured nonlinear transfer characteristics of the solid-

state transmitter modules that will be used in the Profiler. The frequency rejection values were determined numerically from these spectra and are shown in Table 5 for two center frequencies, 405.25 MHz and 404.37 MHz, both of which have been considered for the Profiler network.

Table 5. Frequency rejection, R(f,B) in dB, for two frequencies and three bandwidths

	Bandwidth	f= 405.25 MHz		f= 404.37 MHz	
		High	Low	High	Low
GOES	300 kHz	-61.3	-54.0	-51.5	-49.7
SARSAT	100 kHz	-35.2	-26.2	-50.6	-41.2
TDCS	30 kHz	-73.0	-65.2	-63.8	-59.2

The interference-to-noise ratio is easily found by combining the results in Tables 2, 3, and 4 with Table 5: $INR = R(f,B) P_I/P_n$. Interference-to-noise ratios greater than unity imply that the signal interference is limiting system performance; ratios less than unity imply that interference is not extreme. Table 6 gives the interference-to-noise ratios for Case 1 when a satellite is in the main beam.

Table 6. INR (dB) when a satellite is in the main beam of a Profiler

	f= 405.25 MHz		(hypothetical)	f= 404.37 MHz	
	High	Low		High	Low
GOES	-17.7	-16.4		-7.9	-12.1
SARSAT	+30.0	+33.0		+14.6	+18.0
TDCS	-1.3	+0.5		+7.3	+6.5

Table 7 gives the interference-to-noise ratios for a 31-station Profiler network when the satellite is not in the main beam, the worst case for $\pm 2.5^\circ$ blanking cone. This is equivalent to the case in which the Profiler transmitter is blanked when the satellite is in the main beam.

Table 7. INR (dB) for 31-station Profiler network when satellite is not in main beam

	f= 405.25 MHz		f= 404.37 MHz	
	High	Low	High	Low
GOES	-43.6	-42.3	-33.8	-38.0
SARSAT	+14.2	+17.2	-1.2	+2.2
TDCS	-29.8	-15.3	-7.9	-9.3

Table 8 gives the interference-to-noise ratios for Case 3, in which the Profiler transmitter is blanked whenever the satellite is within 30° of the zenith angle. Simulations show that the satellite will be within 30° of the zenith angle on the average about once per day and it will be in this range about 2.2 minutes on the average. This means that for a total of six satellites, a Profiler will have to blank its transmitter for about 15 minutes per day.

Table 8. INR (dB) for 31-station Profiler network where transmitter is blanked whenever satellite is within ±30° of zenith

	f= 405.25 MHz		f= 404.37 MHz	
	High	Low	High	Low
GOES	-43.6	-42.3	-33.8	-38.0
SARSAT	+1.5	+4.5	-13.9	-10.5
TDCS	-29.8	-28.0	-20.6	-22.0

5. Changes to Original Profiler Specifications

5.1 Change #1 Reduce Low Mode Power

The results in Tables 6, 7, and 8 indicate that the greatest interference potential is with the SARSAT system when the Profilers are in the Low mode. The interference potential is about 3 dB above that in the High mode. Therefore, it is desirable to reduce the transmitted power in the Low mode by 3 dB. This will have little impact on the height coverage of the Profiler system since the Low mode only extends to 9.25 km.

5.2 Change #2 Change Frequency

As expected, lowering the center frequency from 405.25 MHz to 404.37 MHz reduces the interference potential with SARSAT and increases the interference potential with GOES and TDCS. However, the GOES interference potential is still very small since the calculated INR maximum is -33.8 dB. So the expected GOES interference is 33.8 dB below the receiver noise and is negligible. Therefore, it is desirable to change the center frequency from 405.25 MHz to 404.37 MHz. This reduces SARSAT interference by 15 dB.

5.3 Change #3 Inhibit Transmitter

If the Profiler transmitter is blanked whenever a satellite is in the main beam, Table 7 shows that the interference potential is reduced but that there is little safety margin. However, if the transmitter is blanked whenever a satellite is within $\pm 30^\circ$ of Profiler main beam there is an adequate safety margin. Therefore, the orbit parameters for each SARSAT and COSPAS (Russian version of SARSAT) satellite will be maintained in the Hub and transmitter blanking times will be sent to the Profiler sites once per week. Tables 6, 7, and 8 show that this procedure also reduces the interference to TDCS to a negligible level. In the near future the operational TDCS receivers will be on the same American satellites that carry SARSAT receivers. This means that the transmitter blanking times for TDCS will be a subset of the SARSAT-COSPAS inhibit times. This transmitter inhibit capability reduces SARSAT interference by 28 dB.

5.4 Change #4 MSK Signaling

The best approach to solving interference problems is to reduce the frequency spread of the transmitted signal by shaping and modulation techniques. These are being used and have proven useful in reducing interference, however, there are more advanced techniques of spectral control. The signaling technique will be changed from conventional phase shift keying (PSK) to a more advanced technique, minimum shift keying (MSK). This MSK technique will reduce SARSAT interference by from 8-15 dB.

5.5 Change #5 Variable Site Orientation

All of the analysis contained here is for the vertical beam of the Profilers. However, in actuality, the Profiler has two oblique beams at 74° elevation angle displaced from each other by 90° . These two oblique beams can be oriented in any direction to reduce potential interference with GOES. It will be desirable to select the antenna azimuth direction at each site so that the antenna sidelobe response toward the GOES East and GOES West satellites for each beam position is minimized to the extent possible. Generally this will involve pointing the two oblique beams away from the equatorial plane.

6. Summary and Conclusions

An engineering analysis of potential interference between the Wind Profiler Demonstration Network and three satellite-based systems has been presented. This analysis used the specifications for wind Profilers in the contract awarded to Sperry Corporation in June 1986. Because of the analysis several engineering changes to this contract have been negotiated. The effects of these changes are discussed.

The most severe potential interference is with the SARSAT system and so this was analyzed in greater detail. The effects of the engineering changes on interference power and on interference-to-noise ratio at the input to the SARSAT receiver are summarized in Table 9. The first column is the engineering change as discussed in Section 5. The second column is the interference-to-noise ratio at the input to the SARSAT receiver. The third

column is the interference power in a single spectral line at the SARSAT receiver input.

Table 9. Worst case levels at SARSAT receiver

Engineering changes	Interference-to-noise ratio	Power/spectral line
Original	+33 dB	-110 dBm
Reduce low mode power	+30 dB	-113 dBm
Change frequency	+15 dB	-128 dBm
Inhibit transmitter	-13 dB	-154 dBm
MSK signaling	-21 dB	-162 dBm

The SARSAT receiver minimum detectable signal per line is -131 dBm and Table 9 shows that the changes reduce the interference power per line well below this. An acceptable interference-to-noise ratio is not known but a criterion of lowering the effective signal-to-noise ratio by 1 dB has been suggested. This is equivalent to an interference-to-noise ratio of -5.85 dB. Table 9 shows that the worst case interference-to-noise ratio will be significantly below this.

Appendix A. Derivation of Incident Power at Satellite

This appendix derives an expression for the incident power at a satellite for multiple Profilers on the Earth. Specific path loss parameters are given for GOES, SARSAT, and TDCS. Let P_{Ti} be the power transmitted from the i^{th} Profiler through an antenna with gain G_{Ti} . Then the power density (W/m^2) from this i^{th} Profiler at a range R is given by

$$P_i = \frac{P_{Ti}}{4 \pi R^2} G_{Ti}.$$

The incident power at the satellite is collected by an antenna with effective area A_e where $A_e = G_R \lambda^2 / 4 \pi$ and G_R is the gain of this antenna toward the source. Then the incident power from the i^{th} Profiler is

$$P_{Ii} = P_i A_e = \frac{P_{Ti}}{4 \pi R^2} G_{Ti} \frac{G_R \lambda^2}{4 \pi}$$

$$P_{Ii} = P_{Ti} G_{Ti} G_R \left(\frac{\lambda}{4 \pi R} \right)^2.$$

The total incident power from N Profilers is

$$P_I = \sum_{i=1}^N P_{Ii} = \sum_{i=1}^N P_{Ti} G_{Ti} G_R L_R$$

where $L_R = (\lambda / 4 \pi R)^2$ is defined as the path loss.

The various terms can now be specifically related to the GOES, SARSAT, and TDCS satellites. The wavelength is 74 cm; for geostationary satellites the range is 36,000 km, and for a TIROS satellite the range is 850 km. So the path loss terms for GOES and for SARSAT and TDCS are found to be

$$\begin{aligned} L_R &= -175.7 \text{ dB} && (\text{GOES}) \\ L_R &= -143.2 \text{ dB} && (\text{SARSAT and TDCS}) \end{aligned}$$

The GOES receiver antenna has gain of +9.4 dBi, and the range to all Profilers is approximately the same. The SARSAT receiver antenna has gain of -6 dBi looking straight down, and the gain at other angles changes so as to cancel the range variation to the Earth's surface. The TDCS antenna is not well covered in the literature, but since the TDCS mission is somewhat similar to SARSAT, it will be assumed that the TDCS antenna is identical to the SARSAT antenna. So, to a good approximation, GOES, SARSAT, and TDCS can be considered to have one value of range (and hence one value of path loss) and one value of receiver antenna gain.

At any one time all the Profilers will have the same transmitted power P_T . So the incident power at a satellite receiver with N active Profilers is given by

$$P_I = P_T G_R L_R \sum_{i=1}^N G_{Ti}$$

where

$$P_T = \text{Profilers transmitted power} = +61.8 \text{ dBm (High mode)} \\ = +55.8 \text{ dBm (Low mode)}$$

$$G_R = \text{satellite antenna gain} = -6 \text{ dBi (SARSAT, TDCS)} \\ = +9.4 \text{ dBi (GOES)}$$

$$L_R = \text{path loss} = -143.2 \text{ dB (SARSAT, TDCS)} \\ = -175.7 \text{ dB (GOES)}$$

$$G_{Ti} = \text{Profilers antenna gain toward satellite.}$$

Of course, to use these dB terms the incident power equation must be in this form:

$$P_I(\text{dBm}) = P_T(\text{dBm}) + G_R(\text{dBi}) + L_R(\text{dB}) + 10 \log \left(\sum_{i=1}^N G_{Ti} \right).$$

The important case of a satellite in the main beam of a Profiler is a special case where $N = 1$ and the incident power equation becomes

$$P_I(\text{dBm}) = P_T(\text{dBm}) + G_T(\text{dBi}) + G_R(\text{dBi}) + L_R(\text{dB}).$$

Appendix B. Model for Average Antenna Gain Using Sperry Antenna

This appendix derives a model for the "average" gain of the Sperry antenna pattern for different sectors of elevation angle. If θ is departure from vertical angle and ϕ is azimuth angle, then the model for antenna gain $G(\theta, \phi)$ with beamwidth B is

$$G(\theta, \phi) = \begin{array}{ll} G_0 & 0^\circ \leq \theta < B/2 \\ G_1 & B/2 \leq \theta < 30^\circ \\ G_2 & 30^\circ \leq \theta < 60^\circ \\ G_3 & 60^\circ \leq \theta < 90^\circ \\ 0 & 90^\circ \leq \theta < 180^\circ \end{array}$$

The main beam gain G_0 is known. This leaves three unknown parameters, which require three independent equations to be solved. The first of these three equations can be derived from an equation that is true for all antenna patterns:

$$\int_0^{2\pi} \int_0^\pi G(\theta, \phi) \sin\theta \, d\theta d\phi = 4\pi.$$

This becomes

$$\int_0^{B/2} G_0 \sin\theta d\theta + \int_{B/2}^{30^\circ} G_1 \sin\theta d\theta + \int_{30^\circ}^{60^\circ} G_2 \sin\theta d\theta + \int_{60^\circ}^{90^\circ} G_3 \sin\theta d\theta = 2$$

which then becomes

$$G_0[\cos 0 - \cos B/2] + G_1[\cos B/2 - \cos 30^\circ] + G_2[\cos 30^\circ - \cos 60^\circ] + G_3[\cos 60^\circ - \cos 90^\circ] = 2.$$

Using the cosine of small angle approximation and the approximation that $G_0 = 4\pi/B^2$ where B is in radians, the first term becomes $\pi/2$. Then the first of the three equations becomes

$$0.133 G_1 + 0.366 G_2 + 0.5 G_3 = 0.4292.$$

The remaining two equations come from antenna patterns supplied by Sperry. These patterns extend from horizon to horizon and are parameterized in 5° azimuth angles. This gives 72 patterns for each of the elevation angle regions: 0 to $B/2$; $B/2$ to 30° ; 30° to 60° ; 60° to 90° . The peak (numeric value) for each 5° azimuth is determined from the patterns, and the mean of these peaks is found over all 72 azimuth slices. The mean values of the peaks are given in Table B-1.

Table B-1. Mean values of peak sidelobes

θ region	mean value (dBi)
$0^\circ - B/2$	32
$B/2 - 30^\circ$	6.33
$30^\circ - 60^\circ$	-6.92
$60^\circ - 90^\circ$	-16.88

The two equations are obtained by assuming that the average value of gain between regions has the same relative value as the mean peak sidelobe value. Thus,

$$\frac{G_2}{G_3} = 9.96 \text{ dB} = 10^{0.996} = 9.91$$

$$\frac{G_1}{G_2} = 13.25 \text{ dB} = 10^{1.325} = 21.13.$$

The three equations can be solved simultaneously to arrive at the values of gain for each of the elevation angle regions. The final results are in Table B-2.

Table B-2. Average gain values for Sperry antenna pattern

i	θ region	G_{Ti}	G_{Ti} (dBi)
0	$0^\circ - 2.5^\circ$	1585	+32
1	$2.5^\circ - 30^\circ$	2.81	+4.5
2	$30^\circ - 60^\circ$	0.133	-8.8
3	$60^\circ - 90^\circ$	0.0134	-18.7

In the main part of this report the elevation angles are measured from the horizon rather than from the center of the beam as is done here.

Appendix C. Elevation Angles to GOES

This appendix finds the elevation angles to GOES (or any geosynchronous satellite) for the demonstration network. Given that θ is the elevation angle at a Profiler site to a geosynchronous satellite, this angle is

$$\theta = \tan^{-1} \left\{ \frac{\cos \Delta \cos \Gamma - r/R}{\sqrt{1 - (\cos \Delta \cos \Gamma)^2}} \right\}$$

where

$$\begin{aligned} R &= \text{orbit radius (42166 km)} \\ r &= \text{earth radius (6368 km)} \\ \Gamma &= \text{site latitude} \\ \Delta &= \text{satellite longitude minus site longitude.} \end{aligned}$$

The maximum value of θ occurs when $\Delta = 0$, so

$$\theta_{\max} = \tan^{-1} \left\{ \frac{\cos \Gamma - 0.151}{\sin \Gamma} \right\}.$$

At $\Gamma = 30^\circ$ (approximately New Orleans) the maximum elevation to GOES is 55° .
At $\Gamma = 45^\circ$ (the northern edge of Wyoming) the maximum elevation angle is 38° .

Table C-1 gives the elevation angles to both GOES East at 75° long. W and GOES West at 136° long. W from each of the sites of the proposed 31-site demonstration network. Also shown are the elevation angles to a hypothetical GOES satellite directly south of the network at 97° long. W. Clearly, it is reasonable to assume that the elevation angles for the demonstration network lie in the range 30° to 60° .

Table C-1. Elevation angles from Profiler sites to GOES East, GOES West, and a hypothetical GOES satellite directly south of Profiler demonstration network

Site	GOES East (@ -75° long. W)	GOES directly south (@ -97° long. W)	GOES West (@ -136° long. W)
1	34.4°	42.8°	33.5°
2	40.1	44.2	27.4
3	38.2	43.6	29.0
4	39.9	45.6	30.2
5	38.7	50.0	40.1
6	39.6	46.3	31.8
7	41.5	46.6	29.7
8	41.2	47.3	31.3
9	40.9	48.0	33.0
10	42.9	48.3	30.9
11	42.9	49.3	32.5
12	42.6	46.2	27.5
13	38.0	41.4	25.5
14	36.0	41.2	27.9
15	41.4	43.6	24.7
16	37.7	39.6	22.6
17	40.6	41.0	21.2
18	44.3	46.5	25.8
19	44.3	44.2	22.1
20	34.6	38.5	24.8
21	44.5	49.4	30.2
22	47.6	49.3	26.4
23	48.1	52.3	30.4
24	46.4	53.1	33.6
25	42.4	51.2	36.3
26	39.1	48.6	36.7
27	37.7	45.8	33.9
28	36.6	43.4	31.1
29	33.6	40.3	29.8
30	31.2	40.5	34.2
31	35.1	45.7	38.0

Appendix D. Number of Interfering Profilers for SARSAT and TDCS Case

This appendix uses a graphical approach to determine, for a particular satellite position, how many Profilers have elevation angles in the different gain regions of the Sperry Profiler antenna pattern developed in Appendix B. Figure D-1 shows a cross section of the Earth with a SARSAT orbit at 850 km altitude. Lines at 0° , 30° , and 60° are drawn outward from the Profiler site and illustrate the gain region boundaries of Appendix B. These lines intersect the SARSAT orbit and determine diameters of regions illuminated by different gain regions of the Profiler antenna. Figure D-2 shows these regions for a Profiler at Platteville, Colorado. The smallest circle has diameter 75 m and represents the size of the main beam at orbit height. The next larger circle has diameter 900 km and represents the region where the average gain is +4.5 dBi. The largest circle has diameter 2500 km and represents the region where the average gain is -8.8 dBi. The region where the Profiler antenna gain is -18.7 dBi is not shown because it extends beyond the edges of the map. Because of refraction the diameter of this region probably exceeds the 6700 km shown in Fig. D-1.

Figure D-3 shows regions wherein the Profilers have certain average gains toward SARSAT. The smaller circle has diameter 900 km and contains the Profilers that have an average gain of +4.5 dBi toward SARSAT. There are 14 sites in this region. The larger circle has diameter 2500 km and contains 17 sites, each of which has an average gain of -8.8 dBi toward SARSAT when the satellite is over eastern Kansas. This is the worst case for the demonstration network.

This analysis is for the vertical beam case, but it is apparent that the same approach can be applied to the oblique beam case. The results are about the same; i.e., for the worst case, 14 Profilers have gain toward the satellite of ± 4.5 dBi and 17 Profilers have gain toward the satellite of -8.8 dBi.

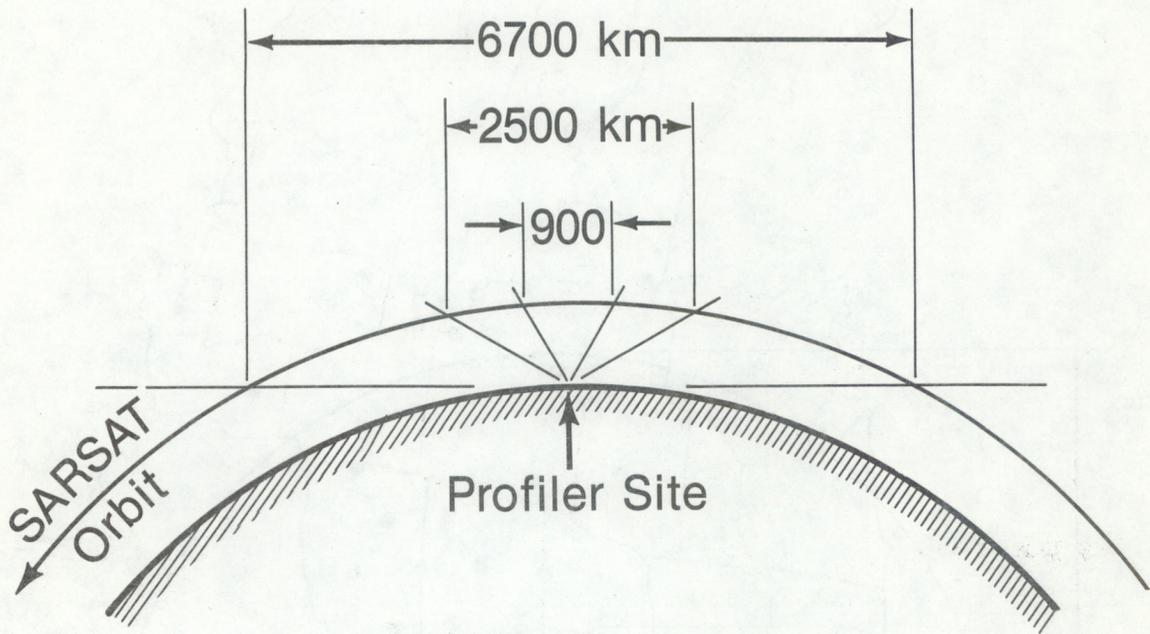


Figure D-1. Antenna gain boundaries and their intersections with SARSAT orbit.

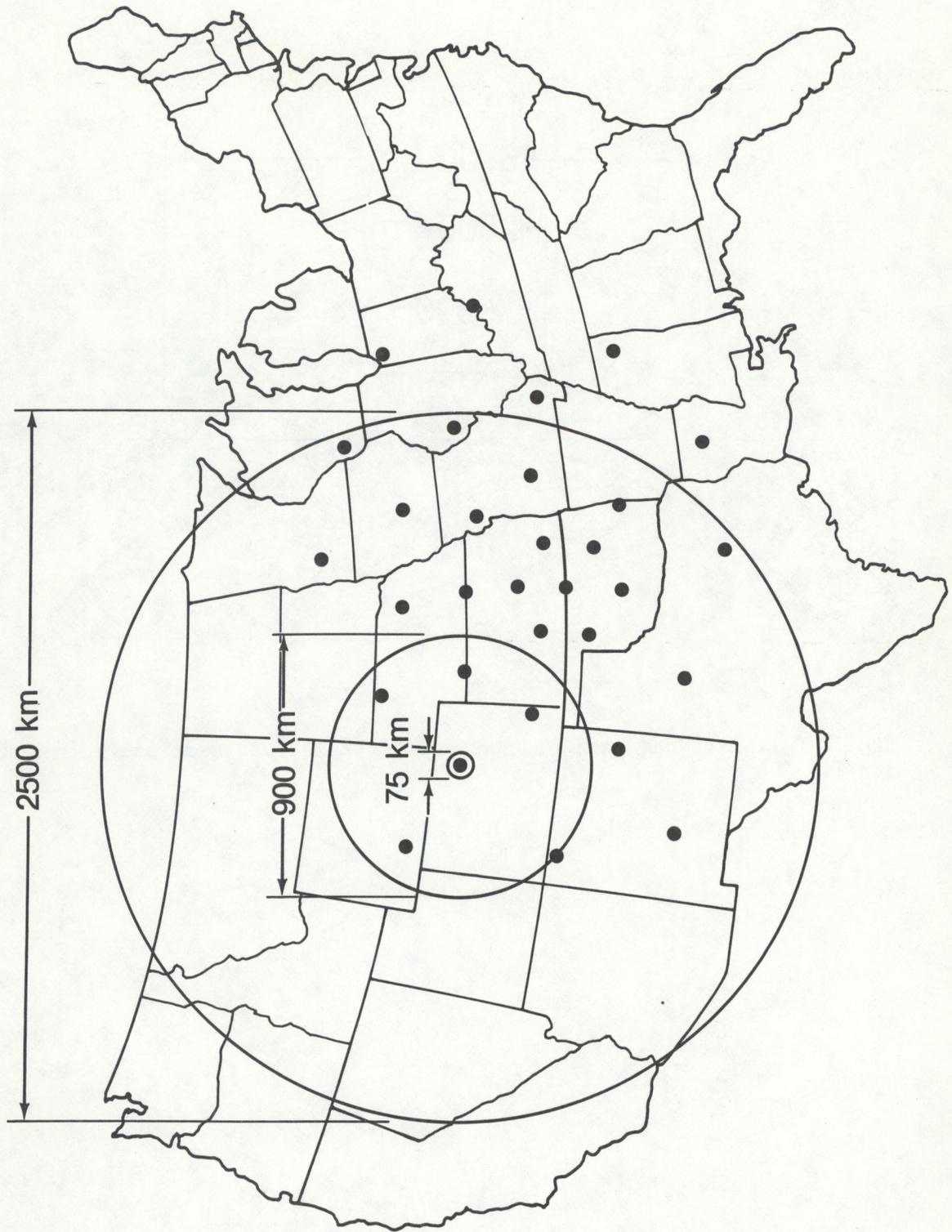


Figure D-2. Antenna gain boundaries at SARSA orbital height for Profiler at Platteville, Colorado.

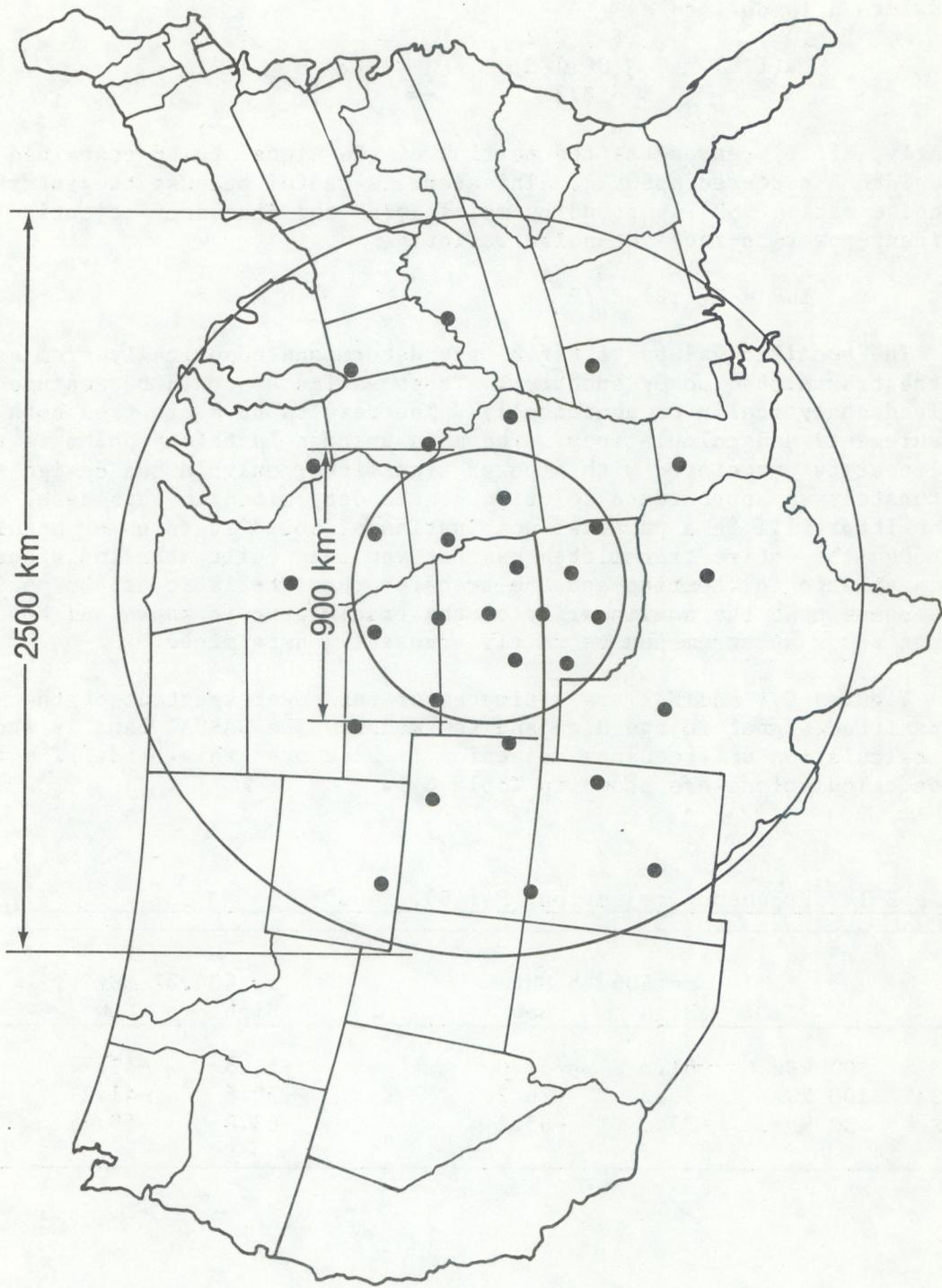


Figure D-3. Regions for Profiler antenna gain for a SARSAT satellite over eastern Kansas.

Appendix E. Derivation of Frequency Rejection

Let $S(\alpha)$ be the power spectrum of the transmitted signal where α is the frequency variable. The frequency rejection for center frequency f and bandwidth B is defined as

$$R(f,B) = \frac{\int_{f - B/2}^{f + B/2} S(\alpha) d\alpha}{\int_{-\infty}^{\infty} S(\alpha) d\alpha} .$$

Clearly, $R(f,B)$ represents the portion of the signal power contained in bandwidth B centered about F . This term is useful because the interference-to-noise ratio (INR) is found by multiplying the frequency rejection by the incident-power-to-receiver-noise ratios:

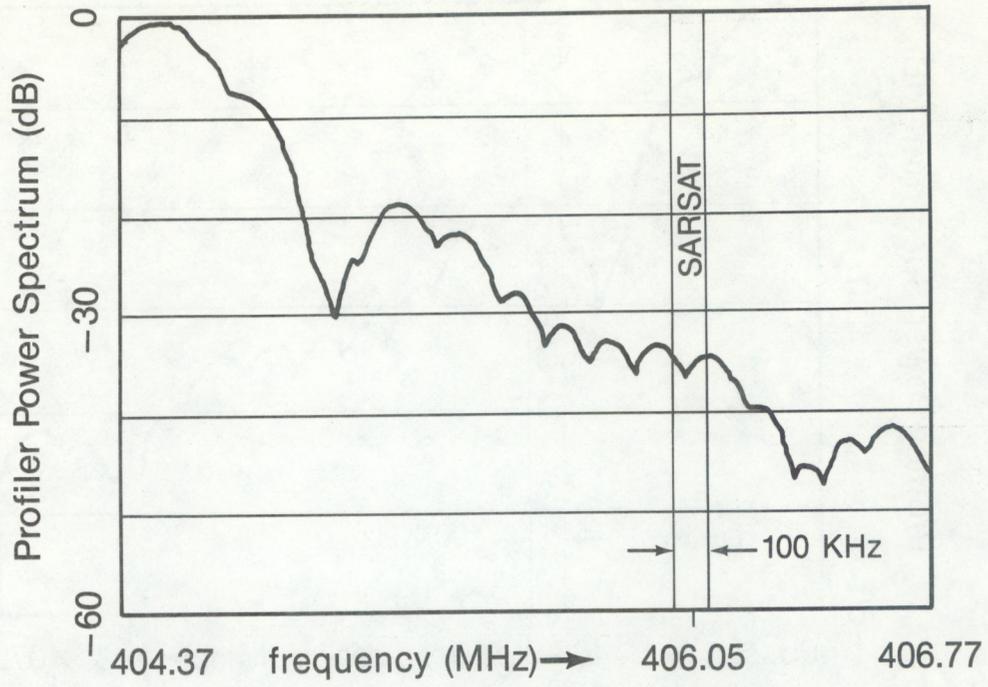
$$INR = R(f,B) P_I/P_n .$$

The specific values of $R(f,B)$ are determined numerically from estimates of the transmitted power spectrum. These estimates could be measured or derived analytically or numerically. The results here are from both measurements and calculations. The main unknown in this problem is the nonlinearity associated with a power transmitter only in the design stage. Fortunately an approximate solution can be determined in this case. The transmitter will be a parallel combination of solid state power modules, and, although the entire transmitter has not yet been built, the individual modules are available for testing and the transfer characteristic can be measured. This means that the nonlinearity of the transmitter is known and hence the output power spectrum can be fairly accurately determined.

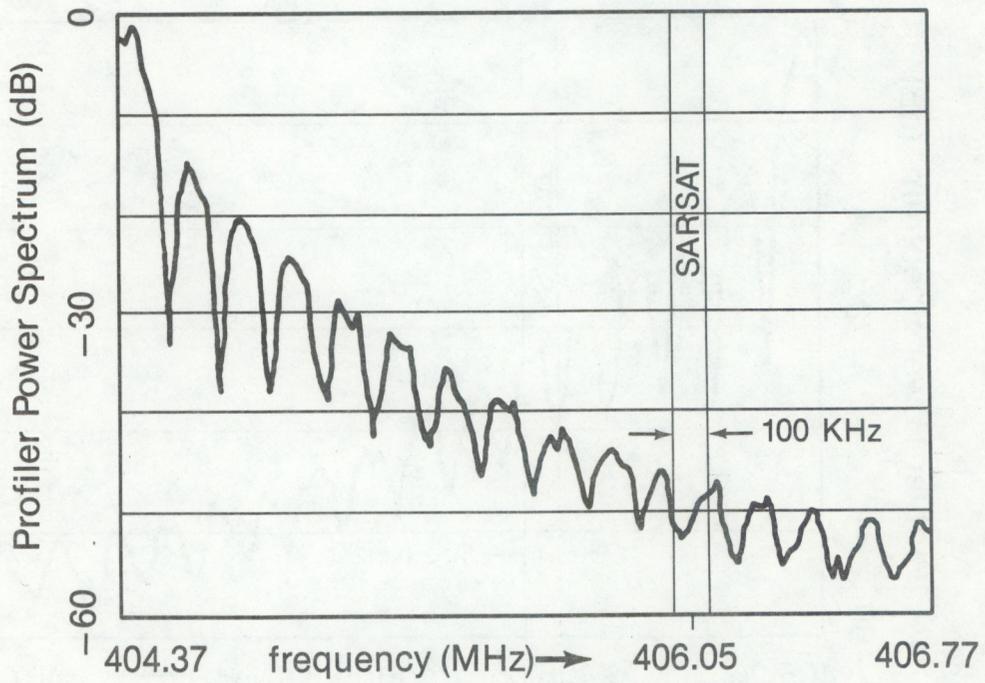
Figures E.1 and E.2 are estimates of the power spectrum of the transmitted signal in the High and Low modes. The SARSAT band is shown and the calculation of frequency rejection is made over this band. The results of these calculations are shown in Table E-1.

Table E-1. Frequency rejection, $R(f,B)$, in dB

		f= 405.25 MHz		f= 404.37 MHz	
		High	Low	High	Low
GOES	300 kHz	-61.3	-54.0	-51.5	-49.7
SARSAT	100 kHz	-35.2	-26.2	-50.6	-41.2
TDCS	30 kHz	-73.0	-65.2	-63.8	-59.2

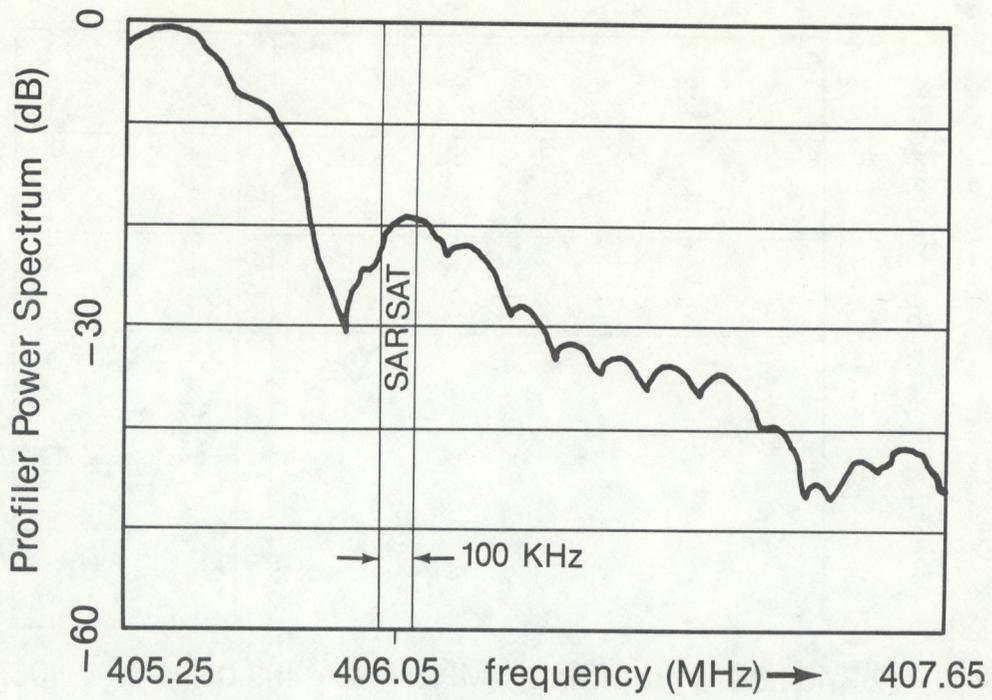


Profiler power spectrum for Low mode and 404.37 MHz center frequency

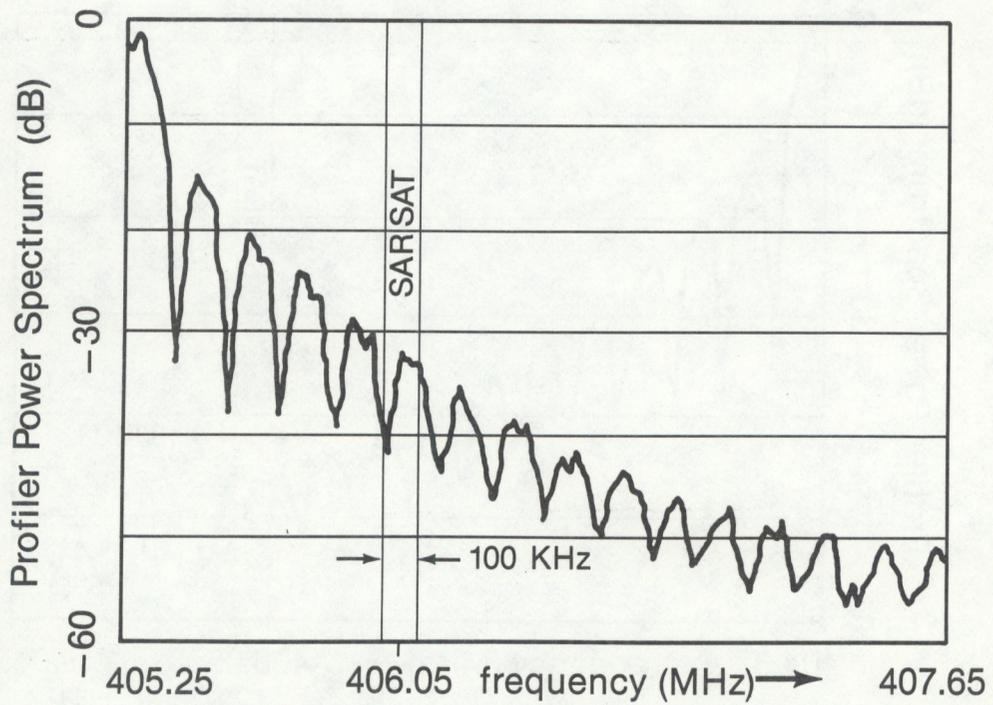


Profiler power spectrum for High mode and 404.37 MHz center frequency

Figure E-1. Power spectra for 404.37 MHz center frequency.



Profiler power spectrum for Low mode
and 405.25 MHz center frequency



Profiler power spectrum for High mode
and 405.25 MHz center frequency

Figure E-2. Power spectra for 405.25 MHz center frequency.