SECTION 4
WIND PROFILER MEASUREMENTS

4.1 INTRODUCTION

The following measurements were conducted on the Unisys wind profiler system at Platteville, Colorado:

1. Profiler short-pulse and long-pulse radiated emission spectra;

2. Profiler radiated harmonic and subharmonic amplitudes relative to the center frequency amplitude;

3. Filter characteristics associated with the profiler's antenna;

4. Horizontal gain of the profiler antenna at ground level relative to an isotropic antenna;

5. Susceptibility of the profiler to various waveforms that represent typical systems operating in the 440-450 MHz band; and

6. Effects of profiler emissions on a typical receiver that is representative of land mobile/amateur operations.

The procedures and results for each of these measurements are described below.

4.2 EMISSION SPECTRUM MEASUREMENTS

The wind profiler radar operates in two range modes: low altitude and high altitude. The profiler pulses are phase coded. The high-mode pulse width is 20 μs, broken into three phase chips of 6.67 μs each, and the low-mode pulse width is 3.3 μs broken into two phase chips of 1.67 μs each.

The wind profiler radar operates in both a low-altitude mode and a high-altitude mode on each of three beams (east, north, and vertical), for a total of six radiation modes. Normally, the wind profiler radar operates in each beam mode for 1 minute and switches through all six modes in 6 minutes. The wind profiler radar's mode progression, using a nomenclature where H and L stand for high and low, respectively, and E, N, and V stand for east, north, and vertical, respectively, is HE, LE, HN, LN, HV, LV. This means that the transmitter changes pulse widths once every minute, and likewise the profiler's radiated spectrum changes once every minute. If a measurement is to be made on a single radiated mode, then either that measurement must be made in less than one minute, or the profiler must be taken out of normal operation and locked into a single mode for the duration of the measurement.

A wideband spectrum measurement of the profiler was required in both pulse modes. It was initially assumed that operating a spectrum analyzer with a peak-hold detector in a maximum-hold mode while sweeping across the frequency band of interest would suffice for this measurement. However, such a technique was determined to be inadequate for our measurements. The spectrum of primary interest for the profiler extends from 385 to 425 MHz, and within this range the amplitude of the profiler's emissions can be expected to vary by as much as 110 dB. The instantaneous dynamic range of a spectrum analyzer will typically be only about 60-70 dB. Thus, a swept measurement across the entire band will result either in saturation of the spectrum analyzer at the profiler's center frequency, or in loss of the profiler's spectrum in the measurement system's thermal noise across parts of the band.

To overcome this limitation, a 0-50 dB RF attenuator was installed ahead of the spectrum analyzer as part of a Hewlett Packard 85685A preselector. Such an attenuator can extend the available dynamic range by 50 dB, for a total available measurement dynamic range of 110 dB. The HP 85685A also provided varactor preselection for the measurement system. The drawback of this arrangement is that the attenuation must be varied as a function of the frequency being measured. This means that a measurement of the profiler's spectrum cannot be performed in a swept-frequency analyzer mode. Rather, the spectrum analyzer must be tuned to a frequency, the attenuation must be adjusted at that frequency, and then the emission amplitude can be measured at that frequency. Then, the entire process must be repeated at the next frequency of interest. This means that the spectrum analyzer must be *stepped,* not swept, in frequency across the band to be measured. To ensure that all energy in the emission spectrum is convolved in the measurement bandwidth, the increment of each step must be less than or equal to the measurement bandwidth.

The optimum theoretical measurement bandwidth for this project would be approximately 1/compressed pulse width. (An accurate peak power measurement at the center frequency cannot be made in a bandwidth narrower than this; if a measurement is made with a bandwidth wider than this, the measured peak power amplitude will be accurate, but the sideband amplitudes will increase relative to the center-frequency amplitude.) Thus, for the high-altitude (long pulse) mode, the measurement bandwidth should be close to $1/\tau = 1/6.67 \times 10^{-6} =$ 150 kHz, and the optimum bandwidth for the low-altitude (short pulse) mode measurement would be $1/\tau = 1/1.67 \times 10^{-6} = 600$ kHz. The nearest available measurement bandwidths in the spectrum analyzer were 100 and 300 kHz for the two modes.

Given that these are the measurement bandwidths, the step sizes for frequency tuning in these measurements must be equal to or less than 100 and 300 kHz for the high and low profiler modes, respectively. This means that, for complete coverage of the 385-425 MHz band, the high and low modes have to be measured in 400 steps and 133 steps, respectively. Allowing 0.1 seconds per measurement step, plus overhead time for analyzer tuning, etc., means that the high and low modes can be measured across the band in 3 minutes and 1 minute, respectively. But the profiler switches directional beams and pulse widths once every minute. This means that a broad dynamic range measurement over the frequency band of interest cannot be performed when the profiler is in its normal mode of operation. As a result, the measurements require that wind profiler personnel lock the profiler into a single beam direction and pulse width for the duration of the measurement. (This is what was done at Platteville, where the profiler was locked into the high and low east beam modes.) The absolute power measured at the center frequency will vary as a function of beam mode and the position of the measurement system in the beam, but the profiler's *relative* emission spectrum (amplitudes at sideband frequencies relative to the main beam level) does not depend on the beam mode or position of the measurement system.

Figure 4-1 shows the schematic measurement arrangement for the radiated profiler spectrum measurement. Because of the emitter's low duty cycle, peak detection was used for the measurements. The measurement was made repeatedly, and the resulting spectra were highly repeatable. Figures 4-2 and 4-3 show the envelope of the short-pulse and long-pulse radiated spectra that were measured. The slightly "rough" features in the spectrum near 412-414 MHz were verified as belonging to the profiler, and were not emissions from other sources. The actual radiated spectra have lines within the envelope with a spacing of PRF/64.

4.3 HARMONIC AND SUBHARMONIC RADIATED POWER MEASUREMENTS

Measurements of the profiler's harmonic and subharmonic power levels relative to the fundamental were performed. The first three radiated harmonic levels and the first radiated subharmonic level were compared to the power received at the center frequency. The level of a harmonic relative to the center frequency level will not depend on the profiler's beam mode.

The measurement arrangement is shown in Figure 4-4. Improperly filtered measurement systems can generate false harmonics. To eliminate this problem, a notch filter tuned to the profiler's center frequency was used ahead of the spectrum analyzer. The notch was used for all measurements except, of course, the measurement of the profiler's fundamental frequency emission. A noise diode calibration was performed through the notch, the RF line, and the spectrum analyzer. A bandwidth wider than the profiler emission bandwidth must be used for this type of measurement. A 300-kHz bandwidth was used for these measurements. The measurement system noise figure was 8 dB, and the preamp gain was 25 dB. The calibration factors are included in the results of this measurement, summarized in Table 4-1.

The profiler emissions at the center frequency were typically measured at about -10 to -20 dBm at the input to the spectrum analyzer. The center frequency power observed varied with the beam mode, both because the profiler's actual power varies between high mode and low mode and also because the profiler's antenna pattern changes with beam direction. The decibels relative to carrier amplitude (dBc) values recorded at the harmonics represent the "average" reading interpreted from the changing spectrum analyzer display; actual power levels were observed to vary by about ± 3 dB while measurements were in progress. Wind profiler measurements showed that subharmonic (202 MHz) and second (808 MHz) and third harmonic (1212 MHz) emissions were in the range of 37 to 60 dB down from the fundamental. Fourth harmonic (1616 MHz) levels were at least 70 dB down from the fundamental.

Subsequently, additional harmonic and subharmonic measurements were made at several locations around the Unisys profiler. These measurements were conducted to determine if significant variability in received power could occur as a function of location. The results of measurements indicated that no significant variability existed (± 3 dB) as a function of location.

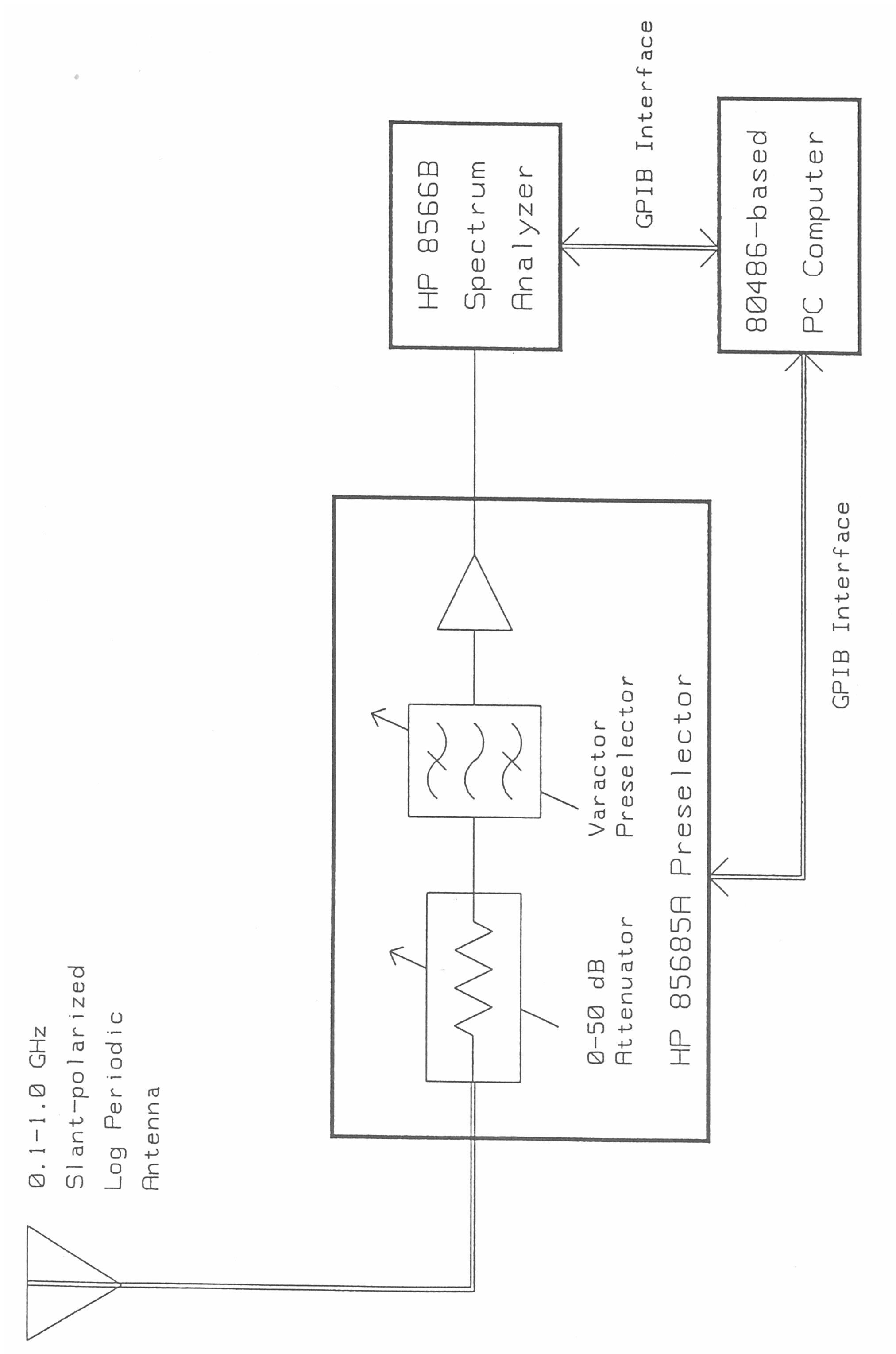

Figure 4-1. Radiated spectrum measurement schematic.

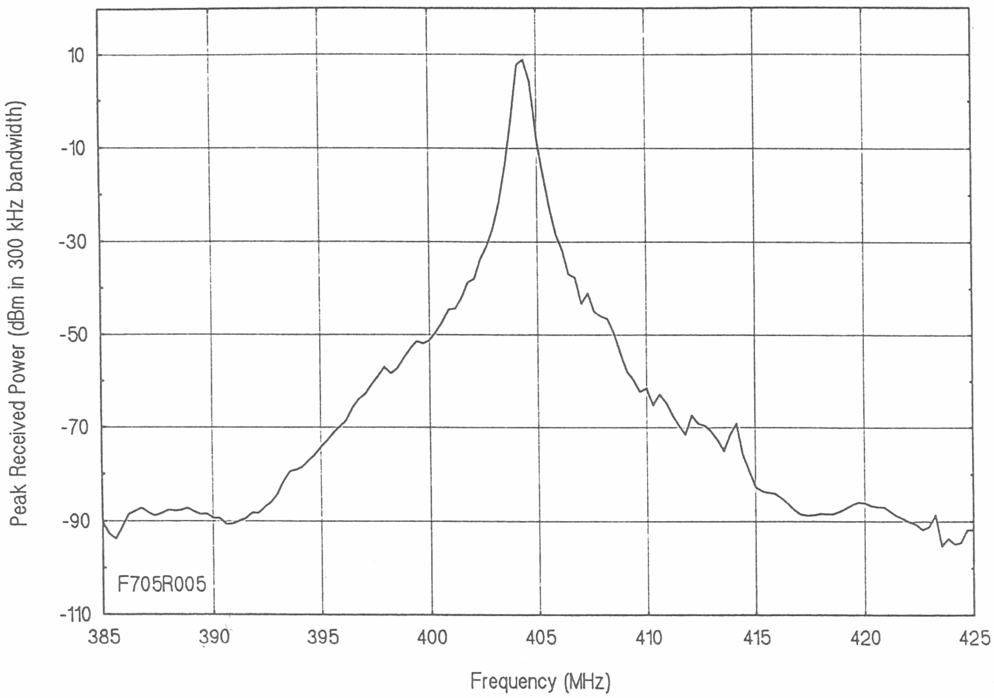

Figure 4-2. Platteville short-pulse radiated spectrum envelope.

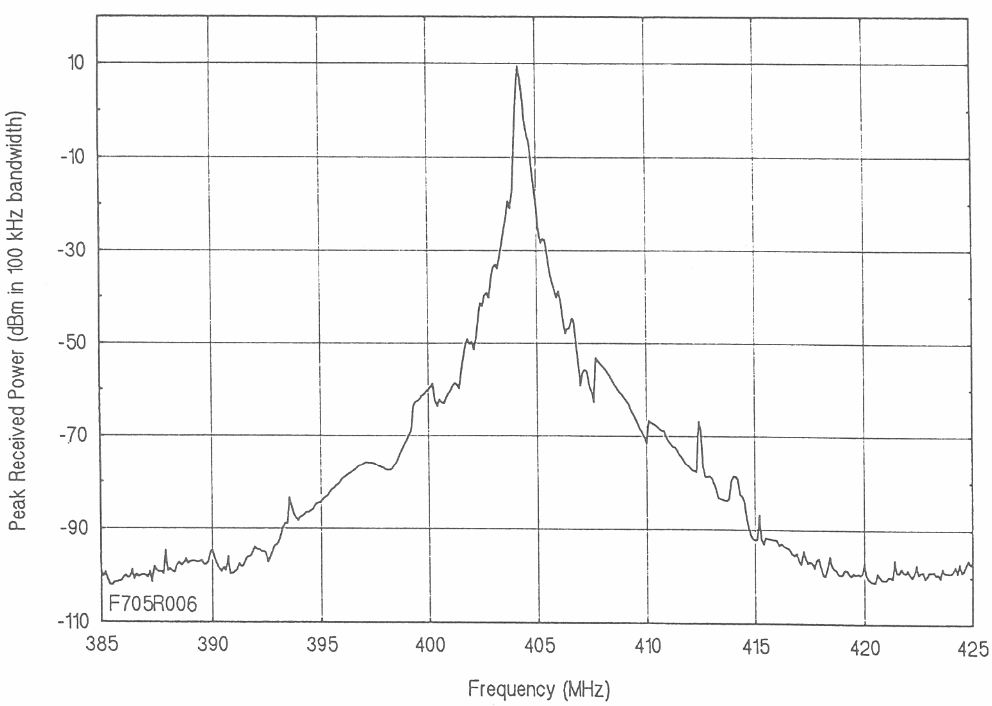

Figure 4-3. Platteville long-pulse radiated spectrum envelope.

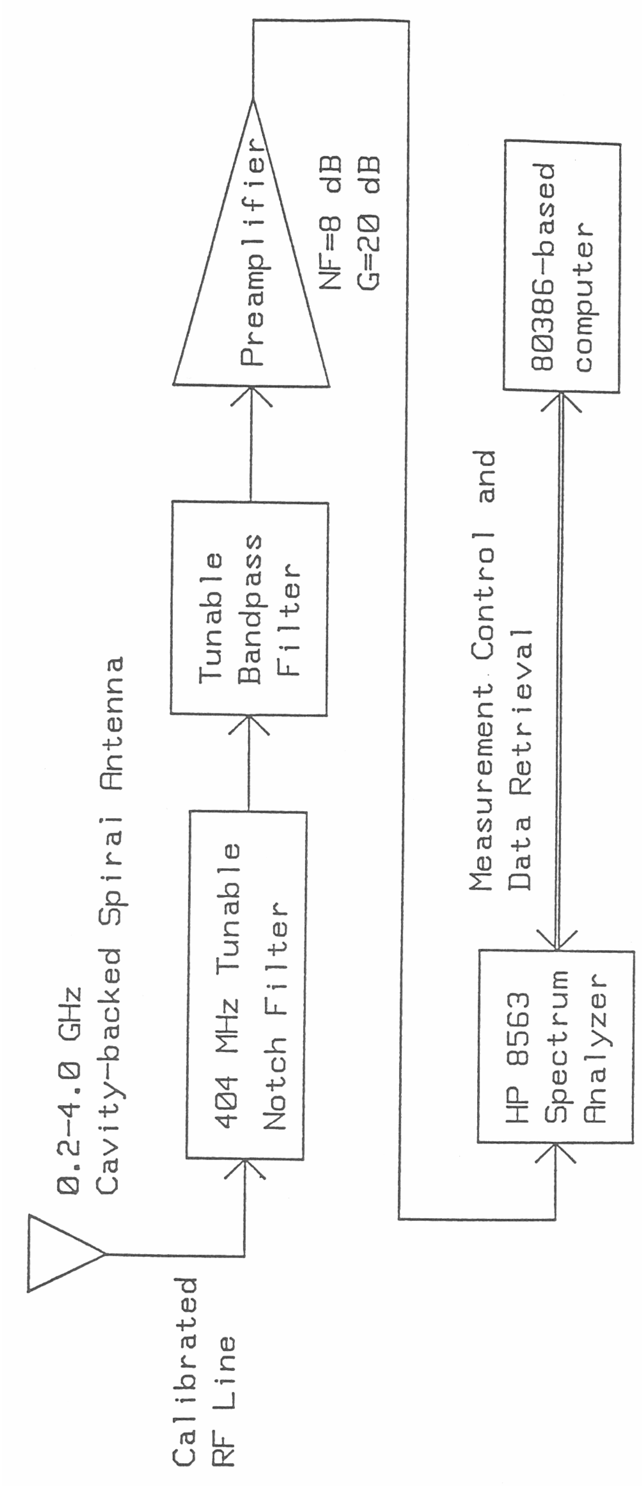

Figure 4-4. Radiated harmonic measurement schematic.

TABLE 4-1
Harmonic and Subharmonic level* (dBc) for the Platteville Wind Profiler Radar

Beam Mode	$f_0/2 \approx 202$ MHz	$f_0 \approx 404$ MHz	$2^*f_0 \approx 808$ MHz	$3^*f_0 \approx 1212$ MHz	$4^*f_0 \approx 1616$ MHz
HE	-47	0.0	-38	-55	-70
LE	-50	0.0	-39	-60	-80
HN	-45	0.0	-37	-41	< -90
LN	-50	0.0	-40	-50	-85
HV	-46	0.0	-39	-55	-87
LV	-50	0.0	-39	-55	< -90

*Where the "less than" sign (<) is used, the profiler harmonic was not received above the measurement system noise floor; the dBc power level of the measurement system noise floor was recorded.

Because the profiler antenna pattern at a harmonic frequency will not be the same as the pattern at the center frequency, the harmonic level in dBc would most likely vary if measurements were made at other locations around the profiler. The results of antenna pattern measurements (Section 4.4) imply that the standard deviation of these levels would be about 8 dB.

4.4 ANTENNA SELECTIVITY MEASUREMENTS

To form a narrow beam, a resonant coaxial-collinear element structure is used by the profiler. That is, the directive gain of the antenna is very frequency dependent. However, we did not assume that the antenna itself was resonant without consideration of antenna directivity. Our measurements were meant to determine the degree to which the antenna could act as a bandpass filter.

The input impedance characteristics were measured using an HP-4195A network analyzer in the reflection mode. In this mode, a swept signal was injected into the antenna via a hardline connection at the antenna's interface with the wind profiler receiving system. The relative amplitudes of the injected signal and the signal reflected back from the antenna to the injection point were measured. Figure 4-5 shows the return loss measurement for the east beam. The other two beams gave similar results. The T/R ratio is displayed across 20 MHz of spectrum on a logarithmic scale from 394.3 to 414.3 MHz. The vertical scale is 5 dB/div. Using this type of display, a bandpass filter would appear as a deep notch in the plot. Figure 4-5 shows that, while the antenna achieves a return loss of -19.9 dB, corresponding to an antenna voltage standing wave ratio (VSWR) of 1.22 at 404.3 MHz, it also maintains a good (-15 dB or lower) impedance match within ± 10 MHz of the center frequency of 404.3 MHz. When the return loss was measured over a wider range of frequencies, it was found that the antenna maintains a -15 dB or better match at ± 50 M Hz of the center frequency. This means that the antenna selectivity across this range is negligible.

Figure 4-6 shows the return loss measurement for the vertical beam between 100 and 1100 MHz. The deep notch at 404 MHz indicates the resonance of the antenna at that frequency. This curve can be interpreted as the broadband selectivity characteristic of the profiler antenna. Over this range, the antenna does show 30 dB selectivity at frequencies greater than 100 MHz away from the center frequency. However, the antenna cannot be viewed as a selective filter for the transmitted signal.

4.5 ANTENNA GAIN MEASUREMENTS

The wind profiler antenna pattern is characterized by a main beam aimed alternately vertically and 16.3° from the vertical in two orthogonal directions (usually north and east). With the exception of satellites and airborne systems, it is likely that most cases of potential interference would be a result of coupling between other systems and the profiler's sidelobes at low (nearly horizontal) angles. As a result, it is important that spectrum management incorporate a realistic representation of the antenna gain at ground level relative to isotropic gain.

From the antenna's operational physics, a representation of the antenna radiation pattern can be derived theoretically with good accuracy at angles substantially above the ground. This will suffice for compatibility studies between the profiler and airborne and satellite systems. (Gathering data on the main beam and its sidelobes would have required airborne measurements, which would have been prohibitively expensive for this project.) However, at and near ground level, the antenna pattern can behave in a singular manner that is difficult to model theoretically. To assess the compatibility of the profiler with terrestrial systems, ground-level far-field antenna pattern measurements must therefore be acquired; measurements of the profiler antenna gain relative to isotropic near ground level were made. This measurement was done for the east, north, and vertical beam modes.

This measurement cannot be performed with the profiler in its normal state of operation, for two reasons: first, the profiler changes its mode, and thus its radiated power or antenna pattern, once every minute, and then takes 5 minutes to return to the desired mode. This makes measurements extremely difficult and time-consuming. Second, because the normal profiler emission is pulsed and thus has a finite emission bandwidth, the S/N of the measurement is bandwidth limited. (Maximum S/N will occur when the measurement bandwidth is approximately equal to 1/compressed pulse width of the profiler.) This S/N may be insufficient to measure the profiler emission when the measurement encounters an antenna pattern null.

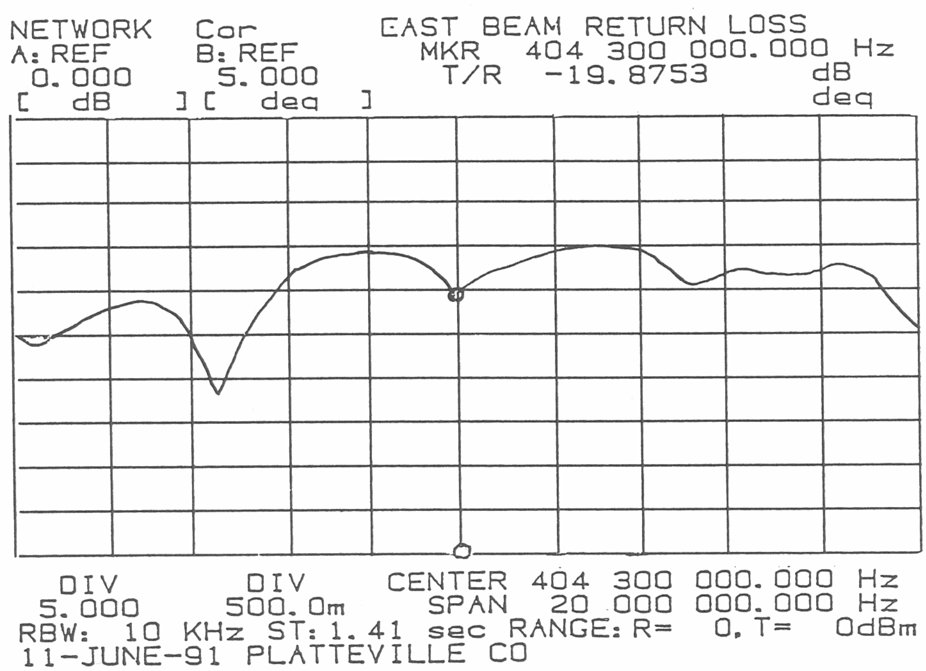

Figure 4-5. Antenna characteristics, 390-410 MHz.

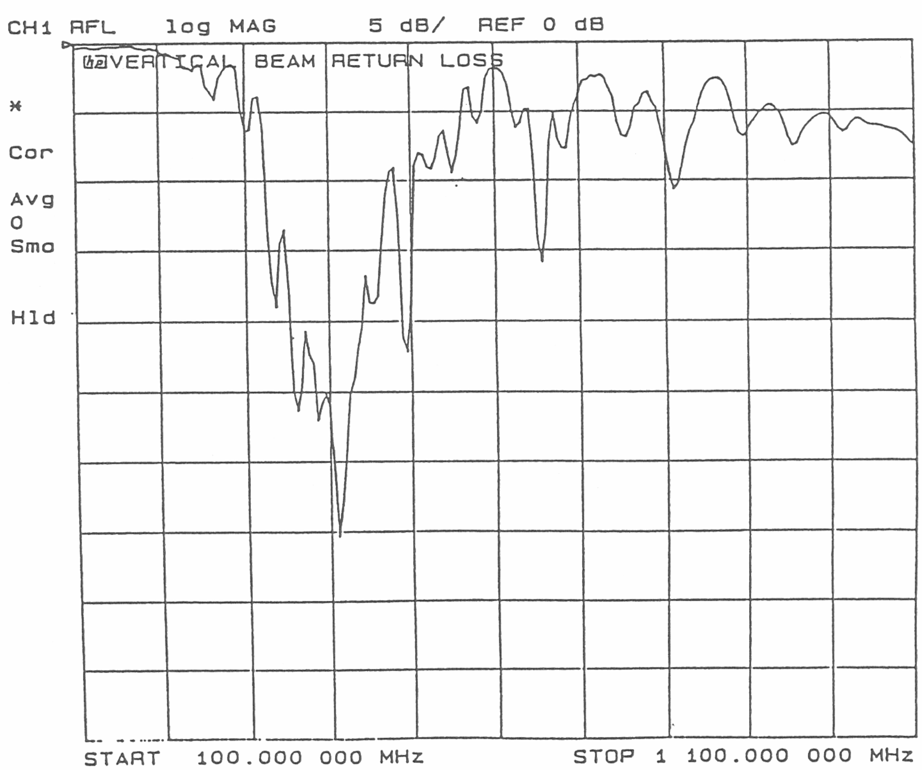

Figure 4-6. Antenna characteristics, 100-1100 MHz.

The first problem can be solved by locking the profiler into a single radiation mode. The second problem can be solved by radiating a signal from the profiler which has a 0-Hz emission bandwidth; a CW signal is required. For the case of the wind profiler, the maximum S/N for pulsed-emission measurements is achieved at 1/chip width, which is 150 kHz. The nearest available spectrum analyzer setting is 100 kHz. However, if a CW signal is measured instead, the minimum available analyzer bandwidth of 300 Hz can be used. The improvement in S/N will be 10*log(100 kHz/300 Hz), or 25 dB. (This improvement is due to the fact that thermal noise that is the limit of spectrum analyzer sensitivity varies in direct proportion to the measurement bandwidth, which translates mathematically as a variation that goes as 10*log of the ratio of any two measurement bandwidths.)

For these two reasons (need for a constant, unvarying signal source and need for a zero emission bandwidth signal, which would allow the best possible measurement S/N), we chose to inject a CW signal into the profiler antenna for these antenna pattern measurements. The antenna pattern is assumed to be not affected by the modulation of the transmitted signal.

To measure the wind profiler antenna pattern in decibels relative to isotropic (dBi), a reference antenna is required. The reference must have a known gain relative to isotropic, and must be collocated with the profiler antenna. A horizontally oriented half-wave dipole was used for this purpose. To perform these measurements, received values were recorded at various points in the far field around a 360° radius from the profiler site. As measurements progressed around the profiler, the dipole was turned to keep the measurement system in the dipole's broadside beam. The measurement schematic is shown in Figure 4-7. The measurement system (the receiver system in the schematic) was mounted in a van. The receiver antenna was an omnidirectional 215-420 MHz discone antenna.

The Platteville profiler is located in an area considered a rolling high plain with few trees. The area surrounding the site is used for farming and includes several manmade structures. These are the profiler equipment shelter, a concrete building, which lies approximately 100 meters from the profiler and subtends about 5° of arc in the northeast quadrant as seen from the center of the profiler antenna, and a significant ground plane (ground screen) to the east of the concrete building. In addition, there are trees to the west and southwest of the profiler as well as power lines coming into the concrete building. In the surrounding area there is oil drilling in progress (numerous derricks) and several collection tanks. For the purpose of the measurements the area is equivalent to a "flat treeless plain". Before the measurements, survey stakes were positioned radially around the profiler at a distance of about 400 m (a sufficient distance for far-field measurements at 400 MHz) and at angular increments of 10°.

During the measurements, the van was positioned for a measurement at each stake and also at a point midway between each pair of stakes, for a total of 72 measurement locations at azimuth intervals of 5°. At each of the 72 locations, the van was stopped, the receiving antenna was positioned at the rooftop level (2.1 m above the ground), and the signal amplitudes from the dipole, east beam, north beam, and vertical beam were recorded. A sample set of measurements at a point is shown in Table 4-2.

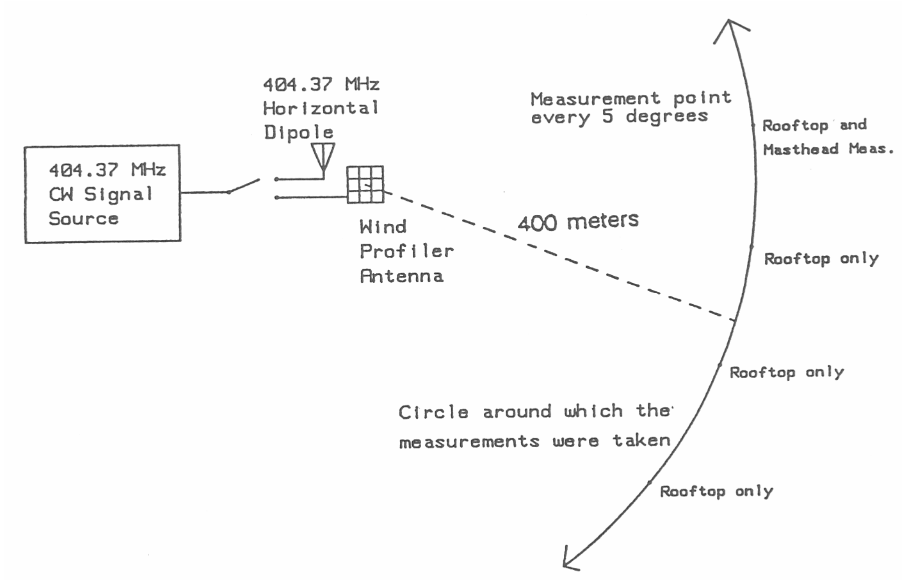

Figure 4-7. Antenna pattern measurement schematic.

TABLE 4-2
SAMPLE OF ANTENNA PATTERN DATA POINTS

			Spectrum analyzer values (dBm) beam			
Point #	Az. (deg.)	Measure antenna position	Dipole	East	North	Vertical
28	135	van rooftop height	-40.2	-83.0	-65.8	-62.3

Antenna Gain Calculations

Referring to Figure 4-7, the power measured, P_m, for the dipole and the profiler sources is given by the following two equations:

Power measured from dipole: $P_{m,d} = P_{out} - L_d + G_d - L_{prop} + G_m - L_m + G_{LNA}$ (12)

Power measured from profiler: $P_{m,p} = P_{out} - L_p + G_p - L_{prop} + G_m - L_m + G_{LNA}$ (13)

where

P_{out} = power output from signal generator (dBm);
L_d = loss in line connecting signal generator to dipole transmitting antenna (dB);
L_p = loss in line connecting signal generator to profiler transmitting antenna (dB);
G_d = gain, relative to isotropic, of dipole antenna (dBi);
G_p = gain, relative to isotropic, of profiler antenna (dBi);
L_{prop} = loss due to propagation between transmit and receive antennas (dB);
G_m = gain, relative to isotropic, of measurement (receiving) antenna (dBi);
L_m = loss in line connecting measurement antenna to low noise amplifier (LNA) (dB);
G_{LNA} = gain in LNA preceding spectrum analyzer (dB).

The unknown quantity to be determined is the profiler antenna gain relative to isotropic, G_p. This value can be found by comparing the received signal strength from the dipole, with known gain, to the received signal strength from the profiler, with unknown gain. This difference is found by subtracting (13) from (12):

Power difference measured: $\Delta P = P_{m,p} - P_{m,d} = L_d - L_p - G_d + G_p$ (14)

Or, rearranging the terms in Eq. (14),

$$G_p = P_{m,p} - P_{m,d} - L_d + L_p + G_d = \Delta P - L_d + L_p + G_d. \quad (15)$$

The value of ΔP is measured at each point in the pattern. The values of line loss for the dipole and the profiler antenna, L_d and L_p, were 5 dB and 0.5 dB, respectively. The gain of the dipole, G_d, was checked by rotating it 90° to a vertical orientation. The signal increased by 4 dB when this was done. The receiving discone antenna was vertically polarized, and the dipole had a theoretical gain of +2 dBi in this orientation. Thus, in the horizontal position, the dipole must have been -2 dBi to be consistent with the 4 dB difference observed between the two orientations. Thus, the value of G_d was -2 dBi, and for our measurements (15) becomes

$$G_p = \Delta P - (6.5 \text{ dB}) \quad (16)$$

For the sample measurements given above, the values of profiler antenna gain at 135 degrees azimuth on the north beam, at the van rooftop height, would be -32.1 dBi.

Using this technique, the profiler's east, north, and vertical beam antenna patterns as measured at ground level are shown in Figures 4-8, 4-9, and 4-10, respectively. Figure 4-11 shows the computed (decibel) average of the three measured patterns.

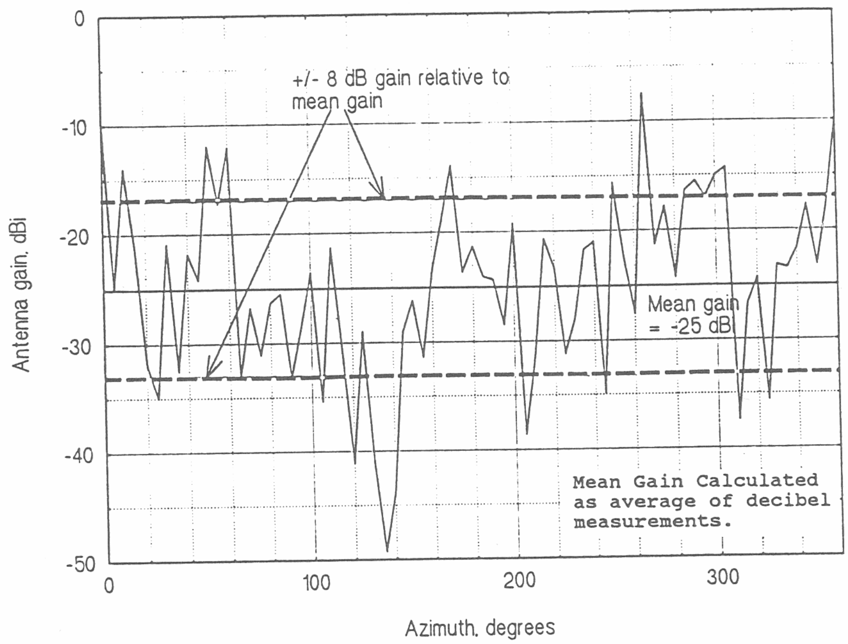

Figure 4-8. Platteville ground-level antenna pattern (east mode).

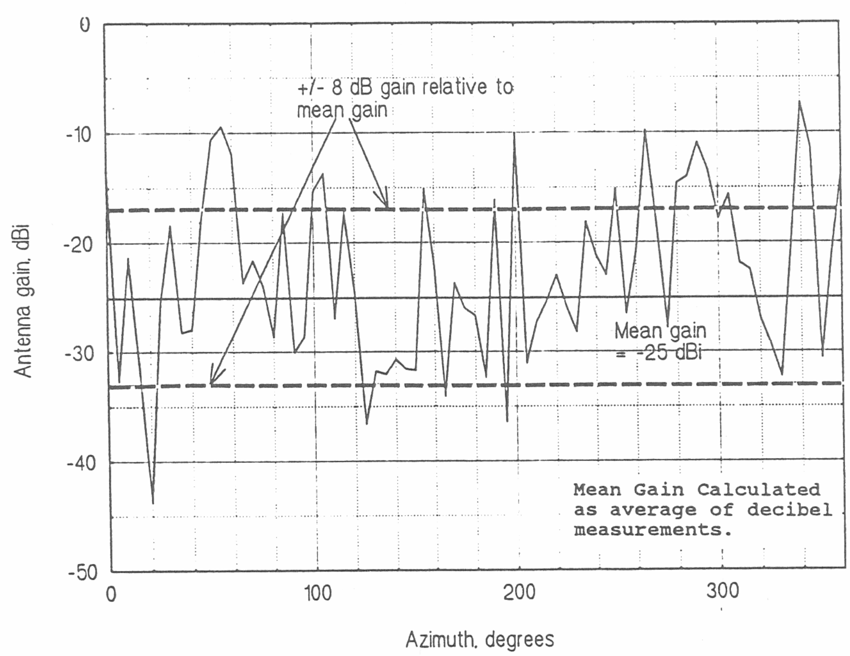

Figure 4-9. Platteville ground-level antenna pattern (north mode).

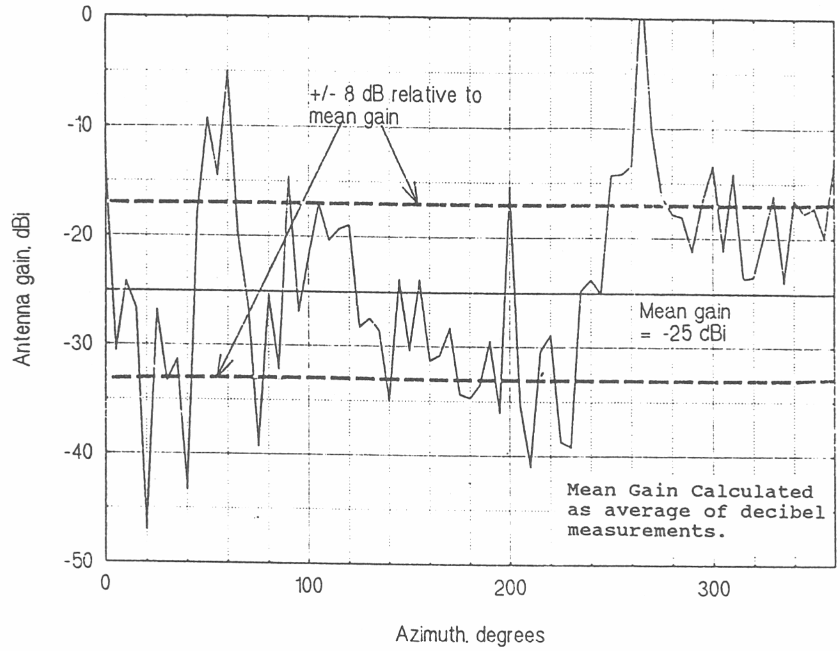

Figure 4-10. Platteville ground-level antenna pattern (vertical mode).

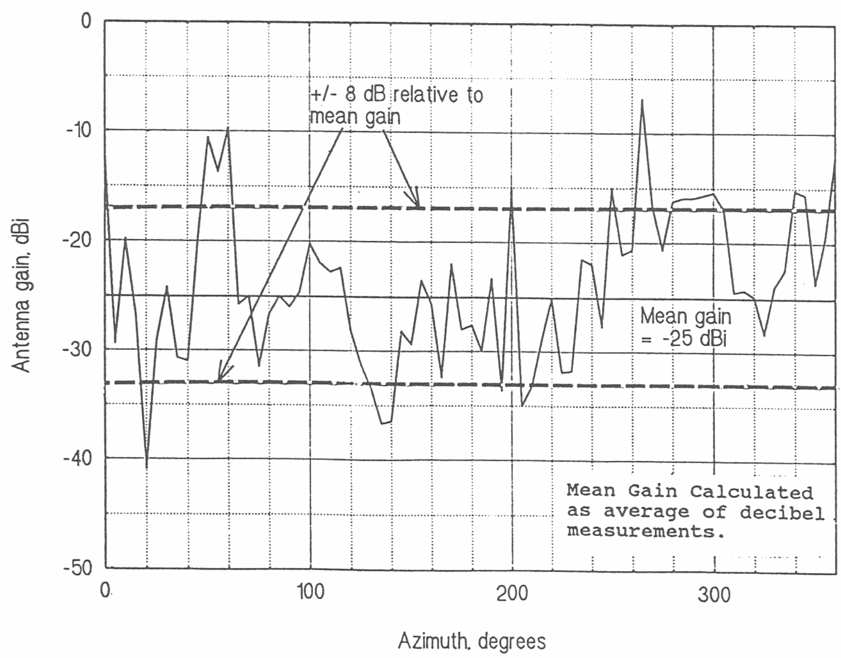

Figure 4-11. Platteville ground-level antenna pattern (decibel average of E, N, and V).

For all patterns measured, the mean ground-level antenna gain was -25 dBi, with a standard deviation of ±8 dB. Given that the main beam has a gain of +32 dBi, the ground-level pattern can be assumed to have a gain of -57 dB relative to the main beam.

4.6 WIND PROFILER INTERFERENCE SUSCEPTIBILITY TESTS

Since wind profilers will be sharing spectra with other operations in the 440-450 MHz band, profiler interference thresholds for emissions from various sources must be assessed. Typical interfering sources in the 440-450 MHz band include narrowband systems having essentially CW characteristics, relatively narrowband (≈16 kHz bandwidth at -20 dBc) FM communications, pulsed CW radar systems ("ordinary" radar), FM radar systems ("chirped" radar).[a] Profiler interference thresholds were established for each of these signal types, both for signals at the profiler's frequency and for signals off-tuned from the profiler center frequency by 1 MHz (see Section 3-8). In addition, simulated 440-450 MHz radar signals were injected into the profiler in two different configurations: (1) with the pulsed interference directed into the profiler continuously for entire 6-minute profiler observation periods, and (2) with the pulsed interference directed into the profiler intermittently (e.g., 1s out of every 10s) during the 6-minute profiler observation period, so as to simulate mechanical rotation, electronic beam steering, and frequency hopping behavior of actual radars in the band.[b]

The goal of the interference susceptibility testing was to establish the profiler's interference threshold for each of the signal modulations listed above. With measured thresholds for these signal types at the profiler's receiver input, it is possible to calculate the interference potential of actual or proposed systems that might interfere with the profiler.

A block diagram of the hardware arrangement for signal injection into the profiler is shown in Figure 4-12. All four test signal sources were connected to the profiler receiver with a -20 dB directional coupler. Input signal amplitudes were always measured on a spectrum analyzer at the point of connection to the directional coupler. These measured numbers were corrected (i.e., reduced by 20 dB) in the interference calculations to represent the signal level into the profiler receiver.

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[a] Not all possible interfering sources and combinations representing 440-450 MHz operations were considered.

[b] Referred to as “intermittent” case.

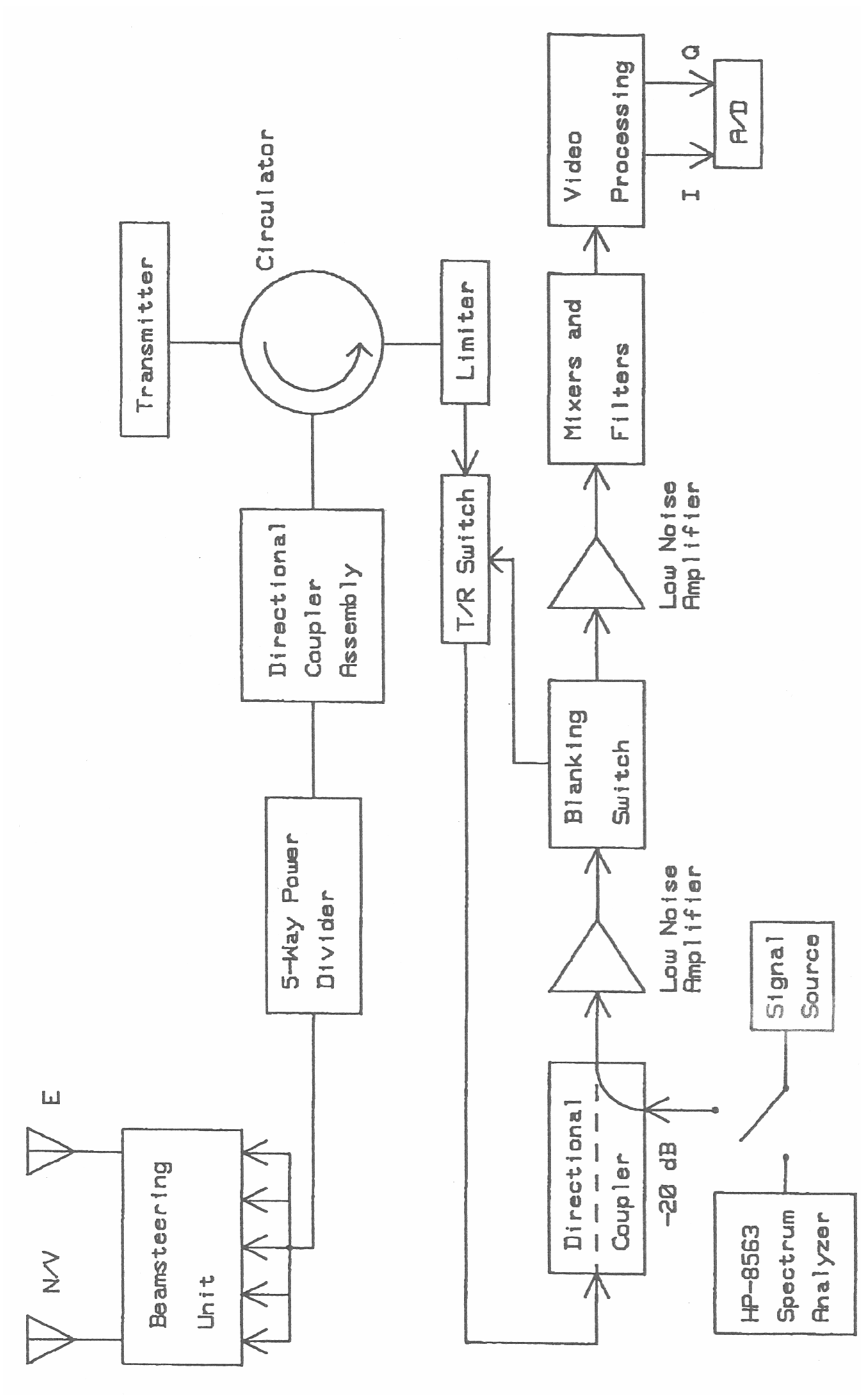

Figure 4-12. Interference injection schematic.

The question of how to assess the effects of the injected "interference" to the profiler is nontrivial, as described in Section 3. The profiler is an integrating device, and it requires six 1-minute integrations to produce a single atmospheric observation. In addition, the observations are the result not only of hardware processing, but also of software processing. The profiler's software is as integral to the system as the hardware, and any realistic assessment of the profiler's susceptibility to interference must take into account the software's algorithmic response as well as the hardware response. Potentially interfering signals that are seen prominently in the profiler's first IF, for example, can be eliminated by subsequent digital signal processing (DSP) to that section (software). If the mitigating effects of DSP are ignored, a grossly pessimistic estimate of the profiler's susceptibility to interference would result.

In addition to the filtering effect of DSP, the coherence of a potentially interfering signal would be expected to affect interference thresholds. The profiler, as a coherent processor, can be expected to be much more susceptible to coherent interference than to noncoherent interference, although it is difficult to assess beyond that generalization, a *priori,* the effects of an interfering signal on the profiler's processing algorithms.

Interference thresholds would be expected to correlate with the interfering signal power and duty cycle, regardless of the interfering signal's spectrum. Since a single profiler observation requires six 1-minute integrations, the percentage of time that an interfering signal is present during a minute will correlate with interference potential.

The profiler's design makes it impractical to perform interference measurements on the profiler component by component. The only realistic way to perform interference testing is to treat the profiler (hardware and software combined) as a black-box, input-versus-output system. The effects on 6-minute observations must be related to known input amplitudes of a given interfering signal. This is achieved most effectively by running the profiler in a normal mode, collecting one or two atmospheric observations as baseline data, and then injecting the interfering signal via a directional coupler. The results of the observations made under the two different conditions (interference ON versus interference OFF) can then be compared. Diagnostic software output is used for the comparison, as described more fully below.

When this testing is performed, significant sources of variation will remain (and are inherent) in the interference thresholds that are measured. The reason is that the atmosphere is itself highly variable, and the quality of profiler returns thus varies from altitude-to-altitude, from day-to-day, and from season to season. In effect, the wind profiler radar's S/N varies as a function of altitude and time, and thus so too will the interference threshold levels. Even if sufficient time and money were available to run interference tests for months or years and to look at all range gates while tests were in progress, the results would still be, at best, statistical guidelines for the effects of various interference levels. The tests that were actually performed could not be conducted over all range gates and over extensive time intervals, but rather were limited to sets of 6-minute observations of specific range gates made available by the diagnostic software.

Observations were repeated on different days, and no significant differences were noted for any test signal as a function of time. Only the upper range gates in the high and low profiler modes were observed, as these normally have the lowest S/N and thus are the most susceptible to interference effects. The repeatability of the test results and the conservatism of range gates selection lead us to believe that (1) the results represent typical profiler operating conditions, and thus the measured interference thresholds can be used by spectrum managers to assess this profiler's compatibility with other systems, and (2) additional useful information would probably not be generated by more extended testing intervals with our test procedures.

An important issue in this testing is to define interference for the profiler, and to determine what level of interference effect in the profiler is then considered to be a problem. Although it is obvious that any level of degradation is undesirable, it is also true that wind profiler operations can proceed with some finite level of effective degradation to the profiler. But how much degradation? Degradation effects can be observed as an effective increase in the profiler's system noise level, and this phenomenon first affects the range gates with the lowest S/N. (Generally, the upper range gates have the lowest S/N; therefore interference effects will usually be observed first in the upper range gates of high and low profiler modes.)

Interference was defined for the purposes of these tests to be a consistently discernible increase in profiler system noise due to the injection of an interfering signal into the profiler receiver. The minimum discernible increase was found to be approximately 3 dB based on observations of a single 6-minute data period. Therefore, for testing purposes, 3 dB was used as the threshold for observation of interference. We do not claim that this is an acceptable interference level for profiler operations but, only that it was the limit of our testing capability. The results of the tests are summarized in Table 4-3, given at the end of this section on page 56.

On-Tune CW Signal Injection

A frequency domain impulse at the radar center frequency was required for this test. The signal source, an HP-8640B signal generator, was tuned to the profiler's center frequency. The profiler and injected frequencies were made coincident by simultaneously observing the profiler spectrum and the signal generator output on a spectrum analyzer, and tuning the interfering signal until the two signals were coincident on the analyzer display. The coincidence was also checked by observing the interfering signal on an oscilloscope attached to the first profiler IF, and tuning the signal until the observed interference effects were maximized. Because an interfering signal would not be expected to be phase locked to the profiler, the test signal was not phase locked to the profiler. Observation of the oscilloscope diagnostic indicated that the signal drifted in and out of coherence with the profiler a few times every minute, on a random basis. Accidental coherence would typically last a few seconds at a time.

Because of the inherently high spectrum analyzer noise figure, the amplitude of the interfering signal was checked on a spectrum analyzer at a much higher level than would be used for the tests. A vernier on the signal generator was used to bring the indicated output level into agreement with the measured level. Then, as the level was reduced in 10 dB steps to the amplitude of the injection tests, the signal was observed on the analyzer to also drop in 10 dB steps. The signal level used for the interference tests was too low to be observed on the spectrum analyzer (which has a 30-dB noise figure), but was inferred to be accurately indicated by the (now calibrated) signal generator indicator. Because a CW signal is an impulse in the frequency domain and thus has zero spectral width (to within the stability of the source oscillator), any measured spectrum of the signal will indicate only the frequency domain impulse response of the measuring device, as shown in Figure 4-13.

Results of On-Tune CW Signal Injection

This test indicated a barely detectable increase (about 1 dB) in the profiler noise level when the interfering signal input level, corrected for the directional coupler factor, was -140 dBm. At -135 dBm, an increase of approximately 3 dB in the profiler's system noise level was observed. At -125 dBm input, all atmospheric signals in the high mode were lost. For this test, the threshold input level of -135 dBm held for a full 6-minute observation cycle should be considered a worst-case scenario. If the signal were present for a fraction of that time, then the threshold level would be higher. If the signal were present only for a few seconds out of each minute, as might be the case for actual interfering signals, then it is doubtful that any input level, no matter how high, would noticeably degrade the profiler's performance as long as the receiver is not driven into saturation.

Off-Tune CW Signal Injection

The same test as above was performed, but with the interfering signal off-tuned from the profiler by 1 MHz.

Results of Off-Tune CW Signal Injection

The CW signal was increased in amplitude to -70 dBm, and no effect was seen by the profiler. Higher levels were not attempted because of concern about possible damage to the profiler receiver's RF front end. The interference threshold (Table 4-3) exceeds -70 dBm, even when the signal is present throughout the profiler observation; as before, the threshold would be even higher if the signal were present for a percentage of that period.

On-Tune FM Signal Injection

A wind profiler radar might operate in the proximity of FM communication transmitters. A 16-kHz FMCW test signal with a 1 kHz modulation tone was used. Actual voice modulation, as a random modulation input, should have no more effect on the profiler, and probably less effect, than the modulation used in these tests. The same techniques were used to tune this signal and to check its amplitude as were used for the CW signal. The measured spectrum of the signal is shown in Figure 4-14. The signal was present throughout the profiler's observation period of 6 minutes (i.e., 100% duty cycle for 6 minutes); a lower interference duty cycle would have yielded a higher interference threshold.

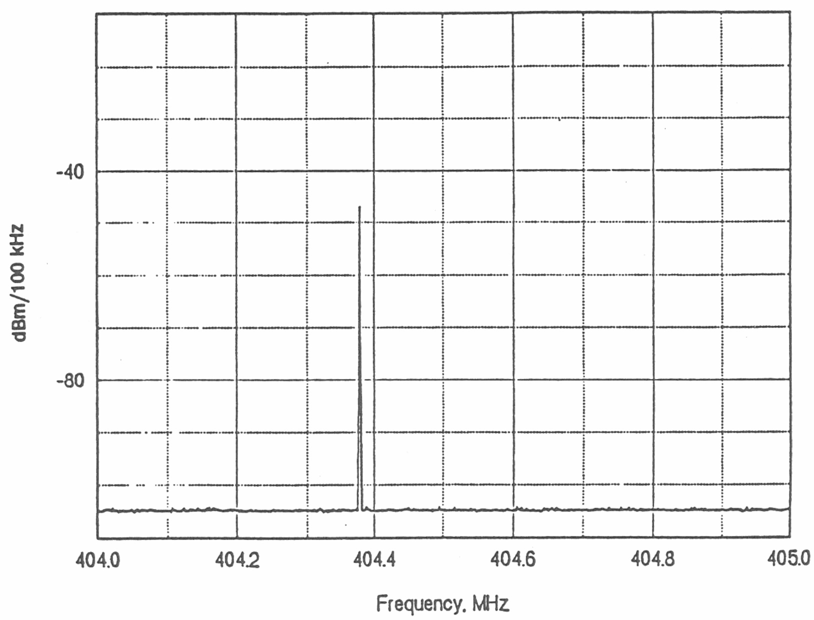

Figure 4-13. CW signal spectrum.

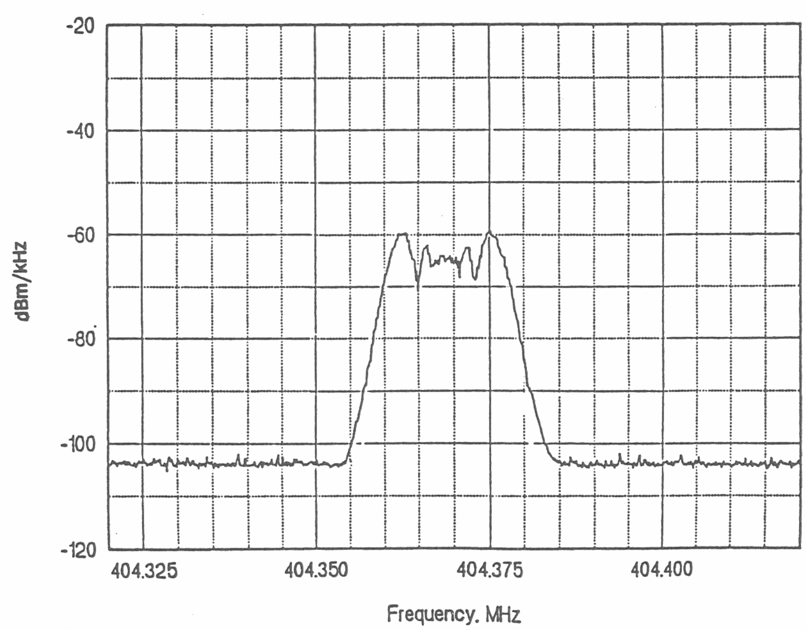

Figure 4-14. FM spectrum.

Results of On-Tune FM Signal Injection

The 16-kHz FM signal produced a barely detectable (about 1 dB) noise increase at an input level of -140 dBm. A 3-dB profiler system noise increase was observed at an input amplitude of -130 dBm. For the purposes of defining an interference threshold, the input level of -130 dBm is used in Table 4-3.

Off-Tune FM Signal Injection

The same test was performed as for on-tune, but with the FM signal off-tuned by 1 MHz. As with the CW signal test, this test was intended to simulate a situation where a wind profiler is off-tune by 1 MHz. The signal was present throughout the profiler's observation period of 6 minutes (i.e., 100% duty cycle for 6 minutes); a lower interference duty cycle would have yielded a higher interference threshold.

Results of Off-Tune FM Signal Injection

An FM signal input level of -100 dBm showed no interference. At -80 dBm, an increase of approximately 2 dB was observed in the system noise floor. At -70 dBm, the RF front end was almost saturated, and the low mode showed an increase of 7 dB in noise. The 3 dB criterion for interference was deemed to have occurred at -80 dBm signal input level.

Non-FMed, On-Tune Pulsed Signal Injection ("continuous" source)

The effects on wind profiler radar operations from other radar emissions in the 440-450 MHz band were assessed. Radar systems in this band are ground based, airborne, and shipborne. They are long-range designs that transmit long pulses (typically from 1 μs to 10 ms). They often employ pulse-compression techniques, either FM ("chirping") or phase coding, to improve their performance. These radars utilize low PRFs, usually around 300 Hz. They transmit high peak power levels (usually about 1 MW, or +90 dBm). To determine the effect on wind profiler operations from such systems, simulated radar signals were injected into the wind profiler receiver. Table 4-3 lists the various parameter combinations used in the tests.

For non-FMed, pulsed signal interference tests, a pulse generator modulated a signal generator. The signal generator output was monitored on a spectrum analyzer to verify that proper frequency, PRF, pulse width, and power were achieved. Typical output spectra are shown in Figures 4-15 and 4-16. The frequency was adjusted to match the wind profiler's frequency on the analyzer. Additionally, the injected signal was tuned back and forth to verify that the maximum effect on the profiler (as observed on an IF oscilloscope output) was being achieved. The PRF was verified by operating the spectrum analyzer in a 0 Hz span, making the instrument in effect a time-domain analyzer. The pulse width was verified by observing the 3-dB bandwidth of the simulated radar signal on the spectrum analyzer. The injected power was measured with a **peak** detector in a bandwidth equal to or greater than the simulated radar's emission bandwidth.

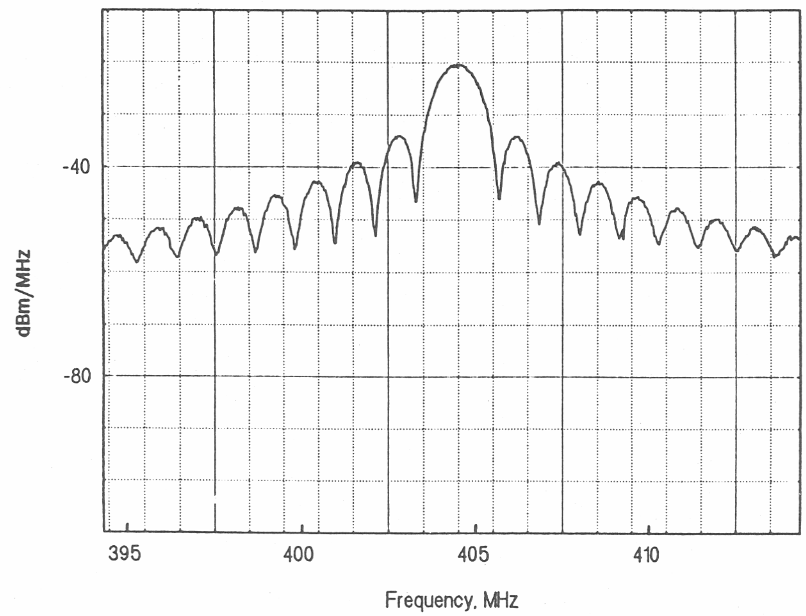

Figure 4-15. Non-FMed pulse spectrum, 1 μs/pulse, 300 pps.

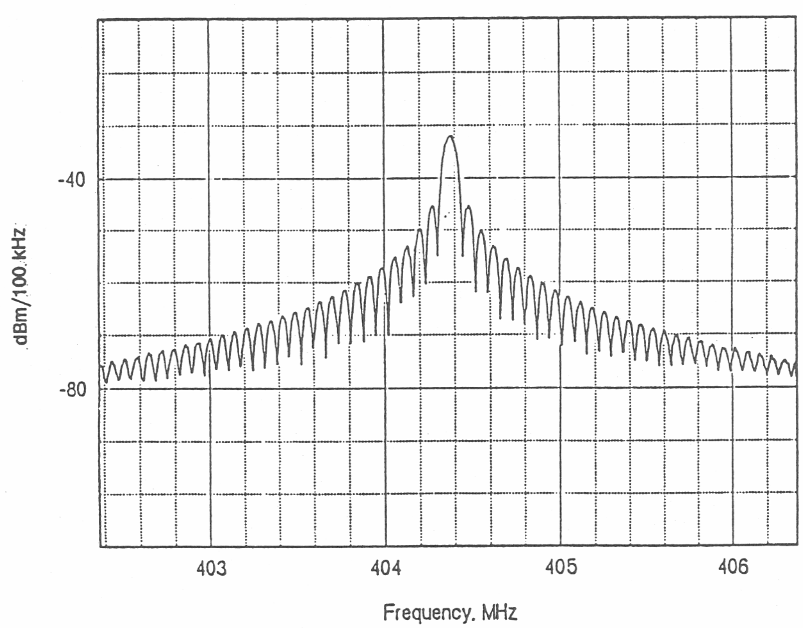

Figure 4-16. Non-FMed pulse spectrum, 10 μs/pulse, 300 pps.

Results of Non-FMed, On-Tune, Pulsed Signal Injection ("continuous" source)

As summarized in Table 4-3, several different combinations of pulse width and a 300 pps PRF were used for this test. These combinations represented typical operational characteristics of radars in the 440-450 MHz band. For a 10-μs pulse at 300 pps, the threshold was -80 dBm, whereas for a 1-μs pulse train at 300 pps, the threshold was -70 dBm. This increased threshold for the 1-μs pulse is due to the 1-MHz bandwidth of the signal and 250-kHz bandwidth of the receiver.

Non-FMed, On-Tune, Pulsed Signal Injection ("intermittent" source)

A complicating factor in testing these simulated radar signals is the difficulty of achieving a true simulation of the scan pattern of the radars used in this band. Typically, radars operating in the 440-450 MHz band use frequency-diversity techniques, which means that they will visit a particular frequency only at irregular intervals. Further, they are typically phased-array systems that scan a point in space (one at or near the wind profiler, for example) at irregular intervals. Even if they do not ever boresight a wind profiler (as would be the case for the proposed deployment of profiler systems), their sidelobes and backlobes would still have an irregular, unpredictable time variation. Both of these effects can be present simultaneously (as with some strategic early warning systems). Or, in some cases (e.g., airborne systems) frequency diversity may exist, but the scan rate may be regular and predictable (e.g., a fixed, 10-s rotation period of an antenna).

Realizing that an attempt to reproduce the frequency-diversity and time-varying characteristics of actual radars would be not only difficult but also contentious, we performed the tests on these signals as follows. For the duration of an entire 6-minute wind profiler observation cycle, the signal was injected with no variation of any signal parameter. As a result, the mitigating effects of an actual radar's frequency hopping and space scanning operations were not included in the test. As such, the test results represent a conservative estimate of the effects of the tested radar emissions on the wind profiler's operation.

The only exception to this methodology was made in some tests devoted to simulating the effects of an airborne radar. In this case, a set of tests was performed at fixed amplitudes for 6-minute observation cycles, but an additional set of tests was also performed in which the interfering signal was turned on for approximately 1 s and then turned off for 9 s, repeated for the entire 6-minute observation period. The intent was to simulate the effect of the airborne system's antenna rotation, with the airborne system's main beam sweeping across the wind profiler once during each rotation. Even here, though, the effect of the actual radar's frequency diversity operation was not simulated. The results indicated that the reduced presence of the interfering signal significantly increased the interference threshold.

The end result of these tests was to test the wind profiler against non-FMed, pulsed signals in modes that represent a more continuous interference pattern than would be expected from systems actually being operated or anticipated in the 440-450 MHz band. As such, we regard the results of these tests as highly conservative from the standpoint of assessing interference thresholds for the wind profiler.

Results of Non-FMed, On-Tune, Pulsed Signal Injection ("intermittent" source)

The intermittent nature of these signals results in interference thresholds that exceeded -70 dBm at the input to the profiler receiver, as summarized in Table 4-3.

Non-FMed, Off-Tune, Pulsed Signal Injection (both "continuous" and "intermittent" sources)

The same test was performed as described for the non-FMed, on-tune test except the interfering source was off-tuned by 1 MHz.

Results of Non-FMed, Off-Tune, Pulsed Signal Injection (both "continuous" and "intermittent" sources)

Tuning the radar signals off-tune by 1 MHz resulted in an interference threshold in excess of -70 dBm at the input to the profiler receiver, as given in Table 4-3.

Chirped, On-Tune, Pulsed Signal Injection ("continuous")

Most of the comments made above for non-FMed signal injection apply for the chirped signal tests. The only difference between these test modes is the modulation of the pulses. For these tests, the pulses were linearly swept across frequency ranges that simulated actual chirped radar operations. An example spectrum of one of the injected signals is shown in Figure 4-17. Radars in this band typically chirp across a range of 5 or 6 MHz in a period of about 13 μs.

As with the non-FMed pulses, it may be assumed that the real radar pulses are phase code modulated. This modulation was not simulated; unless the phase coding should be coherent with the wind profiler, it should have no additional interference effect. Such coherence would never be expected to occur.

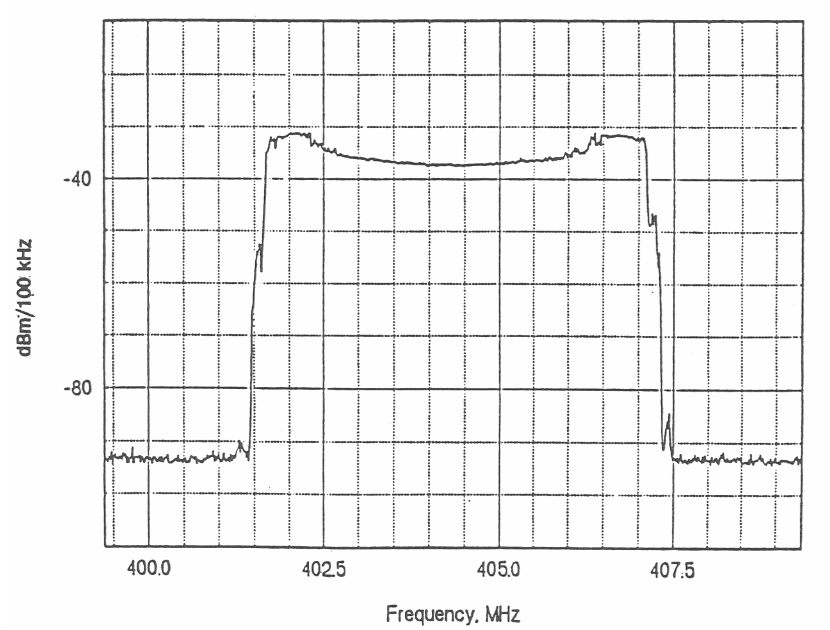

Figure 4-17. Chirped pulse spectrum, 5 MHz FM, 10 μs/pulse, 300 pps.

Also, as above, the signals were injected continuously for entire 6-minute profiler observations. As such, a very conservative estimate of interference thresholds was derived. The tests summarized in Table 4-3 represent a condition in which the simulated radar would have been boresighted continuously on a wind profiler radar for 6 minutes. This is unrealistic. So we also simulated situations in which the radars were intermittently coupling to the wind profiler radar. This was done, as before, by turning the radar interference signal on for 1 s out of every 10 s during a 6-minute test. When this was done, the interference levels could be turned up to -60 dBm, and no interference effects were observed.

Results of Chirped, On-Tune Signal Injection {"continuous"}

Chirping greatly increased the interference thresholds of the profiler. Chirping of 1 MHz or more resulted in interference thresholds of about -60 dBm at the input of the profiler receiver. The thresholds are higher because, when a signal is chirped, only a small part of the interfering signal's energy appears in the profiler's relatively narrow IF sections.

Chirped, On-Tune Signal Injection {"intermittent"}

This test was the same as the one above, except that the interfering radar signal was turned on for only 1 second out of every 10 during the 6-minute test period.

TABLE 4-3
Interference Test Results: 3-dB Profiler System Noise Level Increase

Signal Modulation	On tune/ Off tune (ON/OFF)	continuous intermittent	pulse width (μs)	prf (Hz)	chirp width (MHz)	Receiver Input (dBm)
CW	ON tune	continuous	N/A	N/A	N/A	-135
CW	OFF 1 MHz	continuous	N/A	N/A	N/A	a
FM {16 kHz)[b]	ON tune	continuous	N/A	N/A	N/A	-130
FM {16 kHz)[b]	OFF 1 MHz	continuous	N/A	N/A	N/A	-80
Pulse	ON tune	continuous	1	300	none	a
Pulse	ON tune	continuous	10	300	none	-80
Pulse	ON tune	continuous	50	300	none	-80
Pulse	ON tune	intermittent	1	300	none	a
Pulse	ON tune	intermittent	10	300	none	a
Pulse	ON tune	intermittent	50	300	none	a
Pulse	OFF 1 MHz	continuous	10	300	none	a
Pulse	OFF 1 MHz	intermittent	50	300	none	a
Pulse	ON tune	continuous	10	300	5	-60
Pulse	ON tune	intermittent	10	300	5	c

[a] We stopped at -70 dBm and the exact value could not be determined.
[b] Tone modulated.
[c] We stopped at -60 dBm and the exact value could not be determined.

Results of Chirped, On-Tune Signal Injection ("intermittent")

No interference was observed up to the highest level (-60 dBm) that was deemed acceptable to inject into the profiler.

Chirped, Off-Tune Pulsed Signal Injection

Radars in the 440-450 MHz band are usually chirped in excess of 1 MHz. Hence, off-tuning by 1 MHz (as in previous tests) would not change the results. If a radar is chirped by less than 1 MHz, then off-tuning by 1 MHz would yield substantially higher interference thresholds. How much higher would depend on the exact characteristics of the chirping.

4.7 EFFECTS FROM WIND PROFILER EMISSIONS ON LAND MOBILE/AMATEUR OPERATIONS

Since wind profilers will coexist with land mobile/amateur operations, the possibility of interference from wind profiler emissions was assessed, both on-tune and off-tuned by 1 MHz.

The receiver chosen for these tests was an ICOM RG-7000. The device has a noise figure of about 15 dB which is typical of such receivers. The receiver bandwidth is selectable; for our tests a 10-kHz bandwidth was selected as being representative of the typical bandwidth employed in actual operations.

On-Tune Test

An ICOM receiver was placed in a van, and a vertically polarized omnidirectional, 220-420 MHz discone antenna was mounted at rooftop level (approximately 2.1 m above the ground). The receiver was tuned to the profiler's center frequency, and a manual adjustment and built-in signal meter were used to "peak up" the receiver on the profiler emission. Both FM and AM demodulations were tested.

The van was driven along one radial away from the profiler, and the test continued until the profiler signal was lost in the receiver's internally generated noise. Although AM demodulation received the signal at a slightly longer distance than FM demodulation, both tests lost the profiler signal at a distance of approximately 1.6 km. This test was repeated several weeks later, and the same result was obtained.

Off-Tune Test

This test was identical to the test above, except that the receiver was tuned 1 MHz above the wind profiler frequency. In this case, the maximum distance at which the signal from the profiler was received out of the ICOM noise floor was about 1.1 km.

Summary

The ICOM receiver tests indicate that emissions from this wind profiler would pose no appreciable concern for existing mobile stations, even if those operations were on-tune to the profiler.