

# Emission Measurements of a Cellular and PCS Jammer at a Prison Facility

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*report series*



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**U.S. DEPARTMENT OF COMMERCE**

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## **DISCLAIMER**

Some technical information regarding the cellular jammer that NTIA measured may be considered intellectual property by the manufacturer of the device. The device descriptions that this report provides, its operational parameters, and its emissions are provided solely for the purpose of evaluating what engineering impact, if any, the possible future operation of the device might have on other systems that use the radio spectrum. The device that is described herein is not FCC-certified, nor does a certified standard design or operational configuration for it exist.

Some test and measurement equipment are identified in this report for the purpose of comprehensively describing the methodology and results of the work that NTIA performed. Such identification does not imply endorsement by the Department of Commerce of the equipment so identified, nor does such identification imply that the equipment was the only possible choice for adequate performance of such tests and measurements.



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## ABBREVIATIONS/ACRONYMS

|             |  |
|-------------|--|
| <b>ARA</b>  | Antenna Research Associates company  |
| <b>BOP</b>  | Federal Bureau of Prisons  |
| <b>EIRP</b> | effective isotropic radiated power   |
| <b>GPS</b>  | Global Positioning System  |
| <b>IF</b>   | intermediate frequency (stage of a radio receiver)   |
| <b>ITS</b>  | Institute for Telecommunication Sciences, NTIA, U.S. Department of<br>Commerce                     |
| <b>LMR</b>  | land mobile radio  |
| <b>LOS</b>  | line-of-sight  |
| <b>NIST</b> | National Institute of Standards and Technology (of the U.S. Department of<br>Commerce)             |
| <b>NTIA</b> | National Telecommunications and Information Administration (of the<br>U.S. Department of Commerce) |
| <b>OSM</b>  | Office of Spectrum Management, NTIA, U.S. Department of Commerce                                   |
| <b>PCS</b>  | Personal Communication Service   |
| <b>RF</b>   | radiofrequency   |
| <b>RMS</b>  | root mean square (average power detection)   |
| <b>STA</b>  | Special Temporary Authority (for a radio transmission)   |



## EXECUTIVE SUMMARY

This report describes National Telecommunications and Information Administration (NTIA) emission spectrum measurements of a cellular and Personal Communication Service (PCS) jamming system that was operated under a Special Temporary Authorization (STA) at a Federal Bureau of Prisons (BOP) minimum-security facility at Cumberland, MD.<sup>1</sup> NTIA assisted with the STA and agency-level coordination of the installation between BOP and the manufacturer, but did not participate in the installation itself, which BOP personnel performed with on-site inputs from the manufacturers' representatives. BOP personnel operated the jammer during the measurements.

The jammer emissions were transmitted entirely indoors. The targeted jamming zone was the interior of a two-floor reinforced cinderblock structure measuring 30 meters (m) long by 8 m wide. Jammer emissions were measured both indoors and outdoors, that is, both inside and outside the targeted jamming zone. Each measurement was repeated twice, once with the jammer on and once with the jammer off, so as to show clearly the relative levels of the jammer emissions and the ambient cellular and PCS signal levels at each measurement location.

NTIA performed measurements at four indoor and seven outdoor locations. At the indoor locations, measured differences in power between when the jammer was on versus off showed that cellular and PCS signal power levels were measurable and jammer power was much greater than either the cellular or PCS levels. For the outdoor locations where jamming was not intended, the results showed that jammer power was measurable at distances up to 127 m from the building. However, the differences in power between when the jammer was on and off were not as large as were observed for the indoor locations. Analysis of the in-band (cellular and PCS) potential for harmful interference, if any, of the jammer emissions that were observed outside the jamming zone was beyond the scope of this report. Jammer signal power levels were below measurable levels at the outdoor locations within the Federal land mobile radio (LMR) and Global Positioning System (GPS) bands of 162-174 MHz, 406-420 MHz, 1164-1188 MHz, 1215-1240 MHz, and 1559-1610 MHz.

The measurement results of this study are idiosyncratic to this particular jammer installation and facility. Variations in jammer characteristics, structural characteristics of buildings, and propagation factors will produce different results for different installations at different facilities.

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<sup>1</sup> NTIA measured broadband (100-6000 MHz) spectrum emissions of the jammer earlier inside an anechoic chamber in Boulder, Colorado [1]. While the jammer was the same unit as had earlier been measured, the manufacturer used different radiofrequency (RF) filtering for out-of-band and spurious spectrum control than had been supplied for the measurements in the chamber. The change in RF filtering is not believed to have affected the results of the measurements at the BOP facility relative to the anechoic chamber data, because the measurements at the BOP facility were mostly performed on in-band and adjacent-band jammer emissions.

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# EMISSION MEASUREMENTS OF A CELLULAR AND PCS JAMMER AT A PRISON FACILITY

Frank H. Sanders and Robert T. Johnk<sup>2</sup>

This report describes emission-spectrum measurements of a denial-of-service (jammer) transmitter that was operated temporarily in 800 MHz and 1900 MHz cellular and PCS bands at a prison location. The jammer targeted signals indoors within a minimum-security facility operated by the Federal Bureau of Prisons. Spectrum measurements of the jammer emissions were performed inside and outside the targeted jamming zone with multiple measurement bandwidths and detectors, both in-band and in selected Federal land mobile radio and GPS spectrum bands. Measurements at each location were performed with the jammer on versus off so as to show the relative power levels of the jamming signal and the ambient cellular and PCS signals at each location. In-band jammer emissions were measured outside the targeted zone at distances of up to 127 m from the edge of the targeted zone.

Key words: cellular communications jamming; denial-of-service jamming; emission bandwidth; harmful interference; in-band emissions; personal communication service (PCS) communications jamming; radio jamming

## 1 INTRODUCTION

For correctional facilities in the United States, parties have proposed to operate radio transmitters that produce intentional denial-of-service (jammer) emissions in the base station transmitter frequency bands of 869-894 MHz (cellular band) and 1930-1990 MHz (PCS band).<sup>3</sup> This report describes the results of measurements that the National Telecommunications and Information Administration (NTIA) Institute for Telecommunication Sciences (ITS) laboratory performed on radio spectrum emissions produced by one such jammer transmitter that was operated temporarily at a minimum-security prison operated by the Federal Bureau of Prisons (BOP).

### 1.1 Objective

The objective of this study was to perform emission spectrum measurements on jammer signals inside and outside a jamming zone at a BOP facility at Cumberland, Maryland.

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<sup>2</sup> The authors are with the Institute for Telecommunication Sciences, National Telecommunications and Information Administration (NTIA), U.S. Department of Commerce, Boulder, CO.

<sup>3</sup> For brevity, this report refers to the 869-894 MHz and 1930-1990 MHz frequency bands as the 800 MHz and 1900 MHz bands, respectively.

## 1.2 Approach

The study approach was:

- 1) An experimental Special Temporary Authority (STA) to transmit the jamming signal was obtained by NTIA.
- 2) The manufacturer of the jammer, with BOP cooperation, installed the jammer inside a minimum-security building. NTIA participated in the site selection process and assisted in coordination of the use of the site between the BOP and the manufacturer, but did not participate in or direct any aspect of the jammer installation or configuration.
- 3) NTIA personnel performed a hardline-coupled measurement of the power generated by the jammer transmitter and used this data to determine the effective isotropic radiated power (EIRP) of the jammer signal.
- 4) NTIA personnel used a portable measurement system to measure the in-band and adjacent-band emission levels. The jammer was turned on and off for each measurement, so as to allow ambient cellular and PCS signal levels to be measured separately from the jammer emissions. Measurements were performed at four locations inside the targeted jamming zone (inside the building), and at seven locations outside the zone (outdoors). Five of the outdoor locations had line-of-sight (LOS) propagation to the building; two did not. Distances ranged between 26 m to 131 m from the center of the building.
- 5) NTIA reduced the spectrum measurement data to graphical plots, which are provided in this report. These data show the field-strength emission levels (in units of decibels relative to a microvolt per meter, or dB $\mu$ V/m) of the jammer inside and outside the targeted jamming zone as a function of location and of the measurement bandwidth and signal detection technique. The relative levels of the jammer signal and the ambient cellular and PCS signals are shown in each data graph.



## 2 JAMMER INSTALLATION, MEASUREMENT SYSTEM, AND DATA DESCRIPTION

### 2.1 Jammer Installation

The configuration of the jammer transmitter and its antenna array inside the building where it was installed is shown in Figure 1. The figure is schematic and the building dimensions are approximate.

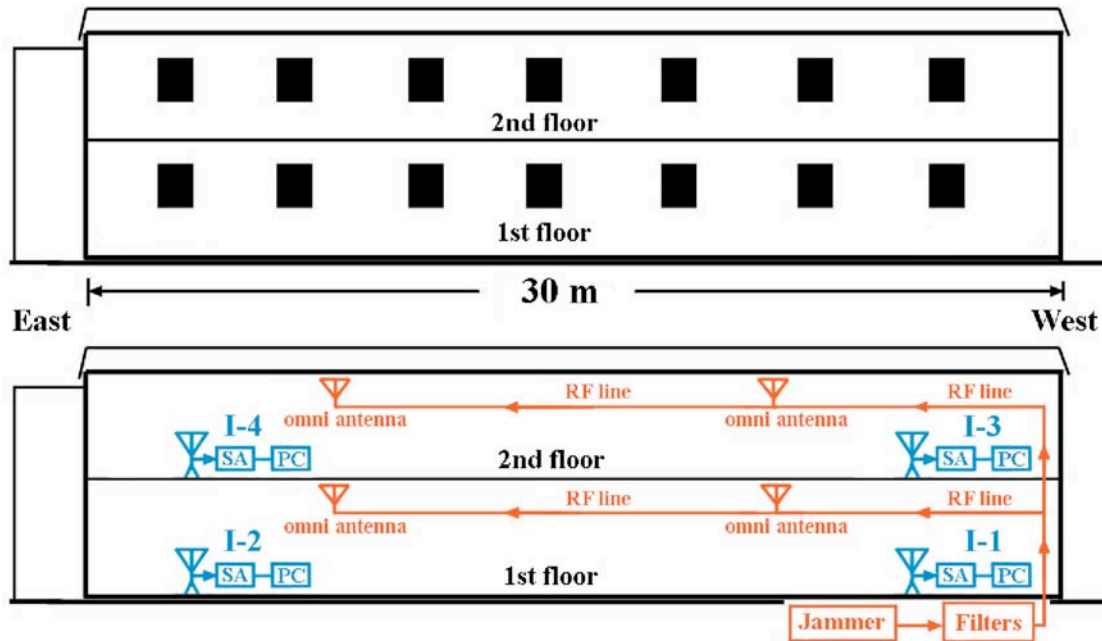


Figure 1. Schematic representation of the interior jammer installation (orange) and spectrum measurement locations (blue). Top: exterior view with approximate window layout. Bottom: Interior view. SA = spectrum analyzer; PC = PC laptop computer. The four measurement locations are indexed as I-1 through I-4.

The building construction was cinderblock with internal steel reinforcement. The approximate building dimensions were 30 m long by 8 m wide by two floors high. The building had a number of exterior windows. The jammer antennas were installed above the two interior ceilings along the building's central hallway axis. The ceiling heights were about 2.5 m above each floor. The jammer antennas were omnidirectional and were of the same model as an omni antenna that was used during previous NTIA anechoic chamber emission measurements of the jammer emission spectra [1].

## 2.2 Jammer Technical Characteristics

The jammer transmitter was the same physical unit as was used for emission-characteristics measurements that had been performed in an anechoic chamber in Boulder, Colorado [1]. The jammer transmitter characteristics are listed in Table 1.

Table 1. Jammer Transmitter Characteristics.

| <b>Chirp Frequency Range (MHz)</b> | <b>Chirp Time (<math>\mu</math>s)</b> | <b>Chirp Rate (MHz/<math>\mu</math>s)</b> | <b>Spectrum Line Spacing (kHz)</b> | <b>Transmitter Output Power (W)</b> |
|------------------------------------|---------------------------------------|---|------------------------------------|-------------------------------------|
| 869-894                            | 5.1                                   | 4.9                                       | 196                                | 100                                 |
| 1930-1990                          | 20.4                                  | 2.9                                       | 49                                 | 100                                 |

The jammer output filtering differed from the diplexer that was used as an out-of-band filter for the anechoic chamber measurements [1]. The filters that were used for the prison installation are not believed to have affected the outcome of the measurements in this study, as these measurements were within the filter passbands (i.e., in-band).

The power level of the jammer transmitter output was measured directly, via a hardline connection to a precision power meter, at +53 dBm for the two bands combined. This is 200 W, or 100 W (+50 dBm) per jammer band assuming the same 50/50 band split as was observed in earlier anechoic chamber measurements [1]. There was 5 dB of filtering loss and 3 dB of cable loss in the jamming system. The 8 dB of filtering and cable losses meant that a total of  $(+50 \text{ dBm} - 8 \text{ dB}) = +42 \text{ dBm}$  or 15.8 W of power was delivered per band to the combination of four jammer antennas.<sup>4</sup> With an approximate gain of 0 dBi for the radiating antennas, the EIRP of the entire jammer system inside the building was therefore  $+42 \text{ dBm} = +12 \text{ dBW} = 15.8 \text{ W}$  per band.

## 2.3 NTIA Spectrum Measurement System

The NTIA measurement system consisted of a broadband antenna, a spectrum analyzer, and a laptop PC control computer that was used to control the spectrum analyzer and record data. The measurement system and its parameters are described below.

### 2.3.1 Measurement System Antenna

The measurement antenna was an omnidirectional Antenna Research Associates (ARA) 100 MHz-2000 MHz spiky discone, model SAS-2201C. The antenna was passive (that is, it did not incorporate a front-end low-noise amplifier). Its gain in the cellular and PCS

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<sup>4</sup> The EIRP radiated by each of the four antennas was  $\frac{1}{4}$  of +42 dBm per band, which was therefore  $(42 - 6) \text{ dBm} = +36 \text{ dBm}$ , or approximately 4 W per antenna per band.

bands was -1 dB relative to isotropic.<sup>5</sup> For indoor measurements, the antenna was mounted on a non-conductive tripod and was connected to the spectrum analyzer by a short length of low-loss radio frequency (RF) line. For outdoor measurements, the antenna was mounted on the roof of the NTIA Radio Spectrum Measurement System model 3 (RSMS-3). The antenna was mounted 1 m above floor level indoors and 3 m above ground level outdoors.

### 2.3.2 Spectrum Analyzer Measurement Parameters

The spectrum analyzer was a portable Agilent E4407B. It was operated with its RF front-end preamplifier turned off and zero RF attenuation at the input. The analyzer’s intermediate frequency (IF) reference level was -20 dBm for 100 kHz measurement bandwidth and -10 dBm for 1 MHz measurement bandwidth. The spectrum analyzer data traces each contained 1001 frequency bins. The data presented in this report were collected in the cellular and PCS bands using the measurement parameters shown in Table 2.

Table 2. Measurement Parameters for In-Situ Prison Emission Measurements.

| <b>Freq. Range (MHz)<sup>6</sup></b> | <b>IF Stage (Resolution) Bandwidth (kHz)</b> | <b>Video Bandwidth (kHz)</b> | <b>Detection</b> | <b>Sweep Time (sec)</b> | <b>Freq. Bin Size (kHz)</b> | <b>Dwell per Bin (μs)</b> | <b>Jammer Sweeps per Bin</b> |
|--------------------------------------|--|------------------------------|------------------|-------------------------|-----------------------------|---------------------------|------------------------------|
| 860-900                              | 100  | 300                          | Peak             | 0.1                     | 40                          | 100                       | 19.6                         |
| 860-900                              | 100  | 1                            | Average          | 1                       | 40                          | 1000                      | 196                          |
| 860-900                              | 1000   | 3000                         | Peak             | 0.1                     | 40                          | 100                       | 19.6                         |
| 1920-2000                            | 100  | 300                          | Peak             | 0.1                     | 80                          | 100                       | 4.9                          |
| 1920-2000                            | 100  | 1                            | Average          | 2                       | 80                          | 2000                      | 98                           |
| 1920-2000                            | 1000   | 3000                         | Peak             | 0.1                     | 80                          | 100                       | 4.9                          |

In the cellular and PCS bands, both peak and average data were acquired in a 100 kHz measurement bandwidth, and additional peak data were acquired in a 1 MHz bandwidth. Peak-power measurements were performed with the analyzer in a maximum-hold trace mode for a total of 10 traces. In this mode, the analyzer’s peak detector latches to the highest level that occurs within each sampling interval for each spectrum analyzer frequency bin (see the last three columns in Table 2), and the maximum-hold trace mode latches to the highest power level in each spectrum analyzer frequency-measurement bin over a series of frequency sweeps. Thus the maximum-hold, peak measurements show the highest power level that occurs in the measurement bandwidth at each frequency in the measured spectrum. Average power was measured by setting the video average filter bandwidth to a fraction of the width of the resolution bandwidth filter, setting the dwell

<sup>5</sup> From a custom calibration by the ARA company.

<sup>6</sup> The measurement band edges were set somewhat wider than the 869-894 MHz and 1930-1990 MHz cellular and PCS band edges so that adjacent-band roll-off of the jammer emissions could be observed in the measurement data.

time in each frequency bin to be much larger than the reciprocal bandwidth of the video average filter, and sampling the output of the video average filter once per frequency bin.

Additional spectrum measurements were performed in two Federal land mobile radio (LMR) bands (162-174 MHz, 406-420 MHz), and three GPS bands (centered around 1176 MHz, 1227 MHz, and 1575 MHz). These data were acquired with a 10 kHz bandwidth in the LMR bands, so as to match typical LMR receiver bandwidths, and in a 1 MHz reference bandwidth in the GPS bands.

### 2.3.3 Measurement Control Software

The spectrum analyzer was controlled by a laptop computer running NTIA data-acquisition (DA) software [2]. The DA software was configured prior to the measurement to automatically run the measurements shown in Table 2. The software ran each of the measurements listed in Table 2 twice, once with the jammer on and once with the jammer off, so that the jammer emissions could be compared to the ambient cellular and PCS signal-power levels.

## 2.4 Measurement Locations

As shown in Figure 1, four measurement locations were used inside the building (the targeted jamming zone), two on the first floor and two on the second floor. These are designated I (for interior) 1-4. The rooftop of the targeted building and the outdoor measurement locations are shown in Figure 2. The outdoor locations are designated O (for outdoor) 1-7. The measurement locations are summarized in Table 3.

Table 3. Measurement Locations and Data-Figure Index.

| <b>Data Point Identifier and Location</b> | <b>Figure Numbers Showing Emission Data</b> | <b>Distance from Center of Targeted Zone (m)</b> | <b>Distance from Edge of Targeted Zone (m)</b> | <b>Line-of-Sight (LOS)</b> |
|---|---|--|--|----------------------------|
| I-1 (Fig. 1)                              | 3, 4, A-1, A-2                              | Inside   | Inside   | Inside                     |
| I-2 (Fig. 1)                              | 5, 6, A-3, A-4                              | Inside   | Inside   | Inside                     |
| I-3 (Fig. 1)                              | 7, 8, A-5, A-6                              | Inside   | Inside   | Inside                     |
| I-4 (Fig. 1)                              | 9, 10, A-7, A-8                             | Inside   | Inside   | Inside                     |
| O-1 (Fig. 2)                              | 11, 12, A-9, A-10                           | 26   | 22   | yes                        |
| O-2 (Fig. 2)                              | 13, 14, A-11, A-12                          | 35   | 30   | yes                        |
| O-3 (Fig. 2)                              | 15, 16, A-13, A-14                          | 37   | 33   | yes                        |
| O-4 (Fig. 2)                              | 17, 18, A-15, A-16                          | 87   | 83   | yes                        |
| O-5 (Fig. 2)                              | 19, 20, A-17, A-18                          | 131  | 127  | yes                        |
| O-6 (Fig. 2)                              | 21, 22, A-19, A-20                          | 52   | 47   | no                         |
| O-7 (Fig. 2)                              | 23, 24, A-21, A-22                          | 74   | 69   | no                         |

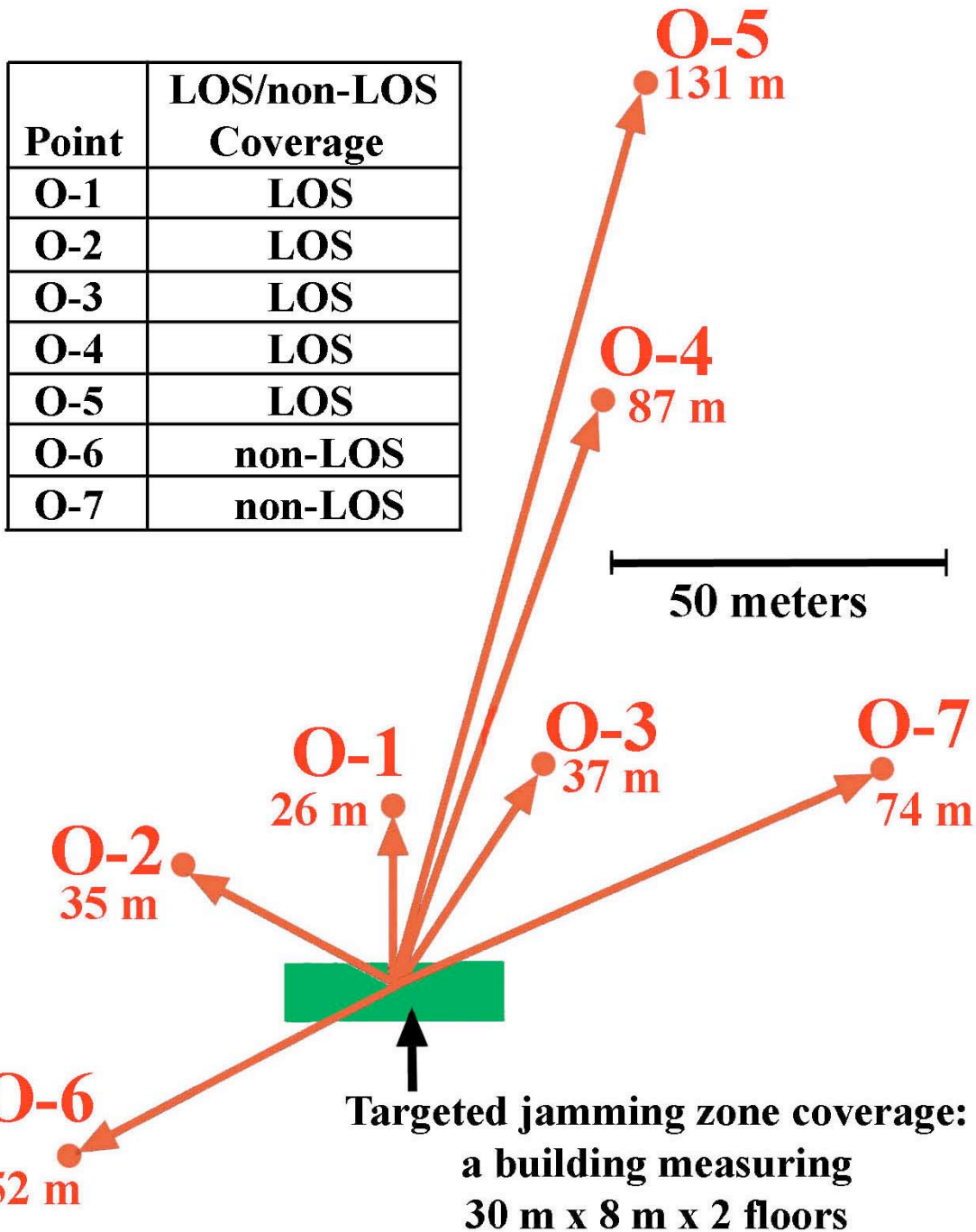


Figure 2. Overhead view of the area outside the targeted jamming zone and the exterior measurement locations. Clear line-of-sight (LOS) coverage existed between the building and measurement system for locations O-1 through O-5; obstructions existed between the building and the measurement system for locations O-6 and O-7.

## 3 MEASUREMENT RESULTS AND ANALYSIS

### 3.1 Measurement Results

Figures 3-24 depict measurements made in the 100 kHz bandwidth. Progressing from the highest-power to lowest-power trace in each figure, these are: positive-peak detected with the jammer on (red), average-detected with the jammer on (black), positive-peak detected with the jammer off (green), and average-detected with the jammer off (blue). The data in Figures 25-29 are peak-detected only; each of those graphs consists of a single trace showing only the background signals in the vicinity of the prison. Additional data, measured in a 1 MHz bandwidth, are provided in Appendix A.

### 3.2 Power Units in Data Plots

The raw data were collected in units of decibels relative to a milliwatt (dBm). The power units in Figures 3-24 and Appendix A have been converted into logarithmic field strength (decibels relative to a microvolt per meter, or dB $\mu$ V/m). The conversion math is given in Appendix B.

Unlike the jammer emission data that were presented in [1] in terms of EIRP, the data in Figures 3-24 cannot be graphed in such units because EIRP calculations require that the distance to a transmitter must be known, and the distances to the local cellular and PCS towers are not known. Moreover, their EIRP levels would differ from the EIRP levels of the jammer emissions. Since the cellular and PCS levels need to be placed on the same graphs for comparative purposes, it is not possible to put the data in these graphs into terms of EIRP.

The data in the LMR and GPS bands (Figures 25-29) are plotted in units of dBm. This is because the spectra in the bands shown in those figures (the land mobile radio (LMR) bands 162-174 MHz and 406-420 MHz, and the Global Positioning System (GPS) bands around 1176 MHz, 1227 MHz, and 1575 MHz) contain no observable jammer emissions. The data in these plots are a null result: only the *noise limit* of the measurement system (the noise in the spectrum analyzer) is in the plots (plus a few ambient, non-jammer signals). Field strength in free space would not refer to a measured power level, but would instead be only be an upper limit on the possible jammer power level in these bands at the location where these data were measured.

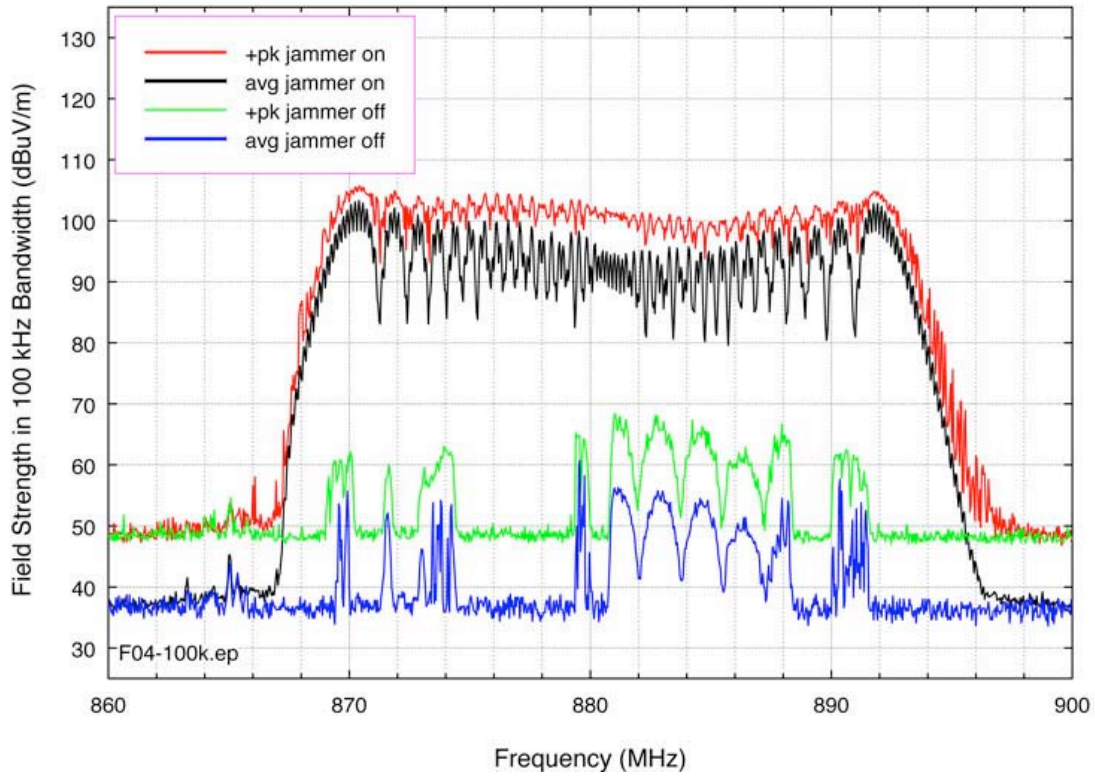


Figure 3. Inside jamming zone, Point I-1 (first floor, west end), cellular band.

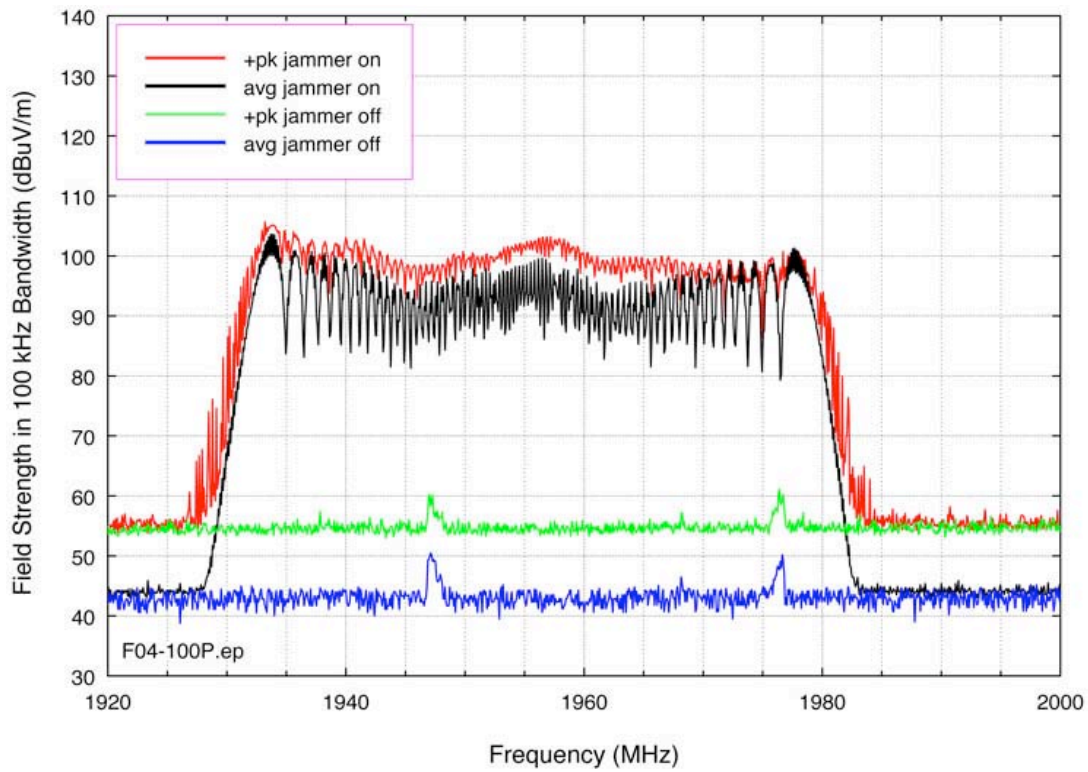


Figure 4. Inside jamming zone, Point I-1 (first floor, west end), PCS band.



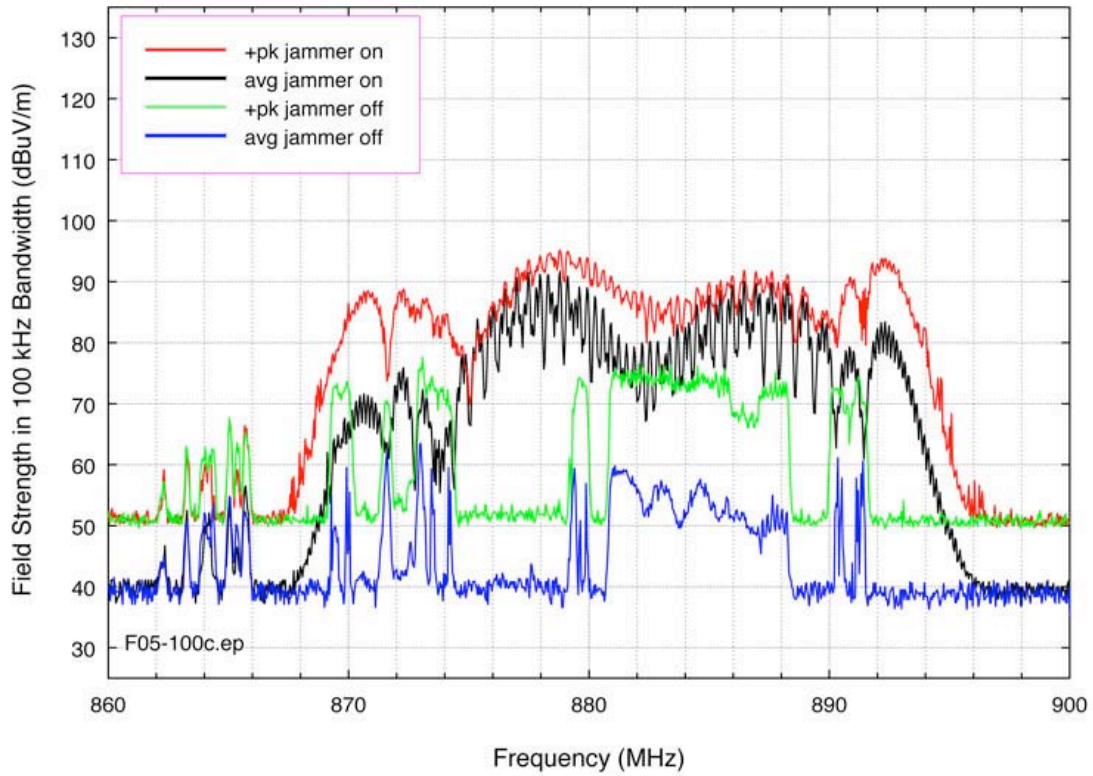


Figure 5. Inside jamming zone, Point I-2 (first floor, east end), cellular band.

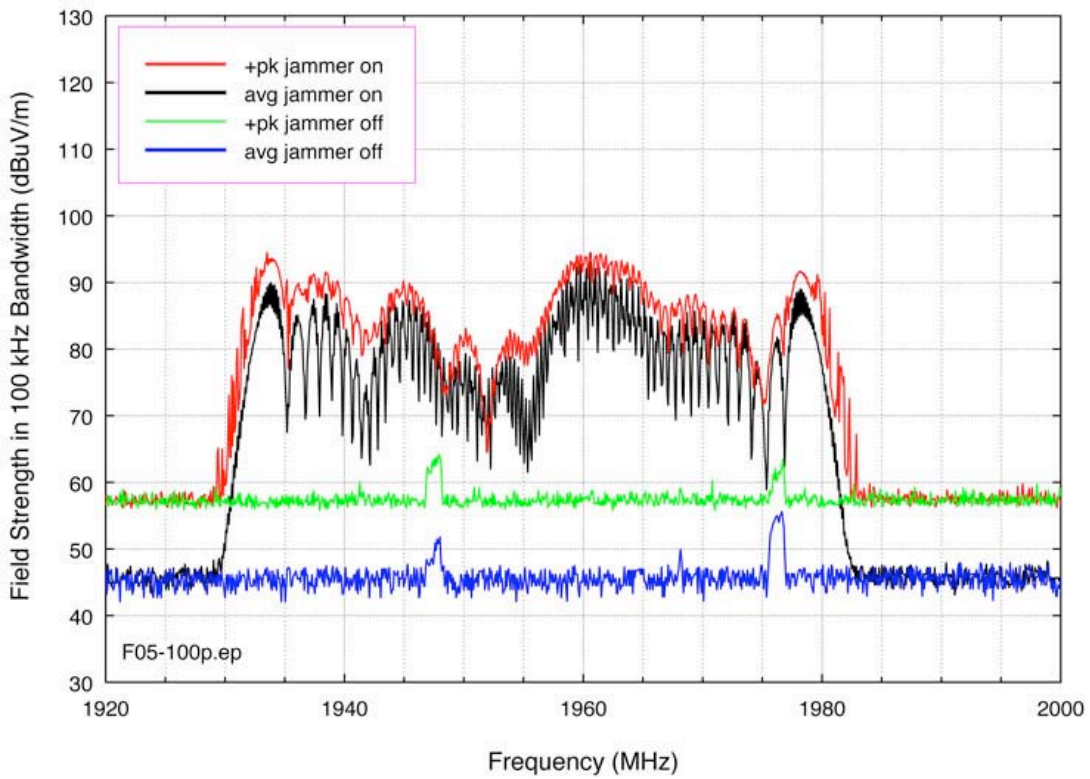


Figure 6. Inside jamming zone, Point I-2 (first floor, east end), PCS band.



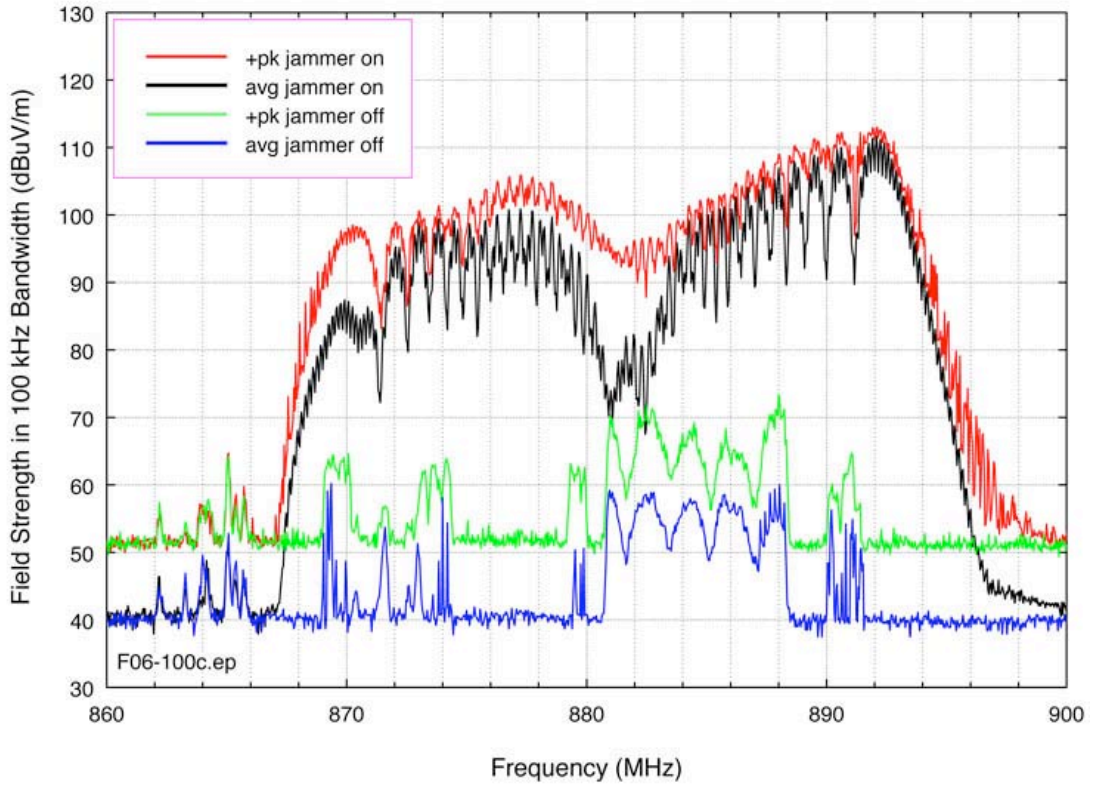


Figure 7. Inside jamming zone, Point I-3 (second floor, west end), cellular band.

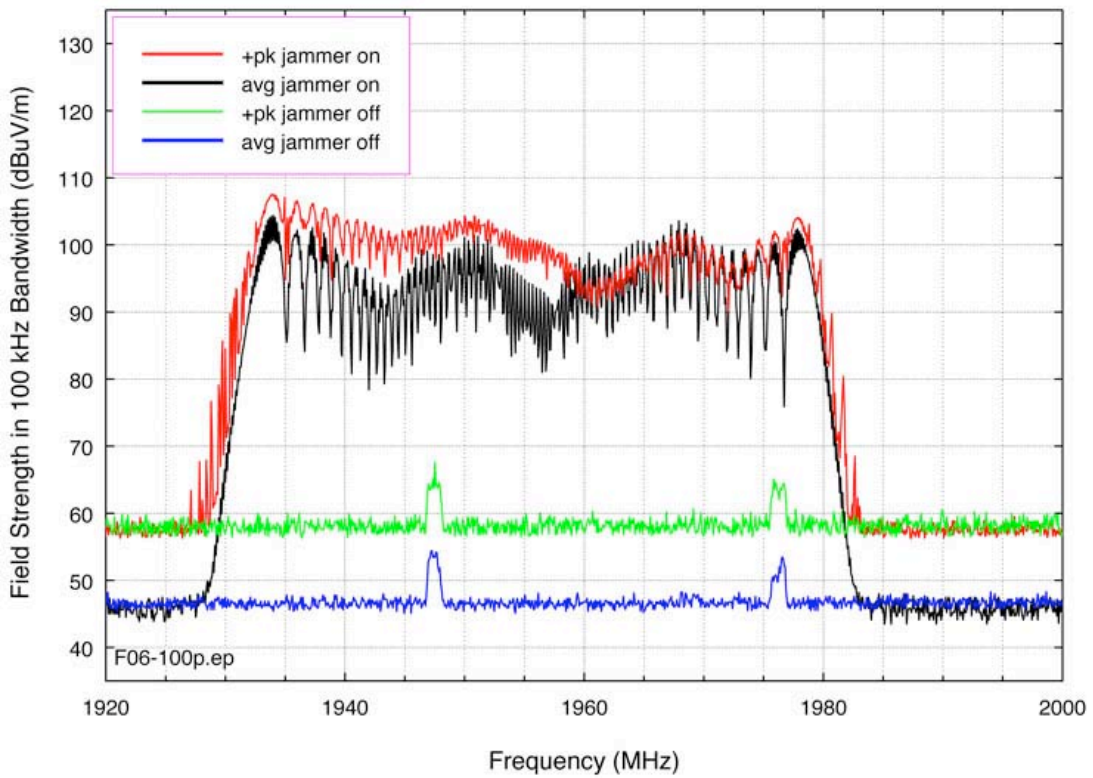


Figure 8. Inside jamming zone, Point I-3 (second floor, west end), PCS band.

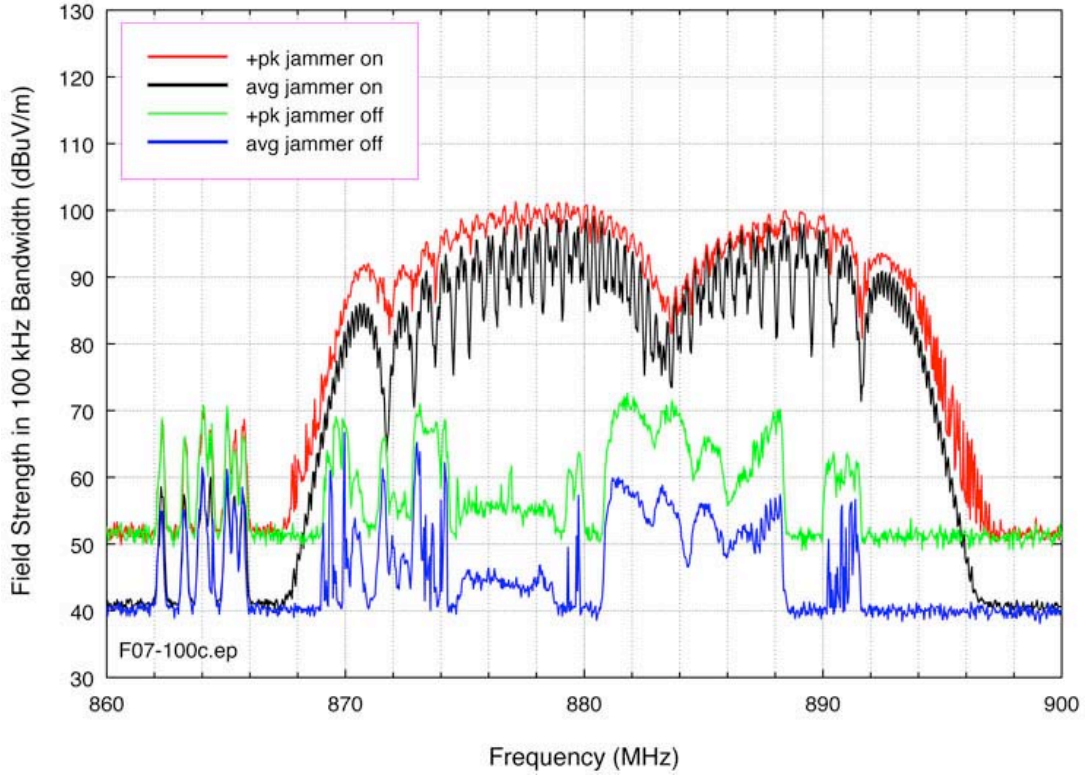


Figure 9. Inside jamming zone, Point I-4 (second floor, east end), cellular band.

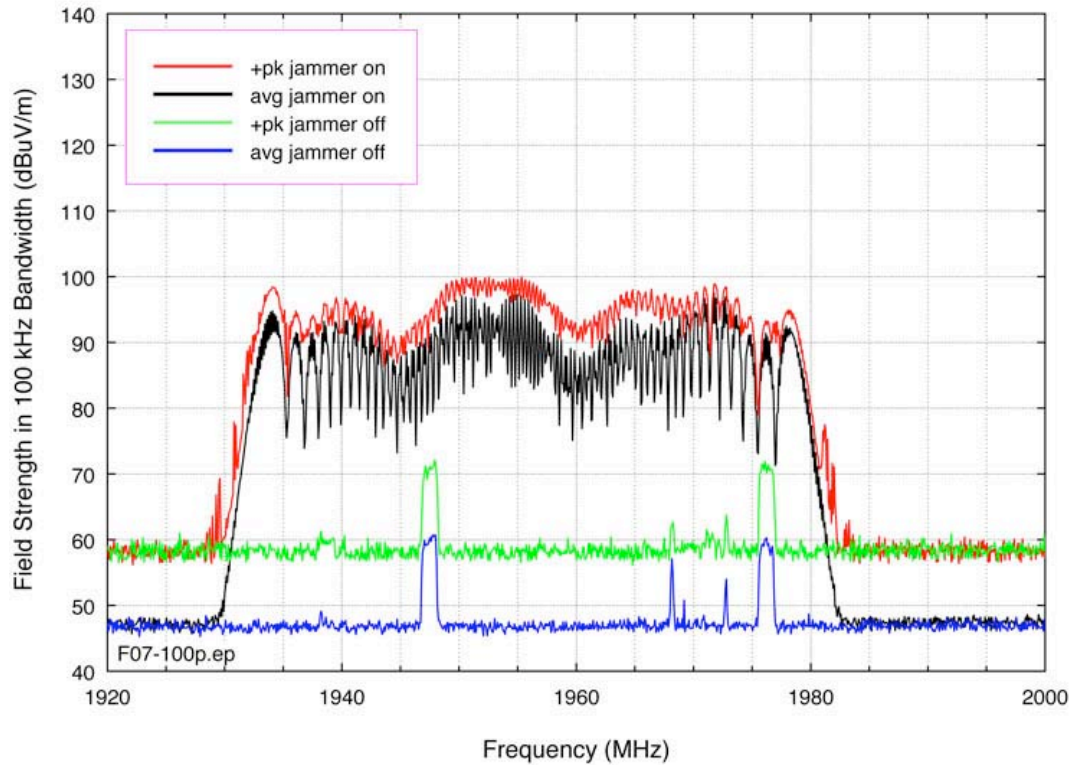


Figure 10. Inside jamming zone, Point I-4 (second floor, east end), PCS band.

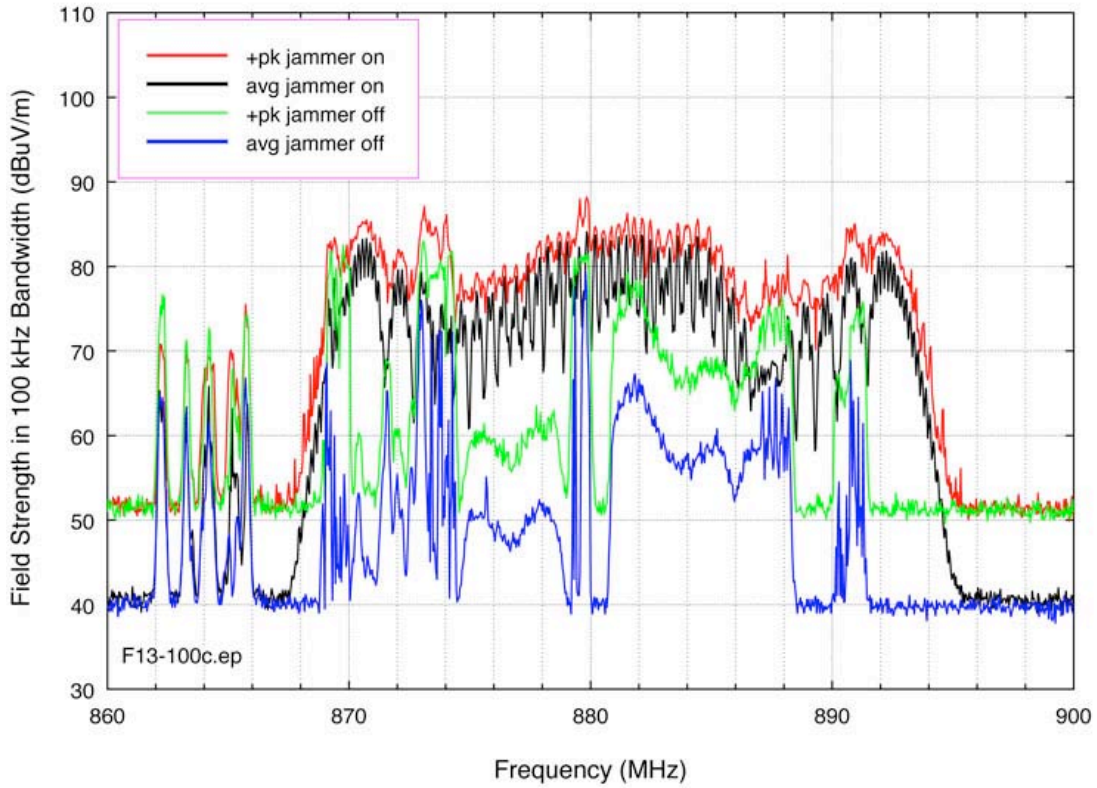


Figure 11. Beyond jamming zone, Point O-1 (26 m from center), cellular band.

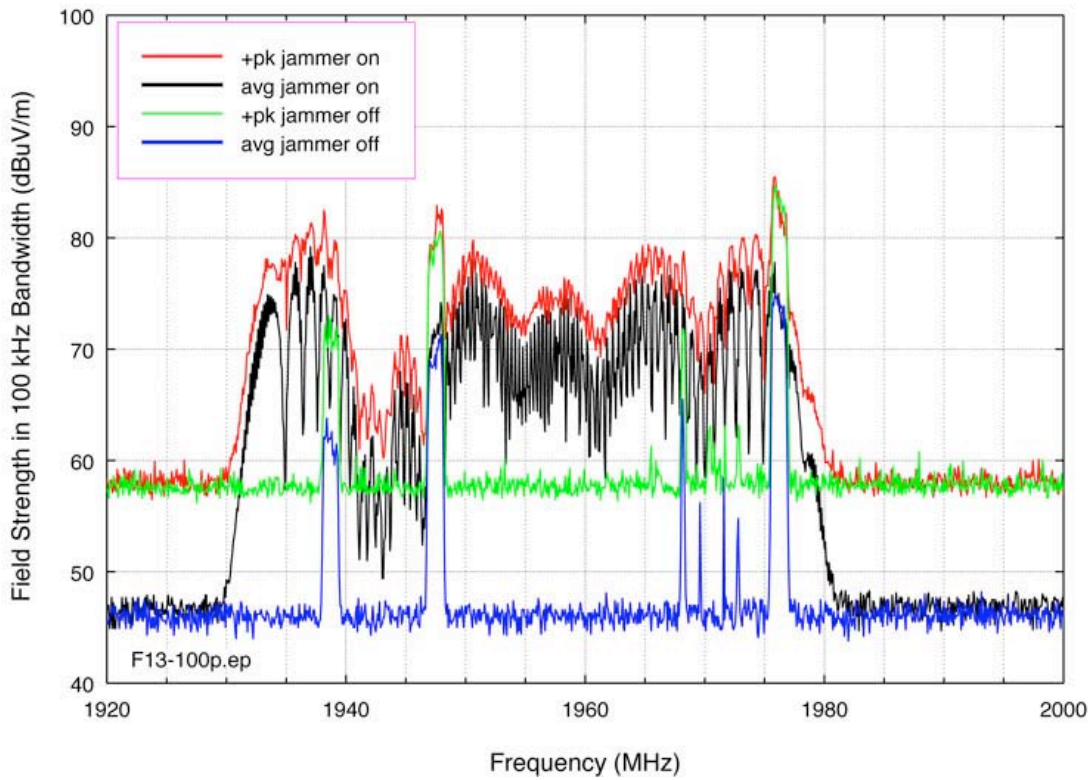


Figure 12. Beyond jamming zone, Point O-1 (26 m from center), PCS band.



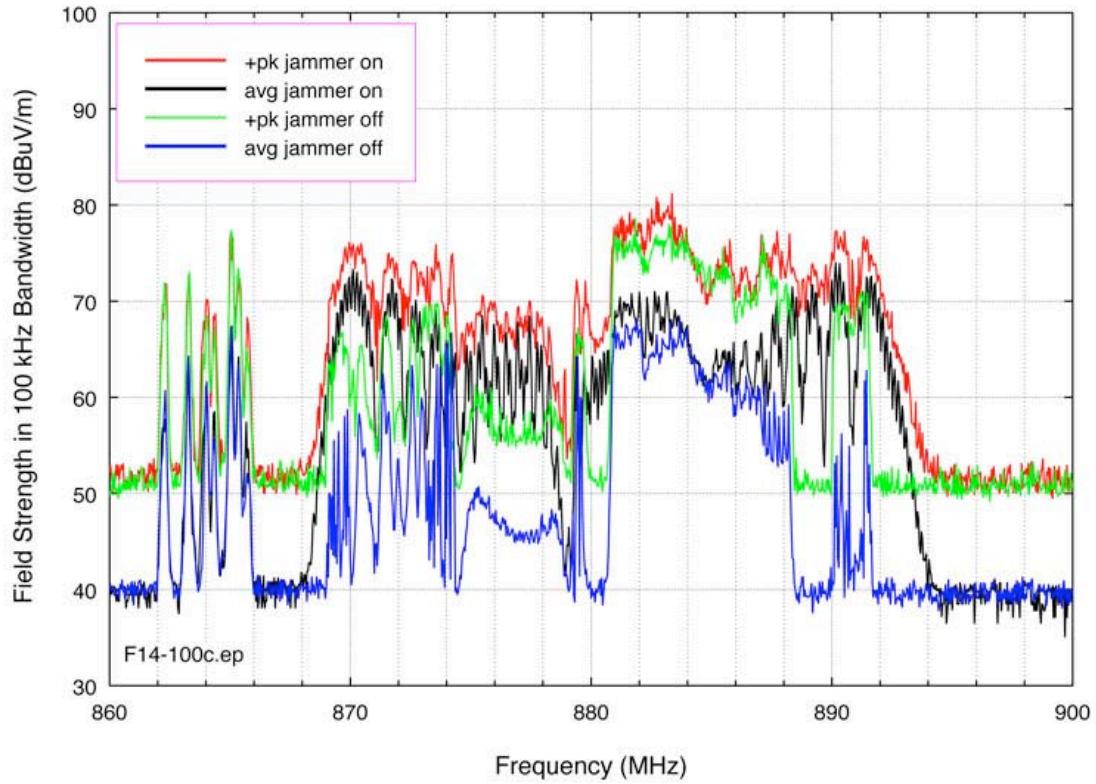


Figure 13. Beyond jamming zone, Point O-2 (35 m from center,) cellular band.

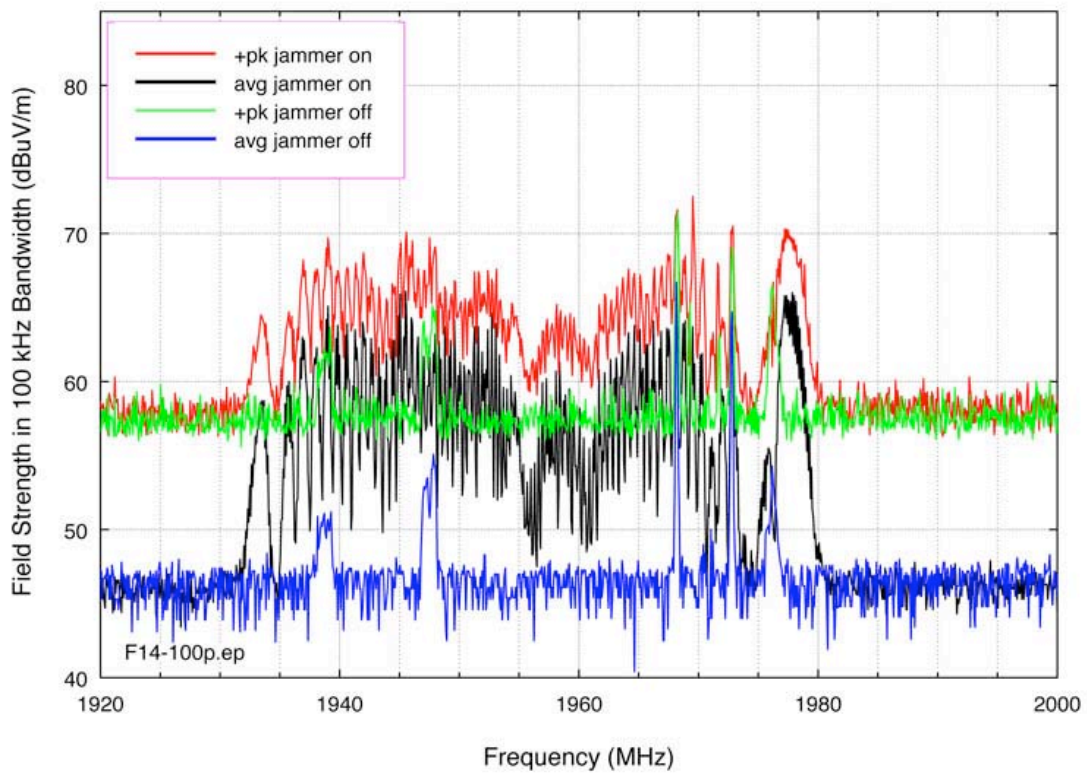


Figure 14. Beyond jamming zone, Point O-2 (35 m from center), PCS band.

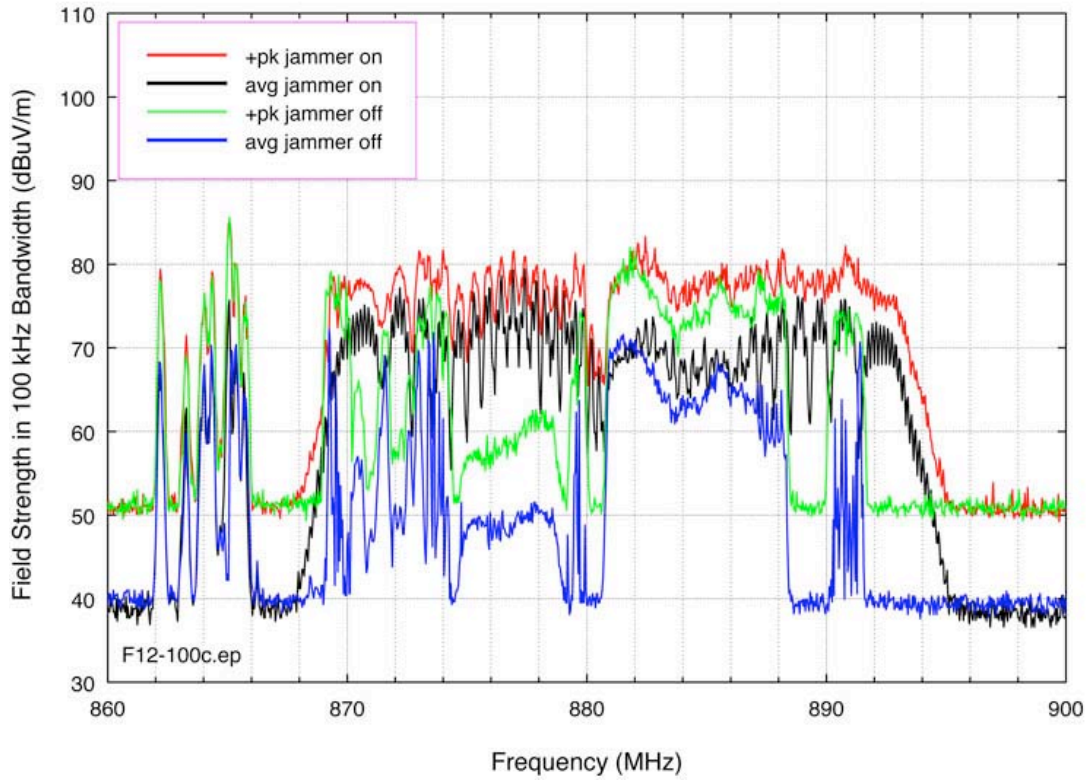


Figure 15. Beyond jamming zone, Point O-3 (37 m from center), cellular band.

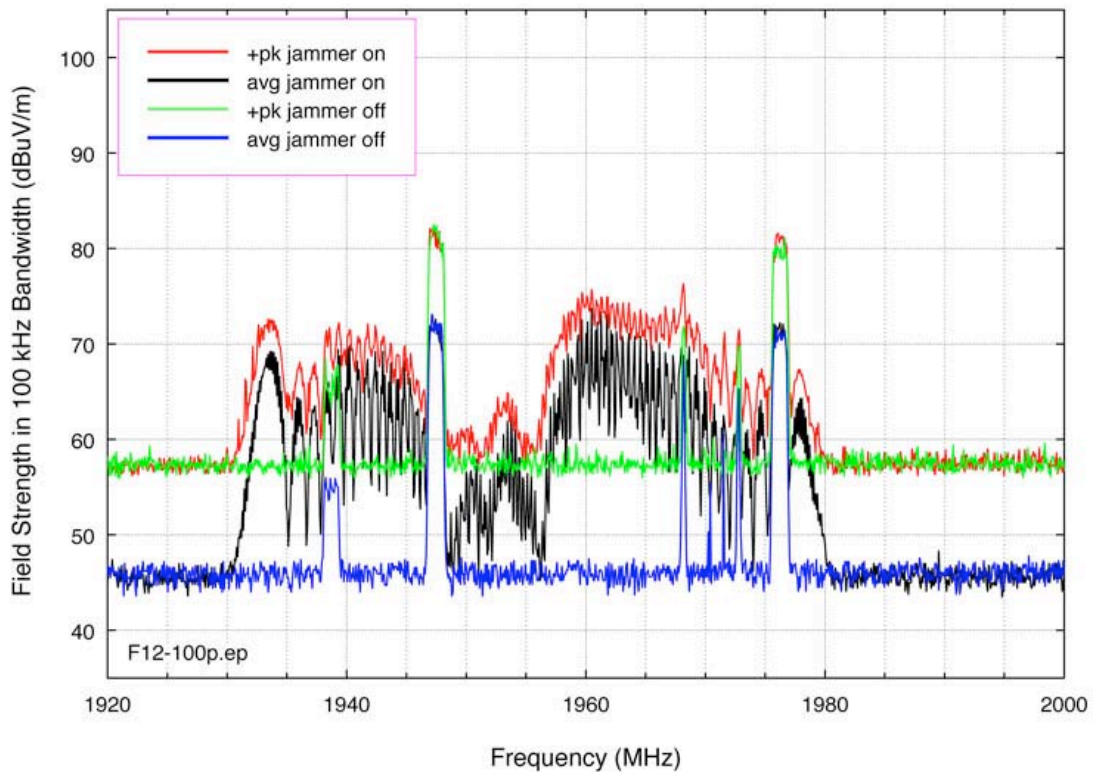


Figure 16. Beyond jamming zone, Point O-3 (37 m from center), PCS band.

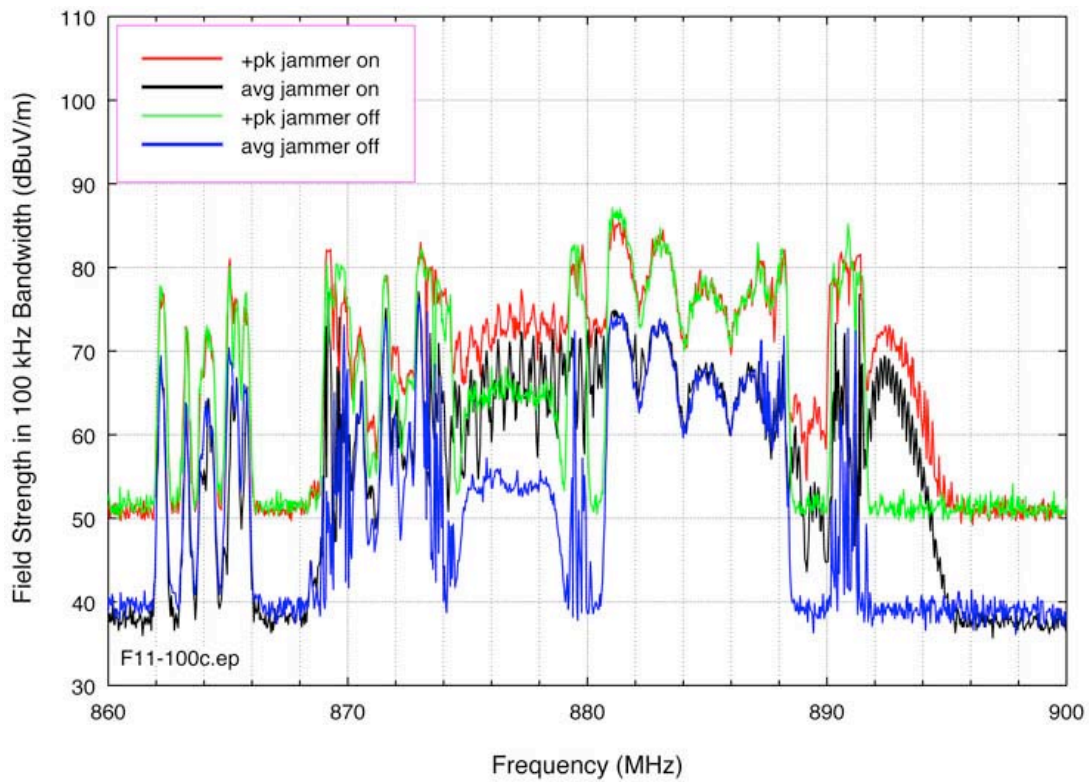


Figure 17. Beyond jamming zone, Point O-4 (87 m from center), cellular band.

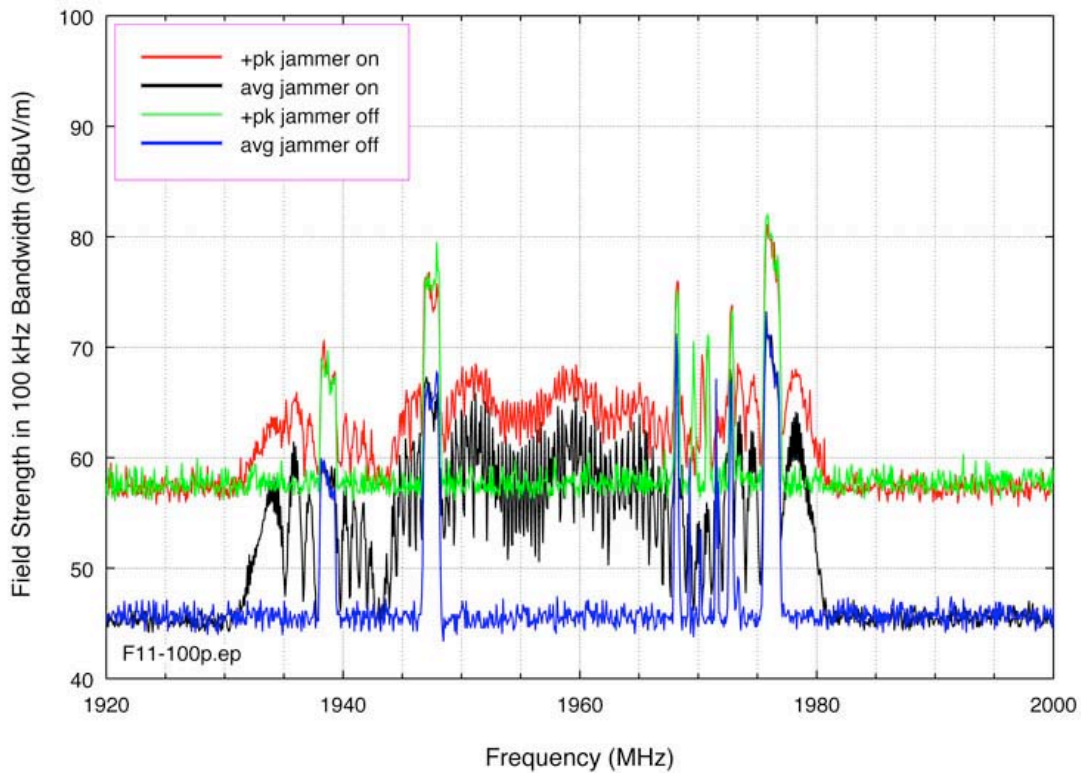


Figure 18. Beyond jamming zone, Point O-4 (87 m from center), PCS band.



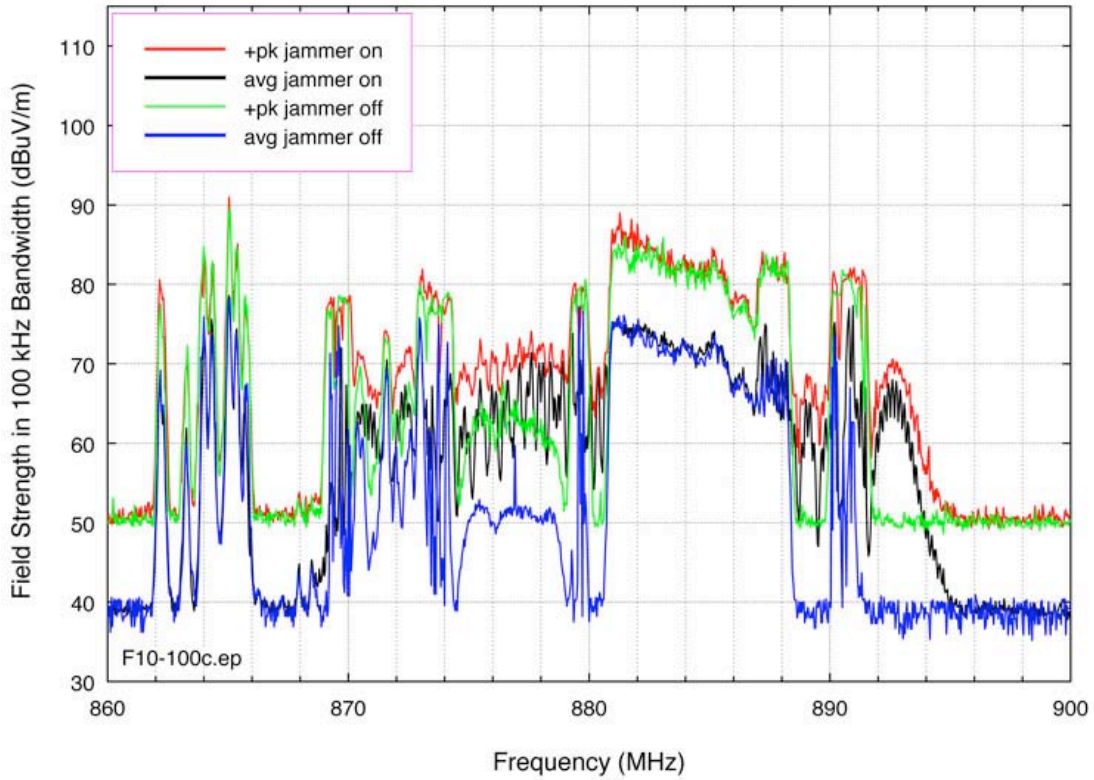


Figure 19. Beyond jamming zone, Point O-5 (131 m from center), cellular band.

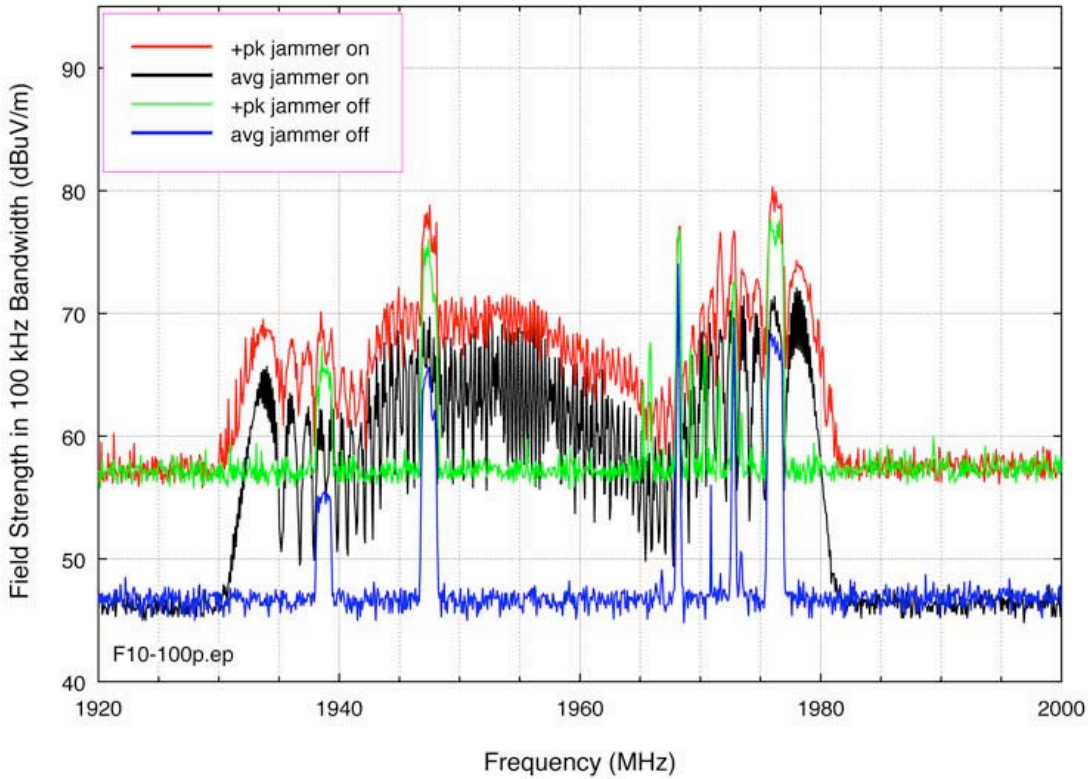


Figure 20. Beyond jamming zone, Point O-5 (131 m from center), PCS band.

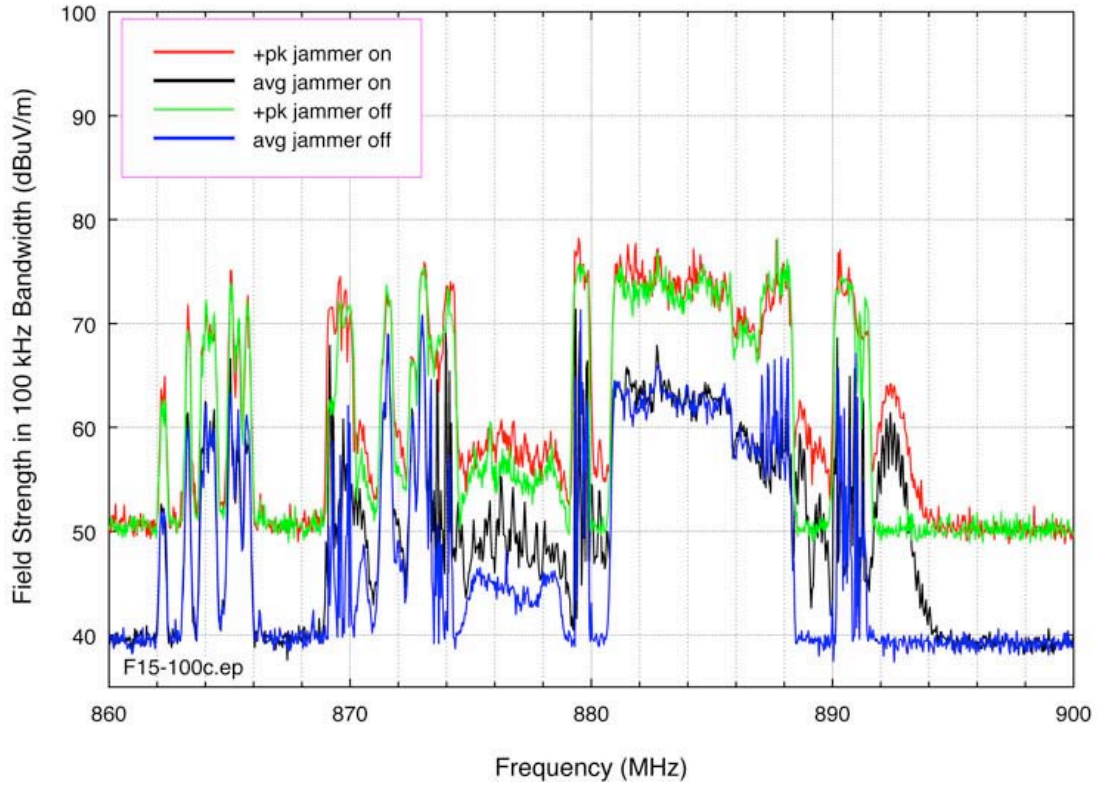


Figure 21. Beyond jamming zone, Point O-6 (52 m, non-LOS), cellular band.

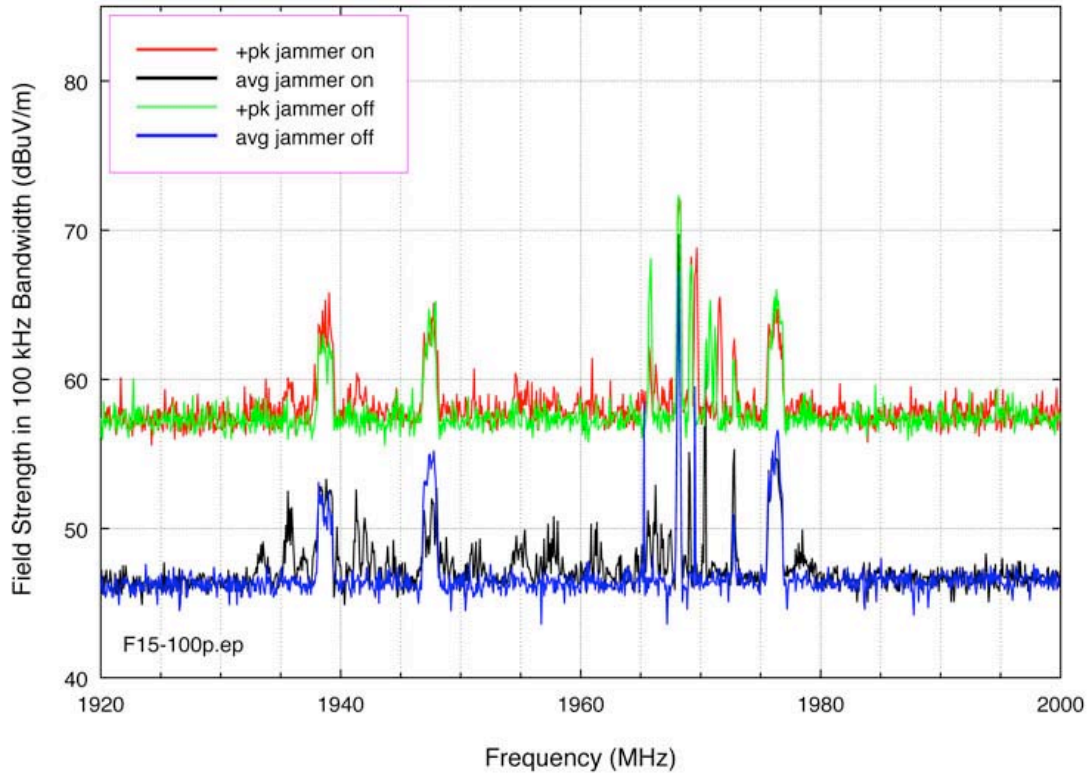


Figure 22. Beyond jamming zone, Point O-6 (52 m, non-LOS), PCS band.



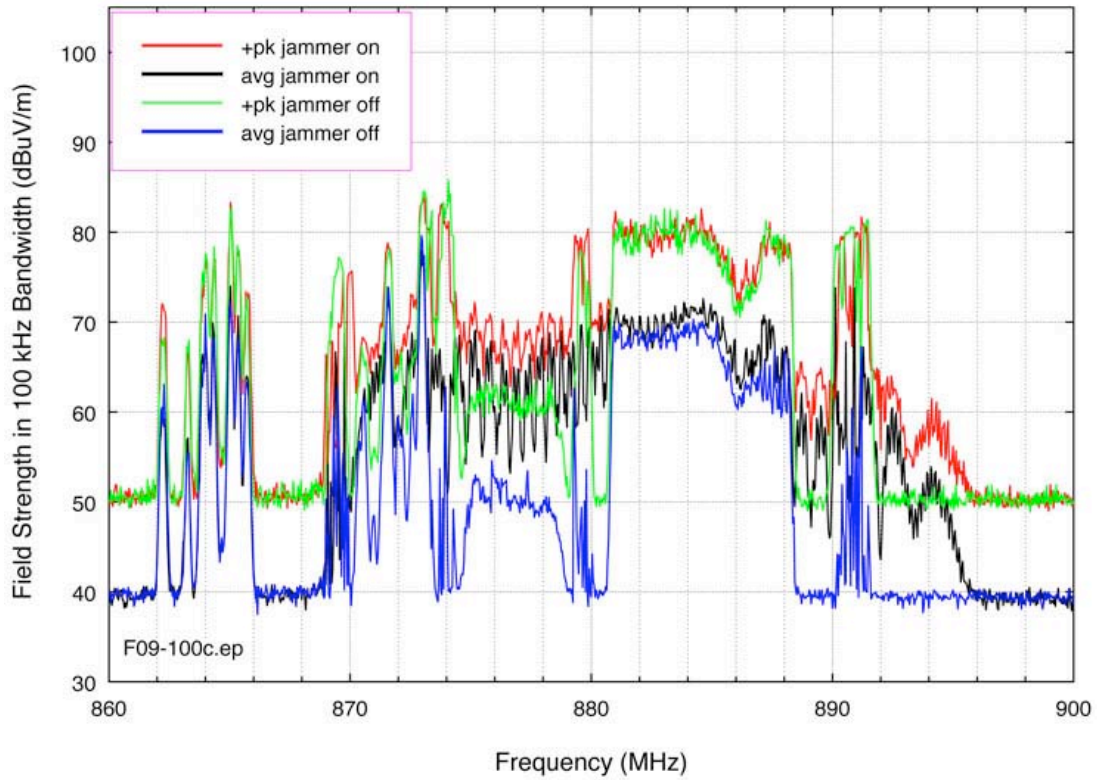


Figure 23. Beyond jamming zone, Point O-7 (74 m, non-LOS), cellular band.

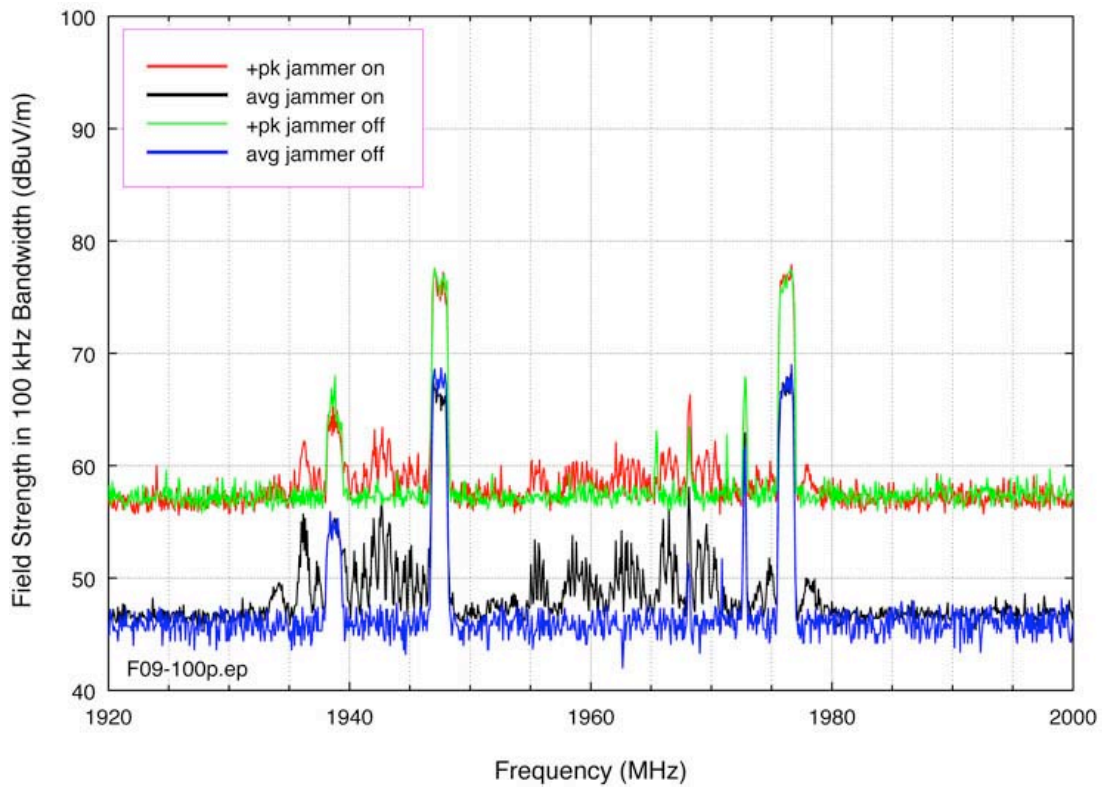


Figure 24. Beyond jamming zone, Point O-7 (74 m, non-LOS), PCS band.

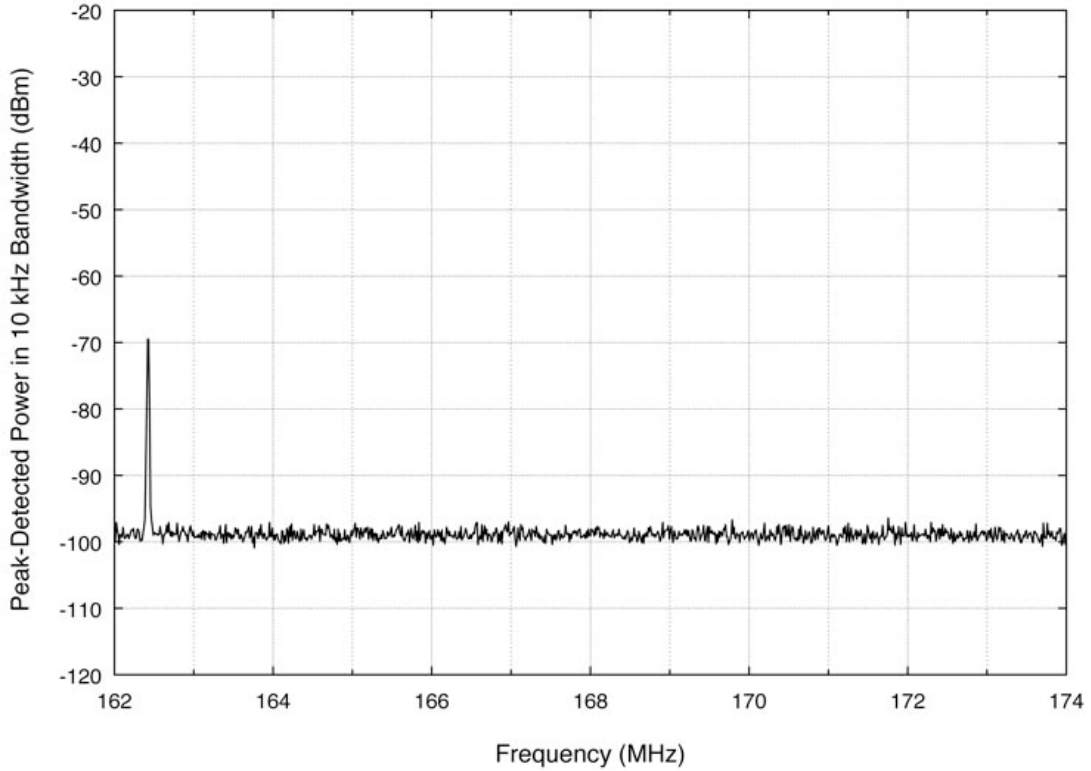


Figure 25. Measured power at Point O-1, 162-174 MHz, no jammer emission observable. A weather service signal is observed.

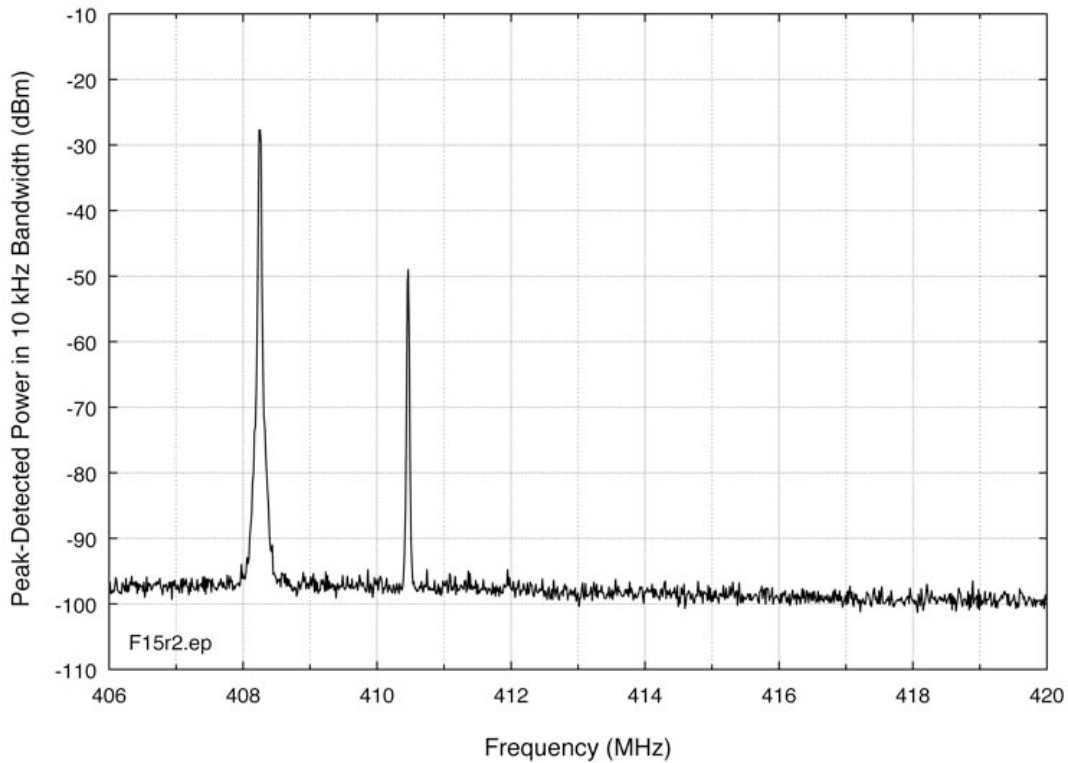


Figure 26. Measured power at Point O-1, 406-420 MHz, no jammer emission observable. Two local land mobile radio signals are observed.

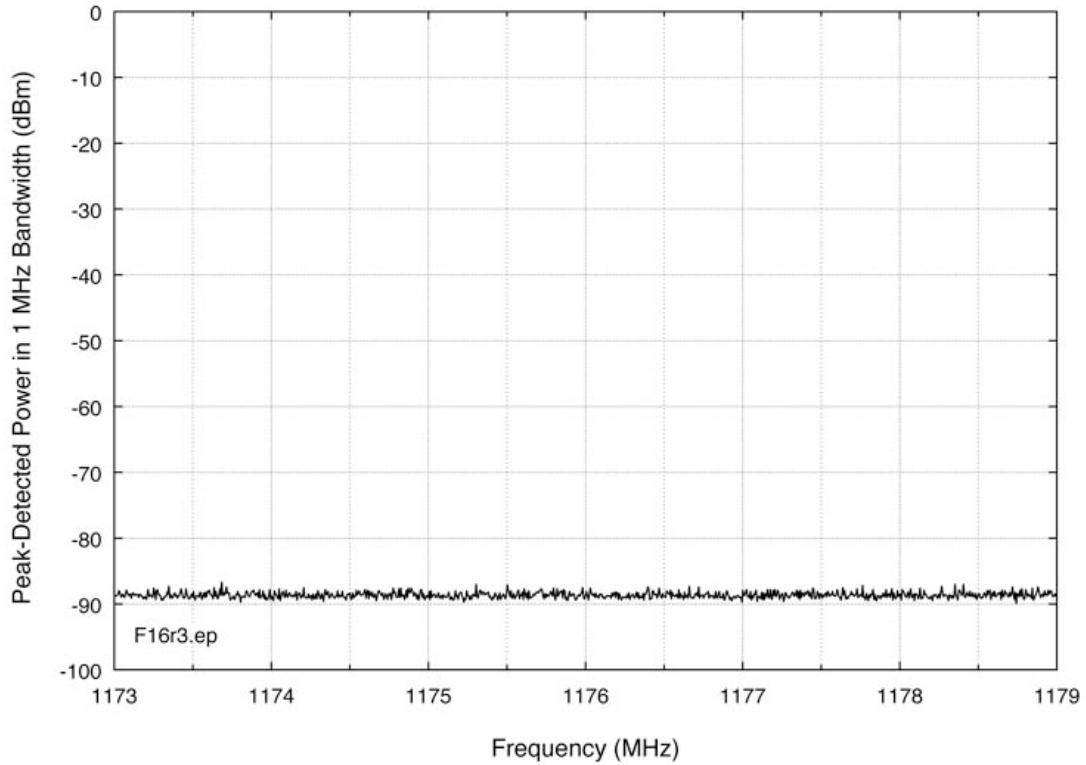


Figure 27. Measured power at Point O-1, 1176 MHz, no jammer emission observable.

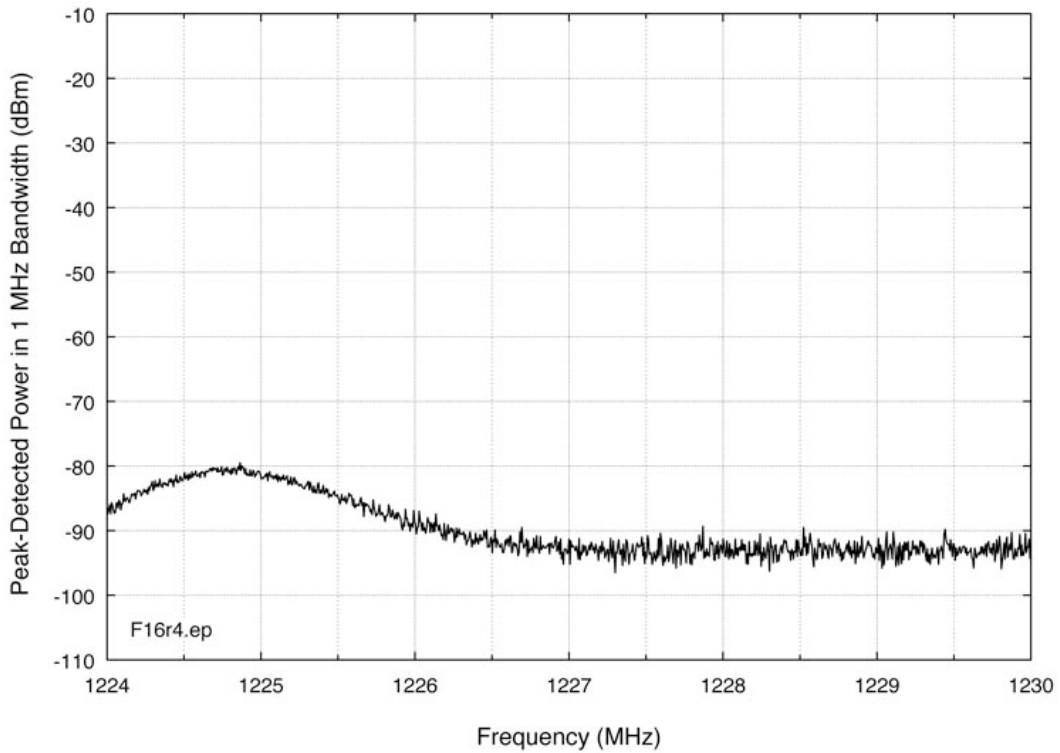


Figure 28. Measured power at Point O- 1, 1227 MHz, no jammer emission observable. The hump at 1224.7 MHz is not a jammer emission.

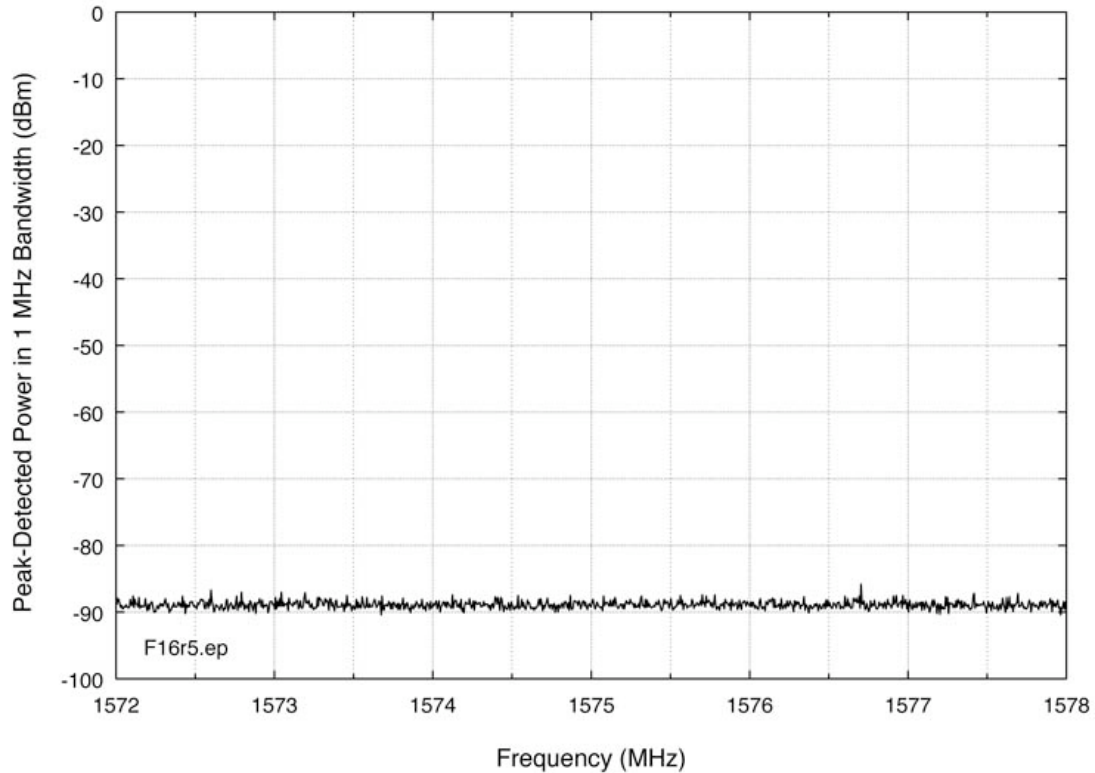


Figure 29. Measured power at Point O-1, 1575 MHz, no jammer emission observable.

### 3.3 Analysis of Measurement Results

At the indoor locations, measured differences in power between when the jammer was on versus off indicated that cellular and PCS signal power levels were measurable and jammer power was much greater than either. For the outdoor locations where jamming was not intended, the results showed that jammer power was measurable at distances up to 127 m from the building (131 from the center of the building). However, the differences in power between when the jammer was on and off were not as large as were observed for the indoor locations. Analysis of the in-band (cellular and PCS) potential for harmful interference, if any, of the jammer emissions that were observed outside the jamming zone was beyond the scope of this report. Given that the jammer’s transmitted in-band power levels were constant with frequency [1], the in-band variations in power level as a function of frequency that were observed in the measurements in this report are believed to be due to frequency-dependent effects of multipath propagation, building penetration, and diffraction. Measurements of jammer emissions at other facilities would produce different results.

Jammer signal power levels were below measurable levels at the outdoor locations within the Federal land mobile radio (LMR) and Global Positioning System (GPS) bands of 162-174 MHz, 406-420 MHz, 1164-1188 MHz, 1215-1240 MHz, and 1559-1610 MHz.

## 4 SUMMARY

- 1) The same jammer system as was measured earlier in an anechoic chamber in Boulder, Colorado was temporarily installed and operated under an STA in cellular and PCS bands at a minimum-security Federal prison at Cumberland, Maryland. The building construction was of steel-reinforced cinderblock, two floors in height, with windows in the exterior walls. The jammer installation was intended to block reception of cellular and PCS signals inside the building while not causing harmful interference to such signals outside the building.
- 2) The EIRP of the jammer system in each band (cellular and PCS) was  $+42 \text{ dBm} = +12 \text{ dBW} = 15.8 \text{ W}$ . This EIRP was radiated via a set of four omnidirectional antennas, two per floor, located above each of the floors' respective ceilings. The antennas that were used were of the same model as had been supplied with the jammer for the earlier anechoic chamber measurements.
- 3) NTIA performed in-band and adjacent-band measurements of the jammer emissions relative to the ambient cellular and PCS signal levels both inside the target jamming zone (the building interior) and outside the building, where jamming was not intended. The results of those measurements are provided in this report.
- 4) The jammer emissions were observed at distances up to the maximum that could be accessed by the measurement vehicle, at 131 m from the center of the jamming zone.
- 5) Inside the targeted jamming zone (the building interior), the jammer signal power levels exceeded the levels of the ambient cellular and PCS signals. Beyond that zone (outside the building, that is), the jammer signal was still measurable. The relative levels of the jammer signal and the ambient cellular and PCS signals varied as a function of distance and azimuth from the building. Non-line-of-sight paths outside the building showed less jammer signal power than line-of-sight paths.
- 6) No measurable signal power was observed outside the jamming zone in the Federal LMR and GPS bands of 162-174 MHz, 406-420 MHz, 1164-1188 MHz, 1215-1240 MHz, and 1559-1610 MHz.
- 7) Analysis of the in-band (cellular and PCS) potential for harmful interference, if any, of the jammer emissions that were observed outside the jamming zone was beyond the scope of this report.
- 8) The results presented in this report are idiosyncratic to the technical particulars of this jammer transmitter and the building in which its signal was radiated. Different results would be expected for any given jammer installation at any given location.
- 9) For in-band measurements of chirped-frequency jammer emissions relative to ambient service-provider communication signals (such as cellular or PCS), it is recommended that the methodology used in this report should be followed. Two

spectrum measurements would need to be performed at each location, once with the jammer turned on and then repeated with the jammer turned off. This approach allows the jammer emissions to be measured relative to the ambient signal power levels. Measurements should be performed in a bandwidth commensurate with the jammer emission-line spacing. If the emission lines are less than 1 MHz apart, additional measurements in a 1 MHz reference bandwidth may also be desirable for EMC analyses. (In contrast, for measurements of spurious and out-of-band (OOB), or unwanted, jammer emission levels relative to the in-band power level of a chirped-frequency jammer signal, the proper measurement bandwidth is equal to or slightly less than the square root of the ratio of the chirp-frequency range divided by the chirp-time interval [1].)

## 5 REFERENCES

- [1] F. H. Sanders, R. T. Johnk, M. A. McFarland, and J. R. Hoffman “Emission measurement results for a cellular and PCS signal-jamming transmitter.” NTIA Technical Report 10-465, Feb. 2010. Available: <http://www.its.bldrdoc.gov/pub/ntia-rpt/10-465/index.php>.
- [2] F. H. Sanders, B. J. Ramsey and V. S. Lawrence, “Broadband spectrum survey at Los Angeles, California,” NTIA Report 97-336, May 1997. Available: <http://www.its.bldrdoc.gov/pub/ntia-rpt/97-336/index.php>.
- [3] F. H. Sanders, “Conversion of power measured in a circuit to incident field strength and incident power density, and corrections to measured emission spectra for non-constant aperture measurement antennas,” Appendix C, *In*: W. Kissick (ed.), “The temporal and spectral characteristics of ultrawideband signals.” NTIA Technical Report 01-383, Jan. 2001. Available: <http://www.its.bldrdoc.gov/pub/ntia-rpt/01-383/index.php>.



## APPENDIX A. JAMMER EMISSIONS MEASURED IN 1 MHZ BANDWIDTH

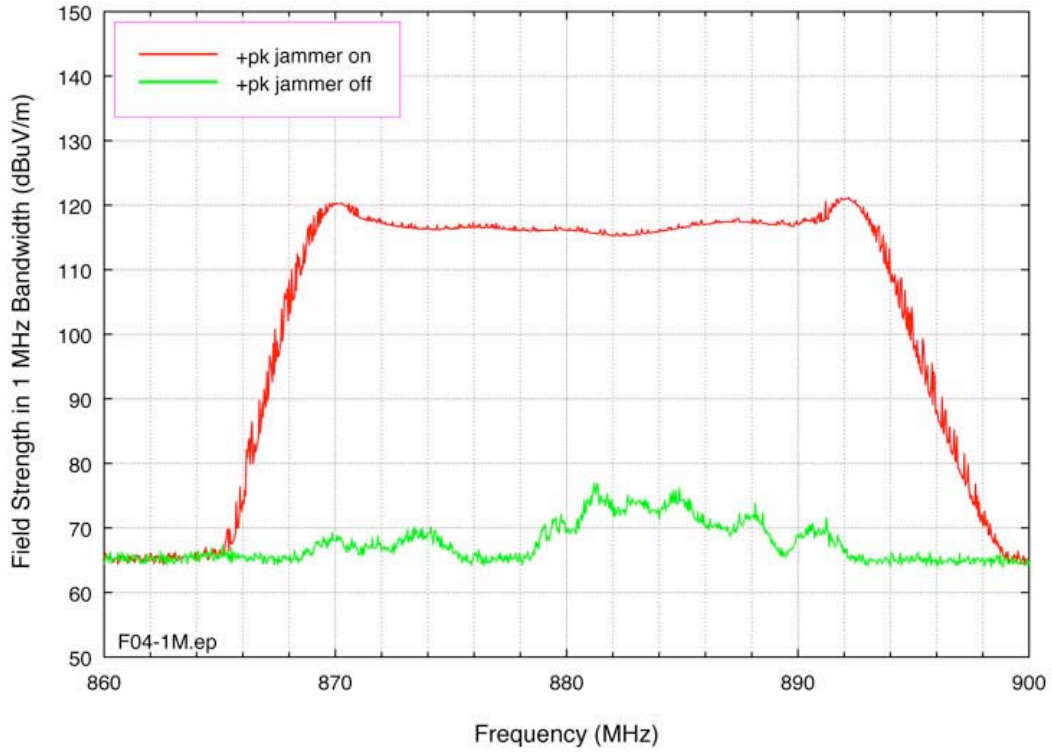


Figure A-1. Inside jamming zone, Point I-1 (first floor, west end), cellular band.

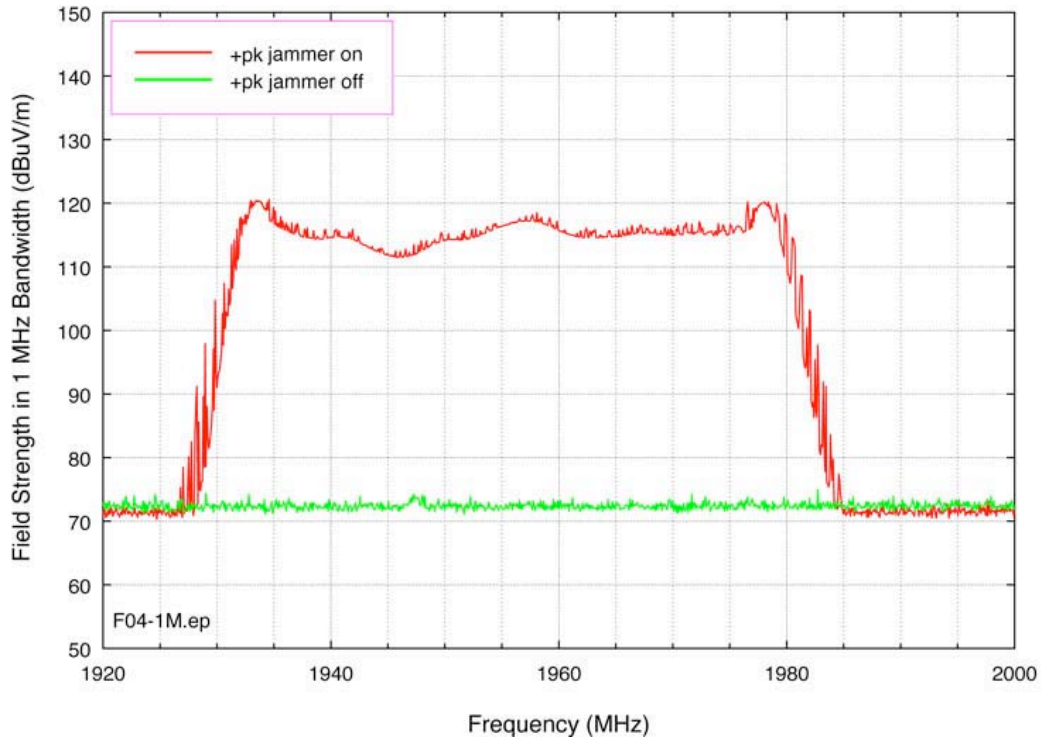


Figure A-2. Inside jamming zone, Point I-1 (first floor, west end), PCS band.



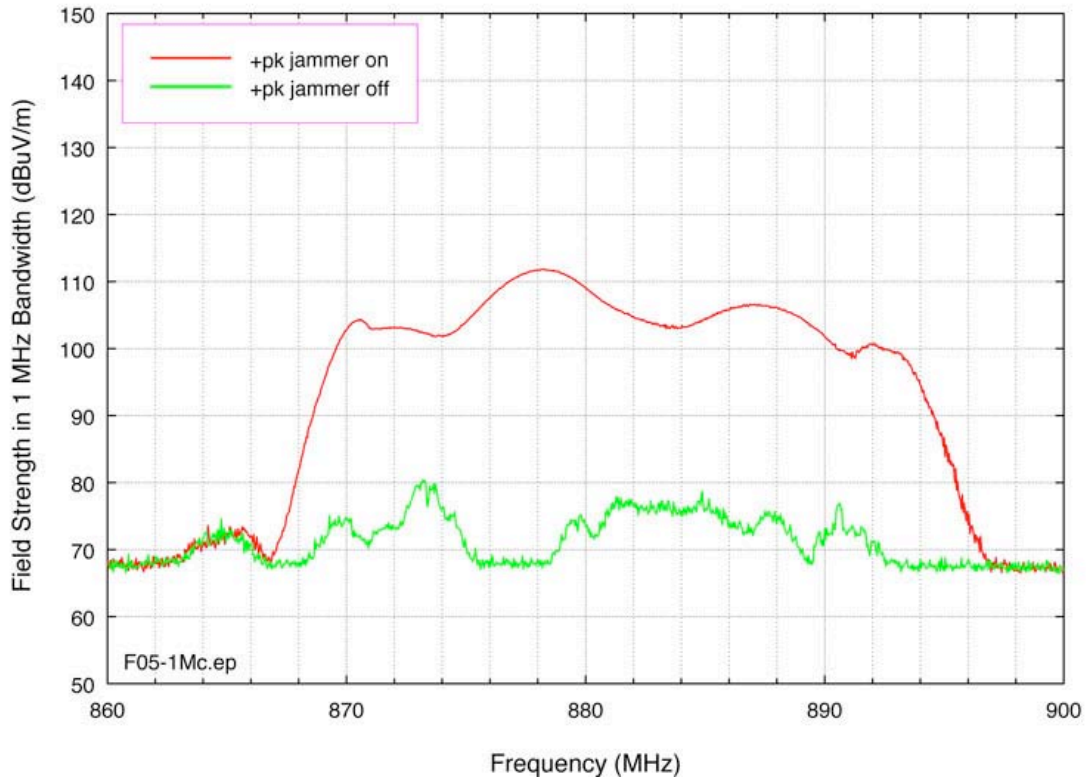


Figure A-3. Inside jamming zone, Point I-2 (first floor, east end), cellular band.

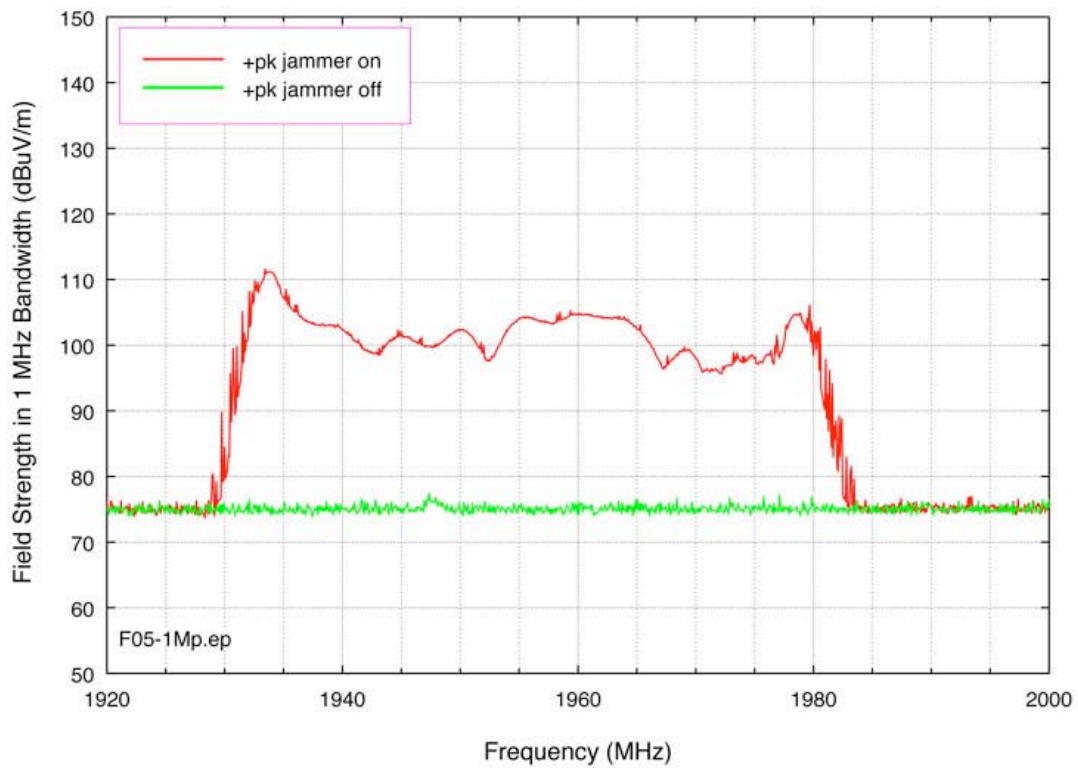


Figure A-4. Inside jamming zone, Point I-2 (first floor, east end), PCS band.

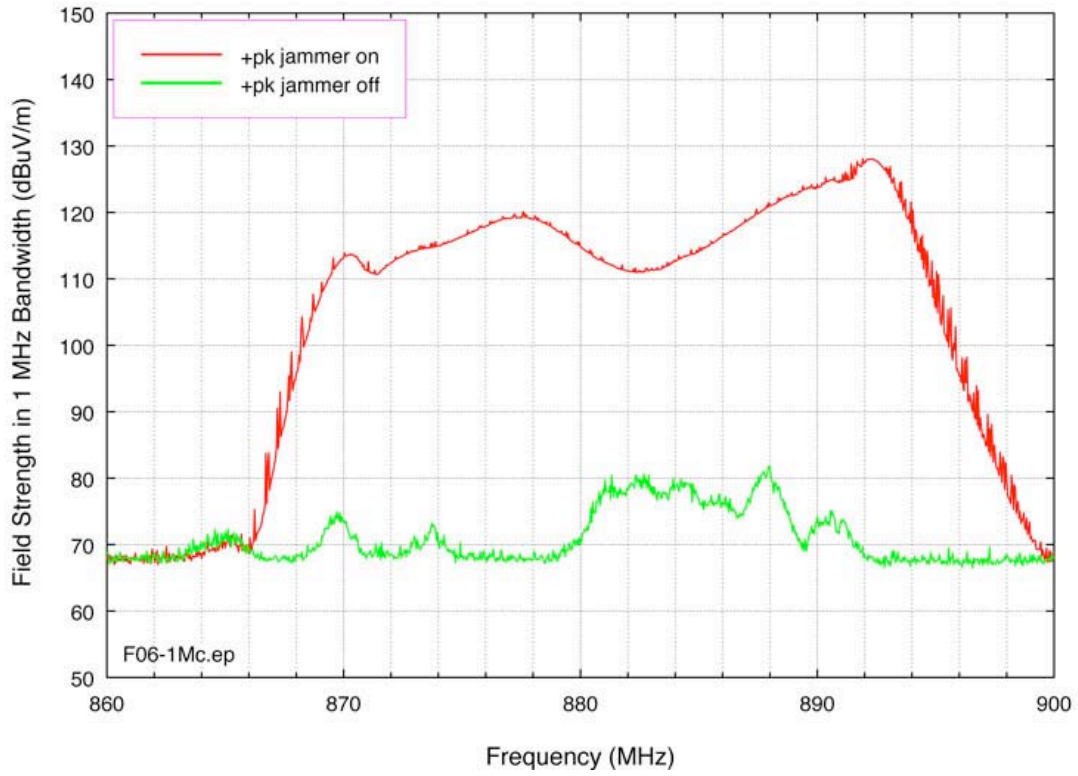


Figure A-5. Inside jamming zone, Point I-3 (second floor, west end), cellular band.

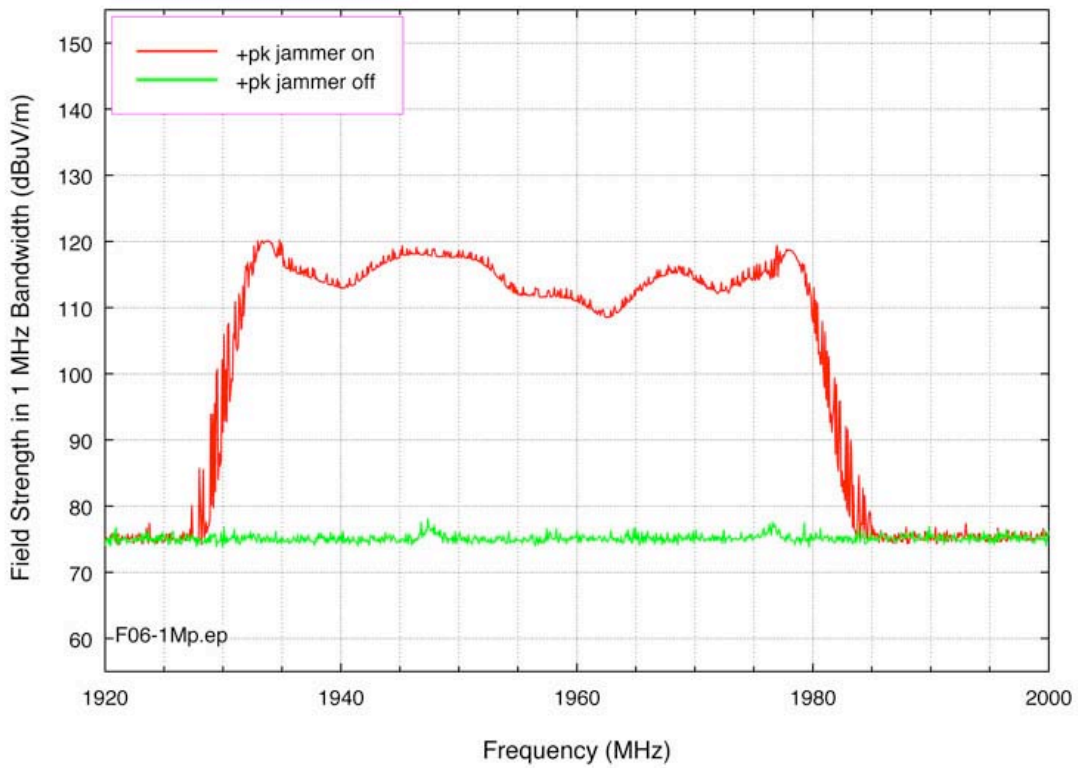


Figure A-6. Inside jamming zone, Point I-3 (second floor, west end), PCS band.

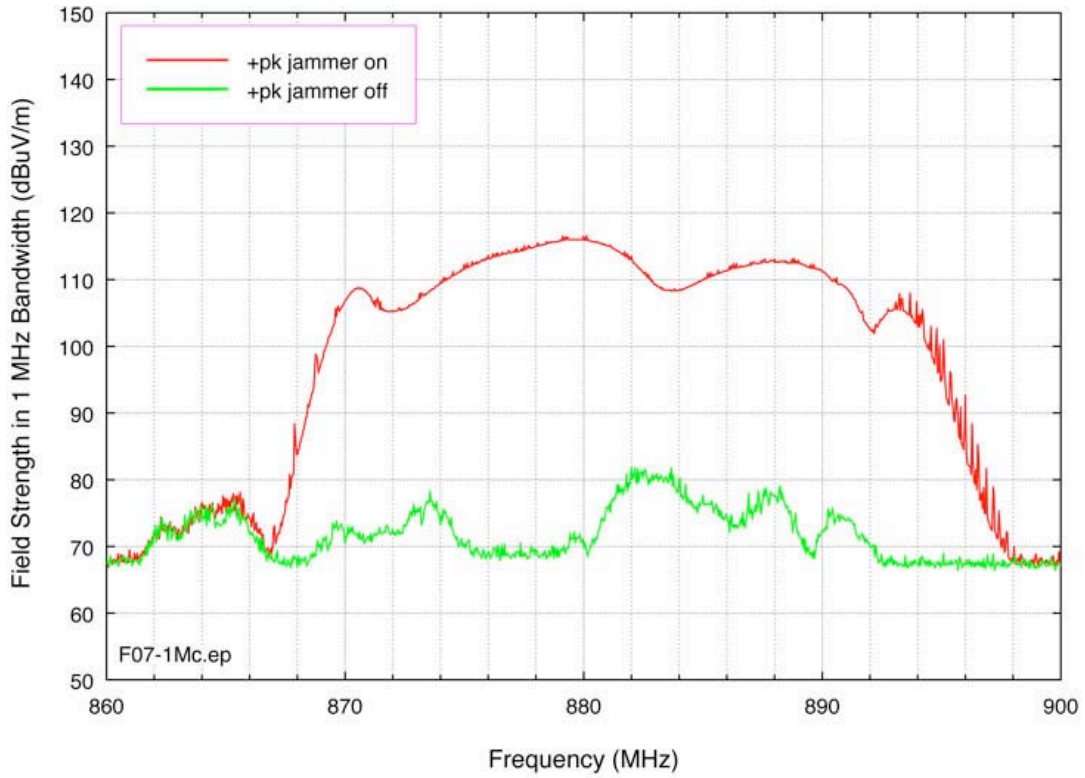


Figure A-7. Inside jamming zone, Point I-4 (second floor, east end), cellular band.

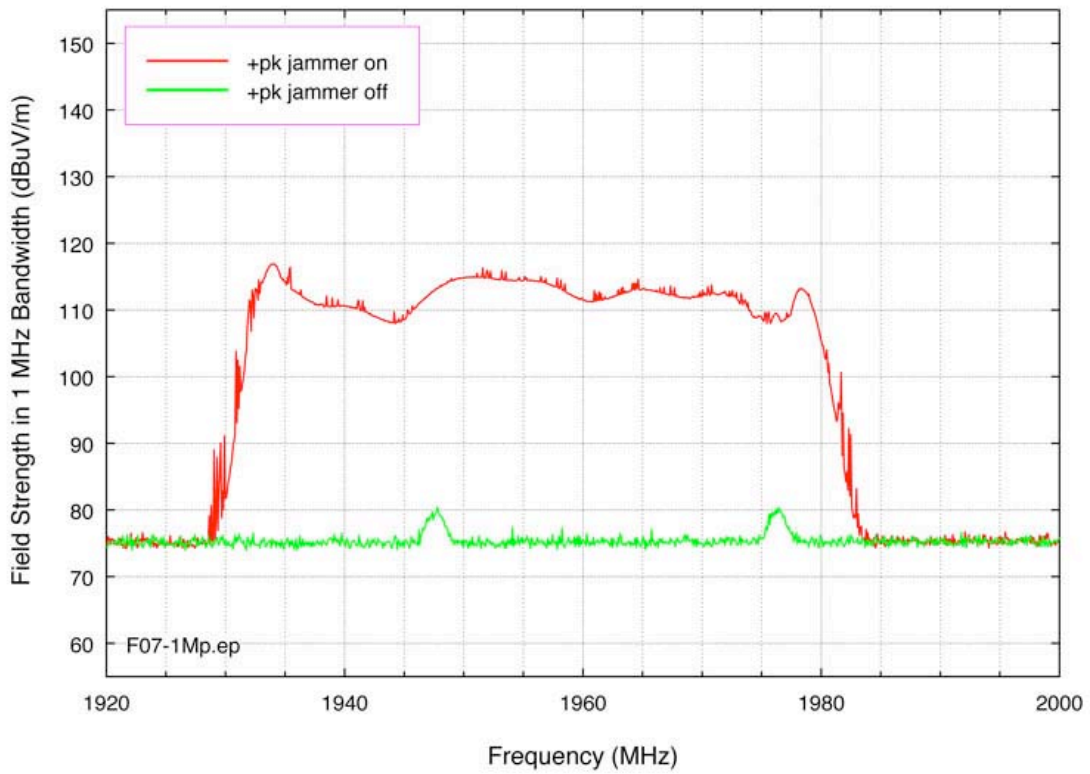


Figure A-8. Inside jamming zone, Point I-4 (second floor, east end), PCS band.

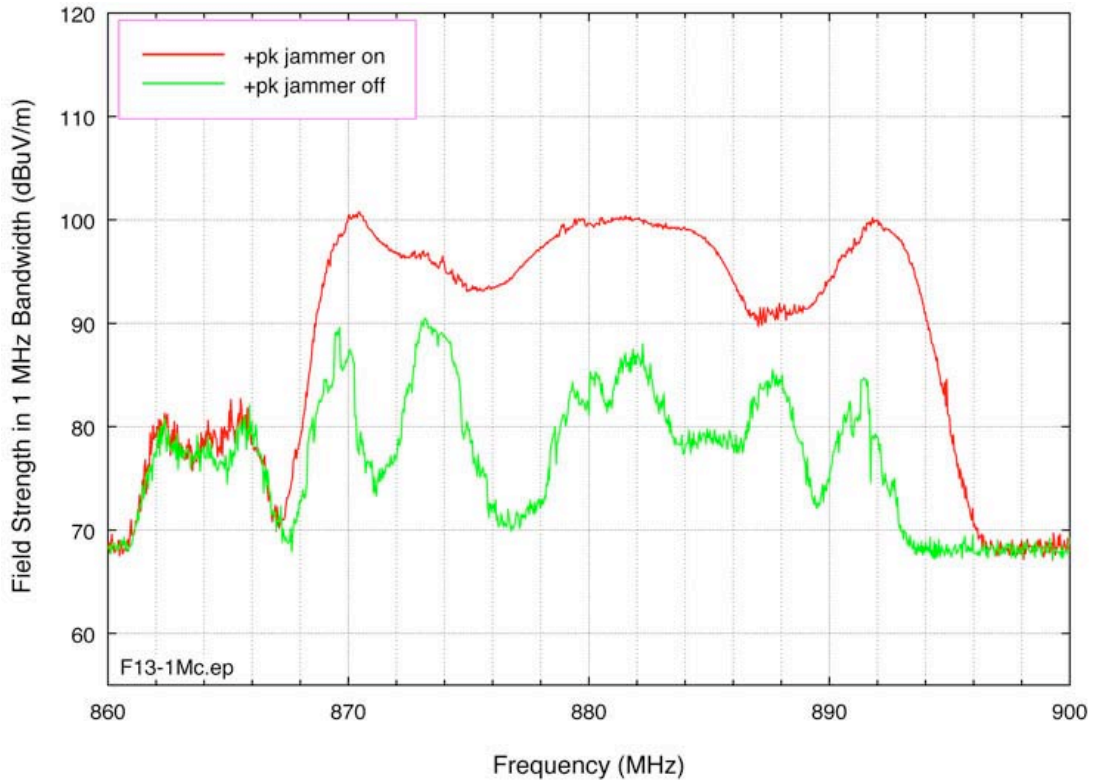


Figure A-9. Beyond jamming zone, Point O-1 (26 m from center), cellular band.

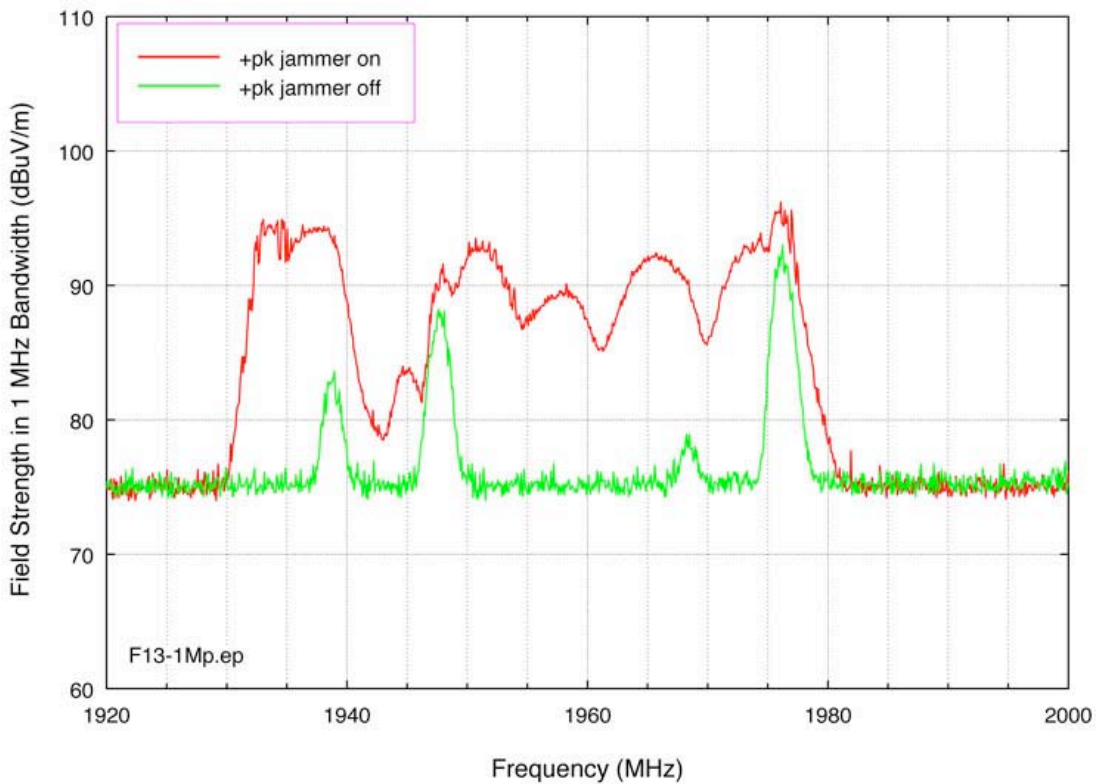


Figure A-10. Beyond jamming zone, Point O-1 (26 m from center), PCS band.



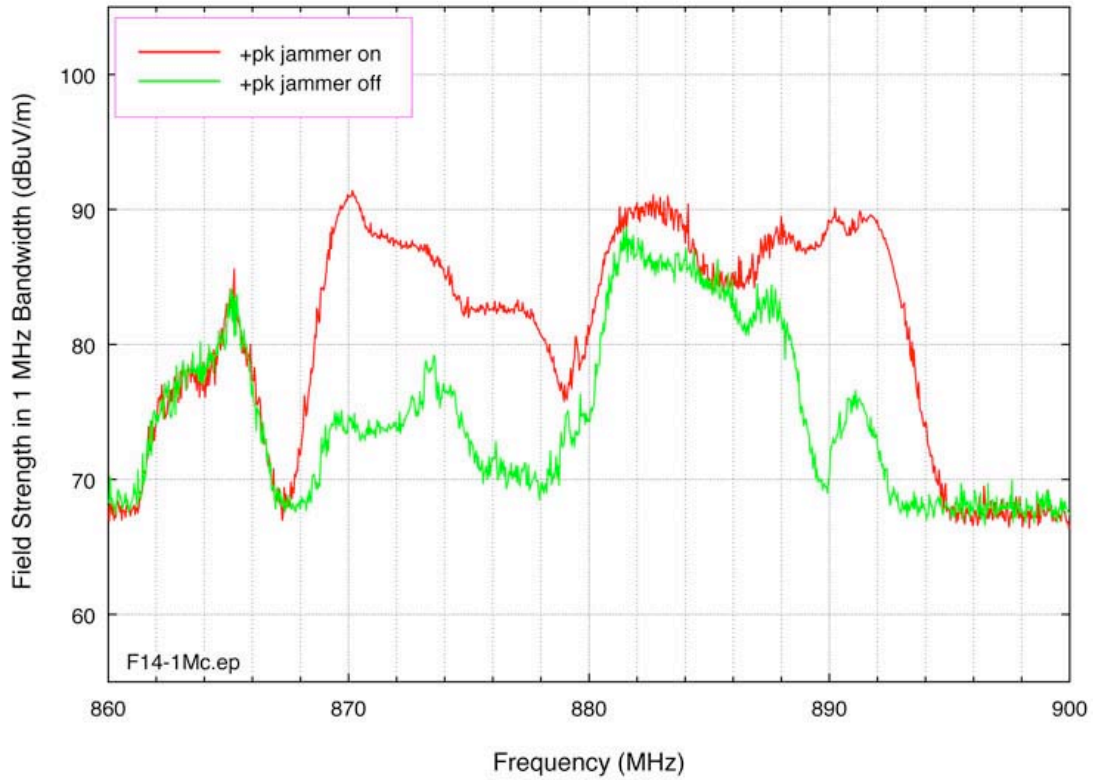


Figure A-11. Beyond jamming zone, Point O-2 (35 m from center), cellular band.

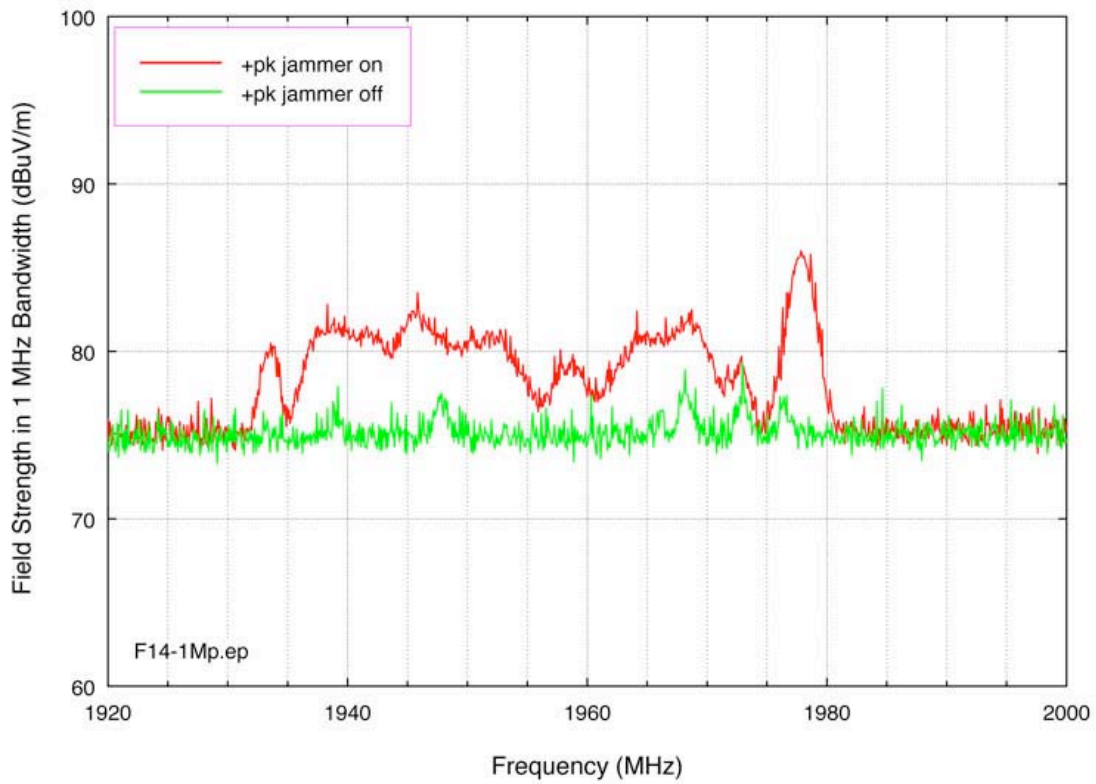


Figure A-12. Beyond jamming zone, Point O-2 (35 m from center), PCS band.

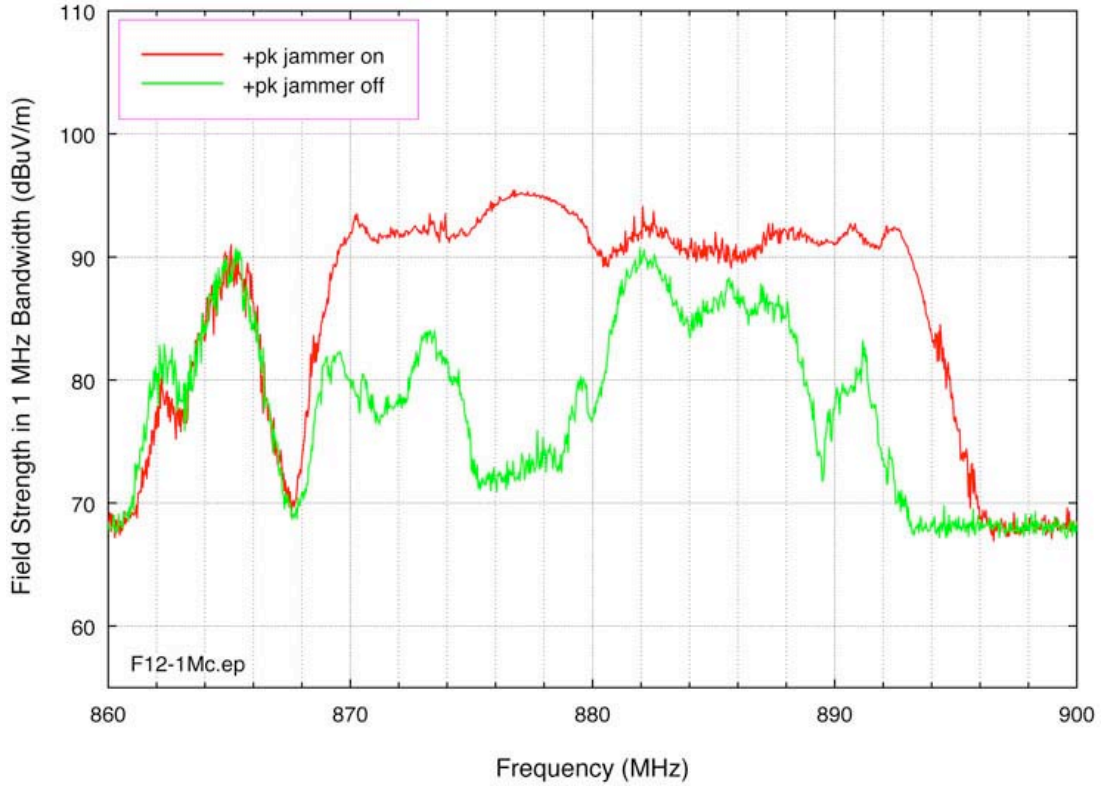


Figure A-13. Beyond jamming zone, Point O-3 (37 m from center), cellular band.

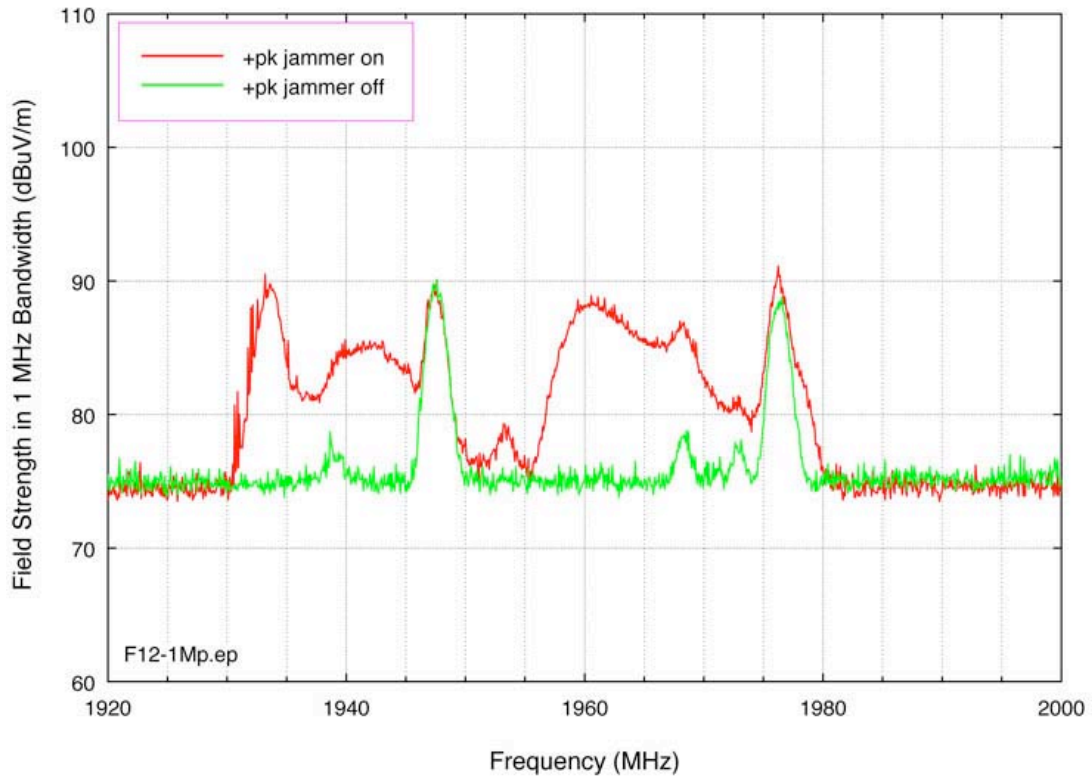


Figure A-14. Beyond jamming zone, Point O-3 (37 m from center), PCS band.

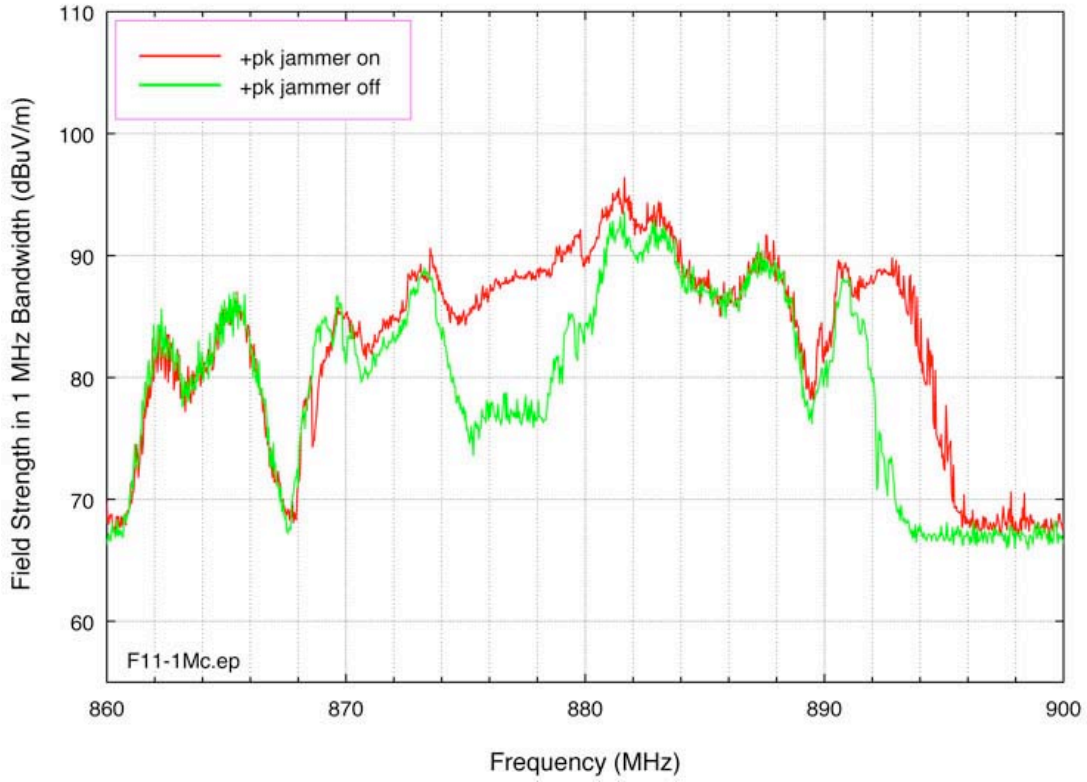


Figure A-15. Beyond jamming zone, Point O-4 (87 m from center), cellular band.

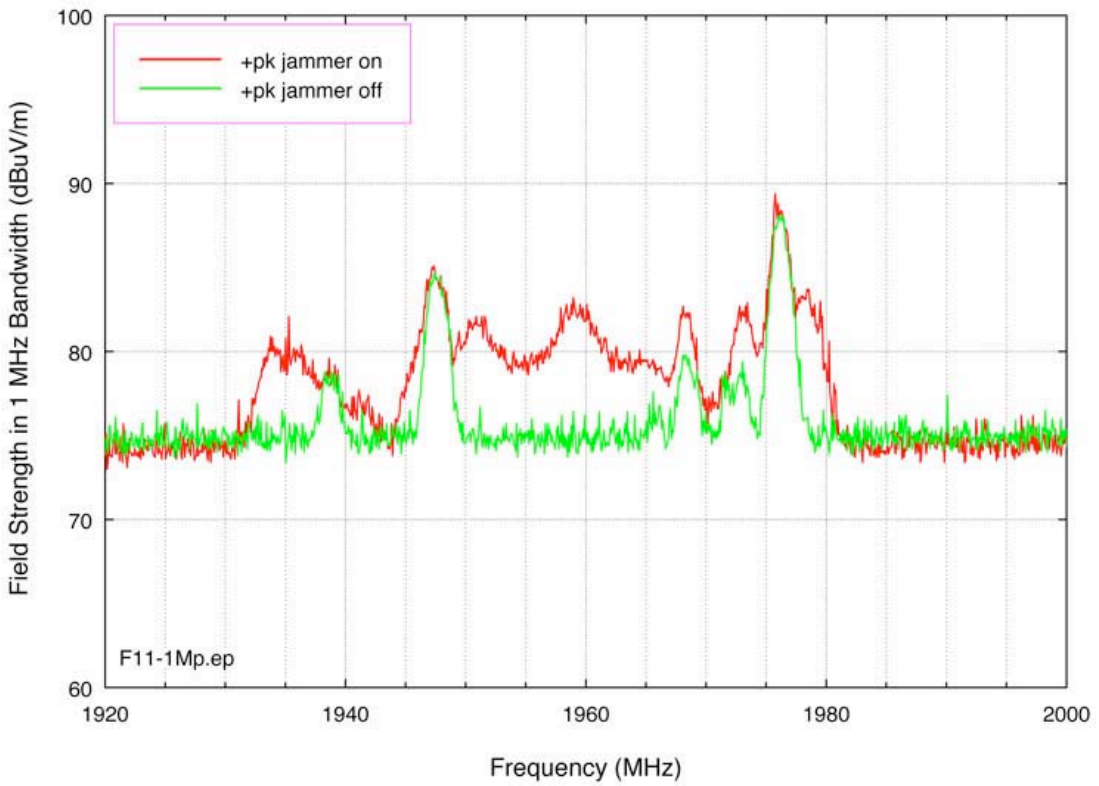


Figure A-16. Beyond jamming zone, Point O-4 (87 m from center), PCS band.

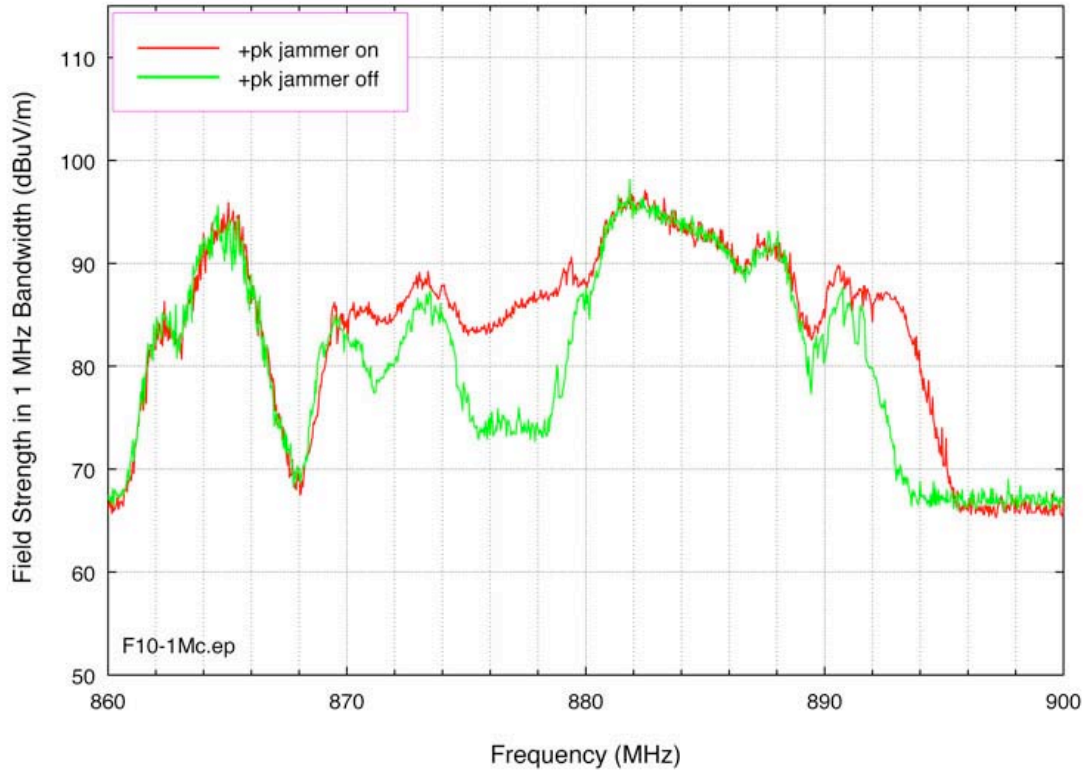


Figure A-17. Beyond jamming zone, Point O-5 (131 m from center), cellular band.

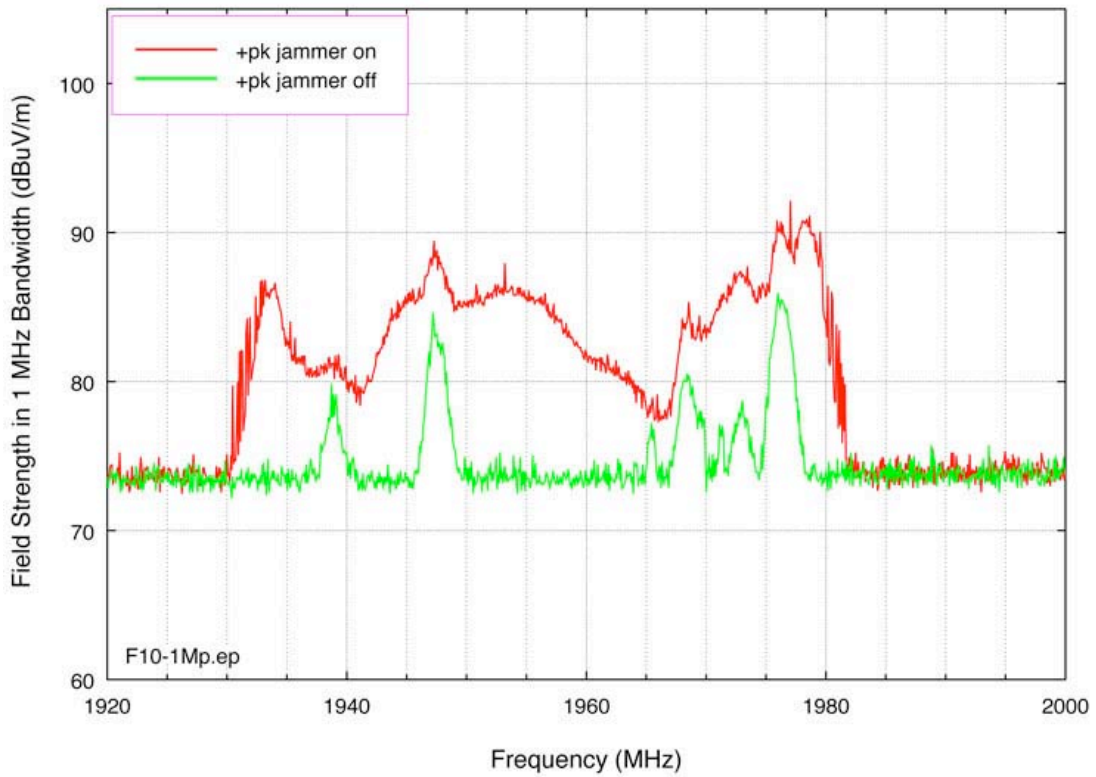


Figure A-18. Beyond jamming zone, Point O-5 (131 m from center), PCS band.



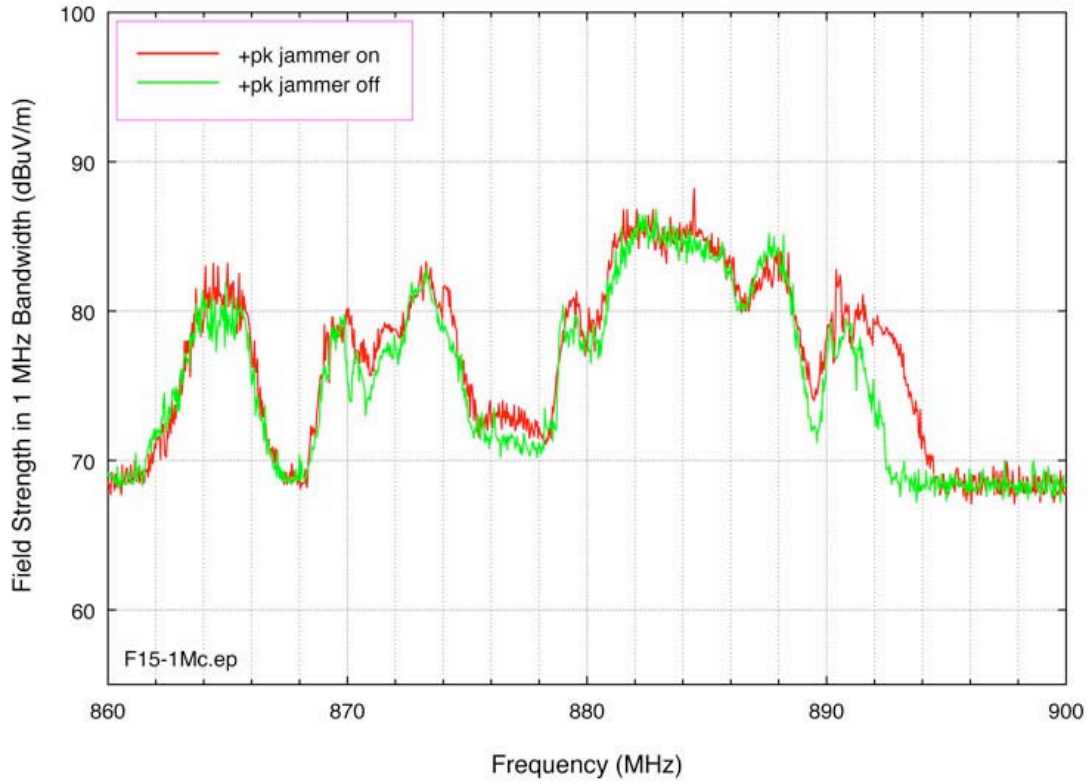


Figure A-19. Beyond jamming zone, Point O-6 (52 m, non-LOS), cellular band.

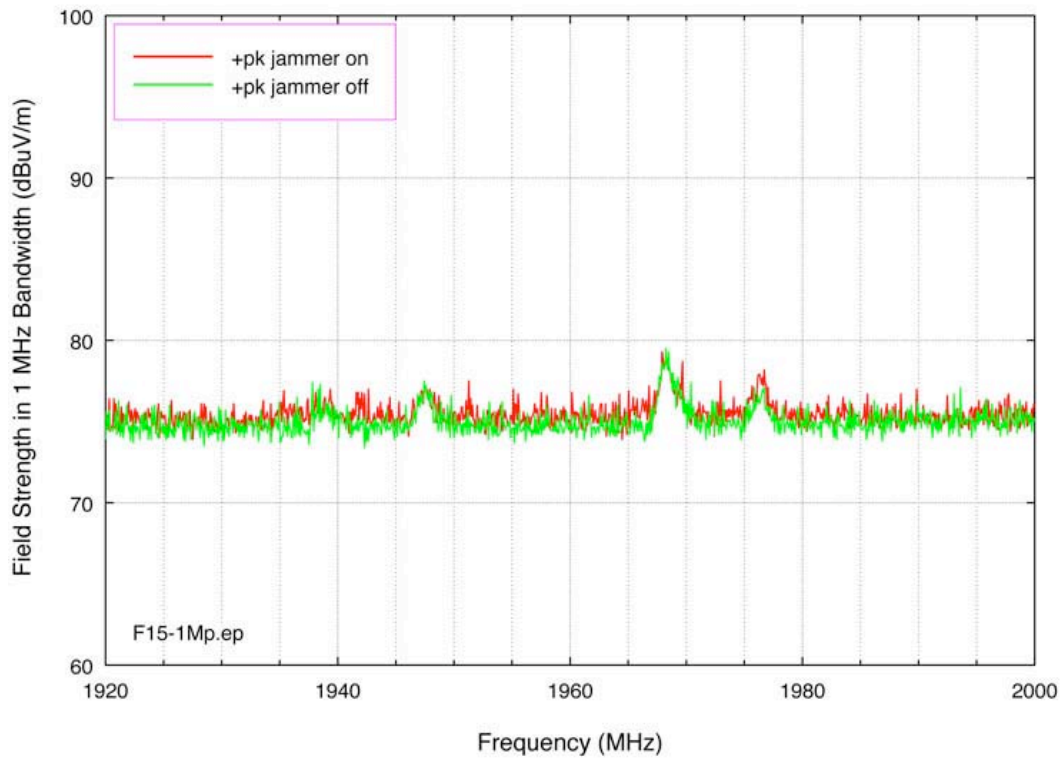


Figure A-20. Beyond jamming zone, Point O-6 (52 m, non-LOS), PCS band.

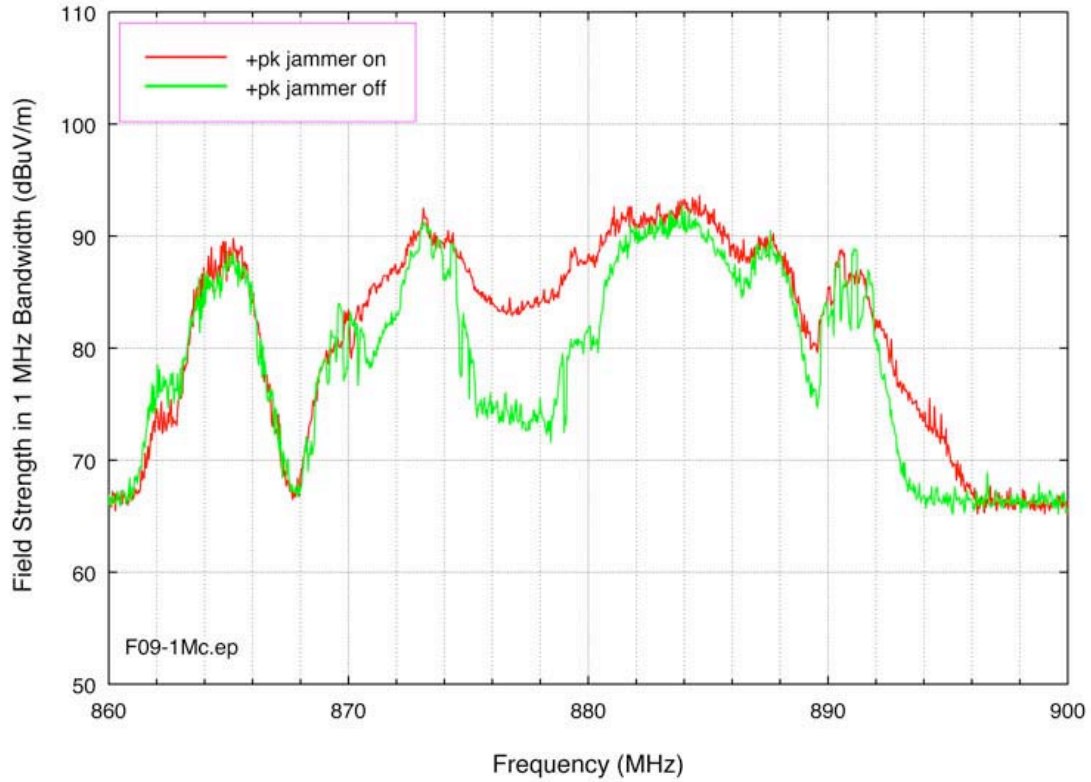


Figure A-21. Beyond jamming zone, Point O-7 (74 m, non-LOS), cellular band.

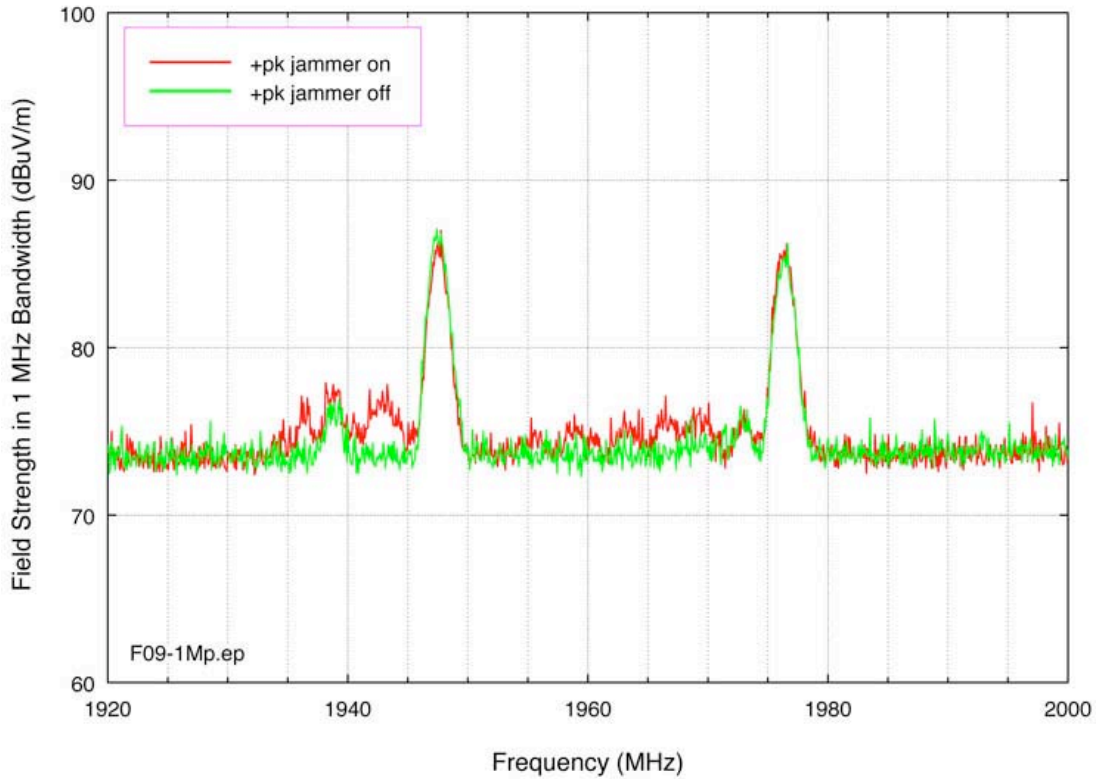


Figure A-22. Beyond jamming zone, Point O-7 (74 m, non-LOS), PCS band.

## APPENDIX B. POWER UNIT CONVERSIONS

### B.1 Power Conversion Between Measured dBm and Displayed Field Strength Units

The power units in Figures 3-24 and Appendix A are logarithmic field strength (decibels relative to a microvolt per meter, or dB $\mu$ V/m). The raw data were collected in decibels relative to a milliwatt, or dBm. The conversion between these units was performed as follows (adapted from [3, Eq. (C.21)]):

$$FS = P_{meas} + 77.2 + 20 \log(f) - G_{rx}, \quad (1)$$

where:

$FS$  = field strength in space of the measured signal (dB $\mu$ V/m);

$P_{meas}$  = measured power in a 50-ohm circuit (dBm);

$f$  = frequency (MHz);

$G_{rx}$  = gain of the receiving (measurement) antenna (dBi).  $G_{rx} = -1$  dBi for these measurements in both bands.

### B.2 Conversion of Jammer Emission Field Strength to EIRP

The EIRP of the jammer emissions in the area outside the building can also be calculated. Using [3, Eq. (C.34)]:

$$EIRP = P_{meas} - G_{rx} - 27.5 + 20 \log(f) + 20 \log(r, meters), \quad (2)$$

and comparing Eq. (2) to Eq. (1), the EIRP is computed from the field strength as:

$$(EIRP, dBm) = (FS, dB\mu V / m) - 104.7 + 20 \log(r, meters) \quad (3)$$

### B.3 Conversion Factor for Power Density

Plotting the data in field strength provides an absolute power level in space of the jammer emissions and removes the effect of the measurement antenna gain from the data. Field strength can be converted to incident power density, if necessary [3, Eq. (C.43)]:

$$\left( \frac{\mu W}{cm^2} \right) = \frac{10^{\left( \frac{FS, dB\mu V / m}{10} \right)}}{377 \cdot 10^{10}} \quad (4)$$



