INVESTIGATION OF SPURIOUS EMISSIONS FROM CELLULAR PHONES AND THE POSSIBLE EFFECT ON AIRCRAFT NAVIGATION EQUIPMENT

Phase I: An Exploratory Study

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The University of Oklahoma

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EXECUTIVE SUMMARY

The purpose of this study is to provide valuable information on the spurious emission levels of wireless phones and the possible effect of those emissions on aircraft navigation equipment. The work was designed to be an exploratory study with objectives being the examination of a limited number of aircraft systems, development of measurement procedures, and the early identification of any serious problems. It was not designed to be an exhaustive study of all phone-avionics combinations, but rather an initial exploratory study to identify any significant problems that may exist.

The phone technologies tested were: CDMA (Cellular), TDMA 11 Hz (Cellular), TDMA 50 Hz Cellular, TDMA 50 Hz PCS, TDMA 217 Hz, GSM 900, TDMA 217 Hz, and DCS 1800. Emissions of wireless phones positioned one meter from a receiving antenna were measured with a spectrum analyzer. If an emission occurs within the frequency range of a particular aircraft system, and the power of the emissions exceeds the sensitivity of the system's antenna, the phone could potentially interfere with that system.

The phone was placed in a semi-anechoic chamber, one meter from a dipole antenna, and was positioned so that its antenna was oriented vertically upward, while the receiving antenna was oriented horizontally. Scans were then run through five separate frequency ranges, each corresponding to the following aircraft systems: Very High Frequency Communication Omni-Range (VOR), Localizer (LOC), Very High Frequency Communication (VHF), Glide Slope (GS), and Global Positioning System (GPS). In addition, scans were performed in the transmission ranges of the wireless phones. The data obtained from the spectrum analyzer consisted of frequency-amplitude pairs, with the power amplitude given in dBm units. Graphs of the data were constructed to show the results and two levels: the sensitivity of the aircraft antenna associated with that frequency range, and an arbitrary level of 10 dBm below that sensitivity.

Analyzing the peak amplitudes of these scans revealed that none of the values exceeded the aircraft sensitivity of any system. The results of this study suggest that, at a distance of one meter from the antenna and in the orientation examined, none of the phones tested would have interfered with the antenna of the aircraft system. Phase II of this study will investigate different relative orientations of the phone and receiving antennas to determine the effects of various polarizations.

ACKNOWLEDGEMENTS

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- Nokia Inc.
- Personal Communications Industry Association

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SECTION 1 INTRODUCTION

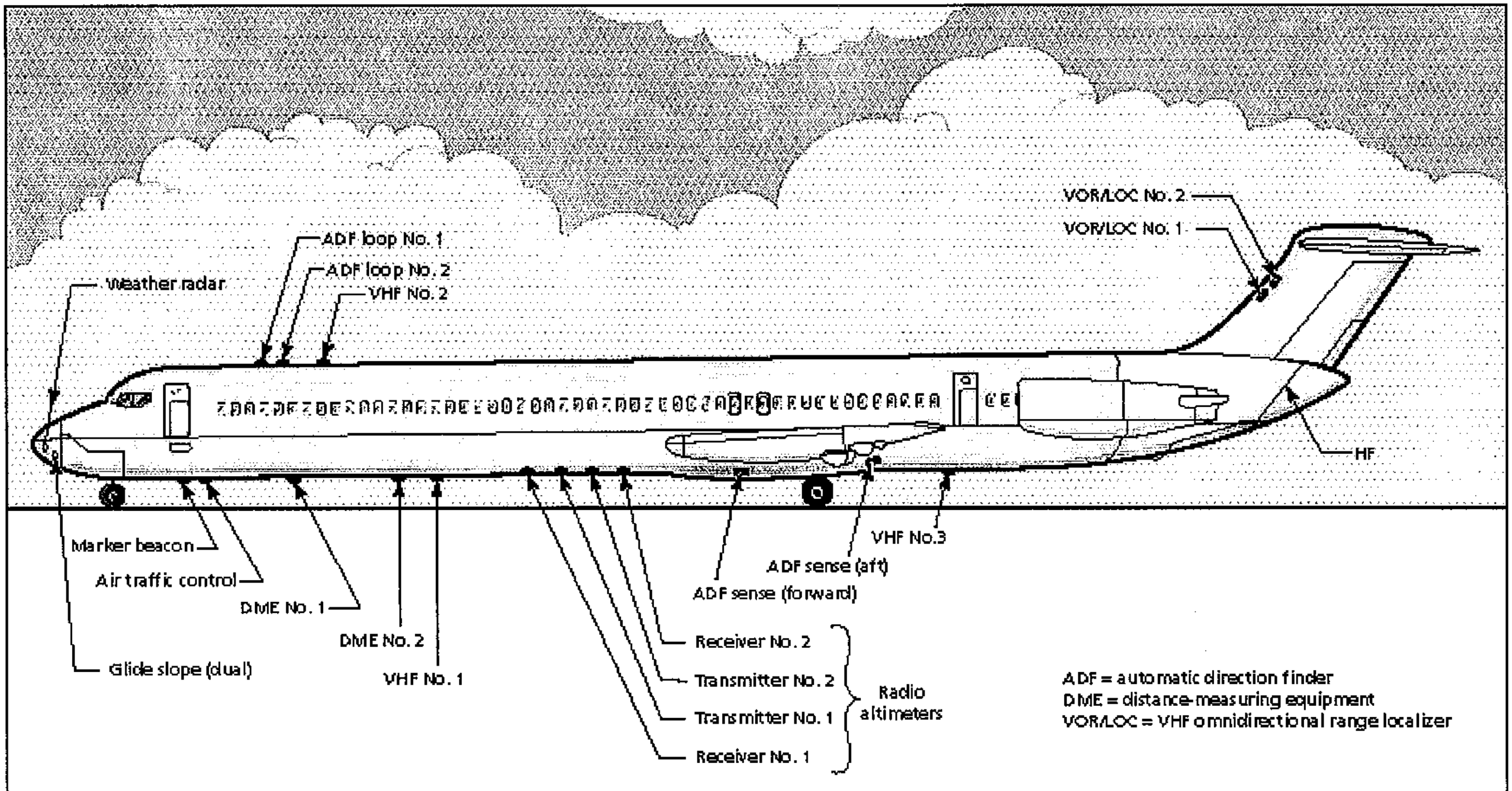
1.1 Project Overview and Objectives

The purpose of this project is to provide valuable information on the spurious emission levels of wireless phones and the possible effect of those emissions on aircraft navigation and communication equipment. The Federal Communication Commission (FCC) standard Part 47 (Federal Communications Commission, 2000) states, "The mean power of emissions must be attenuated below the mean power of the unmodulated carrier wave (P) as follows: ... On any frequency removed from the carrier frequency by more than 45 kHz, up to the first multiple of the carrier frequency: at least 60 dB or, 43 + 10 log P dB, whichever is the lesser attenuation." If an emission exceeds this requirement, it is said to be a *spurious emission*. If the frequency at which an emission occurs overlaps with the receiving range of an aircraft system, and if the power of these emissions exceeds the sensitivity of the aircraft equipment antenna, the antenna could potentially detect the spurious wireless emission. Interference with the antenna of a system may result in equipment malfunction.

The antennae of aircraft systems are extremely sensitive, as much as -115 dBm. The precise values for the systems that were tested and their operating frequency ranges, as reported to the Wireless EMC Center by the Federal Aviation Administration, are listed in Table 1.1. A diagram of where the antennas of these systems are located throughout the aircraft is given in Figure 1.1.

Table 1.1: Aircraft System Frequency Ranges and Antenna Sensitivities.

System Name	Abbreviation	Operating Range (MHz)	Antenna Sensitivity (dBm)
VHF Omni-Range	VOR	108 – 117.95	-99
Localizer	LOC	108.1 – 111.95	-106
Very High Frequency Communication	VHF	117.975 – 137	-99
Glide Slope	GS	329.15 – 335	-93
Global Positioning System	GPS	1575.42	-120



[1] Navigational instruments on this MD-80 detect radio signals broadcast from ground-based transmitters. The automatic direction finders home in on radio signals in the 170–1750-kHz range. Direction is indicated to the pilot as a magnetic bearing. VHF omnidirectional range finders (VOR) detect signals broadcast 360 degrees in azimuth. These signals indicate the azimuthal location of the aircraft relative to the transmitter. Glideslope instruments detect signals transmitted from airports that guide an aircraft's angle of approach to the runway.

Source: McDonnell Douglas

Figure 1.1: Aircraft Antenna Locations
(Perry and Geppert, 1996).

The wireless phone technologies tested in this study and the frequencies at which the phones transmit are presented in Table 1.2. One phone from each of these technologies was tested over the frequency ranges described in Table 1.1. For verification, a scan was also performed over the transmission frequency range of each phone technology, along with an ambient scan of that range. The Wireless EMC Center has accumulated extensive knowledge concerning the operation of wireless phones. This knowledge has enabled the Center to research and develop test protocols that are used for testing various electronic devices and their potential interaction with wireless phones. The Center has previously conducted studies investigating the effects of wireless phones on: hearing aids, implantable cardioverter defibrillators (ICDs), and pacemakers. This work will serve as a background in establishing experimental design and procedures for testing wireless phones.

To provide realistic data, actual cellular phones were used in this study, rather than a dipole antenna simulation. This represents the effects of the phones more accurately.

Table 1.2: Wireless Phone Technologies and Transmission Frequencies.

Phone Technology	Frequency Band (MHz)	Standard
CDMA (Cellular)	800	IS-95
TDMA – 11 Hz (Cellular)	800	8A/XB
TDMA – 50 Hz Cellular	800	TIA/EIA 627 (IS-54)
TDMA – 50 Hz PCS	1900	J-STD-011
TDMA – 217 Hz GSM	900	ETSI GSM 11.22
TDMA – 217 Hz DCS 1800	1800	ETSI GSM 11.22

This study was designed to be an exploratory effort with objectives being the examination of the systems involved, development of measurement procedures, and the identification of any serious problems. Therefore, a limited number of phones were tested, but the selection covered the most prevalent technologies.

1.2 Wireless Phone Technology

To implement a cellular communication system, a metropolitan area is divided into numerous geographic cells of a specific size and shape. Mobile communication within the cell involves three basic units – a cell site or base station, a mobile unit, and a mobile telephone switching office (MTSO). The cell site base station acts as the interface between the mobile unit and the MTSO. The mobile unit is the wireless phone that includes a control unit, transmitter-receiver unit, and an antenna system. The MTSO serves as a connection between land telephone networks (line phones) and mobile units, and contains cellular switches and a processor (Lee, 1995).

Cellular communication systems transmit information in either analog mode (analog transmission format) or digital mode (digital transmission format). In analog mode, the frequency, amplitude, or phase of a high-frequency carrier signal is changed according to the information signal (typically audio). In digital mode, information is converted to a series of 0's and 1's. These discrete signals are then transmitted using one of several methods of varying the carrier signal.

Cellular communication systems use different multiplexing technologies for accommodating multiple users. Multiplexing is the technique of sending multiple signals or streams of information on a carrier at the same time. Analog signals are typically multiplexed using frequency division multiplexing. In addition, digital signals may be multiplexed using time division or code division multiplexing. Among the different multiplexing techniques, two techniques used for digital cellular communication systems are discussed below.

Time Division Multiple Access (TDMA) systems assign users both a specific channel and a time slot so that multiple users can share time on a single channel with no noticeable loss of speech. The first step in digital phone transmission using TDMA is to digitize the analog voice signal using an analog-to-digital (A/D) converter. Pulse Code Modulation (PCM) is implemented for the A/D conversion, where the analog voice signal is sampled at regular intervals and converted to equivalent binary data.

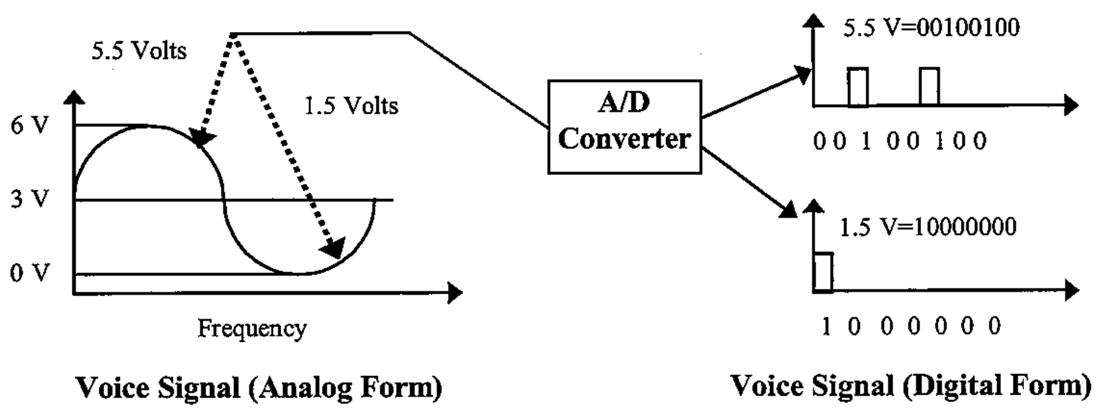


Figure 1.2: A/D Conversion Using Pulse Code Modulation
(Adapted from Swindell and Pitts, 1992).

As illustrated in Figure 1.2, PCM samples the analog voice signal at 5.5 Volts and digitizes it as 00100100 using the A/D converter. After a predetermined time period, PCM then samples the analog voice signal at 1.5 Volts and performs a similar conversion. To improve the efficiency of transmission, a CODEC (CODER/DECODER) unit compresses the binary output data from the A/D converter to an equivalent bit stream that represents the same information using a coding technique called linear predictive coding. In TDMA-50 Hz (cellular), control data are added to the 159-bit voice stream and 312 bits of information are transmitted. The compression is illustrated in Figure 1.3.

The top graph shows the original voice signal in analog form. Through A/D conversion, the analog signal is converted into digital form, as shown in the second graph. The bottom graph shows the compressed digital signal after linear predictive coding is applied. Following the compression, the information is sent through a transmitting medium to a receiver. There are a number of disadvantages to transmitting digitized voice information directly. Instead, a high-frequency signal (the carrier signal) is modulated by the digitized voice information. With analog systems, there is often a loss of signal due to fading and an increase in noise that causes undesirable distortion. A digital system is more immune to this increase in background noise, and can also be more immune to the effects of fading. For this reason, digital transmission techniques have been successfully introduced into modern cellular systems.

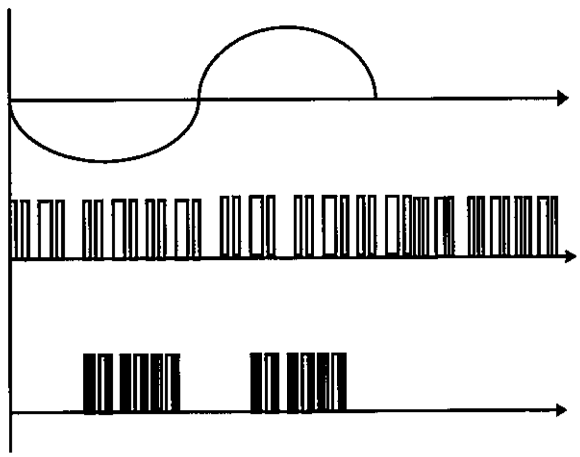


Figure 1.3: Digitized and Compressed PCM Waveform.

Digital modulation techniques include Phase Shift Keying (PSK), Minimum Shift Keying (MSK), and Differential Quadrature Phase Shift Keying (DQPSK). The selection of a particular technique depends on the channel characteristics such as the desired bandwidth and the fading present in the channel (Taub and Schilling, 1991). The TDMA system uses $\pi/4$ Differential Quadrature Phase Shift Keying ($\pi/4$ DQPSK).

Phase shift keying (PSK) is a method of modulating the phase of the carrier frequency based on the binary or modulating information. Each bit is translated into a particular phase change. Quadrature phase shift keying (QPSK) uses four possible phase states corresponding to the four combinations of two data bits: 00, 01, 10, and 11. Instead of representing the two data bits by an absolute phase shift, a relative change in phase is used. This process is called Differential Quadrature Phase Shift Keying (DQPSK). The term $\pi/4$ means that the differential phase change that represents the two data bits is some multiple of $\pi/4$ or 45°. In $\pi/4$ DQPSK modulation, '00' can be represented by +45°, '01' can be represented by +135°, '10' can be represented by -45°, and '11' can be represented by -135° with respect to the previous phase state. An example is illustrated in Figure 1.4, with the absolute phase shift labeled with respect to the initial signal. To represent the data '01', a phase change of +135° from the starting point A would move the phase shift to position B. If the next two data bits are '00' (+45°), then the phase would shift to point C (not D).

To transmit the digitally modulated information for different users on the same cellular channel, the channel is divided into frames of time. The time frames are further subdivided into time slots, which are assigned to different users. Each user transmits bursts of digitally modulated RF during the assigned time slot(s). The frame rate is the number of frames transmitted per second and is calculated as:

frame rate = (1/frame length in seconds) Hz.

Pulse repetition frequency (PRF) or the phone transmission rate is given by the number of pulses transmitted per second. The process for TDMA is shown in Figure 1.5.

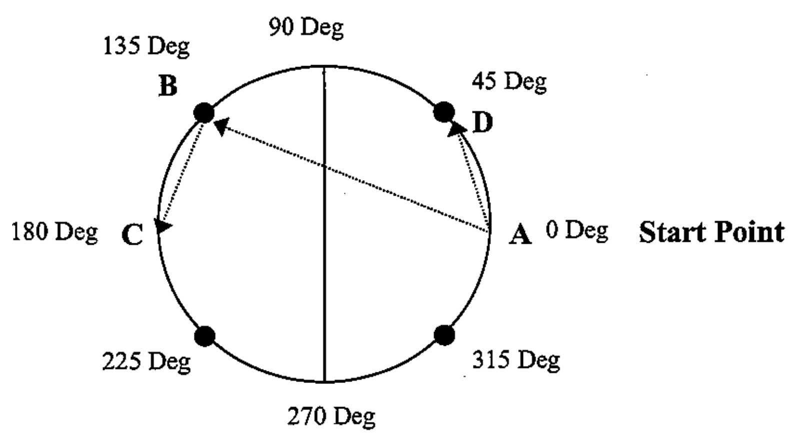


Figure 1.4: Example of π/4 Differential Quadrature Phase Shift Keying
(Swindell and Pitts, 1992).

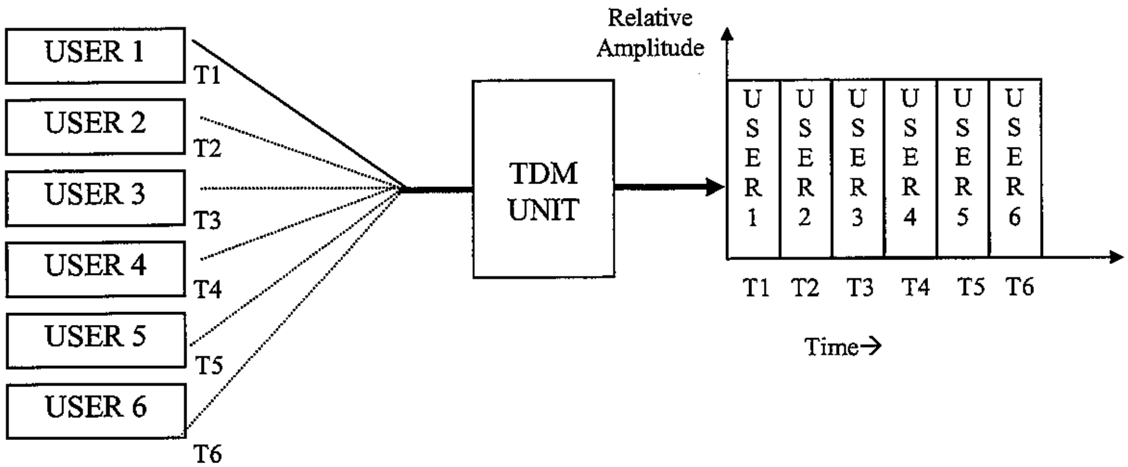


Figure 1.5: TDMA Transmission Structure.

At the receiver, the digitized information is demodulated and converted back to the analog voice signal. The receiver time slot is offset by one from the transmitter time slot (Figure 1.6).

TRANSMITTER	**USER 1**	**USER 2**	**USER 3**	**USER 4**	**USER 5**	**USER 6**
RECEIVER	**USER 6**	**USER 1**	**USER 2**	**USER 3**	**USER 4**	**USER 5**
TIME SLOTS	**SLOT 1**	**SLOT 2**	**SLOT 3**	**SLOT 4**	**SLOT 5**	**SLOT 6**

Figure 1.6: TDMA Transmission Time Offset.

Phone types vary depending on the pulse repetition frequency. TDMA-217 Hz has 8 slots per frame and each phone is assigned to one slot. The time period allotted per frame is 4.617 ms and the duration of one time slot is therefore 0.57 ms. This means that the phone transmits for 0.57 ms every 4.617 ms (Figure 1.7). The pulse repetition rate (PRR) is calculated as the reciprocal of the interval between pulses:

$$\frac{1}{4.617 \text{ x } .001 \text{ seconds}} = 0.21659 \text{ x } 10^3 = 216.59 = 217 \text{ Hz.}$$

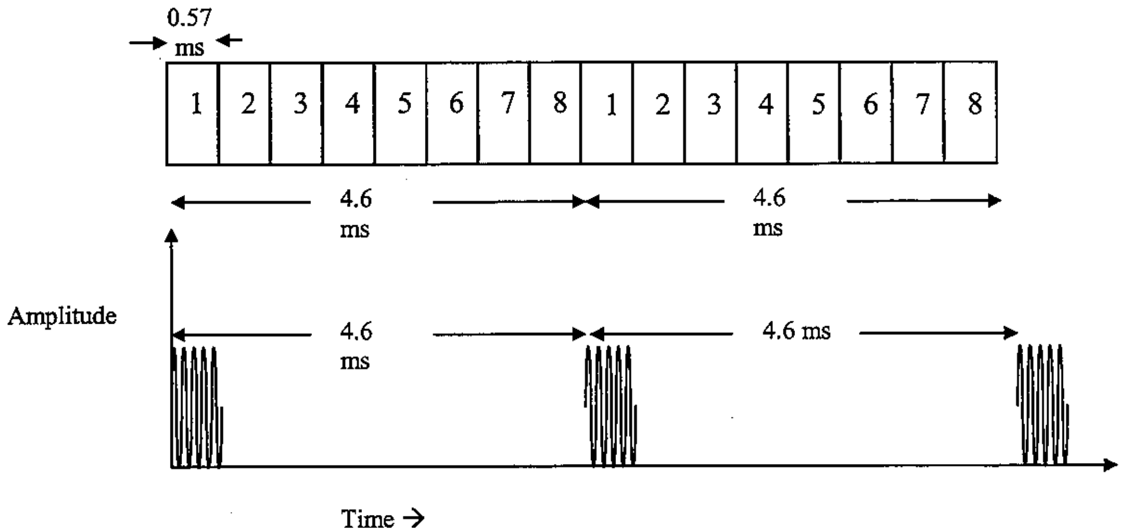


Figure 1.7: Phone Transmission for TDMA-217 Hz.

As governed in the standard TIA/EIA 627, TDMA-50 Hz transmits with a frame length of 40 ms. This 40 ms time frame is divided into six time slots of 6.67 ms each. Each mobile unit is assigned to two time slots spaced 20 ms apart such that Phone 1 will be assigned to slots 1 and 4, as shown in Figure 1.8. Thus, each mobile unit transmits an RF pulse every 20 ms and there are two such pulses within one frame. As a result, the pulse repetition rate is 50 Hz, calculated as:

$$\frac{1}{20 \text{ x } .001 \text{ seconds}} = 0.050 \text{ x } 10^3 = 50 \text{ Hz.}$$

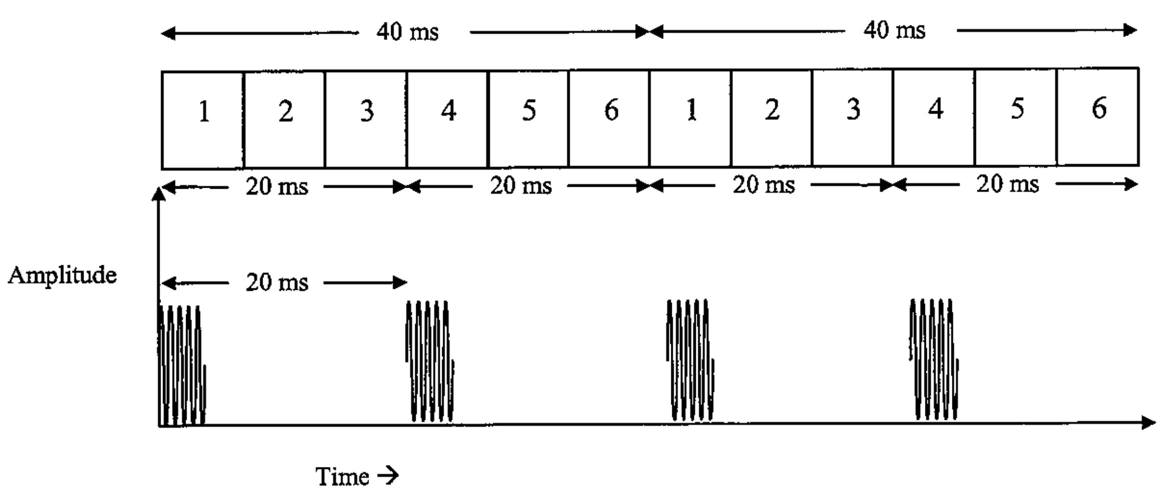


Figure 1.8: Phone Transmission for TDMA-50 Hz.

An alternative multiplexing method is Code Division Multiple Access (CDMA). In CDMA, each transmitter is assigned a pseudo-random binary sequence that modulates the carrier. The sequences that are matched at the receiver are demodulated and other signals are treated as spread spectrum noise. The CDMA system has greater user capacity compared to TDMA (QUALCOMM Inc., 1992).

The RF pulse structure of a CDMA mobile unit depends on the signal structure of the power control units within each frame of data transmission. CDMA uses two different power control systems: forward power control and reverse power control. Control of cell site power is accomplished by the forward power control system while control of mobile unit power is accomplished by the reverse power control system. In the forward power control system, the cell site reduces power by 0.5 dB every 1.25 ms until the mobile phone detects a bit error rate above a threshold value. This event is relayed as an error message to the cell site, which increases its output accordingly.

There are two subsystems in the reverse power control system: open loop and closed loop. In open loop power control, the mobile station measures the strength of incoming signals and adjusts its output power accordingly. Closed loop reverse link power control compensates for the inability of the mobile phone to estimate the path loss on the reverse signal path from the mobile to the base. In closed loop power control, the cell site measures the power from the mobile phone every 1.25 ms and sends a power control message to the mobile station.

Based on speech activity, the CDMA voice coder (vocoder) can use a variety of data rates (FULL, 1/2, 1/4, 1/8, or variable). The data transmission is interleaved every 20 ms. This 20 ms transmission time period is divided into a total of 16 slots of 1.25 ms each. When the cell site is transmitting at half rate, it transmits at full power for 8 of the 16 slots, and transmits at lower power during the remaining 8 slots. The same procedure is applied for the quarter and eighth rates. In variable rate transmission, on average, 40% of the total slots are transmitted at full power while the remaining 60% are transmitted at lower power.

The mobile unit can also transmit at a variety of rates. Half rate would have transmission for 8 slots while the rest of the slots are pseudo-randomly gated (shut) off. Similarly, transmission at a quarter rate would use 4 of the 16 slots, and eighth rate would use 2 slots. In variable rate, on average, 40% of the slots would be used for transmission while the others would be pseudo-randomly gated off. As a result of the activity level of the vocoder, the CDMA pulse repetition frequency varies in a pseudo-random fashion.

There are four call processing states for the CDMA mobile unit: *Initialization*, *Idle*, *Access*, and *Control on the Traffic Channel*. During all states other than the *Idle State*, the mobile station operates in non-slotted mode. In this mode the mobile station monitors all slots of the paging channel. During the *Idle State* the mobile unit performs in slotted mode in which the paging channel is monitored only during certain slots. In this mode the mobile unit can stop or reduce its processing for power conservation.

SECTION 2 EXPERIMENTAL METHODOLOGY

2.1 Experimental Setup

Testing was conducted in a closed, electromagnetically shielded, semi-anechoic chamber at the Lucent Technologies Inc. Open Area Test Site (OATS) in Oklahoma City, Oklahoma. Keypad programming was performed to ensure that the phones were operating at full transmission power, simulating worst-case conditions. The phone was placed on a stationary table with its antenna oriented vertically upward. A receiving antenna was positioned one meter away, oriented horizontally toward the phone antenna. The separation distance between the phone and the antenna was one meter for every trial. It was assumed that cellular phones aboard aircraft systems would not be operating any closer than this to the aircraft equipment antennas. Figure 2.1 indicates the setup of the testing room.

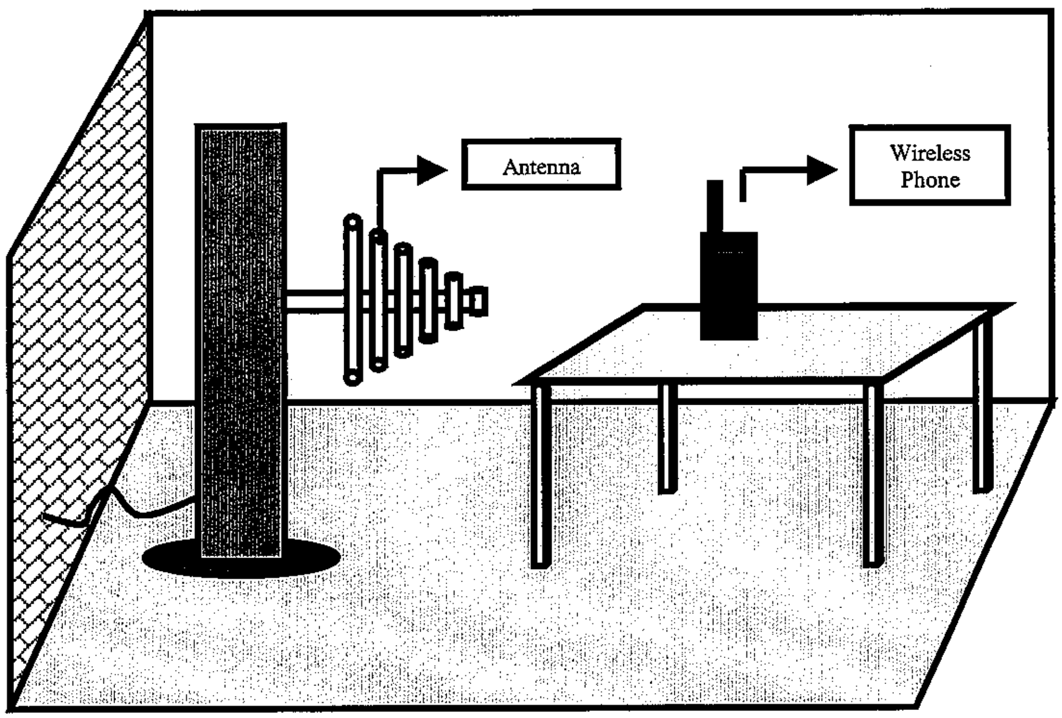


Figure 2.1: Testing Room (Semi-Anechoic Chamber).

The antenna cable was run through an opening in the wall of the chamber out into a room with the receiver and a computer. Several openings are provided for cables, and ones that were not used were shielded with copper tape. The cable from the antenna was connected to the 50Ω input of the receiver. An additional cable was used to connect between the receiver and the computer. The Agilent E4444A BenchLink Spectrum Analyzer program required a physical connection between the interface bus port on the back of the receiver and the IEEE port on the computer.

2.2 Equipment and Test Procedures

The American National Standards Institute (ANSI) lays out guidelines on the equipment and procedures needed for radio frequency (RF) testing in their Standard for Electromagnetic Noise and Field Strength (ANSI C63.4 – 1996). A dipole antenna is required for measurements obtained in the 30-1000 MHz frequency range. This range encompasses the operating ranges of the aircraft systems described earlier, except for the operating range of the Global Positioning System. This system operates at 1575.42 MHz; however, the scan that was performed covered the range from 1574.92 – 1575.92 MHz, which is a sufficiently small range (1 MHz) for the dipole antenna to be used. A CHASE CBL 6140A Bilog dipole antenna was used in testing.

The receiver used was an Agilent 8563EC spectrum analyzer. It is certified to obtain calibrated measurements from 30 Hz up to 26.5 GHz, a range that is sufficient for the scans performed. The receiver calculates a quasi-peak average of the power of instantaneous signals taken over a sample bandwidth and time. This bandwidth, called the resolution bandwidth (RBW), is adjustable, but a fixed number of data points is obtained regardless of the bandwidth chosen. Decreasing the RBW increases the resolution and the accuracy of the average taken because it is taken over a smaller range; however, too narrow of an RBW may result in an error with the spectrum analyzer. The error message, "Measurement Not Calibrated," appears on the screen if the RBW is too narrow or too wide. This was one factor we considered when determining the appropriate RBW for each testing range. Another factor was ambient noise level. It is essential that the ambient noise in the room be attenuated below the antenna sensitivity for each aircraft system. Therefore, trial ambient scans were performed with the receiver over each of the frequency ranges described in Table 1.1 in order to determine the RBW that would not produce the calibration error and would provide a noise floor of at least 10 dBm below the corresponding aircraft system antenna sensitivity. These values are listed in Table 2.1. The sweep time for a particular scan range and RBW is automatically calculated by the spectrum analyzer.

Table 2.1: Scan Ranges, Resolution Bandwidths, and Required Noise Floors.

System	Test Range (MHz)	Appropriate RBW (Hz)	Required Noise Floor (dBm)
VOR	108 – 122	30	-109
LOC	108 – 111.95	10	-116
VHF	117.97 – 137	30	-109
GS	329.15 – 335	300	-103
GPS	1574.92 – 1575.92	1	-130

The BenchLink Spectrum Analyzer program retrieves screen images and trace data from the connected receiver and generates three types of files. Files with the extension ".bmp" are copies of the screen image on the receiver. Files with the extension ".tdx" contain a graph of the actual trace data, and these files can be analyzed with the BenchLink software. Files with the extension ".csv" contain frequency and amplitude pairs of data obtained directly from the ".tdx" file. These files are easily read into Microsoft Excel because the pairs are delimited by commas.

Testing Procedure Summary (see Appendix A for more details):

1. Perform keypad programming on the phone for full power.
2. Place the phone in the center of the table with its antenna oriented upward.
3. Check that the dipole antenna is one meter away from the phone antenna.
4. Secure the door to the testing room.
5. Setup the spectrum analyzer with the frequency range and RBW described in Table 2.1.
6. Initiate the test sequence
7. Check the battery of the phone to ensure the phone did not lose power. If the voltage is too low, recharge the battery for the next scan.
8. Use the BenchLink program to generate the three data files.
9. Save the files.

SECTION 3 RESULTS

A scan for every phone technology, along with two ambient scans (one before the phone scans and one after the phone scans), was performed for each of the five testing ranges described in Table 1.1. In addition, scans were performed over the transmission ranges of the phone technologies being tested to ensure that the phones were properly transmitting. Both an ambient scan and a scan with the phone transmitting were performed. The data for the scans are provided in Appendices B, C, and D. Appendix B contains the scans grouped according to the frequency range of the scan. Appendix C contains the scans grouped according to phone technology. Appendix D contains the scans of the phone transmission ranges.

Microsoft Excel was used to generate graphs of power versus frequency from the data pairs saved in the ".csv" files. Each file contains 601 data points taken over the frequency range of the scan performed. The file was opened in Excel, and a plot was generated of the points. A horizontal line was added to this plot to denote the antenna sensitivity of the aircraft system range being tested. A horizontal line was also added at a level 10 dBm below the aircraft system's antenna sensitivity to provide a marker at an arbitrary level below the antenna sensitivity.

For example, the results of a scan with the CDMA wireless phone through the VOR frequency range are shown in Figure 3.1 (and it is the first graph in Appendix B). The graph shows power in dBm versus frequency in MHz. Two straight horizontal lines across the graph denote the antenna sensitivity (-99 dBm) and the level 10 dBm below the antenna sensitivity (-109 dBm) for this system. It can be seen that the peak value of this scan (-112.7 dBm) does not exceed the sensitivity of the VOR system antenna. Tables 3.1 through 3.5 contain the values of the maximum power measured for each phone technology for the frequency range scanned. Table 3.6 shows the overall results of the study.

In all cases the power of the wireless phone was attenuated below the sensitivity of the aircraft antenna. This indicates that in the specified frequency ranges, radio frequency emissions from the phones tested would have interfered with the antenna of the associated aircraft system, assuming the following limitations: 1) the phone is transmitting at a distance of one meter from the antenna, 2) the phone is oriented vertically, and 3) the antenna is oriented horizontally. Each phone scan was performed only once for each testing range; however, there is considerable uniformity among the results in each testing range.

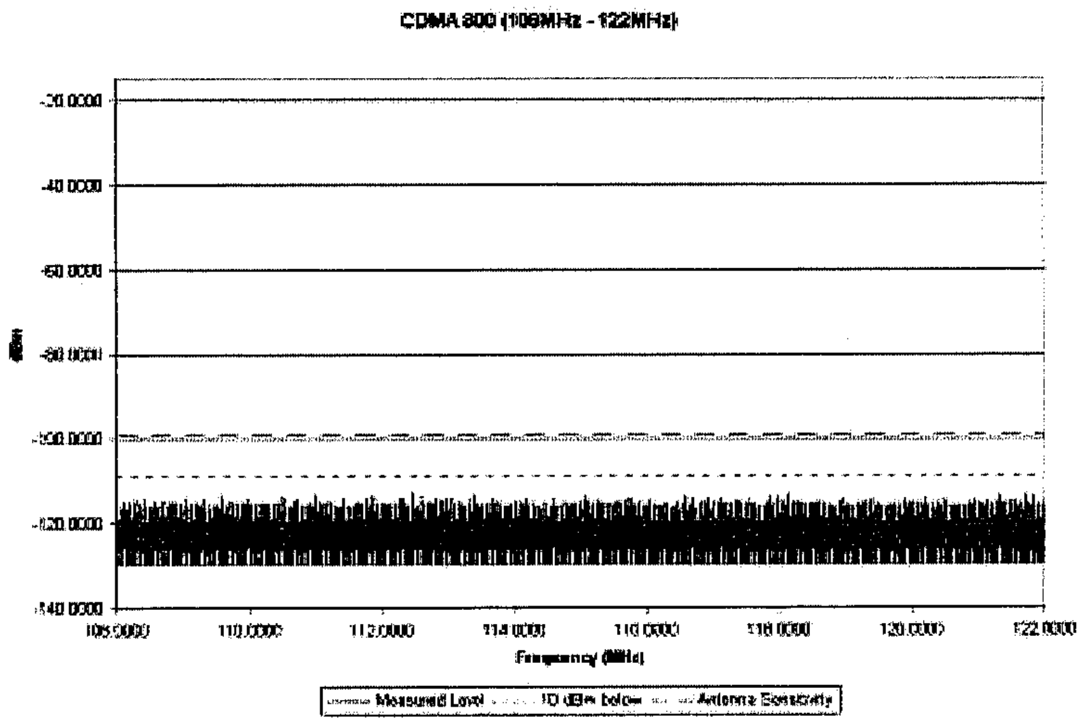


Figure 3.1: Results of CDMA 800 Scan Through VOR Range

Table 3.1: VOR Range Results

Antenna Sensitivity = -99 dBm		
Phone Technology	**Maximum Measured Power (dBm)**	**Maximum Measured Power Interval Below Antenna Sensitivity[1] (dBm)**
CDMA Cellular	-112.7	-13.7
TDMA – 11 Hz Cellular	-113.0	-14.0
TDMA – 50 Hz Cellular	-112.7	-13.7
TDMA – 50 Hz PCS	-112.7	-13.7
TDMA – 217Hz GSM	-112.7	-13.7
TDMA – 217Hz DCS 1800	-113.3	-14.3

[1] Antenna sensitivity minus maximum measured phone emission power

Table 3.2: LOC Range Results

Antenna Sensitivity = -106 dBm		
Phone Technology	**Maximum Measured Power (dBm)**	**Maximum Measured Power Interval Below Antenna Sensitivity (dBm)**
CDMA Cellular	-117.2	-11.2
TDMA – 11 Hz Cellular	-117.7	-11.7
TDMA – 50 Hz Cellular	-117.2	-11.2
TDMA – 50 Hz PCS	-117.7	-11.7
TDMA – 217Hz GSM	-117.5	-11.5
TDMA – 217Hz DCS 1800	-117.3	-11.3

Table 3.3: VHF Range Results

Antenna Sensitivity = -99 dBm		
Phone Technology	**Maximum Measured Power (dBm)**	**Maximum Measured Power Interval Below Antenna Sensitivity (dBm)**
CDMA Cellular	-112.8	-13.8
TDMA – 11 Hz Cellular	-112.8	-13.8
TDMA – 50 Hz Cellular	-112.8	-13.8
TDMA – 50 Hz PCS	-112.8	-13.8
TDMA – 217Hz GSM	-107.7	-8.7
TDMA – 217Hz DCS 1800	-113.0	-14.0

Table 3.4: GS Range Results

Antenna Sensitivity = -93 dBm		
Phone Technology	**Maximum Measured Power (dBm)**	**Maximum Measured Power Interval Below Antenna Sensitivity (dBm)**
CDMA Cellular	-104.8	-11.8
TDMA – 11 Hz Cellular	-103.8	-10.8
TDMA – 50 Hz Cellular	-104.3	-11.3
TDMA – 50 Hz PCS	-104.3	-11.3
TDMA – 217Hz GSM	-113.0	-20.0
TDMA – 217Hz DCS 1800	-104.0	-11.0

Table 3.5: GPS Range Results

Antenna Sensitivity = -120 dBm		
Phone Technology	**Maximum Measured Power (dBm)**	**Maximum Measured Power Interval Below Antenna Sensitivity (dBm)**
CDMA Cellular	-131.2	-11.2
TDMA – 11 Hz Cellular	-130.8	-10.8
TDMA – 50 Hz Cellular	-131.0	-11.0
TDMA – 50 Hz PCS	-133.0	-13.0
TDMA – 217Hz GSM	-129.8	-9.8
TDMA – 217Hz DCS 1800	-130.3	-10.3

Table 3.6: Final Test Results

Aircraft System Range	Number of Scans with Peak Value Exceeding Antenna Sensitivity
VOR	0
LOC	0
VHF	0
GS	0
GPS	0

SECTION 4 CONCLUSIONS

This testing comprises an initial study into the electromagnetic compatibility of wireless phones and aircraft communication and navigation equipment. It was found that none of the six phone technologies tested exhibited a power level greater than the sensitivity of the aircraft system antennae when tested one meter away from the antenna in the orientation examined.

Two variables that were not explored in this study were the various orientations of the phone and receiving antennae and the distance between the phone and the antenna. Various distances were not tested because, due to the assumption that phones would not be operated any closer than one meter to aircraft equipment, one meter was determined to be the "worst-case" condition. The test protocol (see Appendix A) stated that different orientations would be explored if a peak was observed that exceeded the sensitivity of the aircraft antenna. Since there were no peaks that even came close to exceeding the antenna sensitivity, only the configuration in which the phone antenna was vertical and the receiving antenna was horizontal was examined. Suggestions for the next phase of research include the investigation of various phone antenna/receiving antenna orientations and expansion of the protocol to a general procedure for testing the electromagnetic compatibility of electronic devices with aircraft equipment.

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APPENDICES

APPENDIX A

Test Protocol

The University of Oklahoma

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PROTOCOL

Investigation of Spurious Emissions from Cellular Phones and the Possible Effect on Aircraft Navigation Equipment

Version 4.0

December 2000

INTRODUCTION

This purpose of this project is to provide valuable data and information on the spurious emission levels of wireless phones and the possible effect on aircraft navigation equipment. The detected frequencies of spurious emissions will be analyzed for overlap with the receiving ranges of aircraft navigation equipment, such as the Global Positioning System, microwave landing system, weather radar, and air traffic control system. The frequency ranges in which aircraft systems receive information do not typically coincide with the transmitting regions of cellular phones. However, the antennas of aircraft systems are extremely sensitive (as low as -130 dBm) and could possibly detect spurious wireless emissions.

The Wireless EMC Center has accumulated extensive knowledge concerning the operation of wireless phones. This knowledge has enabled the Center to research and develop test protocols that are used for testing various electronic devices and their potential interaction with wireless phones. The Center has previously conducted studies investigating the effects of wireless phones on: hearing aids, implantable cardioverter defibrillators (ICDs), and pacemakers. This work will serve as a background in establishing experimental design for testing the use of wireless phones in aircraft.

BACKGROUND

The FCC standard Part 47 states, "The mean power of emissions must be attenuated below the mean power of the unmodulated carrier wave (P) as follows: …On any frequency removed from the carrier frequency by more than 45 kHz, up to the first multiple of the carrier frequency: at least 60 dB or 43 + 10 log P dB, whichever is the lesser attenuation." The frequencies at which emissions occur and exceed the sensitivity of the aircraft equipment will be examined to determine if there is any overlap with the frequency bands of aircraft navigation and communication systems.

Testing will be conducted in a closed, electromagnetically shielded, and semi-anechoic chamber at the Lucent Technologies Inc. Open Area Test Site (OATS) in Oklahoma City, Oklahoma. The phone will be operating at full transmission power, simulating worst-case conditions. The separation distance between the phone and the antenna will be one meter for every trial. It is assumed that cellular phones aboard aircraft will not be operated any closer than this to the aircraft navigational equipment. Aircraft systems operate at many different frequencies ranging from 10 kHz to 10 GHz. Table 1 lists the systems that will be tested, along with the frequency ranges at which they operate and the antenna sensitivities of the equipment.

Table 1: Aircraft Systems Operating Ranges, and Antenna Sensitivities.

System Name	Abbreviation	Operating Range (MHz)	Antenna Sensitivity (dBm)
VHF Omni-Range	VOR	108 – 117.95	-99
Localizer	LOC	108.1 – 111.95	-106
Very High Frequency Communication	VHF	117.975 – 137	-99
Glide Slope	GS	329.15 – 335	-93
Global Positioning System	GPS	1575.42	-120

The sensitivity of the receiver should be at least 10 dBm below the minimum antenna sensitivity. Trial scans were performed with the receiver at each of the above frequency ranges to determine the bandwidth required to obtain a noise floor of at least 10 dBm below the corresponding system antenna sensitivity. These values are listed in the table below. The sweep time is automatically calculated by the spectrum analyzer and is also listed in Table 2.

Table 2: Scan Ranges, Bandwidths, and Required Noise Floors.

System	Test Range (MHz)	Required Noise Floor (dBm)	Appropriate Bandwidth
VOR	108 – 122	-109	30 Hz
LOC	108 – 111.95	-116	10 Hz
VHF	117.97 – 137	-109	30 Hz
GS	329.15 – 335	-103	300 Hz
GPS	1574.92 – 1575.92	-130	1 Hz

TESTING METHODOLOGY

Phone Technologies

The phone technologies being tested and the frequencies at which these phones transmit are listed Table 3.

Table 3: Phone Technologies and Transmission Frequencies.

CDMA (Cellular)	800 MHz
TDMA - 11 Hz (Cellular)	800 MHz
TDMA - 50 Hz Cellular	800 MHz
TDMA - 50 Hz PCS	1900 MHz
TDMA – 217 Hz GSM	900 MHz
TDMA – 217 Hz DCS 1800	1800 MHz

A scan must be completed over the entire transmitting frequency range of each phone in order to determine the amplitude of the unmodulated carrier wave. This measurement is needed to identify spurious emissions according to the FCC Standard Part 47 mentioned earlier. Keypad programming will be used to allow the phone to transmit at full power.

Phone and Antenna Orientation

For Phase I of the Spurious Emission Study, the phone will be tested in the vertical (upright) position, and the antenna will be positioned perpendicularly to the phone. Additional orientations will be examined in Phase II. The phone antenna will be located at a distance of one meter from the receiving antenna.

EQUIPMENT

EMI Test Receiver

The receiver required to accommodate the scope of frequencies at which aircraft systems receive signals is an Agilent 8563EC Spectrum Analyzer. It is certified to obtain calibrated measurements from 30 Hz up to 26.5 GHz. The receiver displays the frequency and power of an incoming signal, by calculating a quasi-peak average of the power of instantaneous signals taken over a sample bandwidth and time.

Receiving Antennas

The American National Standard Institute in the Standard for Electromagnetic Noise and Field Strength (ANSI C63.4 – 1996) states that a dipole antenna is required to cover the range of frequencies mentioned above. The CHASE CBL 6140A Bilog dipole antenna will be used to obtain measurements from 30 MHz to 2.0 GHz.

BenchLink Software
The Agilent E4444A BenchLink Spectrum Analyzer program provides a communication link between a PC and the HP 8563EC Spectrum Analyzer. The two are physically linked through the interface bus port. The program allows the user to acquire screen images and trace data from the receiver. The data can be saved on disk and analyzed at a later time.

PROCEDURAL SETUP

The initial setup procedure for testing involves the following steps:
(1) Turn on the receiver and the computer.
(2) Link the cable between the interface bus port on the back of the receiver and the IEEE port on the computer.
(3) Open the BenchLink program on the computer.
(4) Connect the proper antenna:
A long yellow cable is used to connect between the antenna and the receiver. One end of this cable is connected to a port on the wall to which another cable on the other side of the wall can be connected. This cable that is on the outside of the room will be connected to the 50Ω input of the receiver.
(5) Place the antenna one meter from the turntable. This distance is marked with black tape.
(6) Make sure the cable ports on the outside of the room have been covered with copper tape.
(7) Use floppy disks store files generated by the BenchLink program.
Files with the extension ".bmp" are the images generated by the BenchLink program, which works through the IEEE port to obtain data directly from the receiver. The .tdx files contain the trace data, which can be easily analyzed with BenchLink tools. The .csv files contain frequency and amplitude data that is delimited by commas, so they can be easily read into Excel. One floppy disk can hold two files of each file type, or two complete scans. The first five disks will contain the ambient scan and the scan with the phone for each frequency range. The sixth disk will contain the scan of the transmitting frequency range of the phone.

TEST PROCEDURE

The following steps comprise the procedure for completing a scan in the RF shielded room:

(1) Performing a scan:
   a) Enter in the frequency range:
      Press "FREQUENCY", then "START FREQ", and enter in the appropriate number. Then, press "STOP FREQ" and enter in the stop frequency.
      *Note: The stop frequency will automatically adjust to agree with the entered start frequency.
   b) Press "BW" under the Control Menu and enter in the appropriate bandwidth. Refer to the table on page 3 of the protocol to determine this value.
   c) Make sure the antenna is connected and is at the one-meter mark.
   d) If the current scan is not an ambient scan, turn on the phone and perform the keypad programming required for transmission at full power. Place the phone in the center of the turntable in the upright position.
   e) Secure the door to the testing room.
   f) Press "SGL SWP" in the Instrument State section of the receiver.

(2) Saving the results of the scan:
   a) Press "MKR" then "PEAK SEARCH" in the Marker section of the receiver.
   b) Press "SAVE" in the Instrument State section of the receiver then "SAVE TRACE A" on the side panel of the display.
   c) Select the trace number under which you wish to save the scan.
      *Note: A maximum of eight scans can be saved in the memory of the receiver. It is strongly suggested that the results be transferred to the PC and then saved on disk immediately.

(3) Transfer the results from the receiver to the computer and to disk:
   a) In the BenchLink program, click on "File", then "New". Select "Instrument Display Image" to transfer the bitmap file, then "OK" to begin the transfer.
   b) Save the file to the floppy disk. Indicate the date, frequency range, and whether or not the scan was an ambient measurement in the *name* of the file.
   c) In the BenchLink program, click on "File", then "New". Now select "Instrument Trace Data" to transfer the data. Select "Trace A", then click "OK" to begin the transfer. Save the file to the disk using the same name designated in the previous step.
   d) Click "File", then "Save As Frequency Amplitude Pairs."

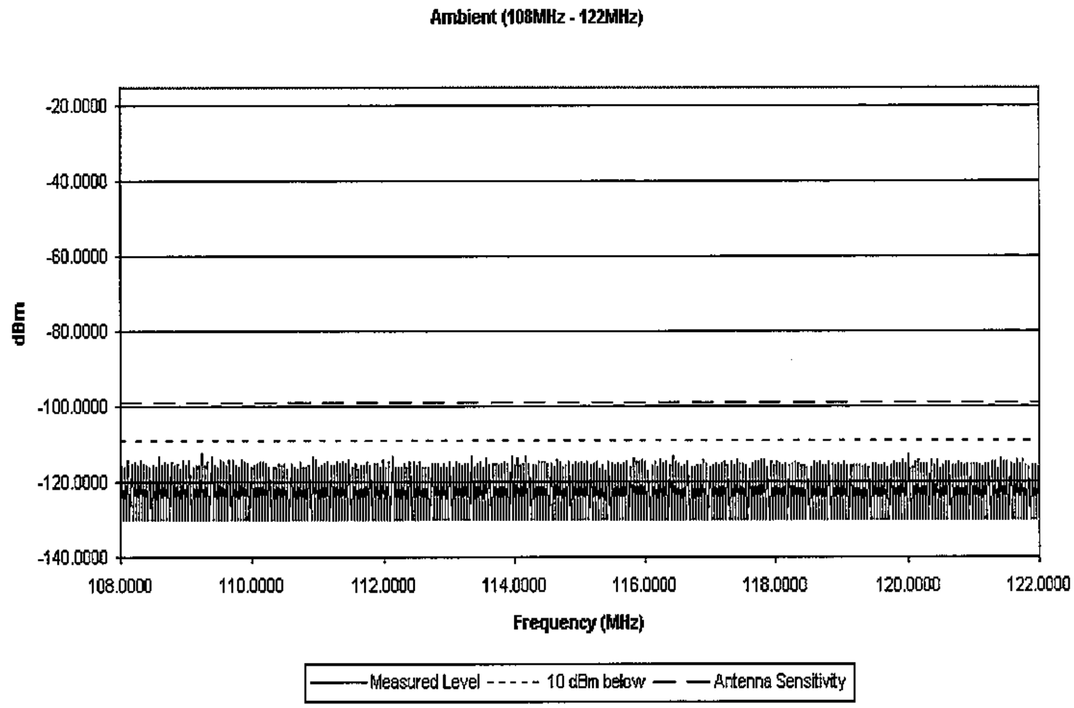
(4) Periodically check the voltage of the phone battery.
   Check the voltage of the phone battery after each run to make sure that the phone is operating at full power. Use a voltmeter to measure the voltage across the battery terminals. If the voltage is too low, recharge the battery and replace it with another battery.

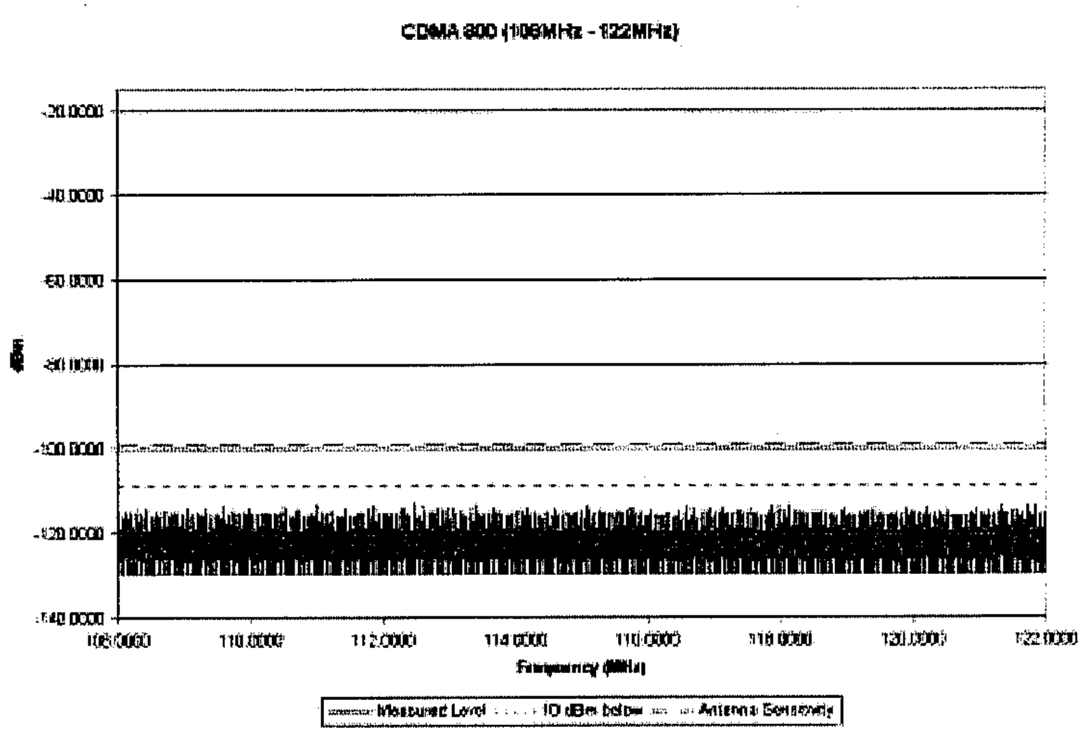
APPENDIX B

Scans According to Testing Range

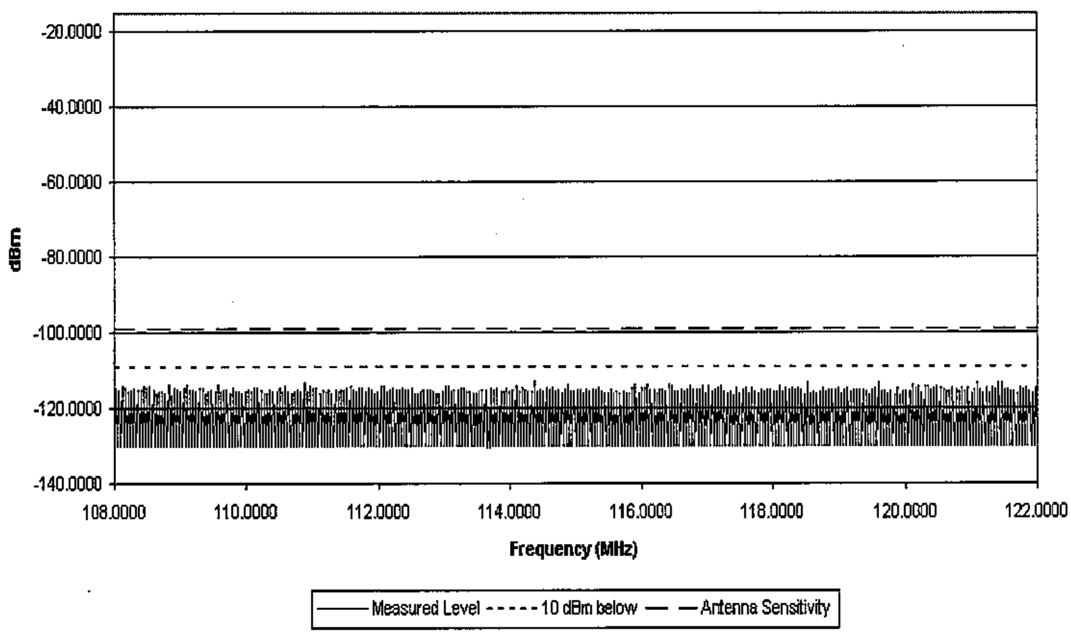
VERY HIGH FREQUENCY (VHF) COMMUNICATION OMNI-RANGE

108 to 122 MHz

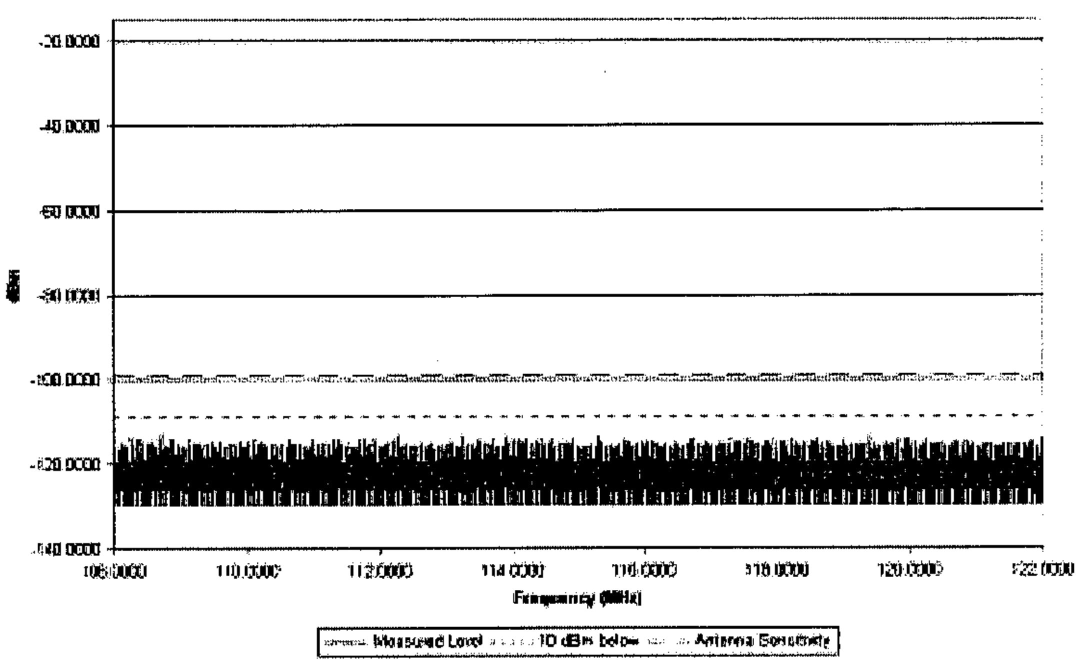

Ambient (108MHz - 122MHz)
-20.0000
-40.0000
-60.0000
-80.0000
-100.0000
-120.0000
-140.0000
dBm
108.0000
110.0000
112.0000
114.0000
116.0000
118.0000
120.0000
122.0000
Frequency (MHz)
Measured Level
10 dBm below
Antenna Sensitivity


CDMA 800 (108MHz - 122MHz)
Measured Level
10 dBm below

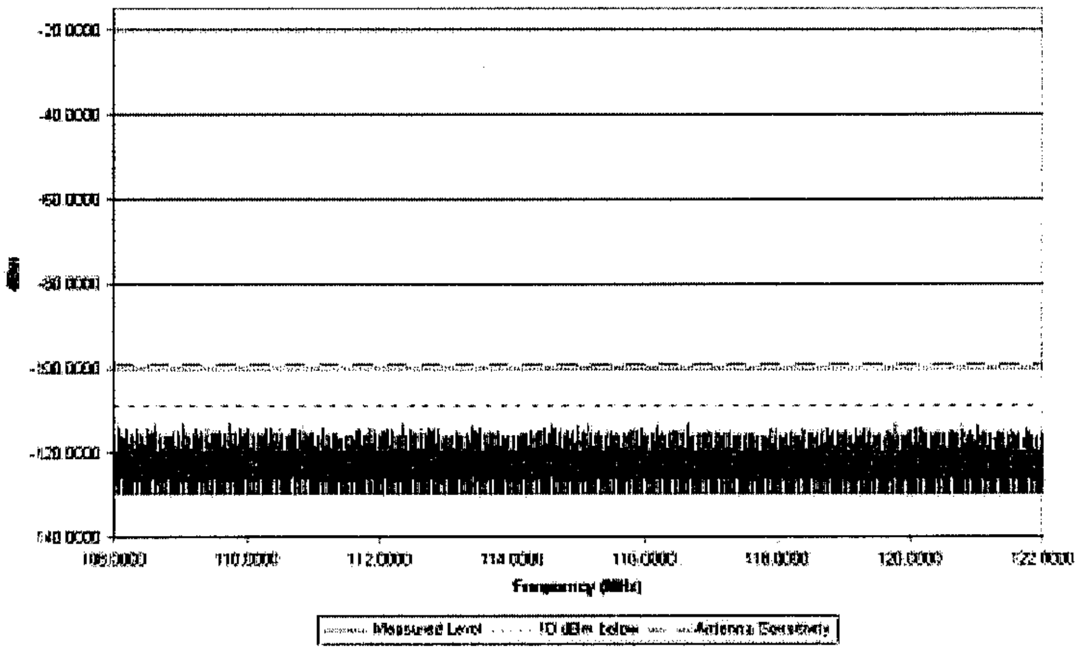
TDMA-11Hz (108MHz - 122MHz)



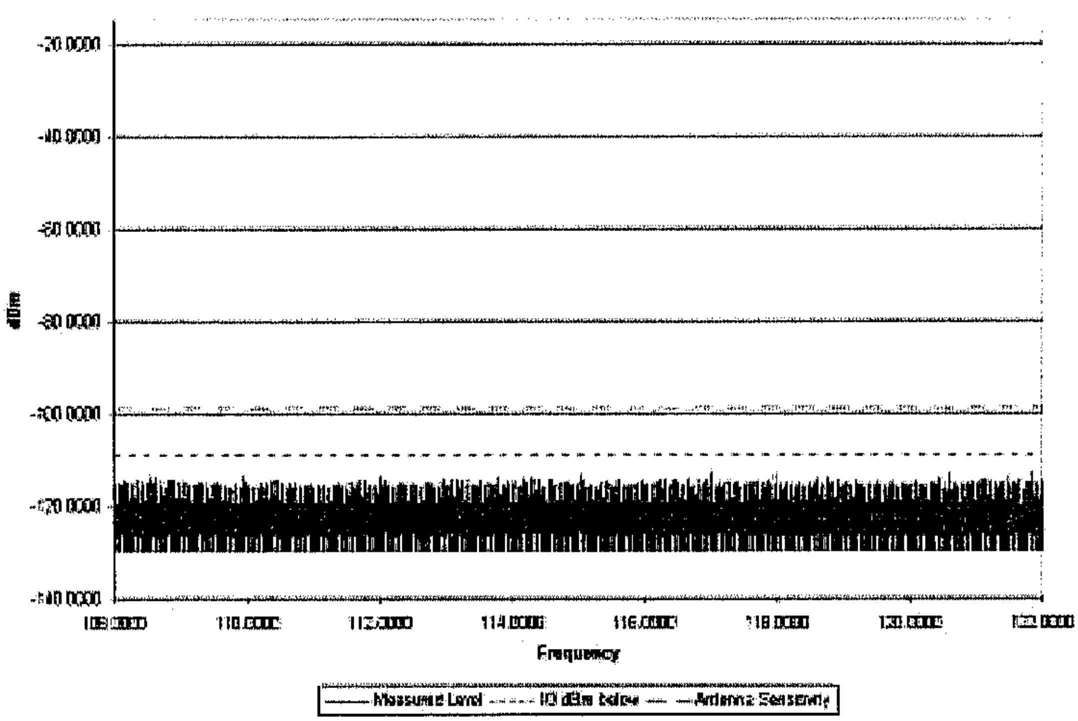
TDMA-50Hz 800 (108MHz - 122MHz)



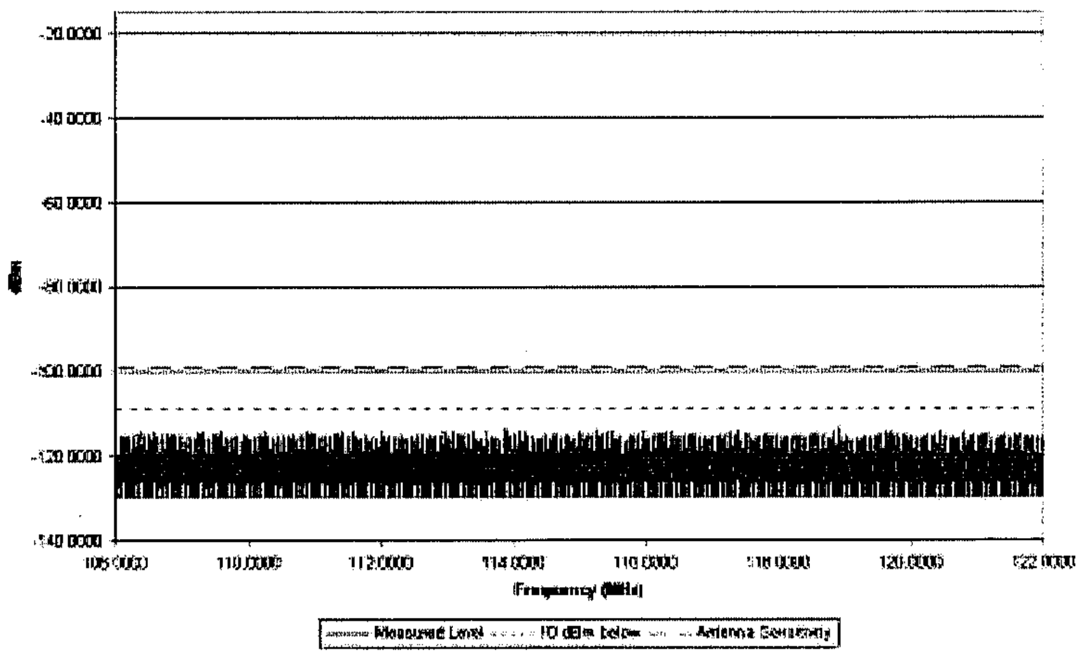
TDMA-50Hz PCS (108MHz - 122MHz)



GSM 900 (108MHz - 122MHz)



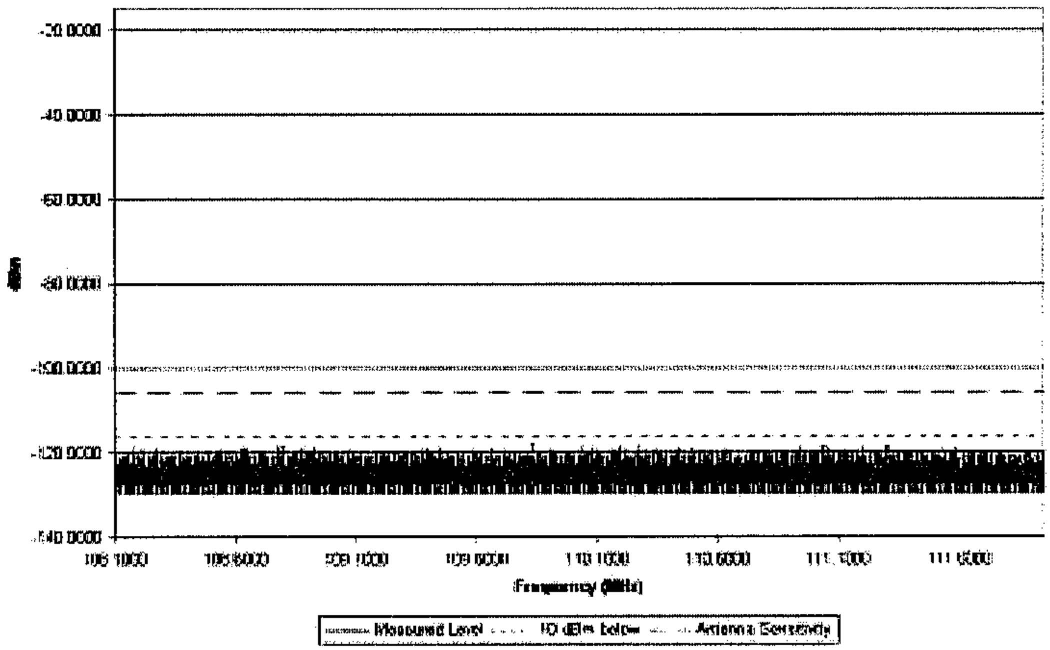
DCS 1800 (108MHz - 122MHz)



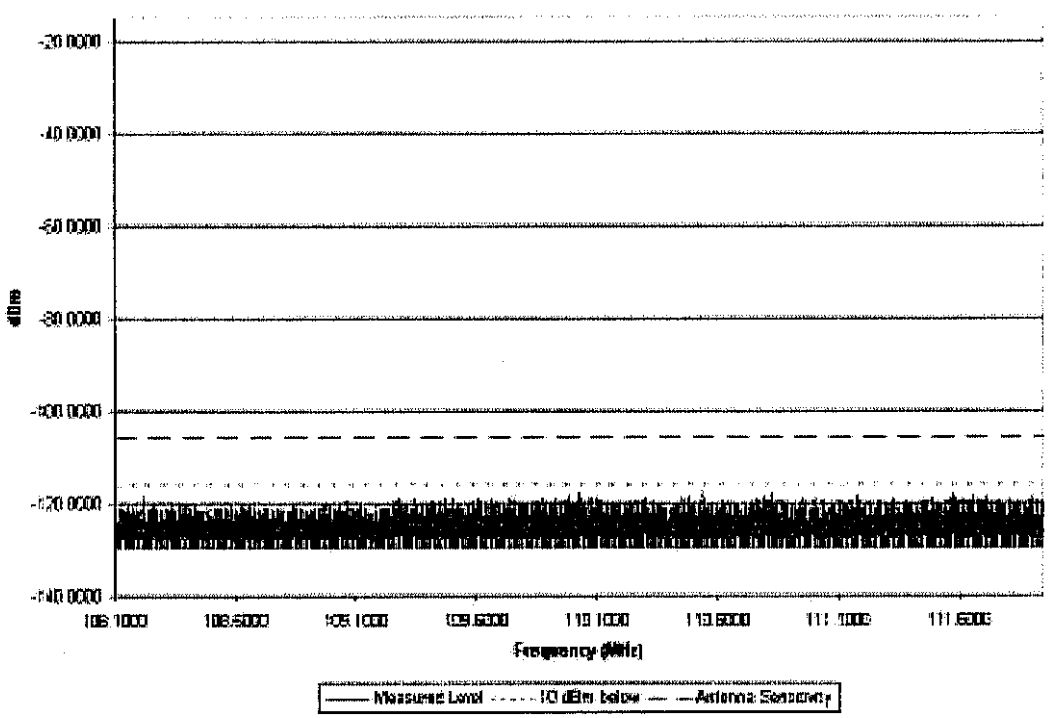
LOCALIZER

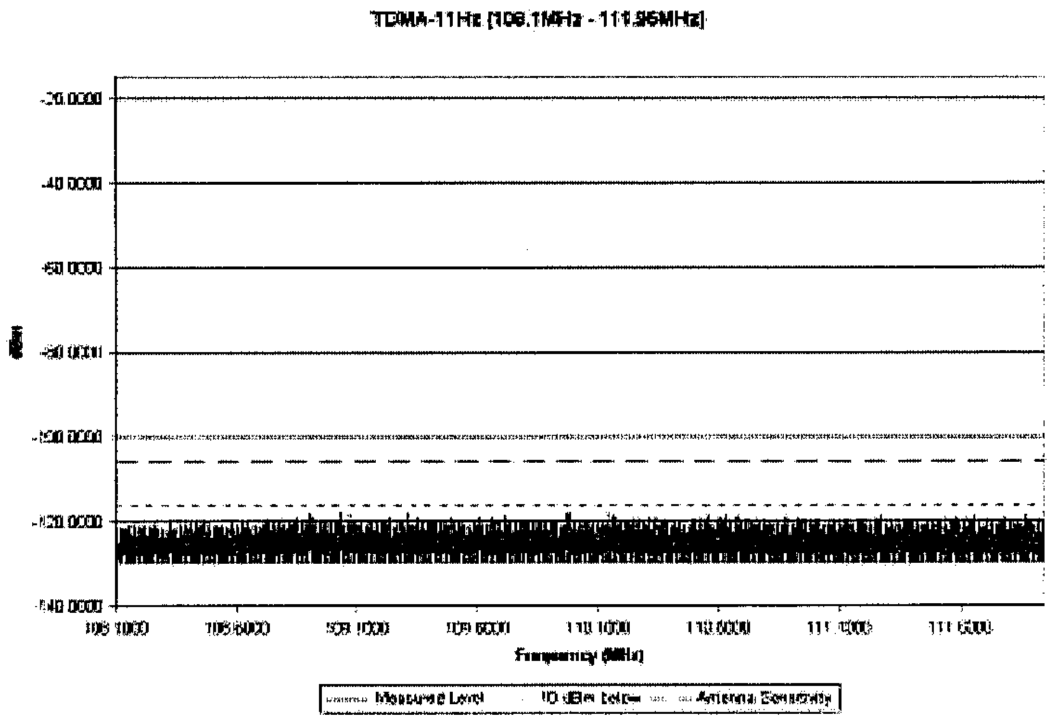
108 to 111.95 MHz

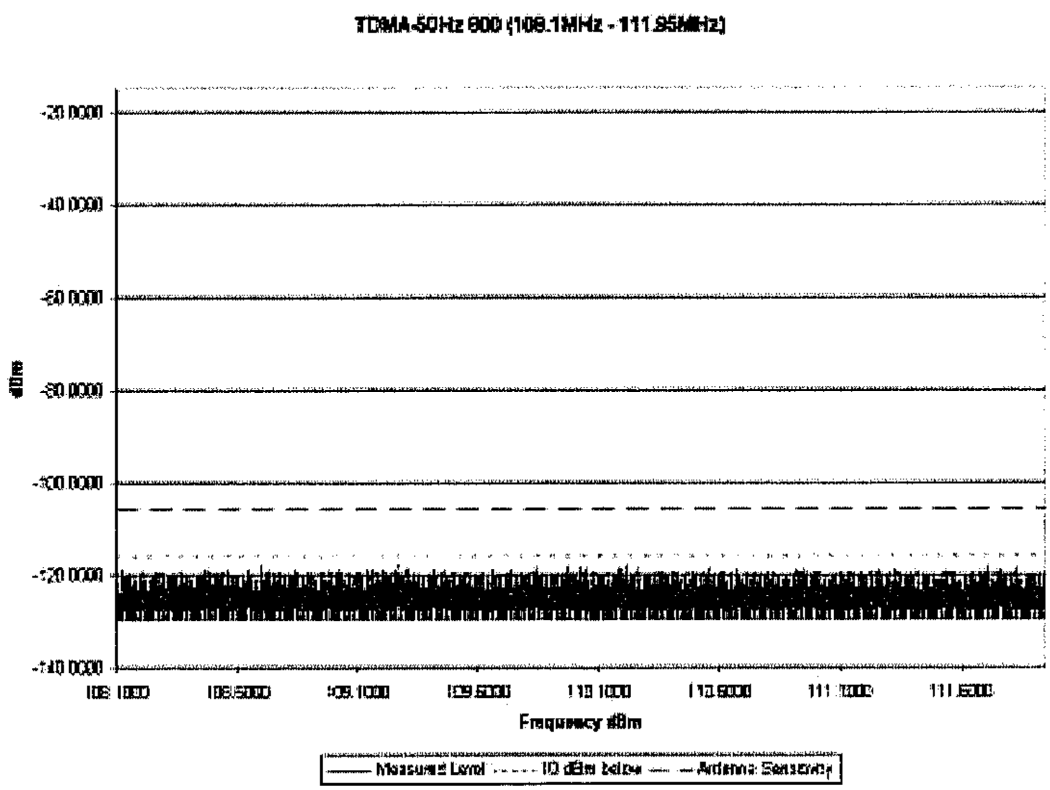
Ambient (108.1MHz - 111.95MHz)

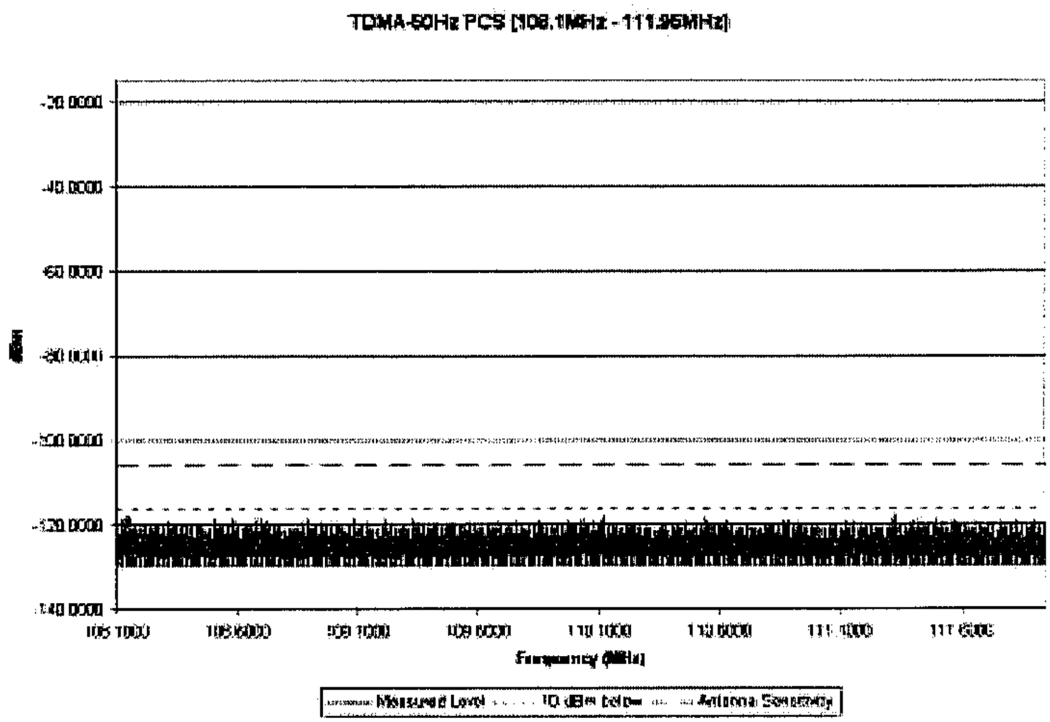


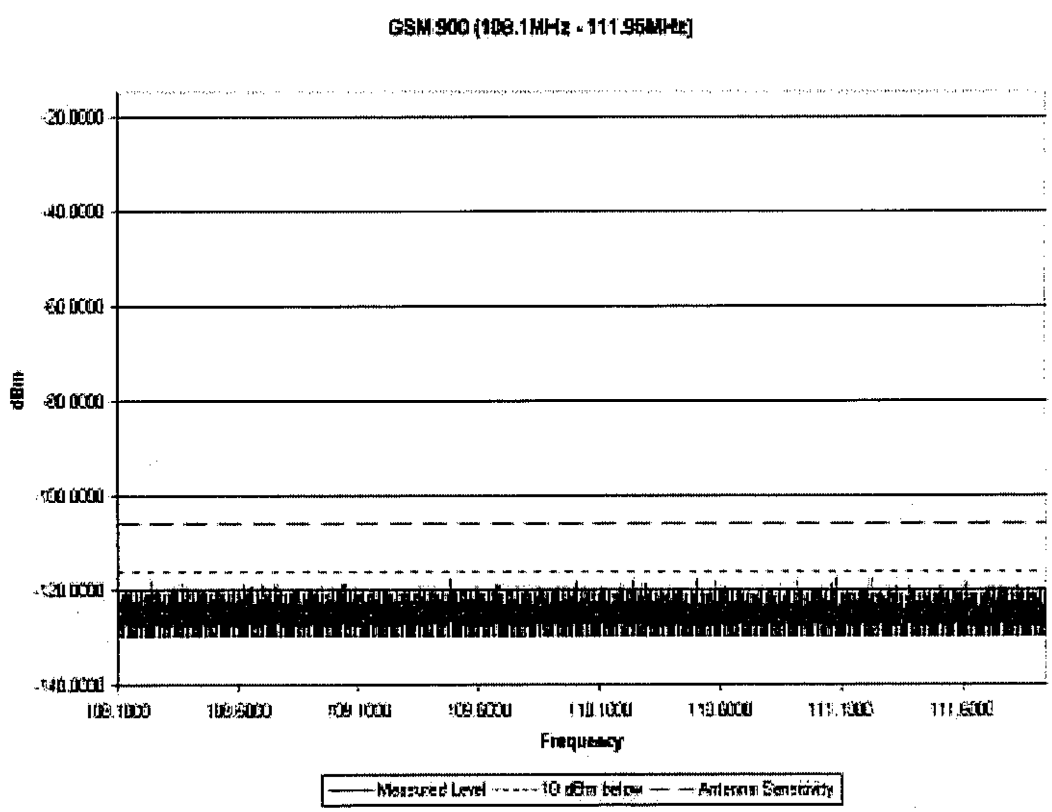
CDMA 800 (108.1MHz - 111.95MHz)



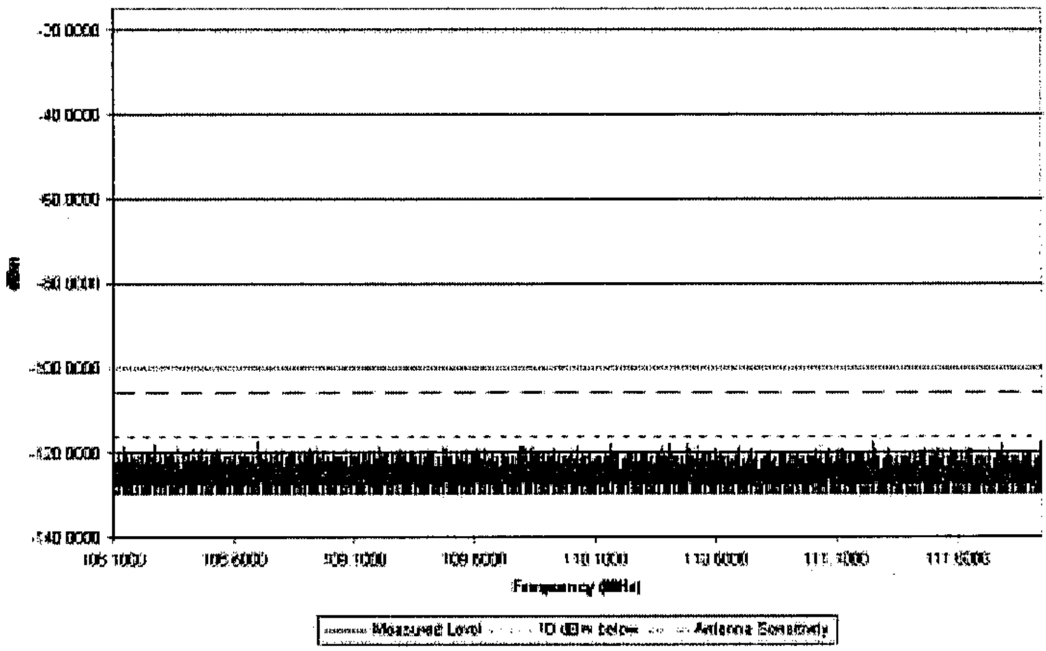

TDMA-11Hz (108.1MHz - 111.95MHz)
dBm
-20.0000
-40.0000
-60.0000
-80.0000
-100.0000
-120.0000
-140.0000
108.1000
108.6000
109.1000
109.6000
110.1000
110.6000
111.1000
111.6000
Frequency (MHz)
Measured Level
10 dBm below
Antenna Sensitivity


TDMA-50Hz 800 (108.1MHz - 111.95MHz)
dBm
-20.0000
-40.0000
-60.0000
-80.0000
-100.0000
-120.0000
-140.0000
108.1000
108.6000
109.1000
109.6000
110.1000
110.6000
111.1000
111.6000
Frequency dBm
Measured Level
10 dBm below
Antenna Sensitivity


TDMA-50Hz PCS [108.1MHz - 111.95MHz]
-20.0000
-40.0000
-60.0000
-80.0000
-100.0000
-120.0000
-140.0000
dBm
108.1000
108.6000
109.1000
109.6000
110.1000
110.6000
111.1000
111.6000
Frequency (MHz)
Measured Level
10 dBm below
Antenna Sensitivity


GSM 900 [108.1MHz - 111.95MHz]
-20.0000
-40.0000
-60.0000
-80.0000
-100.0000
-120.0000
-140.0000
dBm
108.1000
108.6000
109.1000
109.6000
110.1000
110.6000
111.1000
111.6000
Frequency
Measured Level
10 dBm below
Antenna Sensitivity

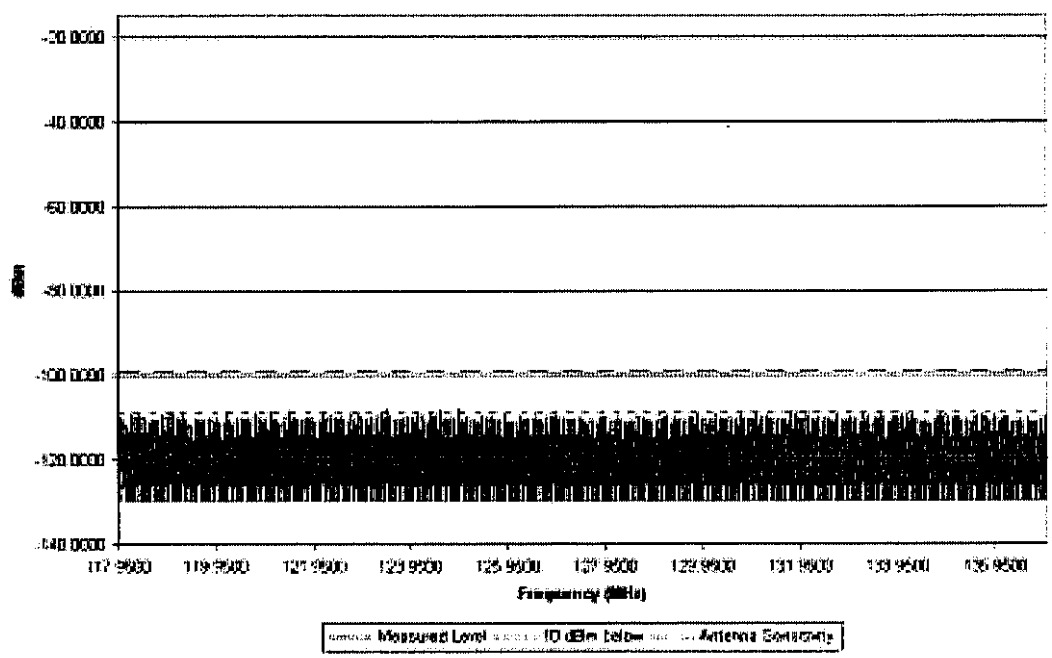
DCS 1800 (108.1MHz - 111.95MHz)



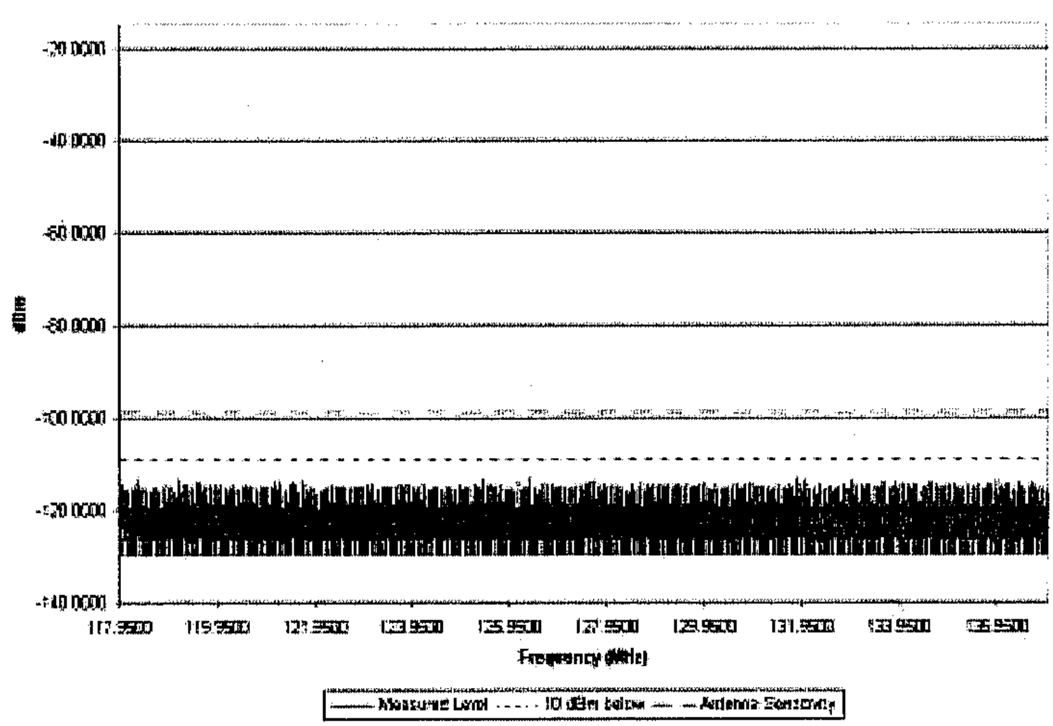
VERY HIGH FREQUENCY COMMUNICATION

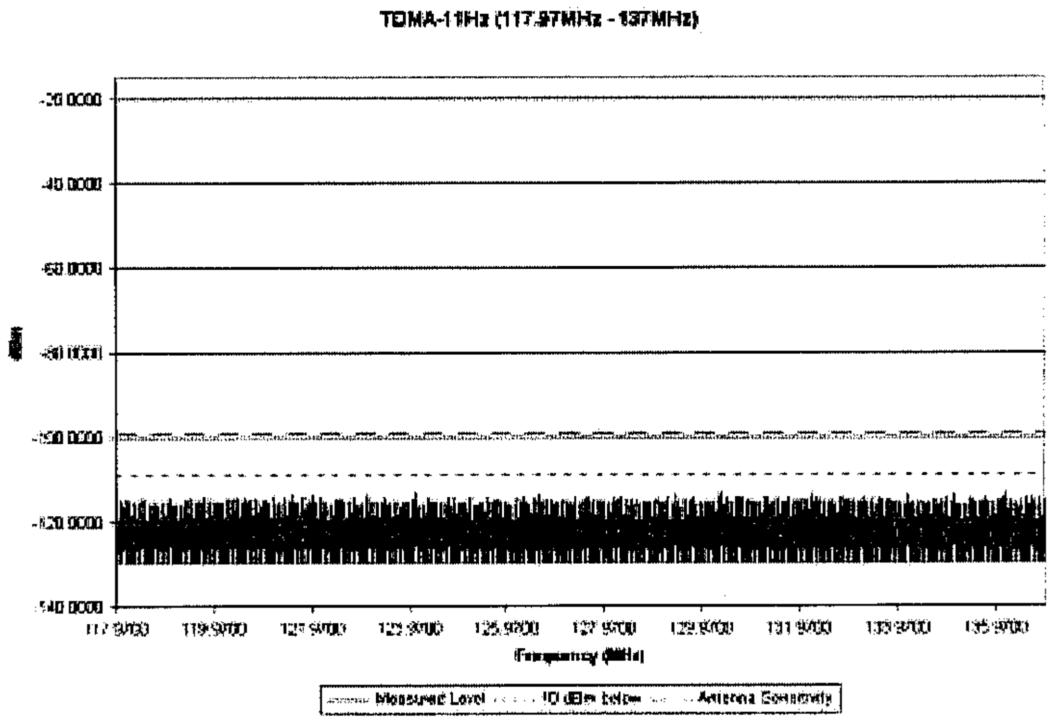
117.97 - 137 MHz

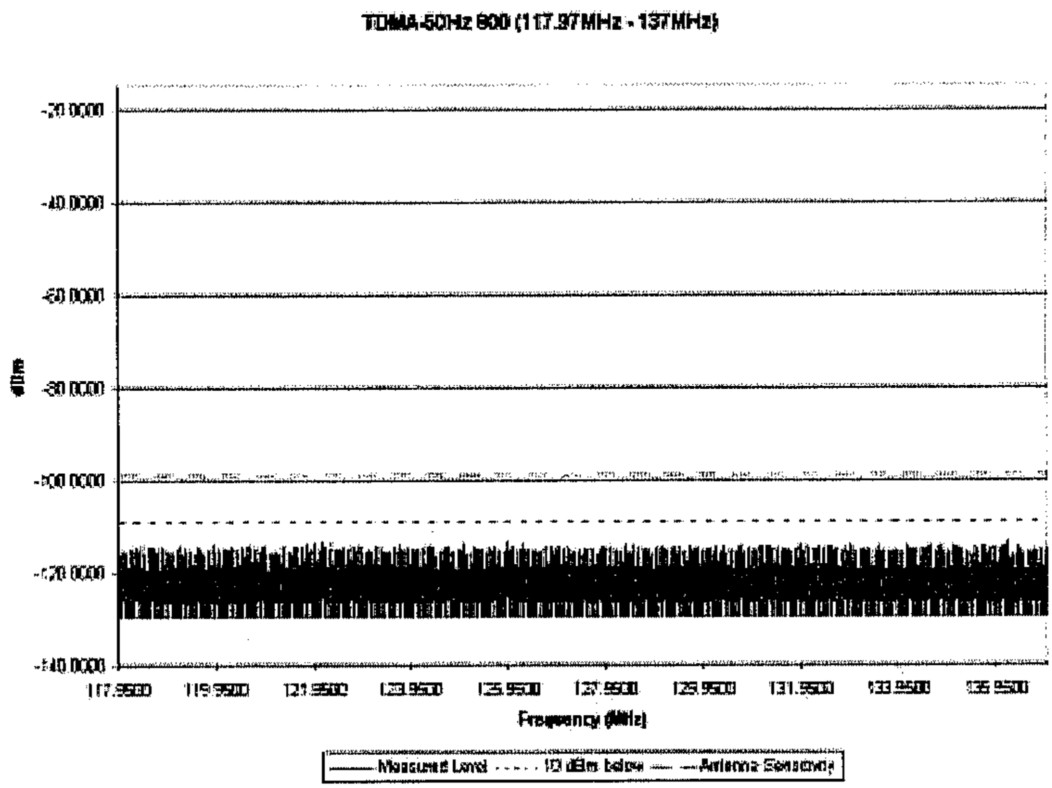
Ambient (117.97MHz - 137MHz)

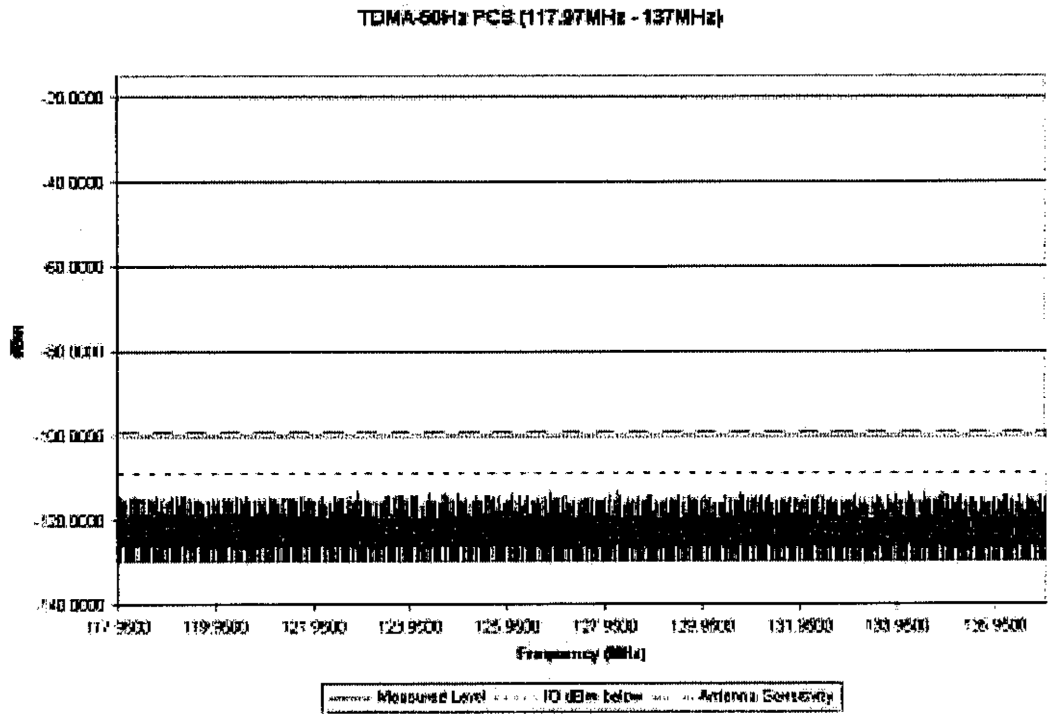


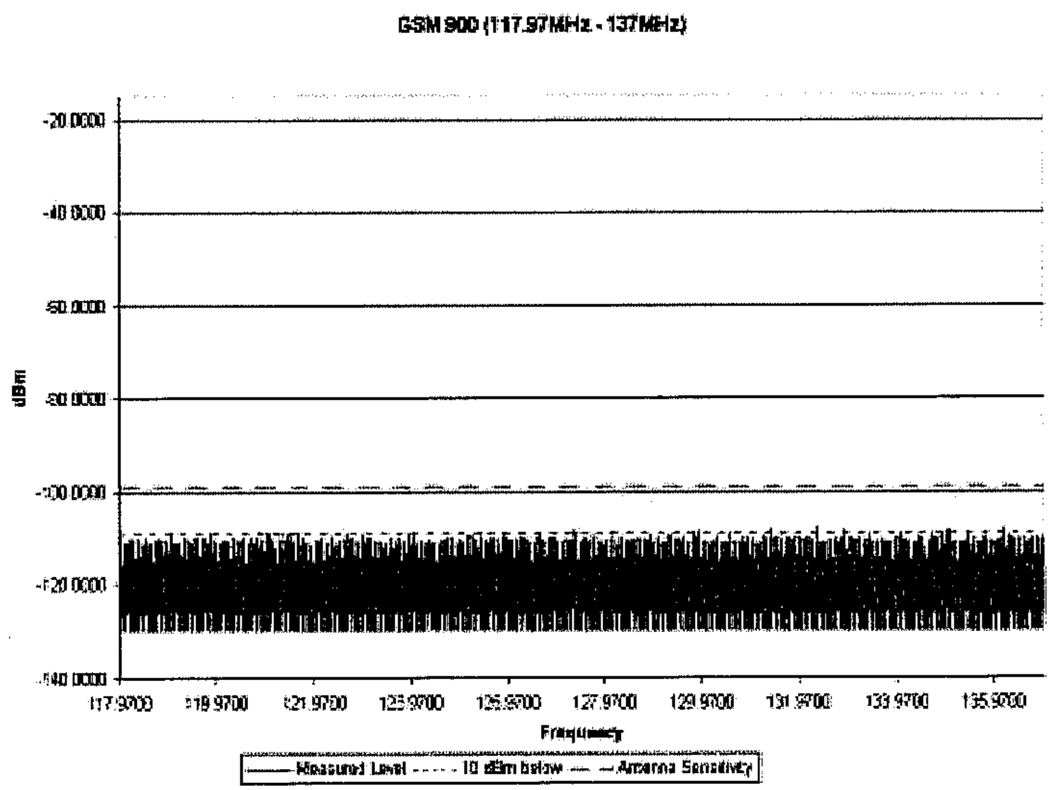
CDMA 800 (117.97MHz - 137MHz)

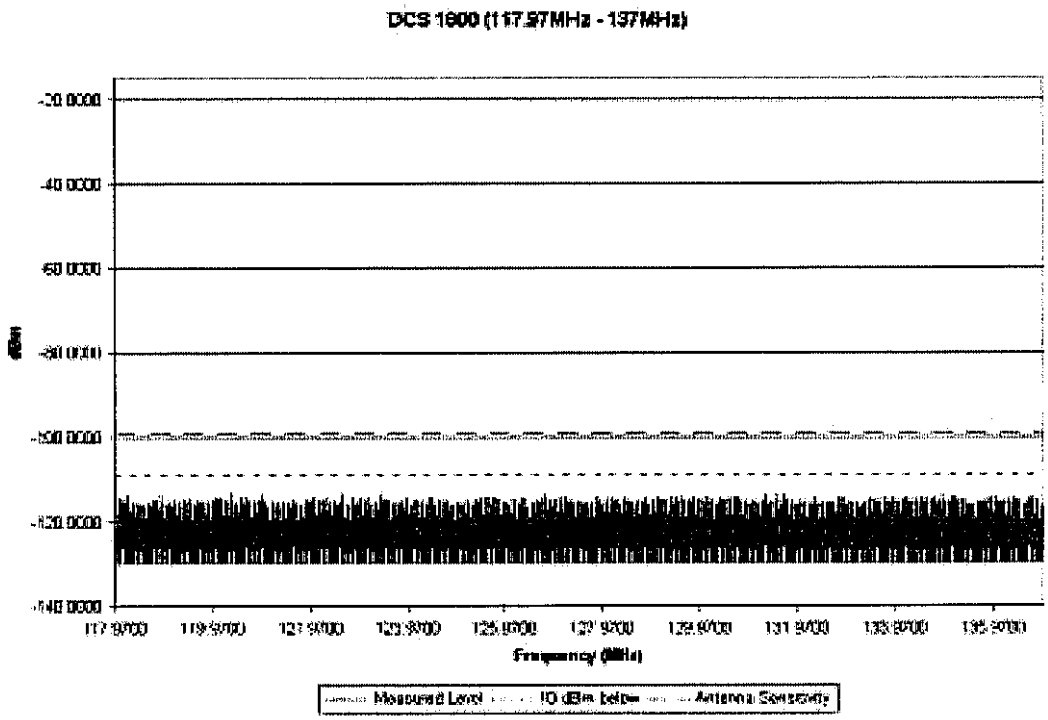



TDMA-1Hz (117.97MHz - 137MHz)
Frequency (MHz)
Measured Level
10 dBm below
Antenna Sensitivity


TDMA-50Hz 800 (117.97MHz - 137MHz)
dBm
Frequency (MHz)
Measured Level
10 dBm below
Antenna Sensitivity


TDMA-60Hz PCS (117.97MHz - 137MHz)
dBm
Frequency (MHz)
Measured Level
10 dBm below
Antenna Sensitivity

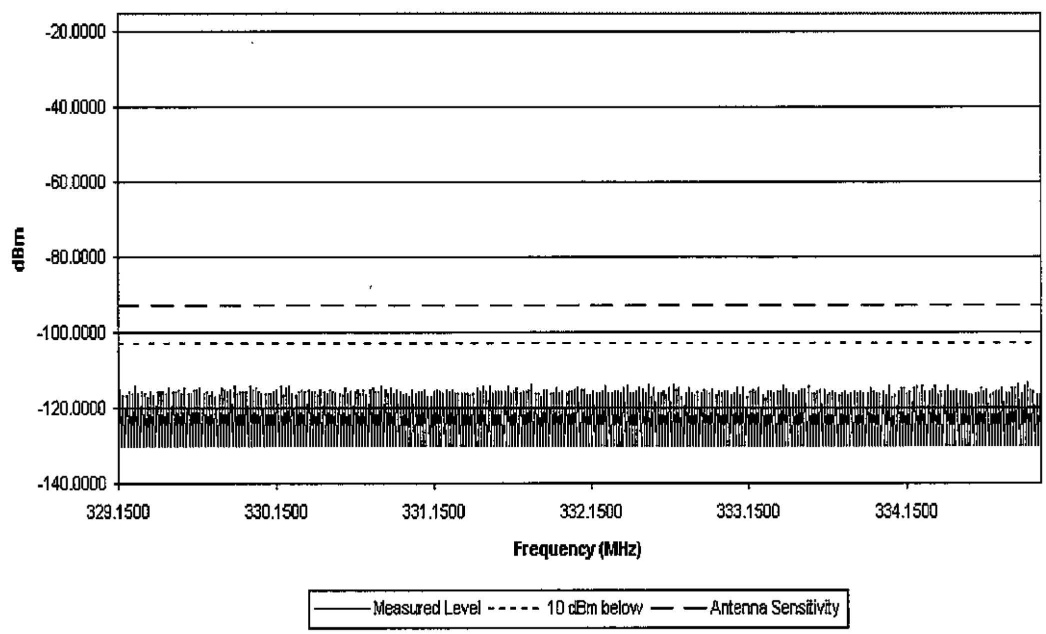

GSM 900 (117.97MHz - 137MHz)
dBm
Frequency
Measured Level
10 dBm below
Antenna Sensitivity


DCS 1800 (117.97MHz - 137MHz)
dBm
Frequency (MHz)
Measured Level
10 dBm below
Antenna Sensitivity

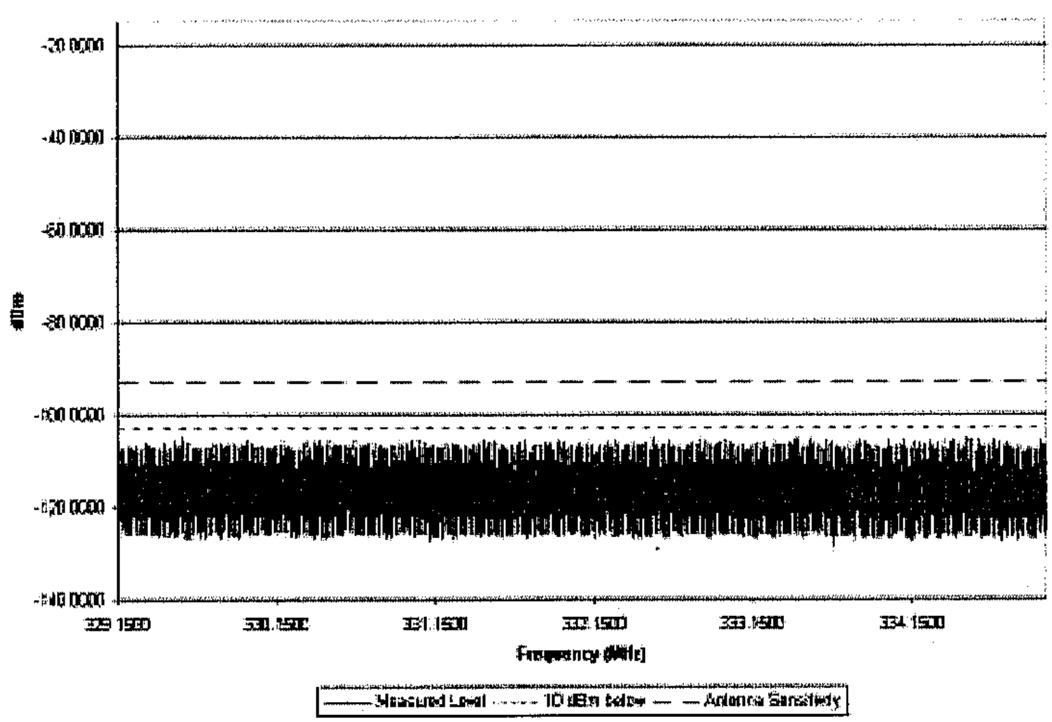
GLIDE SLOPE

329.15 - 335 MHz

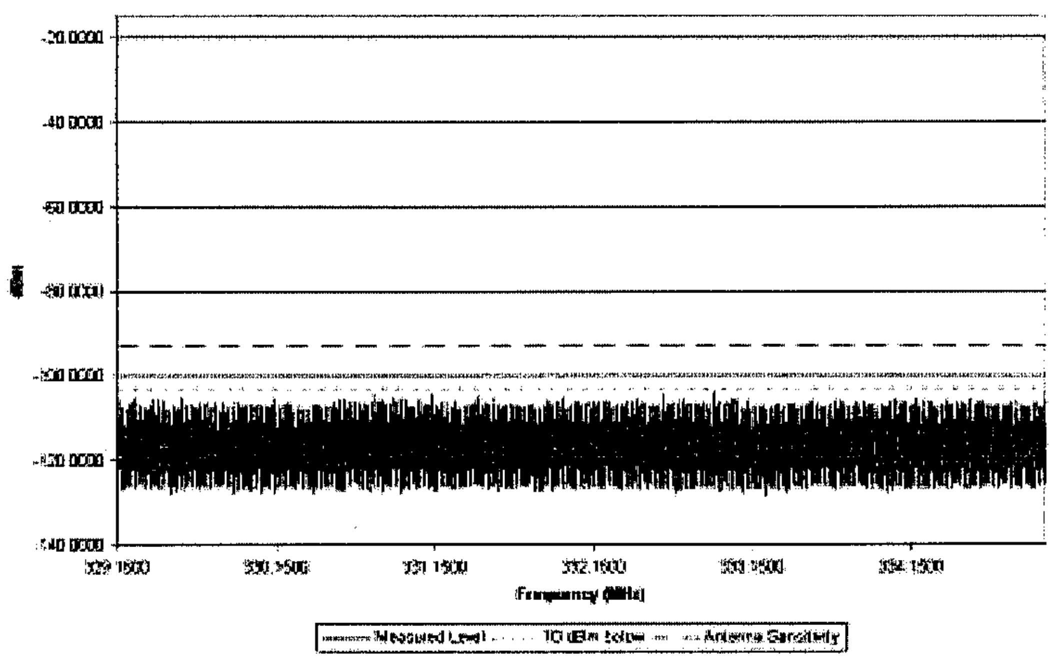
Ambient (329.15MHz - 335MHz)



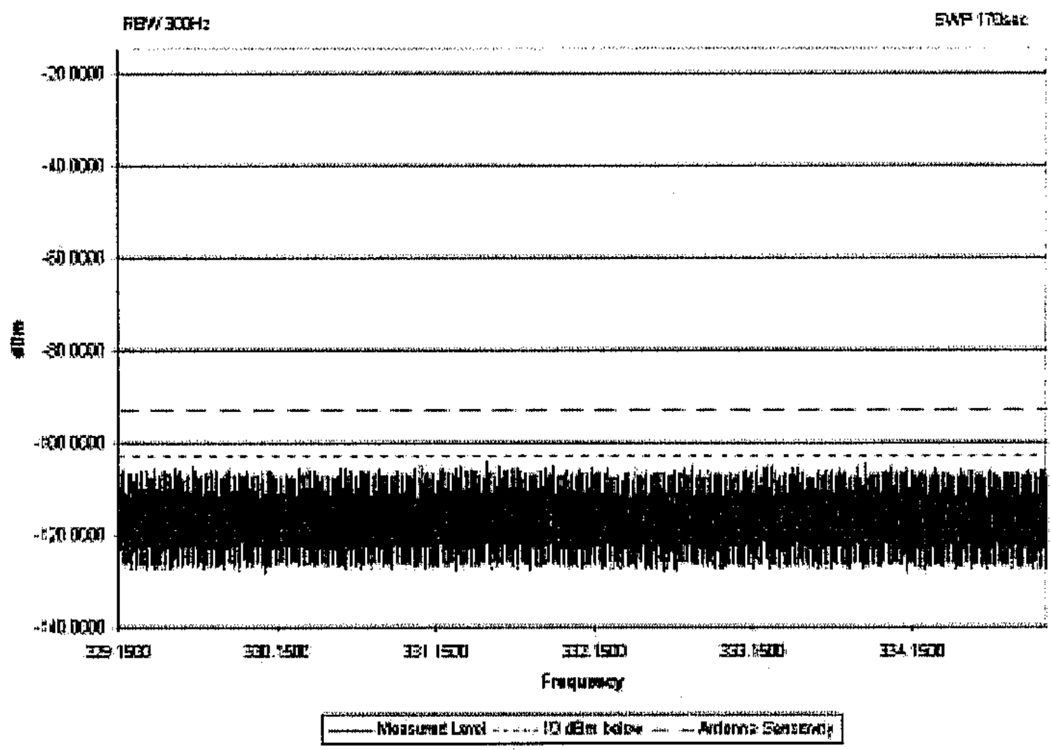
CDMA 800 (329.15MHz - 335MHz)



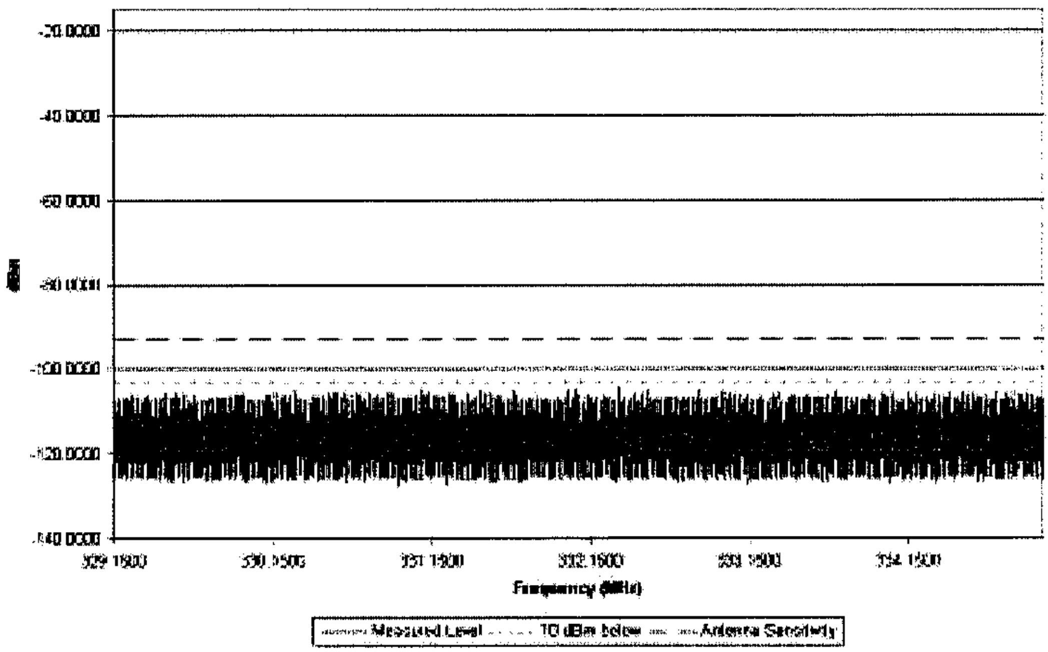
TDMA-1Hz (329.15MHz - 335MHz)



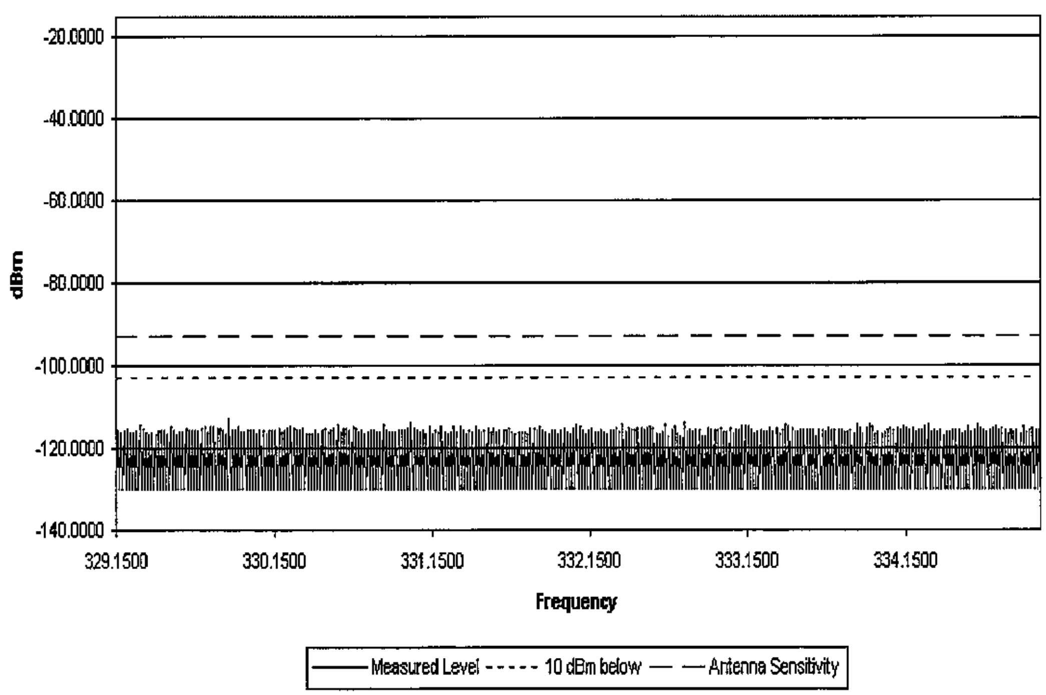
TDMA-50Hz 900 (329.15MHz - 335MHz)

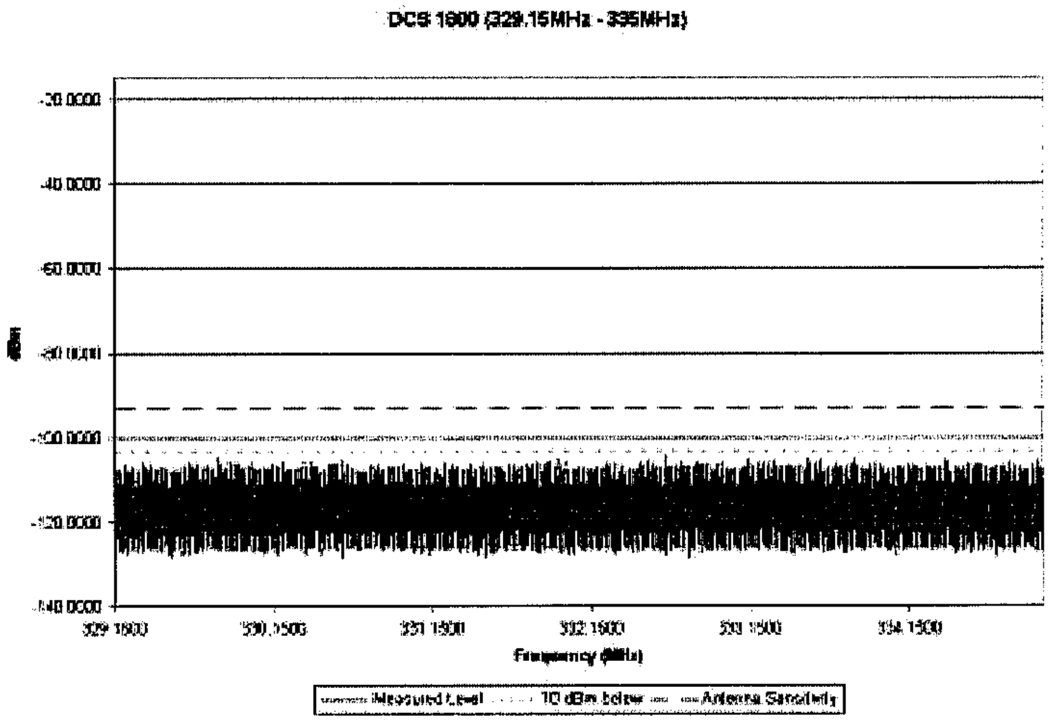


TDMA-60Hz PCS (329.15MHz - 335MHz)



GSM 900 (329.15MHz - 335MHz)

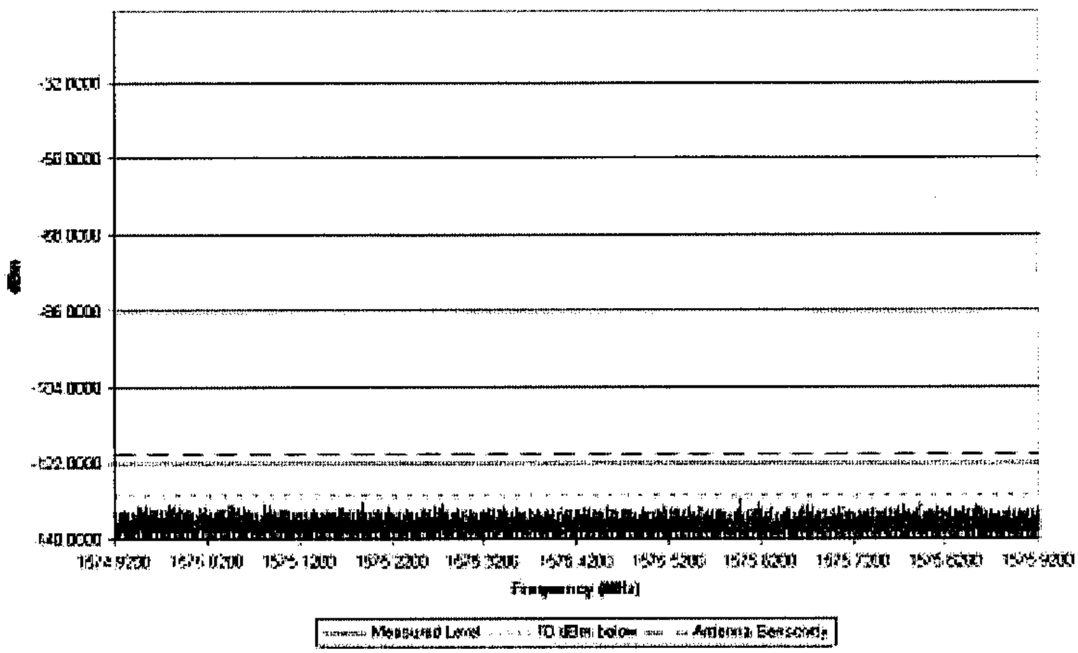



DCS 1800 (329.15MHz - 335MHz)
Frequency (MHz)
Measured Level
10 dBm below
Antenna Sensitivity

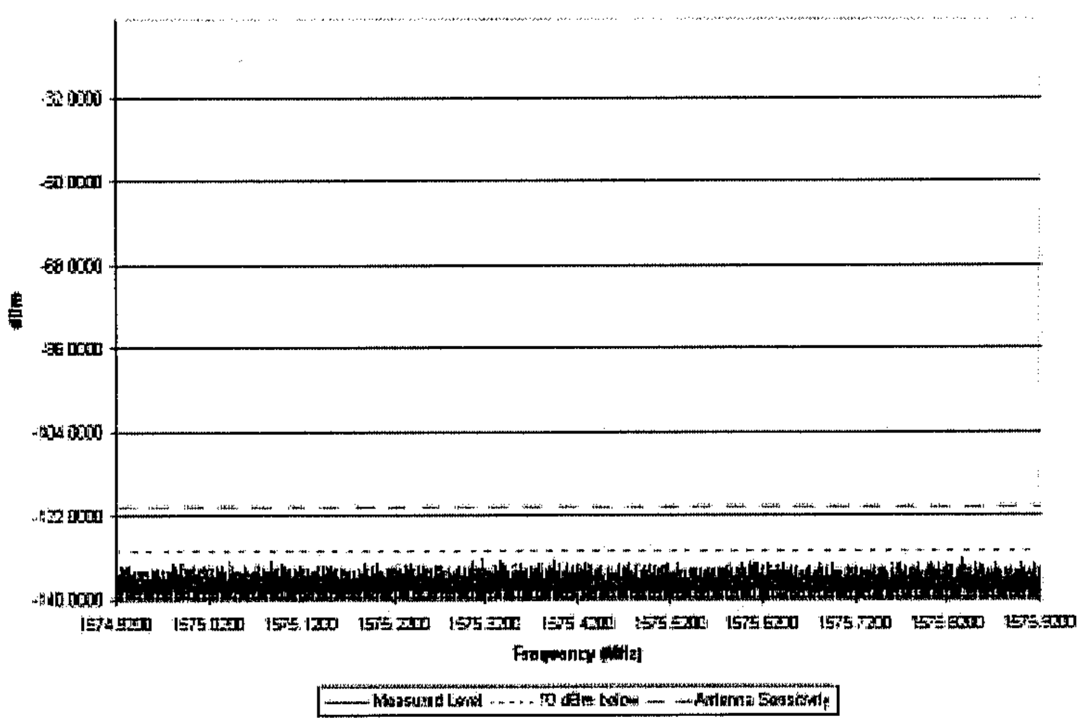
GLOBAL POSITIONING SYSTEM

1574.92 – 1575.92 MHz

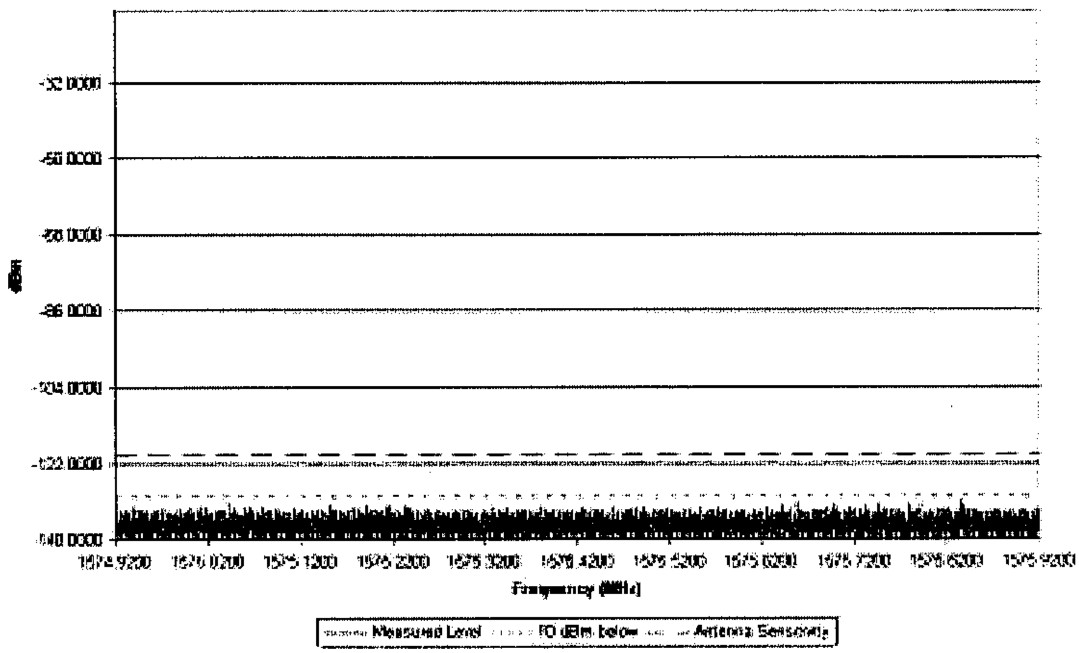
Ambient (1574.92MHz - 1575.92MHz)



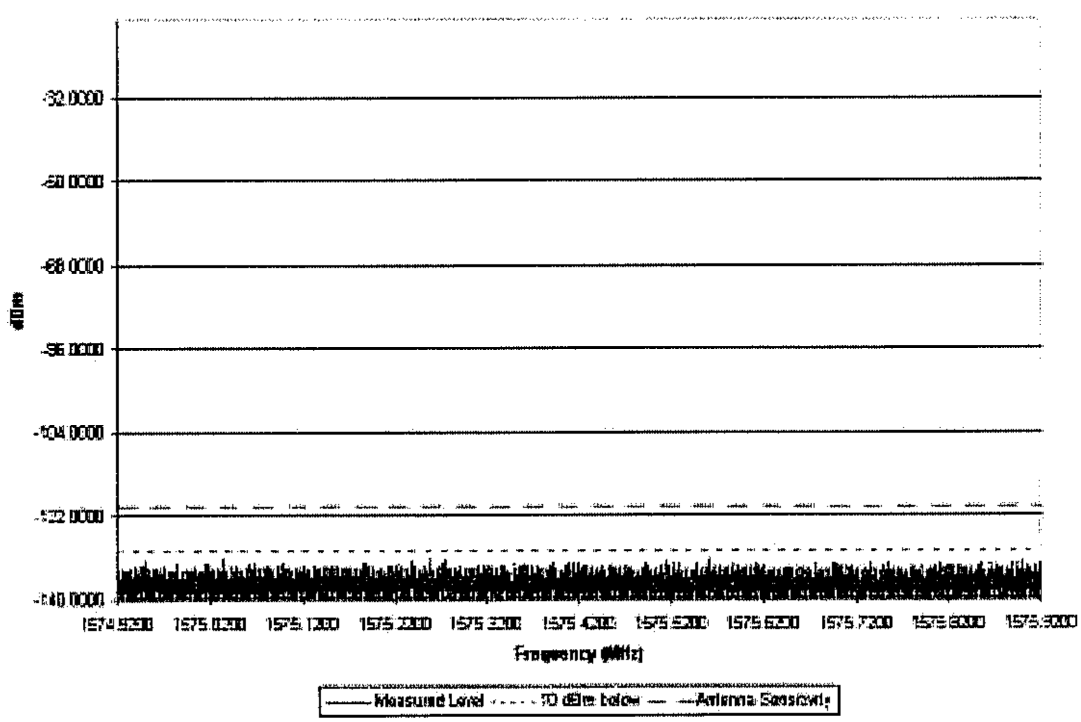
CDMA 800 (1574.92MHz - 1575.92MHz)

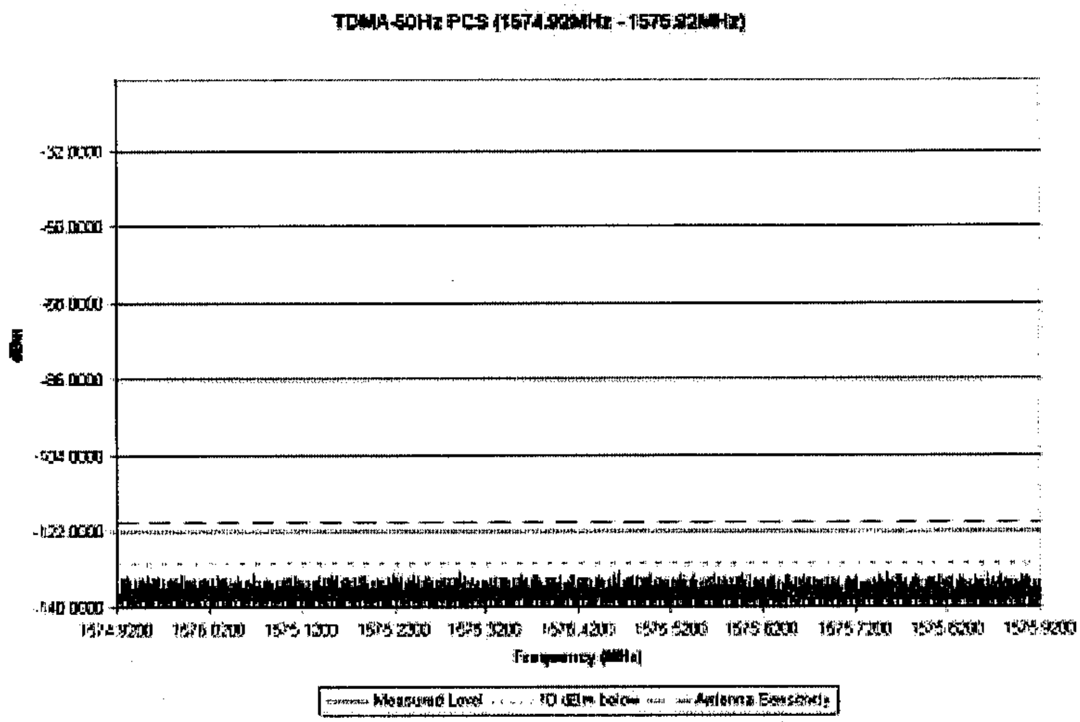


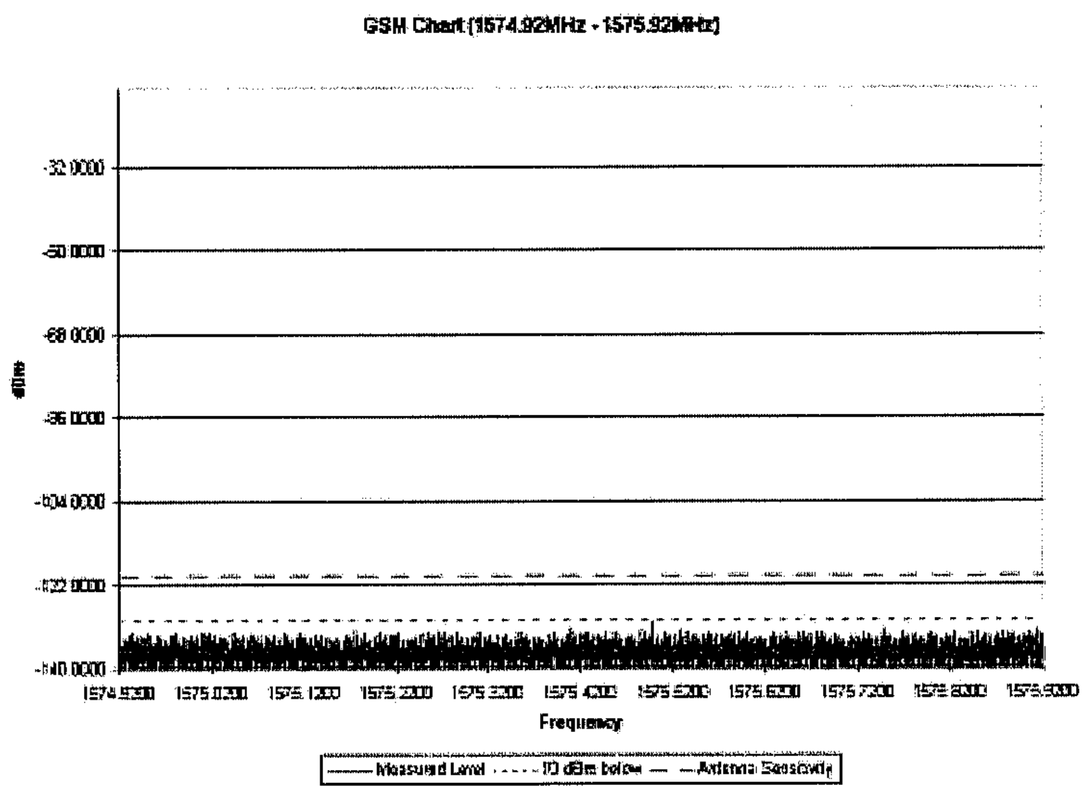
TDMA-11Hz (1574.92MHz - 1575.92MHz)



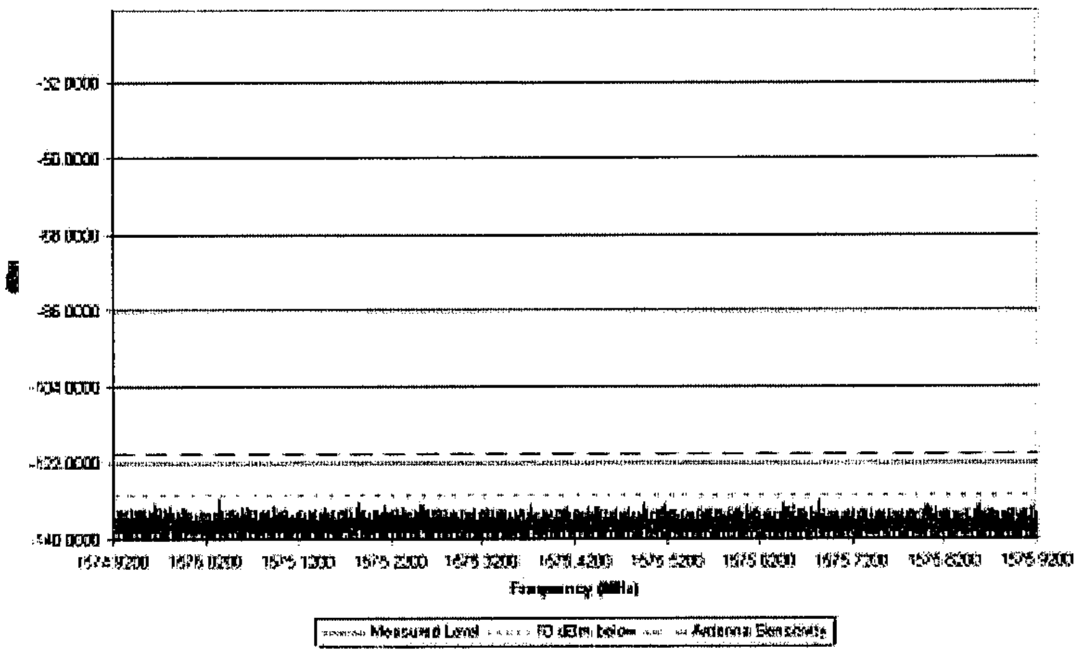
TDMA-50Hz Cellular (1574.92MHz - 1575.92MHz)




TDMA-50Hz PCS (1574.92MHz - 1575.92MHz)
dBm
Frequency (MHz)
Measured Level
10 dBm below
Antenna Sensitivity


GSM Chart (1574.92MHz - 1575.92MHz)
dBm
Frequency
Measured Level
10 dBm below
Antenna Sensitivity

DCS 1800 [1574.92MHz - 1575.92MHz]

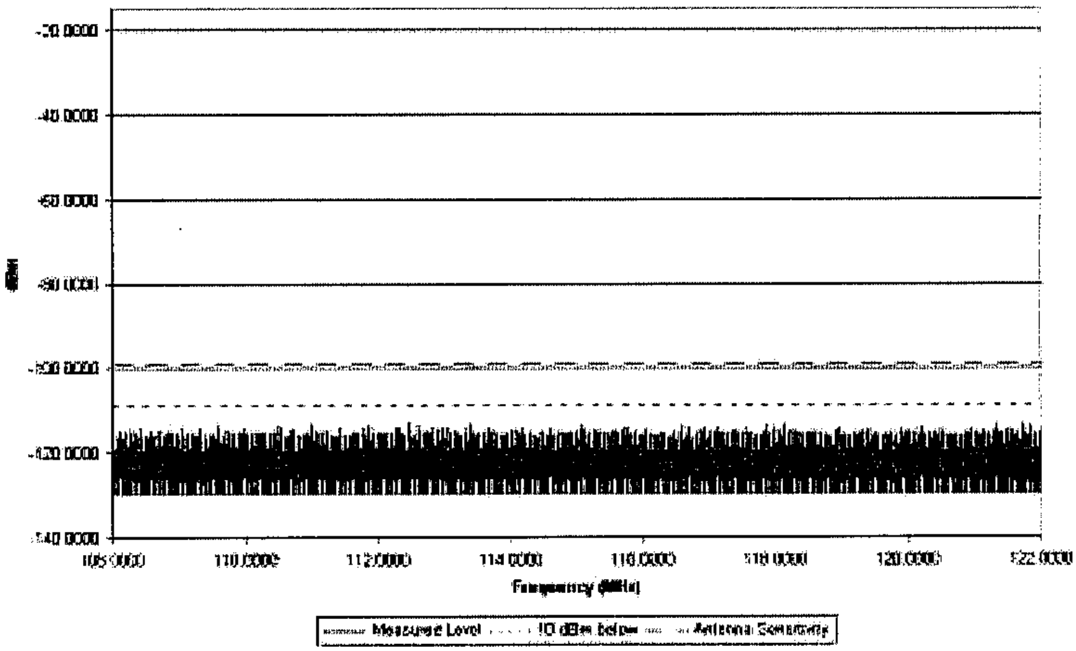


APPENDIX C

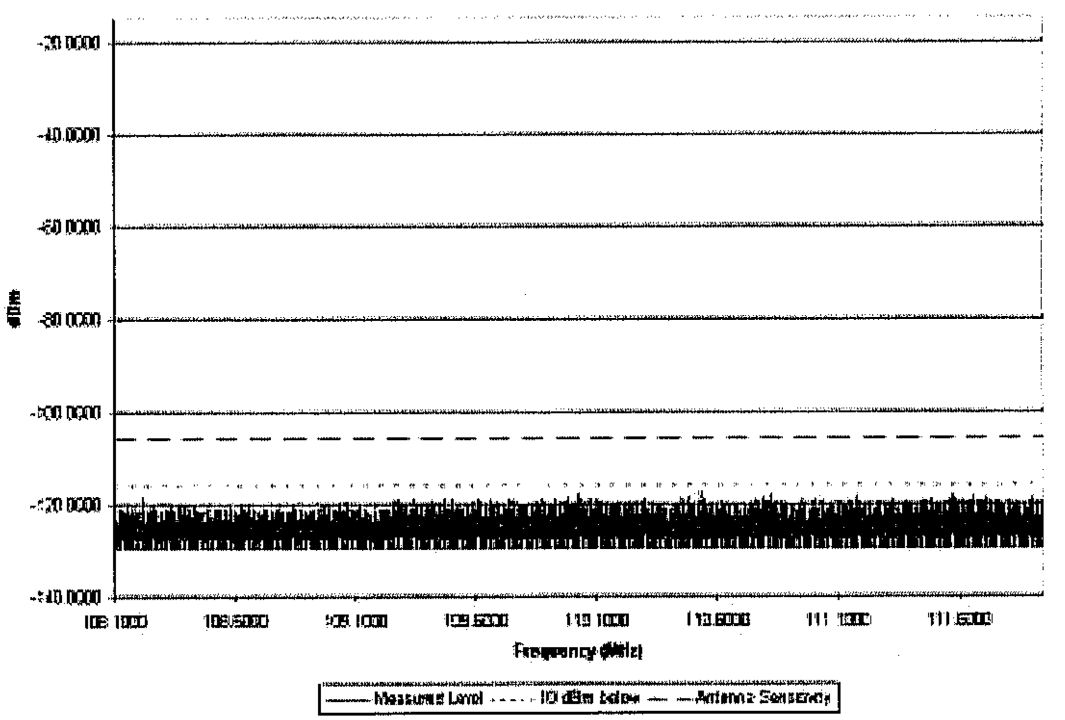
Scans According to Phone Technology

CDMA Cellular

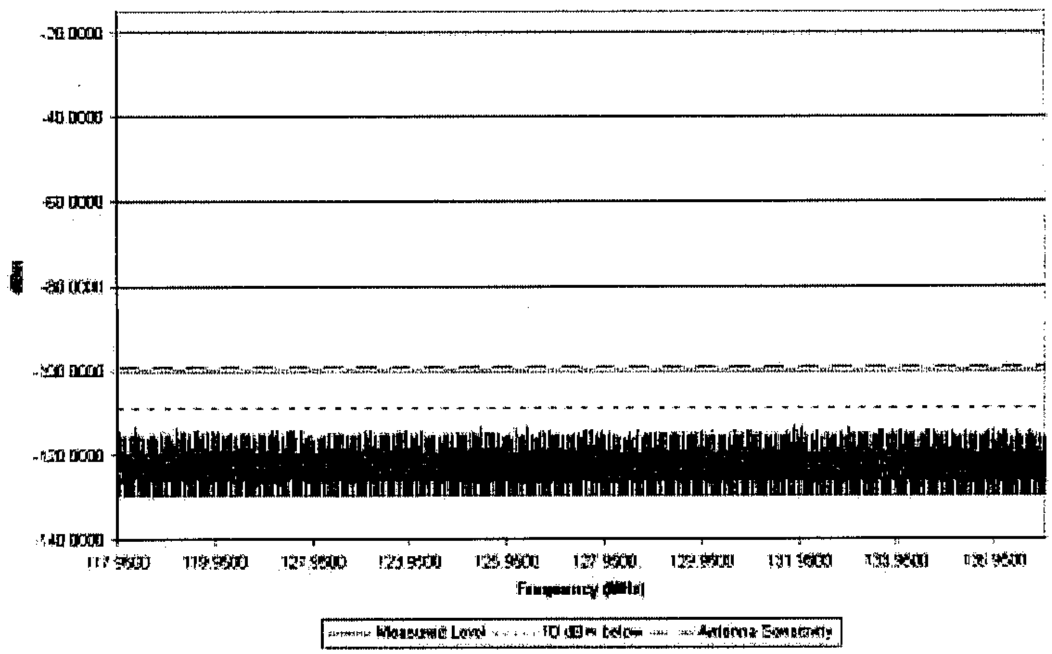
CDMA 800 (108MHz - 122MHz)



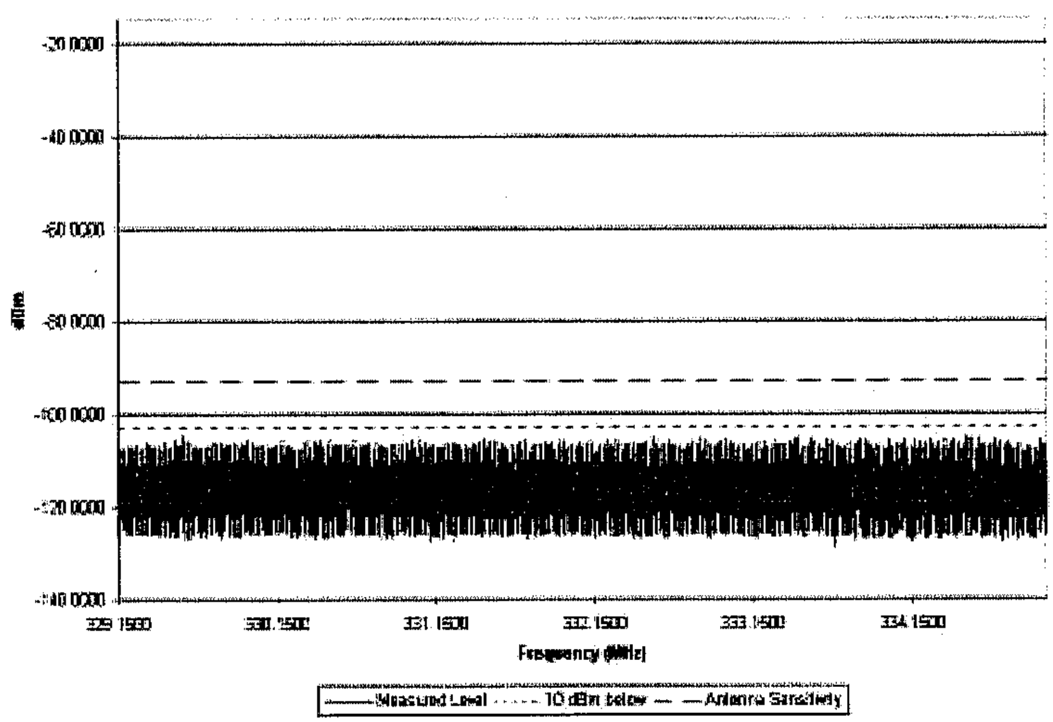
CDMA 800 (108.1MHz - 111.95MHz)

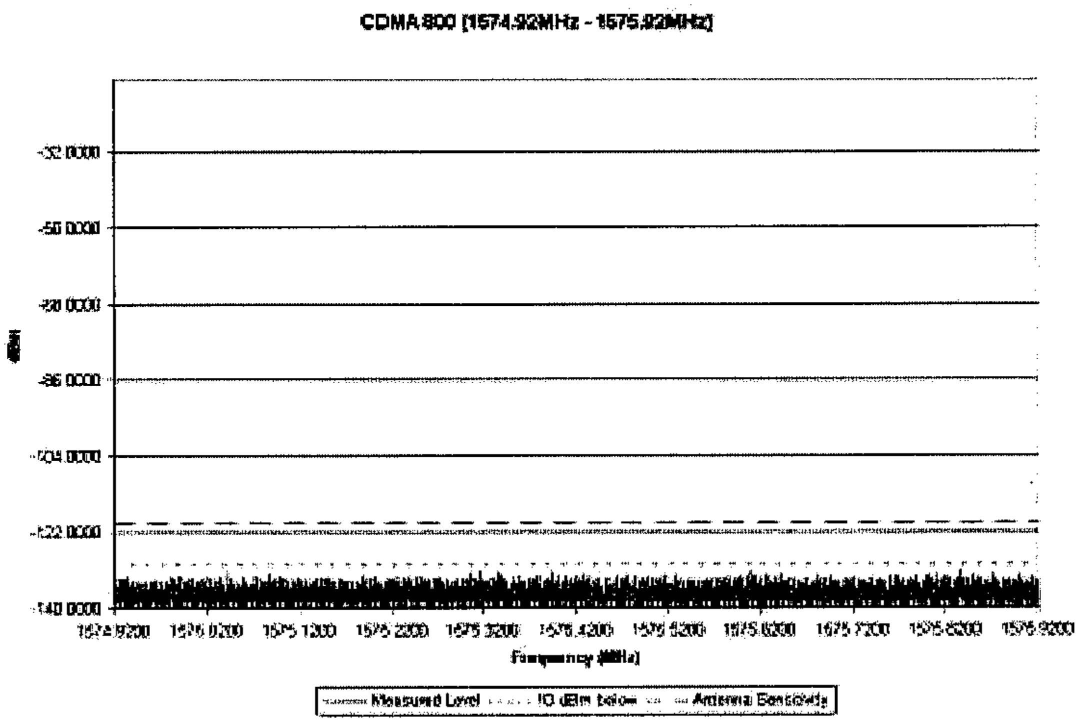


CDMA 800 (117.97MHz - 137MHz)



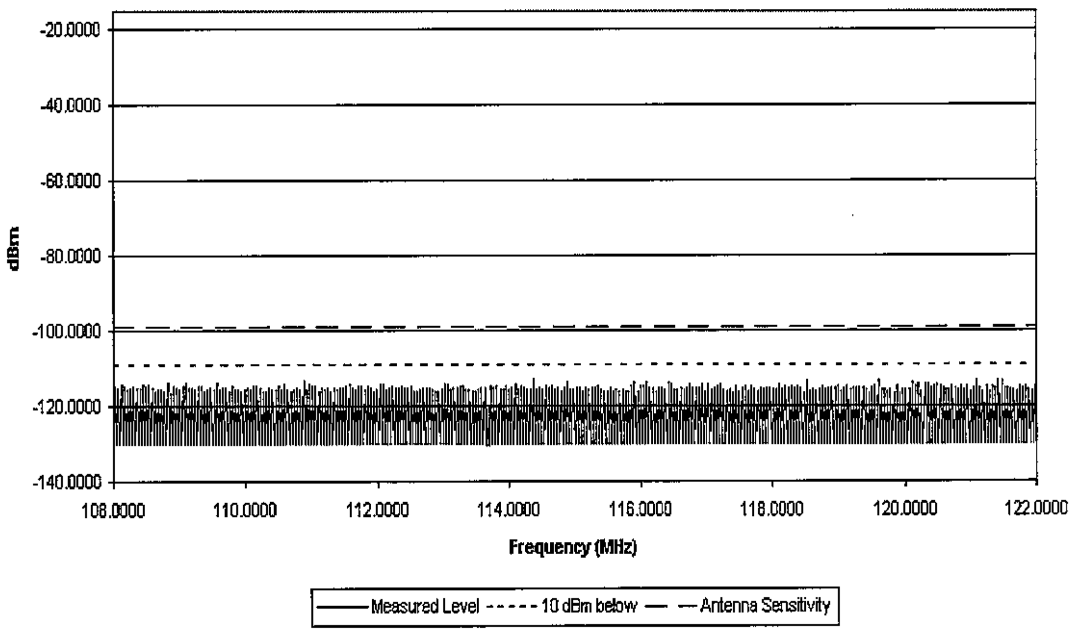
CDMA 800 (329.15MHz - 335MHz)



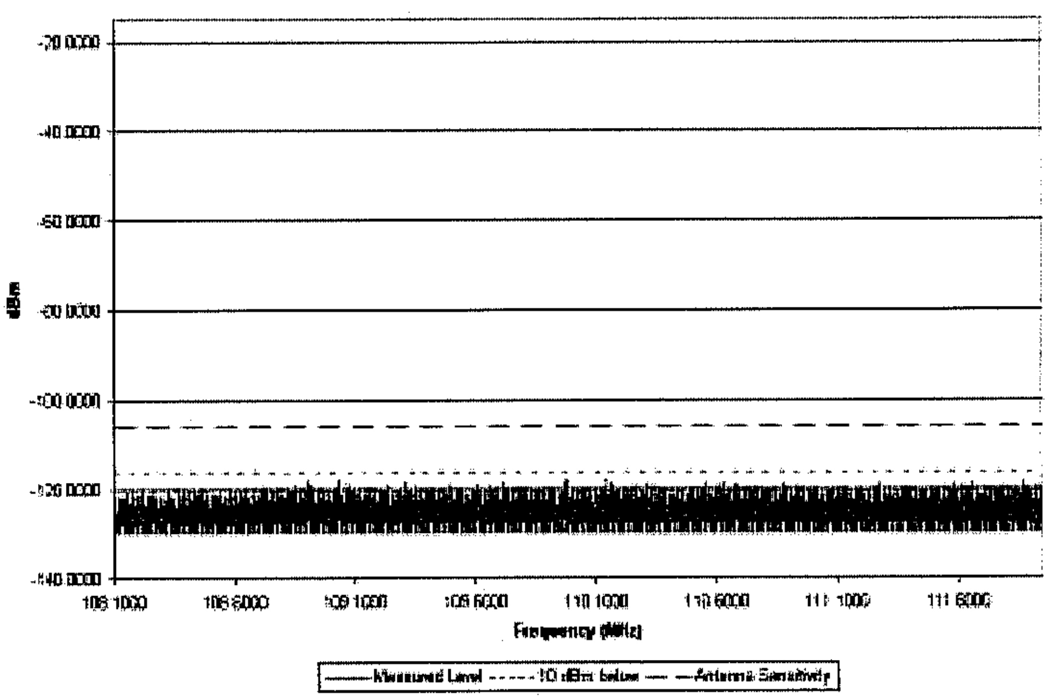

CDMA 800 [1574.92MHz - 1575.92MHz]
Measured Level
Antenna Sensitivity

TDMA 11Hz Cellular

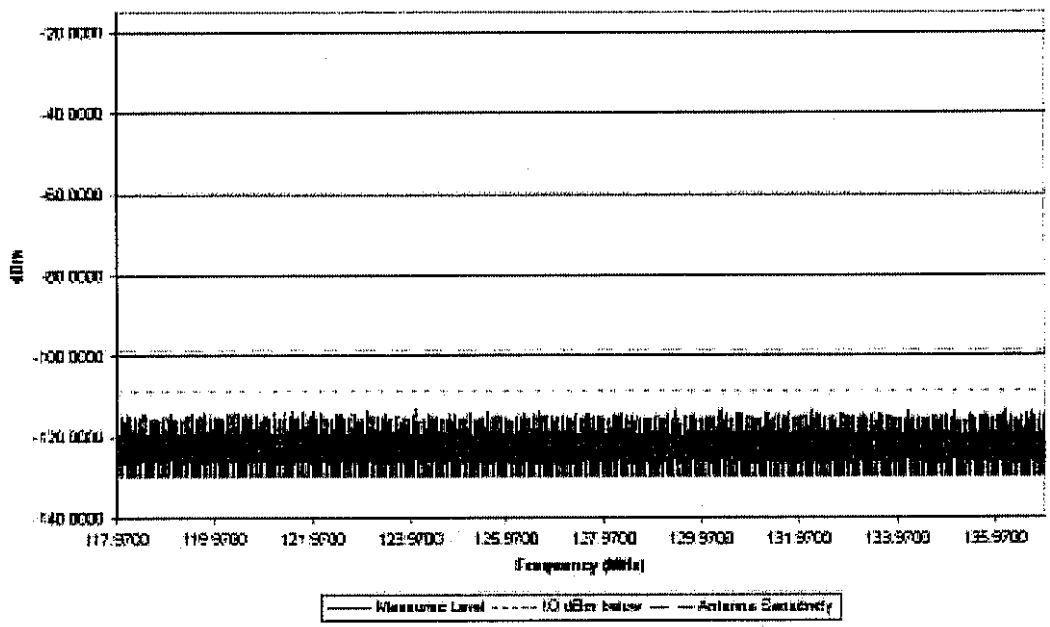
TDMA-11Hz (108MHz - 122MHz)



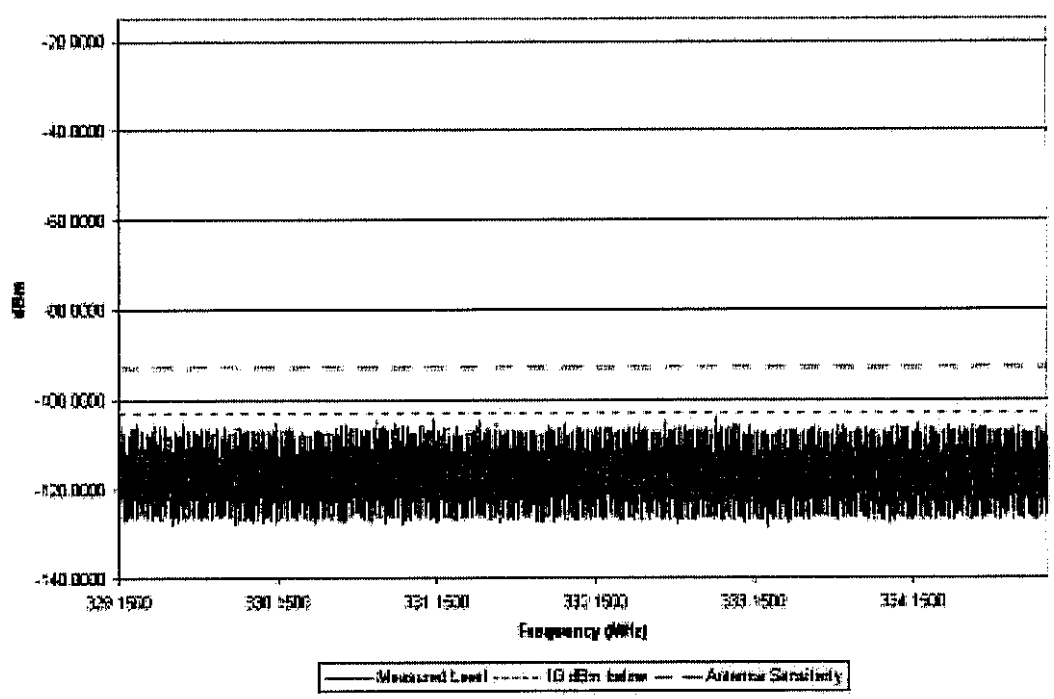
TDMA-11Hz (108.1MHz - 111.95MHz)

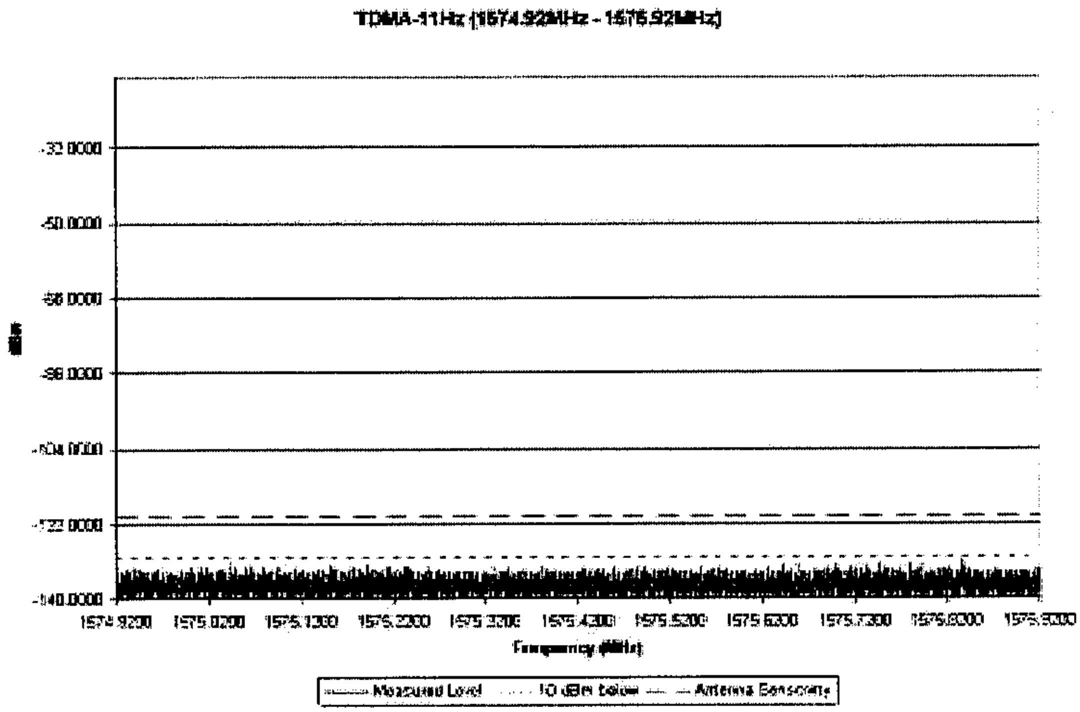


TDMA-11Hz (117.97MHz - 137MHz)



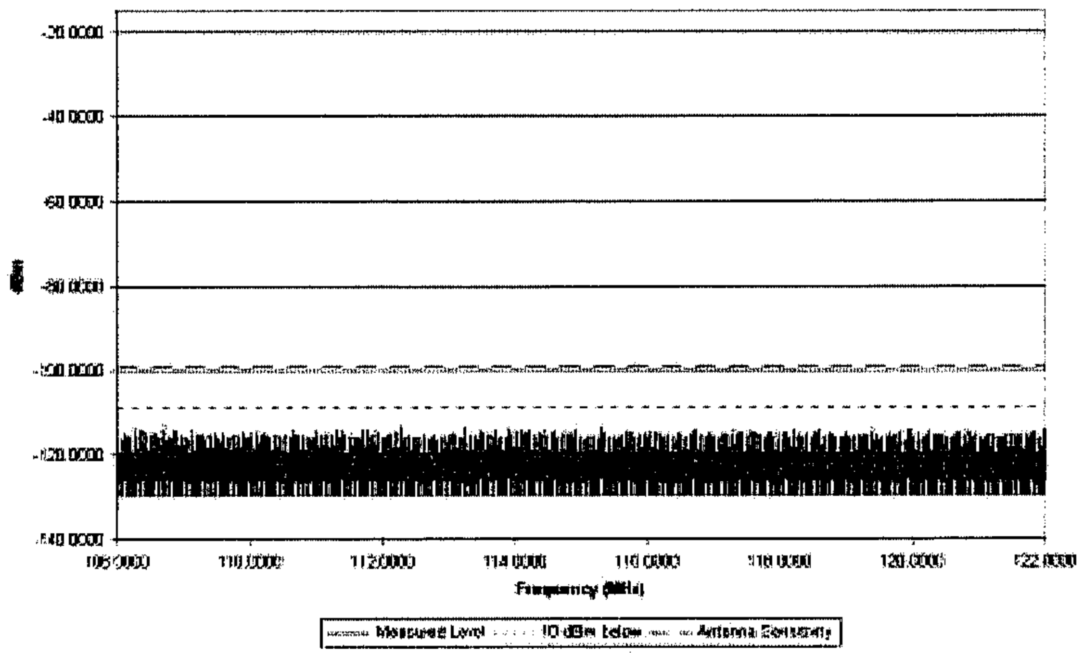
TDMA-11Hz (329.15MHz - 335MHz)



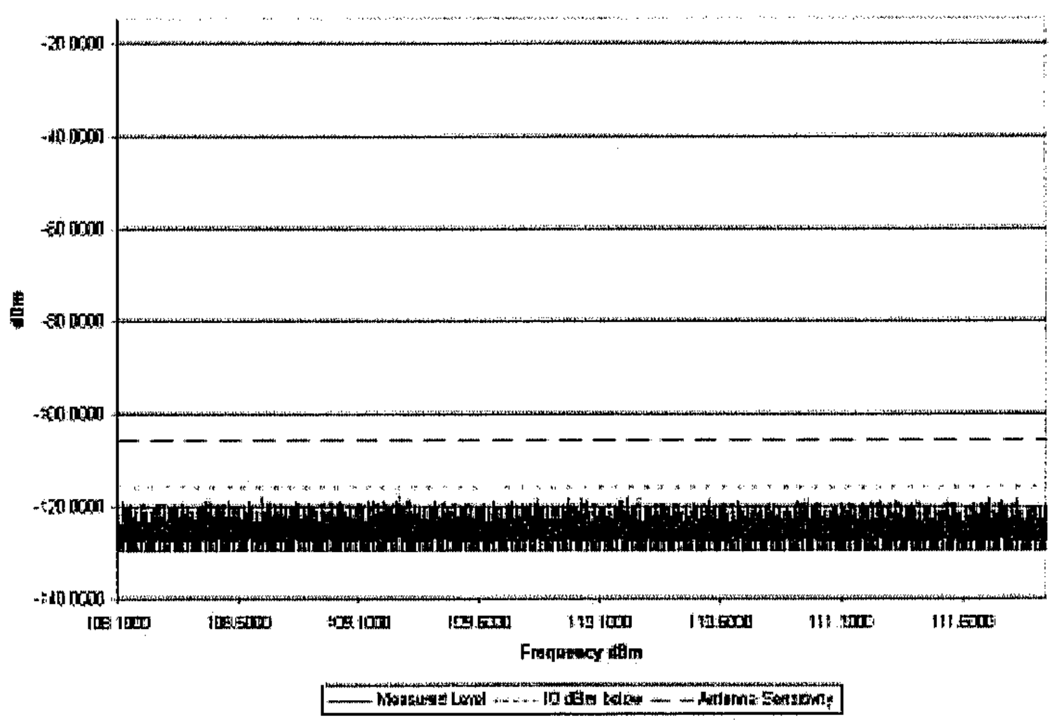

TDMA-1 1Hz (1574.92MHz - 1575.92MHz)
-32.0000
-50.0000
-68.0000
-86.0000
-104.0000
-122.0000
-140.0000
1574.9200
1575.0200
1575.1200
1575.2200
1575.3200
1575.4200
1575.5200
1575.6200
1575.7200
1575.8200
1575.9200
Frequency (MHz)
Measured Level
10 dBm below
Antenna Sensitivity

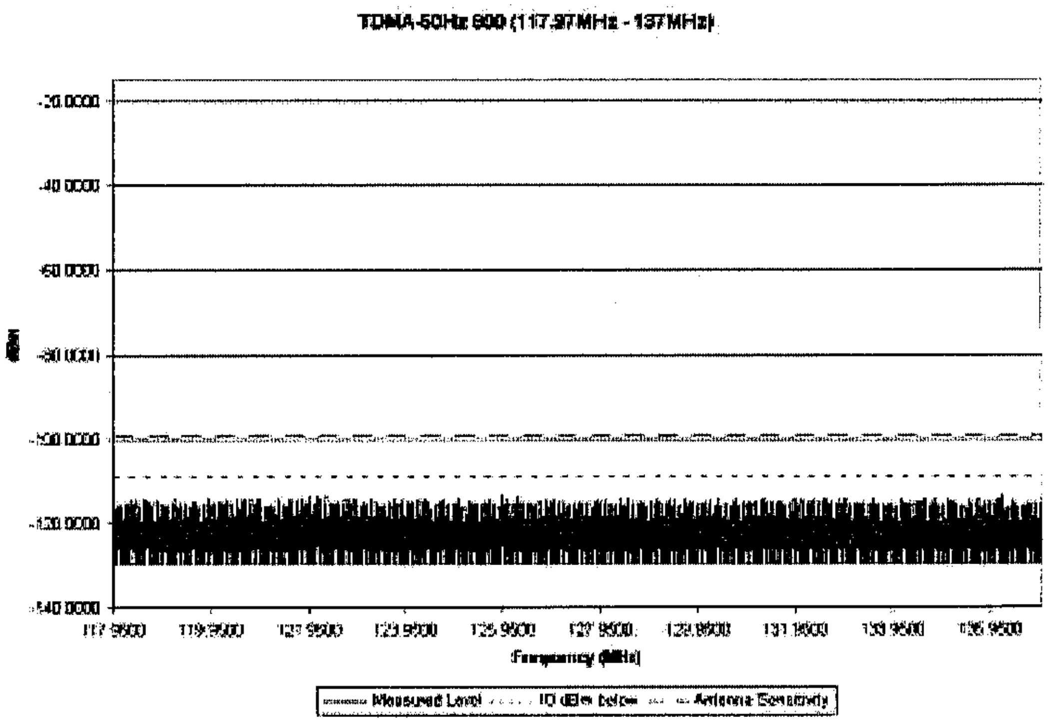
TDMA 50Hz Cellular

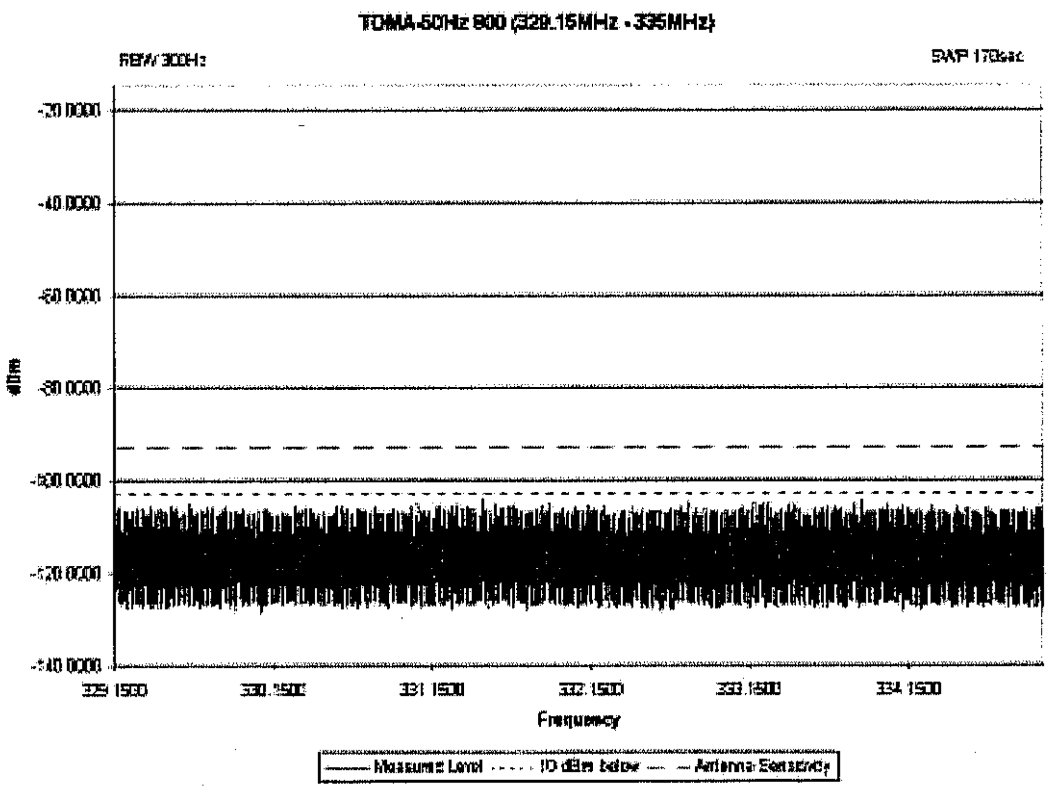
TDMA-50Hz 800 (108MHz - 122MHz)

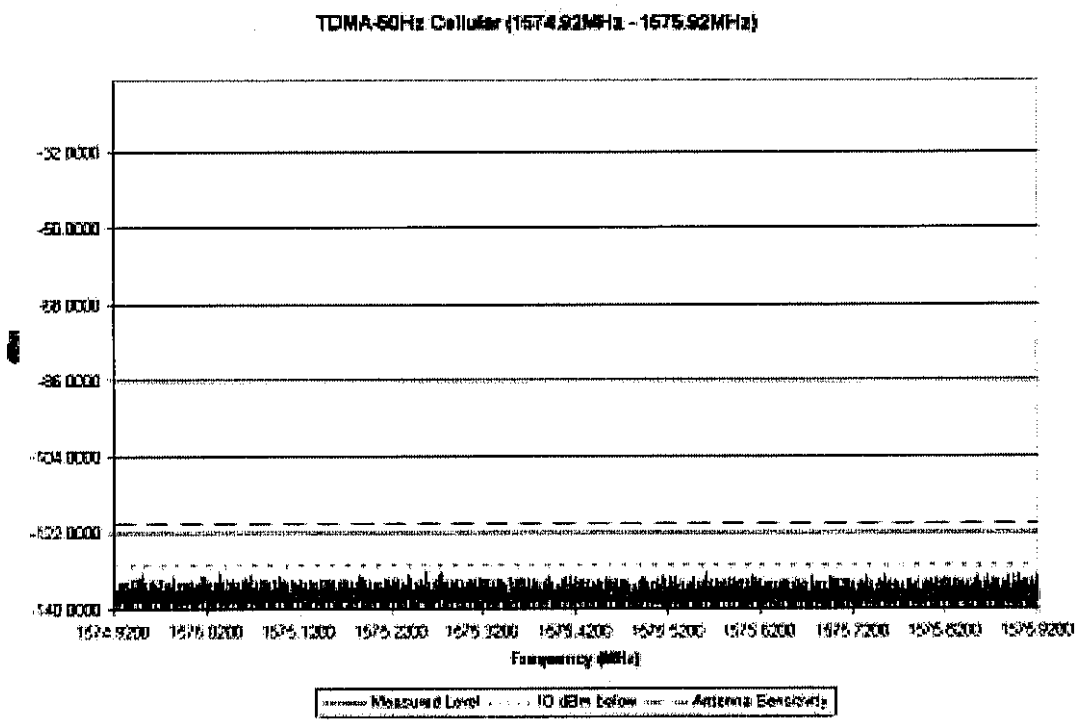


TDMA-50Hz 800 (108.1MHz - 111.85MHz)

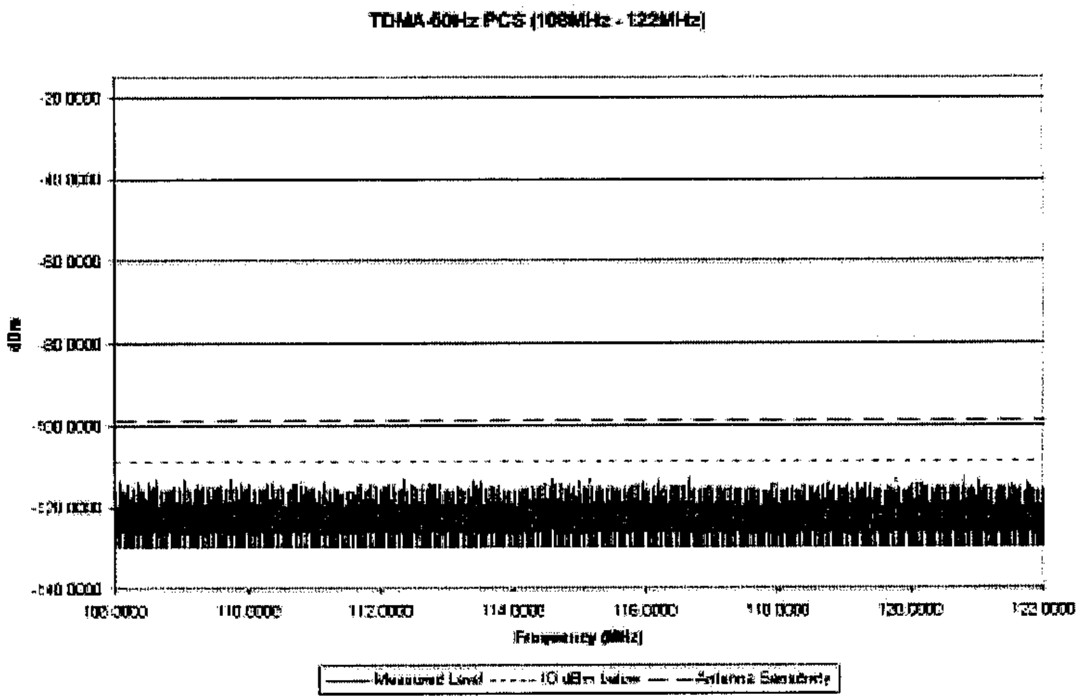


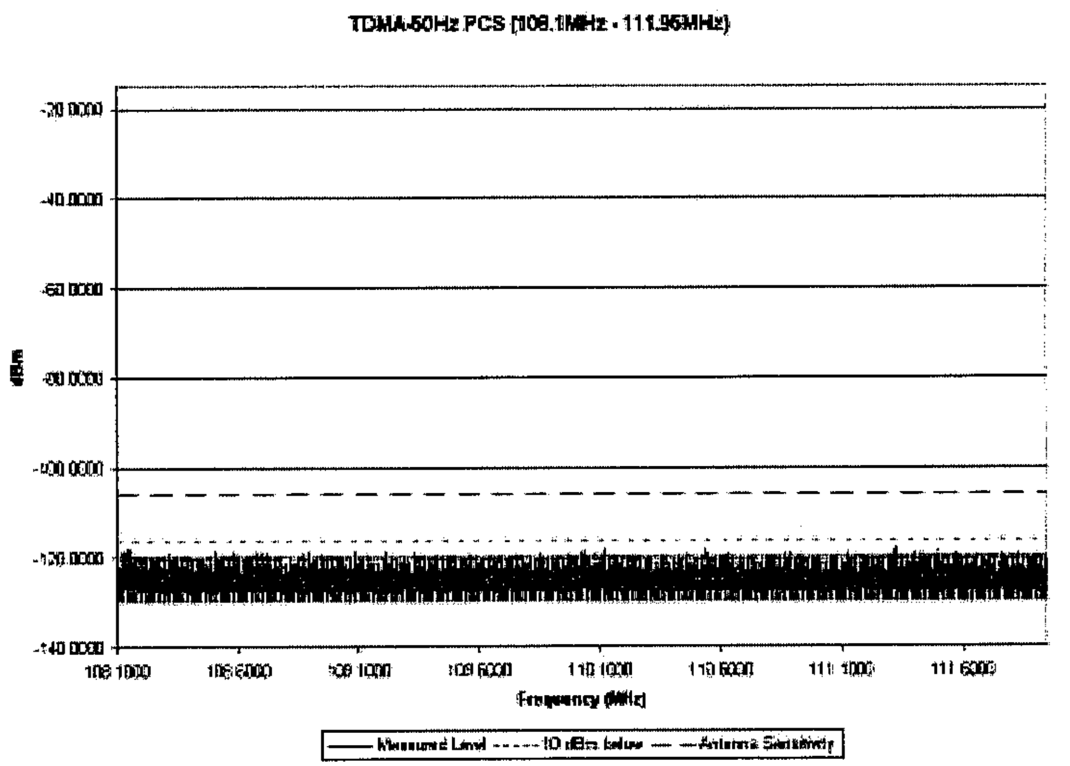

TDMA-50Hz 800 (117.97MHz - 137MHz)
dBm
-20.0000
-40.0000
-60.0000
-80.0000
-100.0000
-120.0000
-140.0000
117.9500
119.9500
121.9500
123.9500
125.9500
127.9500
129.9500
131.9500
133.9500
135.9500
Frequency (MHz)
Measured Level
10 dBm below
Antenna Sensitivity


TDMA-50Hz 800 (329.15MHz - 335MHz)
RBW 300Hz
SWP 170sec
dBm
-20.0000
-40.0000
-60.0000
-80.0000
-100.0000
-120.0000
-140.0000
329.1500
330.1500
331.1500
332.1500
333.1500
334.1500
Frequency
Measured Level
10 dBm below
Antenna Sensitivity

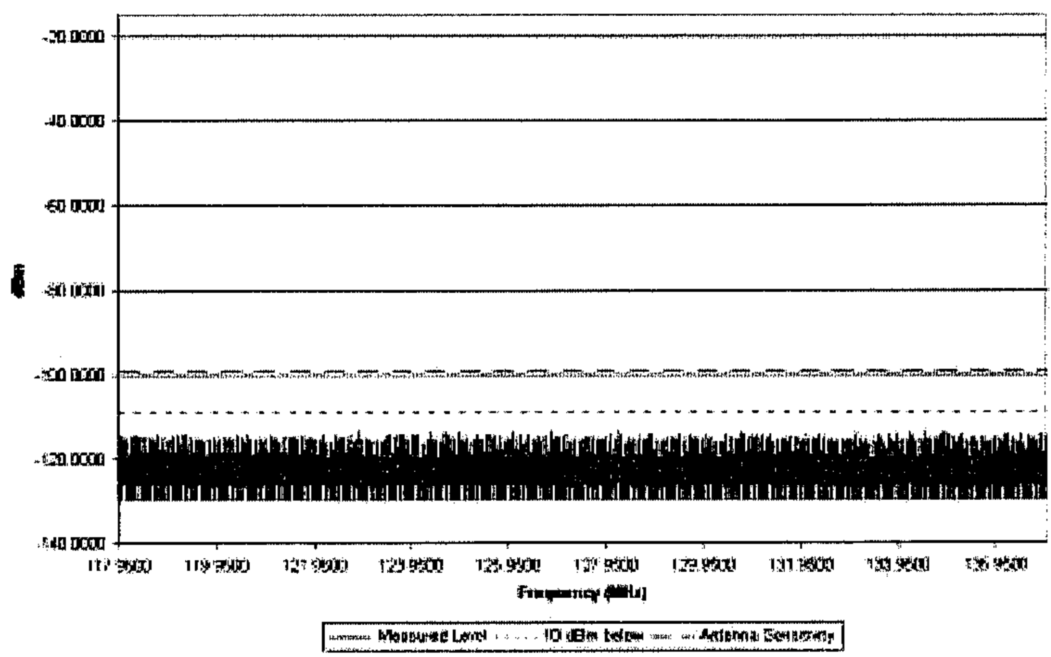

TDMA-50Hz Cellular (1574.92MHz - 1575.92MHz)
-32.0000
-50.0000
-68.0000
-86.0000
-104.0000
-122.0000
-140.0000
1574.9200
1575.0200
1575.1200
1575.2200
1575.3200
1575.4200
1575.5200
1575.6200
1575.7200
1575.8200
1575.9200
Frequency (MHz)
Measured Level
10 dBm below
Antenna Sensitivity

TDMA 50Hz PCS

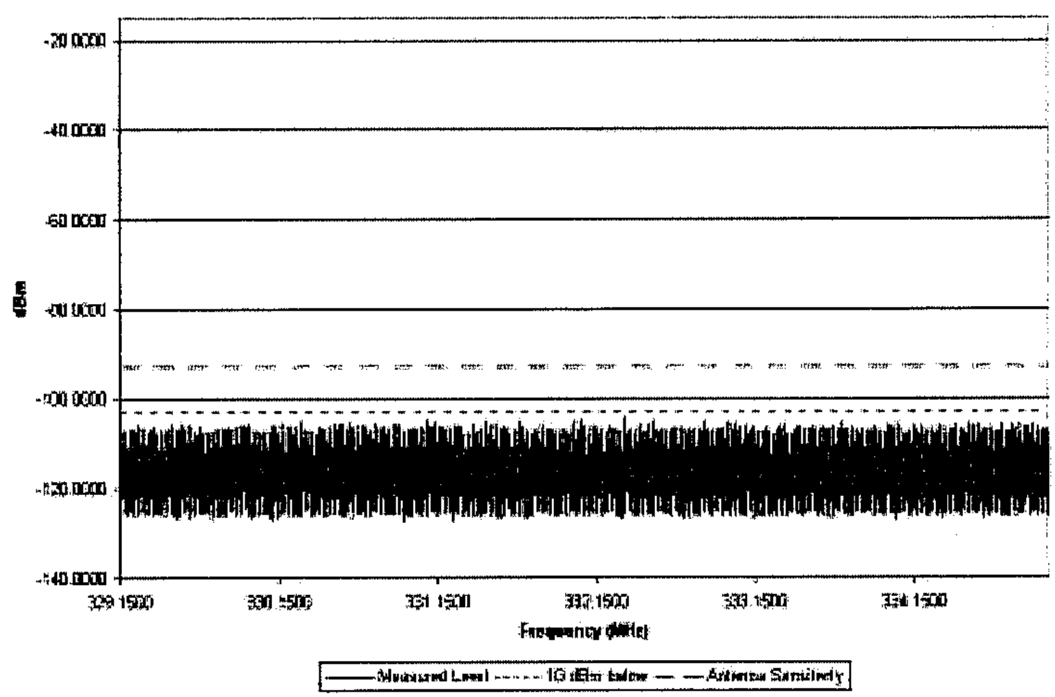

TDMA-50Hz PCS (108MHz - 122MHz)
dBm
Frequency (MHz)
Measured Level
10 dBm below
Antenna Sensitivity

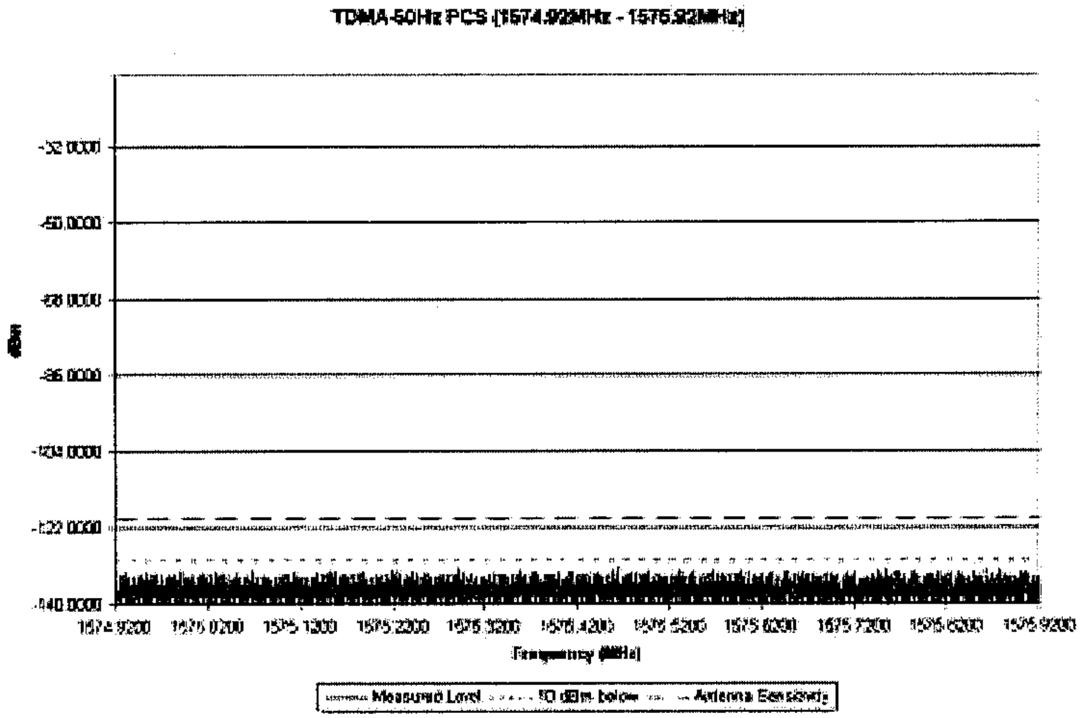

TDMA-50Hz PCS (108.1MHz - 111.95MHz)
dBm
Frequency (MHz)
Measured Level
10 dBm below
Antenna Sensitivity

TDMA-50Hz PCS (117.97MHz - 137MHz)



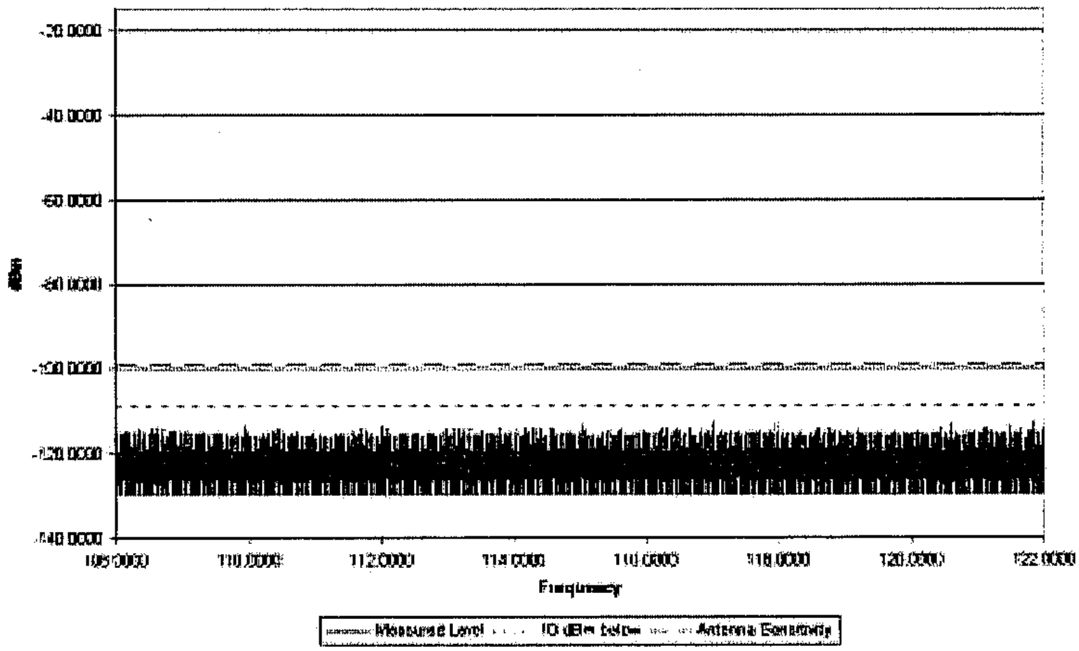
TDMA-50Hz PCS (329.15MHz - 335MHz)



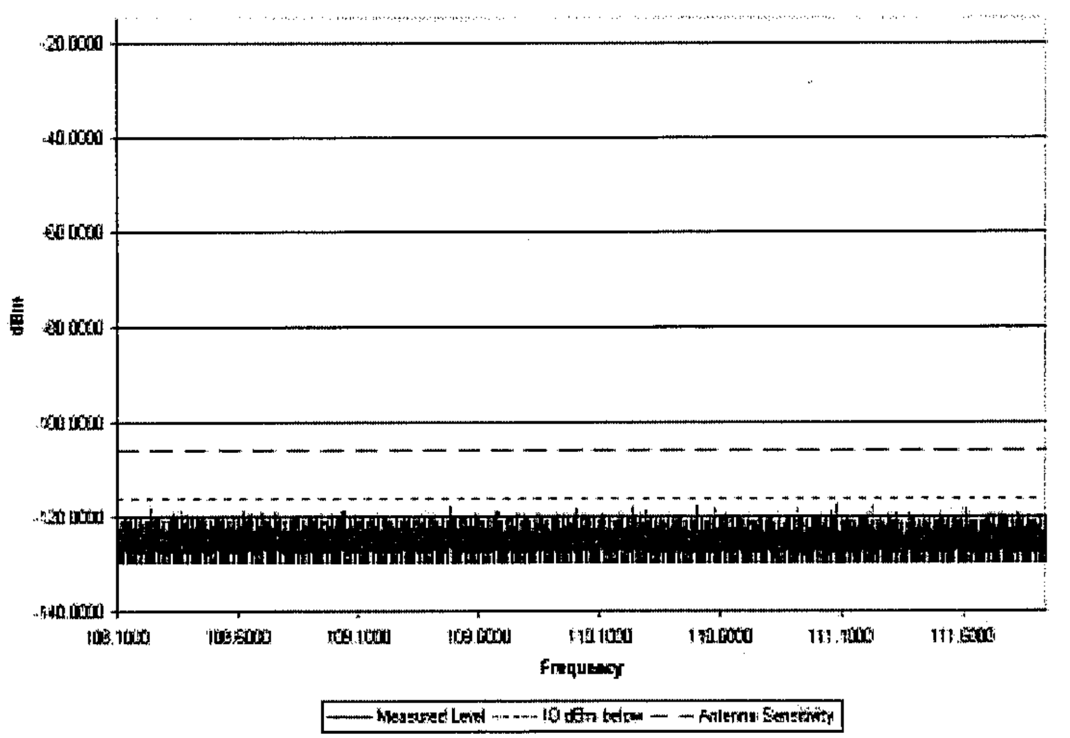

TDMA-50Hz PCS (1574.92MHz - 1575.92MHz)
Measured Level
10 dBm below
Antenna Sensitivity

TDMA 217Hz GSM

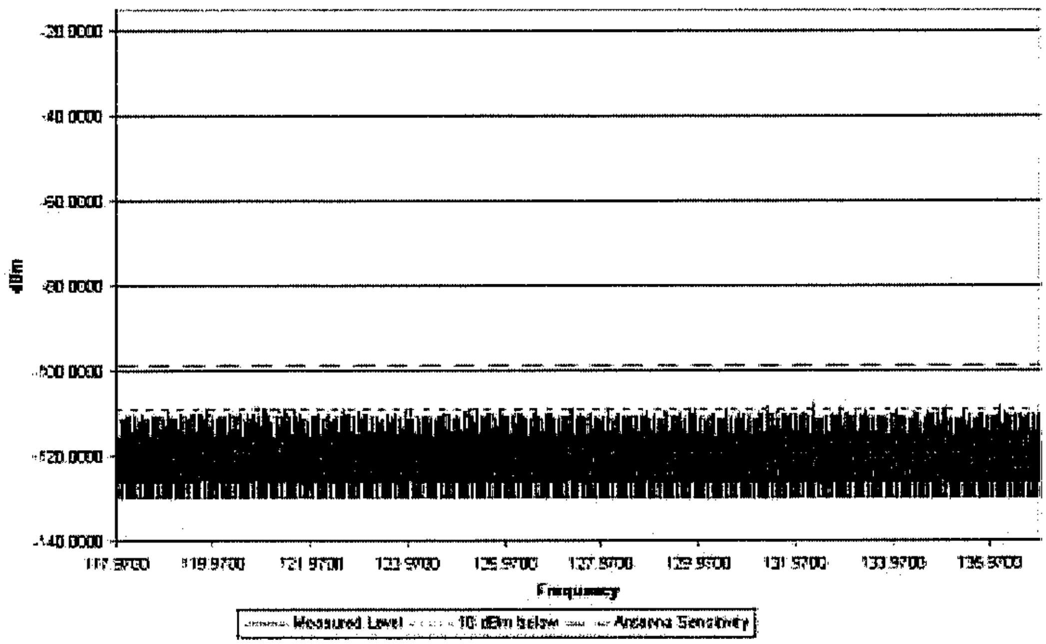
GSM 900 (108MHz - 122MHz)



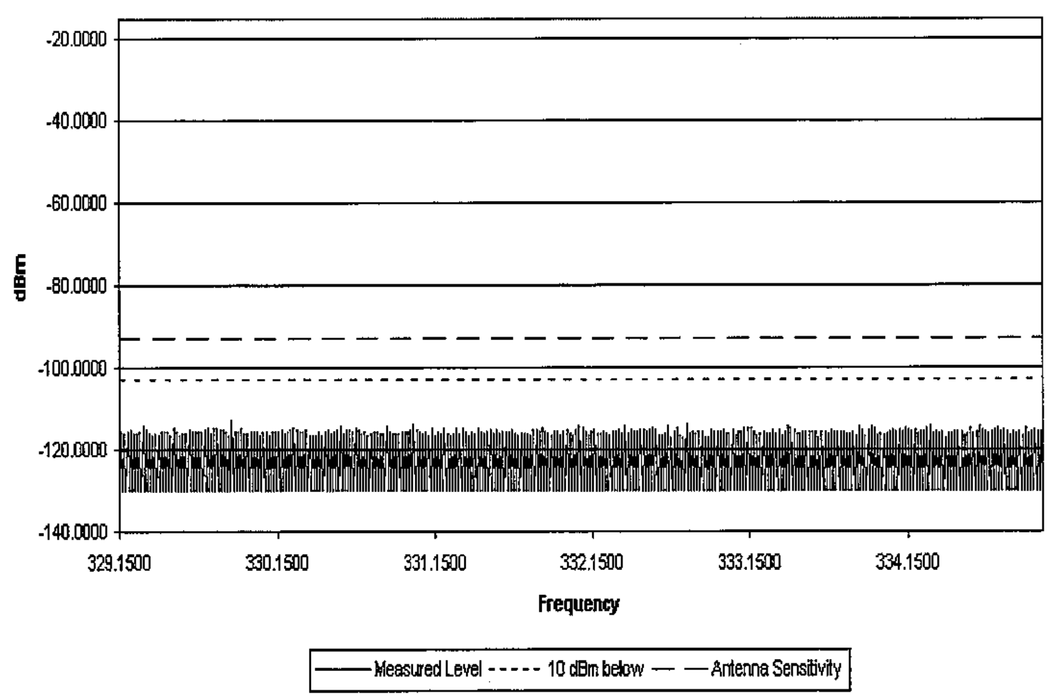
GSM 900 (108.1MHz - 111.95MHz)

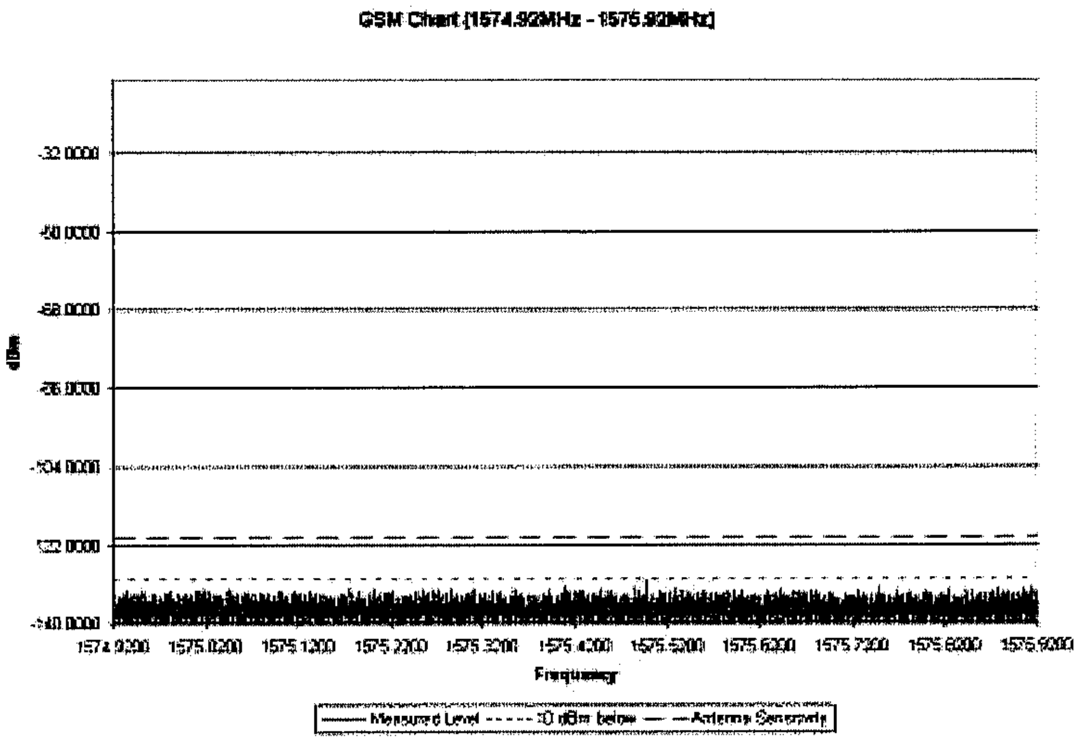


GSM 900 (117.97MHz - 137MHz)



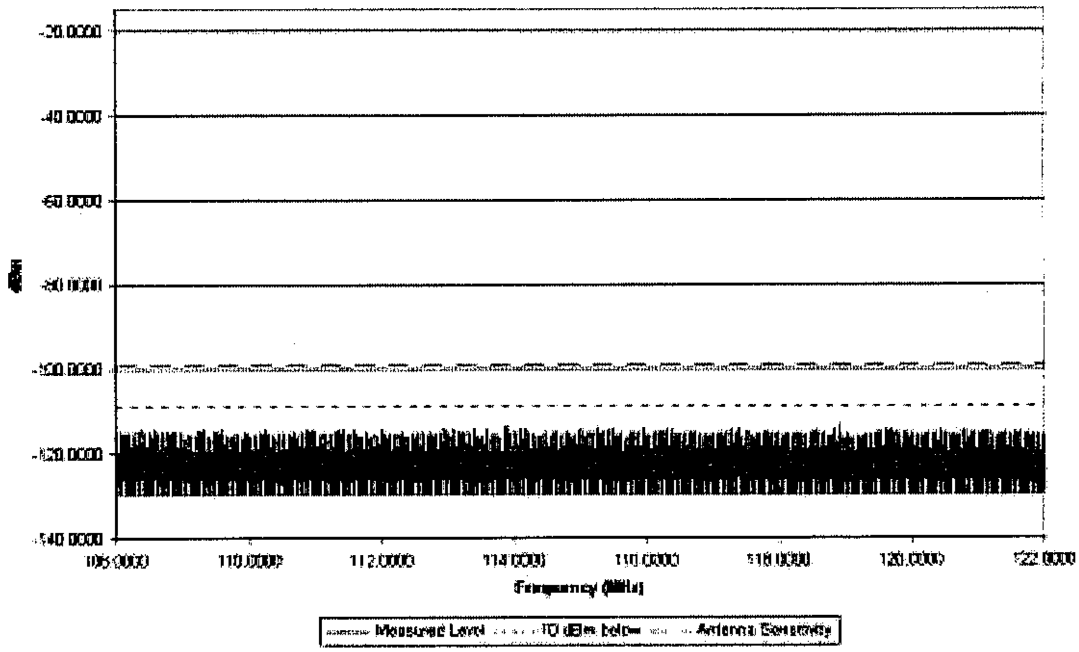
GSM 900 (329.15MHz - 335MHz)



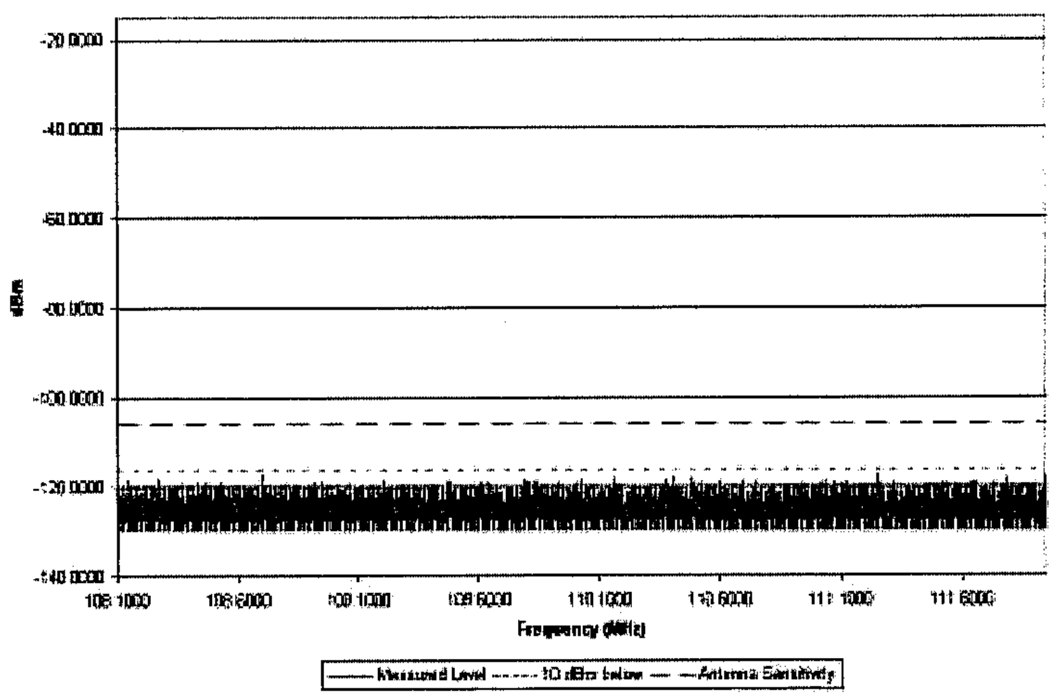

GSM Chart [1574.92MHz - 1575.92MHz]
-32.0000
1574.9200 1575.0200 1575.1200 1575.2200 1575.3200 1575.4200 1575.5200 1575.6200 1575.7200 1575.8200 1575.9200
Frequency
Measured Level
Antenna Sensitivity

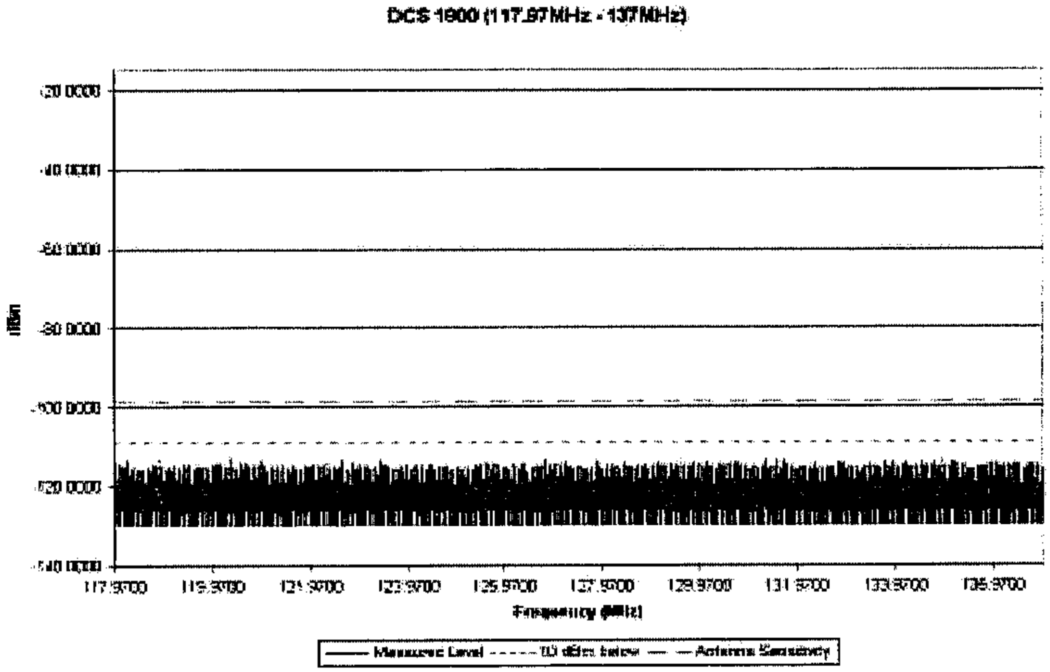
TDMA 217Hz DCS 1800

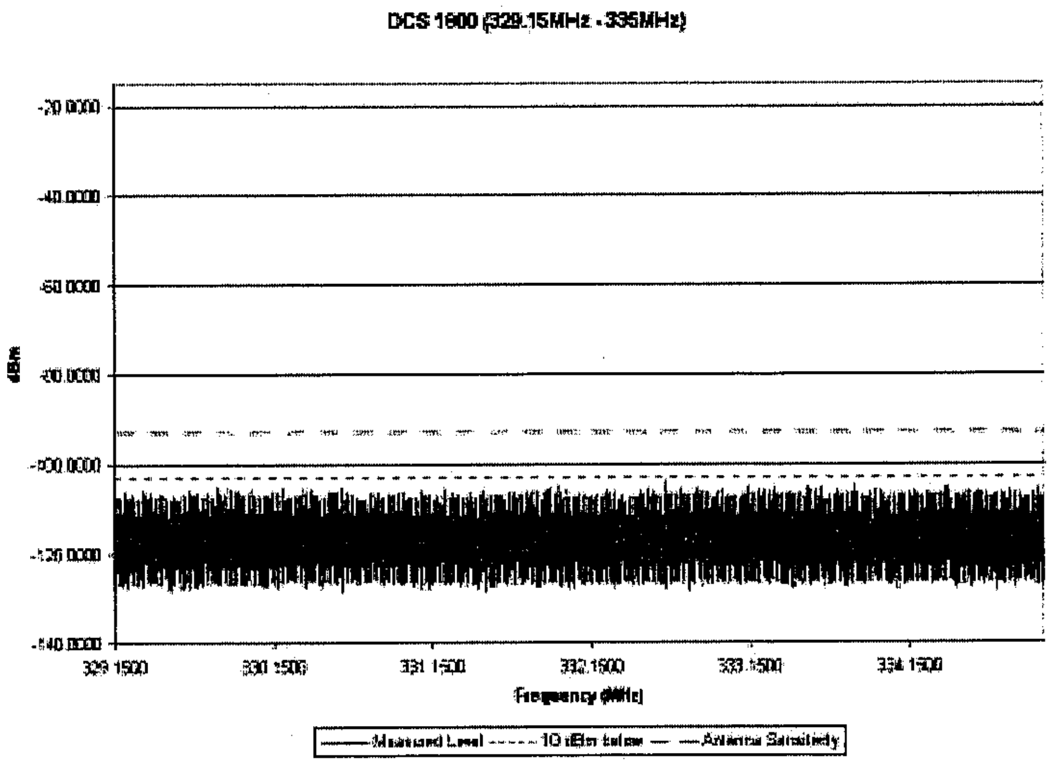
DCS 1800 (108MHz - 122MHz)

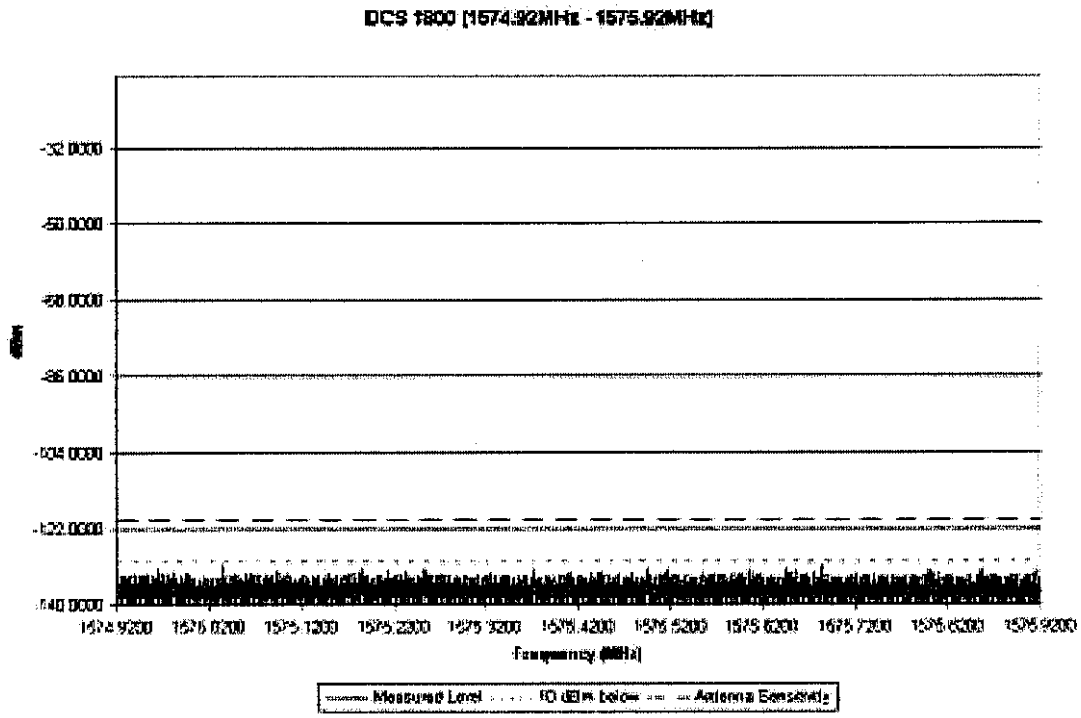


DCS 1800 (108.1MHz - 111.95MHz)




DCS 1900 (117.97MHz - 137MHz)
dBm
Frequency (MHz)
Measured Level
10 dBm below
Antenna Sensitivity

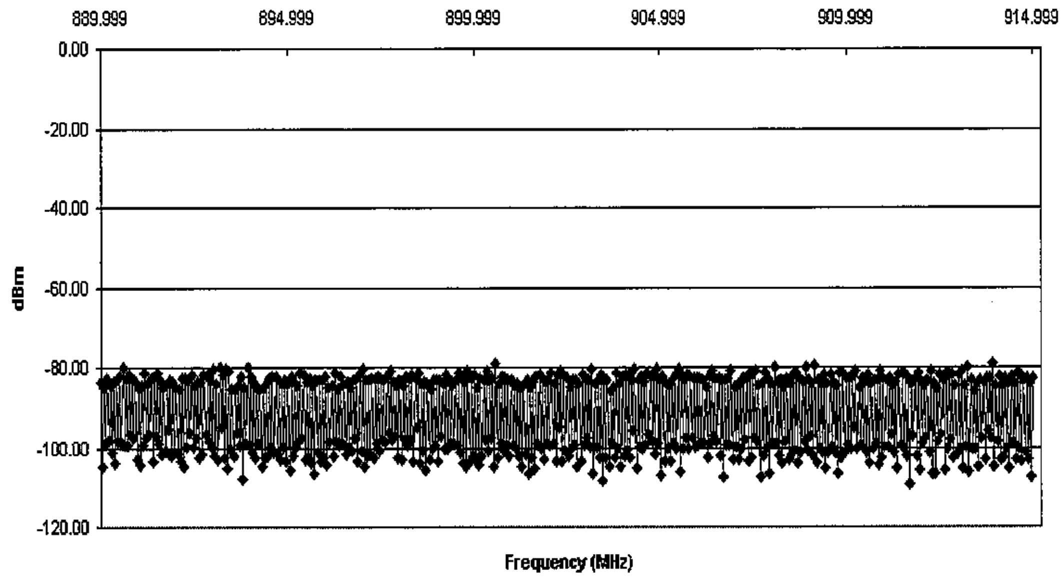

DCS 1900 (329.15MHz - 335MHz)
dBm
Frequency (MHz)
Measured Level
10 dBm below
Antenna Sensitivity


DCS 1800 [1574.92MHz - 1575.92MHz]
Measured Level
10 dBm below
Antenna Sensitivity
Frequency (MHz)

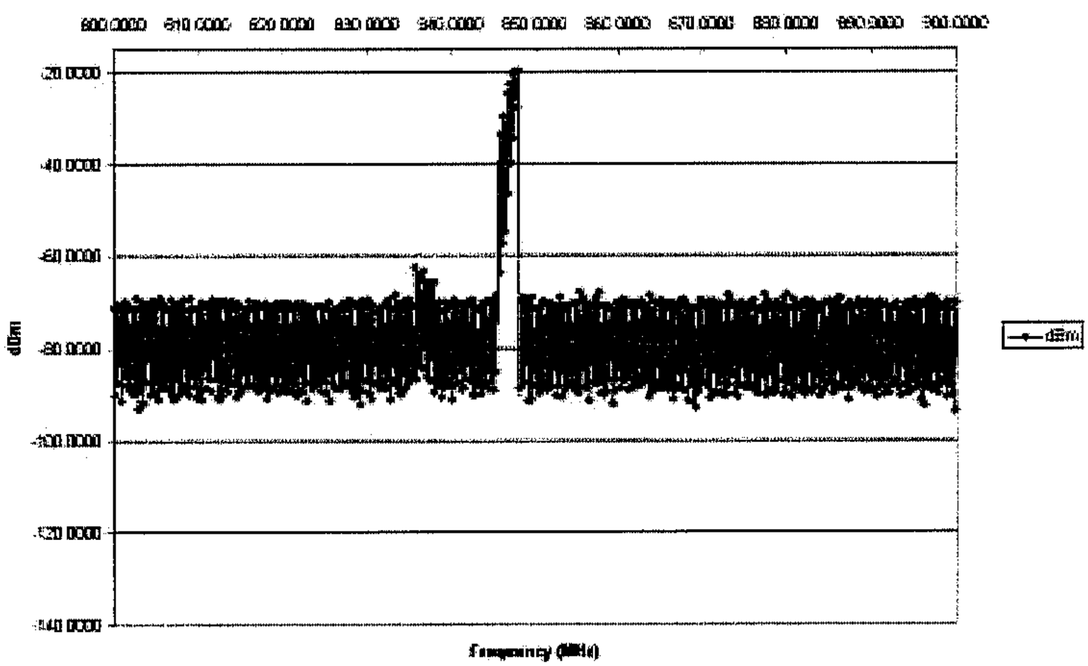
APPENDIX D

Scans of Phone Transmission Ranges

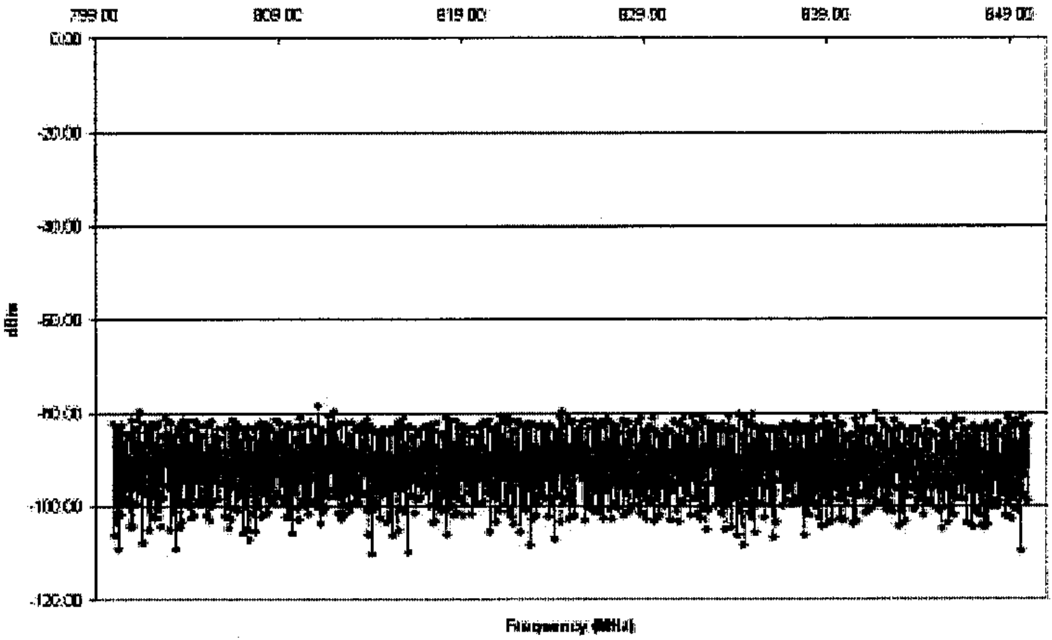
Ambient of CDMA 800 Transmission Range



CDMA 800 Transmission Range



Ambient of TDMA 11 Hz Cellular Transmission Range



TDMA 11Hz (Transmission Range)