Challenges in CDMA2000 1X Base Transceiver Station Testing

COMPUTING COMMUNICATIONS VIDEO

Technical and Application Information to Facilitate Field Testing

Introduction

CDMA2000 systems are transforming Base Transceiver Stations with the addition of increased traffic capacity and higher data rates than previous generations. Cell site technicians and engineers are being challenged to deploy the new CDMA2000 1X systems quickly and keep them operating at peak performance in order to meet intense competitive pressure and customer demands for the new services.

A comprehensive testing program is the most effective way to meet the challenges of CDMA2000 – testing that evaluates critical performance parameters at every stage of the BTS environment quickly and cost effectively. This application note provides you with background information on CDMA2000 technology and describes some of the standardized measurements that are contained in Tektronix NetTek™ YBT250 testers to help cell site personnel install, maintain and troubleshoot CDMA2000 1X Base Stations. Reference information and testing guidelines are also provided to help identify interference sources and analyze traffic and control signals in the RF system.

Note: This application note assumes a basic understanding of CDMA (cdmaOne) technology. For background information, the application note "Troubleshooting cdmaOne BTS Transmitters in the Field" is available from Tektronix as literature number 2GW-14632-0, or may be downloaded from the web site: www.tektronix.com/mobile.

What is CDMA2000?

Code Division Multiple Access (CDMA) technology provides an important pathway to third-generation (3G) global wireless communication systems. CDMA2000 is the 3G standard that enhances cdmaOne networks by providing higher capacity in the same amount of spectrum to meet IMT-2000 global wireless communication specifications.

The transition from cdmaOne (IS-95) to CDMA2000 (IS 2000) has been relatively straightforward under the guidance of the Third Generation Partnership Project 2 (3GPP2), especially when compared to transitions of other technologies. Originating in North America, CDMA2000 technology was quickly adopted around the globe, and became the first of 3G technology to be deployed.

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Table 1. Configurations for cdmaOne, CDMA2000 1X and CDMA2000 3X spreading

Channel	cdmaOne	CDMA2000 1X	CDMA2000 3X
Forward	RC1, RC2	RC1~RC5	RC6~RC9
Data Rate	1,200 to 14,000 bps	1,200 to 230,400 bps	1,200 to 1,036,800 bps
Max Spreading Factor	64 fixed	128	256
Min Spreading Factor	64 fixed	4	4

CDMA2000 is being introduced in three phases. The first phase (CDMA2000 1X) supports 128 Walsh codes for data communications on a single existing 1.25 MHz cdmaOne carrier. The chip rate in 1X systems is 1.2288 Mcps, which is exactly the same as the earlier IS-95 rate.

The second phase includes CDMA2000 1xEV-DV and 1xEV-DO, which use an additional time domain component to increase data rates within a 1.25 MHz carrier. The third phase (CDMA-3X) specifies 256 Walsh codes and accommodates three adjacent 1.25 MHz carriers (to remain backward compatible with cdmaOne). This application note addresses only the initial CDMA2000 1X phase.

Signals transmitted on the forward traffic channel are specified by the radio configuration (RC). CDMA2000 specifies nine RCs in the forward link; five for 1X spreading rates and four for 3X (see Table 1).

Variable Length Walsh Codes

The most significant difference between cdmaOne and CDMA2000 1X is that CDMA2000 1X has a higher number of Walsh codes (128), which increases capacity and variable spreading factors, providing higher data rates.

The new system trades off spreading factor for data rate. The data rate capability of an individual call can be described by the spreading factor of the code channel it occupies – the lower the spreading factor, the wider the code channel and the higher the data rate. The narrowest code channels are those at the highest spreading factor (a maximum of 128, in CDMA2000 1X).

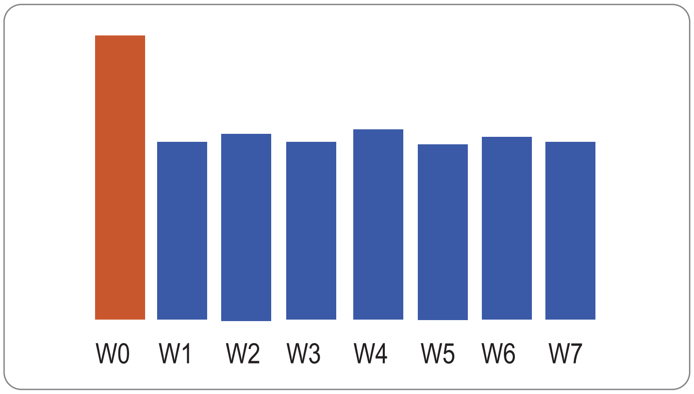


Figure 1. One call, spreading factor of eight.

In CDMA2000 systems, traffic with higher data rates occupies the space of a group of narrower code domain channels (daughter codes). A call (or data connection) gets assigned to only one channel. This wider code channel may look like a group of higher spreading factor (narrower) code channels, but it is actually only one, with a proportionately lower spreading factor.

Here is an illustration of variable-length Walsh code channels. Consider a system with a spreading factor of eight, as shown in Figure 1. There are eight narrow code channels, W0 through W7, defined by eight possible 8-bit (length 8) Walsh codes (see Table 2).

In Figure 1, a call enters the system and is assigned Walsh code W0 (shown in red). However, the call has requested twice the data rate of a single channel. A second narrow channel needs to be added to the call, to reduce the spreading factor to four, thus doubling the data rate, for a length four code of W4(0), as shown in Figure 2. The daughter code W8(4) shares the same first four binary digits (0000) as W8(0) and can be grouped together.

Table 2. Simplified example of variable length Walsh codes

Length 2 Codes	Length 4 Codes	Length 8 Codes	Walsh Code
00 or W2(0)	0000 or W4(0)	00000000 00001111	0 or W8(0) 4 or W8(4)
	0011 or W4(2)	00110011 00111100	2 or W8(2) 6 or W8(6)
01 or W2(1)	0101 or W4(1)	01010101 01011010	1 or W8(1) 5 or W8(5)
	0110 or W4(3)	01100110 01101001	3 or W8(3) 7 or W8(7)

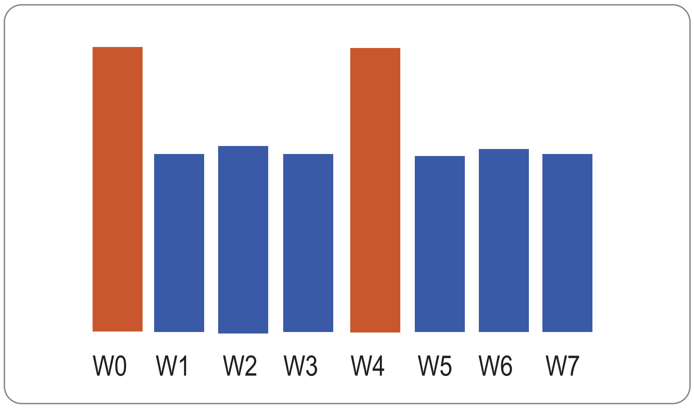


Figure 2. *One call, spreading factor of four.*

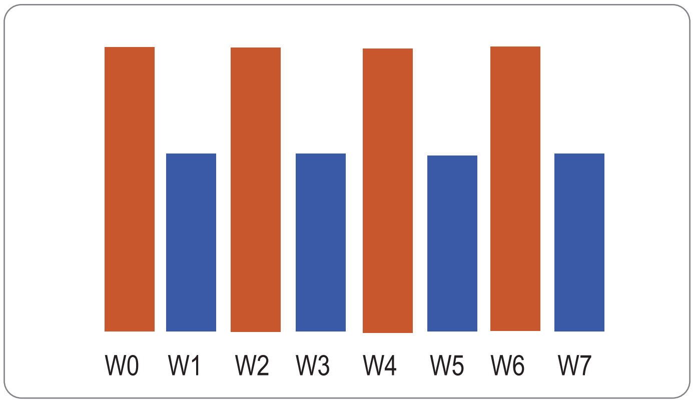


Figure 3. *One call, spreading factor of two.*

To quadruple the data rate, four of the narrow channels, W8(0), W8(2), W8(4) and W8(6), are grouped to lower the spreading factor to two and to use a length two code W2(0). Note that all share the same first half binary digits (00), as shown in Figure 3.

Table 2 has the Walsh codes sorted in a way that each pair shares its first half. In this case W8(0) and W8(4) share the first half (0000). For a higher data rate, W8(2) and W8(6) are added in the same way by grouping 0000 and 0011 from the "Length 4 codes" W4(0) and W4(2) to generate a spreading factor of two (in this case 00). The single call using 00 will occupy half of the resources of this simplified system at a data rate equivalent to 4 single calls that are still at the spreading factor of 8 in the remaining space.

It is fairly easy to recognize the various code widths in this simple example, but what happens when we look at a real life CDMA2000 system with 128 Walsh codes and many calls (or data connections) at different data rates coming and going over time. Call information is scattered in pieces throughout the traditional display of sequential code channels, making it hard to recognize any given call.

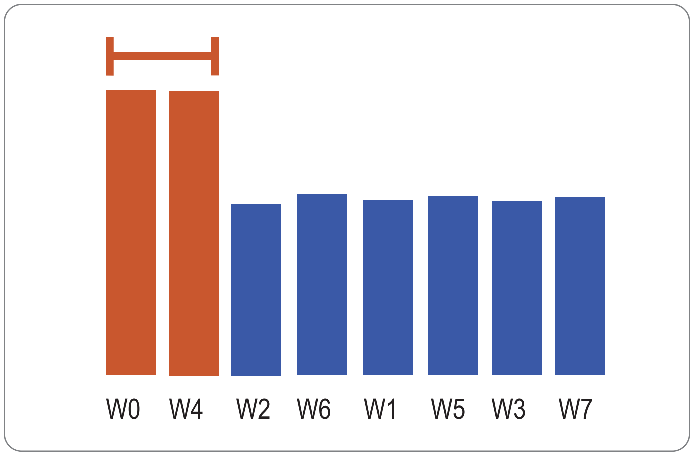


Figure 4. *Bit-reversed display of Figure 2.*

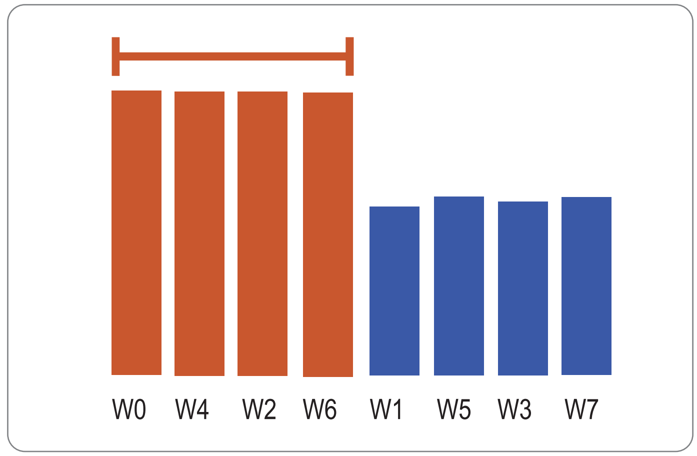


Figure 5. *Bit-reversed display of Figure 3.*

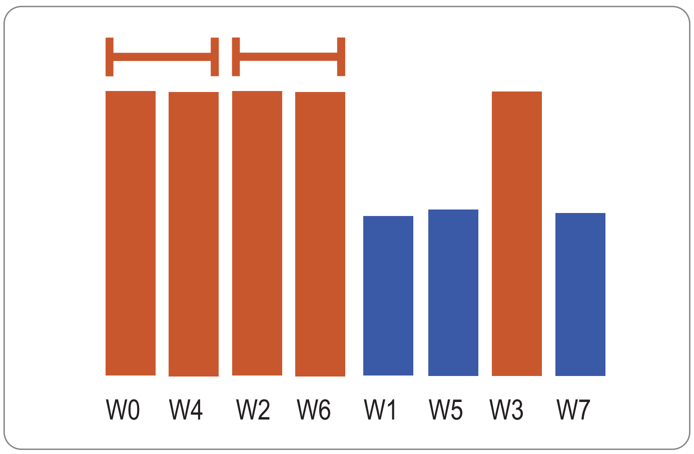


Figure 6. *Bit-reversed display of three calls.*

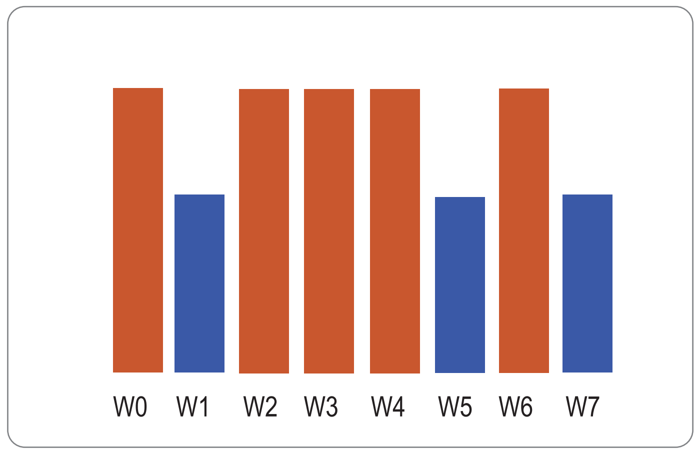
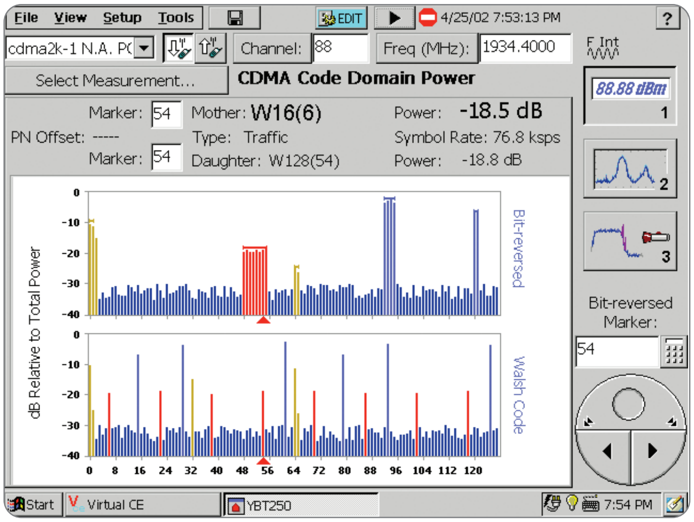


Figure 7. *Sequential display of three calls.*

In the "bit-reversed" display, Walsh codes are no longer ordered by the narrow Walsh code numbers but by their relation to the other narrow Walsh codes that could be used to group them for higher data rates (mother and daughter codes). A good example of bit reversing is the order of the length 8 Walsh codes in Table 2 (0, 4, 2, 6, 1, 5, 3, 7). Figures 4 and 5 illustrate the Bit Reversed displays of Figures 2 and 3. The call data is clearly grouped together and the horizontal bar indicates the Walsh code space that is being used in the call.

When viewing several calls at different data rates, it is much easier to use the Bit Reversed display. Figures 6 and 7 illustrate a scenario of one call with a spreading factor of 8 (W3) and two calls with spreading factors of 4 each (W0,4 and W2,6). The individual calls are clearly defined in the bit-reversed display of Figure 6, but can not be distinguished in the sequential display of Figure 7.

Both the Bit Reversed and the sequential Walsh code displays are highly recommended for CDMA2000 field testing equipment. Ideally, both displays should be available for viewing simultaneously in the same screen, each showing up to 128 Walsh codes.



▶ ***Figure 8.*** *NetTek YBT250 display showing a call at code 7 with a spreading factor of 16.*

A common misunderstanding is that a call or connection has a higher data rate capability when it has a lower spreading factor, when intuitively it seems as though it should be just the opposite. To understand this, consider that, with a spreading factor (SF) of 128 one call or connection is assigned to one Walsh code. Thus, the system sends 128 chips of information for every bit of data. When you select a lower spreading factor, 4 for example, it is the equivalent of having 32 narrow (SF 128) Walsh codes to this connection, and the system is only sending 4 chips for every data bit. This explains why you get a higher data rate, but one that is also more prone to errors.

Figure 8 shows an actual display from the NetTek YBT250 Field Tester. The type of code selected is traffic. In this particular case we find a call with a spreading factor of 16 at Walsh code number 7 ("Mother") with seven daughter codes. Other codes such as Pilot, Paging and Sync are also present, just as they are in cdmaOne. The symbol rate readout, also known as the chip rate over spreading factor (1.2288/SF), indicates a transmission rate of 76.8 k symbols per second is available for the current spreading factor.

Table 3. Measurement Tools for CDMA2000 Base Stations

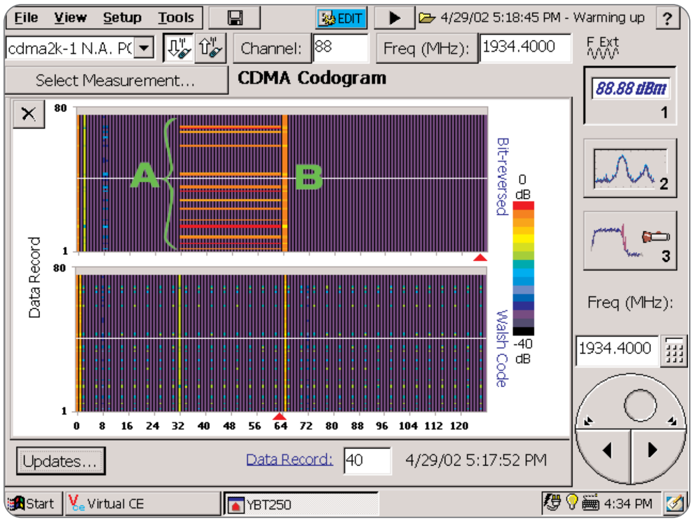
Measurement Tools	Sample Applications
CDMA Waveform Analyzer	Waveform quality of transmitter (Tx) Frequency error (Tx) Pilot time tolerance (Tx) Code domain power (Tx)
Spectrum Analyzer	In-band spurious emissions (Tx) Out-of-band spurious emissions (Tx) General RF interference checks
Power Meter	Base station total output power (Tx)

Basics of Testing CDMA2000 BTS RF Signals

What does a CDMA2000 Transmission Look Like? In the frequency domain, a CDMA2000 transmission will look identical to cdmaOne with a channel bandwidth of 1.2288 MHz. In the code domain, power will be displayed in the Walsh code channels as shown in Figure 8.

What Kinds of Tools are Specified? CDMA2000 base station testing requires the same measurement tools as cdmaOne, including a spectrum analyzer, power meter, a mobile station simulator and a waveform-quality/code-domain power measurement device. Ideally, these functions should be available in a single portable package.

Why Are All of These Tools Specified? Each of the traditional test tools is well suited for making some of the measurements required. Table 3 lists the most common types of traditional tools and their uses. Spectrum analyzers and power meters are used in the same way as described in the application note "Troubleshooting cdmaOne BTS Transmitters in the Field."



▶ ***Figure 9.*** *Codogram display of two calls.*

The Use of CDMA2000 Waveform/Code Domain Analyzers

The CDMA2000 waveform analyzer tunes to the transmission frequency of the base station sector and demodulates the signal. The demodulation process allows the waveform analyzer to display the performance of individual Walsh code channels on the BTS. The code domain display allows the user to determine how much traffic is going though the BTS as well as the power of each call and its data rate (see Figure 8).

A very powerful way to verify and analyze the behavior of the traffic and signaling channels in a BTS is the Codogram. The Codogram shows the code domain power in a color scale, building the display from bottom to top over time on the vertical axis with each successive trace of power versus code channel (horizontal).

Figure 9 depicts an actual CDMA2000 Codogram display in both Walsh code and bit-reversed formats. A high data rate intermittent call can be seen downloading a large file from the Internet at a spreading factor of four ("A" in the figure) while the paging channel is continuously active ("B" in the figure). The effects of the high data rate call are visible in the power changes to the low data rate call, the signaling channels and the noise level.

The Codogram becomes a superb tool to see how the BTS behaves at different data rates and traffic demands. Very often, high data rate (HDR) signals are intermittent and become difficult to observe dynamically, even in a bit-reverse display.

Test Notebook: Common CDMA2000 1x Measurements

The following sections offer guidelines for tests to verify BTS RF performance and solve problems.

1.0 Transmitter Frequency Error Standard: TIA/EIA-97-D

What is being measured? This measurement determines the difference between the actual transmitted carrier frequency of a base station sector and the designated frequency.

Why do I need to test this? If a transmitted signal is slightly "off-center" from a designated frequency, the faulty signal may interfere with neighboring transmissions.

What are the consequences? Frequency errors degrade the overall quality of service and may pollute neighboring systems' operations.

How is frequency error measured? The test set evaluates the CDMA2000 signal, determines the characteristic frequency of the signal and compares it with the desired frequency to determine the error. In the standards, this test is one of the group of "waveform quality" measurements that should be performed with the BTS transmitting only a pilot signal. Since that would require taking the base station offline and disrupting service, test sets have been designed to make the measurements during normal operating conditions in the presence of multiple active signals and Walsh codes.

Note: When the tester uses the BTS reference frequency as its standard, it can only verify the error of the transmitted frequency versus that reference, not any error in the reference itself.

What is the specified limit? TIA/EIA-97-D specifies a frequency error of less than $\pm 5 \times 10^{-8}$ (0.05 ppm) of the frequency assignment. This translates to approximately ±45 Hz for cellular and +90 Hz for PCS frequencies.

2.0 Pilot Time Tolerance (Tau) Standard: TIA/EIA-97-D

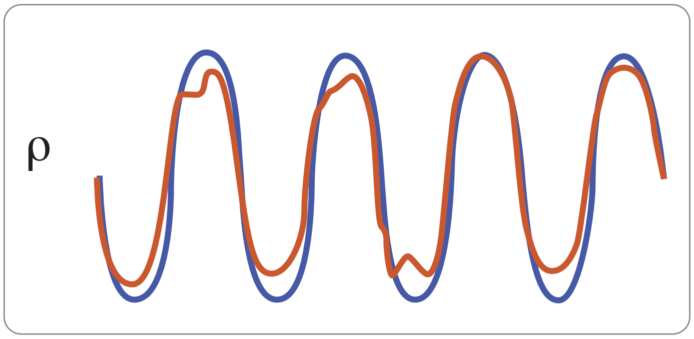
What is being measured? The difference between the transmitted start of the PN sequence of the pilot Walsh code and a system-based external trigger event is measured to determine the Pilot Time Tolerance (see Figure 4).

Why do I need to test this? All base stations must be synchronized within a few microseconds for station ID mechanisms to work reliably. CDMA2000 networks use a Global Positioning System (GPS) to maintain system time. This fundamental measurement ensures that the pilot signal for any given sector of a base station is "tracking" with the network's system time.

What are the consequences? Deviation from network timing could result in dropped calls and missed handoffs, since the faulty base station timing would not match the timing on the remainder of the system's base stations.

How is pilot time tolerance measured? Transmitter output from the base station is demodulated in order to determine the start of the pilot PN sequence. The test set uses the "even second clock" signal (available on all base stations) as the external trigger reference for zero offset. Taking into account the programmed PN offset, the test set then calculates the difference between the time of the trigger and the time of the pilot PN sequence and reports that difference as a single time tolerance value expressed in microseconds. This measurement is another of the waveform quality standards that suggest a pilot-only transmission from a base station. In practice, most testers are able to make the measurement of pilot time-alignment error on a live mixed signal with paging, sync and traffic Walsh codes active, avoiding any disruption of service.

What is the specified limit? TIA/EIA-97-D specifies that the pilot time-alignment error must be less than 10 microseconds. Both specifications also state that the value should be less than 3 microseconds.



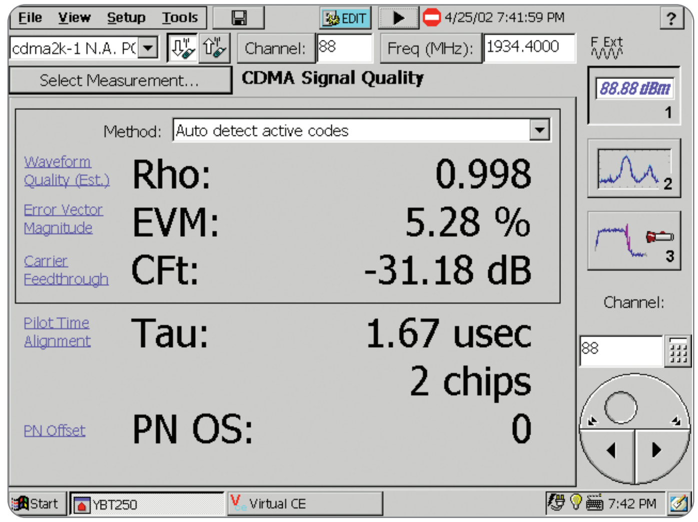
► ***Figure 10.*** *Waveform quality (rho).*

3.0 Waveform Quality (rho) Standard: TIA/EIA-97-D

What is being measured? Waveform quality, often referred to as rho (ρ), is perhaps the most common measurement for CDMA systems. Rho is a correlation that represents how closely the transmitted signal matches the ideal power distribution for a CDMA signal (see Figure 10). Think of the tested signal power distribution as the numerator of a fraction and the ideal distribution as the denominator – a waveform quality constant of 1.0 would represent a perfectly correlated CDMA signal.

Why do I need to test this? This measure is a good tool for judging the modulation quality of the transmitted CDMA signal and offers a quick and easy "snapshot" of the overall performance of the system.

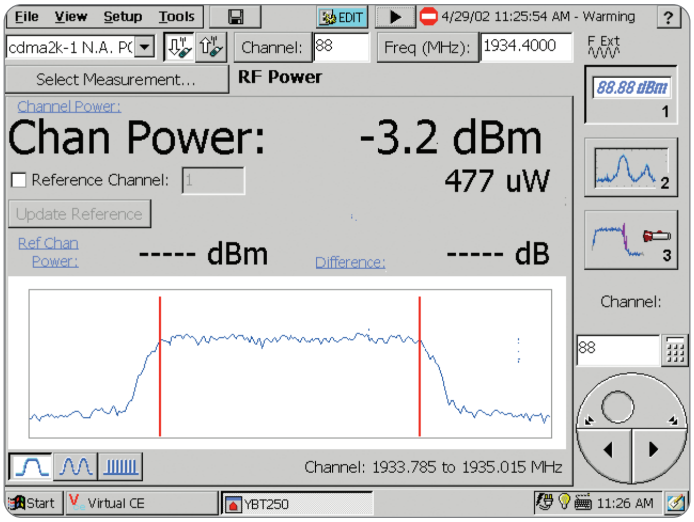
What are the consequences? Deviations in code power distribution degrade system performance for the user and lower efficiency for the operator.



► ***Figure 11.*** *Waveform quality measurements.*

How is waveform quality measured? The test set demodulates the transmitter output from the base station and compares the distribution of power received to the ideal power distribution at specified "decision points" in the CDMA transmission. IS-97 specifies that this measurement is to be made on a pilot-only forward link signal. Furthermore, the test is to be made over a sample period of at least one power control group and an integer multiple of 512 chips (see Figure 11). In practice, a pilot-only transmission from a base station implies that the base station has been removed from service. Most testers now offer an "estimated rho" capability that allows the factor to be derived in the presence of multiple Walsh codes – the approximate rho value can be calculated without taking down a sector of the base station.

What is the specified limit? TIA/EIA-97-D specifies that the waveform quality constant be greater than 0.912.



▶ ***Figure 12.*** *Power measurements.*

4.0 Total Power, or Channel Power Standard: TIA/EIA-97-D

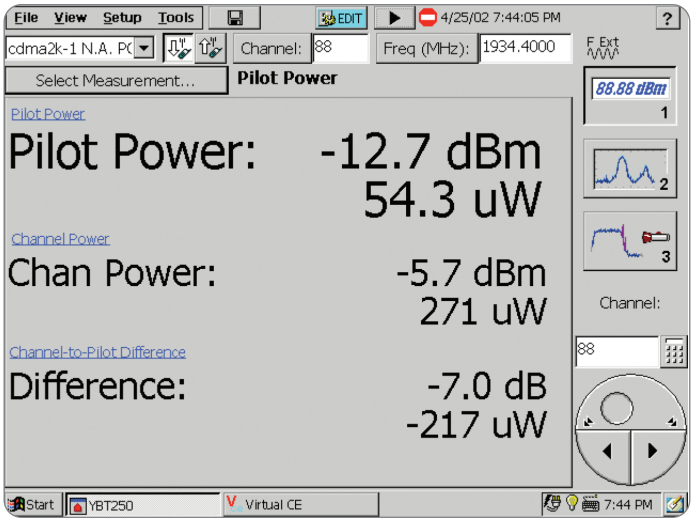
What is being measured? This measurement verifies the total output power from the base station or appropriate sector of the base station (see Figure 12).

Why do I need to test this? Power is the fundamental measurement of BTS range and performance.

What are the consequences? Overall power levels must be contained within limits to prevent interference among neighboring stations while maximizing coverage.

How can total power be measured? The unique composition of a CDMA signal makes the measurement of power more demanding than with other communications systems. The spread-spectrum signal has the appearance of a "noise-like" signal spread over 1.23 MHz bandwidth, but it can contain much higher peak-to-average power ratios than a noise signal, making it very difficult to derive the true RMS values with some types of test equipment. Total power can be measured directly with a dedicated thermal power head meter. Spectrum analyzers have been used to make this measurement by summing the power measurements across the 1.23 MHz wide CDMA bandwidth. However, most spectrum analyzers assume that inputs are CW signals, so power measurements of CDMA signals can be 9 dB or more in error, depending upon which Walsh codes are active. Most CDMA BTS testers now use well-defined DSP sampling techniques to measure power with appropriate RMS computations. TIA/EIA-97-D specifies a base station signal configuration of pilot, paging, sync and six traffic channels active for this measurement (see Table 2).

What is the specified limit? TIA/EIA-97-D specifies that the total power shall remain within +2 dB and –4 dB of the specified base station (or sector) power.



▶ ***Figure 13.*** *Pilot channel power.*

5.0 Pilot Power Standard: TIA/EIA-97-D

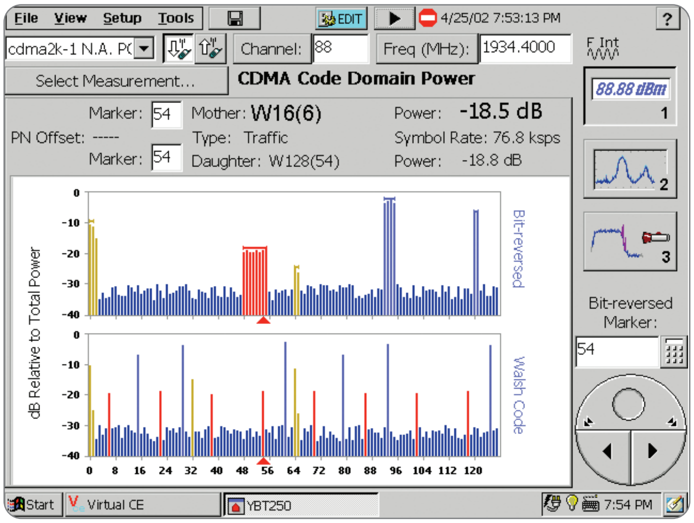
What is being measured? The ratio of power in the pilot channel to the total channel power transmitted (see Figure 13).

Why do I need to test this? Pilot power is a measure of the BTS range to mobile devices.

What are the consequences? A pilot power level that deviates substantially from desired values can affect the coverage characteristics of the network.

How is pilot power measured? The test equipment demodulates the transmitted signal to analyze power levels in the code domain. The power contained in Walsh code 0 is then reported in dBm and watts.

What is the specified limit? TIA/EIA-97-D specifies that the pilot power shall remain within ±0.5 dB of the BTS sector configuration value.



▶ ***Figure 14.*** *Code domain power in Walsh code and bit-reversed formats.*

6.0 Code Domain Power Standard: TIA/EIA-97-D

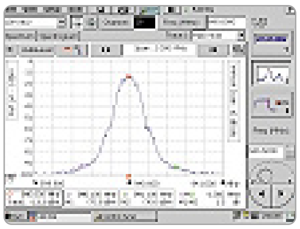
What is being measured? In a CDMA system, individual user transmissions are isolated by their codes. The test equipment measures the ratio of power in each of the forward link Walsh codes, to the total transmitted channel power. Figure 14 shows a graph of the Code Domain power.

Why do I need to test this? A base station's ability to accurately control the power in individual Walsh codes is a prerequisite to properly handle multiple user links with varying RF losses and to ensure interference-free transmissions.

What are the consequences? Loss of quality and channel capacity due to inadequate or unbalanced power.

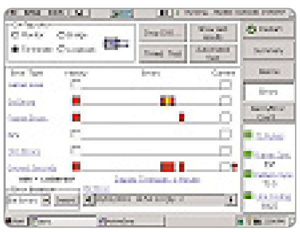
How is code domain power measured? The test equipment demodulates the transmitted signal to analyze power levels in each of the 128 forward link Walsh codes. The power in each of the codes is expressed in dB relative to the total transmitter power in the channel. Code domain power is verified with the base station sector producing a combination of pilot, sync, paging and six traffic channels. The level of the inactive Walsh codes (those forward codes without an overhead or traffic signal), can be compared against the standard, as well.

What is the specified limit? TIA/EIA-97-D specifies that the code domain power in each inactive Walsh code shall be 27 dB or more below the total output power.



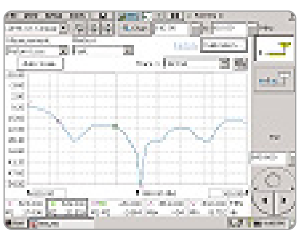
YBT250 BTS Transmitter and Interference Analysis

The YBT250 test module tailors the NetTek platform for fast trouble resolution and easy transmitter verification of W-CDMA/UMTS, GSM, IS-136 and CDMA base stations and Node Bs.



YBT1 Backhaul T1 Tester

The YBT1 enables mobile operators to troubleshoot T1 connections to the base station, with the most common measurements needed to uncover T1 problems affecting a live mobile network.



YBA250 Antenna and Transmission Line Analyzer

The YBA250 enables the NetTek system as a transmission line analyzer, allowing fast identification of base station antenna and transmission line trouble and easy location of faults.

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