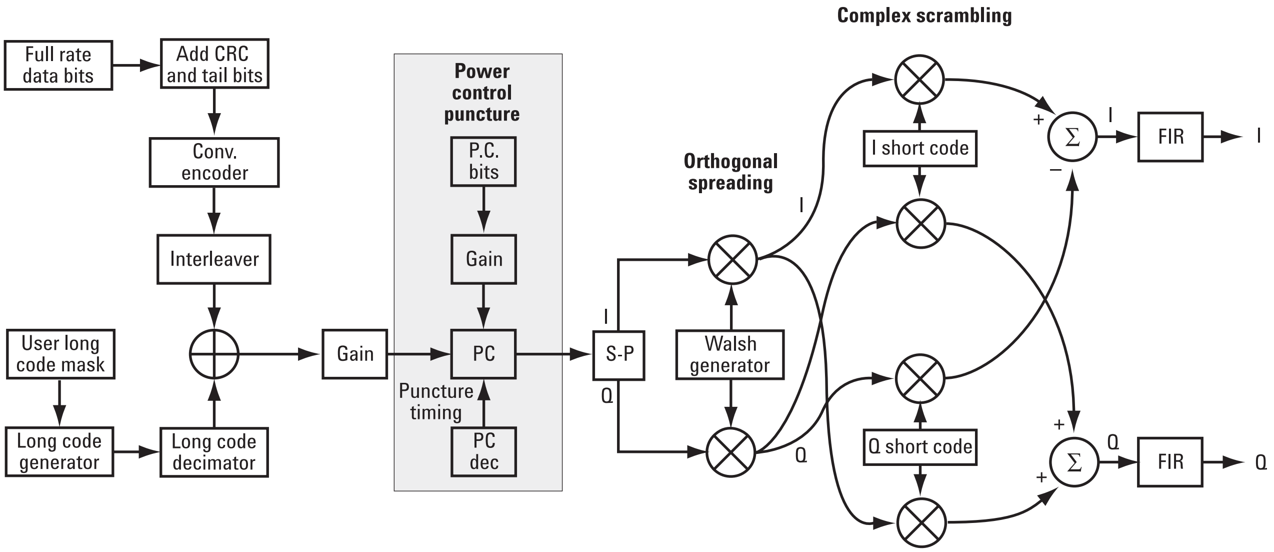
Designing and Testing cdma2000 Base Stations

Application Note 1357



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Introduction

One of the technologies meeting the IMT-2000 requirements for a third generation (3G) global wireless communications system is cdma2000, also known as IS-2000[1]. The Third-Generation Partnership Project 2 (3GPP2) is implementing this wideband CDMA system as a derivative of the IS-95-B CDMA system, also known as cdmaOne. The 3GPP2 organizational partners are Association of Radio Industries and Businesses (ARIB), Telecommunication Technology Committee (TTC), Telecommunications Technology Committee (TIA), and Telecommunications Technology Association (TTA).

As the IS-2000 specifications are finalized, the first base stations are being integrated and tested. This application note describes base station (BS) design and measurement issues at the physical layer (layer 1) that may differ between cdma2000 and cdmaOne. Although it focuses on the last stages of BS development and integration, it is also useful for engineers working in the early stages of manufacturing. The application note also provides a list of Agilent Technologies cdma2000 solutions for these areas.

This application note assumes that you are familiar with cdmaOne measurements and technology basics. cdmaOne is used as a reference throughout this application note. The main differences between cdmaOne and cdma2000 systems and the corresponding design and measurement implications are highlighted. For more information on cdmaOne measurements see **[1]**.

This application note can be downloaded from the web and printed locally: **http://www.agilent.com/find/3G** (under "Technical Papers").

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[1] IS-2000 is the Telecommunications Industries Association's (TIA's) standard for 3G technology that is an evolution of the IS-95 code-division-multiple-access (CDMA) format. cdma2000, which is often used interchangeably with IS-2000, is also used to refer to the access format and system.

1 Basic concepts of cdma2000

The main advantages that cdma2000 offers over other IMT-2000 proposals are backward compatibility with cdmaOne systems and a smooth migration from second-generation (2G) cdmaOne systems to 3G. Figure 1 shows a possible evolution from cdmaOne to cdma2000 systems.

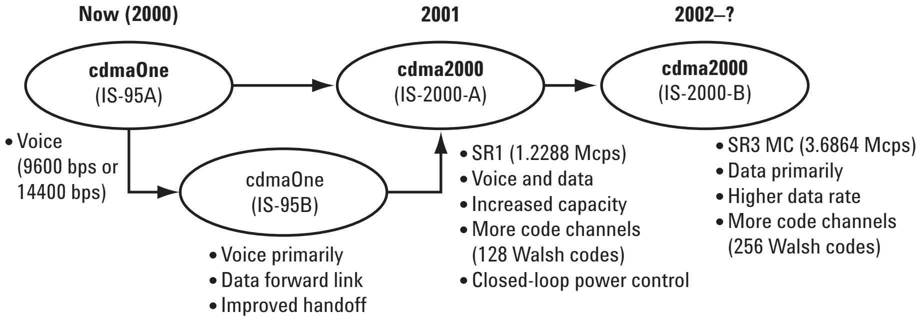


Figure 1. Evolution from cdmaOne to cdma2000

1.1 Spreading rate

Spreading rate (SR) defines the final spread chip rate in terms of 1.2288 Mcps. The two spreading rates are SR1 and SR3.

SR1: A SR1 cdma2000 signal has a chip rate of 1.2288 Mcps and occupies the same bandwidth as cdmaOne signals. The SR1 cdma2000 system doubles the system capacity. Therefore, it can be considered an improved cdmaOne system. The main differences from cdmaOne are

- fast power control and Quadrature Phase Shift Keying (QPSK) modulation rather than dual Binary Phase Shift Keying (BPSK) in the forward link
- pilot signal, to allow coherent demodulation, and Hybrid Phase Shift Keying (HPSK) spreading in the reverse link

SR3: A SR3 signal has a rate of 3.6864 Mcps (3 x 1.2288 Mcps) and occupies three times the bandwidth of cdmaOne. The SR3 system incorporates all the new coding implemented in a SR1 system and supports higher data rates. It is designed to allow SR3 signals to be directly overlaid on top of existing cdmaOne systems. To achieve an overlay system, the SR3 forward link breaks up the data into three carriers, each of which is spread at 1.2288 Mcps (see figure 2). For this reason, the system is known as SR3 MC (multi-carrier). The reverse link uses a single carrier spread at 3.6864 Mcps.

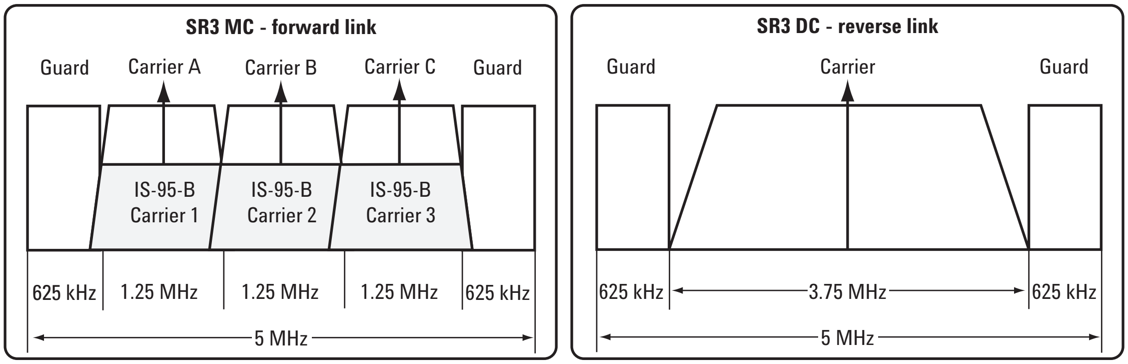


Figure 2. Bandwidth limits for SR3 MC (forward and reverse links)

1.2 Radio configuration

Radio configuration (RC) defines the physical channel configuration based upon a specific channel data rate. Each RC specifies a set of data rates based on either 9.6 or 14.4 kbps. These are the two existing data rates supported for cdmaOne. Each RC also specifies the spreading rate (either SR1 or SR3) and the physical coding. Currently there are nine radio configurations defined in the cdma2000 system for the forward link and six for the reverse link. For example

- RC1 is the backwards compatible mode of cdmaOne for 9600-bps voice traffic. It includes 9.6, 4.8, 2.4, and 1.2 kbps data rates and operates at SR1. It does not use any of the new cdma2000 coding improvements.
- RC3 is a cdma2000 specific configuration based on 9.6 kbps that also supports 4.8, 2.7, and 1.5 kbps for voice, while supporting data at 19.2, 38.4, 76.8, and 153.6 kbps. It operates at SR1.

Each BS or mobile station (MS) must be capable of transmitting using different radio configurations at the same spreading rate. Refer to **[2]** for detailed information on the different RCs.

1.3 Forward link air interface

The forward link air interface for a cdma2000 SR1 channel is very similar to that of cdmaOne. In order to preserve compatibility, cdma2000 uses the same structure as cdmaOne for the Forward Pilot (F-Pilot), Forward Sync (F-Sync), and Forward Paging (F-Paging) channels.

In cdma2000, each user is assigned a Forward Traffic (F-Traffic) channel, which consists of

- one Forward Fundamental Channel (F-FCH)
- zero to seven Forward Supplemental Code Channels (F-SCHs) for RC1 and RC2
- zero to two Forward Supplemental Channels (F-SCHs) for RC3 to RC9

The F-FCHs are used for voice and the F-SCHs are used for data. The BS may also send a number of Forward Dedicated Control Channels (F-DCCHs). An F-DCCH is associated with traffic channels (either FCH or SCH) and may carry signaling data and power control data.

One of the main differences between cdmaOne and cdma2000 is that the latter uses true QPSK modulation (as opposed to dual-BPSK) for all traffic channels from RC3 to RC9. As an example, figure 3 shows the forward link structure for an RC4 F-FCH. The coding is identical to cdmaOne up through the long code scrambling of the voice data. The F-FCH is optionally punctured with the reverse link power control data bits. The data is then converted from a serial bit stream into a 2-bit-wide parallel data stream to produce true QPSK modulation. This reduces the data rate of each stream by a factor of two. Each branch is spread with a 128 Walsh code to generate a spreading rate of 1.2288 Mcps. In this case, the processing gain is doubled for each channel relative to cdmaOne. Each channel is transmitted at one-half the power used before, but there are now two of them for no apparent gain. The actual processing gain for each channel depends on its data rate and RC.

The outputs of the I and Q Walsh spreaders are then complex multiplied against the same I and Q channel short codes used in cdmaOne. Complex scrambling is used in the forward link instead of regular scrambling because it facilitates the receiver descrambling process.

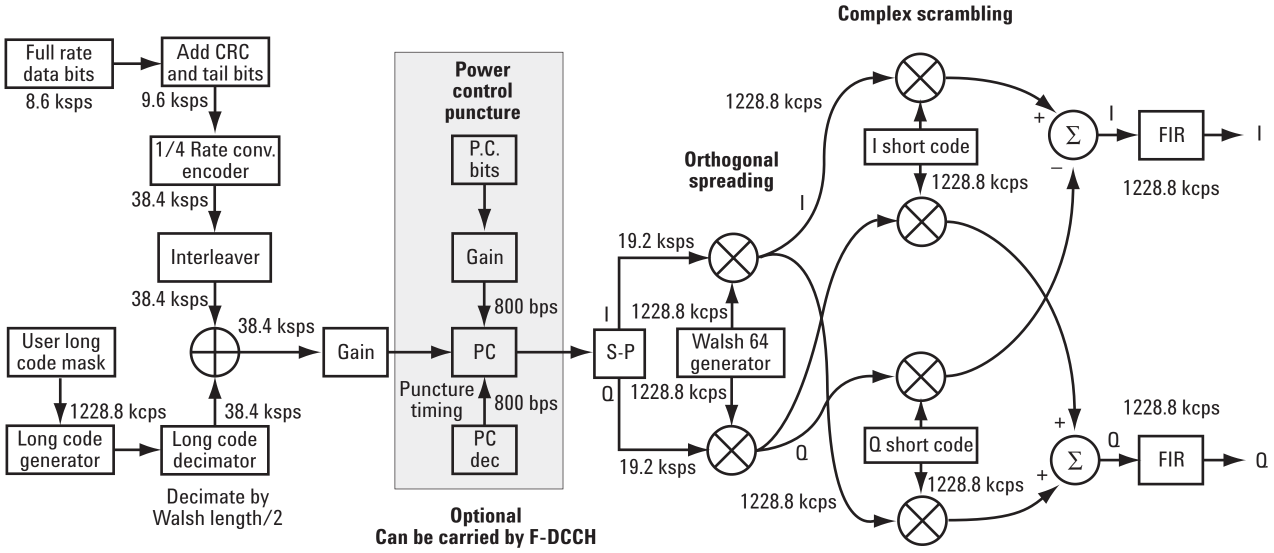


Figure 3. Coding and air interface for a cdma2000 RC4 F-FCH

1.4 Reverse link air interface—HPSK

The cdma2000 reverse link is very different from that of cdmaOne. The MS can transmit more than one code channel to accommodate the high data rates. The minimum configuration consists of a Reverse Pilot (R-Pilot) channel to allow the base station to perform synchronous detection and a Reverse Fundamental Channel (R-FCH) for voice. Additional channels, such as the Reverse Supplemental Channels (R-SCHs) and the Reverse Dedicated Control Channel (R-DCCH) can be used to send data or signaling information.

The different channels are assigned to either the I or Q path. For example, for RC3 to RC6, the R-Pilot is assigned to I and R-FCH is assigned to Q (see figure 4).

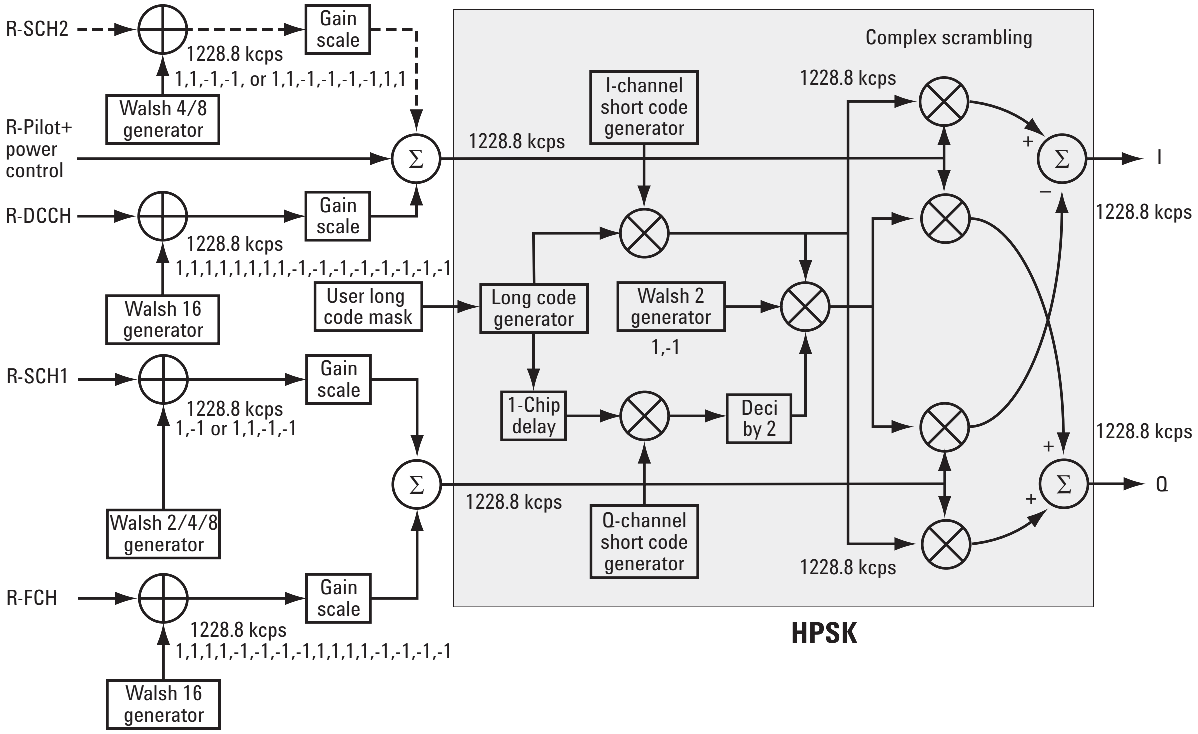


Figure 4. An example of channel summing and HPSK spreading in cdma2000 reverse link (SR1). The SR3 mode has the same reverse link structure. The only difference is that for SR3 the final spreading rate is 3.6864 Mcps.

Channels can be at different rates and different power levels. Complex scrambling facilitates this by continuously phase rotating the constellation and thus distributing the power evenly between the axes.

Without scrambling, unequal channel powers would result in a rectangular four-quadrature amplitude modulation (QAM) constellation (assuming that only R-Pilot and R-FCH are active). With complex scrambling, the constellation for two channels generally has eight points distributed around a circle, with the angular distribution determined by the relative powers of the two channels. For example, an amplitude difference of 6 dB between the two channels results in the constellation shown in figure 5, which is close to an 8-PSK (8-Phase Shift Keying) constellation (an amplitude difference of 7.65 dB would result in a perfect 8-PSK constellation). If the amplitudes for the two channels are equal, then pairs of constellation points merge to give a QPSK-like constellation.

I/Q measured polar vector

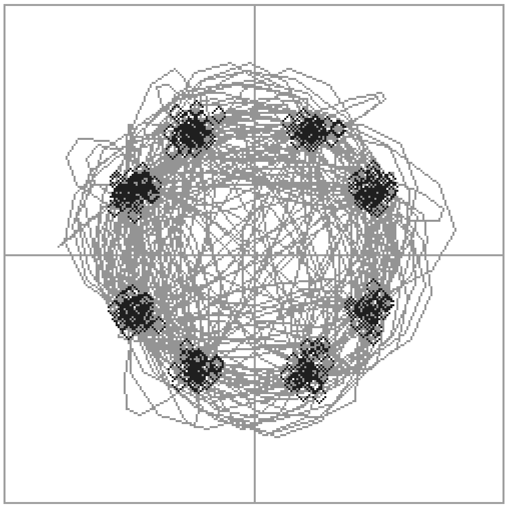


Figure 5. A reverse link cdma2000 SR1 signal with a R-Pilot and a R-FCH. The amplitude of the R-FCH is 6 dB lower than that of the R-Pilot.

Basic complex scrambling applies a phase rotation of 0, ±π/2, or π radians to each chip. HPSK takes this idea a stage further and defines the complex scrambling so that for every second chip, the phase rotation is restricted to ±π/2. This constraint on the phase transitions entering the baseband pulse shaping filter reduces the peak-to-average ratio of the signal (about 1 to 1.5 dB) compared to regular complex scrambling (or regular QPSK). The HPSK technique continues to be advantageous even when the signal has more than two channels. For more information on HPSK see **[3]**.

1.5 Forward link power control

A key improvement in cdma2000 is forward link power control. The MS sends power control data back to the BS by time multiplexing it with the R-Pilot channel. Like the existing reverse link closed loop power control of cdmaOne, the cdma2000 forward link closed loop power control sends 800 power control bits each second. These bits indicate whether the BS should raise or lower its power in 1 dB, 0.5 dB, or 0.25 dB. The finer steps allow tighter power control for low mobility or stationary phones. Tighter control (less power ripple) lowers the average power and thus raises the capacity of the system.

1.6 Differences between cdma2000 and W-CDMA

The Third-Generation Partnership Project (3GPP) W-CDMA is the other main wideband CDMA technology competing for the 3G cellular market. There has been much discussion about the need to harmonize W-CDMA and cdma2000 in an attempt to facilitate global use of 3G phones. However, even though both systems are based in a similar CDMA technology, they are significantly different. The main differences are

- the spreading rate (3.84 Mcps for W-CDMA versus 3.6864 Mcps for cdma2000 SR3)
- the synchronization and BS identification methodology (W-CDMA does not use GPS)

For information on W-CDMA BS design and test issues, please refer to **[4]**.

2. Design and measurement issues

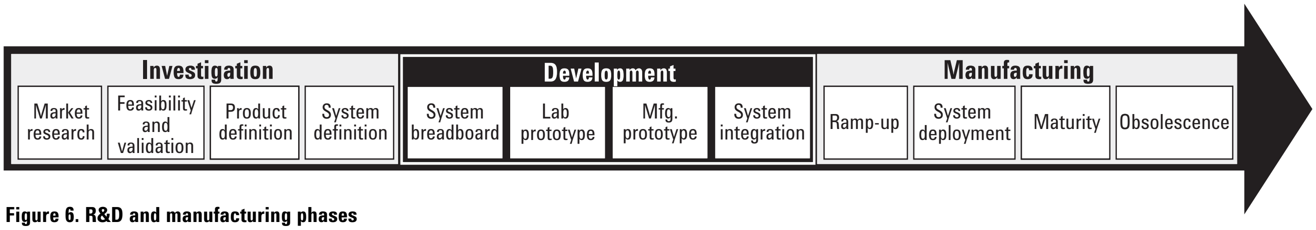


Figure 6. R&D and manufacturing phases

Figure 6 is a generic diagram of the R&D and manufacturing phases of a BS. This chapter focuses on the development phase of the BS, highlighted in black. However, it contains general information that may be useful to engineers involved in any area of the BS life cycle.

This chapter describes design and measurement issues that you may encounter when designing and testing cdma2000 BS, in contrast to cdmaOne. Although the exact cdma2000 measurement specifications are not finalized, in general we can assume that the basic measurement methodology will be similar to cdmaOne. Therefore, in this section cdmaOne measurements are used as a reference. For information on cdmaOne measurements see **[1]**.

Refer to appendix B for a list of Agilent solutions available for BS design and test.

2.1 Handling high peak-to-average power ratios

Peak-to-average power ratio is the ratio of the peak envelope power to the average envelope power of a signal. In cdma2000, as in cdmaOne, the power statistics of the signal depend on its channel configuration, modulation, filtering, clipping level, etc. In general, the peak-to-average power ratio increases as more channels are activated.

Component design, particularly power amplifier design, is challenging because the amplifier must be capable of handling the high peak-to-average power ratios that the signal exhibits, while maintaining a good adjacent channel power ratio performance. The use of multi-carrier power amplifiers pushes design complexity even one step further.

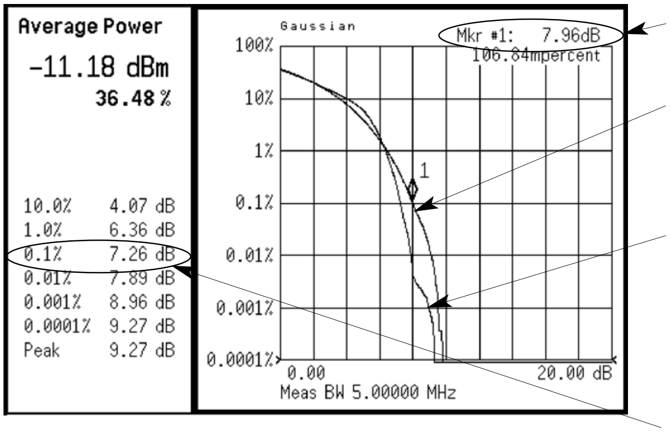
From the measurement perspective, the statistics of the signal may impact the result of the measurement, particularly in the case of adjacent channel power ratio (ACPR). Therefore, it is important to choose the signal configuration carefully.

From both design and measurement perspectives, you must cover the real-life worst cases, such as those with the most stressful signal configurations or highest peak-to-average power ratios. To do that, you need a way to define the statistics of cdma2000 signals. The complementary cumulative distribution function (CCDF) does that for you.

2.1.1 CCDF

The CCDF fully characterizes the power statistics of the signal **[5]**. It provides the distribution of particular peak-to-average power ratios versus probability.

Figure 7 shows the CCDF curves for two cdma2000 SR1 signals with different channel configurations. For a probability of 0.1 percent, the signal with 15 code channels has a higher peak-to-average ratio (7.96 dB) than the signal with 4 code channels (7.26 dB).



Average Power

-11.18 dBm

36.48 %

10.0%	4.07 dB
1.0%	6.36 dB
0.1%	7.26 dB
0.01%	7.89 dB
0.001%	8.96 dB
0.0001%	9.27 dB
Peak	9.27 dB

Mkr #1: 7.96dB
106.84mpercent

0.1% Peak-to-average ratio values for 15-channel signal

15-channel signal

4-channel signal

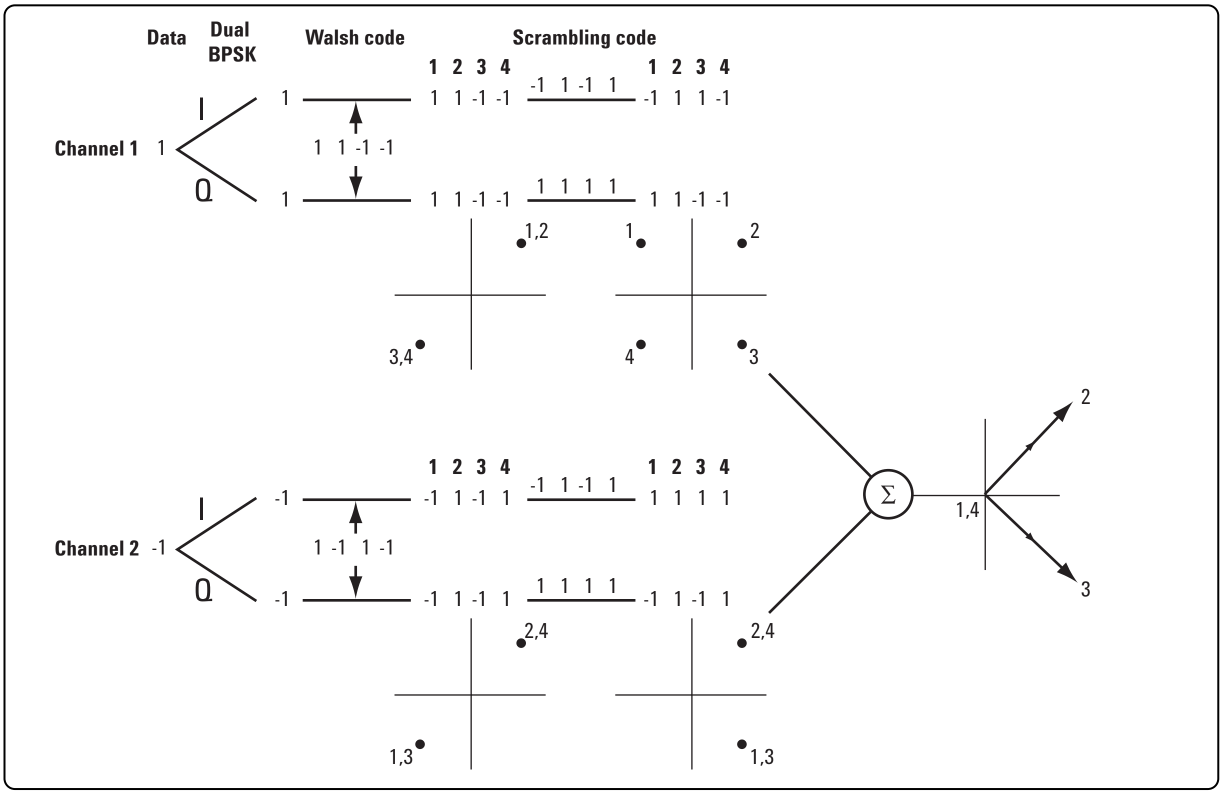
0.1% Peak-to-average ratio values for 4-channel signal

Figure 7. CCDF curves for cdma2000 signals with different code channel configurations — marker at 0.1% probability

So, how do the statistics of cdmaOne compare to the statistics of cdma2000? As mentioned earlier, it depends on the channel configuration. For a single traffic channel, the CCDF of the cdma2000 signal is almost the same as the CCDF of the cdmaOne signal. However, for multi-channel signals, the CCDFs are significantly different.

In general, a multi-channel cdma2000 signal is significantly less stressful than a multi-channel cdmaOne signal with a similar channel configuration. This is mostly because cdma2000 uses true QPSK modulation as opposed to dual BPSK. True QPSK modulation provides more possibilities for the I/Q locations of the chip points than dual BPSK prior to scrambling. Scrambling randomizes the chip locations for a single channel, but all channels use the same scrambling code; therefore, they are synchronously randomized. A higher number of I/Q location possibilities prior to the scrambling results in more random outputs between channels. Dual BPSK always maps the chip signal onto the same two I/Q locations prior to the scrambling (figure 8a), while true QPSK has four I/Q location possibilities (figure 8b). Therefore, QPSK provides less alignment between chip sequences from different channels, which results in a lower peak-to-average power ratio.

(a) Dual BPSK



(b) QPSK

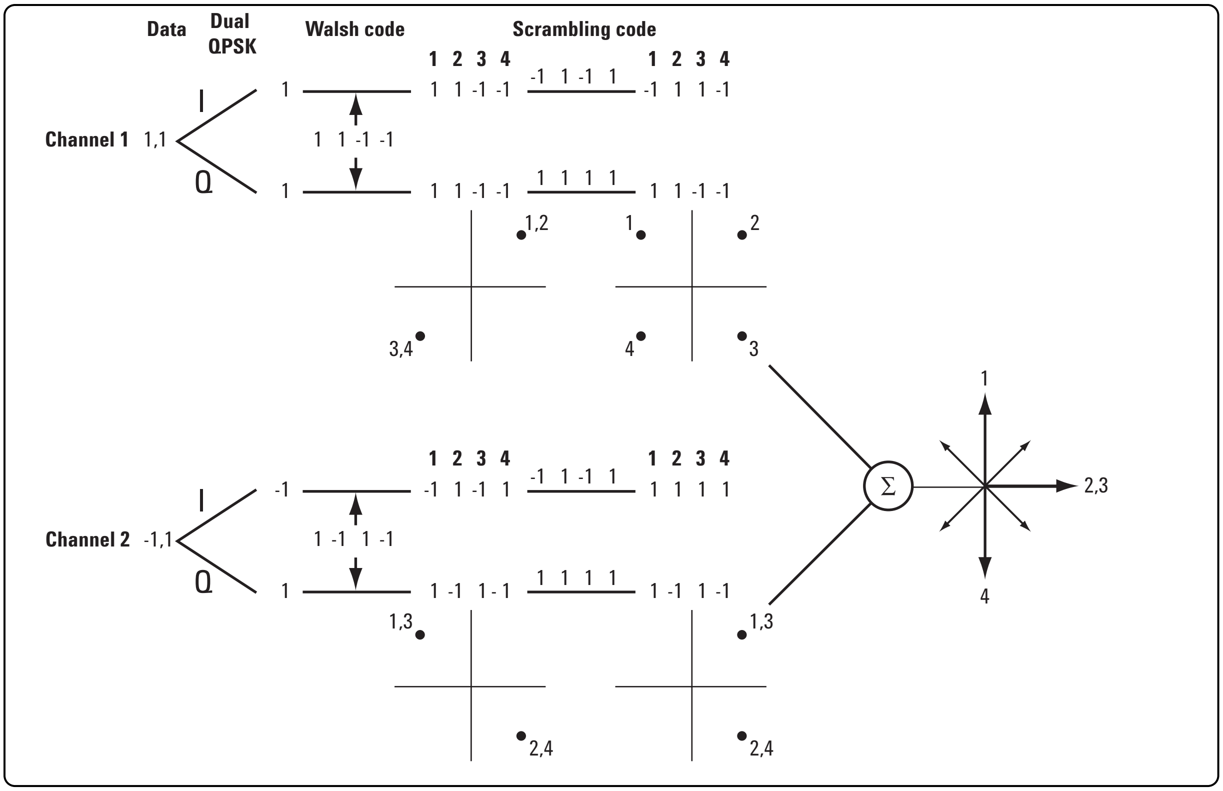


Figure 8. Result of combining (a) two dual BPSK channels, versus (b) two QPSK channels

Figures 9 and 10 compare the CCDFs of cdmaOne signals to cdma2000 SR1 signals with similar configurations. In both cases, the cdma2000 signal is significantly less stressful.

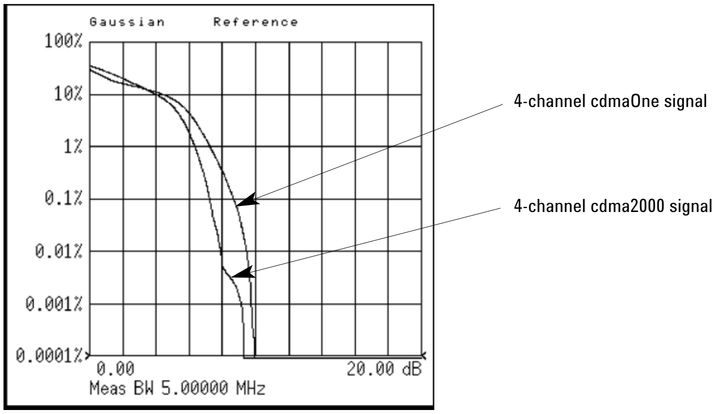


Figure 9. CCDF curves for a cdmaOne signal with four channels (pilot, sync, paging and one traffic channel) and for a cdma2000 signal with four channels (pilot, sync, paging and one RC3 traffic channel). All channels are at the same amplitude.

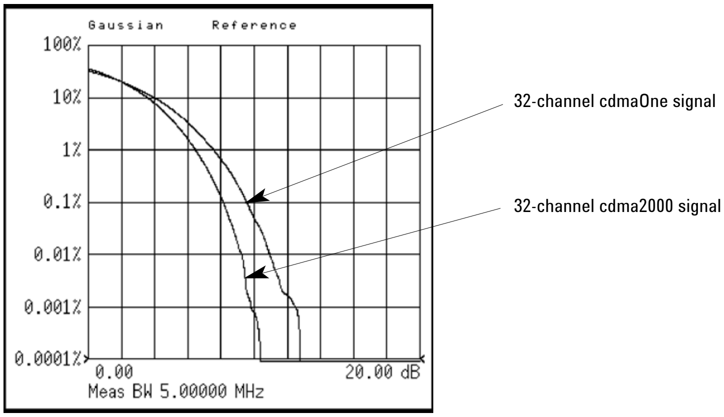


Figure 10. CCDF curves for a cdmaOne signal with 32 channels (pilot, sync, paging, and 29 traffic channels) and for a cdma2000 signal with 32 channels (pilot, sync, paging, and 29 RC3 traffic channels). All channels are at the same amplitude.

CCDF curves can help you in several situations:

- Determining the headroom required when designing a component. Correlate the CCDF curve of the signal with the amplifier gain plots **[5]**.
- Confirming the power statistics of a given signal or stimulus. CCDF curves allow you to verify if the stimulus signal provided by another design team is adequate. For example, RF designers can use CCDF curves to verify that the signal provided by the DSP section is realistic.
- Confirming that the component design is adequate or troubleshooting your subsystem or system design. You can make CCDF measurements at several points of the system design. For example, if the ACPR of the transmitter is too high, you can make CCDF measurements at the input and output of the power amplifier. If the amplifier design is correct, the curves coincide. If the amplifier compresses the signal, the peak-to-average power ratio of the signal is lower at the output of the amplifier.

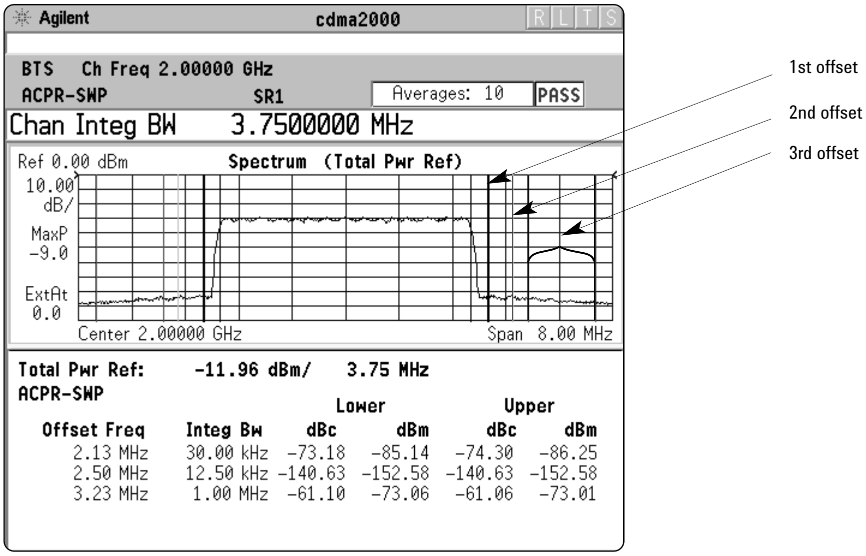
2.1.2 ACPR

The ACPR is usually defined as the ratio of the average power in the adjacent frequency channel (or at a specified frequency offset) to the average power in the transmitted frequency channel. The ACPR measurement is not part of the IS-95 standard. However, individual network equipment manufacturers typically specify ACPR as a figure of merit for component testing **[1]**.

As mentioned earlier, when testing ACPR, it is important to take into account the power statistics of the signal. A signal with a higher peak-to-average ratio may cause more interference in the adjacent channel. Thus, ACPR measurements can provide different results depending on the signal configuration. The safest approach is to select at least one high stress cdma2000 stimulus signal and test with various combinations of channels.

The appropriate ACPR measurement parameters for cdma2000 depend on the spreading rate:

- For SR1, you can use the cdmaOne parameters, since they both use the same chip rate and filtering.
- For SR3 MC, an integration bandwidth of 3.6864 MHz is appropriate. To calculate the appropriate frequency offsets for realistic cdma2000 SR3 ACPR[1] measurements, add the frequency spacing between carriers (1.25 MHz) to the original cdmaOne offset. For example, an offset of 885 kHz in cdmaOne is equivalent to an offset of 2.135 (0.885 + 1.25) MHz in cdma2000 SR3 MC. Figure 11 shows an example of an ACPR measurement for a cdma2000 SR3 MC signal.



```
BTS   Ch Freq 2.00000 GHz
ACPR-SWP              SR1        Averages: 10  PASS
Chan Integ BW     3.7500000 MHz

Total Pwr Ref:     -11.96 dBm/    3.75 MHz
ACPR-SWP
                                 Lower               Upper
  Offset Freq      Integ Bw     dBc      dBm      dBc      dBm
      2.13 MHz    30.00 kHz   -73.18   -85.14   -74.30   -86.25
      2.50 MHz    12.50 kHz  -140.63  -152.58  -140.63  -152.58
      3.23 MHz     1.00 MHz   -61.10   -73.06   -61.06   -73.01
```

Figure 11. ACPR measurement for a cdma2000 SR3 MC signal

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[1] The same calculations may apply to the in-band spurious measurement.

2.2 Measuring modulation accuracy

There are many measurements available to analyze the modulation accuracy of a cdma2000 BS transmitter: rho, QPSK error vector magnitude (EVM), composite EVM, code domain power, symbol EVM per code channel, etc. Apart from their basic algorithms, these measurements differ mainly in three aspects:

- whether you can use them to analyze a signal with a single (QPSK EVM) or multiple (composite rho, code domain power, symbol EVM) code channels
- if you can use them to analyze multi-channel signals, whether they provide information about each channel (code domain power, symbol EVM) or about the overall signal with no differentiation between channels (composite rho)
- how (what degree of demodulation) and at what level (chip, symbol) the reference is computed

The best measurement to use depends on the design stage and the test purpose. In general, these measurements can complement each other by providing additional pieces of information. The following sections intend to clarify what information these measurements provide and when to apply them.

2.2.1 QPSK EVM

In digital communication systems, signal impairment can be objectively assessed by looking at the constellation and taking the displacement of each measured dot from the reference position as an error phasor (or vector), as shown in figure 12.

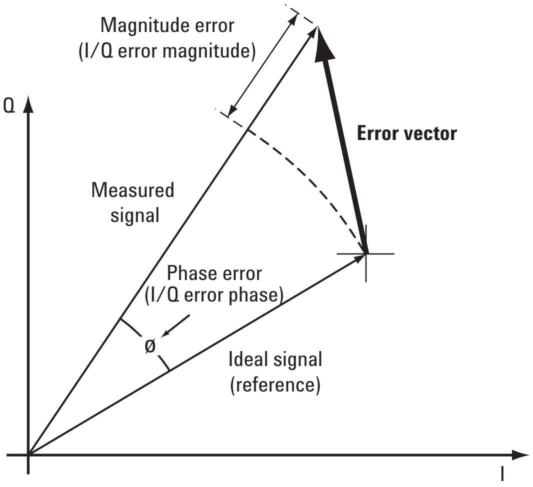


Figure 12. Error vector and related parameters

The reference position is determined from a reference signal that is synthesized by demodulating the received signal to symbols and then remodulating these symbols "perfectly". For example, figure 11 shows how the ideal reference is calculated for a QPSK signal.

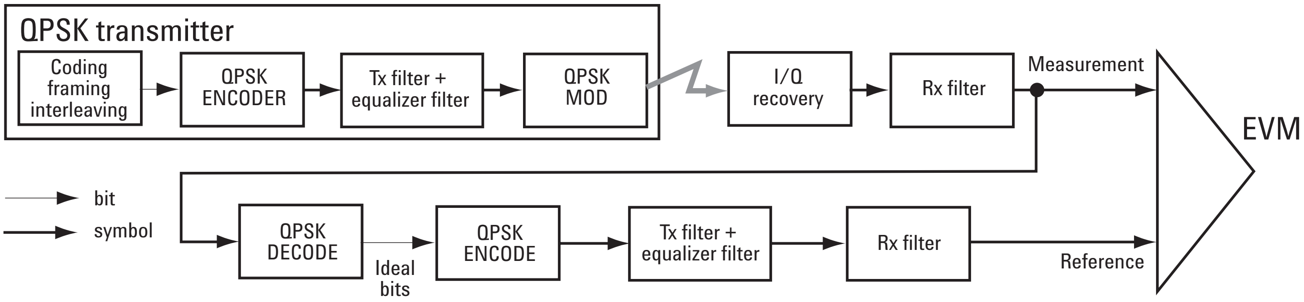


Figure 13. Process to calculate EVM for a QPSK signal

The root mean square (RMS) of the error vectors is computed and expressed as a percentage of the overall signal magnitude. This is the error vector magnitude (EVM). EVM is a common modulation quality metric widely used in digital communication systems. (See **[6]** for more information on using EVM as a troubleshooting tool.)

For a QAM or a PSK signal, the ideal symbol points always map onto a few specific locations in the I/Q plane. cdma2000 uses a QPSK format to modulate the spread signal (chips). However, the signal consists of several code channels. The final constellation at the RF does not typically look like QPSK or any other known constellation, except for some specific channel configurations. For example, a signal with a single code channel does map onto a QPSK constellation.

You can use a regular QPSK EVM (uncoded EVM) measurement to evaluate the modulation quality of the transmitter for a single-code signal. This measurement compares the measured chip signal at the RF with an ideal QPSK reference. The signal analyzer may use either of the following methodologies to make a QPSK EVM measurement:

1. **Measure QPSK EVM on the received signal.** Filter the recovered I/Q signal with a complementary receiver filter and compare it with a reference signal calculated by filtering the demodulated signal with the transmitter, equalizer, and receiver filters (figure 14a).
2. **Measure QPSK EVM on the transmitted signal.** Compare the I/Q recovered signal directly with a reference signal calculated by filtering the ideal bits with the transmitter and equalizer filters (figure 14b).

Both methods yield similar EVM results and you can use either of them to make valid modulation quality measurements of the base station transmitter– however, the resulting constellation looks different. The first method results in four discreet constellation points. The second method results in a fuzzy constellation, as shown in figure 15a. Both constellations are correct. The reason for the difference is that the first constellation shows what the receiver sees after filtering, while the second one displays the constellation of the transmitted signal before applying receiver filtering.

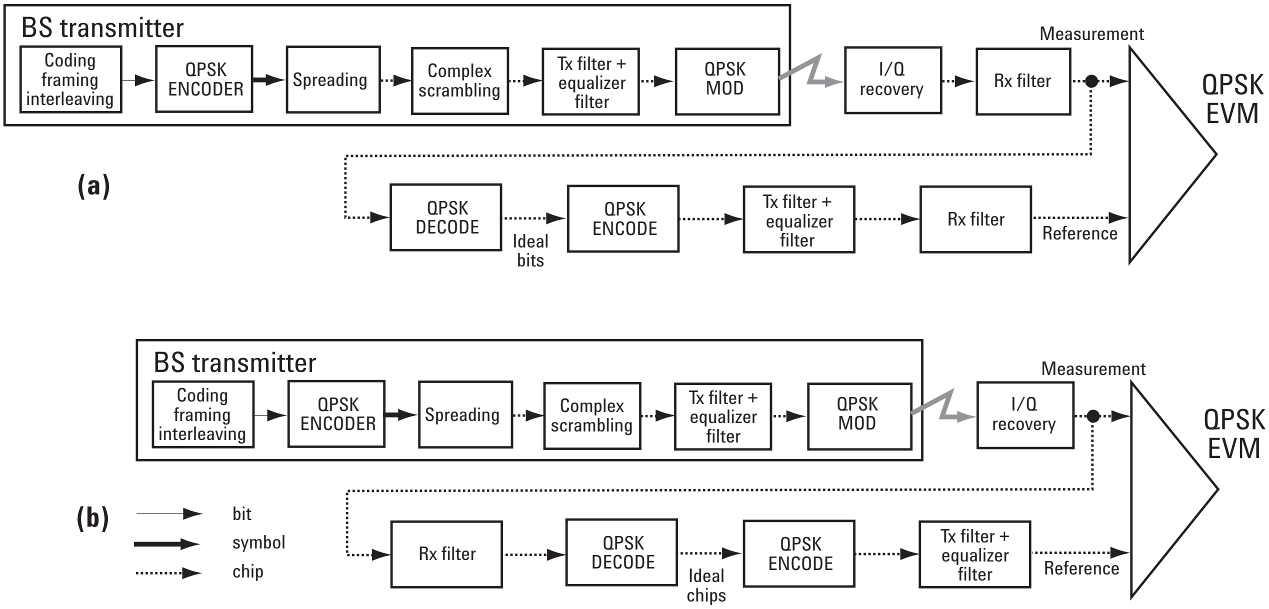
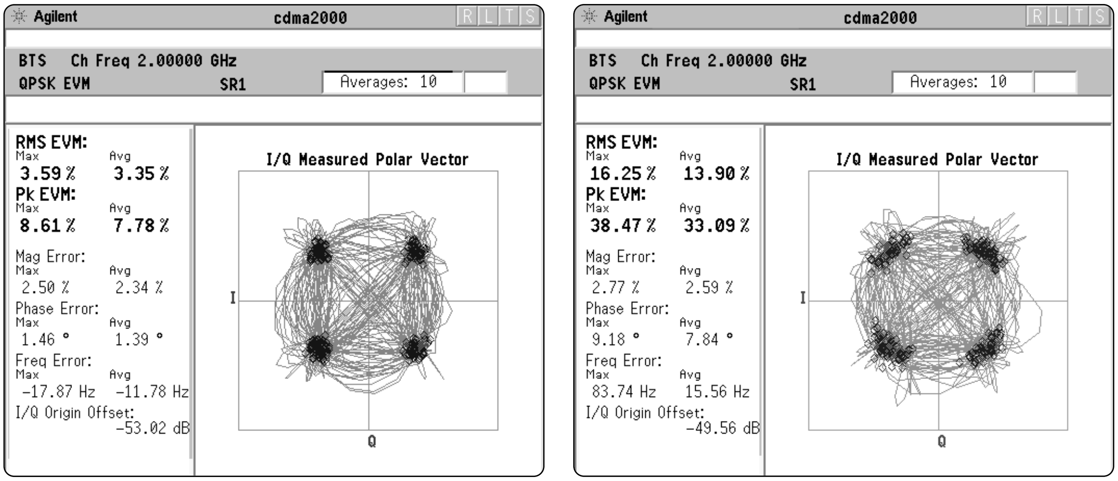


Figure 14. Process to calculate QPSK EVM for a cdma2000 reverse link signal

In any case, QPSK EVM does not descramble and despread the signal into bits and back into chips to calculate the appropriate reference. Therefore, it can detect baseband filtering, modulation, and IF and RF impairments, but does not detect spreading or scrambling errors.

If it is impossible to despread or descramble the signal, the QPSK EVM measurement may be the only choice. In this sense, the QPSK EVM measurement can be useful to RF designers or system integrators to evaluate the modulation quality of the analog section of the transmitter when the spreading or scrambling algorithms are not available or do not work properly. For example, figure 15 shows a QPSK EVM measurement for a single RC3 traffic channel for a transmitter with and without a LO instability (phase noise) problem.



BTS Ch Freq 2.00000 GHz
QPSK EVM SR1
Averages: 10

RMS EVM: Max 3.59 % Avg 3.35 %
Pk EVM: Max 8.61 % Avg 7.78 %
Mag Error: Max 2.50 % Avg 2.34 %
Phase Error: Max 1.46 ° Avg 1.39 °
Freq Error: Max -17.87 Hz Avg -11.78 Hz
I/Q Origin Offset: -53.02 dB

BTS Ch Freq 2.00000 GHz
QPSK EVM SR1
Averages: 10

RMS EVM: Max 16.25 % Avg 13.90 %
Pk EVM: Max 38.47 % Avg 33.09 %
Mag Error: Max 2.77 % Avg 2.59 %
Phase Error: Max 9.18 ° Avg 7.84 °
Freq Error: Max 83.74 Hz Avg 15.56 Hz
I/Q Origin Offset: -49.56 dB

(a) **(b)**

Figure 15. QPSK EVM on a cdma2000 signal (one RC3 traffic channel). (a) Without any impairments, and (b) with a phase noise impairment.

You can use the error vector, magnitude error, and phase error versus time to troubleshoot the impairment. For example, in this case, you could use the phase error versus time display to analyze the interfering signal that is creating the instability in the LO **[6]**.

2.2.2 Composite rho

In the IS-2000 standard, as in IS-95, the specified measurement for modulation accuracy is rho. Rho is the ratio of the correlated power to the total power. The correlated power is computed by removing frequency, phase, and time offsets and performing a cross correlation between the corrected signal and an ideal reference.

Rho has traditionally been defined for a pilot-only signal. The measured signal is compared to an ideal version of the pilot signal, as seen in figure 16.

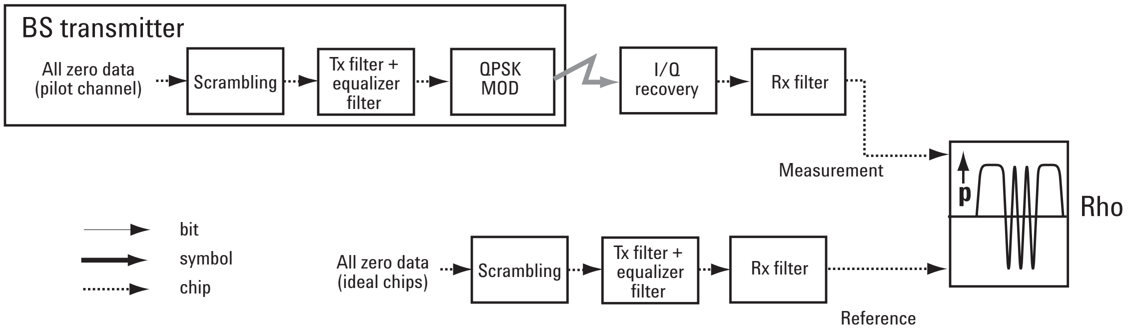


Figure 16. Traditional process to calculate rho for a cdmaOne or cdma2000 SR1 forward link pilot-only signal

As in IS-95, the IS-2000 standard specifies a pilot-only rho conformance test measurement. However, a rho measurement can also be performed on signals with multiple code channels. This measurement is known as composite rho. It allows you to verify the overall modulation accuracy for a transmitter, regardless of the channel configuration, as long as a pilot channel is present. The measurement algorithm involves descrambling and despreading the measured signal to calculate the reference signal, as shown in figure 17.

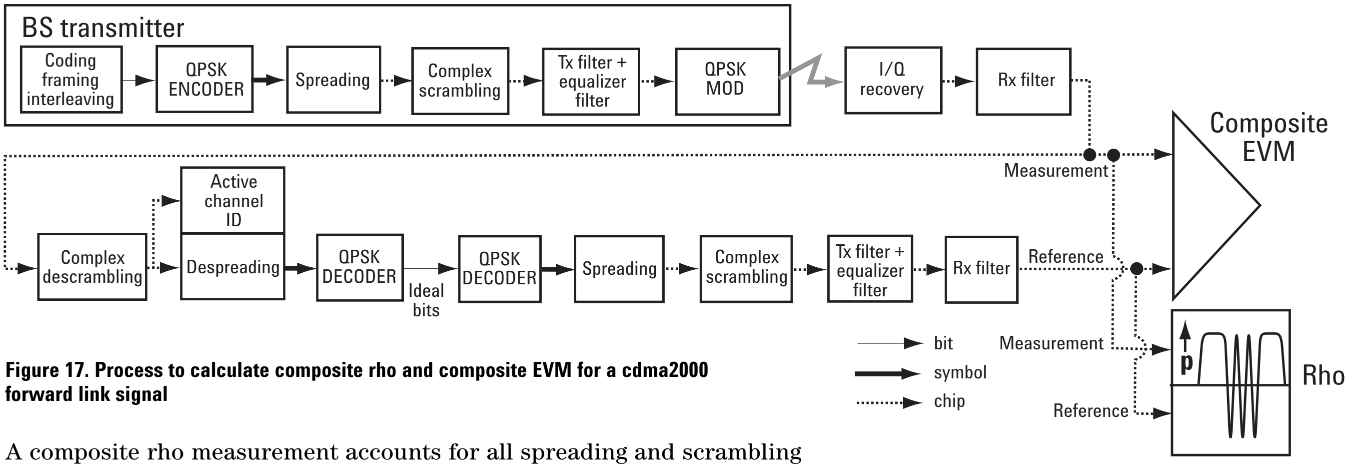
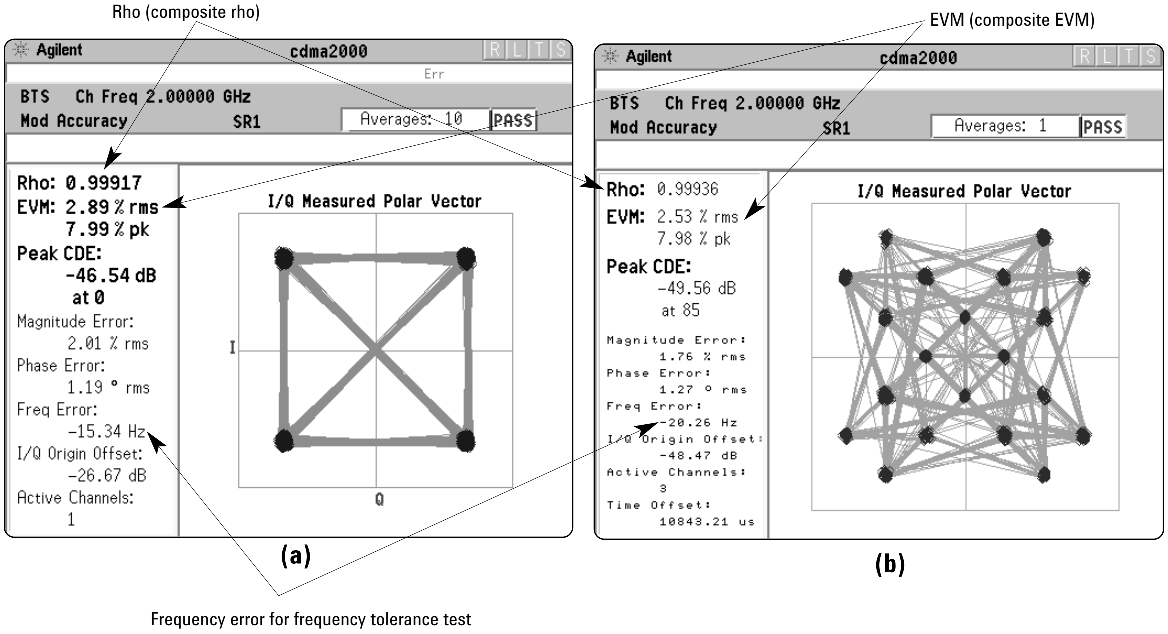


Figure 17. Process to calculate composite rho and composite EVM for a cdma2000 forward link signal

A composite rho measurement accounts for all spreading and scrambling problems in the active channels, and for all baseband, IF and RF impairments in the transmitter chain. However, unless combined with a constellation diagram and other modulation accuracy measurements, rho (or composite rho) does not help you identify the cause of the error. Figures 18a and 18b show composite rho combined with one of these measurements (composite EVM) and the constellation for a single-pilot signal and a multi-channel signal.



(a)

BTS Ch Freq 2.00000 GHz
Mod Accuracy SR1
Averages: 10 PASS

Rho: 0.99917
EVM: 2.89 % rms
7.99 % pk
Peak CDE:
-46.54 dB
at 0
Magnitude Error:
2.01 % rms
Phase Error:
1.19 ° rms
Freq Error:
-15.34 Hz
I/Q Origin Offset:
-26.67 dB
Active Channels:
1

(b)

BTS Ch Freq 2.00000 GHz
Mod Accuracy SR1
Averages: 1 PASS

Rho: 0.99936
EVM: 2.53 % rms
7.98 % pk
Peak CDE:
-49.56 dB
at 85
Magnitude Error:
1.76 % rms
Phase Error:
1.27 ° rms
Freq Error:
-20.26 Hz
I/Q Origin Offset:
-48.47 dB
Active Channels:
3
Time Offset:
10843.21 us

Figure 18. (a) Composite rho measurement for a cdma2000 SR1 signal with a pilot channel. (b) A cdma2000 SR1 signal with a pilot, sync, and RC3 traffic channel (3 dB lower than the other two channels).

Like QPSK EVM, composite EVM calculates the error vector difference between the measured and the ideal signal. The difference is that composite EVM uses the same reference as composite rho. That is, it descrambles and despreads the measured signal to calculate the reference (figure 17).

As with IS-95, the IS-2000 specifications also require testing for frequency and pilot time tolerance to prevent problems such as "island cell" effects in the deployed network **[1]**. The frequency error can be obtained when performing a composite rho measurement, as shown in figure 18. The pilot time tolerance is typically provided as one of the error metrics when performing a code domain power measurement (see figure 22).

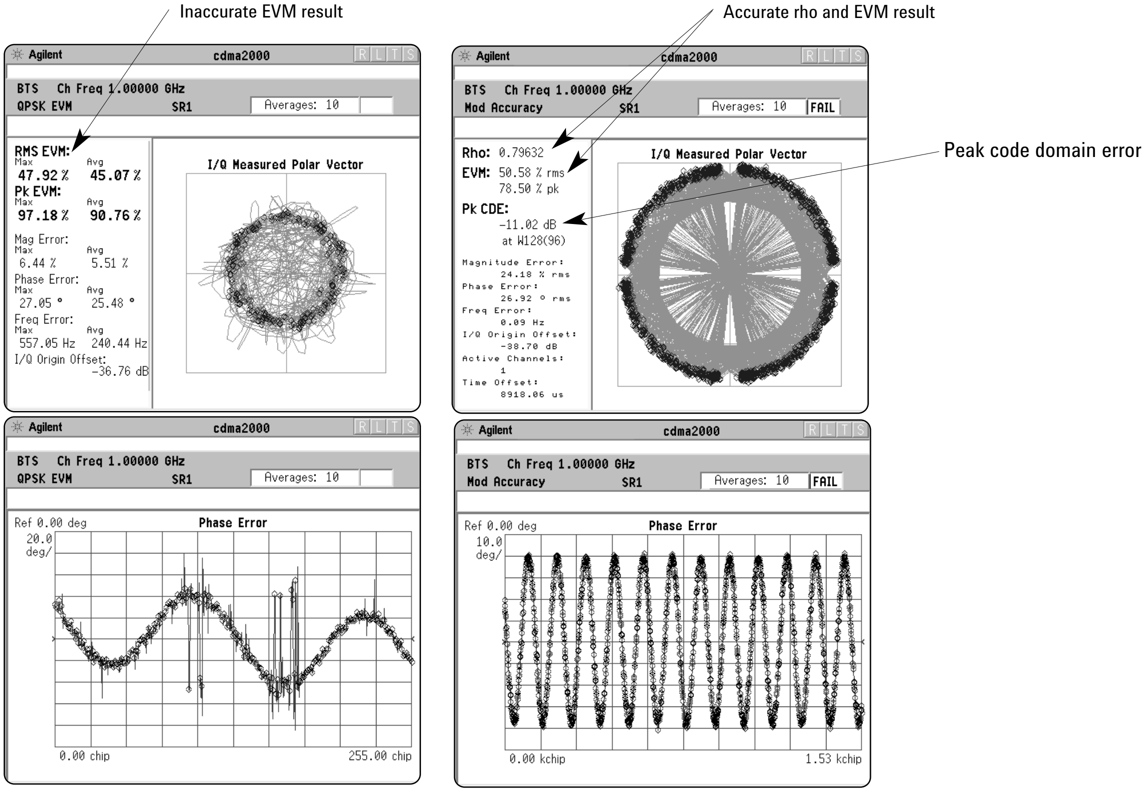
Here are some situations in which you should use composite rho (and composite error vector measurements) instead of a QPSK EVM measurement:

- **To evaluate the quality of the transmitter for a multi-channel signal.** This is particularly important for RF designers who need to test the RF section (or components) of the transmitter using realistic signals with correct statistics. In general, the peak-to-average power ratio of the signal increases as the number of channels increases. By measuring modulation quality on a multi-channel signal, you can analyze the per formance of the RF design for cdma2000 signals with different levels of stress (different CCDFs). Evaluating the modulation quality of multi-channel signals is also important for baseband designers, to analyze the performance of multi-board baseband designs. For example, a small timing error in the clock synchronization between channels on different boards can be detected as a decrease in modulation quality.

- **To detect spreading or scrambling errors.** Depending on the degree of the error, the analyzer may show an intermittent unlock condition or may not be able to lock at all when trying to perform a composite rho measurement. These conditions are mainly of interest to system integrators, to determine errors in the spreading and scrambling. Should this problem occur, you can use the QPSK EVM measurement to confirm that the rest of the transmitter is working as expected. If the scrambling or spreading error does not cause an unlock measurement condition, you can use the error vector versus time display to find the problematic chip.

- **To detect certain problems between the baseband and RF sections.** Again, these cases are mainly of interest to system integrators. You may be able to use QPSK EVM measurement to detect some of these problems. For example, LO instability caused by interference from digital signals can be detected with QPSK EVM, as seen earlier. However, the QPSK EVM measurement will not detect problems that require synchronization. For example, I/Q swapped errors will look perfectly normal if a QPSK EVM measurement is used. On the other hand, it will cause an unlock condition when performing a composite rho measurement.

- **To analyze errors that cause high interference in the signal.** If the interference is too high, the QPSK EVM measurement may not be able to recover the true ideal reference. In this case, the QPSK EVM and its related displays are not accurate. Since the composite rho measurement descrambles and despreads the signal, it takes advantage of its processing gain. This allows the analyzer to recover the true reference even when the signal is well beyond the interference level that will cause multiple chip errors. Therefore, composite rho and composite EVM are true indicators of modulation fidelity even when the signal under test is buried by interference. In this sense, these measurements may be particularly useful in hostile field environments with high levels of interference. R&D engineers can use the measurements to analyze how the interference will affect base station service deployment and to provide BS-to-MS sensitivity curves for the providers. (For instance, how bad the EVM can get before the MS or signal analyzer cannot recover the signal.) The processing gain benefits of composite rho (or EVM) can also be useful to RF designers and system integrators for occasional bad cases of interference. For example, figure 19a shows the phase error versus time for a QPSK EVM measurement and figure 19b shows the phase error versus time for a composite rho (or EVM) measurement, for a pilot-only signal with a very high LO instability. In this case, the analyzer can demodulate the signal and calculate the reference accurately. The phase error display in figure 19b will allow you to analyze the interference.



Inaccurate EVM result

Accurate rho and EVM result

Peak code domain error

```
Agilent                 cdma2000
BTS   Ch Freq 1.00000 GHz
QPSK EVM              SR1        Averages: 10

RMS EVM:
Max         Avg
47.92 %     45.07 %
Pk EVM:
Max         Avg
97.18 %     90.76 %
Mag Error:
Max         Avg
6.44 %      5.51 %
Phase Error:
Max         Avg
27.05 °     25.48 °
Freq Error:
Max         Avg
557.05 Hz   240.44 Hz
I/Q Origin Offset:
            -36.76 dB
```

```
Agilent                 cdma2000
BTS   Ch Freq 1.00000 GHz
Mod Accuracy          SR1        Averages: 10  FAIL

Rho: 0.79632
EVM: 50.58 % rms
     78.50 % pk
Pk CDE:
     -11.02 dB
     at W128(96)
Magnitude Error:
     24.18 % rms
Phase Error:
     26.92 ° rms
Freq Error:
     0.09 Hz
I/Q Origin Offset:
     -38.70 dB
Active Channels:
     1
Time Offset:
     8918.06 us
```

```
Agilent                 cdma2000
BTS   Ch Freq 1.00000 GHz
QPSK EVM              SR1        Averages: 10
```

```
Agilent                 cdma2000
BTS   Ch Freq 1.00000 GHz
Mod Accuracy          SR1        Averages: 10  FAIL
```

(a)

(b)

Figure 19. cdma2000 pilot signal with very high LO instability. (a) Vector diagram and phase error versus time for QPSK EVM. (b) Vector diagram and phase error versus time for composite EVM (provided with composite rho measurement).

Composite rho is useful throughout the development, performance verification, manufacturing, and installation phases of the BS life cycle as a figure of merit for the code multiplex as a whole. However, we are also interested in the code-by-code composition of the composite signal. The primary means of investigating this is to look at the distribution of power in the code domain.

2.2.3 Code domain power

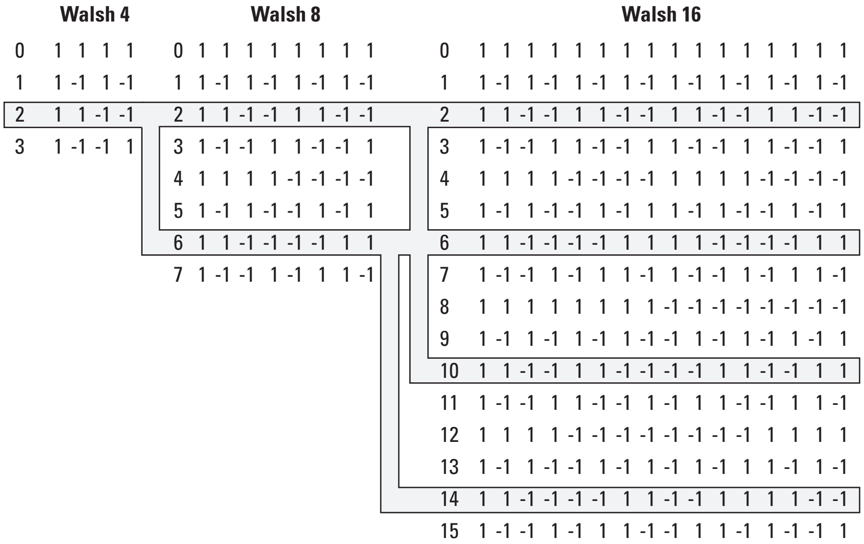
The other indicator of modulation quality in CDMA systems is code domain power. Using this measurement, you can verify that each Walsh channel is operating at its proper level and can quantify the inactive traffic noise level.

In cdma2000, the measurement is complicated by the fact that the length of the Walsh codes varies to accommodate the different data rates and spreading rates of the different radio configurations. In general, as the data rate increases, the symbol period is shorter. For a specific SR, the final chip rate is constant. Therefore, fewer Walsh code chips are accommodated within the symbol period—the Walsh code length is shorter. Table 1 shows the Walsh code length versus bit rate for the different RCs that operate at SR1.

Table 1. Walsh code length for different RCs at SR1

RC	Walsh code length					
	128 bits (Walsh 128)	64 bits (Walsh 64)	32 bits (Walsh 32)	16 bits (Walsh 16)	8 bits (Walsh 8)	4 bits (Walsh 4)
1	N/A	9.6 kbps	N/A	N/A	N/A	N/A
2	N/A	14.4 kbps	N/A	N/A	N/A	N/A
3	N/A	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps
4	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps	307.2 kbps
5	N/A	14.4 kbps	28.8 kbps	57.6 kbps	115.2 kbps	230.4 kbps

One effect of using variable length Walsh codes for spreading is that a shorter code precludes using all longer codes derived from it. Figure 20 illustrates this concept. If a high data rate channel using a 4-bit Walsh code such as 1,1,-1,-1 is transmitted, all lower data rate channels using longer Walsh codes that start with 1,1,-1,-1 must be inactive to avoid conflicts in the correlation process at the receiver.



Walsh 4	Walsh 8	Walsh 16
0 1 1 1 1	0 1 1 1 1 1 1 1 1	0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 -1 1 -1	1 1 -1 1 -1 1 -1 1 -1	1 1 -1 1 -1 1 -1 1 -1 1 -1 1 -1 1 -1 1 -1
2 1 1 -1 -1	2 1 1 -1 -1 1 1 -1 -1	2 1 1 -1 -1 1 1 -1 -1 1 1 -1 -1 1 1 -1 -1
3 1 -1 -1 1	3 1 -1 -1 1 1 -1 -1 1	3 1 -1 -1 1 1 -1 -1 1 1 -1 -1 1 1 -1 -1 1
	4 1 1 1 1 -1 -1 -1 -1	4 1 1 1 1 -1 -1 -1 -1 1 1 1 1 -1 -1 -1 -1
	5 1 -1 1 -1 -1 1 -1 1	5 1 -1 1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 -1 1
	6 1 1 -1 -1 -1 -1 1 1	6 1 1 -1 -1 -1 -1 1 1 1 1 -1 -1 -1 -1 1 1
	7 1 -1 -1 1 -1 1 1 -1	7 1 -1 -1 1 -1 1 1 -1 1 -1 -1 1 -1 1 1 -1
		8 1 1 1 1 1 1 1 1 -1 -1 -1 -1 -1 -1 -1 -1
		9 1 -1 1 -1 1 -1 1 -1 -1 1 -1 1 -1 1 -1 1
		10 1 1 -1 -1 1 1 -1 -1 -1 -1 1 1 -1 -1 1 1
		11 1 -1 -1 1 1 -1 -1 1 -1 1 1 -1 -1 1 1 -1
		12 1 1 1 1 -1 -1 -1 -1 -1 -1 -1 -1 1 1 1 1
		13 1 -1 1 -1 -1 1 -1 1 -1 1 -1 1 1 -1 1 -1
		14 1 1 -1 -1 -1 -1 1 1 -1 -1 1 1 1 1 -1 -1
		15 1 -1 -1 1 -1 1 1 -1 -1 1 1 -1 1 -1 -1 1

Figure 20. Hadamard generation of Walsh codes and the effects of using variable length Walsh codes for spreading

Individual Walsh codes (or functions) are identified by W_n^N, where N is the length of the code and n is the row in the N x N Hadamard matrix. For example, $W_2$4 represents code 2 of the 4 x 4 Hadamard matrix (4-bit Walsh code).

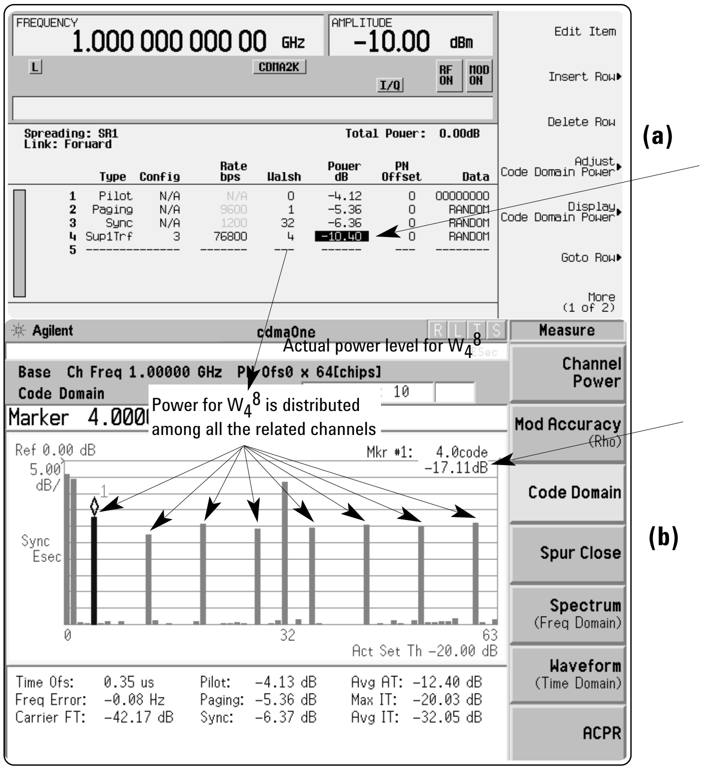
Therefore, $W_2$4 precludes using:

- W_2^8 and W_6^8;
- W_2^{16}, W_6^{16}, W_{10}^{16}, W_{14}^{16};
- W_2^{32}, W_6^{32}, W_{10}^{32}, W_{14}^{32}, W_{18}^{32}, W_{22}^{32}, W_{26}^{32}, W_{30}^{32} (not shown in figure 20); etc.

Appendix A contains a cdma2000 Walsh code table that shows the relationship among Walsh codes of different lengths (determined by the data rate in a specific RC).

In the code domain power measurement, channels with higher data rates (shorter code lengths) occupy more code space. For example, W_2^4 occupies 4 times more code space than W_2^{16}, and 16 times more code space than W_2^{64}. The measurement should provide some way to identify the different layers (Walsh code lengths) of the code channels being measured.

You can use an instrument with cdmaOne capability to make code domain power measurements on SR1 cdma2000 signals, taking some considerations into account. For a SR1 channel with a Walsh code length different from cdmaOne—that is, a channel with a Walsh code shorter than 64 bits[1]—the detected power is spread onto all the Walsh 64 channels with a related Walsh code (a code that starts with the same sequence). Figure 21a shows the actual power levels for a cdma2000 signal with pilot, paging, and sync channels and a RC3 F-SCH with a data rate of 76.8 kbps (W_4^8). Figure 21b shows the code domain power measurement on the same signal. The power in W_4^8 is spread among W_2^{64}, W_{12}^{64}, W_{20}^{64}, W_{28}^{64}, W_{36}^{64}, W_{44}^{64}, W_{52}^{64} and W_{60}^{64}. (You can use the cdma2000 Walsh code table in Appendix A to see the relationship among Walsh codes of different lengths). The total computed power of W_4^8 in the code domain power measurement can be calculated by adding the indicated power levels (in linear units) of all related Walsh 64 channels.



FREQUENCY 1.000 000 000 00 GHz

AMPLITUDE -10.00 dBm

Spreading: SR1
Link: Forward

Total Power: 0.00dB

	Type	Config	Rate bps	Walsh	Power dB	PN Offset	Data
1	Pilot	N/A	N/A	0	-4.12	0	00000000
2	Paging	N/A	9600	1	-5.36	0	RANDOM
3	Sync	N/A	1200	32	-6.36	0	RANDOM
4	Sup1Trf	3	76800	4	-10.40	0	RANDOM
5	-------------		-------	---	------	---	--------

Base Ch Freq 1.00000 GHz PN Ofs0 x 64[chips]

Code Domain

10

Marker 4.000

Ref 0.00 dB

5.00 dB/

Mkr #1: 4.0code -17.11dB

Act Set Th -20.00 dB

Time Ofs: 0.35 us
Freq Error: -0.08 Hz
Carrier FT: -42.17 dB

Pilot: -4.13 dB
Paging: -5.36 dB
Sync: -6.37 dB

Avg AT: -12.40 dB
Max IT: -20.03 dB
Avg IT: -32.05 dB

Actual power level for W_4^8

Actual power level for W_4^8

Power for W_4^8 is distributed among all the related channels

Computed power level for W_4^{64} (to calculate power for W_4^8 power in all related channels must be added)

Figure 21. (a) Signal generation, and (b) code domain power for a cdma2000 signal with the pilot, paging, sync, and an RC3 (76.8 kbps) F-SCH (W_4^8). Measurement performed with an instrument with code domain power capability for cdmaOne.

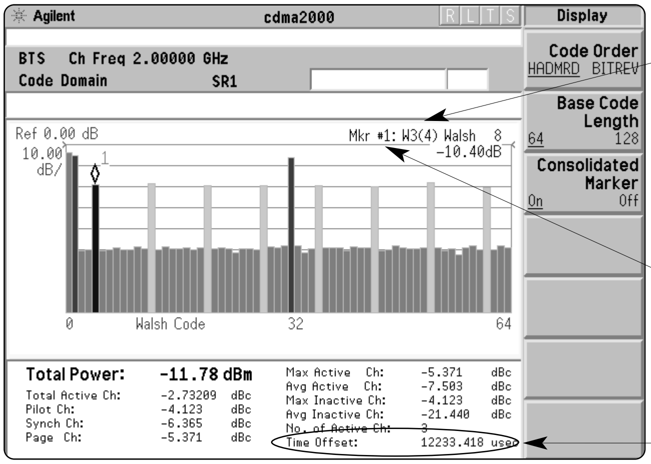
---

[1] RC4 (9.6 kbps) is an exception to this. It is the only RC at SR1 that uses Walsh codes longer than 64 bits.

The only case where the code length of a cdma2000 SR1 channel is longer than 64 bits is for RC4 and a data rate of 9.6 kbps. The energy of a 128-bit code will also map onto the related 64-bit code (in this case, the code that it originates from). For example, W_{84}^{128} will map its energy onto W_{20}^{64} (see the Walsh code table in appendix A). On the other hand, W_{20}^{128} will also map its energy onto W_{20}^{64}. If you use an cdmaOne measurement, you will not be able to calculate the power for each of these two codes separately.

Therefore, a cdmaOne code domain power measurement provides restricted measurement capabilities on SR1 cdma2000 signals. In addition, when multiple code channels with different data rates are active, the measurement process can become tedious.

In any case, an instrument with specific cdma2000 capabilities offers many advantages, such as fast identification of channels with different data rates and accurate power readings for all channels. Figure 22 shows an example of a cdma2000 SR1 code domain power measurement (performed with an instrument with cdma2000 code domain power capability) for the same signal used in figure 21. In this case, the marker indicates the true power for code channel W_4^8 and identifies the code space occupied by this channel distributed in a 64-Walsh Hadamard matrix.



```
BTS    Ch Freq 2.00000 GHz
Code Domain            SR1

Mkr #1: W3(4) Walsh   8
                 -10.40dB

Total Power:       -11.78 dBm     Max Active   Ch:     -5.371    dBc
Total Active Ch:   -2.73209  dBc  Avg Active   Ch:     -7.503    dBc
Pilot Ch:          -4.123    dBc  Max Inactive Ch:     -4.123    dBc
Synch Ch:          -6.365    dBc  Avg Inactive Ch:     -21.440   dBc
Page  Ch:          -5.371    dBc  No. of Active Ch:    3
                                  Time Offset:         12233.418 usec
```

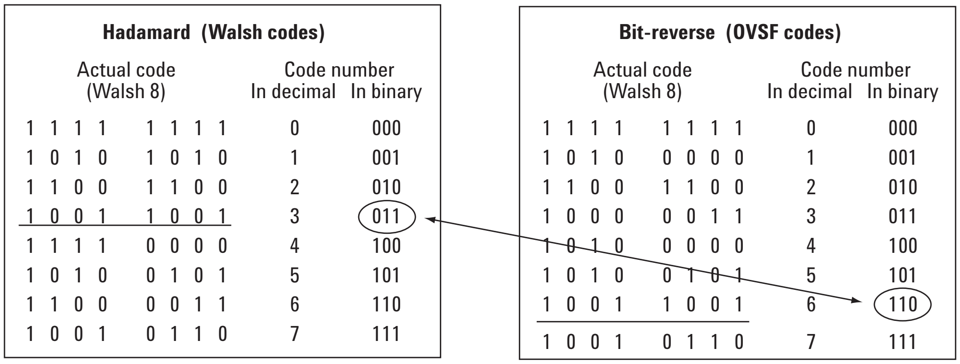
W3 means Walsh 2^3 = Walsh 8

Marker identifies correct code assignment and power level for W_4^8

Time offset measurement for pilot time tolerance test

Figure 22. Code domain power measurement of a cdma2000 signal with the pilot, paging, sync, and an RC3 (76.8 kbps) F-SCH (W_4^8) performed with cdma2000 code domain measurement

Another way to look at the same signal is to reorder the code channels so that related code channels are adjacent to each other. The so-called bit-reverse generation of Walsh channels provides us with this desired code number assignment. This is the code generation method used in W-CDMA **[7]**. The codes derived from this method are called orthogonal variable spreading factor (OVSF) codes, as opposed to Walsh codes, in W-CDMA. OVSF codes and Walsh codes are the same, only their code number assignment is different. The generation method is called “bit-reverse” because the code number in binary form is reversed (MSB is LSB, etc.), relative to the Hadamard method. For example, code channel 3 (binary: 011) in the Hadamard Walsh 8 matrix corresponds to code channel 6 (binary: 110) in the reverse-bit Walsh 8 matrix, as seen in figure 23.



Hadamard (Walsh codes)

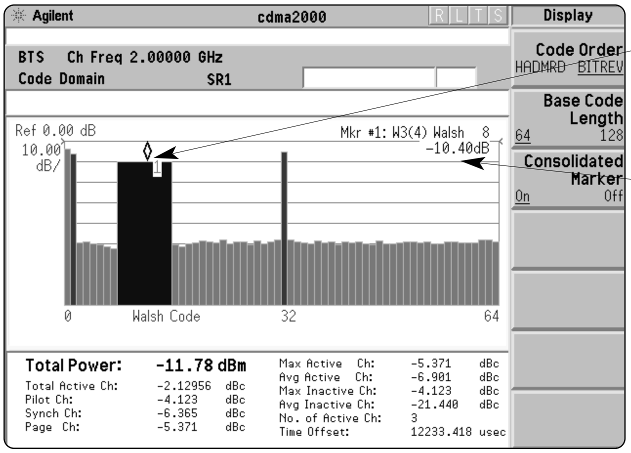
Actual code (Walsh 8)	Code number In decimal	Code number In binary
1 1 1 1 1 1 1 1	0	000
1 0 1 0 1 0 1 0	1	001
1 1 0 0 1 1 0 0	2	010
1 0 0 1 1 0 0 1	3	011
1 1 1 1 0 0 0 0	4	100
1 0 1 0 0 1 0 1	5	101
1 1 0 0 0 0 1 1	6	110
1 0 0 1 0 1 1 0	7	111

Bit-reverse (OVSF codes)

Actual code (Walsh 8)	Code number In decimal	Code number In binary
1 1 1 1 1 1 1 1	0	000
1 0 1 0 0 0 0 0	1	001
1 1 0 0 1 1 0 0	2	010
1 0 0 0 0 0 1 1	3	011
1 0 1 0 0 0 0 0	4	100
1 0 1 0 0 1 0 1	5	101
1 0 0 1 1 0 0 1	6	110
1 0 0 1 0 1 1 0	7	111

Figure 23. Hadamard versus bit-reverse

Figure 24 shows the signal from figures 21 and 22 displayed using bit-reverse order. The different channels at different data rates are easily identified using this display. High data rate channels are displayed as "wide" channels, since they occupy more code space.



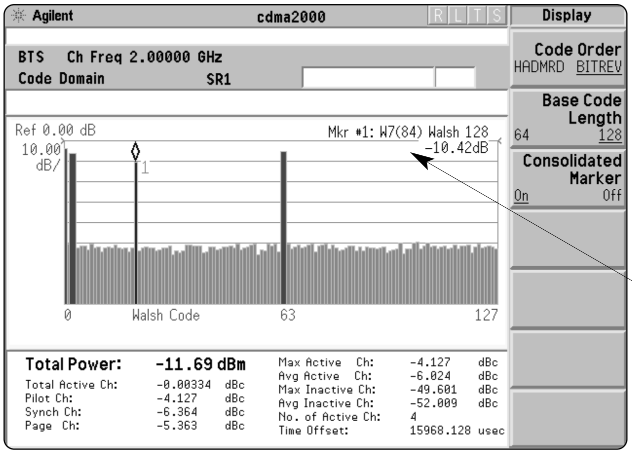
```
BTS    Ch Freq 2.00000 GHz
Code Domain            SR1
Mkr #1: W3(4) Walsh  8
                -10.40dB
Total Power:       -11.78 dBm    Max Active   Ch:     -5.371     dBc
Total Active Ch:   -2.12956  dBc Avg Active   Ch:     -6.901     dBc
Pilot Ch:          -4.123    dBc Max Inactive Ch:     -4.123     dBc
Synch Ch:          -6.365    dBc Avg Inactive Ch:     -21.440    dBc
Page  Ch:          -5.371    dBc No. of Active Ch:    3
                                 Time Offset:         12233.418 usec
```

"Wide" code channel corresponds to a high data rate channel

Marker identifies correct code assignment and power level for W_4^8

Figure 24. cdma2000 code domain power measurement with bit-reverse display for a signal with the pilot, paging, sync, and a RC3 (76.8 kbps) F-SCH (W_4^8)

To cover all RCs at all data rates, it is necessary to be able to look at the energy projected in the 128-code space. Figure 25 shows the code domain power measurement of a signal with a pilot, paging, sync, and a RC4 F-FCH (W_{84}^{128}) at 9.6 kbps.



```
BTS    Ch Freq 2.00000 GHz
Code Domain            SR1
Mkr #1: W7(84) Walsh 128
                -10.42dB
Total Power:       -11.69 dBm    Max Active   Ch:     -4.127     dBc
Total Active Ch:   -0.00334  dBc Avg Active   Ch:     -6.024     dBc
Pilot Ch:          -4.127    dBc Max Inactive Ch:     -49.601    dBc
Synch Ch:          -6.364    dBc Avg Inactive Ch:     -52.009    dBc
Page  Ch:          -5.363    dBc No. of Active Ch:    4
                                 Time Offset:         15968.128 usec
```

Marker identifies correct code assignment and power level for W_{84}^{128}

Figure 25. Code domain power measurement with bit-reverse display for a cdma2000 SR1 signal with a pilot, paging, sync, and a RC4 F-FCH (W_{84}^{128}). Energy projected in the 128-code space.

The code domain power measurement helps you not only verify that each Walsh channel is operating at its proper level, but also helps identify problems throughout the transmitter design, from the coding to the RF section. In particular, the level of the inactive channels can provide useful information about specific impairments **[6]**. The projection of the error signal over the code domain, known as code domain error, is of even more interest. You want the error power to be distributed through the code domain, rather than concentrated in a few codes, to avoid code-dependent channel quality variations. However, many transmitter impairments, such as amplifier compression and LO instability, cause uneven distribution of the error throughout the code domain. In these cases, energy is lost from the active channels and appears in related code channels in deterministic ways **[8]**. For this reason, it is useful to ensure that the code domain error is under a certain limit. The peak code domain error measurement (shown in figure 19b in combination with a composite rho measurement) indicates the maximum code domain error in the signal and to which code channel this error belongs. In case of transmitter impairments, the peak code domain error typically belongs to one of the active channels.

Related to code domain power, cdmaOne standards specify a pilot channel to code channel time tolerance and pilot channel to code channel phase tolerance **[1]**. These tests will probably be part of the IS-2000 standard. However, they are irrelevant if digital summing is used, since digital summing prevents delays and phase shifts between channels.

Apart from looking at the code domain power, it is useful to analyze a specific code channel. The following sections describe some analysis tools and their applications. Figure 26 shows how the references for these measurements are calculated.

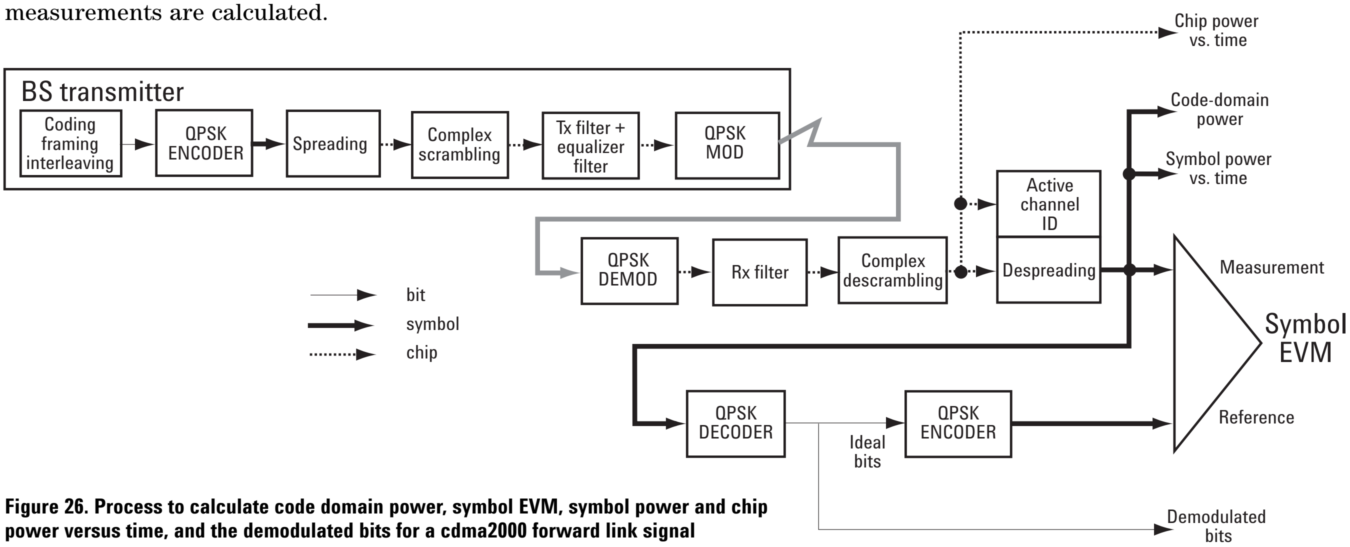


Figure 26. Process to calculate code domain power, symbol EVM, symbol power and chip power versus time, and the demodulated bits for a cdma2000 forward link signal

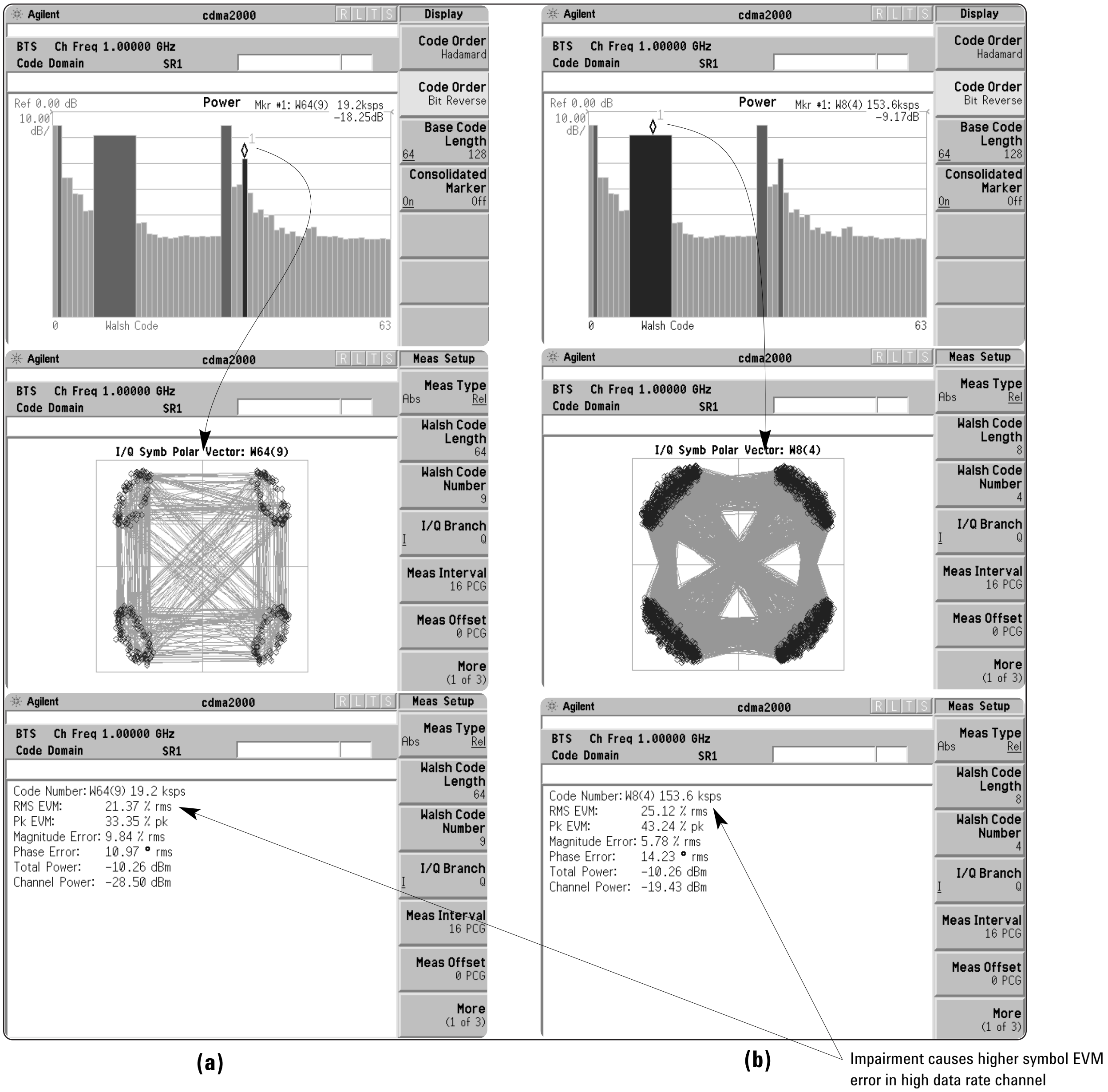
2.2.4 Symbol EVM

By descrambling and despreading the signal, you can analyze the constellation for a specific code channel at the symbol level, even in the presence of multiple code channels. The measured signal is complex descrambled, despread, and QPSK decoded to bits. The ideal bits are then QPSK encoded to obtain the reference at the symbol level. This reference is then compared to the measured despread symbols (figure 26).

An RF impairment that affects symbol EVM will also affect the composite EVM. For example, an amplifier compression problem will appear both in the composite EVM and in the symbol EVM measurement. However, because of the processing gain, symbol EVM will mute the impairment. So, why use symbol EVM?

Symbol EVM provides the bridge between RF and the demodulated bits. Since it includes the processing gain, it provides baseband engineers a measure of modulation quality closer to real-life performance. In this sense, you can think of it as the actual quality that the user in that channel will experience (similar to the reciprocal of BER).

Symbol EVM is important in cdma2000 because the Walsh code length varies. Therefore, there is a compromise between the data rate and the modulation quality. A chip error in a symbol for a higher data rate channel (less processing gain) will result in poorer modulation quality (higher BER) when compared to a chip error in a symbol for a lower data rate channel, if both channels use the same amplitude level. In that sense, it is particularly useful to baseband DSP engineers to analyze how the different impairments affect the quality of channels at different data rates. For example, figure 27 shows the cdma2000 code domain power measurement (bit-reverse display) for a signal with a pilot, paging, sync, one RC3 F-FCH (W_9^{64} at 9.6 kbps and –12.77 dB) and one RC3 F-SCH (W_4^{8} at 76.8 kbps and –3.77 dB). The signal suffers from LO interference. LO interference does not raise the level of the code domain power noise floor evenly for all channels. Instead, it raises the power of some inactive channels (those which are mathematically related to the active channels) more than others **[6]**. Figure 27a shows the constellation and symbol EVM (around 15 percent) for the lower data rate (W_9^{64}) channel. On the other hand, the higher data rate channel (W_4^{8}) suffers from a higher symbol EVM (around 25 percent).



(a)

Code Number: W64(9) 19.2 ksps
RMS EVM: 21.37 % rms
Pk EVM: 33.35 % pk
Magnitude Error: 9.84 % rms
Phase Error: 10.97 ° rms
Total Power: -10.26 dBm
Channel Power: -28.50 dBm

(b)

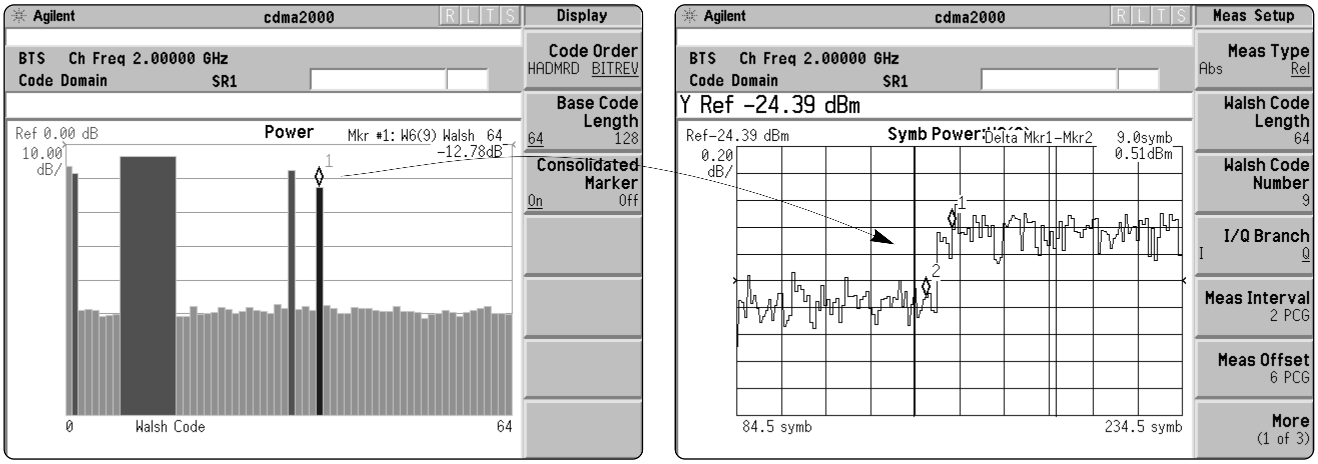
Code Number: W8(4) 153.6 ksps
RMS EVM: 25.12 % rms
Pk EVM: 43.24 % pk
Magnitude Error: 5.78 % rms
Phase Error: 14.23 ° rms
Total Power: -10.26 dBm
Channel Power: -19.43 dBm

Impairment causes higher symbol EVM error in high data rate channel

Figure 27. cdma2000 code domain power measurement (bit-reverse display) for a signal with a pilot, paging, sync, one RC3 F-FCH (W_9^{64} at 9.6 kbps and –12.77 dB), and one RC3 F-SCH (W_4^8 at 76.8 kbps and –3.77 dB). Signal with a LO interference problem: (a) symbol EVM measurement for the F-FCH, and (b) symbol EVM measurement for the F-SCH.

2.2.5 Symbol power versus time

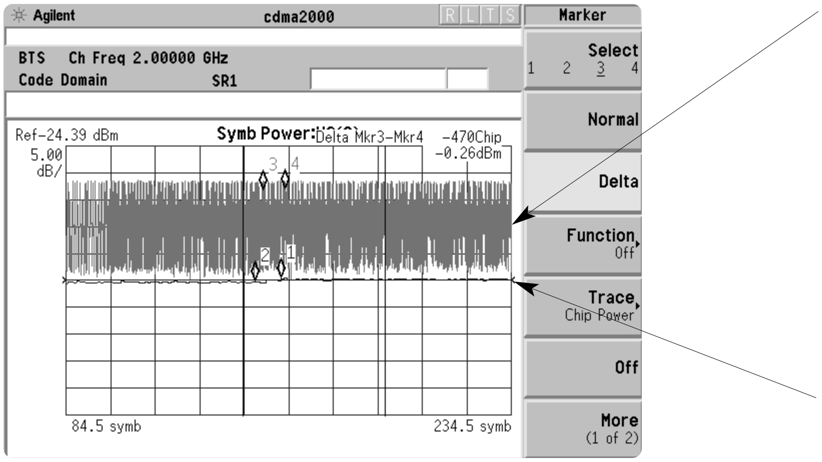
Analyzing the power for a specific code channel versus time (or versus symbol) can be particularly useful to monitor the power and response of the BS power control system. For example, figure 28 shows a symbol power increase of 0.5 dB in the W_9^{64} F-FCH (for the same signal used in figure 27), but with no impairments.



(a) **(b)**

Figure 28. (a) cdma2000 code domain power measurement (bit-reverse display) for a signal with a pilot, paging, sync, one RC3 F-FCH (W_9^{64} at 9.6 kbps and –12.77 dB), and one RC3 F-SCH (W_4^8 at 76.8 kbps and –3.77 dB). (b) Symbol power versus time for the F-FCH.

Figure 29 shows the symbol power versus time in combination with the chip power for the signal versus time. This is particularly useful for system integrators for analyzing the power amplifier response (ripple) to a series of power control commands.



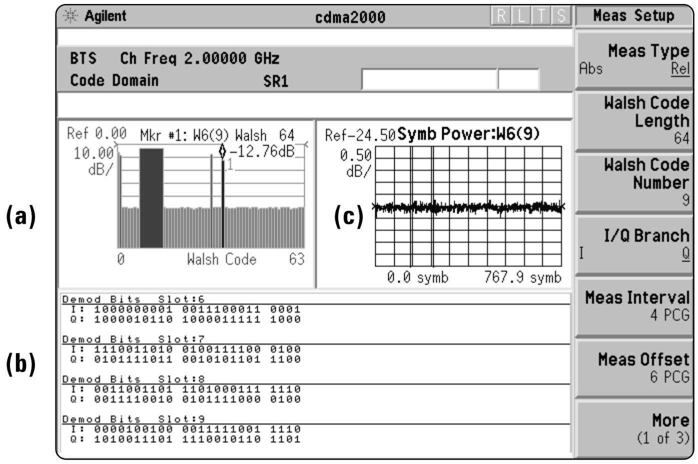
Chip power versus time

Symbol power versus time for F-FCH

Figure 29. Chip power versus time for a signal with a pilot, paging, sync, one RC3 F-FCH (W_9^{64} at 9.6 kbps and –12.77 dB), and one RC3 F-SCH (W_4^8 at 76.8 kbps and –3.77 dB), combined with symbol power versus time for the F-FCH

2.2.6 Demodulated bits

Figure 30 shows the I and Q demodulated bits for the F-FCH of a cdma2000 signal. By obtaining the demodulated symbols after descrambling and despreading for each code channel, the correct symbol patterns can be verified. This is particularly important for the power control bits, since power control is absolutely critical to system performance.



```
Demod Bits  Slot:6
 I: 1000000001 0011100011 0001
 Q: 1000010110 1000011111 1000

Demod Bits  Slot:7
 I: 1110011010 0100111100 0100
 Q: 0101111011 0010101101 1100

Demod Bits  Slot:8
 I: 0011001101 1101000111 1110
 Q: 0011110010 0101111000 0100

Demod Bits  Slot:9
 I: 0000100100 0011111001 1110
 Q: 1010011101 1110010110 1101
```

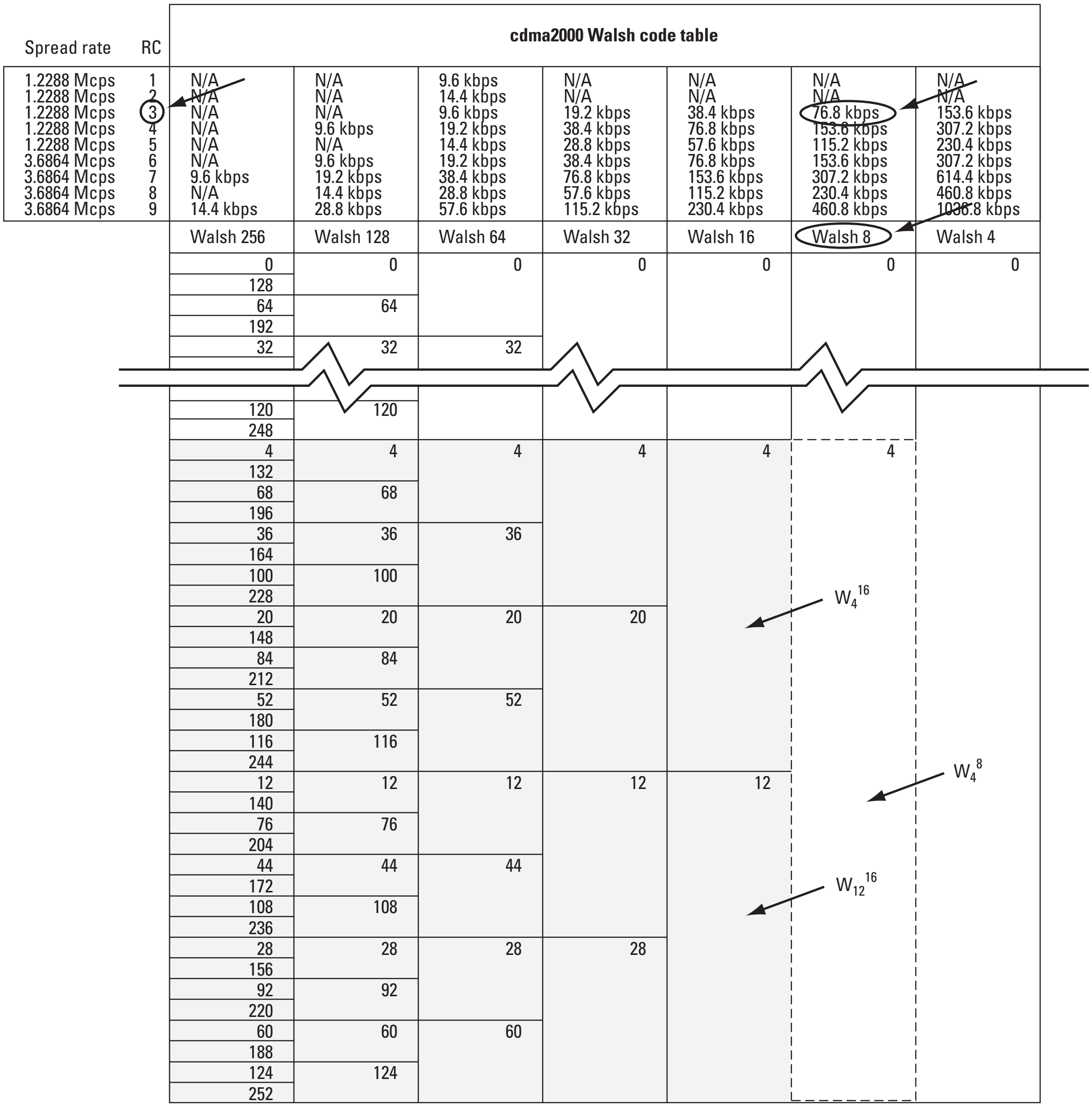
Figure 30. (a) cdma2000 code domain power measurement (bit-reverse display) for a signal with a pilot, paging, sync, one RC3 F-FCH (W_9^{64} at 9.6 kbps and –12.77 dB), and one RC3 F-SCH (W_4^8 at 76.8 kbps and –3.77 dB). (b) Demodulated bits for the F-FCH. (c) Symbol power versus time for the F-FCH.

Demodulated bits is an important troubleshooting tool for baseband engineers to identify coding, interleaving, and power control bit errors. In many cases, it can help clarify situations where the BS and MS are having problems communicating with each other. Analyzing the demodulated bits may confirm whether the error is coming from the MS coding and interleaving or the BS de-interleaving and de-coding process.

Appendix A: cdma2000 Walsh code table

This table shows the relationship between Walsh codes of different lengths for the different RCs at different data rates. The energy in a channel with a shorter code correlates into all channels with longer related codes. Therefore, a shorter code precludes using all longer codes derived from it (from right to left, in the table). For example, RC3 at 76.8 kbps uses Walsh 8 codes. $W_4{}^8$ precludes using:

- $W_4{}^{16}$ and $W_{12}{}^{16}$;
- $W_4{}^{32}$, $W_{12}{}^{32}$, $W_{20}{}^{32}$, $W_{28}{}^{32}$;
- $W_4{}^{64}$, $W_{12}{}^{64}$, $W_{20}{}^{64}$, $W_{28}{}^{64}$, $W_{36}{}^{64}$, $W_{44}{}^{64}$, $W_{52}{}^{64}$, $W_{60}{}^{64}$
- etc.



Spread rate	RC	cdma2000 Walsh code table						
1.2288 Mcps	1	N/A	N/A	9.6 kbps	N/A	N/A	N/A	N/A
1.2288 Mcps	2	N/A	N/A	14.4 kbps	N/A	N/A	N/A	N/A
1.2288 Mcps	3	N/A	N/A	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps
1.2288 Mcps	4	N/A	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps	307.2 kbps
1.2288 Mcps	5	N/A	N/A	14.4 kbps	28.8 kbps	57.6 kbps	115.2 kbps	230.4 kbps
3.6864 Mcps	6	N/A	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps	307.2 kbps
3.6864 Mcps	7	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps	307.2 kbps	614.4 kbps
3.6864 Mcps	8	N/A	14.4 kbps	28.8 kbps	57.6 kbps	115.2 kbps	230.4 kbps	460.8 kbps
3.6864 Mcps	9	14.4 kbps	28.8 kbps	57.6 kbps	115.2 kbps	230.4 kbps	460.8 kbps	1036.8 kbps

Walsh 256	Walsh 128	Walsh 64	Walsh 32	Walsh 16	Walsh 8	Walsh 4
0	0	0	0	0	0	0
128						
64	64					
192						
32	32	32				
120	120					
248						
4	4	4	4	4	4	
132						
68	68					
196						
36	36	36				
164						
100	100					
228						
20	20	20	20			
148						
84	84					
212						
52	52	52				
180						
116	116					
244						
12	12	12	12	12		
140						
76	76					
204						
44	44	44				
172						
108	108					
236						
28	28	28	28			
156						
92	92					
220						
60	60	60				
188						
124	124					
252						

Figure 31. Using $W_4{}^8$ precludes using the codes in the shaded area

Spread rate	RC	cdma2000 Walsh code table						
1.2288 Mcps	1	N/A	N/A	9.6 kbps	N/A	N/A	N/A	N/A
1.2288 Mcps	2	N/A	N/A	14.4 kbps	N/A	N/A	N/A	N/A
1.2288 Mcps	3	N/A	N/A	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps
1.2288 Mcps	4	N/A	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps	307.2 kbps
1.2288 Mcps	5	N/A	N/A	14.4 kbps	28.8 kbps	57.6 kbps	115.2 kbps	230.4 kbps
3.6864 Mcps	6	N/A	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps	307.2 kbps
3.6864 Mcps	7	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps	307.2 kbps	614.4 kbps
3.6864 Mcps	8	N/A	14.4 kbps	28.8 kbps	57.6 kbps	115.2 kbps	230.4 kbps	460.8 kbps
3.6864 Mcps	9	14.4 kbps	28.8 kbps	57.6 kbps	115.2 kbps	230.4 kbps	460.8 kbps	1036.8 kbps
		Walsh 256	Walsh 128	Walsh 64	Walsh 32	Walsh 16	Walsh 8	Walsh 4
		0	0	0	0	0	0	0
		128						
		64	64					
		192						
		32	32	32				
		160						
		96	96					
		224						
		16	16	16	16			
		144						
		80	80					
		208						
		48	48	48				
		176						
		112	112					
		240						
		8	8	8	8	8		
		136						
		72	72					
		200						
		40	40	40				
		168						
		104	104					
		232						
		24	24	24	24			
		152						
		88	88					
		216						
		56	56	56				
		184						
		120	120					
		248						
		4	4	4	4	4	4	
		132						
		68	68					
		196						
		36	36	36				
		164						
		100	100					
		228						
		20	20	20	20			
		148						
		84	84					
		212						
		52	52	52				
		180						
		116	116					
		244						
		12	12	12	12	12		
		140						
		76	76					
		204						
		44	44	44				
		172						
		108	108					
		236						
		28	28	28	28			
		156						
		92	92					
		220						
		60	60	60				
		188						
		124	124					
		252						

Spread rate	RC	cdma2000 Walsh code table						
1.2288 Mcps	1	N/A	N/A	9.6 kbps	N/A	N/A	N/A	N/A
1.2288 Mcps	2	N/A	N/A	14.4 kbps	N/A	N/A	N/A	N/A
1.2288 Mcps	3	N/A	N/A	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps
1.2288 Mcps	4	N/A	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps	307.2 kbps
1.2288 Mcps	5	N/A	N/A	14.4 kbps	28.8 kbps	57.6 kbps	115.2 kbps	230.4 kbps
3.6864 Mcps	6	N/A	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps	307.2 kbps
3.6864 Mcps	7	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps	307.2 kbps	614.4 kbps
3.6864 Mcps	8	N/A	14.4 kbps	28.8 kbps	57.6 kbps	115.2 kbps	230.4 kbps	460.8 kbps
3.6864 Mcps	9	14.4 kbps	28.8 kbps	57.6 kbps	115.2 kbps	230.4 kbps	460.8 kbps	1036.8 kbps
		Walsh 256	Walsh 128	Walsh 64	Walsh 32	Walsh 16	Walsh 8	Walsh 4
		1	1	1	1	1	1	1
		129						
		65	65					
		193						
		33	33	33				
		161						
		97	97					
		225						
		17	17	17	17			
		145						
		81	81					
		209						
		49	49	49				
		177						
		113	113					
		241						
		9	9	9	9	9		
		137						
		73	73					
		201						
		41	41	41				
		169						
		105	105					
		233						
		25	25	25	25			
		153						
		89	89					
		217						
		57	57	57				
		185						
		121	121					
		249						
		5	5	5	5	5	5	
		133						
		69	69					
		197						
		37	37	37				
		165						
		101	101					
		229						
		21	21	21	21			
		149						
		85	85					
		213						
		53	53	53				
		181						
		117	117					
		245						
		13	13	13	13	13		
		141						
		77	77					
		205						
		45	45	45				
		173						
		109	109					
		237						
		29	29	29	29			
		157						
		93	93					
		221						
		61	661	61				
		189						
		125	125					
		253						

Spread rate	RC	cdma2000 Walsh code table						
1.2288 Mcps	1	N/A	N/A	9.6 kbps	N/A	N/A	N/A	N/A
1.2288 Mcps	2	N/A	N/A	14.4 kbps	N/A	N/A	N/A	N/A
1.2288 Mcps	3	N/A	N/A	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps
1.2288 Mcps	4	N/A	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps	307.2 kbps
1.2288 Mcps	5	N/A	N/A	14.4 kbps	28.8 kbps	57.6 kbps	115.2 kbps	230.4 kbps
3.6864 Mcps	6	N/A	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps	307.2 kbps
3.6864 Mcps	7	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps	307.2 kbps	614.4 kbps
3.6864 Mcps	8	N/A	14.4 kbps	28.8 kbps	57.6 kbps	115.2 kbps	230.4 kbps	460.8 kbps
3.6864 Mcps	9	14.4 kbps	28.8 kbps	57.6 kbps	115.2 kbps	230.4 kbps	460.8 kbps	1036.8 kbps
		Walsh 256	Walsh 128	Walsh 64	Walsh 32	Walsh 16	Walsh 8	Walsh 4
		2	2	2	2	2	2	2
		130						
		66	66					
		194						
		34	34	34				
		162						
		98	98					
		226						
		18	18	18	18			
		146						
		82	82					
		210						
		50	50	50				
		178						
		114	114					
		242						
		10	10	10	10	10		
		138						
		74	74					
		202						
		42	42	42				
		170						
		106	106					
		234						
		26	26	26	26			
		154						
		90	90					
		218						
		58	58	58				
		186						
		122	122					
		250						
		6	6	6	6	6	6	
		134						
		70	70					
		198						
		38	38	38				
		166						
		102	102					
		230						
		22	22	22	22			
		150						
		86	86					
		214						
		54	54	54				
		182						
		118	118					
		246						
		14	14	14	14	14		
		142						
		78	78					
		206						
		46	46	46				
		174						
		110	110					
		238						
		30	30	30	30			
		158						
		94	94					
		222						
		62	62	62				
		190						
		126	126					
		254						

Spread rate	RC	cdma2000 Walsh code table						
1.2288 Mcps	1	N/A	N/A	9.6 kbps	N/A	N/A	N/A	N/A
1.2288 Mcps	2	N/A	N/A	14.4 kbps	N/A	N/A	N/A	N/A
1.2288 Mcps	3	N/A	N/A	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps
1.2288 Mcps	4	N/A	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps	307.2 kbps
1.2288 Mcps	5	N/A	N/A	14.4 kbps	28.8 kbps	57.6 kbps	115.2 kbps	230.4 kbps
3.6864 Mcps	6	N/A	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps	307.2 kbps
3.6864 Mcps	7	9.6 kbps	19.2 kbps	38.4 kbps	76.8 kbps	153.6 kbps	307.2 kbps	614.4 kbps
3.6864 Mcps	8	N/A	14.4 kbps	28.8 kbps	57.6 kbps	115.2 kbps	230.4 kbps	460.8 kbps
3.6864 Mcps	9	14.4 kbps	28.8 kbps	57.6 kbps	115.2 kbps	230.4 kbps	460.8 kbps	1036.8 kbps
		Walsh 256	Walsh 128	Walsh 64	Walsh 32	Walsh 16	Walsh 8	Walsh 4
		3	3	3	3	3	3	3
		131						
		67	67					
		195						
		35	35	35				
		163						
		99	99					
		227						
		19	19	19	19			
		147						
		83	83					
		211						
		51	51	51				
		179						
		115	115					
		243						
		11	11	11	11	11		
		139						
		75	75					
		203						
		43	43	43				
		171						
		107	107					
		235						
		27	27	27	27			
		155						
		91	91					
		219						
		59	59	59				
		187						
		123	123					
		251						
		7	7	7	7	7	7	
		135						
		71	71					
		199						
		39	39	39				
		167						
		103	103					
		231						
		23	23	23	23			
		151						
		87	87					
		215						
		55	55	55				
		183						
		119	119					
		247						
		15	15	15	15	15		
		143						
		79	79					
		207						
		47	47	47				
		175						
		111	111					
		239						
		31	31	31	31			
		159						
		95	95					
		223						
		63	63	63				
		191						
		127	127					
		255						

Appendix B:
Agilent solutions for cdma2000 BS design and test

This section provides a list of Agilent solutions that can help develop and test your cdma2000 BS designs.

Design software and simulation

Use the Agilent Advanced Design System (ADS) for cdma2000 systems, circuits, and DSP designs. ADS is a versatile design tool that includes a wide array of RF, analog and DSP models, and simulation capability–all accessible in a single environment.

The cdma2000 design library (E8877A/AN) is a collection of models for the physical layer of cdma2000. The library includes the following models and application examples:

- rake receivers for both the forward link and the reverse link
- forward link transmissions with SR1 and SR3
- reverse link transmissions with SR1 and SR3
- reverse link with HPSK modulation (SR1 and SR3)
- channel encoding with turbo codes with BER/FER measurement
- measurement of ACPR, CCDF and EVM
- a variety of RCs
- transmission power control for both forward and reverse links
- complete RF transmitter and receiver design capability, including nonlinear components, phase noise, and inter-modulation distortion
- signal source Design Guide for convenient configuration of cdma2000 sources

The library includes advanced features such as Hybrid Phase Shift Keying (HPSK) spreading (reverse link), pilot-aided coherent demodulation (reverse link), channel coding (including turbo codes, mapping and de-mapping scheme for rate matching), and orthogonal transmit diversity (OTD).

Signal generation

The Agilent ESG-D/DP series RF signal generator with Option 101 has the capability of simulating statistically correct forward and reverse link cdma2000 signals for BS component and subsystem testing[1]. An easy-to-use interface allows you to

- select the spreading rate (SR1 or SR3)
- select from several predefined cdma2000 multi-channel signals
- use the table editor to fully configure a cdma2000 multi-channel signal per your requirements

An easy-to-use interface link allows you to easily download custom waveforms created with ADS into the ESG signal generator.

---

[1] You can also use arbitrary waveforms in the ESG to create the appropriate cdma2000 reverse link signals for receiver measurements.

Power meters and sensors

The Agilent EPM series power meters and E9300 series power sensors provide average power measurements on RF and microwave signals, regardless of the modulation or complexity, over a wide 80-dB dynamic range. The E9300 power sensors are bandwidth independent, so you don’t have to worry about matching sensor bandwidth to the modulation format of your signal under test. High power measurements up to 25 W (+44 dBm) are available in the E9300 family.

Recommended power meters and sensors for cdma2000 average power measurements are

- E4418B power meter, single channel
- E4419B power meter, dual channel
- E9301A power sensor, 10 MHz to 6 GHz, -60 to +20 dBm
- E9301H power sensor, 10 MHz to 6 GHz, -50 to +30 dBm
- E9300B power sensor, 10 MHz to 6 GHz, -30 to +44 dBm

Other power sensors in the 8480 series are compatible with the E4418B/9B power meters.

Signal analysis

This table provides the list of Agilent signal analyzers and their cdma2000 measurement capabilities (as of August 2000).

Table 2. Agilent signal analysis capabilities for cdma2000

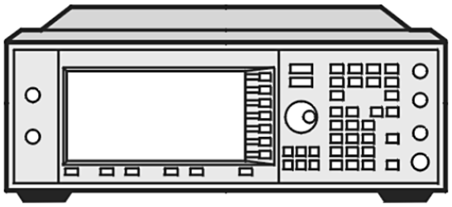
cdma2000		**Agilent signal analyzers**				
		Vector signal analyzers		Spectrum analyzers		
Measurements		E4406A VSA transmitter tester[1]	89400A vector signal analyzer[2]	89600 vector signal analyzer[2]	8560-E series spectrum analyzer[3]	ESA-E series spectrum analyzer[2]
Channel power		●	●	●	●	●
Occupied bandwidth		●			●	●
In-band emissions	ACPR	●	●[5]		●[4]	●
	In-band spurious	●	●[5]		●	●
Out-of-band emissions (spurious/harmonics)		up to 4 GHz[5]	up to 2.6 GHz[5]		●	●
Peak/average power ratio		●	●	●		
CCDF		●	●	●		
Modulation quality (SR1)	QPSK EVM	●	●	●		
	Rho (pilot only)	●	●[6]	●[6]		●
	Composite rho and EVM	●				
	Frequency accuracy	●	●	●		●
	Time offset	●				●
	Code domain power	●				●[7]
	Symbol EVM	●				
	Symbol power vs. time	●				
	Composite chip power vs. time	●				
	Demodulated bits	●				

Notes:

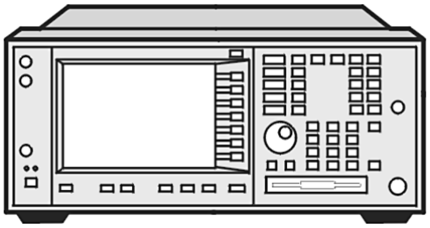
1. Measurements pre-configured for cdma2000.
2. Some measurements pre-configured for IS-95. Measurement parameters can be manually changed to accommodate cdma2000 SR1.
3. Measurements are not pre-configured to a specific standard. Measurement parameters can be manually selected to accommodate IS-2000.
4. Measurement can be performed if same integration bandwidth is used for main channel and offsets. Power (or rms) averaging is not available.
5. Manual measurement (no automatic spurious search or ACPR measurement).
6. There are several interpretations of rho. The 89400 and 89600 vector signal analyzers can make the rho measurement with certain assumptions.
7. IS-95 measurement. cdma2000 measurement can be made with certain limitations.

Instruments used for measurement examples

The measurement examples and screen images in this application note were obtained using the following instruments:



Agilent ESG-D Series RF digital signal generator Option 101



Agilent E4406A VSA Series transmitter tester

Acronym glossary

2G	Second Generation
3G	Third Generation
3GPP	Third-Generation Partnership Project
3GPP2	Third-Generation Partnership Project 2
ACPR	Adjacent Channel Power Ratio
ARIB	Association of Radio Industries and Businesses (Japan)
BPSK	Binary Phase Shift Keying
BS	Base Station/ Base Transceiver Station
CCDF	Complementary Cumulative Distribution Function
CDMA	Code Division Multiple Access
cdmaOne	Name identifying the EIA/TIA standard (commonly referred to as IS-95) for 2G
cdma2000	Name identifying the EIA/TIA standard (IS-2000) for 3G
DS	Direct Spread
EVM	Error Vector Magnitude
F-DCCH	Forward Dedicated Control Channel
F-FCH	Forward Fundamental Channel
F-Paging	Forward Paging
F-Pilot	Forward Pilot
F-SCH	Forward Supplemental Code Channel (for RC1 and RC2) or Forward Supplemental Code Channel (for RC3 to RC9)
F-Sync	Forward Sync
HPSK	Hybrid Phase Shift Keying (same as OCQPSK)
IF	Intermediate Frequency
IMT-2000	International Mobile Telecommunications-2000
I/Q	In-Phase/Quadrature
IS-95	Interim Standard 1995 for US Code Division Multiple Access
IS-2000	EIA/TIA interim standard 2000 (see cdma2000)
LO	Local Oscillator
MC	Multiple Carrier
MSB	Most Significant Bit
OCQPSK	Orthogonal Complex Quadrature Phase Shift Keying (HPSK)
OQPSK	Offset Quadrature Phase Shift Keying
OVSF	Orthogonal Variable Spreading Factor
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RC	Radio Configuration
RF	Radio Frequency
R-CCCH	Reverse Common Control Channel
R-DCCH	Reverse Dedicated Control Channel
R-EACH	Reverse Enhanced Access Channel
R-FCH	Reverse Fundamental Channel
R-Pilot	Reverse Pilot
R-SCH	Reverse Supplemental Channel
SR	Spreading Rate
TIA	Telecommunications Industries Association (U.S.)
TTA	Telecommunications Technology Association (Korea)
TTC	Telecommunication Technology Committee (Japan)
W-CDMA	Wideband-Code Division Multiple Access (3G system)

For more information regarding these acronyms and other wireless industry terms, please consult our wireless dictionary at ***www.agilent.com/find/wireless***.

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[2] Ken Thompson, "Concepts of cdma2000," Wireless Symposium, 1999.

[3] *HPSK Spreading for 3G*, Application Note 1335, literature number 5968-8438E.

[4] *Designing and Testing W-CDMA Base Stations*, Application Note 1355, literature number 5980-1239E.

[5] *Characterizing Digitally Modulated Signals with CCDF Curves*, Application Note, literature number 5968-6875E.

[6] *Testing and Troubleshooting Digital RF Communications Transmitter Designs*, Application Note 1313, literature number 5968-3578E.

[7] *Fundamentals of RF and Microwave Power Measurements*, Application Note 64-1B, literature number 5965-6630E.

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Related Literature

8560 E-Series Spectrum Analyzers, literature number 5968-9571E.

8590 E-Series Spectrum Analyzers, literature number 5963-6908E.

89400 Series Vector Signal Analyzers, literature number 5965-8554E.

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Generating Custom, Real-World Waveforms for 3G Wireless Applications, Application Note 1298, literature number 5968-8388E.

Wide-Range Sensor Gauges Power of Complex Signals (written by Ron Hogan and originally printed in *Microwaves & RF*, September 1999), literature number 5968-8750E.

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