

Keysight Technologies

Manufacturing Test Considerations for cdma2000® Mobiles

A comparison of cdma2000 and cdmaOne test

Technical
Overview



Unlocking Measurement Insights

Introduction

Now that cdma2000-compatible mobile phone designs are starting to ramp up for volume production, many mobile manufacturers are deciding what needs to be implemented in their production process to incorporate cdma2000 mobile functionality. The majority of these manufacturers have existing lines that have been producing TIA/EIA/IS-95-A/B-based CDMA mobile phones for approximately the past year. The new cdma2000 mobile phones, also known as 3GPP2 compliant mobiles, incorporate numerous advancements in spread spectrum technologies. While these mobiles maintain compatibility with the previous 2.5G technologies, such as TIA/EIA/IS-95B, and while there are many similarities between cdmaOne and cdma2000 compliant mobiles, there are also significant differences in their physical RF implementations.

At first glance, the two technologies may appear similar enough to assume that successful testing of one technology implies proper functionality of the other. To some extent, this may be true, however when it comes to providing reliably tested functionality across the product's entire feature-set, this becomes a high-risk position for mobile manufacturers to take. Since the mobile manufacturing market is highly competitive when it comes to launching a mobile phone into a given service market, quality, in addition to the cost of the mobile device, is a key differentiator when it comes to the service provider's choice for deployment. Often, manufacturers avoid taking risks in verification of a mobile's functionality, especially regarding a newly emerging technology. Providing a quality product to the service market is a competitive necessity.

It has been suggested that cdma2000 functionality can be inferred from the testing and verification of cdmaOne functionality. This is a risky assumption based on the following reasons:

- The physical RF channel structures in most cases is different.
- Modulation schemes vary between the cdma2000 radio configurations (RC) and cdmaOne modulation structure.
- cdma2000 has a much higher peak-to-average ratio when fully channelized.

The differences between the two technologies are very significant when it comes to accurately testing the functionality of the device, specifically if the cdma2000 mobile design is marginal in specific RF performance. For example, the mobile's transmit quality may be inaccurately verified by assuming that the previous factors are similar between cdma2000 and cdmaOne.

This paper reviews and compares the differences between the modulation schemes used in cdma2000 and cdmaOne, proving that inferring cdma2000 functionality from cdmaOne testing may not be the best choice for mobile manufacturers. cdma2000 test considerations will also be covered.

Modulation differences

In order to understand the implications of inferring cdma2000 RC 3, 4, and 5 functionality from testing either cdmaOne or cdma2000 RC 1 and RC 2, the differences between their respective modulation methods must first be discussed.

Service providers are concerned about capacity of their networks and battery life of the mobile device. Consequently, there are tight controls and specifications for the power transmission and modulation quality of CDMA mobiles. CDMA technology utilizes a wide bandwidth, spread spectrum technology that uses processing gain to address the issue of capacity, while lowering the average transmission level of individual mobile users. Due to this type of coding scheme, the peak-to-average ratio of the CDMA waveform is substantially higher as compared to other technologies, such as the relatively constant RF envelope of GSM. This fact has implications on the design of the mobile phone. The higher the peak-to-average ratio of the waveform, the more headroom and dynamic range the transmission amplifier has to incorporate. This directly relates to the cost of the mobile phone. Various approaches have been developed to address the issue of high peak-to-average ratio and the dynamic range transition through the I/Q zero origin.

cdmaOne modulation

cdmaOne technologies incorporate an offset quadrature phase shift keyed (OQPSK) approach to deal with the transition of the reverse link through the I/Q zero origin. OQPSK introduces a half-chip delay in the Q channel as compared to the I channel. This causes the waveform to change amplitude and phase on the I axis first before changing amplitude and phase on the Q axis, eliminating the overall transition of the waveform through the I/Q origin, and subsequently minimizing dynamic range requirements of the power amplifier. This approach is primarily successful due to two facts:

1. The I and Q channels contain the same symbol data, both with common gain settings. These identical symbol streams are isolated by individually mixing them with unique short code sequences.
2. Only one channel, the traffic channel, is transmitted on the reverse link.

These two points ensure that the I and Q symbol data are of the same amplitude, which provides a desired balanced transmitted I/Q waveform for cdmaOne mobiles.

cdma2000 modulation

cdma2000 technology is a 2.5G cellular technology that addresses the need for high speed data while providing deployment convenience through maintaining the 1.228 or 8 mcps spread rate. This allows cdma2000 to be deployed on existing cdmaOne networks.

In order to address the I/Q imbalance, zero origin transition (180 degree phase transition), as well as repeated symbol transition (0 degree phase transition) issues of the cdma2000 waveform, a different modulation scheme has been incorporated in cdma2000 devices. This new modulation method is called hybrid phase shift keying (HPSK). This is a variant on a complex modulation scheme that eliminates the transition through the I/Q zero origin on every other chip by using standard orthogonal Walsh codes to designate the particular channels (R-PCH, R-FCH, R-DCCH, and R-SCH0/R-SCH1). Also, specific repeating sequences are used to scramble the signal to produce one of a multiple of ± 90 degree phase transitions. This modulation scheme does not entirely eliminate the zero-origin and repeated symbol transition issues but reduces their number of occurrences. Amplifier compression is still a concern that must be tested. See figures 1a and 1b for a comparison of a cdmaOne reverse channel (using OQPSK) and cdma2000 channel (using HPSK).

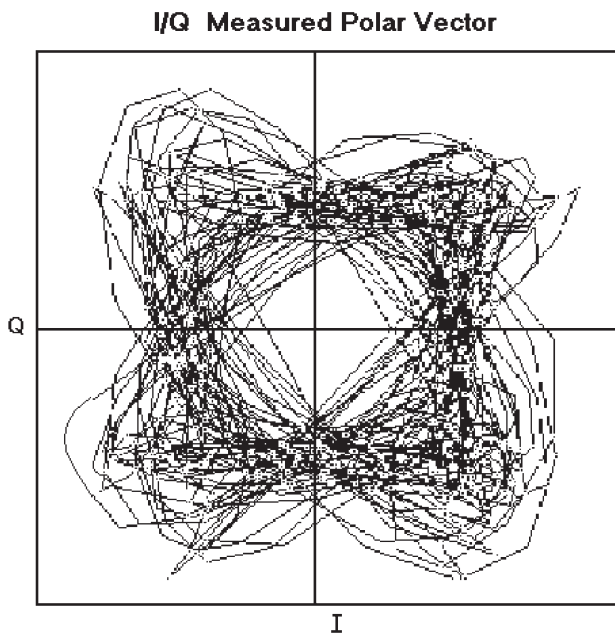


Figure 1a. OQPSK waveform

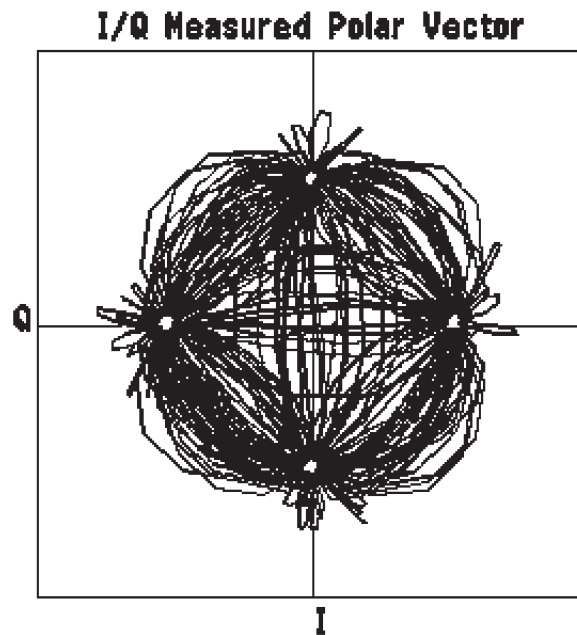


Figure 1b. HPSK waveform (R-FCH in reference to the R-PCH)

Symmetry in the I and Q channels is achieved by the complex scrambling technique used in HPSK. Symmetry is beneficial to both the base station's receiver and the transmission amplifier in the mobile. This ensures that the transmitted waveforms I and Q channel's amplitude and relative phase transition for a particular set of symbols are identical. Complex modulation has the following effect on the transmitted waveform:

- The transmitted waveform amplitude is a product of the individual channel's I and Q amplitudes.
- The transmitted waveform's phase transition is a sum of the individual channel's I and Q phases.

Error mechanisms associated with generation of complex scrambling has the effect of imposing inaccuracies and noise into the opposing axis. If the I channel has noise due to phase instability or spreading inaccuracies, these errors can show up in the Q channel as inactive Walsh channel noise. Amplifier compression or amplitude error will often show up as noise in the active Walsh channel.

Comparing cdmaOne and cdma2000 modulation

There are several significant differences between cdmaOne and cdma2000:

- The cdma2000 reverse link structure incorporates multiple channels, a pilot channel (R-PCH), a fundamental or traffic channel (R-FCH), and the option for up to two supplemental channels (R-SCH0/R-SCH1) and one dedicated control channel (R-DCCH) that can be used for obtaining higher reverse link data rates.
- These multiple channels all can have varying power levels, which, when summed together, dramatically complicate the overall transmitted waveform, causing a much higher peak-to-average waveform.
- The I and Q channels no longer send the same data. Different channels are independently assigned to either I or Q. This is a true QPSK based modulation scheme.
- I and Q data is further isolated by assigning each channel a specific I or Q code with variable lengths (spread factor) depending on each channel's data rate.

These differences preclude the use of OQPSK modulation in cdma2000 devices. Zero origin transitions, repetitive symbol transitions, and unbalanced I and Q channel modulation become issues when multiple channels are individually transmitted on the I or Q channels.

It should be clear from this point on that cdma2000 and cdmaOne modulation structures are entirely different and cannot be assumed to have similar test responses. By testing the transmission quality of OQPSK modulation, the transmission quality of HPSK cannot be inferred to be similar. They are entirely two physically different structures in the device, each with radically different characteristics on similar baseband signals.

For a more detailed discussion of the modulation theory of HPSK and the differences between the modulation schemes of cdmaOne and cdma2000 refer to the following materials:

- Designing and testing cdma2000 mobile stations application note #1358
- HPSK spreading for 3G application note #1335

Key cdma2000 transmitter tests

HPSK's modulation benefits for reducing the peak-to-average ratio of the waveform are reduced when the reverse channel incorporates all possible channels (R-PCH, R-FCH, R-DCCH, and R-SCH0/R-SCH1), especially when the supplemental channels are transmitting at high data rates. This is due to the standardized Walsh spreading sequence of the second supplemental channel. It does not incorporate similar consecutive symbols. Potential for transitions through the zero origin of the I/Q modulator would be much higher in this case, even to the point that the advantages of HPSK are not realized. Even though this would occur in a small percentage of the possible user cases, this is the worst-case situation for the transmitter of the mobile. Amplifier compression is likely to occur. It is this worst case for which the power amplifier's gain range (or headroom) must be designed. Dependent on the mobile implementation, testing for the worst-case scenario is important when considering the accuracy of calibration and verification in the manufacturing process.

Following are three key tests that must be used to accurately verify the performance of a cdma2000 transmitter. TX spurious emissions, multi-code rho, and code domain power.

TX spurious emissions

Typically TX spurious emissions, also known as adjacent channel power (ACP), have not been tested in production of cdmaOne mobiles. However, due to the nature of the cdma2000 waveform having potentially large peak-to-average ratios, especially when the reverse link is transmitting multiple channels at high data rates, the amplifier has more potential for becoming compressed. This in turn will produce increased power leakage into the frequencies outside of the channel, greatly effecting the capacity of adjacent channels that might be utilizing cdmaOne technologies or other cdma2000 deployments. Service providers are especially concerned with spurious emissions that may end up in their competitors' frequency blocks. Service providers may rely heavily on this measurement for determining cdma2000 mobile quality as cdma2000 networks are deployed and populated.

TX spurious emissions (Continued)

Spurious emissions are primarily due to the effects of large peak-to-average ratios causing compression in the mobile's power amplifier. The peak-to-average ratio of a traffic channel in cdmaOne and a R-FCH and R-PCH only implementation in cdma2000 cannot be directly compared. If you were to compare the peak-to-average ratios of these two waveforms, the cdma2000 waveform would actually be about 0.5 dB lower than that of the cdmaOne waveform. This difference proves little about the functionality of the mobile when it is transmitting multiple channels, especially when transmitting one or both supplemental channels.¹ See figures 2a and 2b for the complementary cumulative distribution function (CCDF) comparison of a cdmaOne reverse channel to a fully loaded cdma2000 reverse channel at high data rates. As can be seen by figure 2b, the cdma2000 waveform, with R-PCH, R-FCH, and R-SCH0, has a 2 dB higher possible peak-to-average ratio level as compared to the cdmaOne waveform.

1. In order to initiate a R-SCH0/R-SCH1 or R-DCCH on the reverse link, test modes within the phone will have to be initiated.

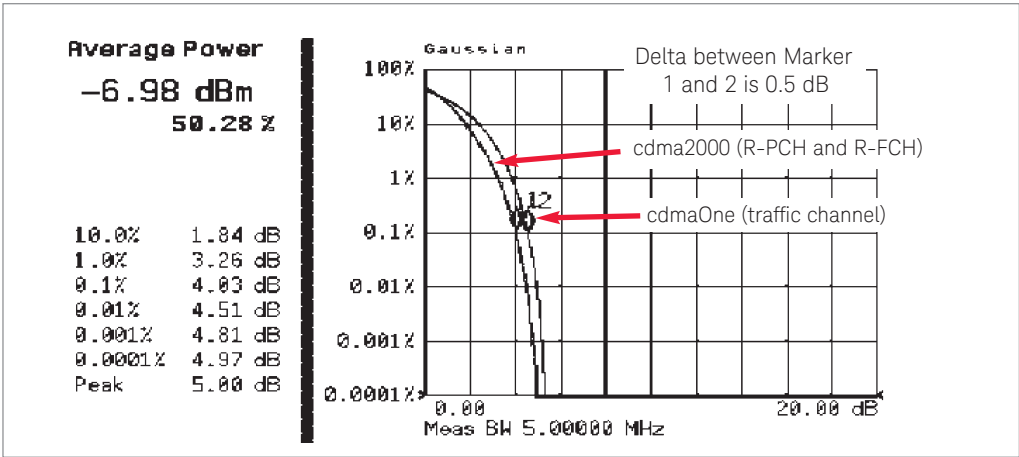


Figure 2a. CCDF plot of cdma2000 with R-PCH and R-FCH channels as compared to IS-95 with a traffic channel

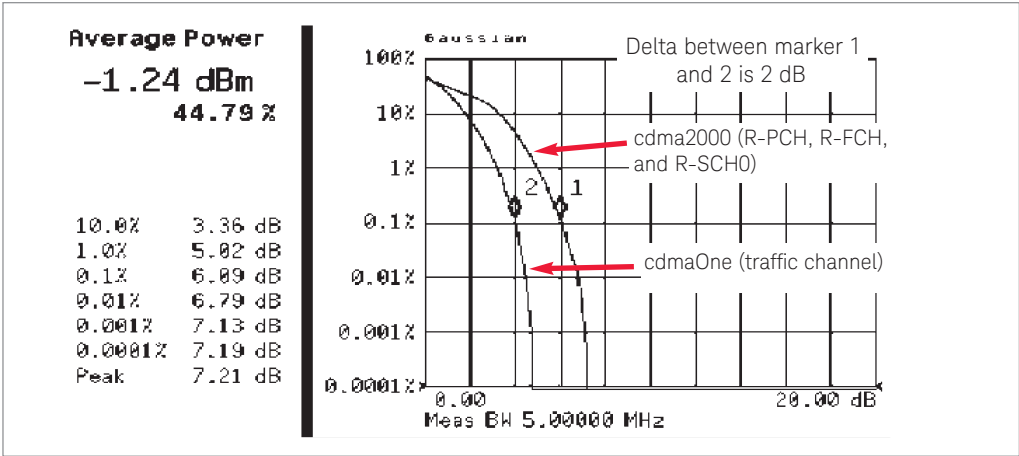


Figure 2b. CCDF plot of cdma2000 with R-PCH, R-FCH, and R-SCH0 channels as compared to IS-95 with a traffic channel

Multi-code rho

Waveform quality, or rho, is the primary test used in manufacturing CDMA mobiles to determine the quality of the mobile's transmitter. Since cdmaOne compliant mobiles only have one channel, the traffic channel on the reverse link, the TIA/EIA/IS-98-A/B (cdmaOne mobile minimum performance standards), only specified this measurement on the traffic channel. The TIA/EIA/98-D (cdma2000 mobile minimum performance standards), specify this test to be performed during a hard preamble handoff where the pilot is the only channel that is transmitted. This raises an issue that the mobile is being tested for transmission quality in a mode that rarely occurs and which is not realistic to the typical waveforms that can impact the capacity of a cdma2000 network.

As a result, Keysight Technologies, Inc. has developed an alternate method of measuring the waveform quality of a cdma2000 mobile phone. This method allows the waveform quality to be determined with all code channels active (R-PCH, R-FCH, R-DCCH, and R-SCH0/R-SCH1). This provides the user with the flexibility to perform concurrent transmitter tests while performing receiver sensitivity tests. In addition, the mobile is tested in a realistic operating mode, with all applicable channels active that would be operational in an active network. This method of determining the quality of the transmitted cdma2000 waveform is the preferred method due to its ability to test in a realistic operating mode, which is with all channels active and at higher data rates.

The TIA/EIA/98-D standards specify a rho limit of 0.944 or 94.4 percent of the power correlated into the appropriate channels. There are various methods of implementing the rho measurement. The basic concept is that the reverse channel waveform is sampled over a given period and then demodulated, and then ideally rebuilt as an ideal reference waveform and compared against the original sample. Adjustments are made in amplitude, phase, frequency, and carrier feed-through until the differences between the ideal and actual waveforms are as closely minimized as possible. These adjustments are reported back as additional measurement results for each channel.

The competitive difference in rho implementation is in how far back the decoding process goes. Ideally, if the waveform is decoded all the way back to the raw data bits then, due to processing gain, all errors injected by the encoder, interleaver, spreading process, gain stages, and modulation stages have been eliminated. This would leave the perfect data sequence to rebuild the perfect waveform. In practice, simply decoding back to the interleaver stage would be sufficient to test the transmitter quality variations between individual mobiles.

Multi-code rho (Continued)

If the decoding process goes through the instrument's I/Q demodulation stage only and the reference waveform is rebuilt from there, then there is no visibility to errors that could be introduced in the encoder, interleaver, spreading process, and gain stages. Spreading and gain calibration stages for each channel are set before the channels are summed together in a cdma2000 reverse signal. Using a measurement method that only partially decodes the reference waveform does not provide complete and realistic data regarding the quality of the cdma2000 mobile's transmitter chain.

The variation in rho measurement implementation in cdma2000 test equipment can be determined by examining the rho measurement range specification of the instrument. If the rho range is specified at 0.9 or above, then the measurement waveform reference is only being built from the I/Q modulator stage; all previous processes are being ignored. Keysight Technologies has specified the rho measurement range to 0.45 that states that the waveform reference has been built from the interleaver stage. This provides much more visibility into the quality of the transmitted cdma2000 waveform. Refer to figure 3 for details regarding the different decoding stages for the ideal reference waveform.

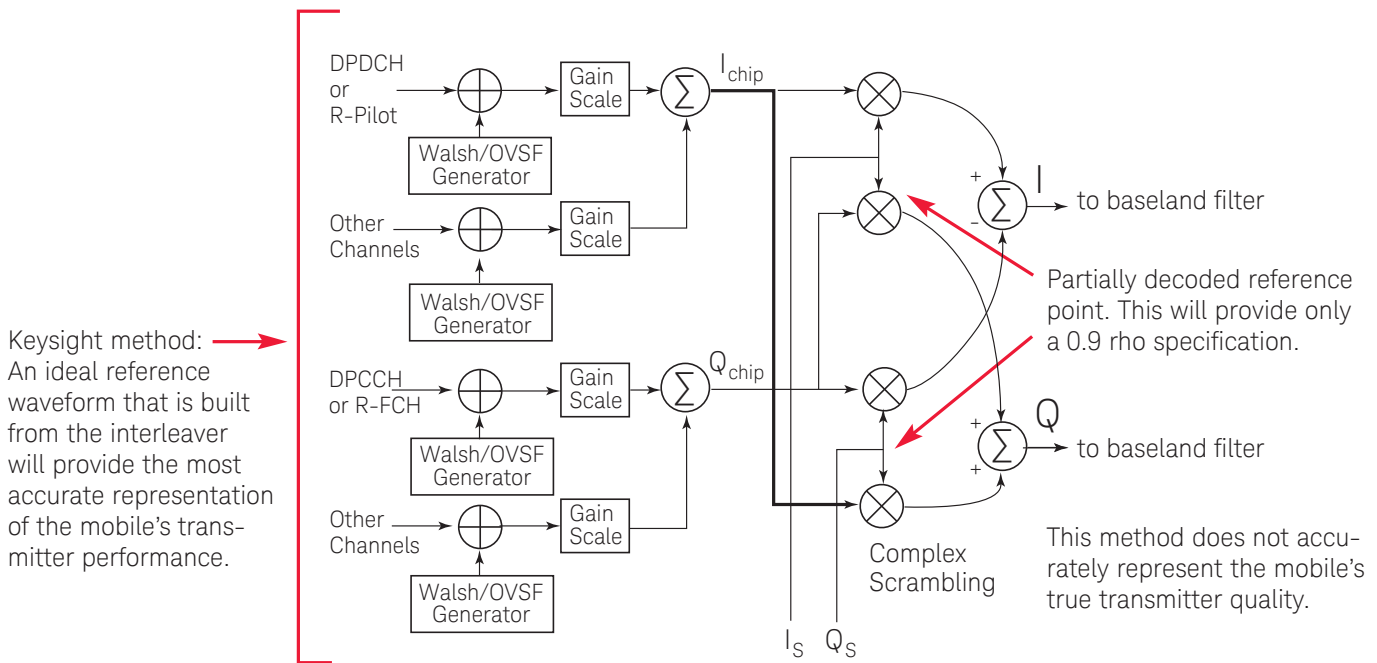


Figure 3. Decoding stages for the ideal reference waveform

Code domain power

TIA/EIA/98-D has incorporated an additional minimum recommended test called code domain power. This measurement is capable of demodulating and analyzing the specific Walsh channels that make up the composite cdma2000 waveform. Due to the complex modulation scheme used in cdma2000 as compared to a BPSK based modulation scheme used in cdmaOne, significant noise in the active, as well as inactive Walsh channels can be detected. As shown in figure 4a, the phase error contribution of the Q channel can impose a noise contribution in the inactive Walsh channels of the opposing I axis. As shown in figure 4b the amplitude error contributes noise in the active Walsh channel.

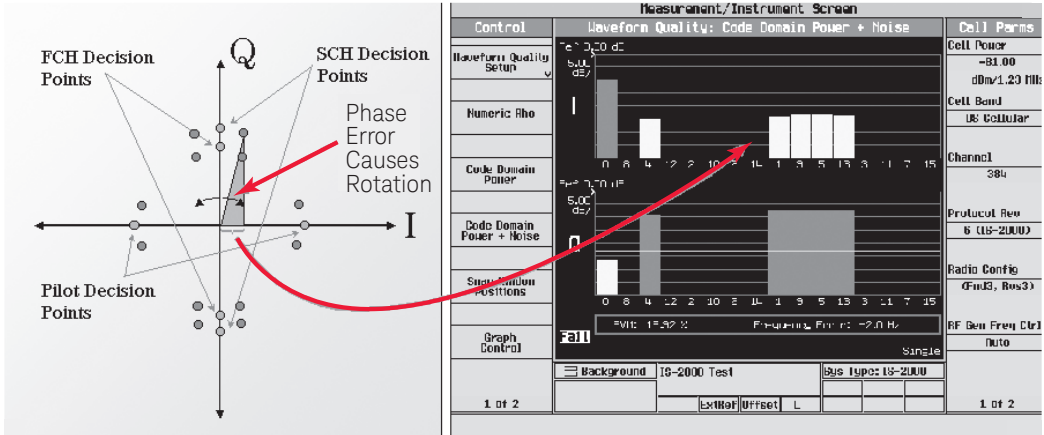


Figure 4a. Phase error contribution to inactive Walsh channel noise

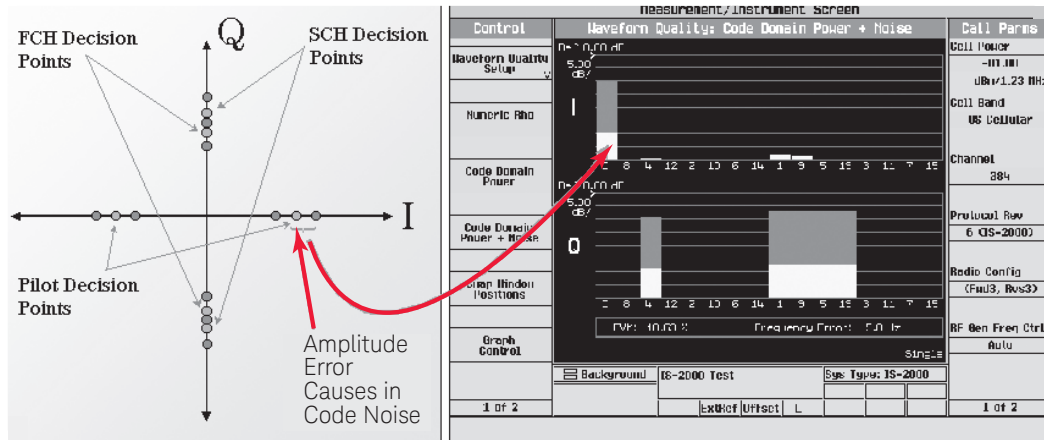


Figure 4b. Amplitude error contribution to active Walsh channel noise

Code domain power (Continued)

Waveform quality is a key measurement for cdma2000 mobiles, but it is not sufficient to fully test the functionality of the cdma2000 transmitter as compared to the cdmaOne transmitter. Simply testing the waveform quality of the cdma2000 waveform, or worse yet, testing the waveform quality of cdmaOne functionality and inferring cdma2000 transmitter quality, will not reveal anything about the noise contributions in and out of the code channel. It is entirely possible to have a passing rho value (0.99 as compared to the 0.944 specification) and still have a code domain noise issue. The TIA/EIA/98-D standards specify that the code domain noise in inactive channels must be 23 dB below the overall power that is transmitted. The primary source for code domain noise, in and out of the active Walsh channels, is from either amplitude error or phase error in the cdma2000 modulated waveform. See figures 5a and 5b for a comparison of the waveform quality passing value and the failing code domain power measurement.

Amplifier compression from high peak-to-average ratios and phase errors due to local oscillator (LO) instabilities as well as other modulation imbalance factors have much higher impact on cdma2000 devices as compared to cdmaOne devices. Inferring cdma2000 transmitter quality by testing cdmaOne or RC1 and RC2 waveform quality is not a good measure of how the mobile will perform in cdma2000 mode. Therefore, you cannot infer cdma2000 performance based on cdmaOne performance.

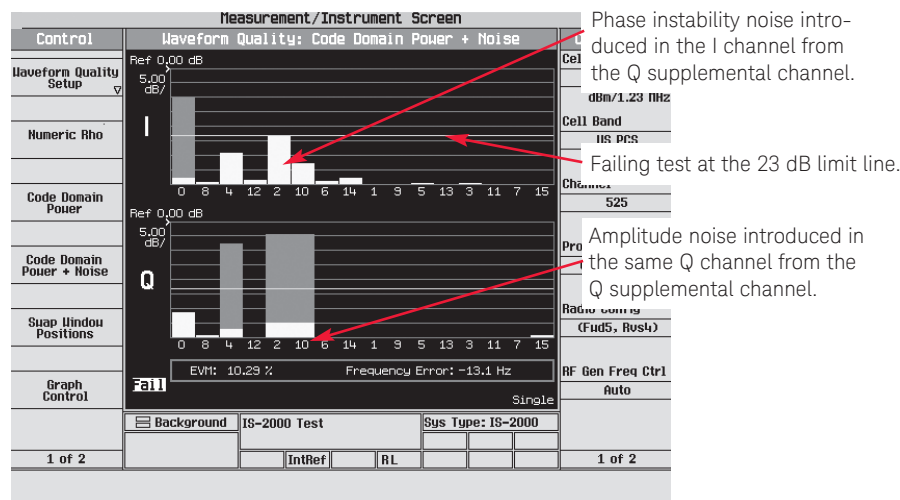


Figure 5a. In-active R-SCH noise failure

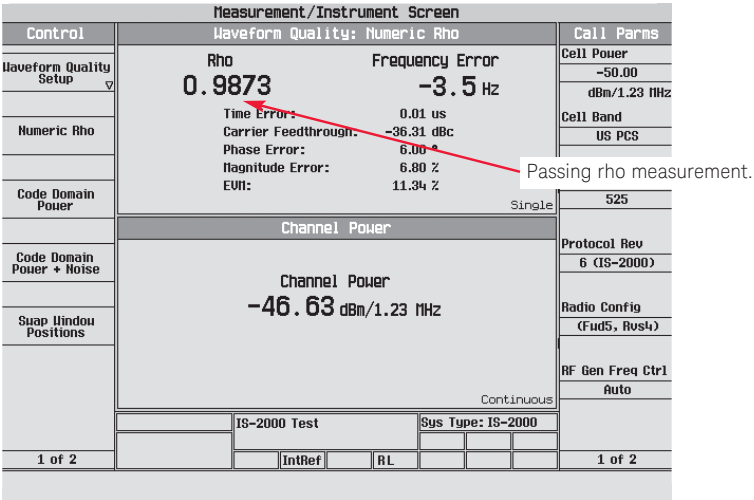


Figure 5b. Passing RHO measurement

cdma2000 receiver and transmitter calibration considerations

Similar to the verification of cdma2000 performance, the calibration of a cdma2000 mobile cannot be inferred by determining the calibration factors, such as maximum power and temperature compensation, from a cdmaOne equivalent transmission or reception.

Maximum power calibration

Now that cdma2000 incorporates multiple channels at high data rates, the high peak-to-average ratio potential increases the inaccuracy of a standard diode power detection method used for cdmaOne measurements.

The desired accuracy for a power detector used for maximum power detection is around 0.2 dB. This is because many service providers require that mobile devices transmit as little power as possible, while still passing the maximum power specification. By calibrating the mobile device's maximum power gain to as close to the lower limit of the specification as possible, battery life is increased and possible noise contributions in neighboring base stations is reduced. The capacity of the network is increased overall. For example, by maintaining a 0.5 dB or better accuracy in the maximum power calibration and verification process, the resolution to which the maximum power can be calibrated and verified becomes at least 0.5 dB. This example takes into account other potential system uncertainties.

Due to the previously stated waveform differences in cdma2000 mobiles, power detectors designed for the cdma2000 waveform differences must be used to provide a comparable level of accuracy in maximum power calibration as compared to cdmaOne.

Other issues to consider regarding the ability to accurately test and calibrate maximum power:

- VSWR specifications for the test instrument as compared to the mobile phone. A seemingly insignificant difference in instrument's VSWR specification of 0.5 percent can improve the overall measurement uncertainty by almost 1 dB.
- VSWR effects are often reduced by the insertion of resistive attenuators into the RF path. The dynamic range of the test set's transmitter and the measurement floor often limit the use of attenuators for particular measurements such as minimum power, dynamic range FER, and range of open loop.

Temperature compensation

Temperature compensation is often used in the calibration process of a mobile device. Due to the high peak-to-average ratio of cdma2000 mobile devices, the power amplifiers used to generate the RF waveforms require more biasing current. This in turn will cause the power amplifier (PA) to heat up differently as compared to a cdmaOne device. Heat generated from the PA causes adjacent components to potentially change their characteristics. Primarily the filters and mixers are subject to variations due to temperature changes.

As stated previously, the cdma2000 implementation has a much higher potential peak-to-average ratio as compared to the cdmaOne implementation. This fact will cause the power amplifier to heat up differently for the various channel implementations as compared to the single traffic channel that is always transmitted by the cdmaOne mobile. Accuracy of the temperature compensation will be degraded by directly inferring cdma2000 calibration factors from the temperature calibration factors of a cdmaOne transmission. It potentially may be observed that the effects of temperature on mixer and filter performance may vary as the transmission channelization of the cdma2000 reverse link changes. A particular temperature calibration for a cdma2000 reverse link with the R-PCH and R-FCH active may not be valid for a cdma2000 reverse link with the R-PCH, R-FCH, R-SCH1, and R-SCH2 active.¹

An assumption that the temperature effects and power transmission accuracy of a reverse link with R-PCH and R-FCH active is the same as a reverse link with all possible channels active may not be correct. Ideally, each possible transmission possibility should be considered individually with respect to temperature compensation. Without considering each case separately, the likelihood that unintended performance at the various channel configurations will become an issue.

The same argument is true for the receiver's temperature compensation. The sensitivity point of the mobile can be different due to the temperature effects on the receiver's front end. This will be especially noticeable if the cdma2000 mobile is marginal in sensitivity, meaning that the actual sensitivity point of the receiver is close to the test specification.

1. In order to initiate a R-SCH0/R-SCH1 or R-DCCH on the reverse link, test modes within the phone will have to be initiated.

Conclusion

At first glance cdma2000 and cdmaOne technologies may seem similar and to some extent this is true. However, when it comes to accurately calibrating and verifying functionality, there are substantial differences that will impact the quality of the mobile if inferences are made based on cdmaOne performance. Inferring cdma2000 functionality based on cdmaOne test processes should not be made due to the following reasons:

- cdma2000 and cdmaOne have different modulation structures which effect the overall transmitted waveform causing variations in peak-to-average power transmission.
- The receiver components have different biasing implementations between the cdma2000 and cdmaOne transmitter and receiver modes. By testing the cdmaOne functionality with its unique biasing, the functionality of the cdma2000 components is not truly determined. This is especially true when it comes to accurately calibrating the receiver and transmitter paths for power level accuracy and temperature compensation.

Due to the difference in the cdma2000 waveform, new measurements must be introduced into the verification process to fully verify the functionality of the individual cdma2000 device. These new measurements are multi-code rho, code domain power, and TX spurious emissions.

A marginally designed cdma2000 mobile with a particular channelization (R-PCH, R-FCH, R-DCCH, and R-SCH0/R-SCH1 active) in which it is being tested may have an effect on the quality of the cdma2000 device that is produced. It is always a good idea to test for the worst case or at least test to the most realistic “real life” scenario.

The following table outlines the key differences between cdma2000 and cdmaOne technologies and the implications on cdma2000 testing:

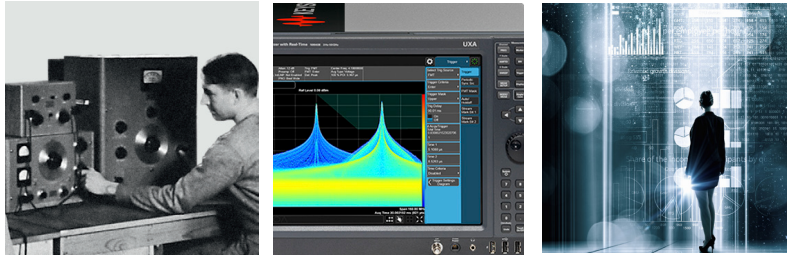
Summary table

Tests/ calibrations	cdma2000	cdmaOne	Implications on cdma2000 test
Modulation	HPSK: - Multiple channelization (R-PCH, R-FCH, R-SCH0, R-SCH1). - Channels have specific Walsh sequences. - Channel's gain can be set independently.	OQPSK: - Only one channel (traffic channel). - Traffic channel is shared between I and Q modulation channels (BPSK implementation).	More thorough testing of the mobile's transmitter is required to verify that mobiles are calibrated and operating properly. Inferences made based on cdmaOne testing is very risky and may introduce costly mistakes that will surface after the mobiles have been deployed.
Code Domain Power (CDP)	Important supplemental test to ensure that excessive noise is not present in active and inactive Walsh channels.	Not defined for IS-95. Only one channel is active on the reverse link.	Without verifying individual Walsh channel noise contribution, leakage from one Walsh channel onto another may effect the ability of the base station to properly decode it, resulting in the base station instructing the mobile to raise the individual channel's power. This will reduce system capacity.
Multi-code rho (waveform quality)	- Due to the standard network operation of a cdma2000 mobile being used with multiple channels, the pilot only waveform quality test does not test the mobile in its typical environment. - The ideal reference waveform should be created from a fully demodulated waveform. Demodulation should go to the interleaver or bit level, not stop short at the intermediate symbol level.	Not defined for IS-95. Only one channel is active on the reverse link.	- A mobile's individual channel amplitude, phase noise, and spreading inaccuracy contributions will not be detected if the reference waveform is defined from the short code only. - Multi-code waveform measurements should be used to verify the full functionality of all functional channels.
TX spurious emissions	- Varying channel implementations with varying data rates will impact the peak-to-average ratio. - The higher the peak-to-average ratio, the higher the probability of compressing the power amplifier (this leads to spurious emissions).	- Less of an impact as compared to cdma2000 since the traffic channel is the only channel on the reverse link. - Consistent peak-to-average ratio.	Mobiles that have excessive ACP will interfere with networks that are implemented within the same channel plans. cdma2000 has been developed to overlay existing networks such as AMPS and cdmaOne.
Maximum power calibration	A cdma2000 specified power detector will take into account the effects of a high peak-to-average ratio.	cdmaOne power detector methods may not be specified for cdma2000 waveforms.	The accuracy of the power measurement method used to calibrate the maximum power of a mobile will limit how close to the lower limit of the maximum power standard that can be achieved. The closer the mobiles can be calibrated to the lower limit, the longer the battery life will be.
Temperature compensation	- Mixers and filters are effected by temperature. The power amplifier will produce varying temperature effects at a given level, based on reverse channel implementation. - Receiver and transmitter calibrations should not be obtained by inference of cdmaOne calibration. - Temperature compensation may vary between cdma2000 channelization (number of channels in the reverse link). - Both transmitter power accuracy and receiver sensitivity will be effected by inaccurate temperature compensation.	Since the reverse channel does not incur variations in peak-to-average ratios, temperature fluctuations in the power amplifier at a given power level will not occur.	Inaccurate temperature compensation will cause the mobile to transmit too little or too much power. If too little power is transmitted, then calls may be dropped around fringe areas of cell sites. If too much power is transmitted, then battery life of the mobile is reduced.

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