Agilent
Understanding Measurement of 1xEV-DO Access Terminals

Application Note 1414

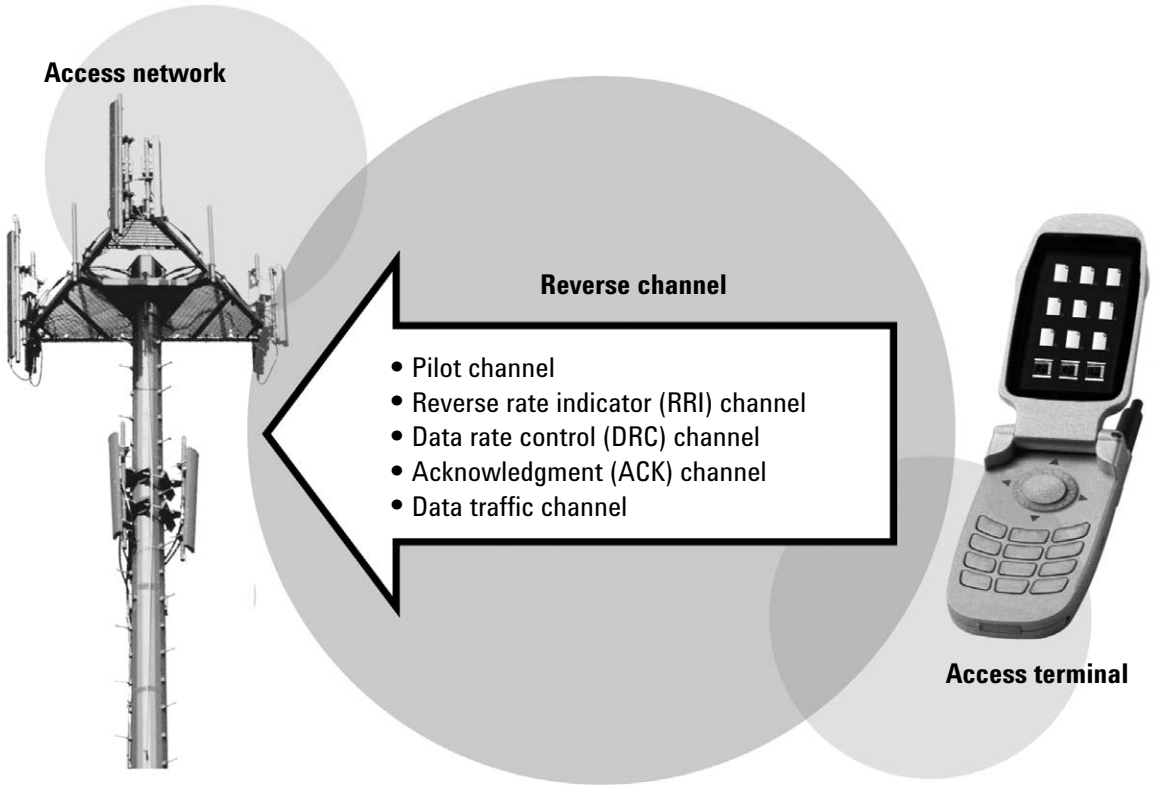

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Table of Contents

Introduction 3
1 Basic concepts of 1xEV-DO 4
1.1 The forward link 4
1.2 The reverse link 8
1.3 Comparison of services with 1xEV-DO, W-CDMA, and cdma2000 11
1.4 Measurement challenges and considerations 12
1.4.1 Phase noise at higher modulation 12
1.4.2 High volume production of dual mode cdma2000/1xEV-DO ATs 14
1.4.3 Test modes for R&D and manufacturing 16
2 Forward link receiver measurements 17
2.1 Basic test practices 18
2.1.1 Test setup 18
2.1.2 Choosing the right equipment 18
2.2 Dynamic channel tests 19
2.2.1 Demodulation of traffic in AWGN 19
2.2.2 Demodulation in fading 20
2.2.3 Power control 22
2.3 Static channel tests 24
2.3.1 Receiver sensitivity and dynamic range 24
2.3.2 Single tone desensitization 25
2.3.3 Intermodulation spurious response attenuation 26
2.3.4 Adjacent channel selectivity and receiver blocking characteristics . . . 27
3 Reverse link transmitter measurements 27
3.1 Basic test practices 27
3.1.1 Test setup 27
3.1.2 Choosing the right equipment 28
3.2 Modulation requirements 28
3.2.1 Waveform quality 28
3.2.2 Frequency accuracy 30
3.2.3 Time reference 30
3.2.4 Code domain power 31
3.3 Output power requirements 34
3.3.1 Max and min controlled output power 34
3.3.2 Open loop power control 34
3.3.3 Closed loop power control 37
3.3.4 Standby output power 38
4 Emissions 38
4.1 Conducted spurious 38
4.2 Radiated spurious 39
4.3 Occupied bandwidth 39
Appendix A – Coding structure for the forward link of 1xEV-DO 40
Appendix B – Band class frequencies 40
Appendix C – Agilent test equipment for testing ATs 41
References 43

Introduction

As the wireless industry moves into its third generation of services, data services are becoming a larger portion of the revenue stream for the industry. Data can be routed through both circuit switched networks and packet switched networks. The most popular data application at time of publication is the short message system (SMS). It is widely expected that with time, most wireless networks will migrate toward an exclusively packet switched network, probably using Internet protocol (IP).

The SMS systems operate on the current circuit switched networks with great efficiency. Since the message length is limited, the data can be sent to a phone in a single message on the control channel or as a message sent concurrently with a voice connection on the traffic channel. However, for applications that require large data packets, such as internet browsing or streaming video, the SMS system can't handle the throughput requirements. The packet data system is an area of major development and is seen as the area with the highest potential for growth.

Packet data systems are different from voice in that, when enabled, the phone is always connected to the network, even if there is no data flow. System resources are assigned only as needed for the data transfer, and may be shared among many users with real time flow control.

One new packet data system is associated with cdma2000, and is officially called High Rate Packet Data System. At the 3GPP2 standards committee, the name used to describe the system was 1x Evolution Data Only, or 1xEV-DO, a name that has been attached to this system throughout the industry. 1xEV-DO is defined in 3GPP2 specification C.S0024 version 3.0, and its US version from the Telecommunications Industry Association (TIA), IS-856. Base stations are called access networks (AN) in the new specification while mobile stations are called access terminals (AT).

1xEV-DO requires a network operator to dedicate a single CDMA channel (1.25 MHz) to the packet data system. This channel cannot carry any voice. The system uses the exact chip rate and emission filters as are used in cdma2000 and IS-95 CDMA systems, so the new system is spectrally identical to the legacy systems.

This application note assumes that you are familiar with CDMA technologies and spreading technologies as used in cdma2000. The focus of this paper is on the conformance measurements required by specification C.S0033 version 2.0, which is the Recommended Minimum Performance Standards for cdma2000 High Rate Packet Data Access Terminals, published by 3GPP2 [3]. This document is not intended to replace the specification; rather it should be used as a companion volume, helping to explain some of the concepts that may be confusing in the specification itself.

The AT measurements are broken up into three sections: forward link (AN transmits to AT) receiver measurements, reverse link (AT transmits to AN) transmitter measurements, and emissions measurements. Differences between 1xEV-DO technology and the older technologies that can carry both voice and data will be discussed, as well as the measurement challenges associated with this new system. A brief introduction to 1xEV-DO technology will begin the paper.

1 Basic Concepts of 1xEV-DO

The main advantage of 1xEV-DO is the data rate it can deliver on the forward link. Under typical conditions, the number of bits per second that can be transmitted from each sector of a cell is up to 10 times the rate of the original IS-95 system, and three times the rate of cdma2000. The reverse link structure is very similar to cdma2000 and can be expected to have similar performance.

1xEV-DO is being deployed by operators who have built a substantial business in data services already. Typically, an operator wants to have a customer base for data that requires above 100 kbps on average from the network, which is about 50 percent of the capacity of a single frequency channel in cdma2000. At this level, it makes economic sense to dedicate the required new CDMA channel to the data only service. Operators in Korea and Japan currently meet this guideline, while those in the US generally do not. That is why, at time of publication, the current interest is centered mostly in Asia.

1.1 The forward link

The fundamental difference in 1xEV-DO and earlier CDMA systems is that the forward link has a major time division multiplexing (TDM) function to it. During data transmission, data is directed to only one AT at a time, using the full power of the AN to allow the highest possible data rate to that one user. There is a dynamic process whereby the AN and other network routing equipment decide which AT will next get the data. While there is TDM, there is no pre-assignment of the time slots; instead, they are dynamically assigned. Figure 1 shows the basic TDM structure of the 1xEV-DO forward link.

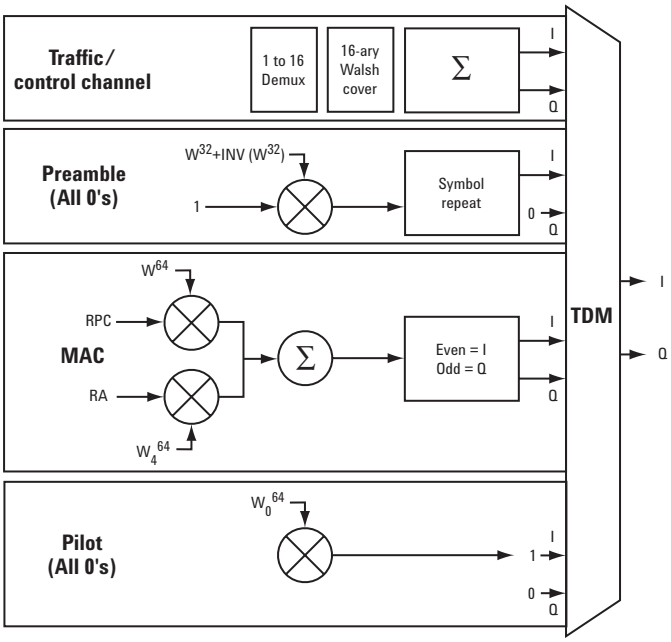


Figure 1. TDM structure of the 1xEV-DO forward link

Of the four TDM channels shown here, only the MAC channel and the control portion of the traffic channel are capable of sending information to more than one AT in parallel. The dominant information on the MAC channel is the Reverse Power Control (RPC) bits, which are sent in parallel, each with its own Walsh cover and mapping onto the I or Q channel. The other three channels have only one code active at a time.

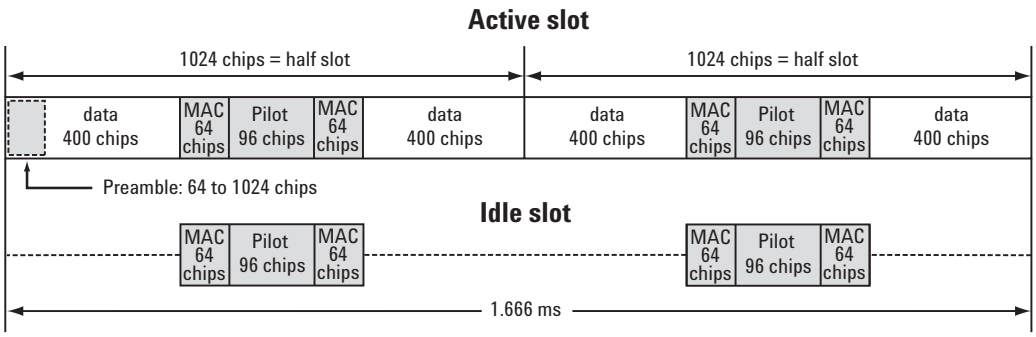


Figure 2. TDM structure for 1xEV-DO active and idle slots

The two TDM structures for the 1xEV-DO forward link are illustrated in Figure 2: one for an active slot when data transmission occurs, and one for the idle transmission, when there is no transmission of data to any user. During idle slot transmission, only the pilot and MAC channels are transmitted, resulting in discontinuous transmission from the AN.

Each AT that is active in a cell will make a request on the network for the highest possible data rate that its current link can support. This request is made in every slot, so the requested rate will change with changes in the quality of the link. Higher data rates require a better link, as less coding will be applied in its transmission. Figure 3 is a graph of minimum signal to noise ratio (S/N) necessary to achieve each rate. At the low rates, there is the expected 3 dB improvement in the link required for each doubling of the data rate. At higher rates, the use of high order modulation and weaker error correction makes the system a little less efficient, with more power needed per bit.

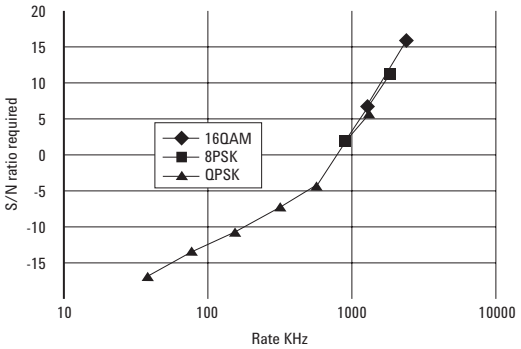


Figure 3. S/N versus data rate

The underlying coding of the traffic channel is quite complex. It can support coding and transmission rates that range from 38.4 kbps at the low end to 2.46 Mbps at the high end. The lower rates are supported by QPSK modulation, while higher rates use 8PSK or 16QAM. The coding structure is shown in Figures 4 and 5.

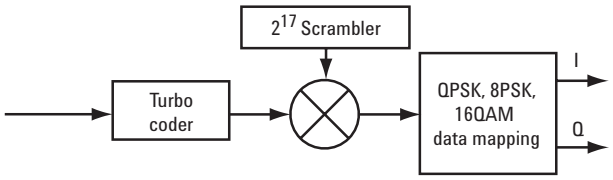


Figure 4. Traffic channel coding for the forward link

The input data is encoded with a turbo coder, which can provide up to 3 dB better performance than the equivalent convolutional encoder used in cdma2000 systems. The data is then scrambled with a code that is unique to each user. This provides voice privacy. The scrambled data then gets symbol-reordered and symbol-permutated in the channel interleaver. The reordering and permutation process differs depending on whether the encoding was 1/3 rate or 1/5 rate. (Less coding equates to a higher end data rate. See Appendix A for details.) Finally the data is mapped into I and Q values. At lower rates, alternate bits map directly into I and Q, which is 2 bits per symbol. For higher rates, the mapping is at 3 bits per symbol, which is 8PSK. At the highest data rates, the mapping is 4 bits per symbol, which results in 16QAM modulation. It should be noted that after modulation, the I and Q signals become signed modulation values.

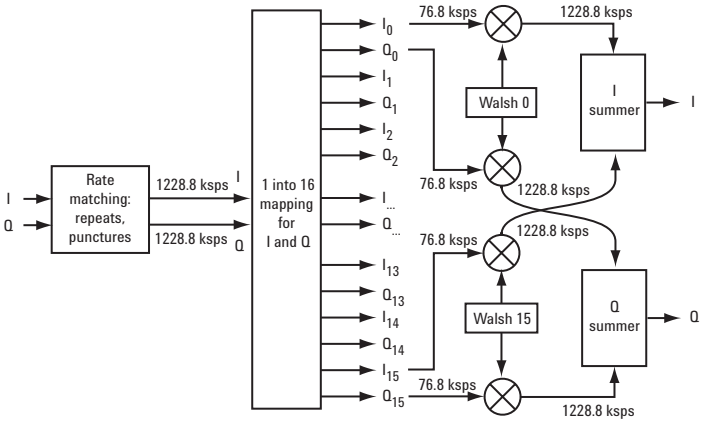


Figure 5. Rate matching and Walsh encoding

The resulting I and Q symbols from the first encode and modulate are then mapped into the process shown in Figure 5. First, there is a rate matching function. In general, this will provide repeats of the input data to the output data so that the output data rate is exactly 1.2288 Msps. The second operation is to demultiplex the I and Q data streams into 16 parallel I and Q data sets. Each of these gets coded with one of the 16 Walsh covers of length 16. Finally all the I and Q signals are added together as the final baseband signals, ready for passing through band limiting low pass filters (the same as is used in IS-95 CDMA) and final I/Q modulation. This final step does not add gain to the system; rather it provides some added time diversity and puts more randomness into the final signal for transmission. This is how it works: the signal starts with one complex channel, which is multiplexed into 16 parallel paths. Each of these paths gets coded with 16 times the gain of the original signal. Since there are 16 of these channels, each with 1/16 of the power, there is 16 times the processing gain but 1/16 the power, for a net unity gain.

Numeric details of the coding rates and rate matching structure are provided in Appendix A for each available data rate.

The performance of a 1xEV-DO system is anticipated at an average rate of about 600 kbps from each sector of each cell in a network. This is about three times better than the cdma2000 forward link.

1.2 The reverse link

The reverse link for 1xEV-DO is very similar to that for cdma2000. There is an imbedded pilot channel, and the system allows for parallel code channels individually on the I and the Q channels of the baseband generation.

There are a few key differences that are important to consider. In cdma2000, there is a dedicated subchannel for fast power control of the forward link. In this system, the network equipment always transmits at full power, so there is no need for power control. Instead, to optimize the link, the system utilizes rate control. Rate control is implemented by adding a dedicated code channel called the data rate channel (DRC). This is transmitted every 1.667 µs from the terminal and tells the network the fastest rate the current forward link can support, and if in soft handoff, which of the available cells has the best link and should provide the data.

Two other channels are added in 1xEV-DO: the acknowledgement channel (ACK), used to acknowledge successful reception of each data packet, and the reverse rate indication (RRI) channel, used by the AT to indicate to the network the rate of transmission of the reverse traffic channel. This allows the AN to decode the reverse transmission without the need for any blind detection of the data rate.

The reverse traffic channel consists of four channels summed together and scrambled with HPSK modulation. The four channels are the pilot/RRI channel, the ACK channel, the DRC channel, and the data channel.

Pilot

In cdma2000, the pilot is punctured in a 3:1 (3 pilot to 1 data) ratio to carry power control bits (PCB). The puncture period is one power control group, or 1.25 µs. The data rate for power control is 16 bits per 20 µs frame. In 1xEV-DO, the puncture pattern is 7:1 on each slot. The underlying data is coded, and the transmission rate is 3 bits per 26.67 µs frame. The pilot is transmitted continuously on the I channel using Walsh cover 0, time division multiplexed with the RRI channel. The pilot/RRI channel coding structure is shown in Figure 6.

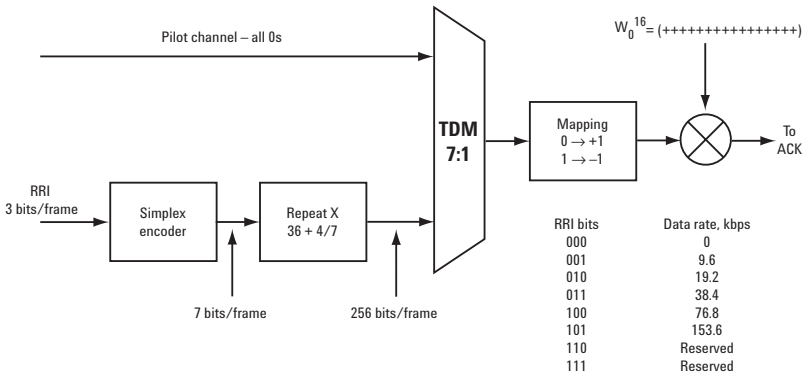


Figure 6. Pilot/RRI channel structure

ACK

The ACK channel is transmitted each time the AT successfully detects a frame with a preamble directed to it. It is BPSK modulated, meaning it can have only one of two values indicating a successful reception or an erasure. A 0 bit corresponds to a success (ACK) and a 1 bit corresponds to a failure (NAK). It is transmitted for 1/2 slot on the I channel using Walsh cover 4. The ACK channel coding structure is shown in Figure 7.

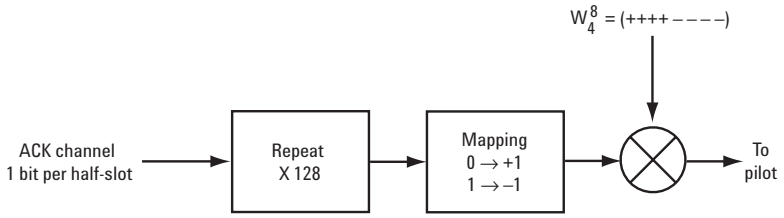


Figure 7. ACK channel structure

DRC

The DRC channel contains a 4 bit word in each slot. This allows for the choice of up to 16 different transmission rates from the serving AN. Different Walsh covers are used to indicate which PN-offset in the active set is preferred for transmission. In other words, which AN should serve the AT. Figure 8 shows the DRC channel coding structure.

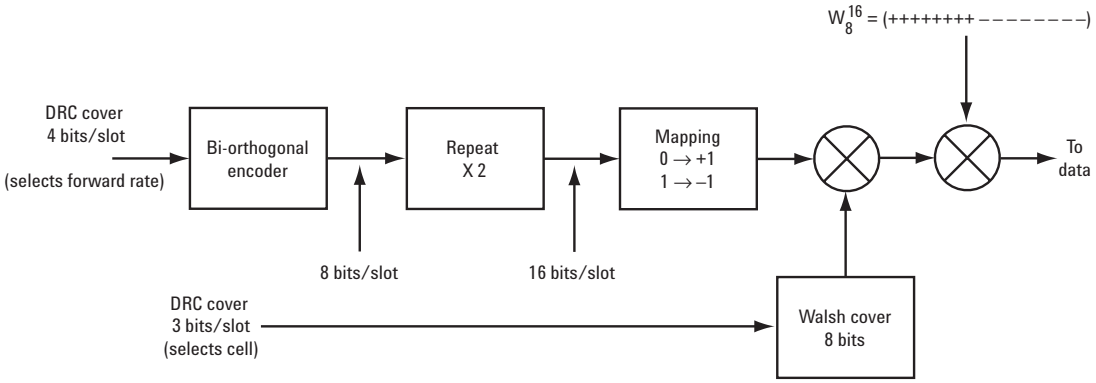
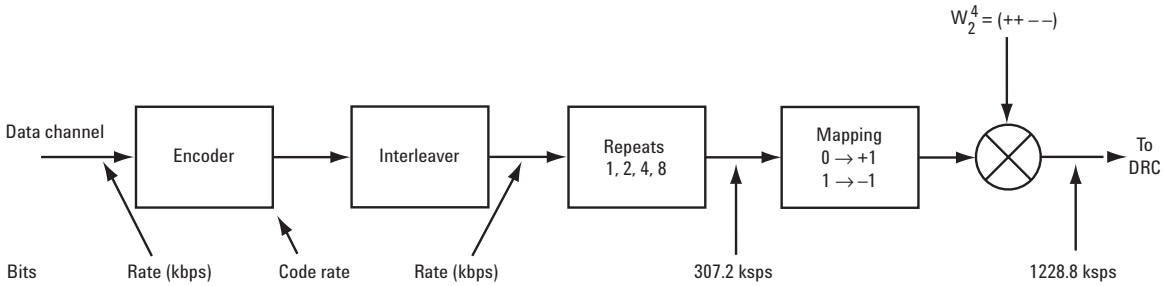


Figure 8. DRC channel structure

Data

The data channel can support five data rates for reverse link transmission, which are separated in powers of two. Four of these rates are achieved by varying the repeat factor. The highest rate uses a turbo coder with lower gain. Figure 9 shows the data channel coding structure.



Bits	Rate (kbps)	Code rate	Rate (kbps)
256	9.6	1/4	38.4
512	19.2	1/4	76.8
1024	38.4	1/4	153.6
2048	76.8	1/4	307.2
4096	153.6	1/2	307.2

Figure 9. Data channel structure

The final coding structure is shown in Figure 10. The channels are added with each other in a manner that maps some into I and some into Q for eventual spreading. The final spreading is very similar to cdma2000, with HPSK employed. The pilot/RRI, ACK, DRC, and data channels together make up the reverse traffic channel (RTC).

The long codes differ somewhat from previous incarnations of CDMA. The long code generator in IS-95 and cdma2000 is based on system time – a continuous clock. In 1xEV-DO, the long code is seeded with a fixed pattern at the start of every pilot sequence, or once every 26.67 µs. There are separate masks for the I and Q long spreading codes.

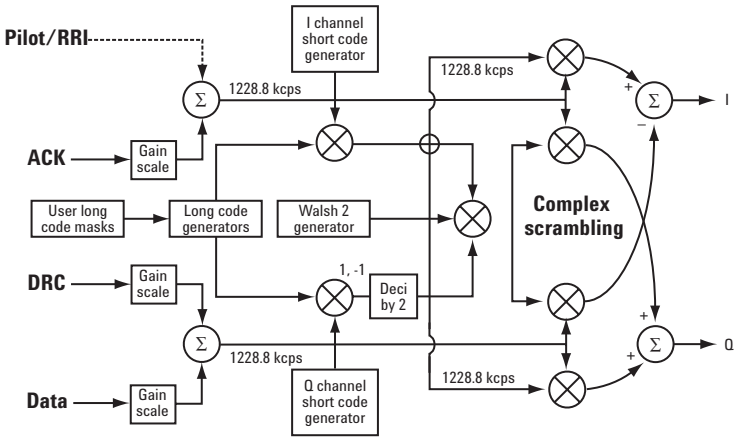


Figure 10. Reverse link combining for 1xEV-DO

The performance of the reverse link is expected to be virtually identical to that for cdma2000.

1.3 Comparison of services with 1xEV-DO, W-CDMA, and cdma2000

W-CDMA is more complex than any variant of the cdma2000 family, but it does have greater flexibility to modify the coding structure to optimally match any set of conditions. Both W-CDMA and cdma2000 have been designed to carry both voice and data, so many of the techniques that allow 1xEV-DO to transmit higher rates are not possible in either system.

The press has always focused on the maximum rate a system can deliver to an individual user under the best of conditions. Usually, this is a perfect link, with no mobility, and no other users. A better figure of merit of a wireless system should consist of two elements: the number of voice users per sector the system can support, and the number of bits per second per sector the system can deliver for data applications. Since 1xEV-DO can only carry data, the first figure is irrelevant for our discussion. When evaluating a system, one needs to consider the system as having continuous coverage over a large area, with numerous cells, each with typically three sectors. And the system needs to have realistic loading and interference.

Under these conditions, it is expected that cdma2000 and W-CDMA will operate approximately equally, when normalized for bandwidth. Many will dispute this with very valid technical arguments that may change capacity estimates by 10 to 20 percent. The statement of equality is considered broad enough to allow for these differences and still be considered the same.

The capacity of the 1xEV-DO system has been modeled and tested extensively. It is estimated that it will deliver three times the bits per second per sector per MHz of either of these systems, but do this without the capability of any voice.

1.4 Measurement challenges and considerations

1.4.1 Phase noise at higher modulation

As shown in the preceding section, 1xEV-DO signals can be sent at data rates much higher than the theoretical limits of cdma2000, and in order to achieve these rates, higher order modulation schemes must be utilized. There is a downside to this situation, in that the design requirements for the AT receiver are more complex. A 1xEV-DO AN must always transmit at the same constant power, whether transmitting at QPSK, 8PSK, or 16QAM. QPSK modulation consists of four constellation points (2 bits per symbol), 8PSK uses eight constellation points (3 bits per symbol), and 16QAM uses sixteen constellation points (4 bits per symbol). Since the higher modulation schemes operate with more bits per symbol than the traditional QPSK, and thus have to squeeze in more constellation points under the same power constraints, their constellation points are closer together in amplitude. Thus, the effects of a given noise source will have drastically different impacts on the successful recovery of a given modulated signal, depending on which modulation scheme that signal utilizes. A source of noise that may have been an insignificant interference to QPSK could completely debilitate a 16QAM-modulated signal, causing the receiver to detect an incorrect symbol. Also, because higher modulation schemes use more constellation points, there is a higher incidence of two-sides decision regions, where the receiver essentially must make an educated guess on which value is correct.

Overall noise can be comprised of many contributing noise sources, with each source interfering constructively or destructively with the overall waveform. Some common sources of error are:

- static amplitude error-characterized as a level offset or modulation DAC level inaccuracy
- random or Gaussian noise distribution – usually caused by random interference or reception within the noise floor of a receiver or wide-band signal interference
- random phase error-caused by instabilities in the receiver's or transmitter's local oscillator (LO), inconsistent automatic gain control (AGC) tracking, and amplifier non-linearities

Of these errors, phase error (or phase noise) can be particularly tricky for designers of CDMA devices, especially devices that employ different modulation schemes. A comparison of the effects of phase noise on different modulation schemes can be seen in Figure 11. On the left is an example of a received QPSK signal, and on the right is an example of a 16QAM signal. In both cases, the arrow pointing to the black dot is the phasor for the ideal symbol sample point, while the arrow pointing to the shaded circle is the phasor for the actual received symbol sample point. The difference in the angle between the two arrows is the phase error. (The example shows no amplitude error.) Z(t) on the vertical axis shows the probability of detecting the correct I value, correct meaning the identical value to what was sent by the transmitter. Z(t) on the horizontal axis shows the probability of detecting the correct Q value.

Note that the ideal symbol points (the reference values) on the constellation correspond to intersections of regions of maximum probability, where Z(t) reaches a peak. Halfway between regions of maximum probability is the decision line, where Z(t) reaches a trough. The closer the actual received value is to a decision line, the more likely it is that the detected symbol is incorrect, since at this point the detected signal is as likely to be the value below the line as it is to be the value above the line. Any signal on the extreme ends of the modulation range (near an ideal symbol location) can be inferred with near certainty as opposed to a value on a decision boundary (exactly halfway between two ideal symbol locations). Since QPSK has only one decision boundary per channel, while 16QAM has three, it follows that 16QAM has a much greater possible number of occurrences where errors could theoretically result. To illustrate, if we restrict ourselves just to looking at points where Z(t) is maximized on one axis and minimized on the other, we find four such points in the QPSK model (two decision lines multiplied by two I and Q values) and 24 on the 16QAM model (six decision lines multiplied by four I and Q values).

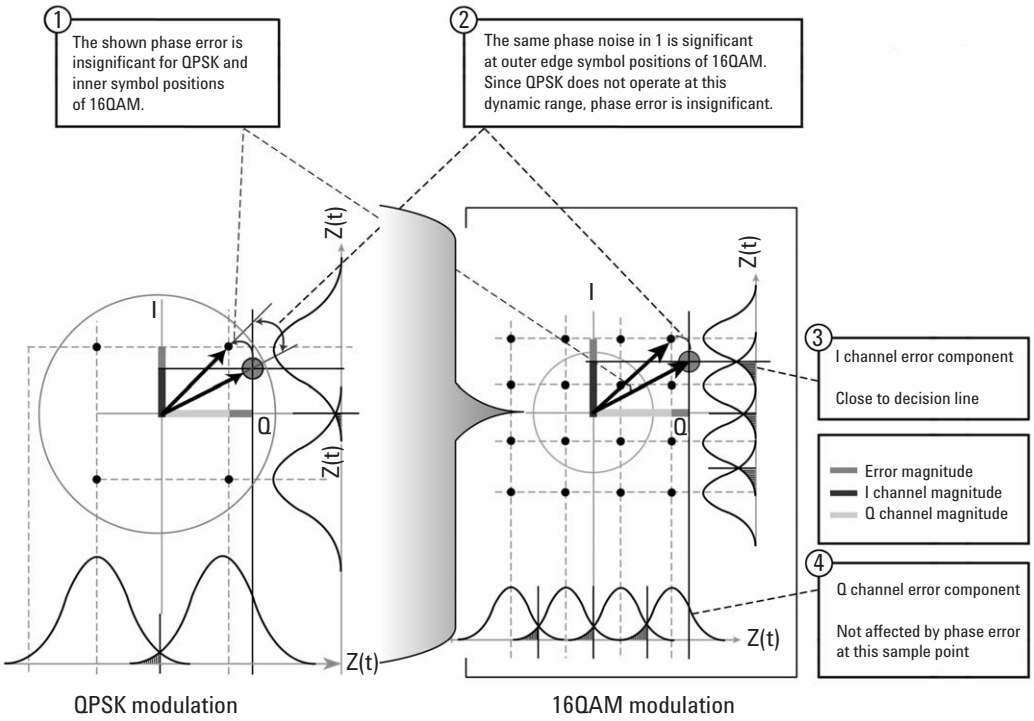


Figure 11. Comparison of phase noise impact on QPSK and 16QAM modulation

Also, because the reference points on the 16QAM constellation are set closer together, a given phase noise has much more impact than in the case of QPSK, where the constellation points are set closer to the origin. It is thus very likely that a given noise source could fall well within acceptable bounds for the QPSK model, but could cause the exterior symbol points of a 16QAM modulated signal to incur errors over 50 percent of the time.

So what is a device designer to do when incorporating several different modulation schemes, each with different noise profiles, into one wireless appliance? There are two choices:

- keep the dynamic range of the receiver/transmitter the same and lower the noise contributions of the system to fall within acceptable bounds for the worst-case scenario. In the case of 1xEV-DO this would be the reception of the 16QAM-modulated signal.
- proportionately increase the level of the received signal (at the LNA, for example) to allow for comparable noise tolerance at different modulations.

When testing a 1xEV-DO device, it is not necessary to test the complete set of possible data rates. It is imperative, however, to at least test the most stringent case, which is 16QAM modulation. The cdma2000 or QPSK modulation modes are considered a subset of the 16QAM superset. It can be assumed that if the noise contribution of a 16QAM signal is within specification, it will be well within specifications for 8PSK and QPSK modulation modes. The opposite is not true. Assuming 6QAM functionality from QPSK results could lead to failure. See Section 1.4.2 for more information on testing dual mode devices.

1.4.2 High volume production of dual mode cdma2000/1xEV-DO ATs

Often in production test processes the thoroughness with which a device is tested must be weighed against the time it takes to perform a set of tests. This becomes especially true when devices incorporate multiple modes of operation, as is the case with cdma2000 and 1xEV-DO dual mode ATs. (Since 1xEV-DO does not incorporate the capability to transmit voice, most wireless devices produced will be dual mode with cdma2000 functionality.) It was shown in the previous section that testing only the low data rates of a dual mode device could lead to failure at higher data rates. Phase noise that may be insignificant in a cdma2000 receiver can become a significant issue with reception of a 1xEV-DO transmission at higher data rates, due to the angular variance that is present farther from the origin of the I/Q modulation plain. However, testing every function of a multiple mode device also isn't feasible, due to time and cost constraints. In a high volume production environment, every second counts.

If a manufacturer has confidence in a device's functionality or can verify performance of similar operations in pre-production, elements of test can be eliminated or can be assumed adequate based upon similar test points. For example, testing the speaker's functionality at multiple transmission channels is not needed. The manufacturer can assume that if it works on one channel it will work on all channels. This is an obvious decision, but it can be compared to less obvious decisions regarding the dual mode operations of a cdma2000 and 1xEV-DO ATs.

One area of similarity is the transmitter of the cdma2000 and 1xEV-DO modes. Both transmission modes are virtually identical and are often driven by the same components at the RF level. An assumption can be made that if the transmitter of the 1xEV-DO mode is within specifications, the cdma2000 transmitter will be within specifications as well. The calibration and verification process of transmitter levels, as well as transmit quality, can be assumed one from another. The actual level calibration, performed at one mode, should also suffice for both transmit modes.

The receivers of the cdma2000 and 1xEV-DO modes are not quite as similar. At first glance a decision to test both modes might be made simply because the reception of the forward link is much different in each. In actuality the need to test the cdma2000 receiver may be eliminated by assuming the 1xEV-DO receiver will perform similarly to the cdma2000 receiver while transmitting at rates that use QPSK (38.4 to 1228.8 Kbps). At the same time, the 1xEV-DO receiver requires testing at the more stringent data rates using the 8PSK and 16QAM modes. The minimum performance standards require that dynamic range be tested at a rate of 2457.6 Kbps, which is the reception of a 1xEV-DO 16QAM waveform.

Setting aside the fact that 1xEV-DO receiver performance must be tested in production at higher data rates, there is a noticeable advantage to testing the 1xEV-DO receiver performance rather than the cdma2000 receiver performance. This advantage is in the potential for dramatic speed improvements of packet error rate (PER) testing over frame error rate (FER) testing. Typically with CDMA based functional testing, the most time-consuming production tests are receiver sensitivity and receiver dynamic range because of their dependence on a frame rate of 20 msec for cdma2000. In order to ensure acceptable confidence in the receiver's performance at a given reception level, a minimum of approximately 300 to 600 frames is required to be tested. This translates to a minimum of 6 to 12 seconds per test. If the test is operating at the threshold of the coding recovery or error correction capability, many more frames may be required to gain a reliable FER result tested with the standard 95 percent confidence.

Due to the packet structure of the 1xEV-DO data transmission on the forward link, the receiver performance can be tested using PER much faster than the traditional FER. The 1xEV-DO packet structure varies depending on the data rate at which the data is transmitted. See Appendix A for a table that shows the 1xEV-DO packet structure for different data rates. A packet can be sent in as little as 1.67 µs or as much as 106.6 µs. Since a frame in cdma2000 is 20 µs long, the following ratios of frame speed versus packet speed can be calculated for different data rates. See Table 1.

Table 1. Comparison of measurement speed between cdma2000 and 1xEV-DO

Modulation rate	Packet/frame speed comparison	Comments
16QAM @ 2457.6 Kbps	12 times faster	Standard Dynamic Range Rate setting
QPSK @ 307.6 Kbps	6 times faster	Standard Receiver Sensitivity Rate setting
QPSK @ 38.4 Kbps	1.33 times slower	—

Furthermore, additional reduction in test processes is possible by assuming that packet error rate (PER) measurements performed at higher data rates utilizing 16QAM modulation modes will test at a more stringent level than that of QPSK and 8PSK. If the receiver has adequate margin and passes with acceptable PER performance at higher data rates, then the lower data rates should pass as well. Therefore, instead of testing full functionality of two modes, it should be safe to assume that the parametric test process for a cdma2000/1xEV-DO dual mode AT can be structured as follows:

1. test only the 1xEV-DO transmitter.
2. test the 1xEV-DO receiver sensitivity using QPSK at a rate of 307.2 Kbps (potentially test sensitivity at higher data rates to take advantage of packet transmission rate improvements).
3. test the 1xEV-DO dynamic range using 16QAM at a rate of 2457.6 Kbps.

1.4.3 Test modes for R&D and manufacturing

There are different methods for AT verification that are optimized for each particular stage of product development. For testing completed terminals in a production environment, the 1xEV-DO standard requires the use of a static procedure called test application protocol, or TAP.[3] For early design verification and incoming inspection, it is important to verify the terminal's performance in real-life, dynamic network conditions. This is supported by throughput testing using default packet data. These two types of test modes are described in more detail below.

Test application protocol

The network is required to deliver data to the AT only at the requested rate. This does two things: maximizes the rate of transmission and allows the terminal to demodulate only at the requested rate, avoiding what is called blind detection, where the receiver must determine the rate of transmission. Unfortunately, this process of rate selection by the AT inhibits the ability to stress the receiver to measure its performance in less than ideal conditions. Since the AT is designed to only request a rate that can be supported by the current conditions, it will simply request a lower rate as conditions change and the noise is increased. Designers need some mechanism to test the AT's performance for every combination of modulation scheme and data rate, regardless of what it "thinks" the ideal rate is.

Having a test mode defined as part of the industry standards solves this problem. This test mode is called test application protocol (TAP) and may be invoked with messages sent over the air from test equipment that simulates a real network. The TAP has two components, one each for the forward (F-TAP) and the reverse link (R-TAP). The F-TAP is used primarily in receiver test on the terminal; the R-TAP can be used to force different types of transmissions for transmitter test. The operation of TAP is explained in C.S0029, Test Application Specification (TAS) for High Rate Packet Data Air Interface [4]. Figure 12 illustrates the F-TAP slot structure for a 2.4 Mbps transmission.

Physical packets in 1xEV-DO are normally made up of 1024-bit MAC packets. At low data rates, there is a one to one mapping of MAC to physical packets. At high data rates, physical packets incorporate multiple MAC packets for extra throughput. Each physical slot in a 2.4 Mbps signal sent with 16QAM modulation contains four MAC packets of 1024 bits each. This corresponds to one physical packet.

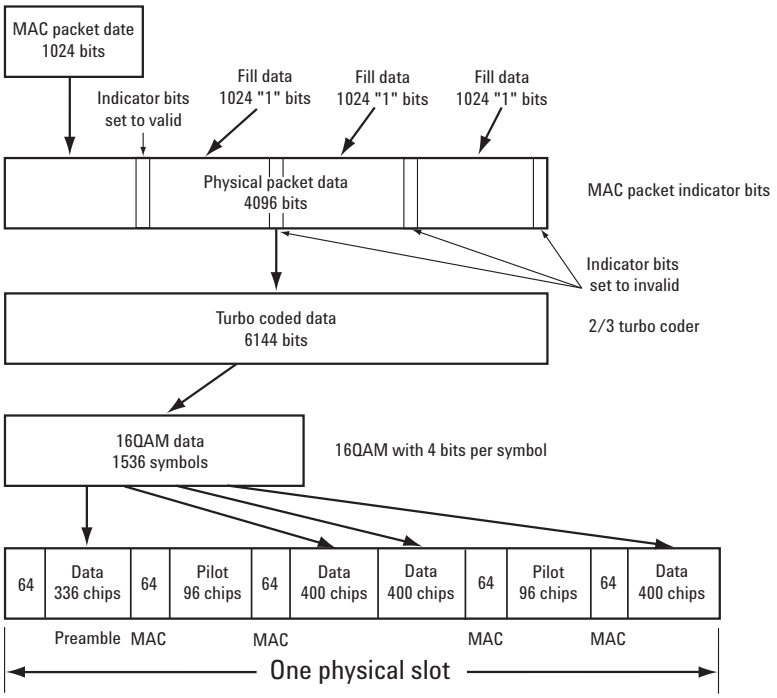


Figure 12. F-TAP slot structure

F-TAP uses forced single encapsulation for PER measurements. This means that each physical packet, regardless of data rate, only supplies one valid MAC packet. This is to ensure that the AT under test has enough computing power to perform the necessary loopback computations at the highest data rate. At 2.4 Mbps, one physical packet includes one MAC packet of "real" data along with three MAC packets of fill data. The entire packet is scrambled, interleaved, and coded, then sent to the AT. The AT receiver then reverses the process, as it would in a call, then performs a PER measurement on the "real" data, which is 1/4 of the raw data received. In essence, F-TAP is a method to test the AT's signal decoding ability without taxing its processing power for test purposes.

As mentioned in Section 1.4.2, this allows the AT to complete a PER test much faster than the FER tests done on a cdma2000 MS. Given that each physical packet is sent in one slot, and there are 16 slots per frame, a total of 16 valid F-TAP packets are sent each frame. This gives a packet transmission rate of:

$$\text{Rate} = 37.5 \text{ frames/second} * 16 \text{ packets/frame} = 600 \text{ packets/second}$$

Compare this to cdma2000, which has a rate of 50 frames/second. 1xEV-DO is 12 times faster!

Default packet data

TAP uses a statically set combination of modulation scheme, data rate, and signal-to-noise ratio to verify receiver performance characteristics like sensitivity and PER in specific network conditions. This is necessary for standards compliance and optimized for speed on a production line. However, it doesn't tell the whole story. To get a good sense of how well the terminal will function in a real-world environment where conditions change, it is critical to also test the chipset's signaling performance. In this case, we want the AT to request a lower rate when noise is increased, and request a higher rate when the link is good, to make sure the receiver is making the right decisions at the right times.

The method for verifying AT performance in dynamic network conditions is to do a throughput test using default packet data. A base station emulator that supports default packet data testing enables the design engineer to establish an RF to IP link and verify everything from physical layer parametric specifications, to MAC layer protocol, to application layer services. Various test scenarios that simulate real conditions are possible, such as:

- How will fading conditions affect the terminal's data rate?
- How long does it take to upload an e-mail with a large attachment?
- How much does network latency affect performance of an online game?

The answers to these questions have a material impact on the type of user experience wireless subscribers are likely to encounter. Service providers need to be confident that ATs connected to their network will be able to maintain high speed data links for their end users. R&D engineers working for major equipment manufacturers need a way to verify AT performance on a test bench before the product is rolled out. Throughput testing that utilizes default packet data is an important tool for verifying value added services like mobile applications, games, messaging services, and Web browsing.

For an introduction to Agilent test equipment that supports both TAP and default packet data testing, please see page 42.

2 Forward Link Receiver Measurements

Digital RF communications systems use complex techniques to transmit and receive digitally modulated signals through the radio channel. The digital radio receiver must extract highly variable RF signals in the presence of interference and transform these signals into close facsimiles of the original baseband information. Because of this complexity, design engineers are challenged to isolate and resolve system problems at every stage of development; the earlier the better. Signal impairments can be traced back to a component, device, or subsystem of the digital RF communications system. Successful receiver design depends on the ability to locate sources of error. For more information on general receiver design troubleshooting and testing techniques, see [2].

Several tests verify receiver performance in the presence of interfering signals. In the 1xEV-DO AT specification, there are two categories: demodulation requirements and receiver performance. The demodulation requirements section includes all the tests that use a channel simulator or fader, an additive white gaussian noise (AWGN) generator, and power control. The receiver performance section tests include sensitivity, dynamic range, single tone desensitization, intermodulation spurious response attenuation, adjacent channel selectivity, and blocking. Since all the aforementioned measurements test receiver performance in some way or another, this document breaks the tests into the more intuitive categories of dynamic channel tests and static channel tests. Emissions testing for receivers is covered in Section 3.

Note: Each test includes a brief explanation of the steps required for setup. These steps are not meant to be exhaustive, but rather to say in a few words what is being done and why. For a detailed step-by-step setup process, see [3].

2.1 Basic test practices

2.1.1 Test setup

Shown in Figure 13 is the basic setup for receiver testing. The two main pieces of test equipment are the AN emulator and the device under test (in this case, a 1xEV-DO AT). No single test uses all of the elements shown. For example, only demodulation in fading uses the channel simulator, and only the handoff tests use the second AN. The figure of merit for most receiver tests is packet error rate (PER).

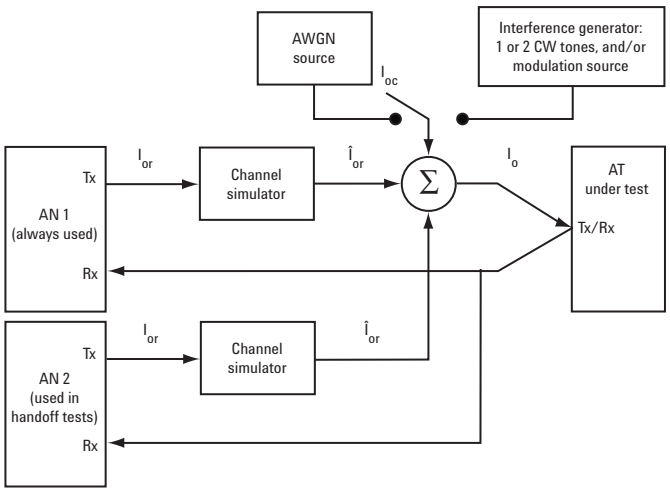


Figure 13. Basic setup for receiver testing. This shows all the necessary elements for receiver testing. This shows signal flow only; additional elements for signal splitting and isolation are not shown and may vary from setup to setup

2.1.2 Choosing the right equipment

The specifications call out minimum performance requirements for the equipment used to perform conformance tests on the AT. The limits suggested in the specifications and outlined in this document for each AT measurement assume the tests are conducted using equipment that meets these requirements.

Transmitter requirements

- Frequency accuracy: ±0.2 ppm
- Frequency resolution: 10 Hz
- Output range: 0 to –110 dBm/1.23 MHz
- Amplitude resolution: 0.1 dB for all channels
- Output accuracy (relative levels between any two channels): ±0.1 dB (external calibration may be required for this)
- Absolute output accuracy: ±2.0 dB
- Minimum waveform quality factor: greater than 0.966 (excess power is less than 0.15 dB)
- Source VSWR: 2.0:1
- ACLR (band class) 6: 80 dB

AWGN generator requirements

- Minimum bandwidth: 1.8 MHz
- Frequency resolution: 1 kHz
- Output accuracy: ±2 dB for outputs greater than or equal to –80 dBm/1.23 MHz
- Amplitude resolution: 0.1 dB
- Output range: –20 to –95 dBm/1.23 MHz

CW generator requirements

- Frequency accuracy: ±1 ppm
- Frequency resolution: 100 Hz
- Output range: –50 dBm to –10 dBm, and off
- Output accuracy: ±1.0 dB for above output range and frequencies
- Amplitude resolution: 0.1 dB
- Output phase noise at –20 dBm power:
  - –144 dBc/Hz at a frequency of 1 GHz as measured at a 285 kHz offset (for band classes 0, 2, 3, 5, 7, and 9)
  - –144 dBc/Hz at a frequency of 2 GHz as measured at a 635 kHz offset (for band classes 1, 4, 6, and 8)

2.2 Dynamic channel tests

2.2.1 Demodulation of traffic in AWGN

Demodulation of forward traffic channel in AWGN is arguably the most important receiver test, for it tests the raw decoder ability of the baseband ASIC of the AT. This test evaluates how well the AT demodulates the forward traffic channel in the presence of noise, or basically how well it extracts the desired signal from the unwanted noise.

In this test, only the AWGN source is used from the setup shown in Figure 13; there is no fading or CW interference. The AWGN source simulates the power coming from surrounding cells in an actual system. There are three important settable parameters in this test: $\hat{I}_{or}$, I_{oc}, and data rate. $\hat{I}_{or}$ is the received power spectral density of the forward channel as measured at the access terminal antenna connector, normalized to the CDMA bandwidth of 1.23 MHz. I_{oc} is the power spectral density of the AWGN source as measured at the access terminal antenna connector. E_b/N_t is the ratio of the combined received energy per bit to the effective noise power spectral density for the forward traffic channel at the AT antenna connector. In simpler terms, $\hat{I}_{or}/ I_{oc}$ is the signal to noise ratio found at the AT's antenna. E_b/N_t is the signal to noise ratio with allowances added for coding gain and traffic channel duty cycle.

To prepare the measurement, follow the steps outlined below. For each data rate, a PER is calculated. The specification sets limits for what the PER result must be under, and what the PER result should be under for best performance at 95 percent confidence level with a specified E_b/N_t. The value for E_b/N_t must be within ±0.2 dB of the value specified in the specification. Note that E_b/N_t is not a settable parameter itself; rather it is calculated from the other settable parameters defined above. For a detailed listing of limits for each test, please see Section 3.1.1.2.1 in [3].

Test setup

1. Connect the AN and AWGN to the AT.[1]
2. Set the AN forward packet activity to 100 percent.
3. Set the Control Channel Data Rate to 38.4 kbps.
4. Set Pilot Drop to –14 dB.
5. Set up a test application session and open an F-TAP connection.
6. Set $\hat{I}_{or}$ to –55 dBm/1.23 MHz.
7. Set I_{oc} and forward traffic channel rate.
8. Calculate PER.
9. Repeat steps 7 and 8 for each data rate. There are 20 tests which evaluate the AT's performance for all forward traffic channel data rates (38.4 to 2,457.6 kbps) for varying E_b/N_t. Set I_{oc} as specified for each test (ranges from –70.4 to –43.6 dBm/1.23 MHz).

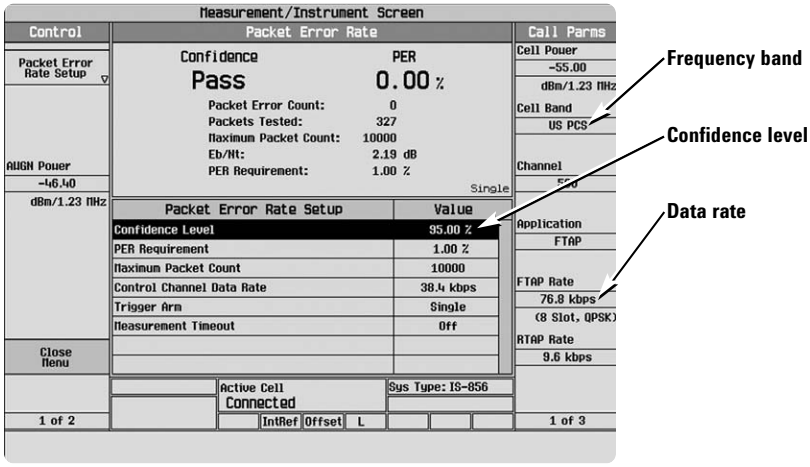


Figure 14. Setup screen for making a PER measurement

2.2.2 Demodulation in fading

The receiver also must be tested to ensure that it can demodulate a signal in a fading environment. Because the wireless transmission channel (air) contains obstacles and reflectors (buildings, trees, people), the transmitted signal arrivals at the receiver from various directions over a variety of different paths, or "rays." The received signals can interfere with each other constructively or destructively, resulting in fluctuations of the signal amplitude and phase. This causes intersymbol interference (ISI), where adjacent bits get crammed together and cause errors. The phenomenon is called multipath fading.

1. According to the standard [3], forward packet activity must consist of a random distribution of two types of packets; one type is directed to the AT under test and the other type is a filler packet emulating other users. On average, half of the transmitted packets should go to the AT, while the other half should be filler. Therefore, a 100 percent "forward packet activity rate" actually equates to a 50 percent "AT-directed packet rate". Please note this subtle but important distinction when setting up access network emulation equipment.

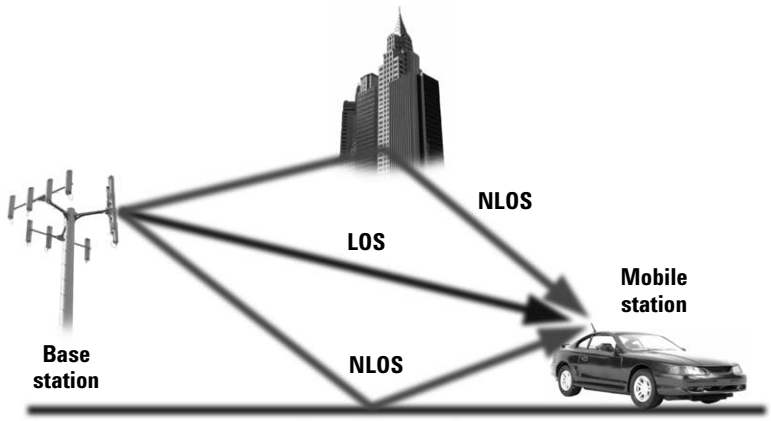


Figure 15. LOS (line of sight) is the ideal, unobstructed path between the transmitter and receiver. NLOS (non line of sight) represents all the other different paths that the signal takes on its way to the receiver, reflecting off of, and getting attenuated by, obstacles along the way

In this measurement, the channel simulator and the AWGN source are used. PER is calculated in four different test cases for two data rates (38.4 kbps and 76.8 kbps) in each case. The test cases are summarized as follows:

Case 1 – 8 km/hr (~5 mph) with 2 paths
Case 2 – 3 km/hr (~2 mph) with 1 path
Case 3 – 30 km/hr (~19 mph) with 1 path
Case 4 – 100 km/hr (~62 mph) with 3 paths

Each case attempts to simulate certain scenarios to stress the receiver. In the slower speeds, the fade comes and goes slowly, which in the real world would test the receiver's feedback loop in the rate request process. At faster speeds, the fade comes and goes very quickly, which tests the AT's interleaver. Because the downtime is brief, the receiver's interleaver will spread the lost bits roughly uniformly among the good data. Then the turbo decoder goes to work to recreate the original signal. The reason multiple paths are used is to verify that the rake receiver in the AT's searcher ASIC can keep up in a dynamic noise environment.

Test setup

1. Connect the AN to the AT with a forward packet activity of 100 percent.[1]
2. Set the Control Channel Data rate to 38.4 kbps.
3. Configure the F-TAP with data rate specified in each case.
4. Configure the fading profile specified in each case.
5. For each data rate, perform a PER test.

The specification sets limits for what the PER result must be under, and what the PER result should be under for best performance at 95 percent confidence level. The value for E_b/N_t must be within ±0.5 dB of the values set forth in the specification for cases 1, 2, and 4. The value for Eb/Nt must be within ±0.2 dB of the values set forth in the specification for case 3. Note that this is not a settable parameter itself; rather it is calculated from the other parameters, which are settable. For details on the limits, see Section 3.1.1.2.2 of [3].

1. According to the standard [3], forward packet activity must consist of a random distribution of two types of packets; one type is directed to the AT under test and the other type is a filler packet emulating other users. On average, half of the transmitted packets should go to the AT, while the other half should be filler. Therefore, a 100 percent "forward packet activity rate" actually equates to a 50 percent "AT-directed packet rate". Please note this subtle but important distinction when setting up access network emulation equipment.

2.2.3 Power control

The power control tests verify the combining logic of the AT during handoff. Handoff occurs when an AT receives a signal from more than one sector simultaneously. It can be characterized as hard, soft, or softer, depending on what happens to the transmission of the signal during the occurrence. Hard handoff occurs when the AT changes to a new CDMA frequency between different sectors. It is characterized by a temporary disconnection of the traffic channel. Soft and softer handoff happen between sectors using the same frequency. Soft handoff occurs when the transmitting sectors have differing reverse power control channels and softer handoff occurs when the transmitting sectors have identical reverse power control channels. Since the signals at this point are at a high level (the signal is received from two sectors), errors from demodulation should not be a big factor.

Power control is tested for both the soft handoff and softer handoff cases. Note that these tests require two active transmitting sectors and do not require an AWGN source.

Soft handoff

The combining logic used in soft handoff is called "or of the downs." Basically, the AT should only raise its reverse link transmit power when it receives an "up" power control bit (PCB) from all sectors from which it receives a signal. If the AT receives a "down" PCB from any transmitting sector, it should decrease its power. See Figure 16 for an illustration of this concept. The only exception to this rule occurs when one of the transmitting sectors has a value of E_c/I_o that drops too low. E_c/I_o is defined as the ratio between the average energy per PN chip over the total received power spectral density at the AT antenna. If the value for E_c/I_o from any transmitting sector drops more than 12 dB below the other sectors, the low sector should not figure into the "or of the downs" logic.

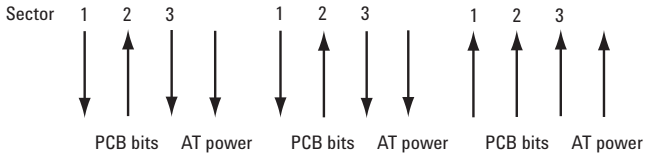


Figure 16. "Or of the downs" power combining

Test setup

1. Connect two transmitting channels to the AT, each with its own arbitrary PN offset.
2. Set the DRCLockPeriod to 16 slots.
3. Set the R-TAP reverse data rate to 9.6kbps.
4. Set $\hat{I}_{or}$ to –55 dBm for both transmitting channels. ($\hat{I}_{or}$ is defined in section 1.2.1.)
5. Send an alternating pattern of fifteen '0' PCBs followed by '1' PCBs on both channels synchronously while measuring the output power of the AT for a period of 64 slots.
6. Send an alternating pattern of fifteen '0' PCBs followed by fifteen '1' PCBs on channel 1 while sending only '0' PCBs on channel 2. Measure the output power of the AT for a period of 64 slots.

If the AT is combining properly, you should see the following recurring pattern in the AT output power: increase for 15 out of 16 slots, with one slot remaining unchanged, then decrease for 15 out of 16 slots, with one slot remaining unchanged. The reason the power should remain unchanged for one out of every 16 slots is because the data rate control lock (DRCLock) bit, which is sent out one of every 16 slots, should not affect the output power. The DRC channel is time division multiplexed with the RPC channel and sent out on the same MAC channel in walsh code space. The DRCLock bit signifies whether the AN can decode the rate request made by the AT.

Softer handoff

In softer handoff, the AT should use diversity combining. The AT should only use one PCB from each RPC channel received.

Test setup

1. Connect two transmitting channels to the AT, each with its own arbitrary PN offset.
2. Set the DRCLockPeriod to 16 slots.
3. Set the R-TAP reverse data rate to 9.6kbps.
4. Set $\hat{I}_{or}$ to –55 dBm for both transmitting channels. ($\hat{I}_{or}$ is defined in Section 1.2.1.)
5. Send an alternating pattern of one ‘0’ PCB followed by one ‘1’ PCB on channel 1 while sending only ‘1’ PCBs on channel 2. Measure the output power of the AT for a period of 42 slots.
6. Perform step 5 at least 11 times.

If the AT is combining properly, it will follow the pattern of alternating PCBs sent on channel 1. Out of the 11 test trials, the AT should follow this pattern at least 90 percent of the time, with at most one bit per trial in error.

2.3 Static channel tests

2.3.1 Receiver sensitivity and dynamic range

The tests for receiver sensitivity and dynamic range verify whether the receiver can perform at both ends of the power spectrum – very low level signals (sensitivity) and very high level signals (dynamic range). The two cases simulate the real world scenarios of an AT being:

1. at the periphery of a cell
2. very close to a high power AN

Receiver sensitivity
This measurement verifies that the noise figure of the AT is within tolerance (~10 dB). The noise figure is dominated by a combination of losses from the antenna to the input low noise amplifier (LNA), and the noise figure of that LNA. Noise figure becomes more influential as the AT reaches the fringe of a cell, because as the signal strength drops, noise doesn't. This causes the S/N ratio to decrease, eventually resulting in a dropped call due to erroneous packets. The figure of merit in this test is a PER measurement. Sensitivity is defined as the minimum received power, measured at the AT antenna, at which the PER does not exceed a certain value.

Dynamic range
This test checks the overload capacity of the AT receiver. If the AT is very close to a transmitting AN, and receives a high level signal, it is possible to get receiver errors from power amplifier compression and other distortion related receiver errors. It is important to know whether enough headroom is designed into the receiver before automatic gain control (AGC). The figure of merit for this test is again packet error rate (PER). The definition of dynamic range is the input power range at the AT antenna over which the PER does not exceed a specific value.

The tests outlined above utilize use both extremes of the AT's modulation schemes. The receiver sensitivity tests the AT using QPSK based modulation at a specified rate of 307.6 Kbps, while the dynamic range is tested using 16QAM based modulation at the highest data rate of 2457.6 Kbps. Figure 17 shows how the two tests simulate real network conditions.

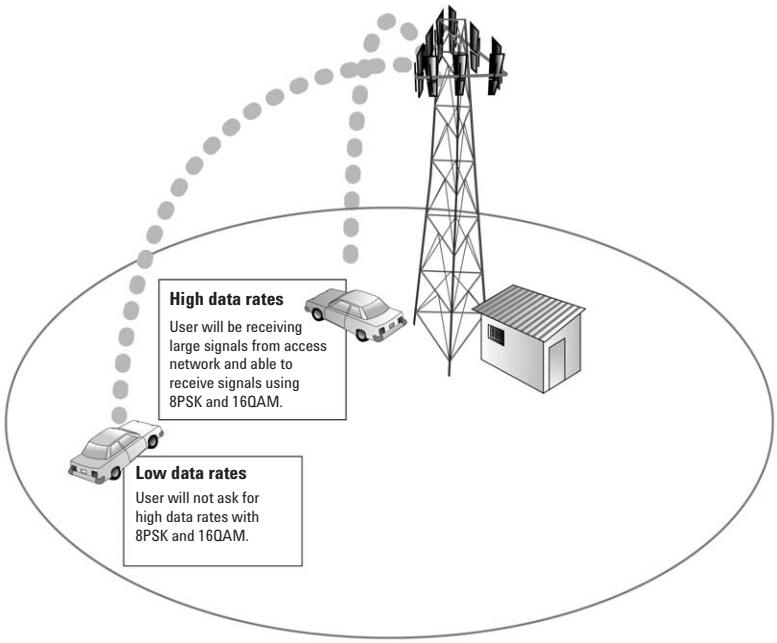


Figure 17. Sensitivity (low rate) and dynamic range (high rate) in a cell

Test setup

1. Connect the access network emulator to the AT.
2. Set up a test application session and open an F-TAP connection.
3. Test 1 – receiver sensitivity: Set the Forward Traffic Channel rate to the 2-slot version of 307.2 kbps and $\hat{I}_{or}$ to –105.5 dBm/1.23 MHz. Calculate PER.
4. Test 2 – dynamic range: Set the Forward Traffic Channel rate to 2,457.6 kbps and $\hat{I}_{or}$ to –25 dBm/1.23 MHz. Calculate PER.

The PER must be less than or equal to 0.5 percent with 95 percent confidence.

2.3.2 Single tone desensitization

Single tone desensitization measures the receiver's ability to recreate an accurate signal in its assigned frequency channel in the presence of an interfering tone outside of the channel. The interfering tone simulates power from analog transmissions in adjacent frequency channels. For most receiver designs common in today's wireless devices, this means verifying the effectiveness of the AT's intermediate frequency (IF) filter. Figure 18 shows a basic receiver block diagram[1]. After the radio frequency (RF) signal received at the antenna is amplified by the LNA, a typical terminal down converts the RF signal to a fixed intermediate frequency (IF). A sharp band pass filter is then used to cut out any tones that are not supposed to be there. Usually this filter is some sort of surface acoustic wave (SAW) device. The sole purpose of this filter is to attenuate the interfering tones to a level small enough not to cause problems with demodulation, which is the next stage.

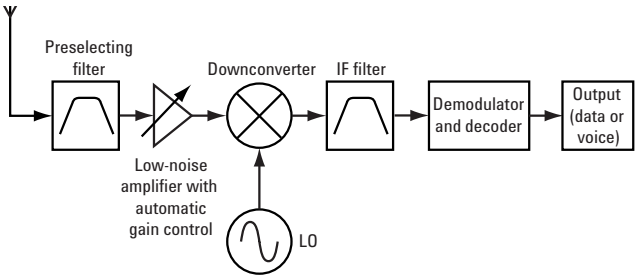


Figure 18. Receiver block diagram

1. Note that this block diagram is a generalization. Other receiver designs (such as zero-IF) do not employ all of these same stages, yet still must pass the single tone test.

Test setup

1. Connect the AT to the AN and the interfering CW tone generator.
2. Configure the F-TAP to a forward traffic channel rate of 307.2 kbps. (2-slot version.)
3. Set the $\hat{I}_{or}$ to –102.4. (This is 3 dB up from the sensitivity specification.)
4. Set up interfering tones:
   a. For band classes 0, 2, 3, 5, 7, and 9: insert a tone of –30 dBm power at 900 MHz above and 900 MHz below the carrier. Calculate PER.
   b. For band classes 1, 4, and 8: insert a tone of –40 dBm at 1250 MHz above and 1250 MHz below the carrier. Calculate PER.

In this test, the PER must remain at 1.0 percent or below with 95 percent confidence. Note that this test is not required for operation in band class 6.

2.3.3 Intermodulation spurious response attenuation

This test is similar in nature to the desensitization test, except in this case there are two interfering tones. Any nonlinearities in the front end of the AT will mix these two tones together, resulting in a third order intermodulation product that shows up in the assigned frequency channel. For that reason, this test is sometimes called TOI, or Third Order Intermodulation. If the mixer and LNA have good linearity, these products will not affect the overall signal beyond a certain point. This test verifies the linearity of those components.

Test setup

1. Connect the AT to the BTS and the interfering CW tone generator seen in Figure 13. The generator will source two tones in this test.
2. Configure the F-TAP to a forward traffic channel rate of 307.2 kbps. (2-slot version.)
3. Set the $\hat{I}_{or}$ to –102.4. (This is 3 dB down from the sensitivity specification.)
4. Set up interfering tones.
   a. For band classes 2, 3, 5, 7, and 9 there are two tests: Set tone power to –40 dBm[1]. Test 1 – insert tones at 900 kHz above and 1700 kHz above the carrier. Calculate PER. Test 2 – insert tones at 900 kHz below and 1700 kHz below the carrier. Calculate PER.
   b. For band classes 1, 4, and 8 there are two tests: Set tone power to –40d Bm[1]. Test 1 – insert tones at 1250 kHz above and 2050 kHz above the carrier. Calculate PER. Test 2 – insert tones at 1250 kHz below and 2050 kHz below the carrier. Calculate PER.
   c. For band class 6 there are two tests: Set tone power to –48 dBm. Test 1 – insert tones at 2500 kHz above and 4900 kHz above the carrier. Calculate PER. Test 2 – insert tones at 2500 kHz below and 4900 kHz below the carrier. Calculate PER.
   d. For band class 0 there are six tests: Test 1 and 2 – follow step 4a. Test 3 and 4 – set $\hat{I}_{or}$ to –91.4 and tone power to –32 dBm. Insert tones at 900 kHz above and 1700 kHz above the carrier. Calculate PER. Insert tones at 900 kHz below and 1700 kHz below the carrier. Calculate PER. Test 5 and 6 – Set $\hat{I}_{or}$ to –80.4 and tone power to –21 dBm. Insert tones at 900 kHz above and 1700 kHz above the carrier. Calculate PER. Insert tones at 900 kHz and 1700 kHz below the carrier. Calculate PER.

In this test, the PER must remain at 1.0 percent or below with 95 percent confidence. Tests 3 and 4 for band class 0 are considered optional.

1. This specification is for Class I ATs. For Class II-V, the power for both tones is –43 dBm.

2.3.4 Adjacent channel selectivity and receiver blocking characteristics

These tests are only required for operation in band class 6. They are similar in setup to the test for single tone desensitization. The differences are:

1. in adjacent channel selectivity, the interfering signal is CDMA modulated, and
2. in receiver blocking, the interfering signals are in frequencies outside the adjacent channels.

3 Reverse Link Transmitter Measurements

The reverse link channel structure for 1xEV-DO is very similar to that for cdma2000. As a result, many of the transmitter measurements are also very similar. To learn about the modulation quality and power measurements that are common to cdma2000 Mobile Station (MS) testing, see [7].

Transmitter measurements for 1xEV-DO ATs can be broken down into three categories: emissions, precision of modulation, and power characteristics. Emissions testing for transmitters is covered in Section 3.

Note: Each test includes a brief explanation of the steps required for setup. These steps are not meant to be exhaustive, but rather to say in a few words what is being done. For a detailed step-by-step setup process, see [3].

3.1 Basic test practices

3.1.1 Test setup

Figure 19 shows the general setup for transmitter testing. In general, the base station simulator is a one-box-test set (OBT). This equipment performs all the call setup and call processing needed to put the terminal under test into the appropriate states for testing. The OBT typically is very good at power measurements and the quality of the waveform, but has limited capabilities in the frequency domain. For good measurements of the spectrum of the transmission of the terminal, a good spectrum analyzer must be used. Modern spectrum analyzers can also measure the modulation quality of the terminal. See Appendix C for a description of Agilent test equipment that can perform these measurements.

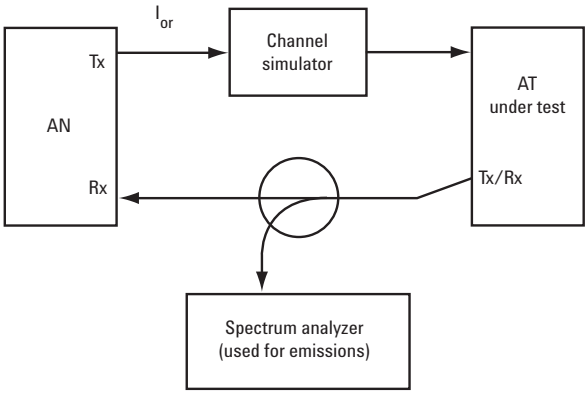


Figure 19. Typical transmitter test setup. The signal flow for transmitter testing is shown here. The base station simulator makes many of the measurements, but a high performance spectrum analyzer is required for emissions testing

3.1.2 Choosing the right equipment

The specifications call out minimum performance requirements for the equipment used to perform conformance tests on the AT. The limits suggested in the specifications and outlined in this document assume the tests are conducted using equipment that meets these requirements. The following requirements can be fulfilled by the base station emulator or auxiliary instruments.

Spectrum analyzer requirements

- Frequency resolution: 1 kHz
- Frequency accuracy: ±0.2 ppm
- Displayed dynamic range: 70 dB
- Display log scale fidelity: ±1 dB over the above displayed dynamic range
- Amplitude measurement range for signals from 10 MHz to either
  - 2.6 GHz for band classes 0, 2, 3, 5, 7, and 9, or
  - 6 GHz for band classes 1, 4, 6, and 8
- Power measured in 30 kHz resolution bandwidth: –90 to +20 dBm
- Integrated 1.23 MHz channel power: –70 to +40 dBm
- Noise floor: –140 dBm/Hz
  - External attenuation may be used to meet the high power end of the range and may be considered as part of the equipment.
- Absolute amplitude accuracy (for integrated channel power measurements):
  - ±1 dB over the range of –40 dBm to +20 dBm
  - ±1.3 dB over the range of –70 dBm to +20 dBm
- Relative flatness: ±1.5 dB over frequency range 10 MHz to either
  - 2.6 GHz for band classes 0, 2, 3, 5, 7, and 9, or
  - 6 GHz for band classes 1, 4, 6, and 8
- RF input impedance: nominal 50 ohms
- Waveform quality accuracy for code domain measurements: $\pm 1 \times 10^{-3}$ from 0.97 to 1.0

Power meter requirements

- Frequency range: 10 MHz to either
  - 1 GHz for band classes 0, 2, 3, 5, 7, and 9, or
  - 2 GHz for band classes 1, 4, 6, and 8
- Power range: –70 dBm (100 pW) to + 40 dBm (10 W)
  - Different sensors may be required to optimally provide this power range
  - External attenuation may be used to meet the high power end of the range and may be considered as part of the equipment
- Absolute and relative power accuracy: ±0.2 dB (5 percent)
- Sensor VSWR: 1.15:1

3.2 Modulation requirements

3.2.1 Waveform quality

Most modulation accuracy measurements involve measuring how close either the constellation states or the signal trajectory is relative to a reference (ideal) signal trajectory. The transmitted signal is demodulated in an ideal receiver and compared with a reference signal numerically generated in the test equipment. Error vector magnitude (EVM) and rho are two methods of measuring the "likeness" of the actual transmitted signal to the ideal reference signal. EVM, used in 3GPP specifications, is defined as the percentage error, so a perfect signal would have an EVM of 0 percent. Rho, used in 3GPP2 specifications, calculates the correlation rather than the error. Rho is expressed as a decimal value between 0 and 1; a perfect signal would have a rho value of 1. Rho will be discussed in this document; EVM will not.

In the 1xEV-DO specification, like in cdma2000, modulation accuracy is measured by rho, the normalized correlation coefficient between the actual transmitted signal and the reference signal. The correlated power is computed in DSP by compensating for frequency, phase, and time offsets in the received signal, then performing a cross correlation between the corrected signal and an ideal reference. For details on the algorithms involved in this measurement, see Chapter 11 of [3]. Unlike cdma2000, which only specifies rho for the reverse pilot channel, measuring rho for 1xEV-DO involves a composite rho measurement. Called $\rho_{overall}$, it takes into account the modulation accuracy of the time division multiplexed reverse traffic channel, which includes pilot/RRI, DRC, ACK, and data. In order to pass the test, the value for ρ should stay under a specified limit, measured in dB relative to the ideal reference value. This measurement also returns values for carrier frequency offset and transmit time offset. See sections 2.2.2 and 2.2.3 for descriptions of these tests.

Test setup

1. Connect the AT to the BTS.
2. Configure the R-TAP with a Reverse Data Channel rate of 9.6 kbps.
   The ACK Channel is transmitted in the first half-slot of each timeslot.
3. Set $\hat{I}_{or}$ to –75 dBm/1.23 MHz.
4. Measure the waveform quality factor, frequency error, and transmit time error.

The value for $\rho_{overall}$ must be at least 0.944 to pass this test. Remember that the ideal value for ρ, that of a perfect signal, is 1.0. The decimal value 0.944 is 0.25 dB down from the decimal value 1.0. In other words, the value for overall reverse channel waveform quality (the correlated code channel power) must be within 0.25 dB of the ideal reference value.

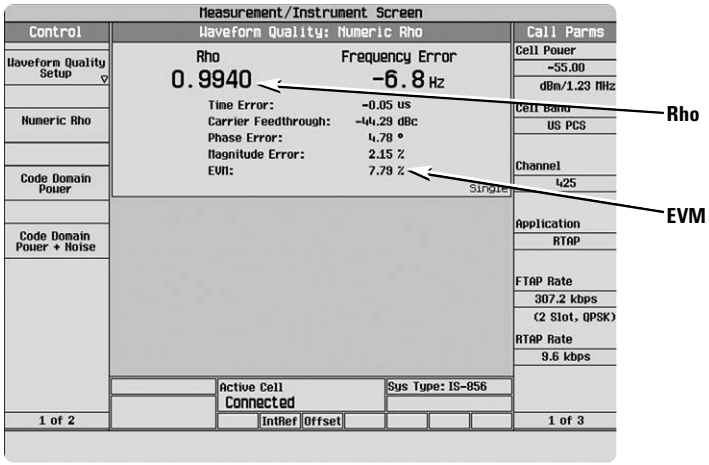


Figure 20. Waveform quality measurement screen

3.2.2 Frequency accuracy

Frequency accuracy is measured at the same time as waveform quality. It is defined as the ability of an AT transmitter to transmit at an assigned carrier frequency. Limits are set in the specification for how far off the transmission frequency can be from the carrier frequency of the forward channel. The values for each band are given in Table 2. The specification is more stringent for higher frequency band classes because Doppler shift effects are worse at higher frequencies. The frequency accuracy specs are therefore tightened so that the sum error of Doppler effects plus frequency accuracy error end up the same at high or low frequency band classes.

Table 2. Frequency accuracy test limits

Band class	Description	Frequency accuracy test limit
0	800 MHz	Within ±300 Hz of 45 MHz below carrier
1	1900 MHz	Within ±150 Hz of 80 MHz below carrier
2	TACS	Within ±300 Hz of 45 MHz below carrier
3	JTACS	Within ±300 Hz of 55 MHz below carrier
4	Korean PCS	Within ±150 Hz of 90 MHz below carrier
5	450 MHz	Within ±300 Hz of 10 MHz below carrier
6	2 GHz	Within ±150 Hz of 190 MHz below carrier
7	700 MHz	Within ±300 Hz of 30 MHz below carrier
8	1800 MHz	Within ±150 Hz of 95 MHz below carrier
9	900 MHz	Within ±300 Hz of 45 MHz below carrier

See Section 3.2.2 of [3] for the frequency accuracy test setup procedures.

3.2.3 Time reference

The AT determines system time (time reference used by the system) from the AN. The AT time reference is derived from the earliest arriving multipath component from the AN. This time reference is then used as the transmit time of the reverse channel. The timing information in the AN signal is offset from actual system time due to propagation delay, and the earliest arriving multipath can change frequently. The AT must constantly adjust its time corresponding to changes in the first arriving multipath signal from the AN.

This test, also called "transmit time offset," has two parts. Test 1 verifies how accurately the AT has aligned its timing to the reference signal broadcast from the AN in static conditions. Test 2 checks the time reference slew rate in dynamic conditions.

Test setup

1. Connect AN to AT.
2. Configure the R-TAP with a Reverse Data Channel rate of 9.6 kbps.
3. Set $\hat{I}_{or}$ to –75.
4. Test 1 – Measure time reference using rho meter.
5. Test 2 – Add in a channel simulator to make the AN signal alternate between two different paths with timing that differs by 10 chips (unfaded, just like 8 µs delay generator). Each path has a duration of 20 seconds with an alternating period of 40 seconds. Measure rho for at least two minutes.

The AT must alternately adjust its time reference to match the received signal. This measurement determines the AT time reference error and calculates the time reference slew rate. In test one, the time reference must be within ±1 µs of the timing of the AN. In test two, as the path switches, the AT error is 8 µs, and it takes time to correct back down to 0 µs. After 20 s on this path, it's switched to the other path and must correct again. This goes on for two minutes. If AT time reference correction is needed, it must be corrected no faster than 203 ns in 200 µs period and no slower than 305 ns in any one second period. Time error is returned with waveform quality on the screen shown in Figure 20.

3.2.4 Code domain power

Code domain power (CDP) is the power in each code channel of a CDMA reverse link transmission. The time and phase reference used in the code domain power test is derived from the reverse channel overall waveform ($\rho_{overall}$ from above) and is used as the reference for demodulation of all other code channels. Code domain power is measured relative to the pilot/RRI channel power level. In each test, a value for ρ is calculated, like in the waveform quality measurement, corresponding to the correlated power in each Walsh code channel. Limits in each case are given as a decimal value for ρ. This decimal value is easily converted to a power ratio in dB.

The CDP measurement verifies that the AT is transmitting the correct power in each of the code channels. Errors in the code domain can arise from the channel elements that construct the individual channels, from incorrect network software settings, or from impairments in the baseband or RF chain. Some common causes of these errors are amplifier compression, LO interference, and I/Q gain imbalance. See Figure 21 for an example of a code domain power measurement.

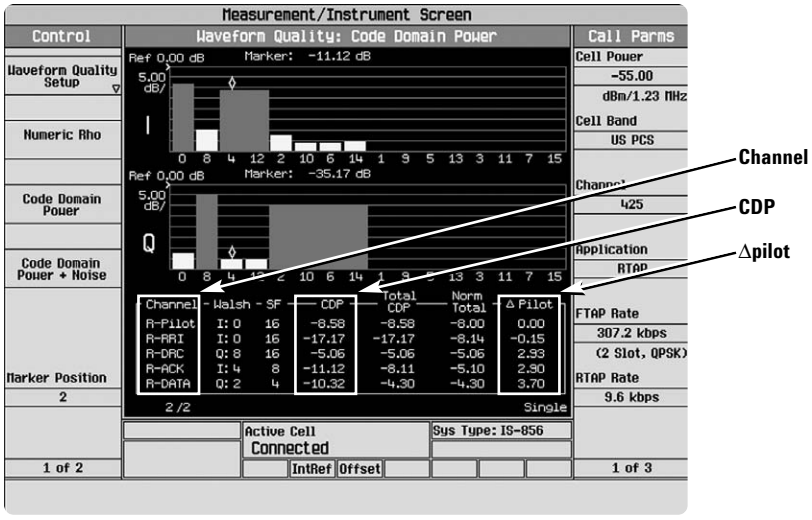


Figure 21. Code domain power measurement

There are four code channels of interest in the reverse link 1xEV-DO signal: the pilot/RRI, the DRC, the ACK, and the data channel. These code channels make up the reverse link traffic channel. The measurement screen for code domain power shown in Figure 21 includes a graphical display and a table of data.

The graphical display illustrates the power in the 32 Walsh codes of the AT's reverse link signal as a histogram. The code channels are listed in bit reverse order, which allows for the Walsh codes comprising a single reverse channel to be grouped together on the display. The height of the histogram bars indicate power level, and when the marker is positioned on a single Walsh code, the power of that Walsh code is displayed. This is the average power in the Walsh code integrated over a slot, divided by the total power in all of the Walsh codes during the same slot.

The table of data provides information about each of the reverse link code channels, such as Walsh code, spread factor (SF), and code domain power (CDP). The total CDP column is derived mathematically from the CDP column, by multiplying CDP for each channel by the base spread factor 16 and dividing by the spread factor of the particular channel. The normalized CDP column is then derived mathematically from the total CDP column, normalizing the power in each reverse channel to one slot. The delta pilot column is derived by subtracting the R-Pilot norm total power (in dB), from each reverse channel's norm total power (in dB).

RRI channel output power

When an AT is connected to an AN, the first 256 chips of every slot contain the RRI transmission. The RRI is time division duplexed with the pilot, and both are supposed to be transmitted at the same nominal power. This is measured with a gated code domain power analyzer. Ideally, the value in the Δpilot column in Figure 21 should be 0.

Test setup

1. Connect the AT to the BTS.
2. Set $\hat{I}_{or}$ to –75.
3. Measure the code domain power of the RRI channel and the pilot channel.

The value of code domain power for RRI and pilot must be within ±0.25 dB of each other.

DRC

The ratio of the power level between the DRC channel and the pilot/RRI channel, called DRCChannelGain, is a parameter set by the serving AN. This test verifies that the code domain power ratio is correct. This can be verified by checking the value in the Δpilot column of Figure 21.

Test setup

1. Connect the AT to the BTS.
2. Set $\hat{I}_{or}$ to –75.
3. Set gain to 0 dB. Measure ρ_{pilot} and ρ_{DRC}.
4. Set gain to 3 dB. Measure ρ_{pilot} and ρ_{DRC}.

The ratio of DRC to pilot code domain power should be within ±0.25 dB of the DRCChannelGain setting.

ACK

The ratio of the power level between the ACK channel and the pilot/RRI channel, called ACKChannelGain, is a parameter set by the serving AN. This test verifies that the code domain power ratio is correct. The value for Δpilot is given in the code domain power measurement screen. See Figure 21.

The test setup and measurement result limits are identical to the case for the DRC channel.

Data

The ratio of the power level between the data channel and the pilot/RRI channel, called DataChannelGain, varies according to the reverse data channel rate, which means that it is not a settable parameter by itself. This test verifies that the ratio is correct within a certain tolerance for each reverse link data rate. The value for Δpilot is given in the code domain power measurement screen. See Figure 21.

Test setup

1. Connect the AT to the BTS.
2. Set $\hat{I}_{or}$ to –75.
3. Configure the R-TAP with the data rate shown in the following table. Each data rate corresponds to a particular value for the gain. Measure ρ_{pilot} and ρ_{data} for each case. The ratio should be within ±0.25 dB of the values shown in Table 3.

Table 3. Data channel gain parameters

Rate (kbps)	DataChannelGain (dB)
9.6	3.75
19.2	6.75
38.4	9.75
76.8	13.25
153.6	18.5

4. Measure the code domain power in all the inactive channels. The value for ρ in all inactive channels must be less than 0.005. This is equivalent to a correlated power in each inactive code channel that is 23 dB less than the total transmit power.

3.3 Output power requirements

3.3.1 Max and min controlled output power

Max

This is the maximum limit of the AT's RF output power, when open loop power control is at the highest setting. Maximum power level is important because it sets the range of the cell. The AT can go no further than where the AN will still be able to receive its transmission. There is an upper limit on maximum power to keep from radiating too much power near the user. An upper limit is given in the specification, but is also set by local government bodies (such as the FCC in the US), as a limit on SAR (specific absorption ratio), which overrides this specification if more stringent.

Test setup

1. Connect the AT to the BTS.
2. Configure the R-TAP for a reverse data channel rate of 153.6 kbps.
3. Configure the F-TAP for a forward traffic channel data rate of the 2-slot version of 307.2 kbps. The ACK channel is transmitted in the first half of all the slots.
4. Set $\hat{I}_{or}$ –105.5.
5. Send continuous '0' power control bits to the AT. Measure output power.

A table of limits for each band class and AT power class can be found in Section 3.1.2.3.4 of [3].

Min

This is the AT's RF output power when both closed loop and open loop power control indicate minimum output. The minimum controlled output power of the AT is important because as the AT comes close to a AN, if it can't transmit low enough, it can interfere with signals from other ATs which are further away, causing them to increase power and reducing the capacity and radius of the cell.

Test setup

1. Connect the AT to the BTS.
2. Configure the R-TAP with a reverse data channel rate of 9.6 kbps.
3. Set $\hat{I}_{or}$ to –25.
4. Send continuous '1' power control bits to the access terminal. Measure output power.

For this test, the mean output power of the access terminal must be less than –50 dBm/1.23 MHz centered at the CDMA channel frequency.

3.3.2 Open loop power control

These tests measure the ATs response to open loop power control. The AT monitors the received power from the AN and continuously adjusts its own output power according to the open loop power equation. This equation assumes the loss is similar on the forward and reverse paths. For most AT's the open loop power equation is simple:

AT transmit power = offset power – received power
(This is the same as TIA/EIA-95-B.)

The offset power value in the equation depends on the band class of operation.

Range

This test measures the range of the estimated open loop output power. The terminal must operate over a range of almost 80 dB, prior to closed loop power control corrections.

Test setup

1. Connect the AT to the BTS at 100 percent forward packet activity.[1]
2. Set $\hat{I}_{or}$ to –25.
3. Send a page to the AT. Measure its output power.
4. Set $\hat{I}_{or}$ to –65.
5. Send a page to the AT. Measure its output power.
6. Set $\hat{I}_{or}$ to a value between –81 dB and 103 dB, depending on the class of terminal. For the exact value, see Section 3.1.2.3.1 of [3].
7. Send a page to the AT. Measure its output power.

In each case, the mean output power of the pilot channel, signified here as Xo, must be within ±9 dB of the value given by:

$$Xo = -\text{mean input power (dBm)} + \text{OpenLoopAdjust} + \text{ProbeInitialAdjust}$$

where the parameters OpenLoopAdjust and ProbeInitialAdjust are set by the access network through the AccessParameters message. The access terminal output power shall satisfy the range specified for any forward packet activity. The limits are given in a table in Section 3.1.2.3.1 of [3]. See Figure 22 for an example of an open loop power control measurement.

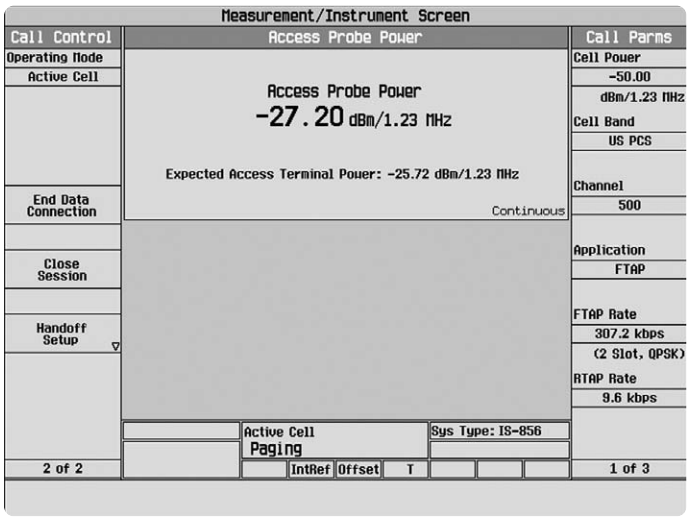


Figure 22. Access probe power

Time response

In this test, the power transient of the terminal transmitter is measured as a result of a 20 dB step at the receiver. Following a step change in the mean input power, the mean output power of the AT changes to compensate. This results from the open loop power control. This test measures the open loop power control time response to a step change in the mean input power.

1. According to the standard [3], forward packet activity must consist of a random distribution of two types of packets; one type is directed to the AT under test and the other type is a filler packet emulating other users. On average, half of the transmitted packets should go to the AT, while the other half should be filler. Therefore, a 100 percent "forward packet activity rate" actually equates to a 50 percent "AT-directed packet rate". Please note this subtle but important distinction when setting up access network emulation equipment.

Test setup

1. Connect the AT to the BTS at 100 percent forward packet activity.[1]
2. Configure the R-TAP with a Reverse Data Channel rate of 9.6 kbps.
3. Set Cell Power to –60 dBm/1.23 MHz.
4. Send alternating ‘0’ and ‘1’ power control bits on the Forward Traffic Channel.
5. Change the input power by a step of +20 dB. Measure the output power as a function of time after the step change for 100 µs.
6. Change the input power by a step of –20 dB. Measure the output power as a function of time after the step change for 100 µs.
7. Change the input power by a step of –20 dB. Measure the transmitted output power as a function of time after the step change for 100 µs.
8. Change the input power by a step of +20 dB. Measure the transmitted output power as a function of time after the step change for 100 µs.

The absolute value of the change in mean output power due to open loop power control must be a monotonically increasing function of time. This means that the power control should increase or decrease the AT’s output power in a steady manner, rather than in big chunks that vary in magnitude. If the change in mean output power consists of individual steps, no single step should be greater than 1.2 dB. In Figure 23, we see the upper and lower limit lines of output power versus time. The line in the middle is the mean measured output power of the AT. If this line crosses the upper or lower limit line at any time during the 100 µs test period, the measurement fails.

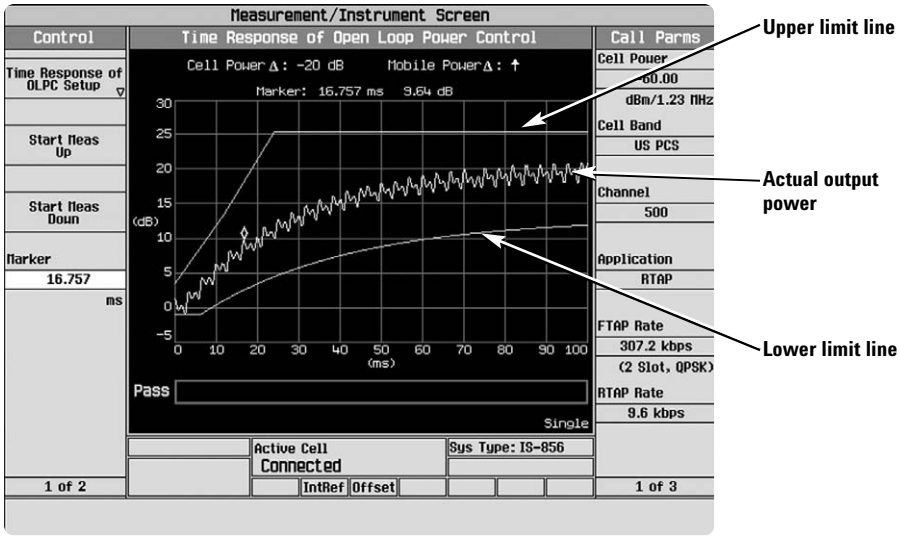


Figure 23. Time response of open loop power control

1. According to the standard [3], forward packet activity must consist of a random distribution of two types of packets; one type is directed to the AT under test and the other type is a filler packet emulating other users. On average, half of the transmitted packets should go to the AT, while the other half should be filler. Therefore, a 100 percent “forward packet activity rate” actually equates to a 50 percent “AT-directed packet rate”. Please note this subtle but important distinction when setting up access network emulation equipment.

3.3.3 Closed loop power control

In addition to open loop power control, the AT makes closed loop adjustments to its power as well. These adjustments are made in response to the PCBs transmitted by the AN according to two calculations: the difference between the max power and the open loop estimate, and the difference between the min power and the open loop estimate. The AN transmits PCBs in response to the received E_b/N_t of the AT reverse link signal. The adjustment is performed 800 times per second and the power adjustment step size is 0.25, 0.5, or 1 dB.

Range

In this test, the range of power due to power control bits is measured with varying starting powers and data rates. This verifies that the AT is capable of tuning its output at least 24 dB above and below the open loop estimate when directed to by the AN. This test also verifies that the AT responds quickly to changes in power control and changes its power at the appropriate rate. There are six tests to perform.

Test setup

1. Connect the AT to the BTS.
2. Set the forward channel attenuation to the output power shown in Table 4.
3. Configure the R-TAP with a reverse data rate shown in Table 4.
4. Send alternating '0' and '1' PCB's, then 120 consecutive '0' bits, then 120 consecutive '1' bits, then 120 consecutive '0' bits. Measure the output power as it changes in response to the PCBs.

Table 4. Closed loop power parameters[1]

Rate (kbps)	DataChannelGain (dB)
9.6	3.75
19.2	6.75
38.4	9.75
76.8	13.25
153.6	18.5

There are several responses to verify in each stage:

1. The AT should decrease its power in response to a change from '1's to '0's in 3.33 µs or less.
2. The average rate of change in power per frame (26.6 µs) should be between 12 dB and 18 dB.
3. After the AT receives a PCB, its mean output power should settle to within 0.3 dB of its final value in less than 500 µs.

1. This table is slightly altered from the corresponding table in [3]. The original specifications contained typographical errors in the open loop power column. They have been corrected here.

3.3.4 Standby output power

This test verifies the transmitter power when no transmissions are active. This occurs when the AT is in the initialization state or the idle state.

Test setup

1. Connect the AT to the BTS.
2. Set $\hat{I}_{or}$ to –75.
3. Send a page to the AT. Measure its output power.

The output noise power spectral density must be less than –61 dBm, measured in a 1 MHz resolution bandwidth.

4 Emissions

One area that is common to both transmitter and receiver is that of emission testing. There are limits on both conducted and radiated emissions. Conducted emissions are those that are active on the antenna, while radiated emissions are from all radiating sources other than the antenna.

Note: Each test includes a brief explanation of the steps required for setup. These steps are not meant to be exhaustive, but rather to say in a few words what is being done. For a detailed step-by-step setup process, see [3].

4.1 Conducted spurious

In CDMA systems, the number of users that can coexist on one channel depends upon the level of interference in that channel. Power leakage from adjacent channels contributes to the noise floor of the channel. Thus, it is important that ATs transmit energy only in the assigned frequency channel. This test is similar to the W-CDMA specification of adjacent channel leakage ratio, or ACLR. ACLR quantifies the integrated power that falls into either an adjacent (up or down one) or alternate (up or down two) channel. The spectral mask limits in 1xEV-DO are actually more stringent than the corresponding ACLR limits, so ACLR is not a required test for 1xEV-DO.

Conducted emissions fall into two categories: those that are close to the desired transmission frequency, and those that are out of the assigned band of operation. This second class is measured much like the radiated emissions, the difference being the cable connection between the transmitter of the terminal and the test equipment. The in-band emissions must meet a spectral mask, and for some bands of operation, a limit on occupied bandwidth.

Receiver test setup

1. Connect the AT to a spectrum analyzer.
2. Sweep the spectrum analyzer:
   a. band classes 0, 2, 5, 7 – from 1 MHz to 2600 MHz
   b. band class 3 – from 1 MHz to 3 GHz
   c. band classes 1, 4, 8 – from 1 MHz to 6 GHz
   d. band class 6 – from 30 MHz to 12.75 GHz
3. Measure the spurious emission level at the antenna connector.

The limits for spurious emissions are –76 dBm for frequencies in the receive band and –61 dBm for frequencies in the transmit band, measured at 1 MHz resolution bandwidth.

Transmitter test setup

1. Connect the AT to the BTS.
2. Configure the R-TAP with a Reverse Data Channel rate of 153.6 kbps. Configure the F-TAP with a forward traffic channel data rate of 307.2 kbps. (2-slot version)
3. Set $\hat{I}_{or}$ to –105.5.
4. Send continuous '0' PCBs to the AT. Measure the spurious emission levels at the antenna.

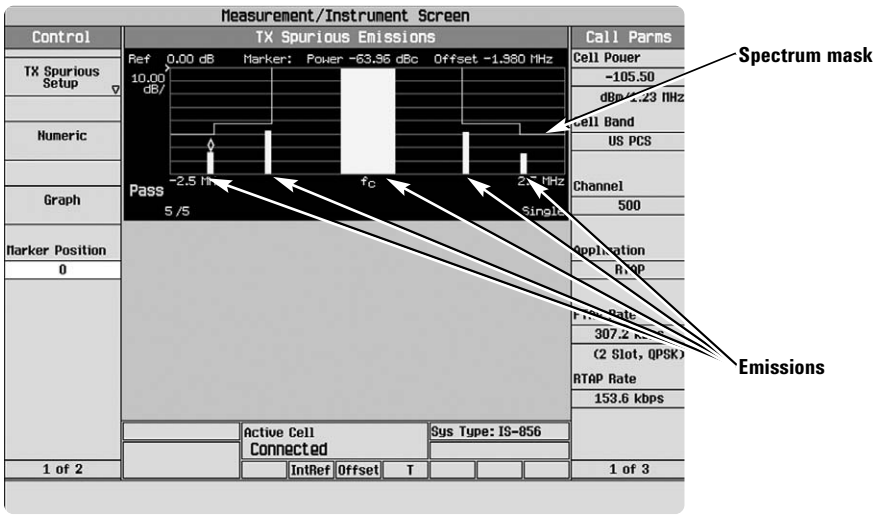


Figure 24. Transmitter spurious emission test

The limits on spurious emissions can be found in Section 3.1.2.4.1 of [3].

4.2 Radiated spurious

Radiated spurious emissions are those that are generated in the receiver or transmitter and radiated by AT case, power, control, and audio leads. Radiated measurements require a calibrated open space and generally are made over a very wide range of frequencies, a minimum of 25 MHz, and up to 12.75 GHz for some bands.

4.3 Occupied bandwidth

The occupied bandwidth is defined as the frequency range, whereby the power of emissions averaged over the frequency above and under the edge frequency are 0.5 percent each of the total radiation power of the modulated carrier. It verifies that the transmission of the AT does not affect transmissions outside of its assigned frequency channel. This measurement is identical to its cdma2000 counterpart and is only required for band classes 3 and 6.

Test setup

1. Connect the AT to the BTS.
2. Configure the R-TAP with a Reverse Data Channel rate of 9.6 kbps. Configure the F-TAP with a forward traffic channel data rate of 307.2 kbps. (2-slot version)
3. Set $\hat{I}_{or}$ to –105.5.
4. Send continuous '0' PCBs to the AT. Measure the occupied bandwidth at 30 kHz resolution.

The calculated value in this test must be equal to or less than 1.48 MHz.

Appendix A – Coding Structure for the Forward Link of 1xEV-DO

Data rate, kbps	Packet size, bits	Turbo code rate	Repeats	Slots used	Mod type
38.4	1024	1/5	9.6	16	QPSK
76.8	1024	1/5	4.8	8	QPSK
153.6	1024	1/5	2.4	4	QPSK
307.2	1024	1/5	1.2	2	QPSK
614.4	1024	1/3	1.0	1	QPSK
307.2	2048	1/3	2.04	4	QPSK
614.4	2048	1/3	1.02	2	QPSK
1228.8	2048	2/3	1	1	QPSK
921.6	3072	1/3	1.02	2	8PSK
843.2	3072	2/3	1.0	1	8PSK
1228.8	4096	1/3	1.02	2	16QAM
2457.6	4096	2/3	1.0	1	16QAM

Appendix B – Band Class Frequencies

Band class	Description
0	800 MHz
1	1900 MHz
2	TACS
3	JTACS
4	Korean PCS
5	450 MHz
6	2 GHz
7	700 MHz
8	1800 MHz
9	900 MHz

Appendix C – Agilent Test Equipment for Testing ATs

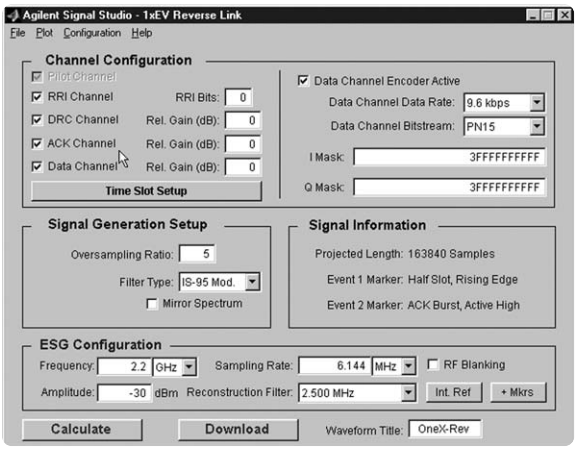
Early design verification

Agilent's factory test mode with ESG, Signal Studio, and PSA

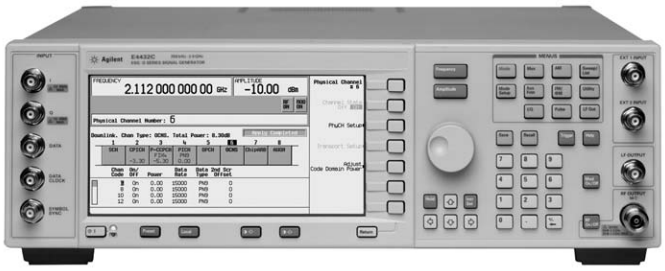
The 1xEV-DO Signal Studio software is an intuitive Windows®-based tool for creating single and multi-carrier 1xEV-DO waveforms for use with the E4438C ESG vector signal generator. The software provides a simple graphical user interface to configure all the physical layer channels required to create a 1xEV-DO test signal. Forward link channels include the pilot, MAC, traffic, and control. Reverse link channels include the pilot, MAC, ACK, and data. If call processing is not needed, access terminal receiver tests like PER and BER can be performed with the fully coded, single-carrier, forward link, factory test mode (FTM) application. Set the quantity of packets, packet payload data, data rate per modulation type, and MAC index. To simulate a realistic packet transmission sequence, the software conveniently sets the traffic and control waveform sequence automatically. Common measurements include receiver sensitivity, maximum input level, and demodulation performance in the presence of interference. **A trial version of the user interface can be downloaded at no cost from www.agilent.com/find/signalstudio.**

The E4438C ESG vector signal generator is an adaptable platform with optional capabilities to customize baseband and RF test applications ranging from simple distortion test and general purpose troubleshooting, to baseband coding algorithm development, advanced transceiver design verification, and high volume manufacturing.

For analysis, the 1xEV-DO measurement personality, available in both the high performance PSA Series spectrum analyzers and the low cost E4406A VSA transmitter tester, offers one-button power measurements and modulation analysis to help you quickly and easily test your 1xEV-DO access terminal.



Agilent 1xEV-DO Signal Studio reverse link setup screen



Agilent ESG E4438C vector signal generator

Agilent PSA high performance spectrum analyzer with the 1xEV-DO measurement personality

For more information, visit **www.agilent.com/find/1xEVDO**

Product design: Protocol and parametric verification

Agilent E6706A 1xEV-DO lab application

The Agilent E6706A 1xEV-DO lab application for the E5515C (8960) test set is the first full-featured network in a box that ensures confidence that your 1xEV-DO handset design will work under real network conditions. For the R&D engineer performing design validation testing, this configurable base station emulator acts as a powerful multifunction toolbox that enables you to find and resolve problems in the wireless device.

Features

- support for default packet data testing – verify mobile applications by measuring throughput performance in real-world, dynamic network conditions
- data throughput monitor – enables the real time data rate measurement of a circuit switched or packet switched data channel for *user experience testing* – such as WAP browsing and e-mail
- wireless protocol advisor – a real time protocol logging tool with a friendly user interface that captures both cell and BTS signals to troubleshoot problems from the MAC layer to the IP layer *while they are happening*
- every lab application also includes all of the measurement functions of the test application (shown below)

High volume production test: Parametric and user functionality

Agilent E1966A 1xEV-DO access terminal test application

The Agilent E1966A 1xEV-DO test application for the E5515C (8960) test set provides the first one-box manufacturing solution for testing at high data rates giving you confidence in your wireless access terminals. Developed for mobile manufacturers as well as developers and designers of leading-edge 1xEV-DO ATs, the E1966A runs on Agilent's industry-standard platform, the E5515C, ensuring efficient test times, accuracy, and repeatability in your 1xEV-DO test processes.

Features

- reduce the risk of returns and recalls by testing QPSK, 8PSK, and 16QAM modulation modes
- for dual-mode cdma2000 and 1xEV-DO test, combine the E1966A 1xEV-DO test application with the E1962B cdma2000 test application for the ***first*** *one-box test solution*
- wireless test manager available – powerful, flexible, all-in-one test system software application that makes automated test development and support easier than ever
- easily upgraded from the cdma2000 test application with a simple firmware update

For more information, visit **www.agilent.com/find/E1966A.**

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[4] Test Application Specification (TAS) for High Rate Packet Data Air Interface. 3rd Generation Partnership Project 2. Ballot Resolution Version C.S0029-0 Version 2. July 12, 2001

[5] "1xEV-DO Modulation Schemes: Noise Impact on Receiver Measurements", Test & Measurement Magazine for Quality in Electronics, September 2002, Vol. 7, pg. 57

[6] "Manufacturing Test Considerations for 1xEV-DO Wireless Technologies", EP&T Canada, November/December 2002, pg. 67

[7] Designing and Testing cdma2000 Mobile Stations, Agilent Technologies Application Note 1358, literature number 5980-1237E

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