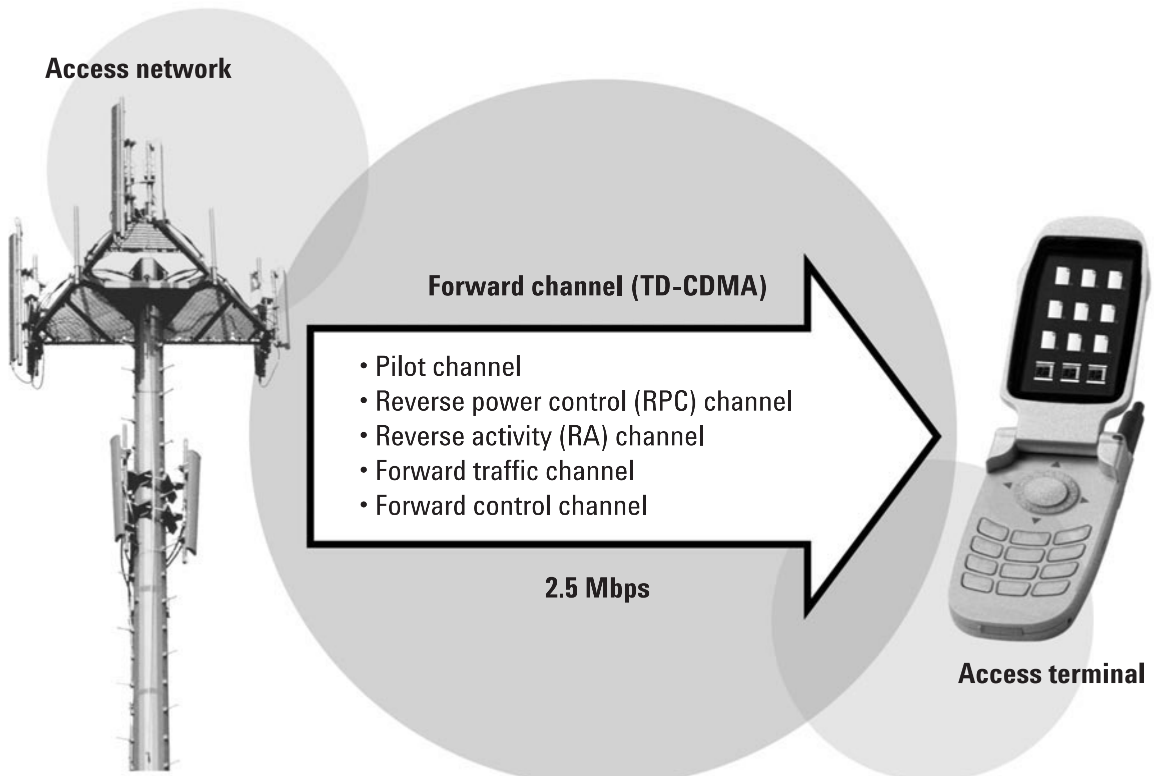
Agilent
Forward Link Measurements for 1xEV-DO Access Networks

Application Note 1398



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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. The focus on data is taking two forms: short message service (SMS), and packet data.

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. However, for applications that require large data packets, such as Internet browsing or streaming video, the SMS system cannot handle the throughput requirements. The packet data system is an area of major development and is seen as having 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. With packet-data systems, 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 was originally called High Rate Packet Data System. The 3GPP2 standards committee settled on 1x Evolution Data Only (or 1xEV-DO), which now has been attached to this system throughout the industry. 1xEV-DO is defined by the 3GPP2 in specification C.S0024 and by the Telecommunications Industry Association (TIA), in IS-856 in the U.S.

1xEV-DO requires an 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 that 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 and spreading technologies used in cdma2000. The focus of this paper is on the forward link conformance measurements required by specification C.S0032, Recommended Minimum Performance Standards for 1xEV-DO Access Networks, published by 3GPP2 [3]. An access network (AN) is the 1xEV-DO terminology for base station. The AN measurements are broken up into two sections: power and modulation quality. 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 the 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. It is up to ten 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 services that requires above 100 kbps on average from the network, which is about 50 percent of the capacity of a single cdma2000 channel. 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 U.S. generally do not. That is why, at the time of publication, the current interest in 1xEV-DO is centered mostly in Asia.

1.1 The forward link

The fundamental difference between 1xEV-DO and earlier CDMA systems is that the forward link in 1xEV-DO has a major time division multiplexing (TDM) function to it. During data transmission, data is directed to only one access terminal (mobile station) 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 network equipment decides which access terminal (AT) will get data next. 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.

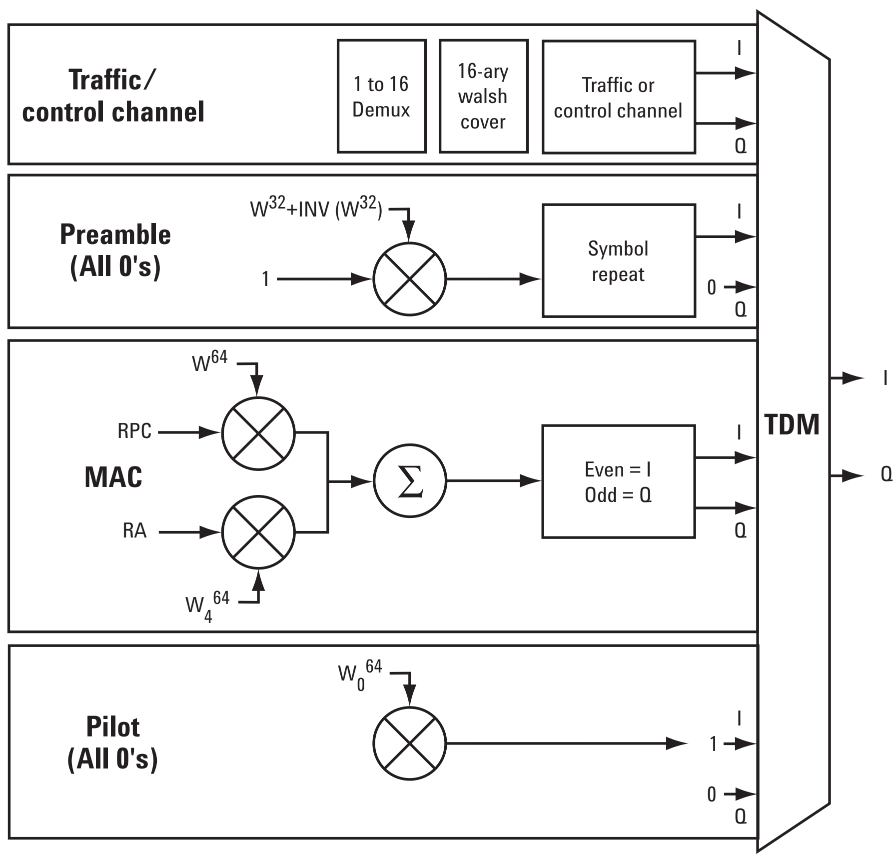


Figure 1. TDM structure of the 1xEV-DO forward link

Of the four TDM channels shown in figure 1, only the medium access control (MAC) channel is capable of sending information to more than one AT in parallel. The dominant information on the MAC channel are 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.

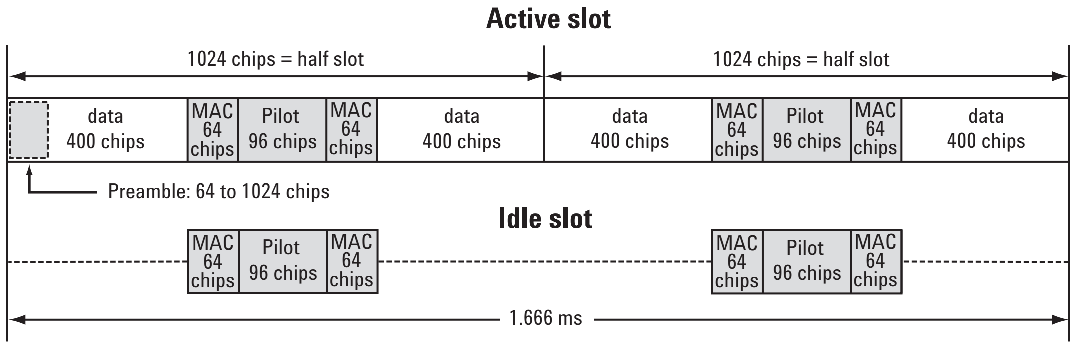


Figure 2. TDM structure for 1xEV-DO active and idle slots

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 slot 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 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 vary 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.

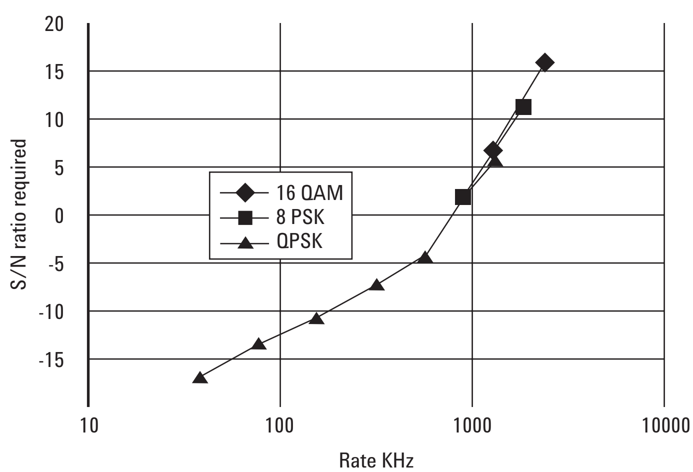


Figure 3. S/N versus data rate

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 makes the system a little less efficient, with more power needed per bit. 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 8 PSK and 16 QAM. The structure is shown in figures 4 and 5.

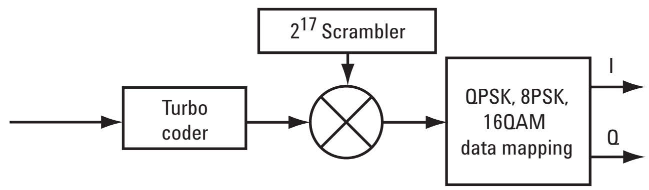


Figure 4. Traffic channel coding for the forward link

The input data is encoded with a turbo coder, which can provide up to 3 dB better performance than an equivalent convolutional encoder. The data is then scrambled with a code that is unique to each user, providing security. Finally the data is mapped into I and Q values. At lower rates, alternate bits map directly into I and Q with QPSK modulation, which results in two bits per symbol. For higher rates, the mapping is at three bits per symbol, which is 8 PSK. At the highest data rates, the mapping is four bits per symbol, which results in 16 QAM modulation. It should be noted that after modulation the I and Q signals become signed modulation values.

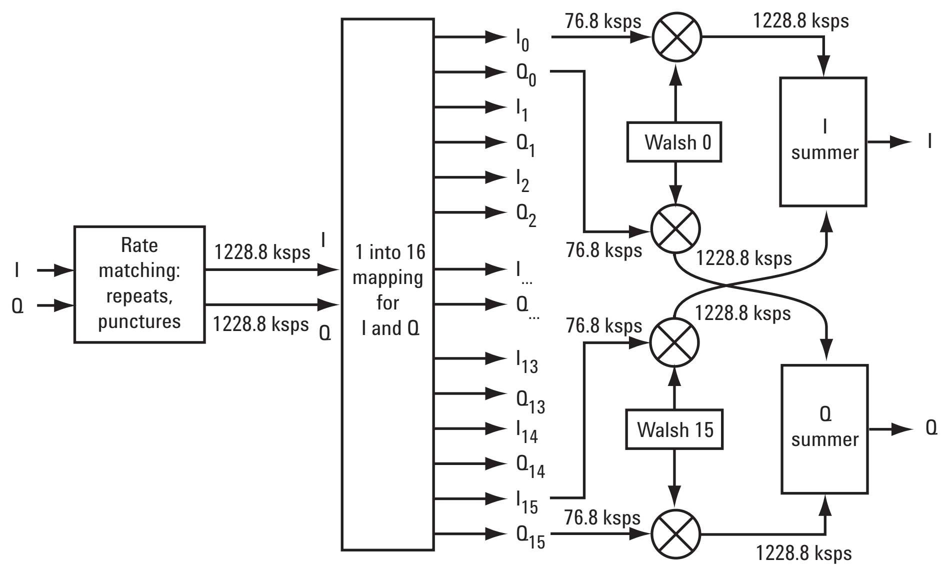


Figure 5. Rate matching and Walsh encoding

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 the data sets 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; the signal starts with one complex channel that is multiplexed into 16 parallel paths. Each of these paths gets coded with 16 times the gain of the original signal. However, there are 16 of these channels each with 1/16 the power; so there is 16 times the processing gain, but 1/16 the power, for a net unity gain. This process provides some added time diversity and puts more randomness into the final signal for transmission.

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 to have 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 embedded 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 differences. In cdma2000, there is a dedicated sub channel 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. In 1xEV-DO rate control is accomplished by adding a dedicated code channel called the data rate channel. This is transmitted every 1.667 ms from the terminal and tells the network the fastest rate the current forward link can support, as well as 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 confirm 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 equipment to decode the reverse transmission without the need for any blind detection of the data rate. The RRI is punctured onto the pilot channel.

The final coding structure is shown in figure 6. The first coding and rate matching are not shown.

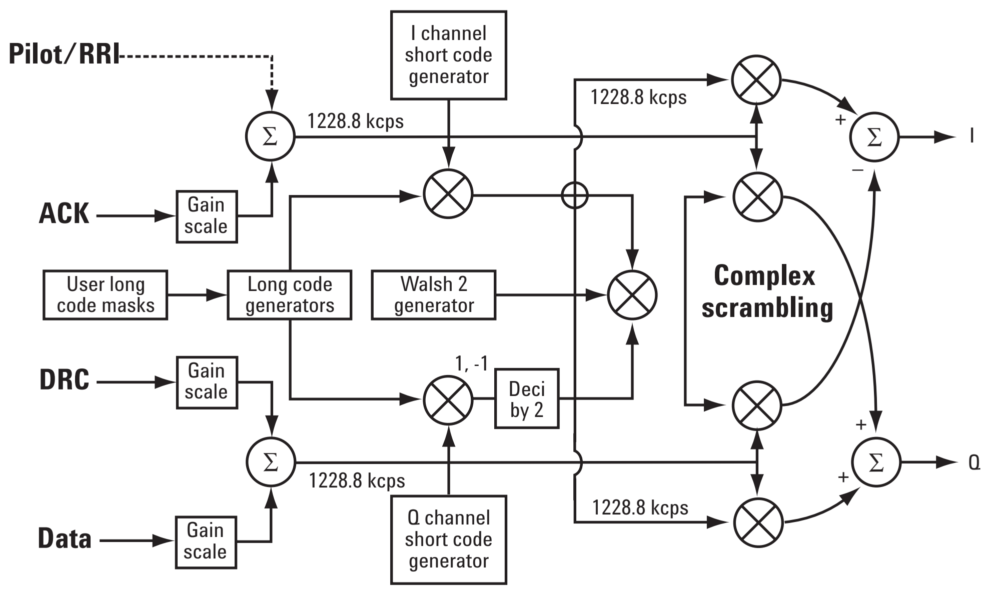


Figure 6. Reverse link combining for 1xEV-DO

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 and has greater flexibility to modify the coding structure optimally to 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 those systems.

The focus when evaluating a system is generally on the maximum rate it 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. The data that supports voice-over-IP applications will be treated as data bits when computing the data delivery rate of a given network. 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. The system also 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 – 20 %. 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 the other systems, but do this without the capability of any voice.

1.4 Measurement challenges of 1xEV-DO

The forward link of 1xEV-DO generates signals that have unique test challenges. These challenges occur in several categories of measurement: waveform quality, power measurements while pulsing, and spectral emission limits, particularly when in pulsed operation.

Waveform quality

The original metrics for waveform quality included two general specifications, rho and code domain power (CDP). In prior CDMA systems, rho has only been defined on a single code channel, the pilot, for base stations. In 1xEV-DO, the TDM structure necessitates multiple types of rho measurements during different times of the transmission. There are separate transmission measurements required by the network equipment performance specification, one just for the pilot channel and two for the total transmission with traffic. CDP is a measure of the power in every code channel. In prior CDMA systems, numerous code channels were active at one time, but the majority of the code space was inactive. CDP limits were set both on the accuracy of the active channels, as well as the minimum noise floor of the inactive channels. In 1xEV-DO, all possible code channels are used during the data portions of transmission. The CDP limits now require that every code channel be within ± 0.5 dB from the nominal value, which is 1/32 of the total power in the forward-traffic channel. An additional specification during the MAC transmission requires each active AT be assigned a unique 64-ary Walsh code channel. These MAC-code channels send power control bits for each terminal. In this case, there is a limit on the noise floor of the unused codes.

Power measurements while pulsing

This challenge is not new to CDMA; first generation CDMA phones pulse whenever the rate of transmission is less than 100 percent. At 1/8 rate the phone transmits at a duty cycle of 1/8. The power measurement is a report of the average power when transmitting, not the average power over all time. The noisy nature of the signal adds additional complexity to the accuracy of the detection. In 1xEV-DO systems, this complication has been moved to the AN and away from the AT. A typical implementation is to digitize the waveform while it is transmitting, and to determine the RMS voltage of the signal, then convert this to watt or dBm units. The sample rate must be high enough to ensure the capture of peaks and valleys with proper accuracy.

Spectral emission limits

These limits do not change from active slots to idle slots. However, the measurements made during idle slots need to sample the transmission only when power is on. The anticipated problem with network equipment has to do with the pulsed operation. The pulsed nature of the signal during idle slots creates problems for practical high-power amplifiers used in ANs. The problem is that feed-forward and feedback designs behave differently when the input signal is taken to zero. The 3GPP2 minimum performance standards for the network equipment only suggest a 7 dB on-to-off ratio between full power and the off state. This allows noise or CDMA signal insertion during the off periods to limit the effects of the power transients. Spectral problems related to the transients are not caused by the RF rise time itself, but by delays in the feedback or feed-forward structure of the amplifiers. A typical test setup will trigger the measurement equipment at the beginning of a slot, then delay the start of sampling until just before the beginning of the MAC transmission. The gate time is set so that the sampling is completed just after the end of the second MAC slot. This sampling is repeated over several slots to allow for averaging.

2 Forward link transmitter measurements

The performance of a wireless communications system depends on the transmitter, the receiver and the air interface over which the two communicate. This section details some of the conformance tests that verify that the forward link transmitter is working properly. It describes the power and modulation quality tests that are required in the 1xEV-DO standard, as well as some other measurements that are common to the wireless communications industry for testing transmitter and component performance.

Transmitter measurements are typically made at the antenna port, where the final signal is emitted. In this case, the measurement equipment is used as an ideal receiver. It may also be necessary to examine individual parts of the transmitter, such as the power amplifier module (see figure 7). If so, a stimulus signal might be required to emulate those sections that are not available or not used in the particular test configuration. The measurement equipment then acts as an ideal substitute for the missing circuit or sections.

Sometimes individual blocks or components cannot be isolated and the measurement can only be made at the final stage of the transmitter. Therefore, you may be forced to infer the causes of problems from measurements at the antenna port. The ideal testing tool is not only able to perform the measurements but also has the flexibility to provide insight about system impairments by analysis of the transmitted signal. For a more in-depth analysis of transmitter design troubleshooting techniques, see [1]

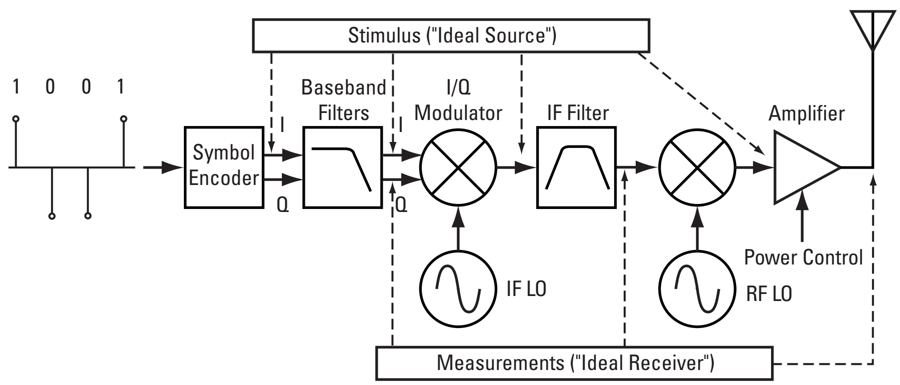


Figure 7. Transmitter chain measurement model

2.1 Power

Power is the fundamental parameter of any communication system. The goal in wireless systems is to satisfy the end consumer by maintaining a strong link between AN and AT, without wasting expensive power. In cdma2000 systems, the link is optimized through dynamic power control in the base station and the mobile station. In 1xEV-DO, the AN always transmits at full power to every AT in the cell. Since the power is constant in these systems, the link is optimized through rate control. Rate control is communicated between AN and AT on the forward- and reverse-MAC channels. In the forward link, the MAC channel consists of one reverse activity (RA) channel, which provides an indication of reverse link interference levels, and up to 59 reverse power control (RPC) channels, which control the transmission power of the ATs. The 1xEV-DO standard requires conformance testing on RF output power and spurious emissions. In this document, the tests are called power versus time (PvT) and spectrum emissions mask (SEM).

2.1.1 Power versus time

Within each timeslot (see figure 2), the pilot, MAC, and traffic or control channels are time-division multiplexed. The final signal, which is the sum of these channels, must always be transmitted at equal, full power. The PvT measurement checks to make sure this requirement is met in both the discontinuous mode (all idle slots) and the continuous mode (all active slots). PvT measures the time response of the mean output power in each of these modes.

Active slot

Active slots consist of two pilot/MAC channel bursts, each 224 chips in length, and four data bursts, each 400 chips in length. For an active slot measurement, the forward-traffic channel rate for the device under test (DUT) should be set to 2,457.6 kbps. The MAC channel should be configured with 14 MAC indices set to active, i.e. the RA channel and 13 RPC channels. (For power amplifier measurements, the pilot and MAC channels can be configured in an ideal signal source to provide the stimulation. See Appendix D for a partial list of Agilent signal sources and signal generation software that can provide this type of stimulus.)

The test instrument will measure the time response and the mean power at the sector's output port, averaged over at least 512[1] active half-slots. The time response of the stream average must stay within the limits shown in figure 8. In other words, the mean peak power variance of the signal must stay under 5 dB.

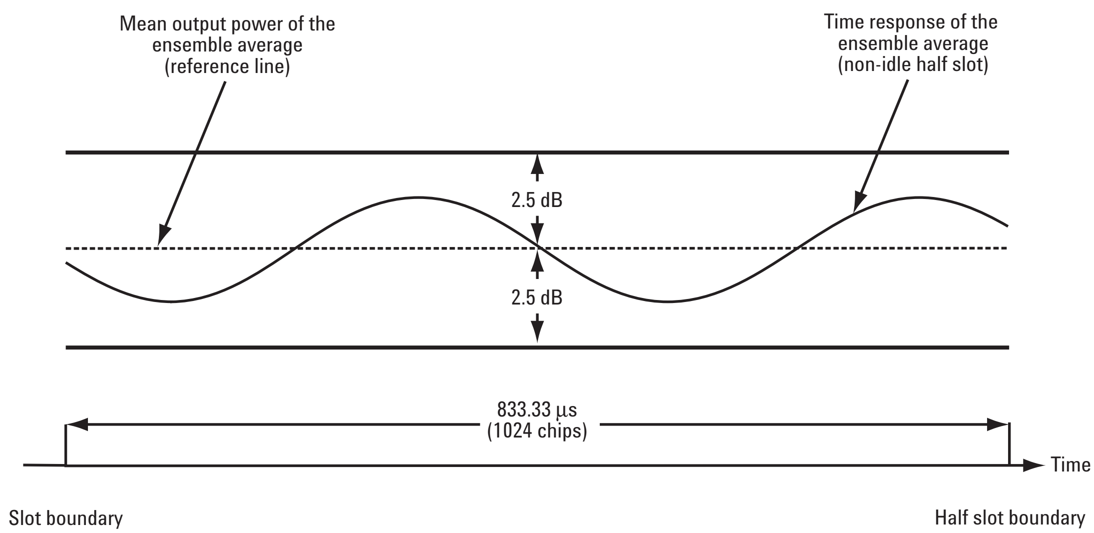


Figure 8. Transmission envelope mask of average active half-slot

What to look for in an active slot measurement:

- Is the duration of each traffic burst correct? 400 chips corresponds to 325.5µs. Bursts can be measured in time or chip length.
- Is the power level varying with time? As mentioned earlier, the AN always transmits at full power.

1. In the official released version of the standard, the number 100 is used here. The working committee realized this number was too small, and this change has been added as errata. The number 512 will be inserted into the next version of the standard at this point.

Idle slot

Idle slots consist of two pilot/MAC channel bursts, each 224 chips in length. These bursts are gated in time, each separated by two 400-chip blocks of inactive, or "idle" power. There is no data transmitted on the control or forward-traffic channels in an idle slot.

When making the measurement, the instrument will average an ensemble of 512 idle half-slots. The time response of this ensemble average should be within the limits shown in figure 9. This means that the mean power variance of the peaks of the pilot/MAC bursts must remain less than 5 dB, relative to the reference line. The reference line for the mean output power of the pilot/MAC burst ensemble average is equal to the value obtained in the active slot measurement above. It is recommended that the reference line be at least 7 dB above the noise floor at all times; however this is not a requirement. See figure 10 for an example of a PvT measurement on an idle slot.

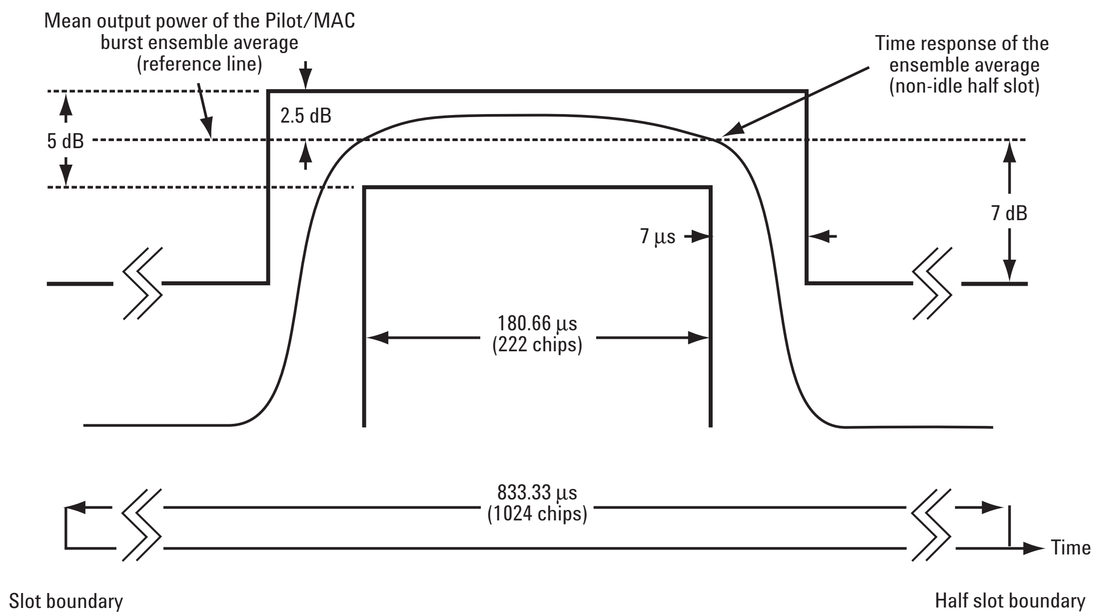


Figure 9. Transmission envelope mask for average idle half-slot

What to look for in an idle slot measurement:

- Is the noise floor at an optimum level? The recommended minimum on-to-off ratio for idle slots was set to 7dB in the standard to allow AN manufacturers to protect the power amplifiers from large output power swings between on portions of the signal during bursts and off portions of the signal in idle slots. The noise floor can be varied, of course, to optimize performance. This is called idle slot gain.
- Is power rising or falling within the burst? As mentioned earlier, the AN always transmits at full power.
- Is there overshoot from off power to on power? This can cause problems for the power amplifier.
- Is the duration of the pilot/MAC burst correct? Duration can be measured in chip length (222) or in time (180.6 µs).
- Make sure the mean power of bursts in the idle slots is at the same level as the mean power of the active slots. This is different from cdma2000, where the forward link changes output power of the base station according to the power control bits. In 1xEV-DO, the MAC adjusts the power of the AT transmitter only.

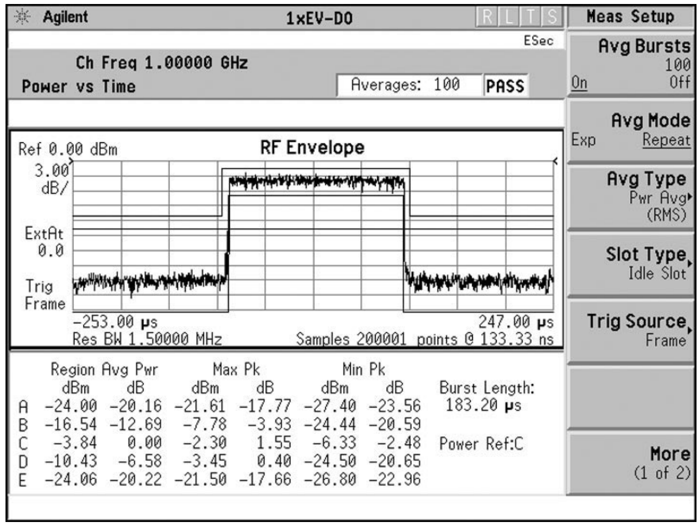


Figure 10. Power versus time measurement

2.1.2 Conducted spurious emissions

Conducted spurious emissions are power leakages at frequencies that are outside the assigned CDMA channel, measured at the sector RF output port. These emissions can be caused by different combinations of signals in the transmitter. The spurious emissions from the transmitter that fall within the system's band should be below the level specified to guarantee minimum interference with other frequency channels in the system. Refer to Appendix B for a table that lists the limits of spectral emissions for each band class.

2.1.2.1 Spectrum emissions mask (SEM)

For 1xEV-DO ANs, spurious emissions must be measured under two test conditions: continuous data mode (no idle slots) and idle mode (all idle slots, except the control channel).

Continuous data mode

When making continuous data mode measurements, configure the transmitter or source to transmit a stream of active slots. The forward-traffic channel data rate should be set to 2,457.6 kbps. The MAC channel should be configured with 14 active MAC indices – the RA channel and 13 RPC channels. First, measure the average carrier power. This value will be needed to do idle mode measurements. The values obtained for emissions measured at specified resolution bandwidths and offset frequencies must fall within the limits described in Appendix B.

Idle mode

When making idle mode measurements, configure the transmitter or source to emit a stream of idle slots. The control channel can be optionally transmitted or inhibited. The MAC channel should be configured with 14 active MAC indices – the RA channel and 13 RPC channels. The test instrument should gate the measurement in a window of 5-15 μs before and after the burst. (This can be implemented with time gating or with triggering.) First, measure the average carrier power of the gated transmission. Then measure the emissions at resolution bandwidths described in Appendix B for different offset frequencies.

For limits specified in dBc: These are relative limits to the average carrier power just measured in continuous data mode.

For limits specified in dBm: These are absolute limits, measured relative to one in milliwatts. If the gated power measured in idle mode is lower than the carrier power measured in continuous data mode by more than 1 dB, a correction factor equal to the difference of the carrier power levels must be added to the gated power measurements in idle mode. This aggregate power must adhere to the requirements for emissions at the resolution bandwidths shown in Appendix B at various offset frequencies. This requirement is to ensure that transmission power doesn't overstep the absolute limits put on all radio formats by the FCC.

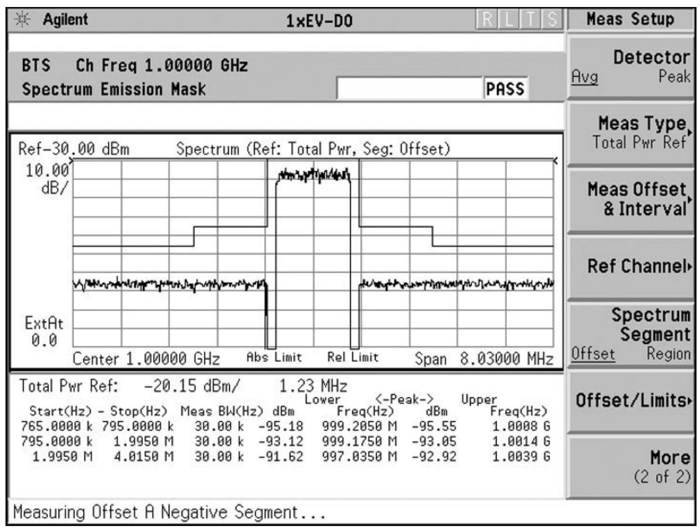


Figure 11. SEM measurement for idle mode

2.1.2.2 Adjacent channel power (ACP)

The ACP measurement is typically defined as the ratio of the average power in the adjacent frequency channel to the average power in the transmitted frequency channel. It is usually measured at multiple offsets. The offset frequencies immediately above and below the transmitting frequency are called the adjacent channels, while the offset frequencies above and below the adjacent channels are referred to as alternate channels. While ACP is not specified in the 1xEV-DO standard, this measurement is useful in characterizing the frequency performance of the transmitter. Both ACP and SEM are very useful in conjunction with complementary cumulative distribution function (CCDF) curves (see section 2.1.3) to characterize the back-off required in a power amplifier design. Often, clipping is used to reduce peakpower levels in the amplifier, but spectral regrowth is an unfortunate side effect. The ability to switch between an ACP-type of measurement and a CCDF-type of measurement enables the power amplifier designer to evaluate this tradeoff between power efficiency and spectral efficiency.

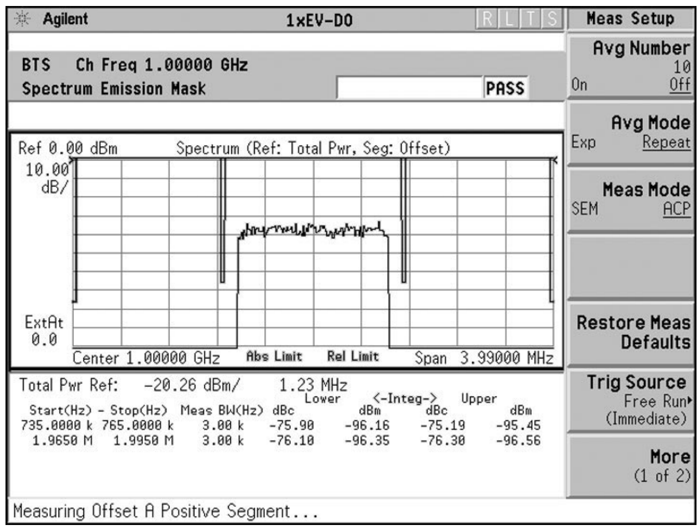


Figure 12. ACP measurement results

2.1.3 Complementary cumulative distribution function (CCDF)

The CCDF is a statistical method used to interpret the peak-to-average ratio of noise-like signals. The peak-to-average ratio is the ratio of the peak envelope power to the average envelope power of a signal during a given period of time, expressed in dB. CCDF curves are used to show how much time a signal spends at or above the signal's average power level.

Each 1xEV-DO frame has 16 time slots. Depending on the number of users being served by the network, any number of slots may be transmitting data in any given frame. Figure 12 shows the CCDF curves for two 1xEV-DO signals. The active signal has all 16 slots coded and transmitting data. The idle signal is only transmitting the pilot. (In a real system, idle slots would contain pilot and MAC bursts.) Point 1 in figure 12 corresponds to a peak-to-average ratio of 10.04 dB. This means the signal, which consists of pilot bursts in the idle mode, is 10.04 dB above the average signal power for 0.1% of the time. Idle slot transmissions will exhibit a higher peak-to-average distribution than active slot transmissions and cause the most stress to AN components, especially power amplifiers. Also, the higher modulation schemes (8PSK and 16QAM) will exhibit higher peak-to-average ratios than QPSK, due to the greater variance in constellation power.

CCDF curves can help you in several situations:

- Determining the headroom required when designing a component. Correlate the CCDF curve of the signal with the amplifier gain plots.
- Confirming the power statistics of a given signal or stimulus. Verify if the stimulus signal provided by another design team is adequate. Example: RF designers can use CCDF curves to verify that the signal provided by the digital signal processing (DSP) section is realistic.
- Confirming that the component design is adequate or troubleshooting your sub-system or system design. CCDF measurements can be made at several points of the system design. Example: If the adjacent channel power ratio (ACPR) of the transmitter is too high, a CCDF measurement can be made at the input and output of the power amplifier. If the amplifier is compressing the signal, the peak-to-average power ratio of the signal is lower at the output of the amplifier.

For more information on using CCDF curves to characterize digitally modulated signals, see [5].

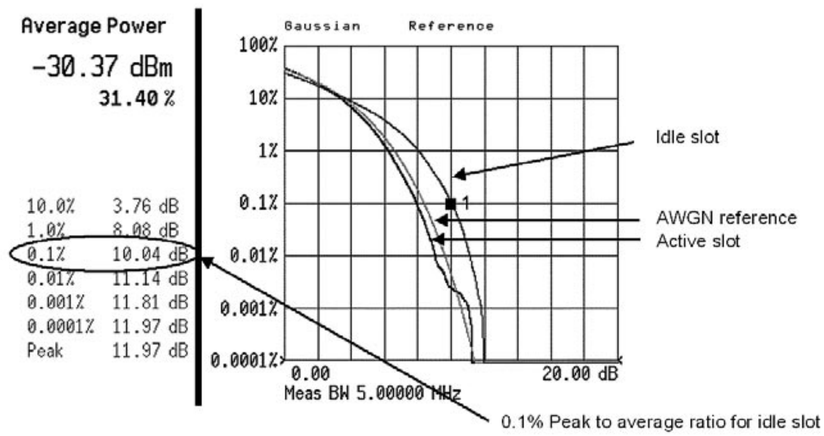


Figure 13. CCDF curves for an active slot (QPSK) and an idle slot (pilot only)

2.1.4 Occupied bandwidth

The occupied bandwidth is defined as the frequency range, whereby the power of emissions averaged over the frequency above and below the edge frequency are 0.5% each of the total radiation power of the modulated carrier. The limit for occupied bandwidth as specified in the 1xEV-DO specification is 1.48 MHz. This measurement is identical to its cdma2000 counterpart.

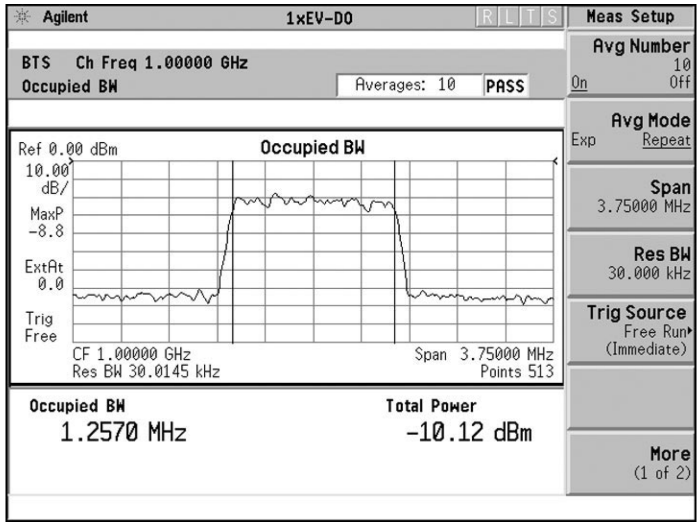


Figure 14. Occupied bandwidth measurement

2.1.5 Channel power

Channel power is the average power of the transmitted signal in the bandwidth of interest. In the case of 1xEV-DO, this means the power is integrated over 1.23 MHz. Channel power is measured in absolute terms (dBm or watts). This measurement is identical to its cdma2000 counterpart. There is no absolute power limit specified in the 3GPP2 standard; rather it is left up to network equipment manufacturers to rate the ambient temperature range and input power supply voltage under which the equipment will operate. The output power must be such that all of the requirements in the standard for spectrum emissions are met. (See section 2.1.2)

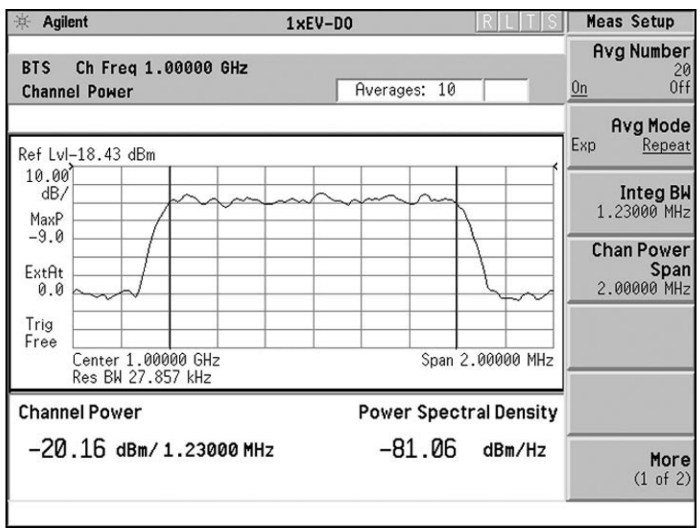


Figure 15. Channel power measurement

2.2 Modulation 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 is defined as the percentage error, so a perfect signal would have an EVM of 0%. Rho has an opposite scale, because it 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.

Modulation quality measurements such as EVM and rho are powerful in that they signify when something is wrong in the transmit chain. To figure out where the problem is, other measurements must be used in conjunction, such as constellation error, phase noise, or error vector versus time. The error signal can be examined in many ways; in the time domain or (since it is a vector quantity) in terms of its I/Q or magnitude/phase components. Another common modulation quality measurement that is specified in the 1xEV-DO standard is code domain power, which measures the orthogonality of the code channels. Code domain power, rho, and EVM are the focus of this section of the document.

2.2.1 Rho

In the 1xEV-DO standard, like in cdma2000, modulation accuracy is measured by rho, the normalized correlation coefficient between the actual transmitted signal and the reference signal, as stated previously in the introduction to this section. (See section 2.2) The correlated power is computed 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 3GPP2 reference [3]. Unlike cdma2000, which only specifies rho for the pilot channel, measuring rho for 1xEV-DO involves two other composite rho measurements. Composite rho measurements take into account all of the active channels together – the pilot, MAC, and traffic or control. The three measurements, signified ρ_{pilot}, $\rho_{overall\text{-}1}$, and $\rho_{overall\text{-}2}$, are explained in the following sections.

The basic measurement is usually conducted as shown in figure 16. First, the AN starts transmitting with a known data structure on the forward link. The test equipment samples, demodulates, and decodes the transmitted signal to some level (the level depends on the implementation). The test equipment then re-encodes and mathematically regenerates the signal, thus creating an essentially ideal signal. The actual transmitted signal is compared to this ideal signal, producing the rho measurement. Each measurement specifies 1024 complex-valued samples (the number of chips in one half-slot) over a time interval of N half-slots. The value of N is specified individually for each measurement. Typically this measurement also produces a number of other results, such as frequency accuracy, static time offset, amplitude error, phase error and carrier feedthrough. These are not specified in the 1xEV-DO standard, but are useful measurements of the nature of the error and the performance of the I/Q modulator.

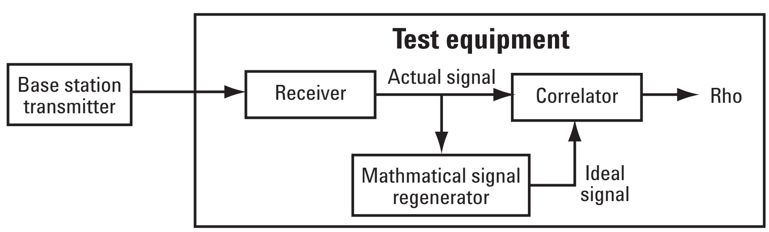


Figure 16. Typical rho measurement setup

Pilot

Equation 1 is a scaled-down version of the function that calculates ρ_{pilot}.

$$\rho\ \text{Pilot} = \frac{\sum_{j=1}^{N}\left\{\left|\sum_{k=1}^{1024} Z'_{j,k} R'^{*}_{j,k}\right|^2 \Big/ \sum_{k=1}^{1024}\left|R'_{j,k}\right|^2\right\}}{\sum_{j=1}^{N}\sum_{k=1}^{1024}\left|Z'_{j,k}\right|^2}$$

Equation 1

where $Z'_{j,k} = z'[1024(j - 1)+k]$ is the k_{th} sample in the j_{th} half-slot of the output of the actual signal, and $R'_{j,k} = r'[1024(j - 1)+k]$ is the corresponding sample of the ideal output. This measurement must be made over a time interval of at least 20 half-slots. (N = 20) The result for ρ_{pilot} must be greater than 0.912 and it is recommended for a good link (necessary for the highest data rates) that ρ_{pilot} be greater than 0.97. See figure 17 for an example of a ρ_{pilot} measurement.

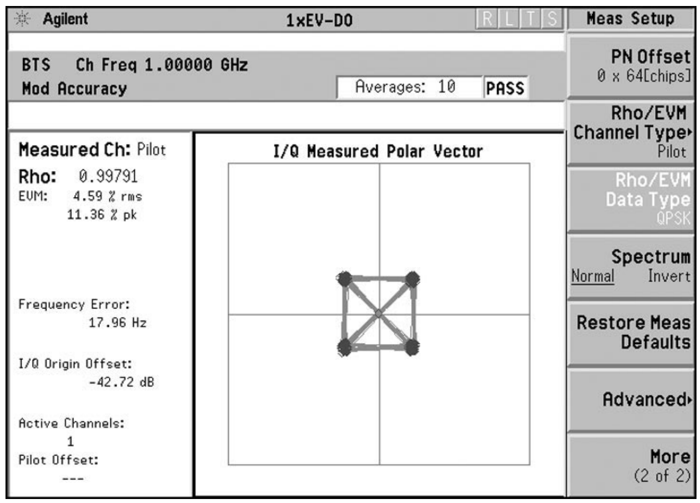


Figure 17. Modulation accuracy of pilot channel

Figure 17 shows the measured results in the left window and the I/Q constellation in the right window. This shows the pilot channel's rho/EVM, magnitude error, phase error, frequency error, and I/Q origin offset. In this case, the rho value is very good, 0.998, resulting in a green "pass" designation in the top right of the window.

Overall 1

The function for calculating the first overall rho measurement is shown in equation 2.

$$\rho\ \text{Overall -1} = \frac{\sum_{j=1}^{N}\left\{\left|\sum_{k=1}^{1024} Z_{j,k} R^{*}_{j,k}\right|^2 \Big/ \sum_{k=1}^{1024}\left|R_{j,k}\right|^2\right\}}{\sum_{j=1}^{N}\sum_{k=1}^{1024}\left|Z_{j,k}\right|^2}$$

Equation 2

where $Z_{j,k}$ = z[1024(j-1)+k] is the k_{th} sample in the j_{th} half-slot of the output of the actual signal, and $R_{j,k}$ = r[1024(j-1)+k] is the corresponding sample of the ideal output. The measurement sampling starts at $z(t_1)$, which is the first chip of a first half-slot and ends at $z(t_{1024N})$, which is the last chip of a first half-slot. This measurement must be made over a time interval of at least two half-slots. (N = 2) The result for $\rho_{overall-1}$ must be greater than 0.912 and it is recommended for a good link (necessary for higher rates) that $\rho_{overall-1}$ be greater than 0.97. See figure 18 for a graphical illustration of how $\rho_{overall-1}$ and $\rho_{overall-2}$ compare to each other.

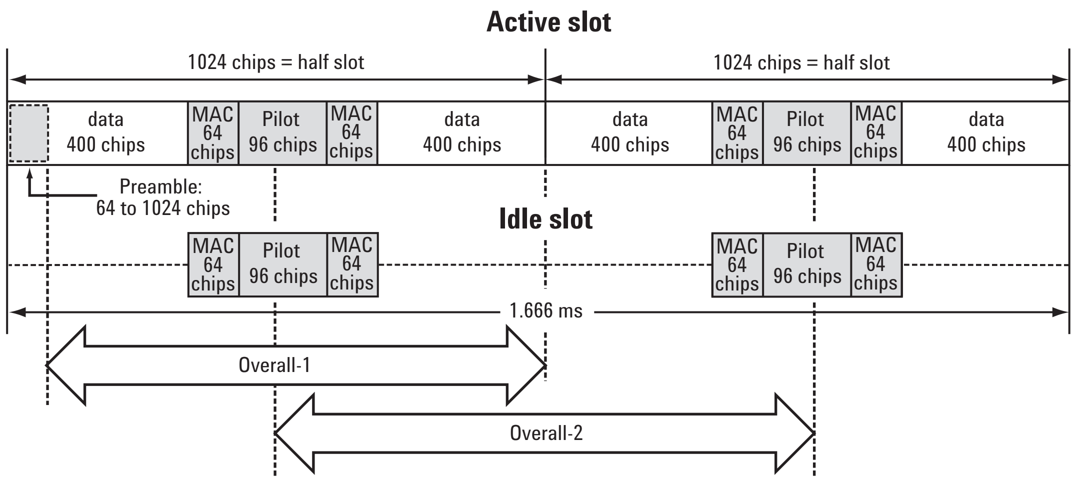


Figure 18. Overall rho

Overall 2

The equation for the second overall rho measurement is shown in Equation 3.

$$\rho\ \text{Overall -2} = \frac{\sum_{j=1}^{N}\left\{\left|\sum_{k=513}^{1536} Z_{j,k} R^{*}_{j,k}\right|^{2} \Big/ \sum_{k=513}^{1536}\left|R_{j,k}\right|^{2}\right\}}{\sum_{j=1}^{N}\sum_{k=513}^{1536}\left|Z_{j,k}\right|^{2}}$$

Equation 3

where $Z_{j,k}$ = z[1536(j-1)+k] is the k_{th} sample in the j_{th} 1024-chip interval of the actual output , and $R_{j,k}$ = r[1536(j-1)+k] is the corresponding sample of the ideal output. The sampling starts at $z(t_{513})$, which is the 513_{th} chip of a first half-slot and ends at $z(t_{1536N})$, which is the 513_{th} chip of a second half-slot. This measurement must be made over a time interval of at least two half-slots. (N = 2) The result for $\rho_{overall-2}$ must be greater than 0.912 and it is recommended for a good link (necessary for higher data rates) that $\rho_{overall-2}$ be greater than 0.97. See figure 19 for an example of an overall rho measurement.

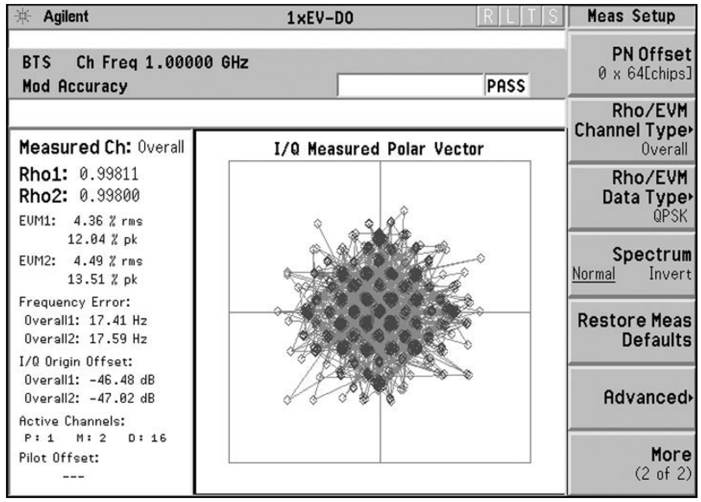


Figure 19. Modulation accuracy of composite forward link

Figure 19 shows the measured numerical results in the left window and the I/Q constellation in the right window. This shows the forward link's overall rho/EVM (both 1 and 2), frequency error, and I/Q origin offset. It also displays how many code channels are active in the pilot, MAC, and data channels.

2.2.2 Code domain power (CDP)

Like rho, CDP is a measure of correlated power. Instead of correlating an actual signal to an ideal signal, however, in CDP we are correlating the power in each Walsh code channel of a CDMA signal to the total integrated power over the entire channel. An interesting result of this difference is that now the desire is for the correlation coefficient to be small, or close to zero, instead of large, or close to one. The time and phase reference used in the CDP test is derived from the forward pilot channel and is used as the reference for demodulation of all other code channels. CDP is measured relative to total power in the carrier (displayed in dBc).

The CDP measurement verifies that the AN is transmitting the correct power in each of the code channels. In order to get the greatest efficiency from the Walsh codespace, each code channel must remain orthogonal from all other 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.

There are three code channels of interest in the forward link 1xEV-DO signal: the pilot, the MAC, and the traffic. Limits for the MAC and traffic channels are specified in the 1xEV-DO standard.

Pilot channel

The pilot is all zeros, with a zero Walsh cover. This results in transmission of just the final spreading sequence during the pilot channel TDM bursts. This test is to ensure that the pilot signal is sufficiently above the other uncorrelated noise in the signal to be “heard” by the AT. In figure 20, the pilot channel is marked by a different color to illustrate that it is active, whereas all other channels are inactive. It is detected as being active because its power is over a specified threshold. The standard does not require the measurement of pilot channel CDP. It is useful to measure, though, as the other two tests require the pilot channel to be transmitted properly.

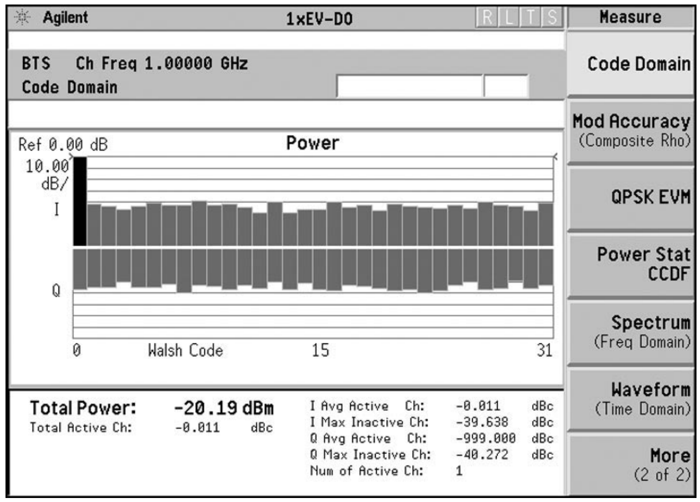


Figure 20. Code domain measurement with only pilot active

MAC channel

The MAC channel is composed of up to 60 orthogonal code channels – 1 RA and 59 RPC channels. The RA channel is assigned MAC index 4 and the RPC channels are assigned MAC index 5 – 63. The MAC indices are used to distinguish different ATs in the sector, by controlling their power. The Walsh code assigned to the MAC index values are determined using the following equations:

$W^{64}_{i/2}$ for MAC Index i = 0,2,4,...,62
$W^{64}_{(i-1)/2 + 32}$ for MAC Index i = 1,3,5,...,63

Even values of the MAC index are assigned to the I channel while odd values are assigned to Q. This test verifies that orthogonality is maintained among these code channels. The instrument measures the CDP of the signal after the 64-ary Walsh cover. The forward MAC must be configured so that the RA channel is active and at least one RPC channel is active. The object of this measurement is to make sure that the noise floor of the inactive channels is not too high. According to the 1xEV-DO standard, the CDP in all inactive channels must be at least 27 dB below the total MAC power. This corresponds to a correlation value, or ρ_{MAC} of 0.002 for the “off” channels. (0.002 is 27 dB down from unity, which would correspond to full power.)

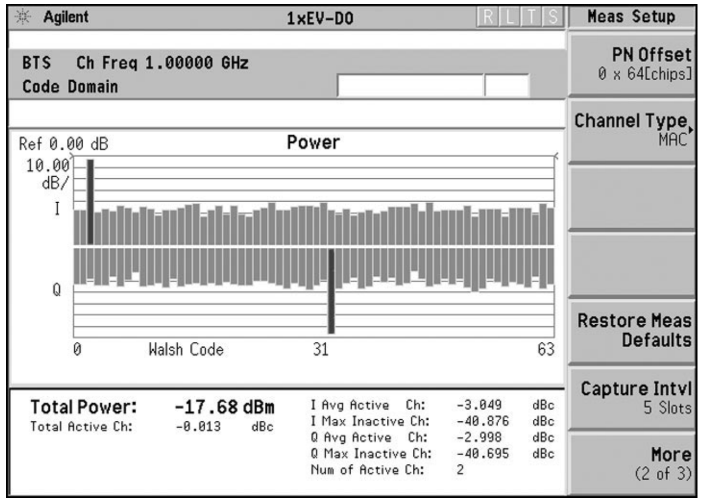


Figure 21. Code domain measurement with two MAC channels active

Notice there are four metrics in the lower right of figure 21. These four metrics give the average power in the active I and Q code channels, as well as the maximum power in the inactive channels. In this case, the inactive channels are 40 dB below the carrier, while the active channels are 3 dB below carrier. This signal therefore passes the 27 dB limit test.

Traffic channel

The control and forward traffic channels are composed of 16 orthogonal code channels, each with an I and a Q component. This test verifies that the allocated power for each code channel is within a specified tolerance range. The instrument measures the traffic signal after the 16-ary Walsh cover. Note: these are 16 error-corrected versions of the same data stream, not 16 different data streams to different users. This is unlike cdma2000, in which orthogonal codes in the traffic channel are used to distinguish different mobile stations. Each channel must be within ±0.5 dB of $1/32^{nd}$ of the total nominal power, since 16 codes on the I and 16 codes on the Q equals 32 equally powered code channels. In terms of power correlation, the value for ρ_{DATA} must be between 0.02875 and 0.035. The mathematics is simple to show:

1/32 = 0.03125
0.05 dB up is .035
0.05 dB down is 0.02875

The preamble is not included in traffic channel measurements. Three separate tests are required in the 1xEV-DO standard for traffic channel code domain power. The above power requirement must be met with the traffic configured for the following data rates:

Test 1 – 614.4 kbps
Test 2 – 1,843.2 kbps
Test 3 – 2,457.6 kbps

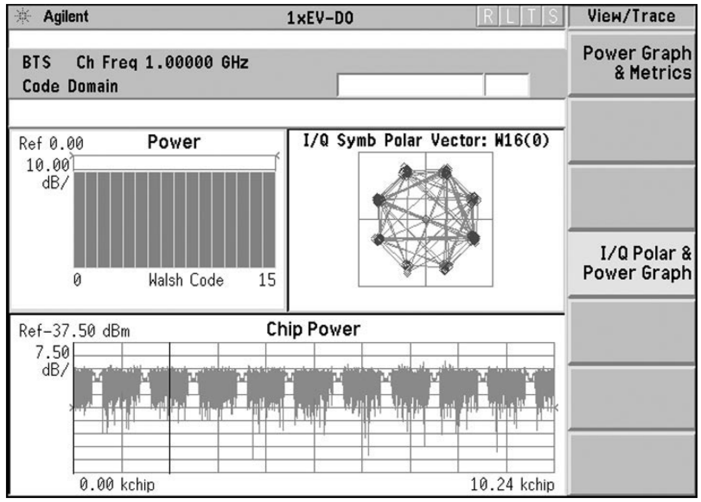


Figure 22. Code domain measurement with traffic channels active with 8PSK modulation

In figure 22, the upper left window shows a power graph, the upper right shows the symbol I/Q constellation of data in 8PSK, and the lower window shows chip power versus time. (The blank sections are the pilot/MAC bursts, where no data is transmitted.) This view offers qualitative information more than quantitative information. It would be obvious if the CDP were off by more than 0.5 dB in any of the traffic channels. Also, if there were significant modulation errors, they would show up in the constellation diagram. It is useful to have the ability in your instrument to switch displays between tabular numerical results and views like this one, which show a great amount of easily applied information on one screen.

2.2.3 Error vector magnitude (EVM)

The EVM measurement is virtually identical to the rho measurement for multi-channel configurations. In fact, it is possible to mathematically derive EVM when the rho value is known.

The equation for converting rho to EVM is:

$$EVM = \sqrt{\frac{1}{\rho} - 1}$$

See Appendix C for a brief proof of this derivation. While EVM is not specified in the 1xEV-DO standard, it is a common modulation quality metric used in many of the major digital communication formats. Like rho, EVM can be measured for a single channel (called QPSK EVM) or multiple channels (called composite EVM.) QPSK EVM verifies the waveform quality of the RF modulation in a single channel, while composite EVM and rho verify the waveform quality of the RF modulation plus spreading and scrambling. See figure 23 for an example of a QPSK EVM measurement.

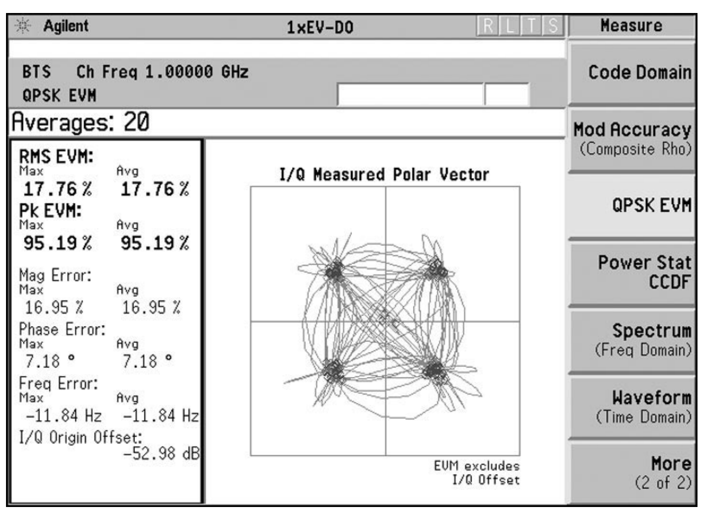


Figure 23. QPSK EVM measurement results

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	8 PSK
1843.2	3072	2/3	1.0	1	8 PSK
1228.8	4096	1/3	1.02	2	16 QAM
2457.6	4096	2/3	1.0	1	16 QAM

Appendix B

Transmitter spurious emission limits

Table 1 of 2. Band classes 0, 2, 3, 5, 7, and 9 transmitter spurious emission limits

For |Δf| Within the range	Emission limit
750 kHz to 1.98 MHz	-45 dBc / 30 kHz
1.98 MHz to 4.00 MHz	-60 dBc / 30 kHz; $P_{out} \geq 33$ dBm -27 dBm / 30 kHz; 28 dBm $\leq P_{out} < 33$ dBm -55 dBc / 30 kHz; $P_{out} < 28$ dBm
> 1.98 MHz within 832 MHz to 834 MHz 838 MHz to 846 MHz 860 MHz to 870 MHz (Band Class 3 only)	-60 dBc / 30 kHz
3.25 MHz to 4.00 MHz (Band Class 7 only)	-46 dBm / 6.25 kHz
> 4.00 MHz (ITU Category A only)	-13 dBm / 1 kHz; 9 kHz < f < 150 kHz -13 dBm / 10 kHz; 150 kHz < f < 30 MHz -13 dBm / 100 kHz; 30 MHz < f < 1 GHz -13 dBm / 1 MHz; 1 GHz < f < 5 GHz
> 4.00 MHz (ITU Category B only)	-36 dBm / 1 kHz; 9 kHz < f < 150 kHz -36 dBm / 10 kHz; 150 kHz < f < 30 MHz -36 dBm / 100 kHz; 30 MHz < f < 1 GHz -30 dBm / 1 MHz; 1 GHz < f < 12.5 GHz

Note: All frequencies in the measurement bandwidth shall satisfy the restrictions on |Δf| where Δf = center frequency - closer measurement edge frequency (f). Compliance with the -35 dBm / 6.25 kHz limit is based on the use of measurement instrumentation such that the reading taken with any resolution bandwidth setting should be adjusted to indicate spectral power in a 6.25 kHz segment. For additional band class 3 emissions limits, see Chapter 3 of [3].

Band class	Description
0	800 MHz
2	TACS
3	JTACS
5	450 MHz
7	700 MHz
9	900 MHz

Table 2 of 2. Band classes 1, 4, 6, and 8 transmitter spurious emission limits

For |Δf| Within the range	Emission limit
885 kHz to 1.25 MHz	-45 dBc / 30 kHz
1.25 MHz to 1.98 MHz	More stringent of -45 dBc / 30 kHz or -9 dBm / 30 kHz
1.25 to 1.45 MHz (Band Class 6 only)	-13 dBm / 30 kHz
1.45 to 2.25 MHz (Band Class 6 only)	-[13 + 17 x (Δf – 1.45 MHz)] dBm / 30 kHz
1.98 MHz to 2.25 MHz	-55 dBc / 30 kHz; P_{out}t ≥ 33 dBm -22 dBm / 30 kHz; 28 dBm ≥ P_{out} < 33 dBm -50 dBc / 30 kHz; P_{out} < 28 dBm
2.25 MHz to 4.00 MHz	-13 dBm / 1 MHz
> 4.00 MHz (ITU Category A only)	-13 dBm / 1 kHz; 9 kHz < f < 150 kHz -13 dBm / 10 kHz; 150 kHz < f < 30 MHz -13 dBm / 100 kHz; 30 MHz < f < 1 GHz -13 dBm / 1 MHz; 1 GHz < f < 12.5 GHz
> 4.00 MHz (ITU Category B only)	-36 dBm / 1 kHz; 9 kHz < f < 150 kHz -36 dBm / 10 kHz; 150 kHz < f < 30 MHz -36 dBm / 100 kHz; 30 MHz < f < 1 GHz -30 dBm / 1 MHz; 1 GHz < f < 12.5 GHz

Note: All frequencies in the measurement bandwidth shall satisfy the restrictions on |Δf| where Δf = center frequency - closer measurement edge frequency (f). The –9 dBm requirement is based on CFR 47 Part 24 –13 dBm/12.5 kHz specification. For additional band class 6 emissions limits, see Chapter 3 of [3].

Band class	Description
1	1900 MHz
4	Korean PCS
6	2 GHz
8	1800 MHz

Appendix C

Converting rho to EVM [6]

Let $R(t)$ be the complex envelope of the ideal transmitter signal, referred to as the reference signal
Let $Z(t)$ be the actual signal from the transmitter.
Model $Z(t) = R(t) + E(t)$ where $E(t)$ is an error vector.

$$(EVM)^2 = \frac{\int_0^T |Z(t - R(t)|^2 \, dt}{\int_0^T |R(t)|^2} = \frac{\int_0^T |E(t)|^2 \, dt}{\int_0^T |R(t)|^2 \, dt}$$

But the definition of rho is the following (* indicates complex conjugate):

$$\rho = \frac{\left| \int_0^T R(t)[R(t)+E(t)]^* dt \right|^2}{\int_0^T |R(t)|^2 \, dt \int_0^T |R(t)+E(t)|^2 \, dt}$$

Expanding the numerator of the rho equation:

$$\int_0^T R(t)[R(t)+E(t)]^* dt = \int_0^T |R(t)|^2 \, dt + \int_0^T R(t)\, E^*(t)\, dt$$

If we assume that $E(t)$ has zero mean value and is independent of $R(t)$, then

$$\int_0^T R(t)\, E^*(t)\, dt \approx \int_0^T R(t)\, dt \int_0^T E^*(t)\, dt \approx 0$$

$$\int_0^T |R(t)+E(t)|^2 \, dt = \int_0^T |R(t)|^2 \, dt + \int_0^T |E(t)|^2 \, dt - 2\Re\varepsilon \int_0^T R(t)\, E^*(t)\, dt$$

$$\approx \int_0^T |R(t)|^2 \, dt + \int_0^T |E(t)|^2 \, dt$$

By substituting the above relationships into the rho equation, we get

$$\rho = \frac{\left| \int_0^T |R(t)|^2 \, dt \right|^2}{\left| \int_0^T |R(t)|^2 \, dt \right|^2 + \int_0^T |R(t)|^2 \, dt \int_0^T |E(t)|^2 \, dt}$$

This can be rewritten as

$$\rho \approx \frac{1}{1 + \frac{\int_0^T |E(t)|^2 \, dt}{\int_0^T |R(t)|^2 \, dt}}$$ or as the following $$\rho \approx \frac{1}{1+(EVM)^2}$$ or $$EVM = \sqrt{\frac{1}{\rho} - 1}$$

Appendix D

Agilent solutions for 1xEV-DO AN test

Agilent provides a complete solution for 1xEV-DO base station test, including design software, signal generation, and signal analysis. This section provides an introduction to Agilent products that can help develop and test your 1xEV-DO BTS or power amplifier.

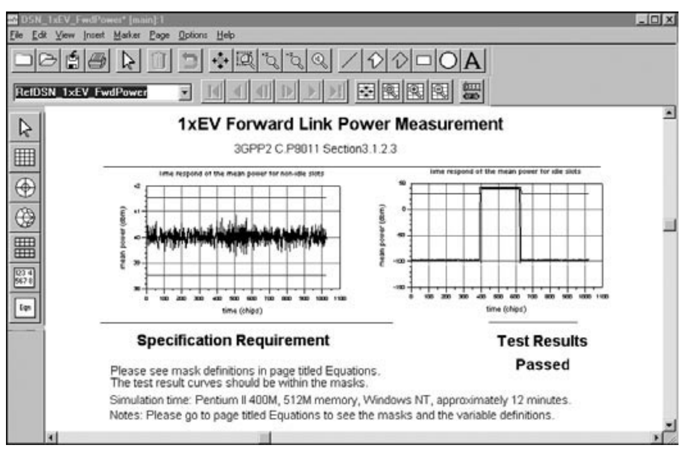
Design software and simulation

Agilent Advanced Design System (ADS) is a powerful electronic design automation software system that includes a broad array of RF, analog, and DSP modeling and simulation capability, all accessible in a single design environment. Design libraries created for use with ADS provide powerful wireless design and verification capability for many of today's complex wireless signal formats, including 1xEV-DO.

The 1xEV-DO Design Library released in December 2001 as an add-on to the ADS 2001 is focused on full forward link system functionality. The models in this release are upgraded with channel coding/decoding, receiver blocks, subsystems, test and verification designs, and BER performance. The library includes new projects for AN and AT transmitters and receivers as well as upgraded projects for PA testing and signal generation. The 1xEV signal generation in the new release is aligned with the Agilent signal generator and signal analyzer solutions. (See below)

Wireless verification capability extends beyond simulation verification when using the ADS design libraries. “Real-world” wireless signals can be created in ADS and downloaded into the Agilent ESG signal generator. This powerful, integrated capability can create a test signal for early prototype testing and virtual design verification. This same signal can also be passed through a device-under-test (DUT), measured with an Agilent vector signal analyzer (VSA) or spectrum analyzer (PSA), and brought back into ADS for seamless verification between the design and test domains.

For more information on ADS, please visit our web site at
www.agilent.com/find/advanced



ADS Forward link power simulation

Signal generation

Signal Studio is a suite of PC based software tools used in conjunction with Agilent hardware to create waveforms for popular communication formats. Signal Studio has an intuitive, easy-to-use graphical user interface that allows the user to set various signal parameters for flexible waveform generation. The waveforms are downloaded to an Agilent signal generator, and then the instrument is automatically setup to generate the signal.

Signal Studio-1xEV-DO simplifies the creation of 1xEV-DO forward and reverse link test signals. Instead of spending valuable time hand coding proprietary test signals, use Signal Studio-1xEV-DO to quickly configure standard-based test signals. This software features an intuitive user interface, which allows the designer to quickly create 1xEV-DO frames by configuring channels in each time slot.

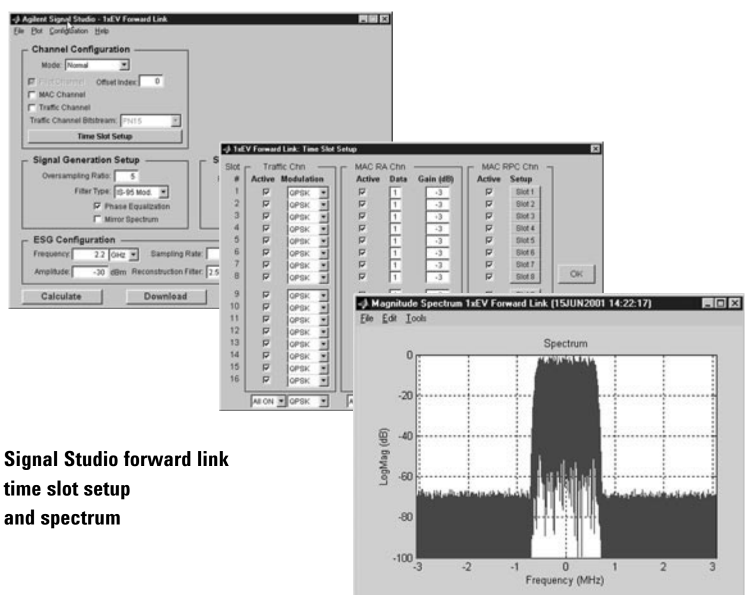
- Pilot, MAC, & traffic channels supported in forward link
- Pilot, MAC, ACK, & data channels supported in reverse link
- Continuous pilot channel operating mode
- Baseband signal filtering: rectangular, IS-95 standard/modified, and phase EQ
- Mirrored spectrum signal generation
- Plot I/Q signals, spectrum, and CCDF curves
- Specify noise level in idle slot

For more information on Signal Studio, see our web site at **www.agilent.com/find/signalstudio**

After the signal is configured in Signal Studio, it is downloaded into the arbitrary waveform memory of the ESG. The New Agilent E4438C ESG vector signal generator sets a new level of performance by offering exceptional baseband signal generation operation. Its wide RF modulation bandwidth, fast sample rate, and large memory are key for evaluating the performance of 2.5G, 3G, and broadband wireless communications systems and components.

For more information on the ESG, please see our web site at **www.agilent.com/find/esg**

ESG 4438C vector signal generator

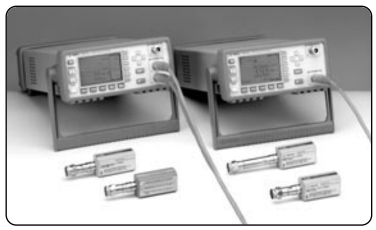


Signal Studio forward link time slot setup and spectrum

Power meters and sensors

Agilent EPM-P high-performance, single and dual-channel power meters and E9320 peak and average power sensors provide a low-cost solution for peak, peak-to-average ratio, average power and time-gated measurements for complex modulation formats like cdma2000 and 1xEV-DO. The E9320 power sensors come with a choice of video bandwidth to suit your 2G/3G applications and maximize the usable dynamic range; therefore, one sensor can cover all your 2G/3G bandwidth requirements. They include analyzer software for statistical and pulse analysis, as well.

For more information on power meters and sensors, please see our web site at **www.agilent.com/find/powermeters**



EPM-P Power meter with E9320 power sensors

Signal analyzers

Agilent offers two families of signal analyzers to test 1xEV-DO base station transmitters, the VSA series and the PSA series. The PSA series is the industry's most accurate spectrum analyzer, featuring comprehensive one-button power measurements, an in-depth phase noise measurement capability, and an optional built-in FFT mode to measure digitally modulated signals. The VSA series is designed to provide confidence in manufacturing test, offering fast in-band modulation analysis, a new baseband I/Q input option, and new software support for increased flexibility and enhanced demodulation capability. Both analyzers help you evaluate the critical margins and tradeoffs in base station performance, efficiency and cost.

For more information on Agilent signal analyzers, see our web sites at **www.agilent.com/find/vsa** and **www.agilent.com/find/psa**

VSA vector signal analyzer

PSA performance spectrum analyzer

References

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[2] Designing and Testing cdma2000 Base Stations
Agilent Technologies Application Note 1357, literature number 5980-1303E

[3] 3rd Generation Partnership Project 2. Recommended Minimum Performance Standards for cdma2000 High Rate Packet Data Access Network. Release TSG-C C.S0032. December 7, 2001

[4] 3rd Generation Partnership Project 2. cdma2000 High Rate Packet Data Air Interface Specification. Release C.S0024 Version 2.0. October 27, 2000

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

[6] Derivation provided by Ray Birgenheier, Agilent Technologies

Acronym glossary

1xEV-DO	1x Evolution Data Only (originally called High Rate Packet Data System)
3GPP2	Third-Generation Partnership Project 2
ACP	adjacent channel power
ACPR	adjacent channel power ratio
AN	access network (1xEV-DO equivalent of base station)
AT	access terminal (1xEV-DO equivalent of mobile station)
CCDF	complementary cumulative distribution function
CDMA	code domain multiple access
cdma2000	name identifying the EIA/TIA standard (IS-2000) for 3G (3GPP2)
CDP	code domain power
DSP	digital signal processing
EIA	Electronic Industries Association
EVM	error vector magnitude
I/Q	in phase/quadrature
MAC	Medium Access Control
PSK	phase shift keying
PvT	power versus time
QAM	quadrature amplitude modulation
QPSK	quadrature phase shift keying
RA	reverse activity
RMS	root mean squared
RPC	reverse power control
RRI	reverse rate indication
SEM	spectrum emissions mask
SMS	short message service
TDM	time division multiplexing
TIA	Telecommunications Industries Association
W-CDMA	wideband-code division multiple access (3GPP system)

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