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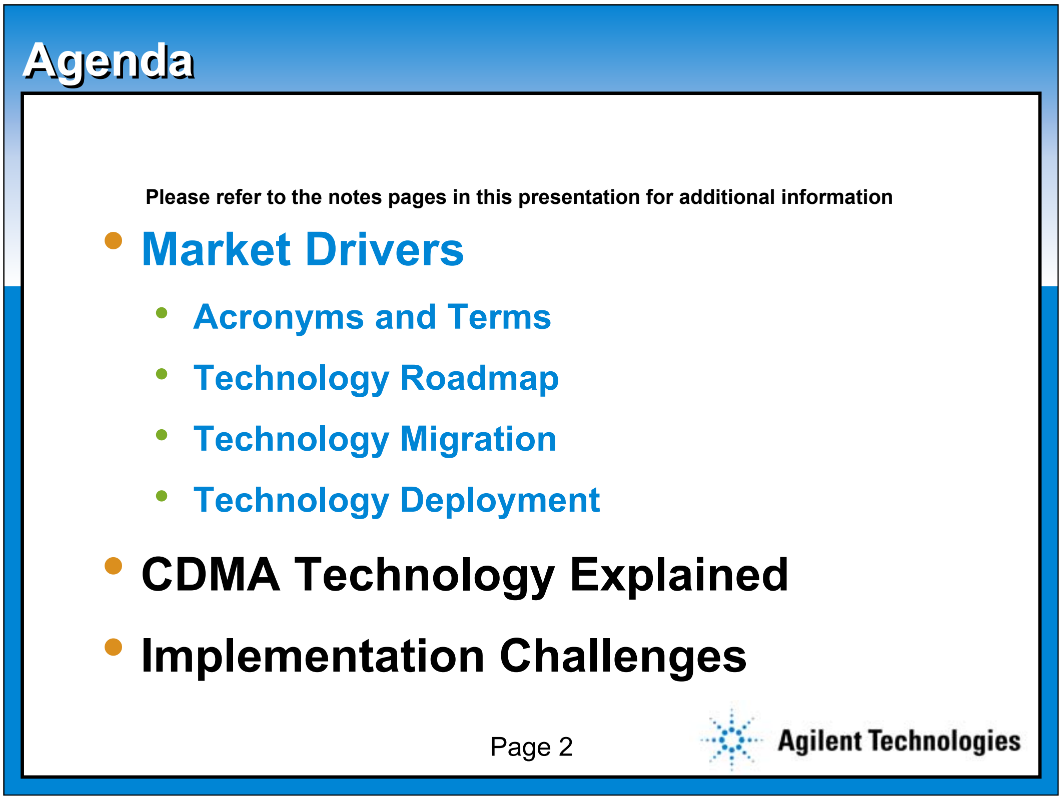
2001 Wireless Technology Seminar

W-CDMA Basics

presented by:

Moray Rumney


Agenda
Please refer to the notes pages in this presentation for additional information
Market Drivers
Acronyms and Terms
Technology Roadmap
Technology Migration
Technology Deployment
CDMA Technology Explained
Implementation Challenges
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Acronyms and Terms (3GPP)

- ITU - International Telecommunications Union
- IMT-2000 - International Mobile Telecommunications 2000
- ETSI - European Telecommunications Standards Institute
- 3GPP - Third Generation Partnership Project
- UMTS - Universal Mobile Telecommunications System (synonymous with W-CDMA)
- UTRA - Universal Terrestrial Radio Access
- FDMA - Frequency Division Multiple Access
- TDMA - Time Division Multiple Access
- CDMA - Code Division Multiple Access
- W-CDMA - Wideband CDMA, as developed by 3GPP
- TD-SCDMA - Time Domain - Synchronized CDMA
- UE - User Equipment (mobile terminal)
- Node B - The Base Station in a W-CDMA network

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Here is a list of some of the more common W-CDMA acronyms and terms. Many come directly from standards. Others come more from the ITU and its documentation.

The ETSI vocabulary document is 01.04.

The 3GPP vocabulary document is 21.905

The 3GPP documents can be found at www.3gpp.org

What is the market force for 3G?

W-CDMA

- Europe - Data
- Japan - Data, Voice Capacity, worldwide market

cdma2000

- US - Voice Capacity, some Data
- Korea - Voice Capacity, Data

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The initial force behind the development of 3G systems originated in Japan where potential capacity of the current (PDC) system was seen to be a limit on future growth of mobile communications.

Europe leads the world in data delivery. The Wideband CDMA system proposed by NTT DoCoMo was recognized as a major improvement over GSM for data delivery. While W-CDMA will also offer voice services, data is seen as the path to the future.

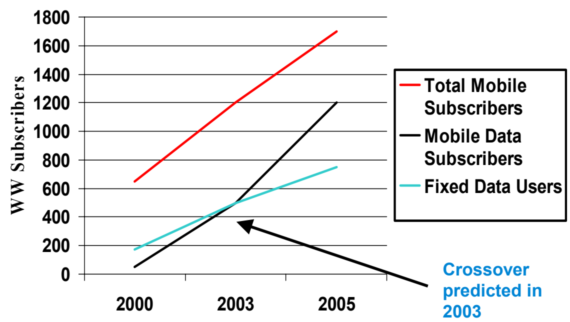
Within the United States, there are today several different, incompatible, systems in use. One requirement for a new system was to offer a compatible path from today's systems whilst providing better capacity and improved data facilities than the systems currently in use. The cdma2000 system - heavily based on IS-95 - has achieved rapid acceptance in the IS-95 community. There is no upgrade path from the other US technologies to cdma2000.

Although IS-95 began in the US, Korea has the highest concentration of IS-95 users in the world. They will continue in leading this technology with the rollout of cdma2000.

The 3GPP W-CDMA system is being designed to inter-work with GSM, although here is no direct relationship between the GSM and W-CDMA air interfaces as there is with IS-95 and cdma2000.

Market Demand for Data Services

- Demand for wireless data services expected to grow significantly
- Driven by new services:
  - ✓ e-mail/messaging
  - ✓ m-commerce
  - ✓ location-based services
  - ✓ entertainment



Source: Arc Group, Oct. 2000

- Low availability of applications will limit the customer use of data services
- Network Operators are looking to promote data services to increase revenues

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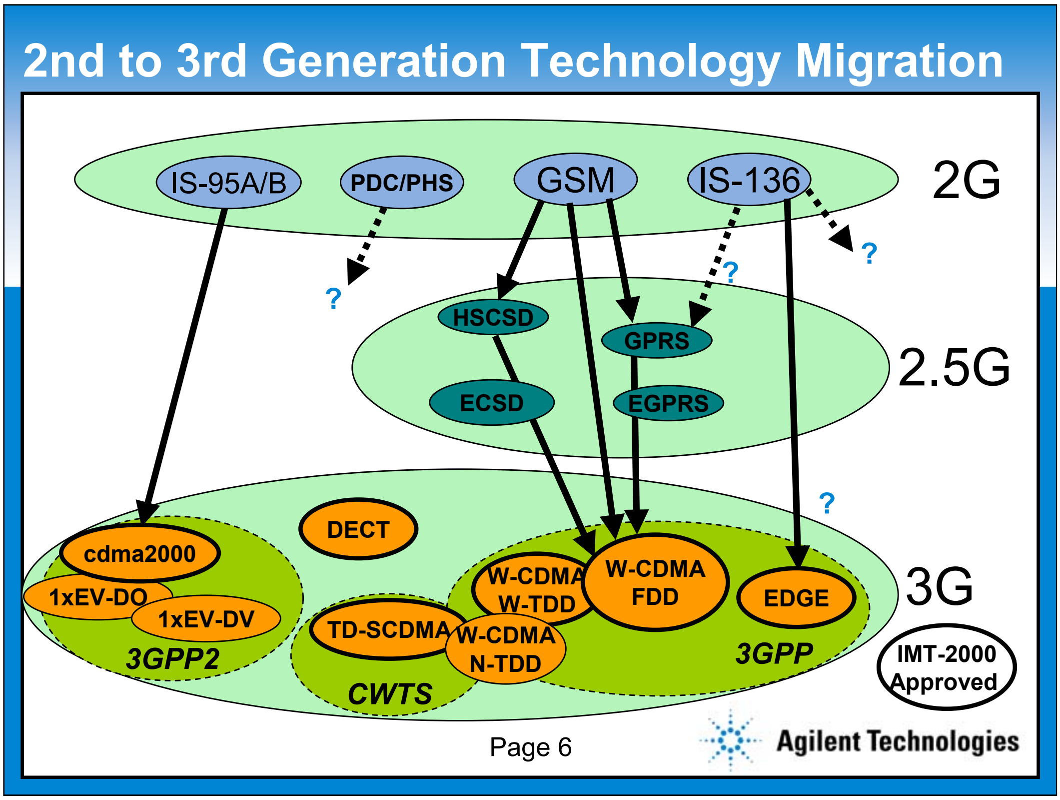
Data services are seen as a key growth area for wireless mobile communications. The huge growth in the internet market is seen as key driver for the wireless market. The ARC Group predicts total mobile data users will be 1.2 billion worldwide by 2005 with mobile data users exceeding fixed in 2003. Wireless data revenues are predicted to exceed wireless voice revenues in 2005 (Ovum). Fixed Internet subscribers will grow to about 750 million during same time.

Even if the market acceptance is slower than shown, which is highly likely, wireless data is still a significant opportunity that is important to be investing in today to carve out future market positions. The market acceptance will depend on several factors such as pricing, smarter internet applications, new mobile applications, resolution of technical communications problems, handset availability and ease of use.

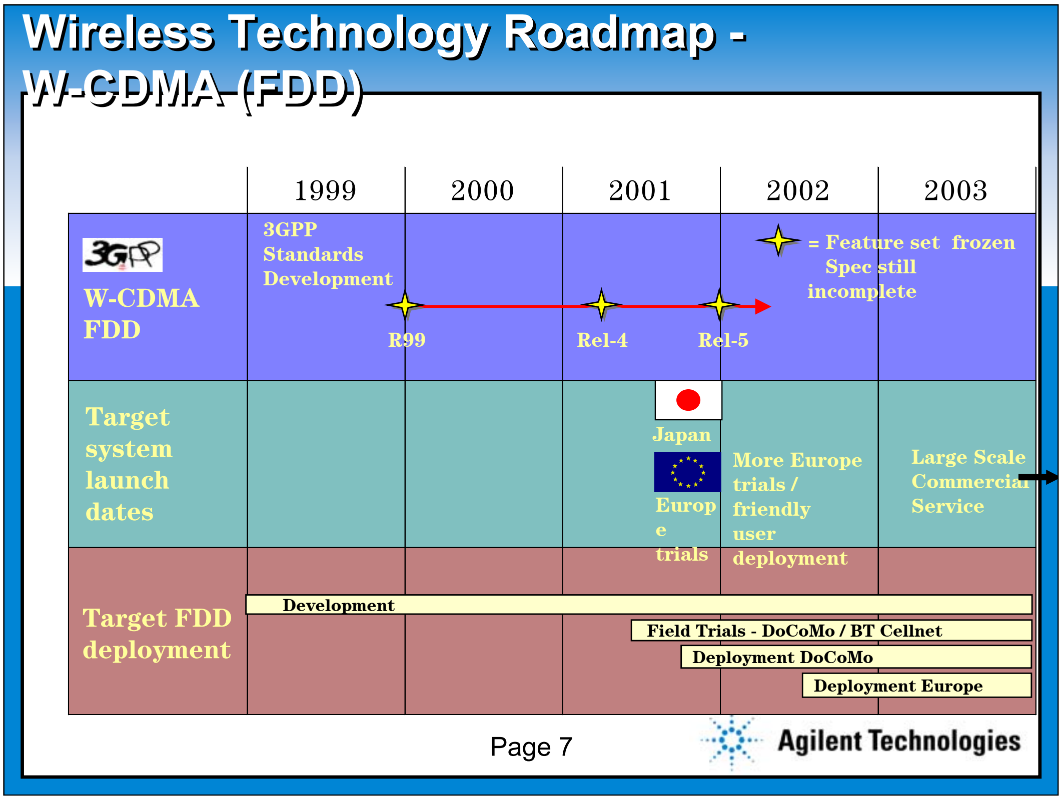
Although GPRS has been slow to take off in GSM markets, it is still expected to be the forerunner of data delivery prior to the introduction of W-CDMA. GPRS deployment has been delayed over original expectations but has started commercial service during 2001.



A look at the evolutionary path from 2G to 3G shows the likely migration path for service providers of each major format. The W-CDMA system looks like it will receive the most subscribers as operation is started in the IMT-2000 band. The SR3 (Spread Rate 3) multi-carrier standard appears to be dead. The delivery of higher data rates for the current IS-95 community will be met with 1x Evolution (1xEV). The first version of this is Data Only (1xEV-DV). Future versions of this will be capable of data and voice (1xEV-DV). The IS-136 operators do not have a direct evolution path to 3G. Instead, they will transition first to GPRS-capable networks then on to W-CDMA.

EDGE, originally envisaged as a high data rate, evolutionary path for GSM, was for a while adopted as a way for IS-136 operators to offer data services to existing subscribers. This now looks much less certain to happen but it is still expected that EDGE will be implemented to complement data services in 2G and combined 2G/3G networks. Asymmetric EDGE/GSM with EDGE on the downlink and GMSK on the uplink is an attractive way of getting value out of EDGE technology without complicating the mobile.

Note, there is no technical evolution from PDC to W-CDMA, and there are no plans for dual-mode PDC/W-CDMA terminals unlike most all other evolution paths.

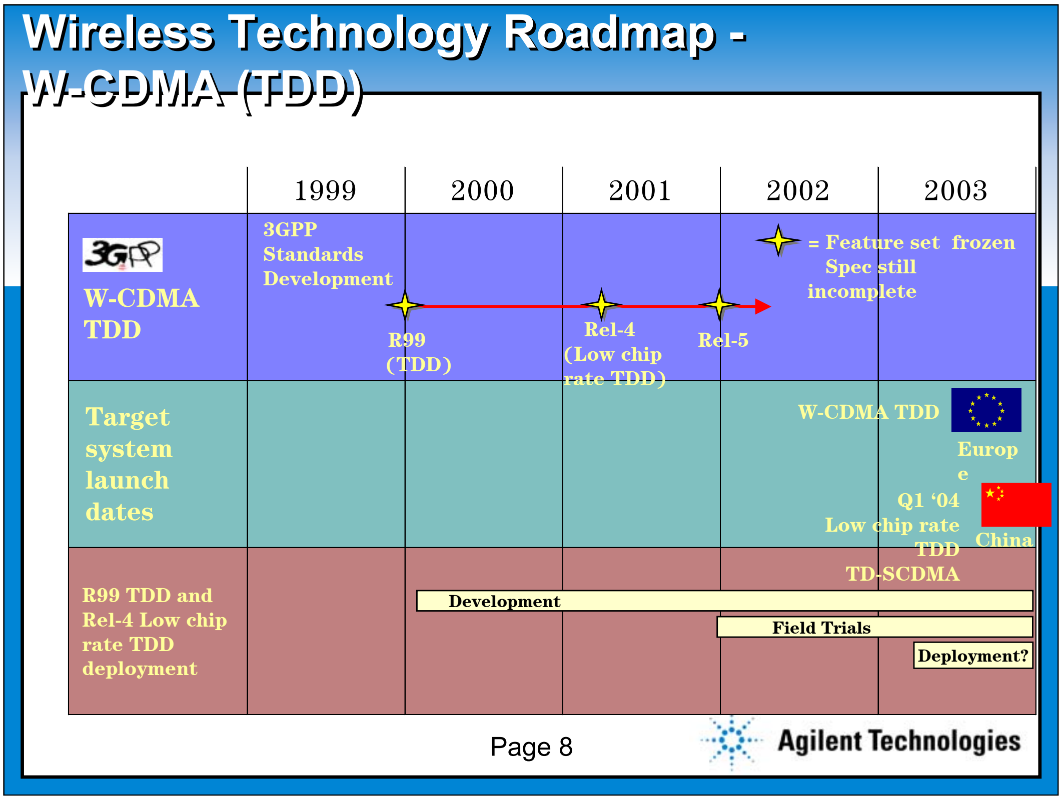


The feature set for the first W-CDMA release - called Release 99 - was frozen in December 1999. Since then considerable work has been done to draft the detailed standard which consists of over 400 documents. The stability of the Dec 2000 version of R99 is sufficient for Layer 1 equipment to be built. Delays in the standards work resulted in a re-naming of future releases, R00 is now Rel-4, R01 becomes Rel-5 etc. Typically there is at least two years delay between freezing the feature set of a release and finishing the drafting work and starting deployment.

NTT DoCoMo plans commercial launch their W-CDMA system in October 2001, although the stability of the specifications and availability of equipment is a major issue. The Japanese ministry of post and telecommunications wants to delay launch until early 2002 or even later in order to ensure stability and quality of service. This service will be based on a minimal version of R99, with no inter-operability to GSM.

The Spanish operator Xfera has announced plans for service in August, 2001, based on the terms of the 3G license, but this schedule is not feasible. All UK and German operators paid approximately $6B for licenses and they are under severe pressure to get revenues from this as quickly as possible.

Initial deployment in GSM markets will be based on a limited set of R99 features, however, unlike Japan, it is essential that GSM inter-operability is included.



The original UMTS standard was a battle between competing FDD and TDD technologies. In the end, both were chosen, with FDD being applicable to the paired spectrum bands, and the TDD to the unpaired bands. Co-existence of TDD and FDD in the paired bands is not ruled out, however there are severe technical difficulties. Hence the immediate opportunity for TDD appears to be limited to the much smaller unpaired bands. The original 3GPP TDD uses the 3.84 Mcps rate, however there is also a narrower rate of 1.28 Mcps being developed in China called TD-SCDMA. This has also been approved by the ITU as an IMT-2000 standard. 3GPP TDD and TD-SCDMA are very similar, and Rel-4 of the 3GPP specification will include a harmonized "low chip rate" TDD option, based on the TD-SCDMA specification. Due to China's population, TD-SCDMA has huge potential if it is adopted there, especially for low mobility apps.

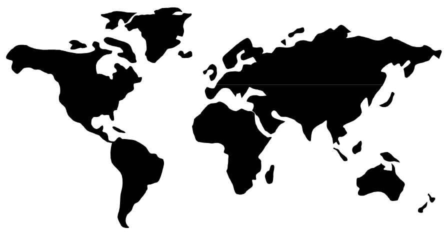
Either TDD system could be a candidate for use in unpaired spectrum in Europe as licenses were not specific as to which TDD technology applied.

R99 includes the 3.84 TDD specification although it is generally agreed it is at least a year behind FDD developments. TDD is being considered by the European operators whose licenses include unpaired spectrum. TDD is useful for applications where the uplink and downlink are unbalanced, such as for Internet access, though synchronization issues may mean the network is fixed at near the 50/50 operating point.

Where will CDMA technology be deployed?

W-CDMA

- Europe
- Japan
- Korea
- USA
- China?



cdma2000

- USA
- Latin America
- Korea
- Japan
- East Europe?
- China?

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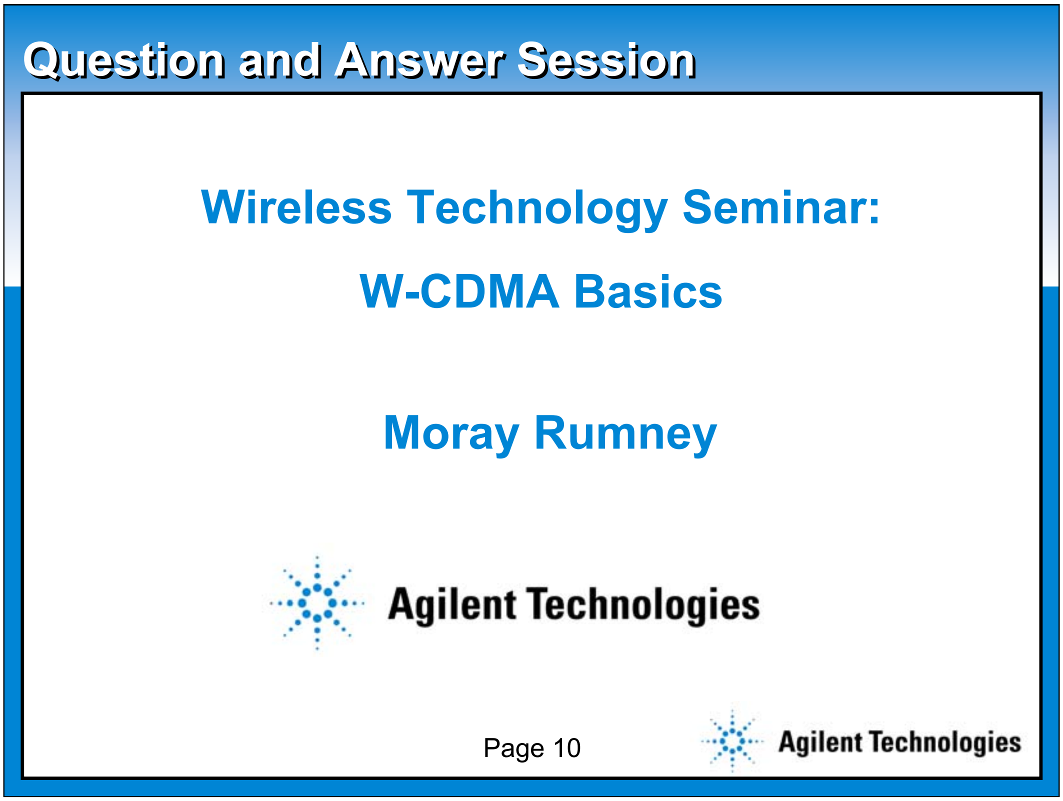
In Europe, many GSM operators will migrate to W-CDMA for increased data capabilities. Voice capacity is a need for Japan's PDC network, but improved data capability is seen as a major driver for early deployment in the near future.

Korea is evaluating W-CDMA along with cdma2000. The Korean government has ruled at least one of the three 3G licenses will go to a service provider using cdma2000 technology. China is also exploring several options including W-CDMA, cdma2000, and TD-SCDMA.

In the Americas, existing IS-95 operators will migrate to cdma2000 for increased voice capacity and the added bonus of data capabilities. Korea has the highest concentration of IS-95 users in the world. They will continue in this technology with the rollout of cdma2000. Japan will deploy cdma2000 in the IMT-2000 band boosting existing IS-95 networks.

Existing NMT systems that operate in the 450 MHz band are being replaced with newer generation (2, 2.5,3G) systems based on GSM and perhaps even cdma2000 in Eastern Europe. If China deploys a cdma2000 system, it will be a new installation in an existing frequency band. The cdma2000 systems in the rest of the world will be deployed on top of existing IS-95 systems.

Also, recent announcements from AT&T and NTT DoCoMo mean that W-CDMA is now planned to be deployed in the USA instead of (or as well as) EDGE.


Question and Answer Session
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Agenda

- Market Drivers
- CDMA Technology Explained
  - Why CDMA?
  - CDMA Frequency reuse
  - Rejection of unwanted signals
  - OVSF Spreading codes
  - Code domain power analysis
- Implementation Challenges

Why CDMA?

Advantages

- Re-use of adjacent cell frequencies enhances system capacity
- Air interface is software configurable for different data rates
- Broadband channel less prone to frequency dependent fading

Challenges

- High and linear dynamic range required for mobile RX and TX
- High speed accurate power control essential for high capacity
- No "time" to monitor neighbor cells for handover
- Operation and optimization of the network will be difficult

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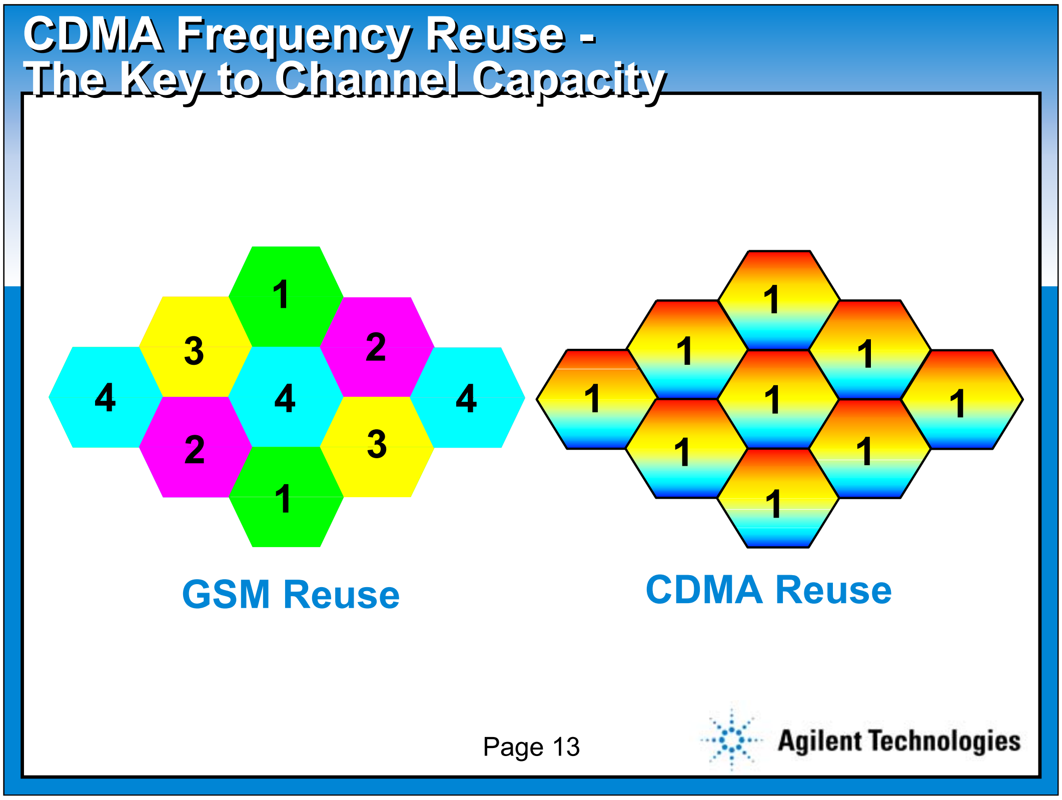
CDMA technology offers a number of advantages over conventional FDMA and TDMA access technologies, however these advantages do not come for free. The basic complexity of layer 1 in CDMA is very high, although once the initial design has been integrated into high-volume ASICs, the costs will come down.

CDMA effectively makes use of a new "domain" previously unused in other mobile communications technologies. This is the ability to give each user in each cell a unique "code" or signature that allows its signal to be differentiated from another user on the same frequency in the same or adjacent cell.

Another key advantage is that since the air interface operates at the system chip rate, it can be software configured using different code lengths to operate at multiple different user data rates. Making such data rate modifications in other systems requires major re-work as evidenced by GSM multi-slot and EDGE activities. Comparisons of 8 slot GPRS and EDGE mobiles as challengers to W-CDMA are unrealistic.

However, the challenges in implementing W-CDMA are significant. Some of the most difficult are related to power control and the ability to manage radio resources for the purpose of capacity management and mobility. The complexity of "compressed mode" - which enables measurement of adjacent cells on different frequencies during a call for mobility management purposes - is an example.

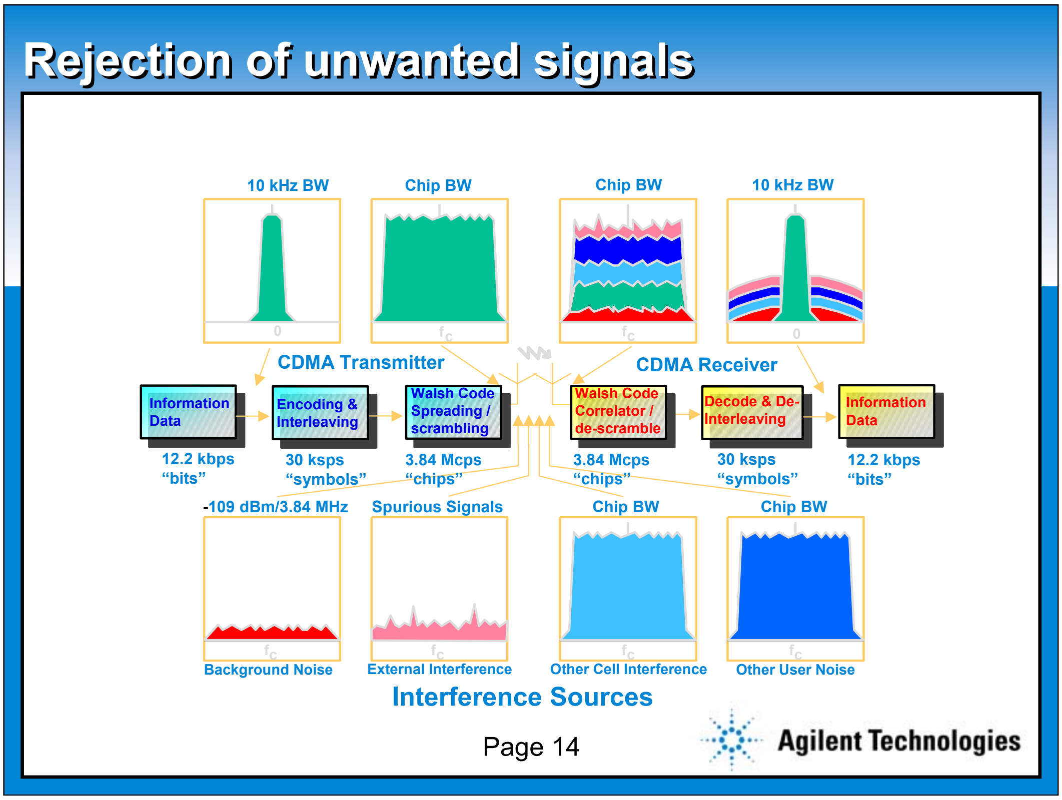


The capacity advantage of CDMA is realized by many technical innovations. One of the most important is the reuse of the same frequency in every sector of every cell. In IS-136 and analog cellular systems, there is a 7 cell repeat factor, with 3 sectors. This means that only one out of every 21 channels is available to each sector. GSM usually uses a repeat of 4, with 3 sectors, for a reuse of one out of twelve.

This is not the only factor that has influence on network capacity, but a working estimate based on extrapolation of real networks (rather than theoretical studies) is that cdma2000 and W-CDMA will be about the same capacity, which is about twice that of GSM and IS-95.

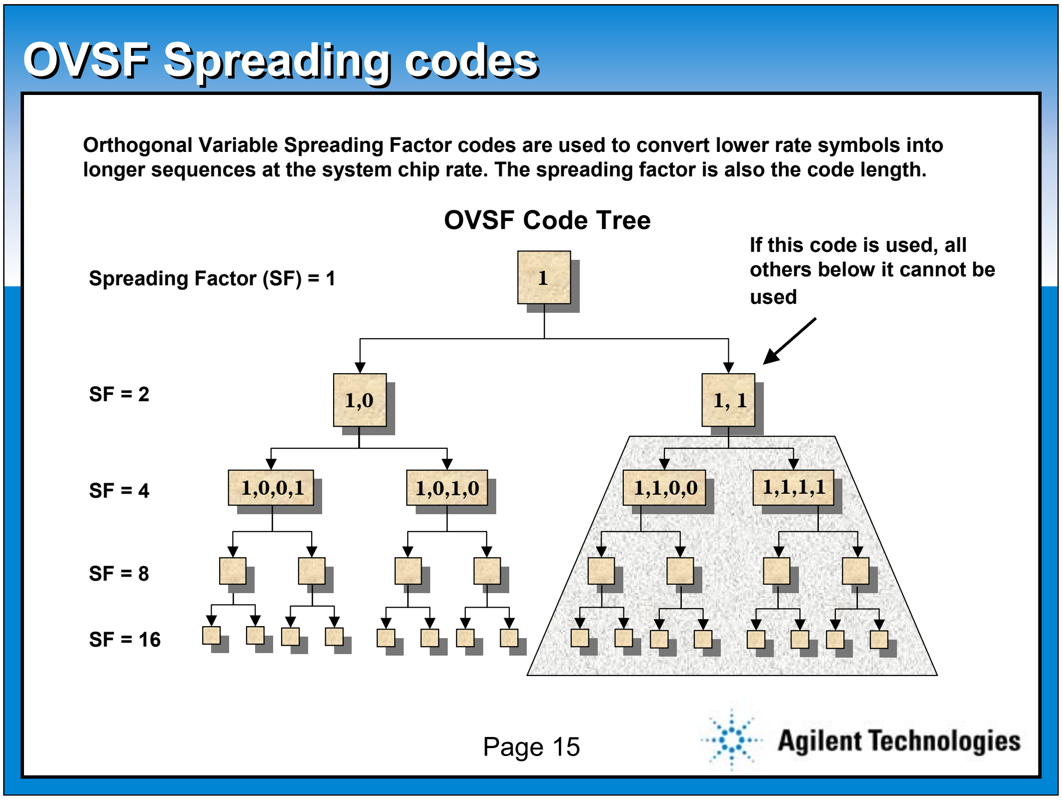
The use of different codes to differentiate CDMA users on the same frequency is a bit like the use of different languages. Two people talking at the same time and rate in the same language will be hard to comprehend, but if one were speaking German and the other Cantonese, the receiver could “tune in” to one language or the other and be much more able to comprehend each speaker independently.

This analogy also leads to another key requirement of CDMA and that is that for best performance, all signals should be received at the same level. This requirement mandate the need for high speed power control to overcome channel fading.



The fundamental concept of CDMA is that each user up-converts their symbol data rate to the system chip rate using a unique spreading code. In the example above, the symbol data rate of 30 ksps is up-converted to the system chip rate: 3.84 Mcps for 3GPP FDD or 1.28 Mcps for Narrow TDD and TD-SCDMA. All users in a cell transmit on the same frequency but the different 'orthogonal' spreading codes allow the users to be separated again by special correlators which search for each user's code in the receiver. When the signal is de-spread using the correct code, the symbol data appears back at the original rate, while other users using different spreading codes appear as uncorrelated noise at the chip bandwidth. The portion of energy from the uncorrelated wide signal that falls into the user's bandwidth is very small. Signals on the same frequency from adjacent cells are also rejected as these use a different "scrambling" code on top of the spreading codes.

The spectrum view above showing stacked signals in the traditional spectrum analyzer frequency/power domain is not a useful method of analysis for CDMA signals. A new approach has been developed which displays the multi-code CDMA signals using the code V.S. power domain - or "code domain" analysis. This is shown on the next slide.



The codes used in CDMA to distinguish one user from another are mathematically derived to be orthogonal, i.e. they are as different from each other as is possible to be given their length.

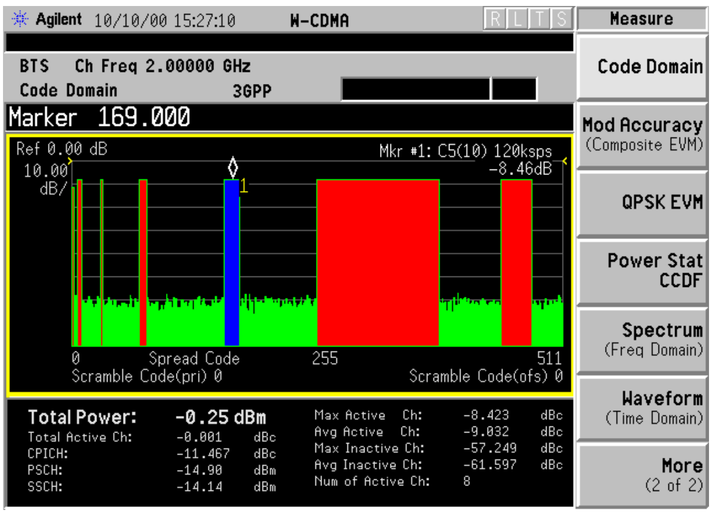
The amount by which the symbol rate needs to be increased to reach the system chip rate is defined as the spreading factor, and is always a power of 2. For instance in the example from the last slide, a 30 ksps rate needs to be spread by a factor f 128 to reach 3.84 Mcps.

The spreading works by taking every “1” in the symbol stream and replacing it by a sequence of 128 bits from the chosen code, and every “0” is replaced by the inverse of that 128 bit sequence.

The length of an OVSF code is the same as the spreading factor which also equals the number of different codes available at that spreading factor. For example, at SF = 8, the OVSF codes are 8 bits long and there are 8 different codes to choose from.

Another key point about OVSF codes is that there is a hierarchy of codes such that if a code is used, then none of the higher factor codes below it in the tree can be used as they would not be orthogonal with the parent code and the receiver would be unable to tell the codes apart.

Code Domain analysis of W-CDMA



The symbol rate of a channel is represented by its width as a fraction of the system chip rate (3.84 Mcps).

The power of a channel is represented by its height.

The marker is on channel C5(10) 120ksps. C5 is the spreading factor of 2^5 or 32. So the channel is 1/32 the width of the total code space. The code number is 10 since this is the tenth such channel of the 32 possible at this spreading factor. The symbol rate of 120 ksps is 3.84 Mcps/32.

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This is a display of the Code Domain Power (CDP) of a composite multi-channel W-CDMA downlink signal. The signal is shown broken down into into its constituent orthogonal spreading codes. In the code domain display, the height of a channel represents the relative power of that channel in the overall signal. The widest red bar on the right is the highest symbol rate channel in this signal - 960 ksps or one quarter of the system chip rate. Higher user data rates are obtained when the spreading factor (or spreading gain) is lower, which means the symbol rate is closer to the system chip rate. Higher symbol rate channels occupy the same "code space" as many adjacent lower rate channels. This is the reason high symbol rate channels are represented as wider than others. Two channels cannot occupy the same code space.

In the extreme, the symbol rate could equal the system chip rate by using a spreading factor of 1, but then we no longer have a CDMA system since the "code domain" would be fully occupied with one user. Usually, the spreading factor will be at least 4 and usually much higher.

A key trade-off in CDMA systems is the power of each user which must be as low as possible. When higher symbol rates are used, the transmission power needs to increase to maintain adequate signal to noise ratio after de-spreading.

Some W-CDMA / cdma2000 differences

W-CDMA	cdma2000
3.84 Mcps (Narrow band - 1.28 Mcps)	1.2288 Mcps (SR3 - 3.6864 Mcps)
Self synchronized	GPS synchronized
New standard	Extension of IS-95B
New Equipment	Upgrade Existing
GSM-MAP Network	IS-41 Network

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3GPP W-CDMA and cdma2000 are both wideband CDMA systems with many similarities in the capabilities that they offer but with many differences in the details of the implementation. The most obvious difference is in the chip rates used for the carrier channel. W-CDMA uses a chip rate of 3.84 Mcps while cdma2000 uses 1.2288 Mcps - the same rate used by the IS-95A standard with a 3x version proposed as a future upgrade - but this advance is looking less likely to happen. At the detailed level there are considerable differences in the coding, synchronization and BS identification methodologies adopted by the two standards.

W-CDMA is a major new system for the new IMT-2000 band as well as DCS1800 and PCS 1900 bands. It will require major new equipment installation by the network operators.

The cdma2000 system is an upgrade to IS-95. It has been designed to share the same frequency in each sector of each cell. For each user that uses cdma2000 coding rather than IS-95, the system is more efficient. Existing equipment can be upgraded to install the new technology.

Question and Answer Session

Wireless Technology Seminar:

W-CDMA Basics

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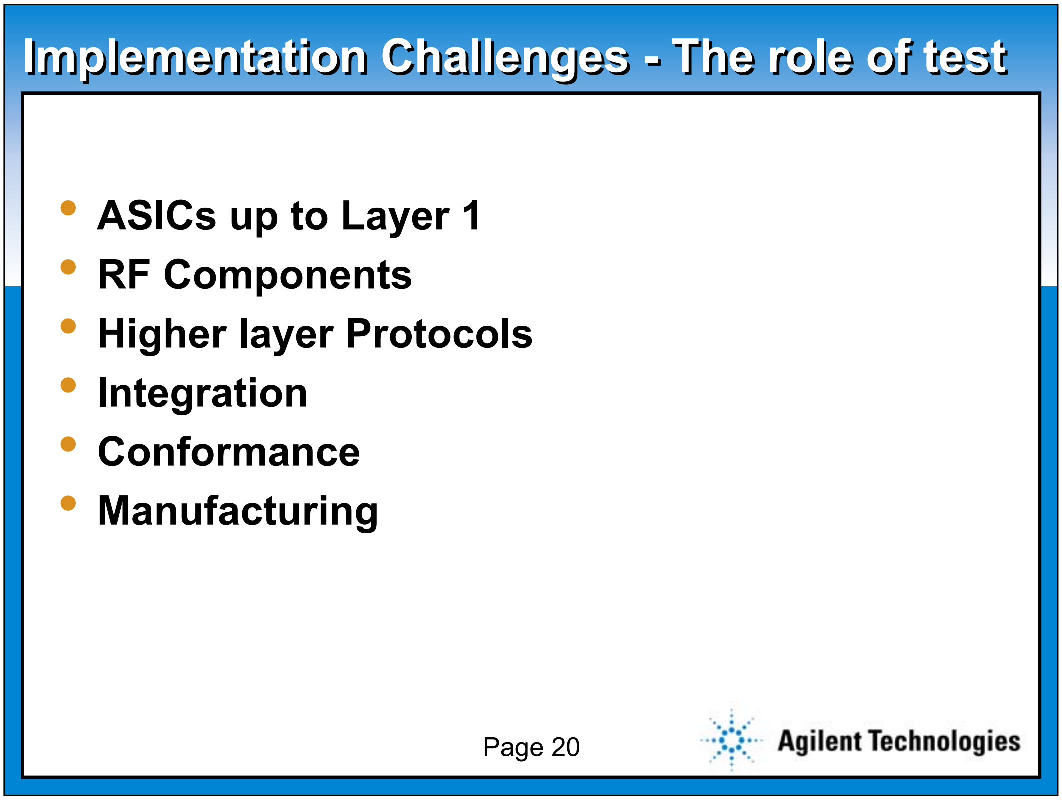
Agenda

- Market Drivers
- CDMA Technology Explained
- Implementation Challenges
  - The role of test
  - Power statistics and amplifier headroom
  - Spectral purity
  - Error vector magnitude
  - Peak code domain error



There are many different ways of partitioning the tasks required to successfully deploy a new wireless technology. The slide above indicates the main areas where test is necessary to ensure compliance with different stages of the process.

Agilent provides solutions for ASIC simulation and design as well as protocol analysis and system test solutions for the wireless network. However, these are beyond the scope of this presentation.

The remainder of this presentation will look in more detail at some of the RF measurements for which Agilent provides solutions. These measurements are critical to many of the areas above.

RF Testing

- Wide Dynamic Range
- Real Time Control
- Calibration Data Required for Each Phone
- Trade-off Battery Life vs Performance

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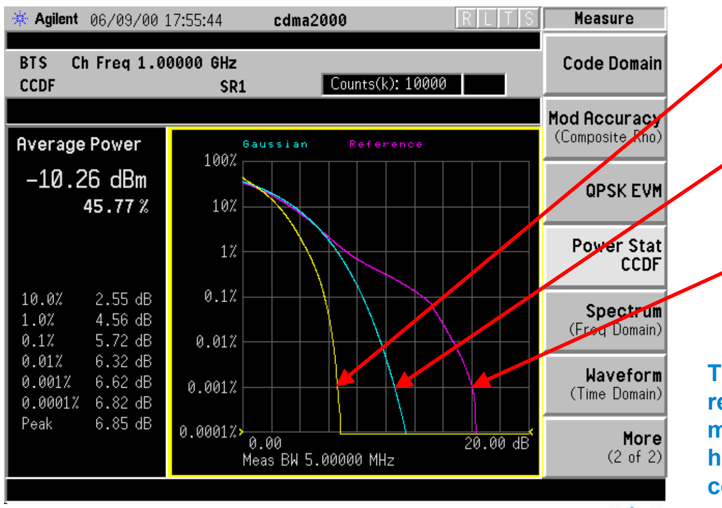
There are several key differences between CDMA technologies and analog or other TDMA technologies. One of the biggest differences is the transmit dynamic range requirement. GSM phones operate over no more than 40 dB transmit power range. CDMA phones have to operate over a much wider range, up to about 80 dB. In addition, there are design specs on the accuracy of this level, as well as the accuracy of the phone to measure the receive level over this entire range.

Typically, each phone needs custom power calibration.

Trade-offs are made between RF performance and battery life in the UE and between peak power handling and performance in the Node B.

Power statistics and amplifier headroom

CCDF curves of noise and W-CDMA signals with different numbers of code channels



6.8 dB peak to average ratio at 0.001% probability

Gaussian noise reference

16.2 dB peak to average ratio at 0.001% probability

The second signal requires 9.4 dB more amplifier headroom to avoid compression

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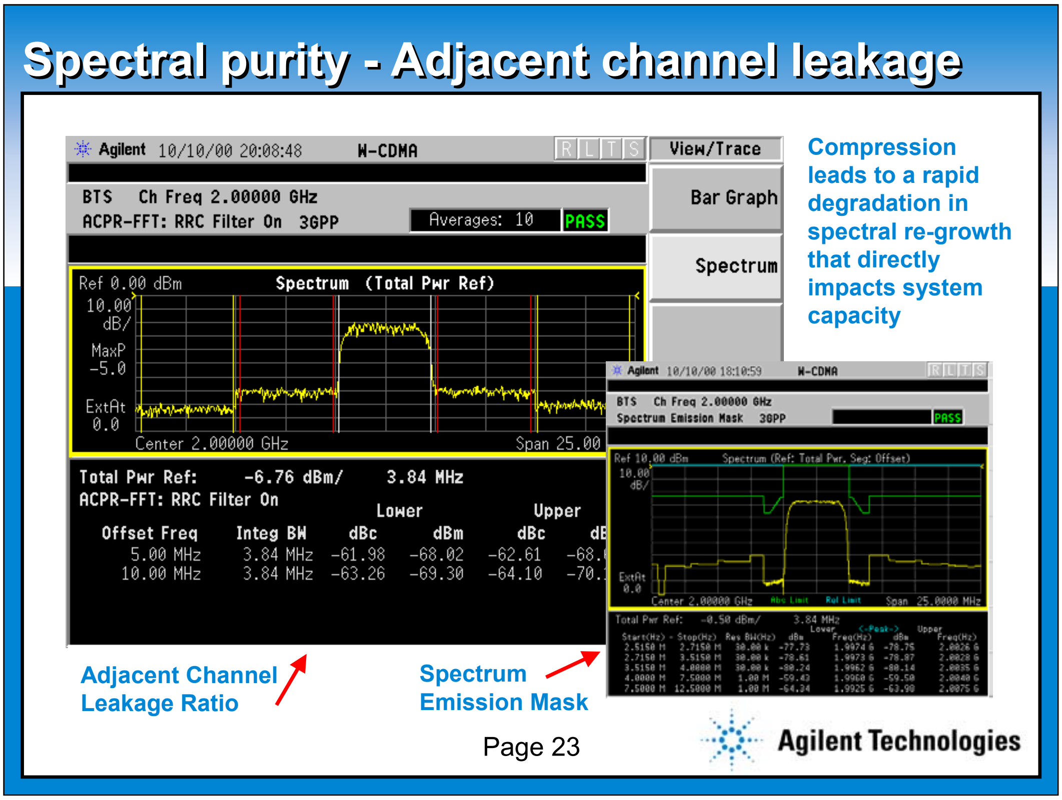
This slide shows a measurement of the Complimentary Cumulative Distribution Function (CCDF) for three different signals. This measure shows, on a log/log scale, the percentage of the time the signal spends above the long term average power. This is also known as the "peak to average ratio" and, for W-CDMA where the baseband signal statistics vary with loading, should always be quoted in conjunction with a probability.

The plot in the centre represents the statistics of White Gaussian Noise. The plot on the left shows a base station signal containing only a few code channels. The plot on the right is a heavily loaded base station signal.

For the lightly loaded base station, to avoid clipping, there needs to be 6.8 dB of headroom in the amplifier above the average power of the signal. For the heavily loaded signal, that headroom increases to 16.2 dB.

It is impractical and uneconomical to design a power amplifier that can operate at typical base station output powers with 16dB of headroom and so there will be a trade off between the design of the base station power amplifier and the number of codes that can be achieved.

The CCDF measurement is a simple but invaluable tool for analyzing the power statistics of complex CDMA signals, as well as helping identifying compression characteristics in the transmit chain. The combination of these measurements can be used to accurately set the operating point of the system in order to minimize costs without sacrificing performance.

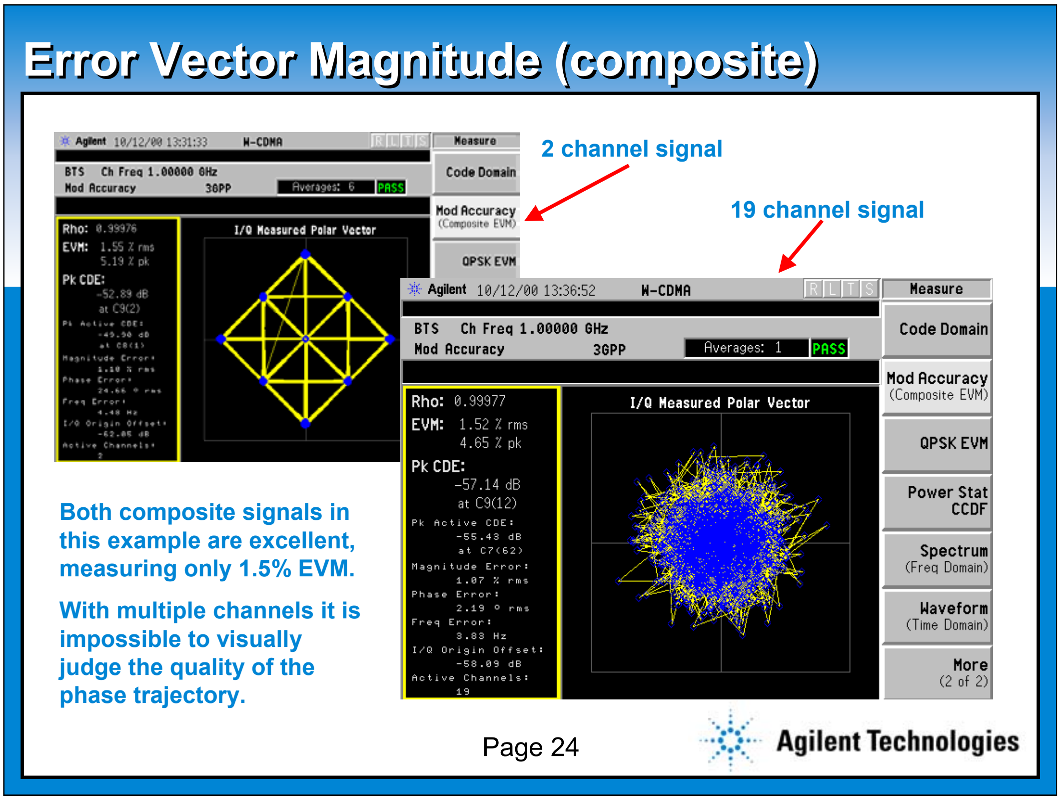


Using the example from the last slide, a base station with 25 watts average power and 16 dB of headroom, would need to be designed for 1 kilowatt of peak power! However, the CCDF curve shows that this highest peak only occurs 0.001% of the time. If we decide that it is OK to clip the signal 0.1% of the time, a new headroom figure of 12.5 dB is seen to suffice. This represents a significant reduction in peak handling to only 450 Watts. Whether this amount of clipping is acceptable can be determined in part by examining the impact on the signal's spectral density in the adjacent channels.

This slide above shows the adjacent channel power of a typical W-CDMA signal. The signal must be within specified limits if system performance is to be maintained. If we allow the PA to clip then spectral re-growth occurs and the amount of energy in the adjacent channel will increase - rapidly reducing the capacity of the adjacent channel.

It is desirable to provide the minimum PA headroom possible while still meeting the ACLR and spectrum mask at maximum output power using the worst-case channel loading the Node B needs to carry.

The mobile has similar spectral problems, but trades power amplifier bias current for the out of band emissions. This is usually a dynamic bias vs. output level and needs accurate equipment for characterization of performance.

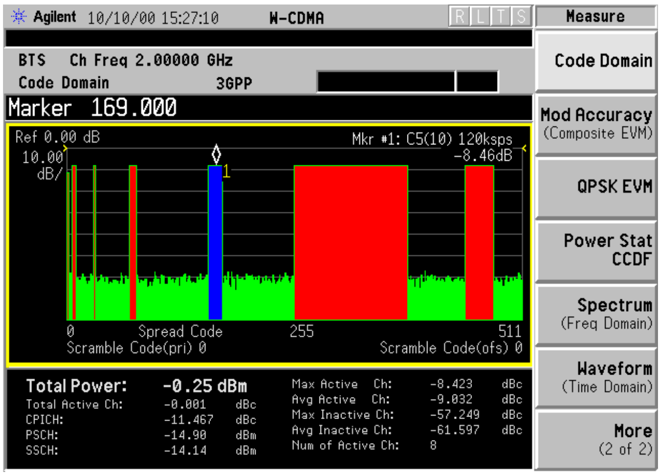


The Error Vector magnitude is a measure of how far from the ideal phase trajectory the composite signal is. Traditionally, EVM has been done on simple QPSK signals without the need for demodulation of the data. However, in W-CDMA where complex composite signals exist, it is necessary to demodulate the signal in the code domain in order that an ideal reference signal can be constructed. Except for some very simple composite signals (such as the two channel signal above), a typical W-CDMA downlink signal looks just like noise in the IQ plane.

The slide shows two W-CDMA signals in the IQ plane. The figure on the left is of two-channels of equal magnitude. It can be clearly seen here how the two individual QPSK signals have combined to form the more complex 9 state signal. On the right hand side is a composite signal consisting of 19 different channels at different relative levels. The result looks like a mess, however,the EVM of both signals is the same at about 1.5% versus a system requirement of 17.5%. It is impossible to visually judge the modulation quality of a multi-channel composite signal. Most typical W-CDMA downlink signals are indistinguishable in the IQ plane from noise.

EVM can be directly related to system capacity based on the principle that the EVM energy adds to the system noise level.

Peak Code Domain Error



Peak code domain error is the highest code power left after the wanted signal has been removed. It is computed by projecting the EVM energy across the code domain.

Usually the largest error is on an unused code. Errors on used codes are just errors in estimating the original code power.

In this example, the highest unused code is -57.249 dB, well above the system limit of -33dB.

A bad PCDE means codes will be blocked.

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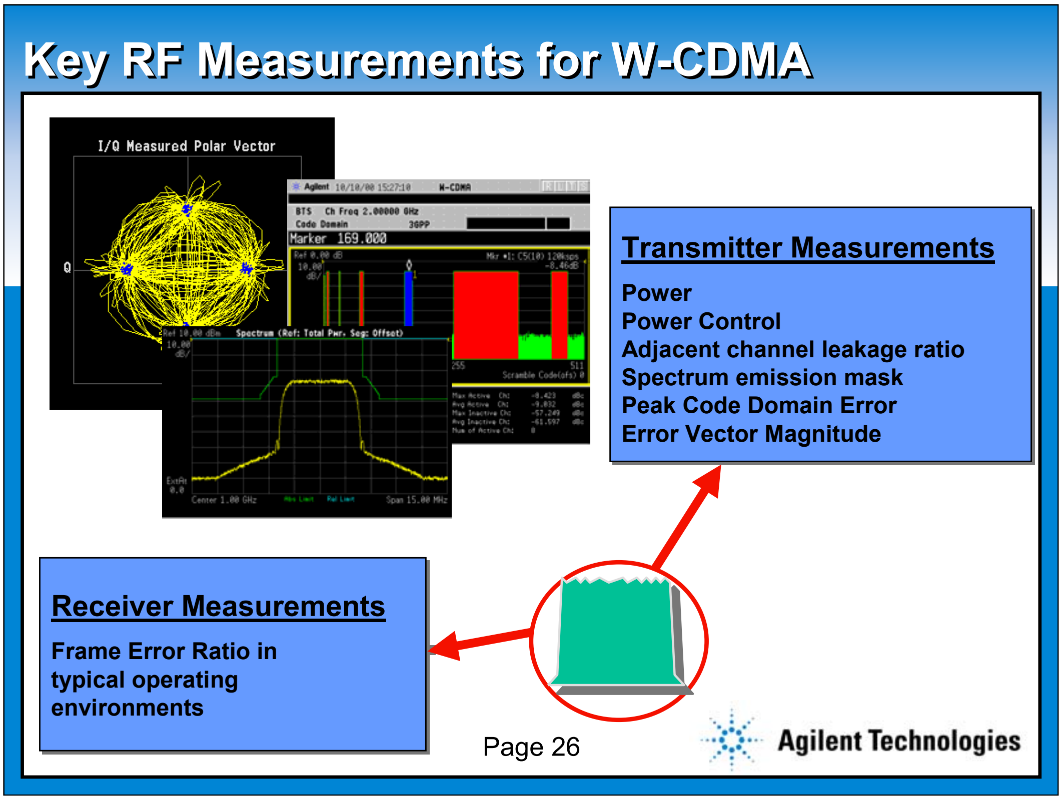
Peak Code Domain Error (PCDE) is an important measure of modulation quality in W-CDMA. The PCDE is the largest measurable code power due to modulation error. In the above example, the eight used codes are clearly visible, and all other codes are seen as noise. The maximum inactive channel power is - 54.249 dB at a factor of 512 which is well above the system specification of -33 dB at a spreading factor of 256.

The PCDE is calculated by projecting the power computed for the EVM measurement into the code domain. In theory it would be expected that the EVM energy would be equally distributed across the code domain. However, there are some circumstances that can cause the EVM energy to correlate more with some codes than others. This is a problem for the system since if the EVM energy is not well distributed, this could result in certain codes being blocked. This reduces system capacity due to excessive power being needed to overcome the interference.

It is important when measuring PCDE to know if a particular signal is meant to be there or not. Certain combinations of downlink channels can, in the presence of distortion mechanisms, generate code “spurs”. An example could be a coherent spur in a transmitter LO which introduces a time delayed image of the downlink signal. Such a delay causes the code orthogonality to fail, and the result can be a significant code spur whose presence and size will depend on the particular codes in the signal.



Some key RF measurements for W-CDMA are shown here

- Power	**Wide dynamic Range**
- Power Control	**Open Loop and Closed Loop**
- EVM/PCDE	**New metrics based on analysis of modulation accuracy and code domain error.**
- Adjacent channel power	**Tight specs with trade-offs**
- Frame/Block Error Ratio	**Requires call processing or test modes**

Test solutions from Agilent

- Agilent is heavily involved in the development of the emerging 3G Standards
- We are developing Test Equipment for all major Formats
- Early test solutions may require special test modes and cooperation with equipment manufacturers

Visit www.agilent.com/find/3G for more information

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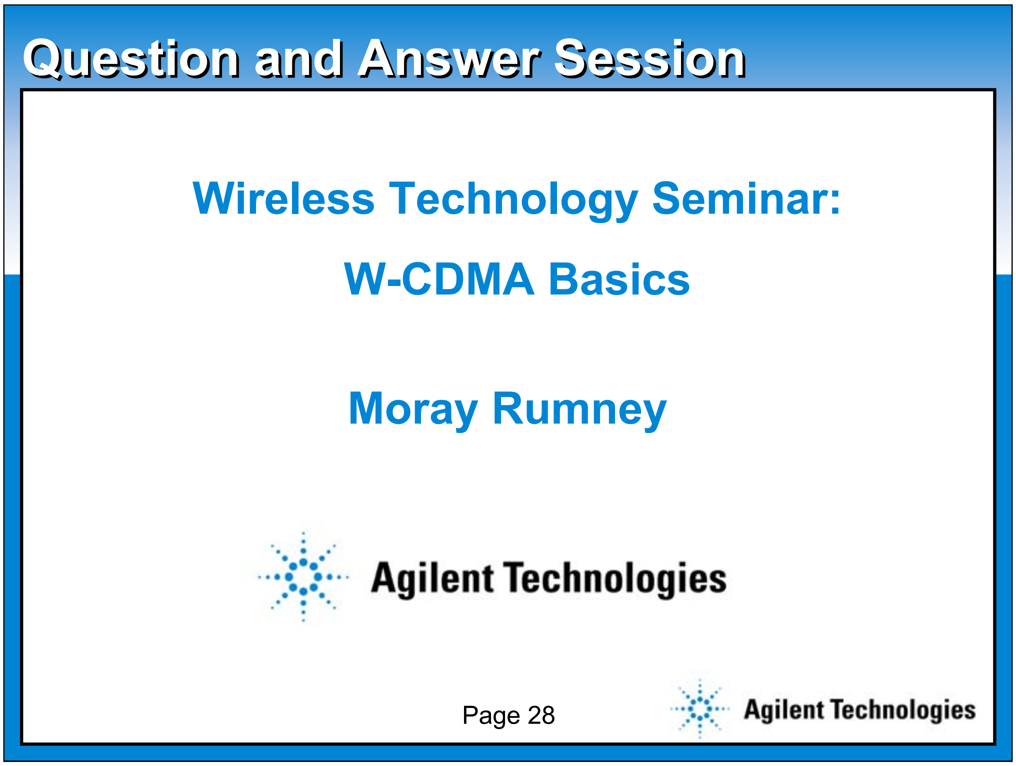
Agilent Technologies is committed to providing competitive and innovative test solutions for the emerging 3G standards. These are designed to compliment our existing portfolio of 2G and 2.5G solutions to generate true multi-format test capability for the next generation of multi-mode products.


Question and Answer Session
Wireless Technology Seminar:
W-CDMA Basics
Moray Rumney
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