Feb 16, 2004

WCDMA TX Theory and Measured Results from Maxim's WCDMA Reference Design v1.0

In discussing the evolution of mobile telecommunications towards a third-generation (3G) standard, this article offers a broad technical overview of the key requirements for 3G transmitters. It presents the design and measured performance of transmitters for frequency-division duplex (FDD) wireless code-division multiple-access (WCDMA) systems, illustrated with transmitter ICs currently available from Maxim.

Evolution of Mobile Telephony: Roadmap to 3G

First generation (1G) phones were analog cellular devices based on a large number of similar but non-compatible technologies. They offered a limited range of services, based mainly on those of fixed telephone networks.

Second generation (2G) phones employ digital channels modulated directly onto the radio carrier using TDMA or CDMA schemes. The result—greater spectrum efficiency—adds value in terms of signal quality, security, provision of real data services, and international roaming.

The intent of third generation (3G) terminals is to provide seamless global mobility as well as global compatibility with chosen access technologies such as wireless local loop, cellular, cordless, and satellite systems. One technical challenge to the advent of seamless global-terminal mobility is the difficulty in achieving a common global-frequency plan. In every world region, at least part of the necessary spectrum is already allocated for other radio services.

The Birth of 3G

Following a spectrum allocation around 2GHz by the World Radio Conference (WRC) in 1992, the International Telecommunication Union—Radio-communication sector (ITU-R) began to define a wish list for 3G-system requirements. A range of technologies were proposed to meet these requirements, including WCDMA, OFDM, TDSCDMA, and ODMA.

A technical body called the 3rd-Generation Partnership Project (3GPP) was then appointed to analyze the proposed technologies. As a result of that work, WCDMA stood out as the technology most preferred for 3G systems. 3GPP has since written a technical-requirements specification in which chapter 25.101 includes the key performance requirements for the RF-hardware portion of a WCDMA mobile terminal. 3GPP also defined two choices of operation for a WCDMA terminal:

Frequency-Division Duplex [FDD] mode:

- Physical channels defined by two parameters: RF-channel number and channelization code
- Suitable for fast mobile use
- Uplink and downlink separated in the frequency domain
- Greater downlink capacity than uplink capacity
- 100% duty cycle on both uplink and downlink

Time-Division Duplex [TDD] mode:

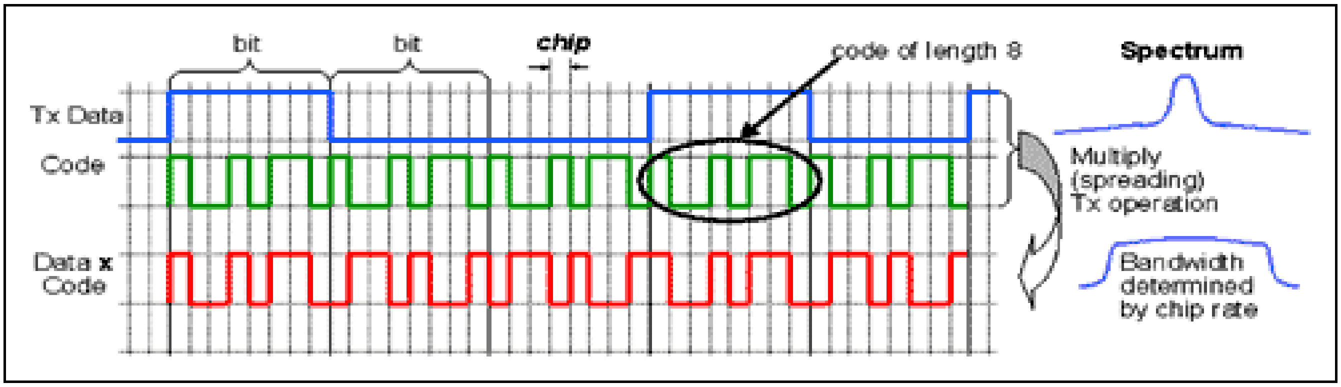
- Physical channels defined by three parameters: RF-channel number, channelization code, and time slot
- Suitable for indoor or slow-moving mobile use
- Uplink and downlink have similar capacities and occupy the same channel
- DTx on both uplink and downlink

DTX (discontinuous transmission) is a method for optimizing the efficiency of wireless voice communications systems by momentarily powering-down or muting a mobile or portable telephone in the absence of voice input. Each party in a typical 2-way conversation speaks slightly less than half the time, so if a transmitter is on during voice input only, the phone's duty cycle can be cut to less than 50%. That condition conserves battery power, eases the workload of transmitter components, and frees the channel, allowing the system to take advantage of available bandwidth by sharing the channel with other signals. DTX circuits operate with voice-activity detection (VAD), which in wireless transmitters is sometimes called voice-operated transmission (VOX).

3GPP also specifies FDD terminals for 60MHz chunks only, with 190MHz duplex spacing: 2110MHz-2170MHz for mobile RX, and 1920MHz-1980MHz for mobile TX.

Principles of CDMA

Before discussing WCDMA transmitters, this section offers a brief overview of CDMA principles. "Direct sequence" is the method used for signal spreading in CDMA systems. To spread the signal, it multiplies the unmodulated baseband data by a unique code called the spreading code, which contains a nominal number of chips:



The resulting spread data is then modulated onto a carrier for transmission, and the modulated-carrier bandwidth is influenced directly by the chip rate of the spreading code. WCDMA uses a 3.84MHz chip rate that creates a very wide-bandwidth transmission spectrum, hence the term "wideband."

To extract the original information, a CDMA receiver demodulates the information carrier and uses a correlator (with the original transmitter spreading code) to regenerate (despread) only the wanted signal. The extracted data then passes through a narrow-bandpass filter before any further processing that may be required.

3G WCDMA-Transmitter Requirements

Chapter 25.101 of the 3GPP specification (mentioned earlier) covers the Rx/Tx electrical requirements for FDD 3G mobile terminals. Before discussing the requirements of a WCDMA transmitter, this section describes a few key transmitter parameters and their importance in transmitter design.

Adjacent Channel Power Ratio [ACPR]: ACPR measures the amount of interference or power in an adjacent-frequency channel. Usually defined as the ratio of the average power in the adjacent frequency channel (or offset) to the average power in the transmitted-frequency channel, ACPR describes the amount of distortion due to nonlinearities in the transmitter hardware.

ACPR is critical for WCDMA transmitters, because CDMA modulation produces closely spaced spectral components in a modulated carrier. Intermodulation of those components causes a spectral regrowth of "shoulders" around the center-carrier frequency, and transmitter nonlinearities can disperse those spectral-regrowth components into adjacent channels.

Error Vector Magnitude [EVM]: The error vector (a complex quantity containing magnitude and phase) is the vectorial difference at a given instant between an ideal error-free reference and the actual transmitted signal. Because it changes continuously during every symbol transition, this new parameter (EVM) is defined as the RMS value of the error vector over time.
EVM is critical for WCDMA transmitter performance because it indicates modulation quality in the transmitted signal. A large EVM degrades transceiver performance by causing poor detection accuracy.

Frequency Error: the difference between specified and actual carrier frequencies. A large frequency error degrades transceiver performance by causing adjacent-channel interference and poor detection accuracy.

Spurs and harmonics: Spurs are signals produced by different signal combinations in the transmitter, and harmonics are distortion products produced by nonlinear behavior in the transmitter. Harmonics occur at integer multiples of the transmitted signal.

Having defined some key transmitter parameters, we now list some key requirements used in specifying and designing 3G WCDMA transmitter terminals (Table 1).

Table 1. 3GPP Transmitter Requirements

<table>
<tr><th>Parameter</th><th colspan="2">3GPP Specification</th><th>Reference</th></tr>
<tr><td>RF frequency range</td><td colspan="2">1920 - 1980MHz</td><td>25.101 [5.2]</td></tr>
<tr><td>Channel spacing</td><td colspan="2">Nominally 5MHz</td><td></td></tr>
<tr><td>Chip rate</td><td colspan="2">3.84Mcps</td><td></td></tr>
<tr><td>Maximum output power</td><td colspan="2">24dBm +1/- 3dB [power class 3]</td><td>25.101 [6.2]</td></tr>
<tr><td>Minimum output power</td><td colspan="2">-50dBm</td><td>25.101 [6.4.3.1]</td></tr>
<tr><td>Transmit off power</td><td colspan="2">< -56dBm</td><td>25.101 [6.5.1.1]</td></tr>
<tr><td>Adjacent channel leakage power</td><td colspan="2">> -33dBc [if adjacent channel power is > -50dBm]</td><td>25.101 [6.6.2.2.1]</td></tr>
<tr><td>Alternate channel leakage power</td><td colspan="2">>-43dBc</td><td>25.101 [6.6.2.2.1]</td></tr>
<tr><td>Frequency error</td><td colspan="2">Within +/- 0.1ppm</td><td>25.101 [6.3]</td></tr>
<tr><td>Transmit intermodulation</td><td colspan="2">> -31dBc [@5MHz offset]
> -41dBc [@10MHz offset]</td><td>25.101 [6.7.1]</td></tr>
<tr><td>Error Vector magnitude</td><td colspan="2"><17.5%</td><td>25.101 [6.8.2.1]</td></tr>
<tr><td rowspan="6">Spurious emissions</td><td rowspan="4">100kHz RBW</td><td>-67dBm ; 925 ≤f≤ 935MHz</td><td rowspan="6">25.101 [6.6.3.1]</td></tr>
<tr><td>-79dBm ; 935 ≤f≤ 960MHz</td></tr>
<tr><td>-71dBm;1805 ≤f≤ 1880MHz</td></tr>
<tr><td>-36dBm ; 30 ≤f≤ 1000MHz</td></tr>
<tr><td>300 KHz RBW</td><td>-41dBm ; 1893.5 =f= 1919.6MHz</td></tr>
<tr><td>1MHz RBW</td><td>-30dBm ; 1GHz =f= 12.75GHz</td></tr>
</table>

	10KHz RBW	-36dBm ; 150KHz =f= 30MHz	
	1KHz RBW	-36dBm ; 9KHz =f= 150KHz	

WCDMA Transmitters

Maxim offers a range of WCDMA-transmitter ICs that cover most of the common frequency architectures. Devices for superheterodyne systems, for instance, include what is arguably the most highly integrated transmitter chip in the industry (MAX236X), offering a typical Tx IF of 380MHz. Also for superheterodyne systems is the MAX2383 upconverter driver, which handles high Tx IF frequencies to 570MHz. To demonstrate hardware suitability for the 3GPP specifications (with margin), this section presents a selection of system-level and discrete-component test results based on the first-generation Maxim WCDMA transmitter ICs, as part of the v1.0 WCDMA Reference Design. Contact the factory for more information on newer zero-IF WCDMA Reference Designs.

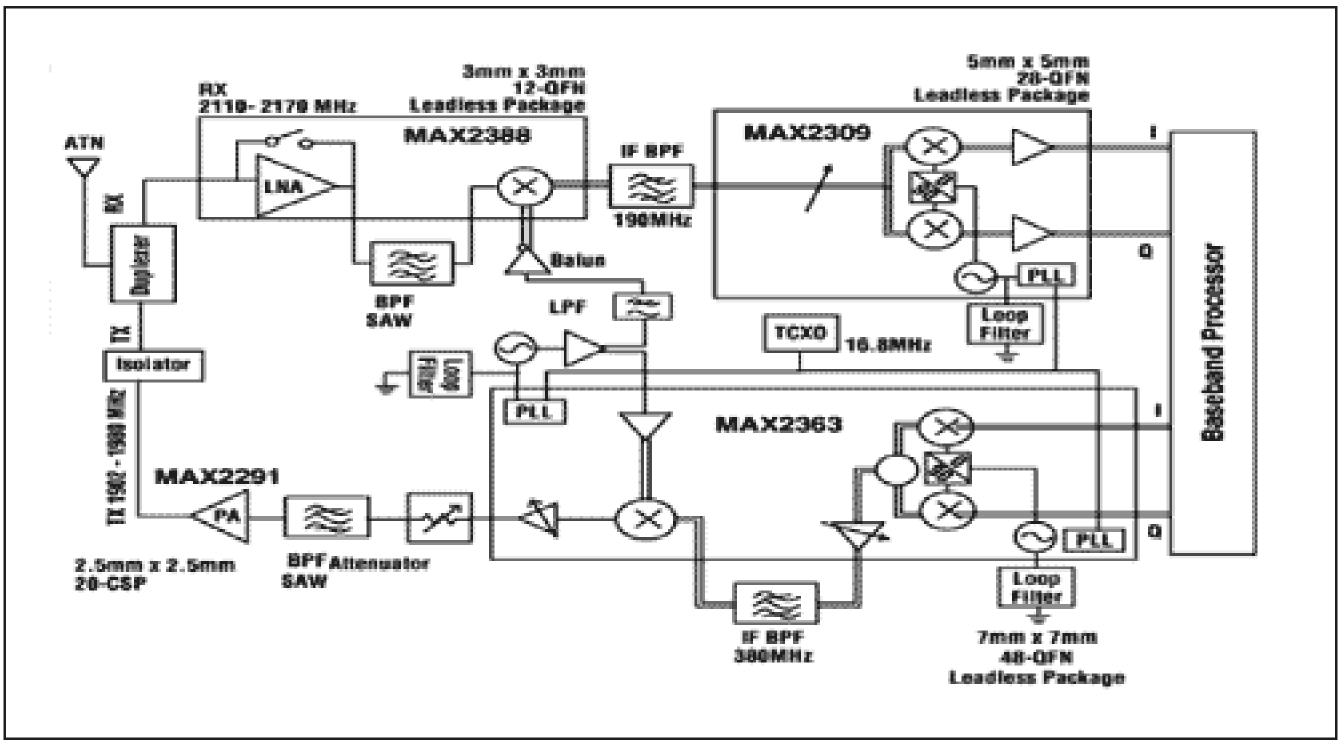


Figure 1. Block diagram of WCDMA transceiver.

WCDMA Superheterodyne Transmitter

This transmitter is part of a reference design for a complete WCDMA transceiver, which includes four key ICs:

- The MAX2388 receive front end
- The MAX2309 IF quadrature demodulator
- The MAX2363 quadrature modulator/upconverter transmit IC
- The MAX2291 RF power amplifier

The transmitter hardware assumes an IF of 380MHz and a Tx frequency of 1920MHz to 1980MHz. A duplexer filter allows full-duplex operation by connecting the Tx path (and Rx path) to an antenna.

At the Tx strip back end, the MAX2363 accepts baseband-transmit I and Q differential-input signals as inputs, and performs quadrature modulation, IF and RF LO synthesis, and RF upconversion. The IF LO is synthesised by an internal VCO and PLL, which runs at 760MHz. An external RF VCO module allows a high-side injection of -7dBm into the MAX2363 upconverter. On-chip RF drivers allow the chip to drive an external PA directly.

At the Tx strip front end, a chip-scale-packaged linear PA (MAX2291) provides 28dB of gain in this application and as much as +28dBm of output power. With a post-PA insertion loss of approximately 4dB, the system achieves a maximum antenna output of 24dBm.

When fully mature, WCDMA systems are expected to operate at mid-power rather than full power most of the time. The MAX2291 addresses this need by offering two optimised modes for output power, allowing increased talk time with the following expected performance:

Measurements in high-power mode, with Vcc at 3.5VDC:

Pout = 28dBm
Frequency = 1.95GHz
ACP1 = -39dBc (measured at 5MHz offset, in 3.84MHz bandwidth)
Power-added efficiency = 37%
Idle Icc = 97mA

Measurements in low-Power mode, with Vcc at 3.5 VDC:

Pout = 16dBm
Frequency = 1.95GHz
ACP1 = -38dBc (measured at 5MHz offset, in 3.84MHz bandwidth)
Power-added efficiency = 14%
Idle Icc = 30mA

The 3GPP specification shown earlier states that a WCDMA transmitter must deliver power between +24dm and -50dBm to achieve the required dynamic range of 74dB. Allowing for some margin, the v1.0 reference board is designed to achieve over 80dB dynamic range.

The dynamic range of a transmitter chip is limited—usually by ACPR at the high-power end and by the noise floor at the low-power end. To obtain more than 15dB carrier-to-noise ratio (C/N) at the low-power end, an additional 20dB of variable attenuation (introduced by a gain-control attenuator for the PA) was designed into the v1.0 reference board. Key performance parameters extracted from extensive test results (Table 2) verify the suitability of Maxim's v1.0 WCDMA transmitter.

Table 2. Tx Output Characteristics at Full Power.

Parameter	Specification	Data @1980MHz	Data @ 1920MHz
O/p power @ antenna port	24dBm	24.8dBm	25.5dBm
+/- 3.8MHz ACP *	-50dBc	-52dBc	-52dBc
+/- ACPR1 *	-33dBc	-37dBc	-37dBc
+/- ACPR2 *	-42dBc	-54dBc	-54dBc
Icc @ 3.3V (TX only)	-	620mA	615mA
Noise @ Rx. band		-137dBm/Hz	-137dBm/Hz
Noise @ 1880MHz			-135dBm/Hz

* For detailed min/max power ACP plots, see Figures 2-5 below.

Tx Strip EVM and ACPR Performance

An EVM of approximately 5.7% was measured at +24dBm Tx output power from the V1.0 WCDMA reference board (attributing 3.5% to the MAX2291 PA, and 4.6% to the MAX2363 Tx chip). That overall EVM value is well within the 3GPP requirement (<17.5%). EVM and ACP for the TX strip were measured as follows:

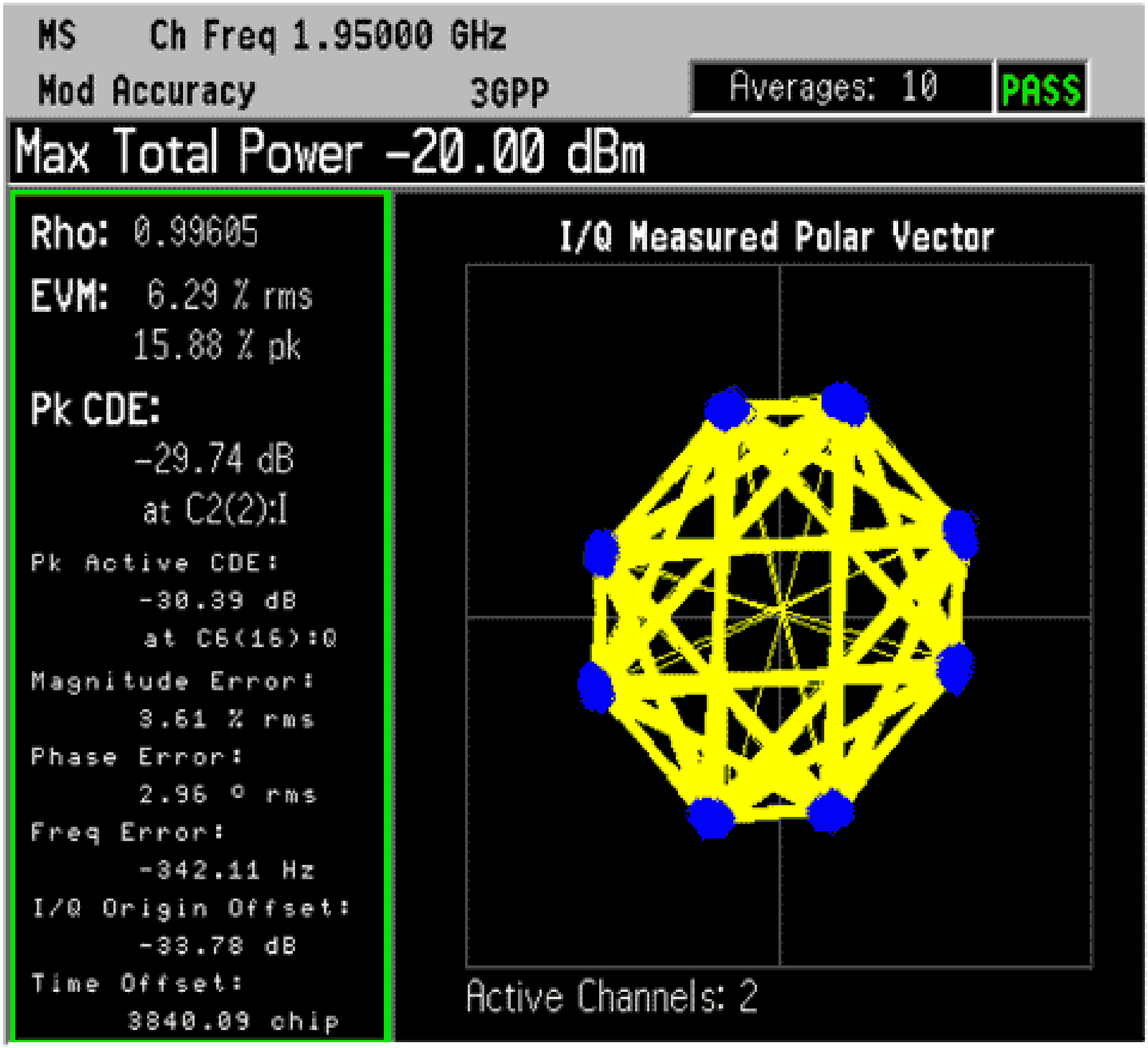


Figure 2. Tx strip EVM at -20dBm.

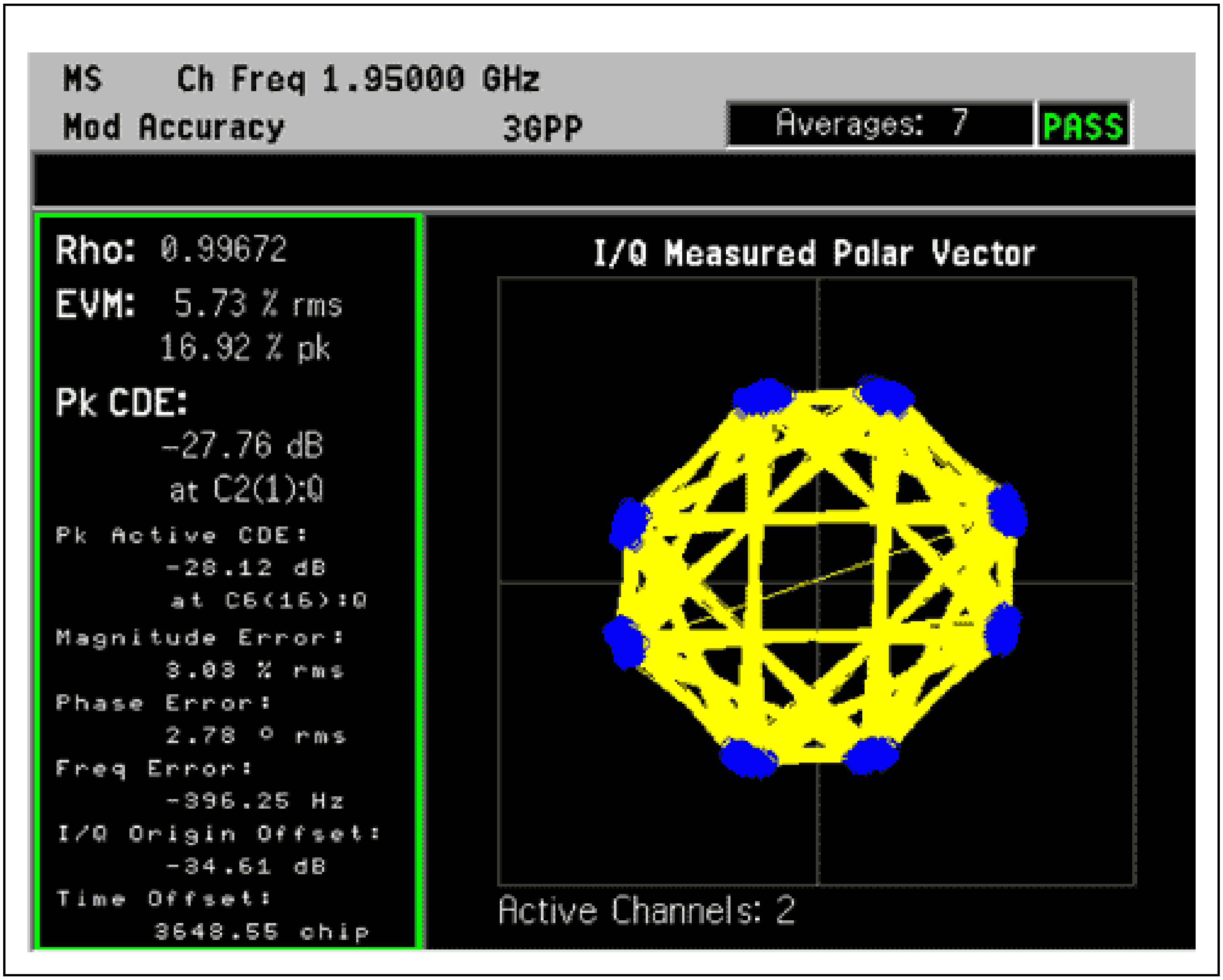


Figure 3. Tx strip EVM at +24dBm.

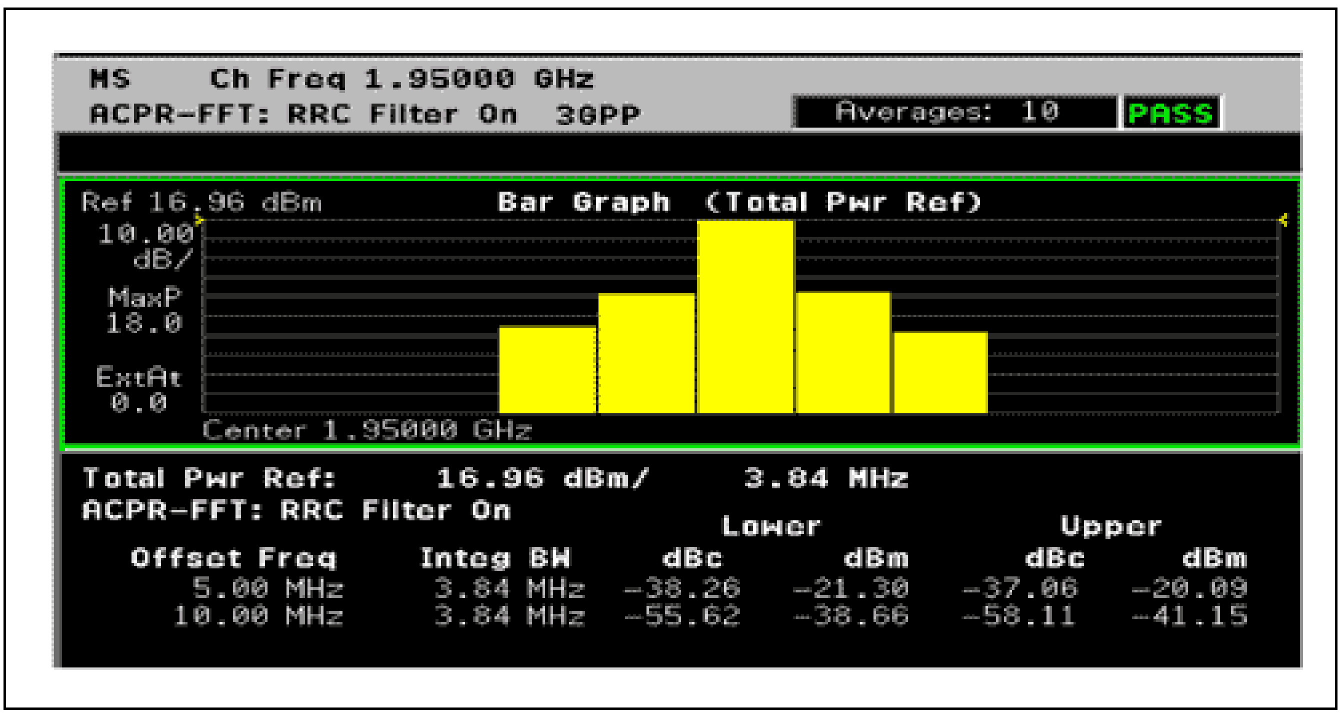


Figure 4. Tx strip ACP at +24dBm.

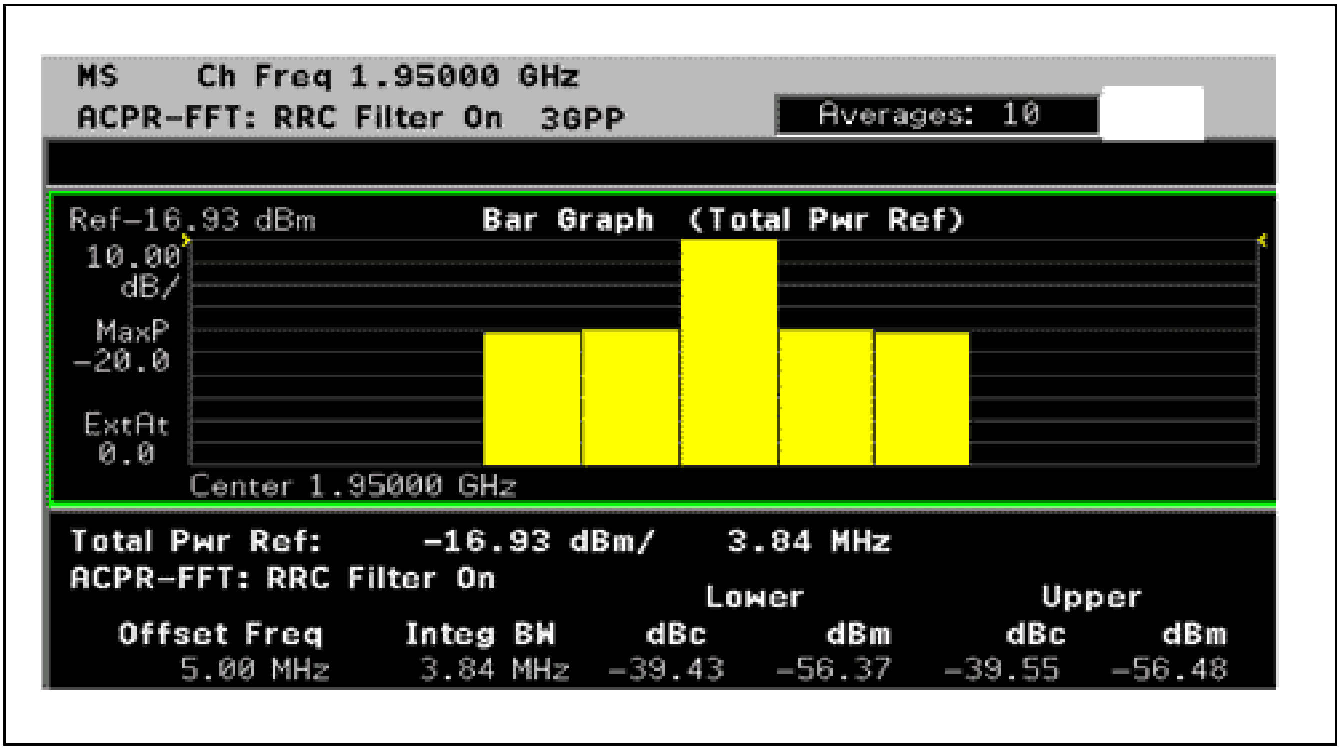


Figure 5. Tx strip ACP at -20dBm.

Based on a surburban voice-output power distribution function (a statistical figure of merit that describes power variation according to urban vs. rural, data vs. voice, etc.), the Tx strip current measures 550mA at maximum output power, and 365mA at 22dBm.

Tx noise in the Rx band measures -137.0dBm/Hz at maximum Tx power. If the isolation between Tx and Rx is -50dB, then Tx noise in the Rx path calculates as -187.0dBm/Hz, which is much lower than the thermal noise. That is, the Tx contributes almost nothing to Rx total noise. (This calculation has been backed up and verified by supporting measurements at maximum and reduced power.)

Two plots indicate the typical frequency-domain spectral mask expected at the antenna port of the V1.0 Tx strip. At 24dBm antenna output power (Figure 6), the conditions are

- Icc = 490mA (TX only), and 535mA (TX + RX)
- MAX2363 IF DAC setting = 110
- VGC = 2.4V.

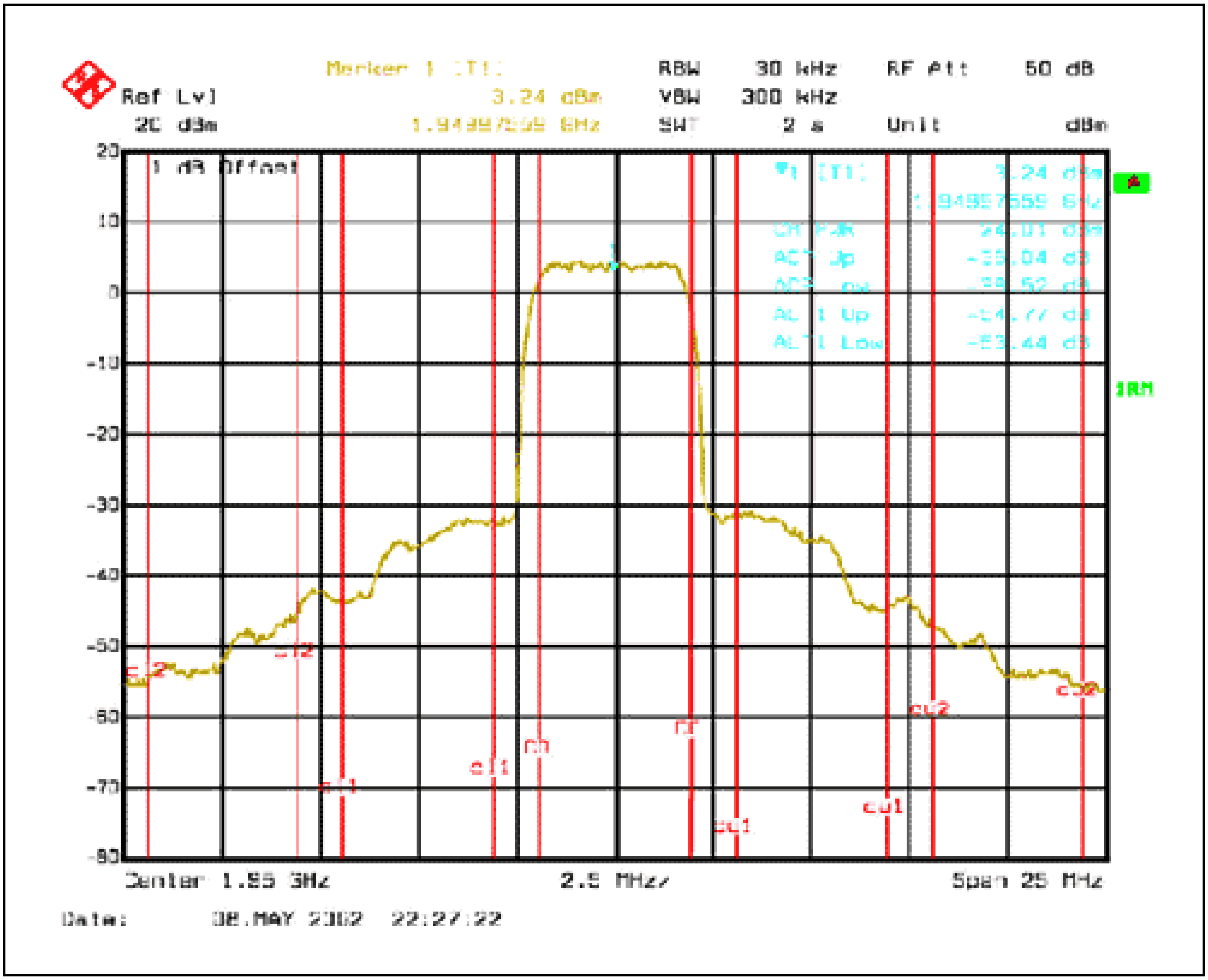


Figure 6. Typical spectral mask at antenna port of v1.0 Tx strip, with 24dBm antenna-output power.

At -53dBm antenna output power, i.e., low Tx output power for which VGC = 1.35V and the absolute output power = -38dBm (Figure 7), the conditions are

- Icc = 166mA (TX only)
- VGC = 1.35V
- IF DAC = 000
- PA bias setting = 1
- Pout attenuation = MAX.

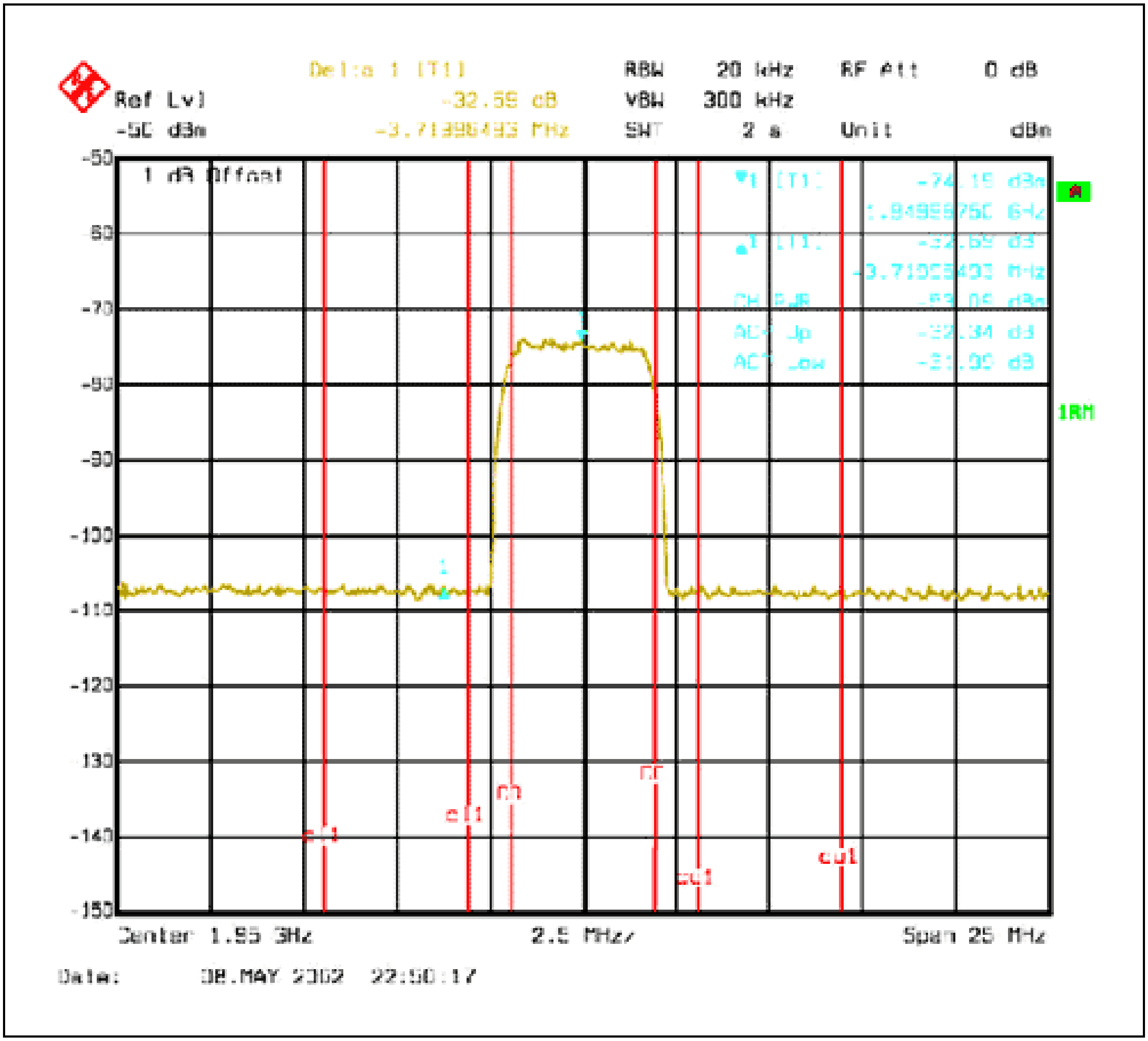


Figure 7. Typical spectral mask at antenna port of v1.0 Tx strip, with low (-53dBm) antenna-output power.

Conclusion

The intent of this article has been to provide the reader with a suitable overview of the theory, design, and requirements of WCDMA transmitters, illustrated with the first-generation Maxim WCDMA super-het Reference Design. Current products from Maxim include direct-conversion (zero-IF) WCDMA transceivers.

References

1. v1.0 reference design preliminary performance report, Maxim Integrated Products Inc.
2. Maxim website: http://dbserv.maxim-ic.com/an_prodline2.cfm?prodline=14

More Information

MAX2309:	QuickView	-- Full (PDF) Data Sheet	--	Free Samples
MAX2363:	QuickView	--	--	Free Samples
MAX2388:	QuickView	-- Full (PDF) Data Sheet	--	Free Samples