Keywords: femto, femtocell, base station, basestation, small cell, macrocell, transceiver, 3G, UMTS, WCDMA, cdma2000, cellular, TS25.104, EVM, transmitter, receiver

APPLICATION NOTE 5331

Employing a Single-Chip Transceiver in Femtocell Base-Station Applications

By: Jerry Wei
Apr 11, 2012

Abstract: This application note discusses the development and deployment of 3G cellular femtocell base stations. The technical challenges for last-mile residential connectivity and adding system capacity in dense urban environments are discussed, with 3G femtocell base stations as a cost-effective solution. Maxim's 3GPP TS25.104-compliant transceiver solution is presented along with complete radio reference designs such as RD2550. For more information on the RD2550, see reference design 5364, "Femtocell Radio Reference Designs Using the MAX2550–MAX2553 Transceivers."

Why Femtocell Base Stations?

Click here for an overview of the wireless components used in a typical radio transceiver.

The third-generation cellular phone system under 3GPP was designed to offer a fully mobile multimedia experience. In many cases, widespread adoption has been limited by the available reception, especially in residences and remote areas. In dense urban areas, and especially in high-rise buildings, the challenge is to add system capacity and overcome poor quality of service (QoS) that may result in these environments.

In both of these deployment scenarios, the "femtocell" cellular base station is the logical answer. The general classifications of base stations are as follows:

- +45dBm: macro base station covers an outdoor cell site of ~5km
- +30dBm: pico base station covers a campus of ~0.5km
- +15dBm: femtocell base station covers an indoor residence or building to ~50m

For residential deployment, femtocells access the network through the publicly switched telephone network, which is typically available through a residential DSL line. The handset only communicates to the femtocell in the home, and this completely offloads that user from the macrocell. In high-rise buildings, the femtocell can be connected to the building's wired Ethernet system, which again reduces loading on the macro cell base stations. In the following paragraphs, we review the basis for femtocell deployment and demonstrate how Maxim's radio solution offers key advantages for this technology.

Improving Cellular Coverage

Cellular systems are deliberately designed to trade off handset battery life, handset computing power, and cell site user loading. In addition, cellular standards are continually evolving to take advantage of the constantly increasing mobile-DSP performance. Cellular carriers leverage this trend to provide more and better multimedia content so that they can increase revenue and attract new customers. The user ultimately benefits from "anywhere" mobility. For example, because the cellular adoption rates are in the 100 millions per year, a very streamlined and well-understood competitive supply chain exists to keep pricing low and performance high.

Broadband Wireless Compared to Cellular RF Service

In parallel with this cellular development effort, wide-area broadband wireless systems were developed and deployed, following a market/use model. Initially, so-called "coffee-house" Wi-Fi® gave users 802.11 Internet access when they parked near or sat in certain enabled restaurants. Later, some cities built experimental metro-Wi-Fi access points to serve the downtown cores. The models were so successful that, in 2004, a better wireless system, 802.16 WiMAX® (and Korean WiBro®) was launched, with a view to provide "metro area broadband wireless access" service.

Using orthogonal frequency division multiplexing (OFDM) instead of single-carrier modulation permits, these broadband wireless systems to overcome urban multipath effects, but they require four times the transmit power. This is because OFDM 802.16d peak-to-average ratio (pk-avg) is approximately 11dB, as compared to WCDMA 3GPP pk-avg of 5dB. Intel® has championed WiMAX as the RF-connectivity standard for ultra-mobile PCs (UMPCs) whose form factor is defined to be approximately six times the size of a typical cellular handset. Therefore, the UMPC case makes sense for WiMAX service, but is not so easy to deploy in a thin/folded handset with small battery, as WiMAX requires a much bigger battery.

Tower Build-Out

One hurdle common to both cellular and WiMAX deployments is tower build-out and right-of-way access. Costs to lease right-of-way and municipal regulations limiting "ugly" towers mean that both systems can build out at approximately the same pace in any given location. However, cellular carriers started build-out about 20 years before WiMAX and, therefore, they have the clear upper hand for base station tower coverage and new build-out.

Where Wired Fixed-Residential Services Fit

Wired residential-access systems compete directly with fixed-residential WiMAX. Residential services commonly include fiber to the home (PONs), telephone-line DSL, and cable TV Internet-access systems. In developed countries, these services benefit from long-established installations with sophisticated network terminating equipment. PONs are a newer entry, however the network local exchange carriers (LECs) already own the right-of-way and merely schedule the new fiber plant build-out as older copper lines require replacing.

For the femtocell base station deployment, these services are complimentary and will be reviewed in the next section.

Basic Femtocell Base station Implementation

Figure 1 compares traditional cellular connection through a node-B macrocell base station, as compared to femtocell base station installation.

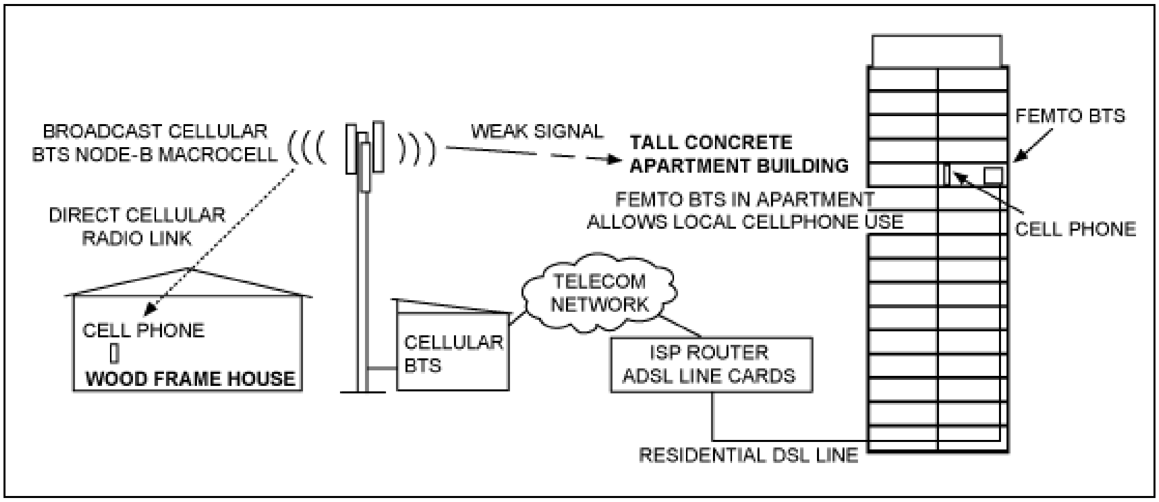


Figure 1. Traditional node-B macrocell cellular connection vs. femtocell base station connection.

The left-hand scenario in Figure 1 is a traditional direct connection from a cell phone handset to the cellular tower. Here, we show a wood-frame house, which has relatively low loss through the walls and is somewhat close to the cellular macro base station.

The right-hand scenario shows a concrete high-rise building with a femtocell base station installed in the apartment or common office area. The network feed to the femtocell base station is through a residential DSL line or commercial wired Ethernet. In this scenario, we show that the signal to the apartment building is weak. The femtocell station acts as a "personal, dedicated base station" and does not talk to the macrocell(s).

It should be added that the ability of the femtocell station to ignore macrocell and other femtocell cell transmissions is a key design problem that has been overcome by several baseband DSP providers.

Cellular System Problems that Femtocell Base Stations Overcome

Key Capacity Limiters

Traditional macrocell base stations are typically caller-capacity-limited at peak loading hours. The system is statistically designed, employing traffic queuing theory, to handle a certain quantity of calls that will last for a mean duration. Therefore, long phone calls limit capacity during peak loading hours.

Also, when the cell site needs to service handsets that are operating at the boundary, it forces the macrocell transmitter to increase power, and hence occupy a larger portion of the available dynamic range for all callers. As a result, edge of cell phone calls limit capacity because they "hog" dynamic range (see **Figure 2**).

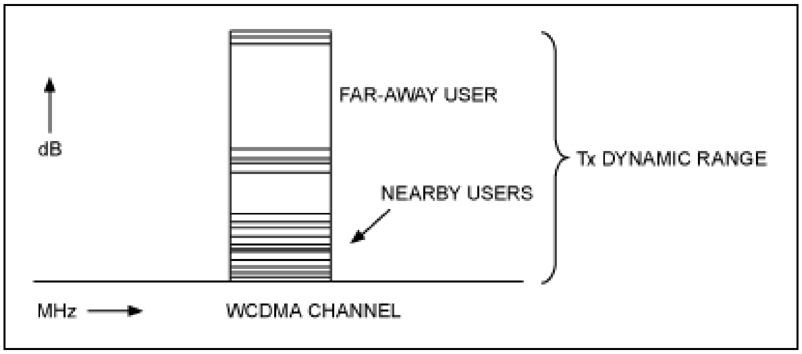


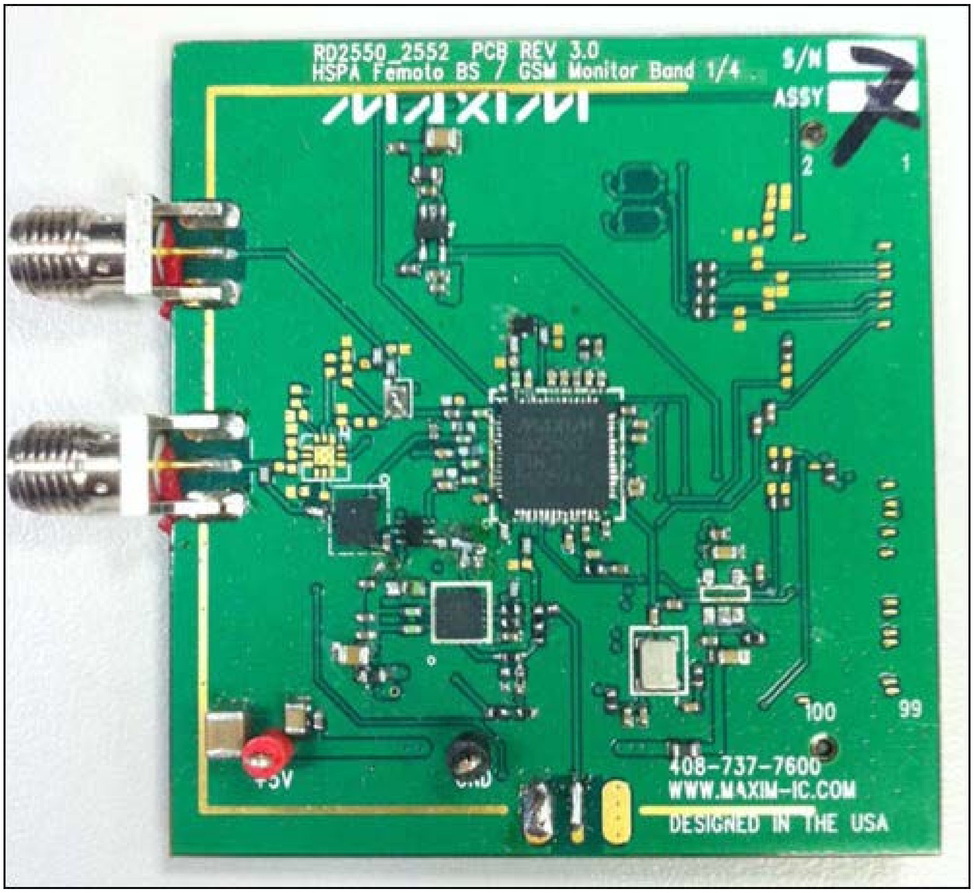
Figure 2. Conceptual caller power occupancy for a macrocell transmitter.

These two factors limit macrocell site capacity and, therefore, they limit cellular carriers' revenues and ultimately slow down new-user adoption.

Maxim's Femtocell Base station RF Single-Chip Transceiver

Maxim's RD2550 femtocell base station reference design was designed to meet the TS25.104 requirements for WCDMA band 1. WCDMA band 2, 4, and 5 reference designs are also available. At the heart of this reference design is a single-chip transceiver with a delta-sigma bit-stream digital interface to the baseband DSP/modem. The transceiver uses a reduced-level LVDS interface and the channel filtering is done on the baseband DSP/modem, which allows for software-reconfigurable radio.

A complete reference design for the RF transceiver section has been designed. It supports macrocell monitor-mode using an integrated LNA in the transceiver. A photograph of the reference board is shown in Figure 3. For more information, see reference design 5364, "Femtocell Radio Reference Designs Using the MAX2550–MAX2553 Transceivers."



More detailed image (PDF, 1MB)

Figure 3. Maxim femtocell base station reference design.

Meeting the UTRA Band 1 Femtocell Base-Station Standard (3GPP TS25.104)

The main requirements of the femtocell base station standard are shown in **Table 1**. For a WCDMA femtocell base station, meeting both the receiver and the transmitter TS25.104 dynamic range requirements is more stringent than meeting the requirements for a TS25.101-compliant handset, by at least 10dB. However, the anticipated production volumes require handset-like circuit integration and BOM cost. Therefore, the system should ideally be designed around a handset chipset with low cost and high integration, but also be capable of exceptional performance with the reversed Tx-Rx bands (as required for a base station).

Table 1. TS25.104 Main Requirements

Uplink Requirements		
Description	**Specification**	**Condition**
Frequency band	1920MHz to 1980MHz	Band 1
Rx sensitivity	-107dBm	12.2kbps data rate, BER shall not exceed 0.1%

Adjacent channel selectivity (ACS)	-101dBm	-38dBm, 5MHz offset WCDMA modulated interfering signal
Blocking (1900MHz to 2000MHz)	-101dBm	-30dBm (min), 10MHz offset WCDMA modulated interfering signal
Blocking (1MHz to 12,750MHz, except 1900MHz to 2000MHz)	-101dBm	-15dBm CW carrier
Intermodulation	-101dBm	-38dBm, 10MHz offset CW signal and -38dBm, 20MHz offset WCDMA signal
Downlink Requirements		
Description	**Specification**	**Condition**
Frequency band	2110MHz to 2170MHz	Band 1
Maximum output power	Less than +24dBm	—
Adjacent channel leakage ratio (ACLR)	-45dB/-50dB	Offset frequency 5MHz/10MHz
Error vector magnitude	17.5%/12.5%	QPSK/16QAM, RMS

In the receiver, for example, the 5MHz offset in-band blockers for measuring ACS are specified to be at -38dBm, which is much harsher than -52dBm blockers required for handset. Similarly, the 10MHz offset in-band blockers for measuring channel selectivity are specified to be -30dBm, as compared to -56dBm for handset. Therefore, the receiver must be capable of much higher IIP2 and IIP3 performance.

The transmitter linearity is similarly much tougher for a femtocell base station to meet than it is for a handset. For a WCDMA handset, ACPR is specified at -33dBm, whereas for TS25.104 femtocell base station it is about -45dBm.

System Performance Measurement Condition and Analysis

Receiver sensitivity is a system specification that is very much influenced by signal quality in the RF channel and baseband processing in the DSP modem section. Under minimum input signal level conditions, the RF channel quality is purely limited by the receiver's noise contribution, which is determined by its NF.

The measured receiver sensitivity is calculated from the measured system NF. For the sensitivity calculation, 7.5dB is required for E_b/N_o to meet 0.1% BER for a QPSK signal (processed in the baseband demodulator). The sensitivity can be calculated as follows:

Reference sensitivity = KTB + NF + (E_b/N_o) - PG

Where:
BW = chip rate of 3.84MHz
KTB = -174dBm/Hz + 10 log (3.84MHz) = -108.13dBm
PG = bit rate of 12.2kbps relative to spreading BW = 10log (3.84MHz/12.2kbps) = 25dB

If NF is 10.5dB, the sensitivity is calculated as:

-108.13dBm + 10.5dB + 7.5dB - 25dB = -115.13dBm

ACS and blocking performance are also calculated same way. The system NF is measured with specified interference conditions. In this case, the NF is worse than the sensitivity measurement due to the additional noise generated from the interference effect.

The Tx performance is measured using the Test Model 1 (TM1) signal specified in TS25.141. The TM1 signal simulates a realistic traffic scenario that may have a high pk-avg.

The maximum power level is measured in the 3.84MHz WCDMA bandwidth. The ACLR is measured at the 5MHz offset position. The transmit ACLR performance is mainly dominated by the external PA performance, in this case.

RD2550 UMTS Band 1 Femtocell Base-Station Reference Design Measured Performance

Table 2. RD2550 Reference Design Measured Performance

Uplink Requirements		
Description	**Specification**	**Maxim's Radio Performance**
Frequency band	1920MHz to 1980MHz	Band 1
Rx sensitivity	-107dBm	Exceeds
ACS	-101dBm	Exceeds
Blocking (1900MHz to 2000MHz)	-101dBm	Exceeds
Blocking (1MHz to 12,750MHz, except 1900MHz to 2000MHz)	-101dBm	Exceeds
Intermodulation	-101dBm	Exceeds
Downlink Requirements		
Description	**Specification**	**Measured Performance**
Frequency band	2110MHz to 2170MHz	Band 1
Maximum output power	Less than +24dBm	With external PA
ACLR	-45dB/-50dB	Exceeds
Error vector magnitude	17.5%/12.5%	Exceeds

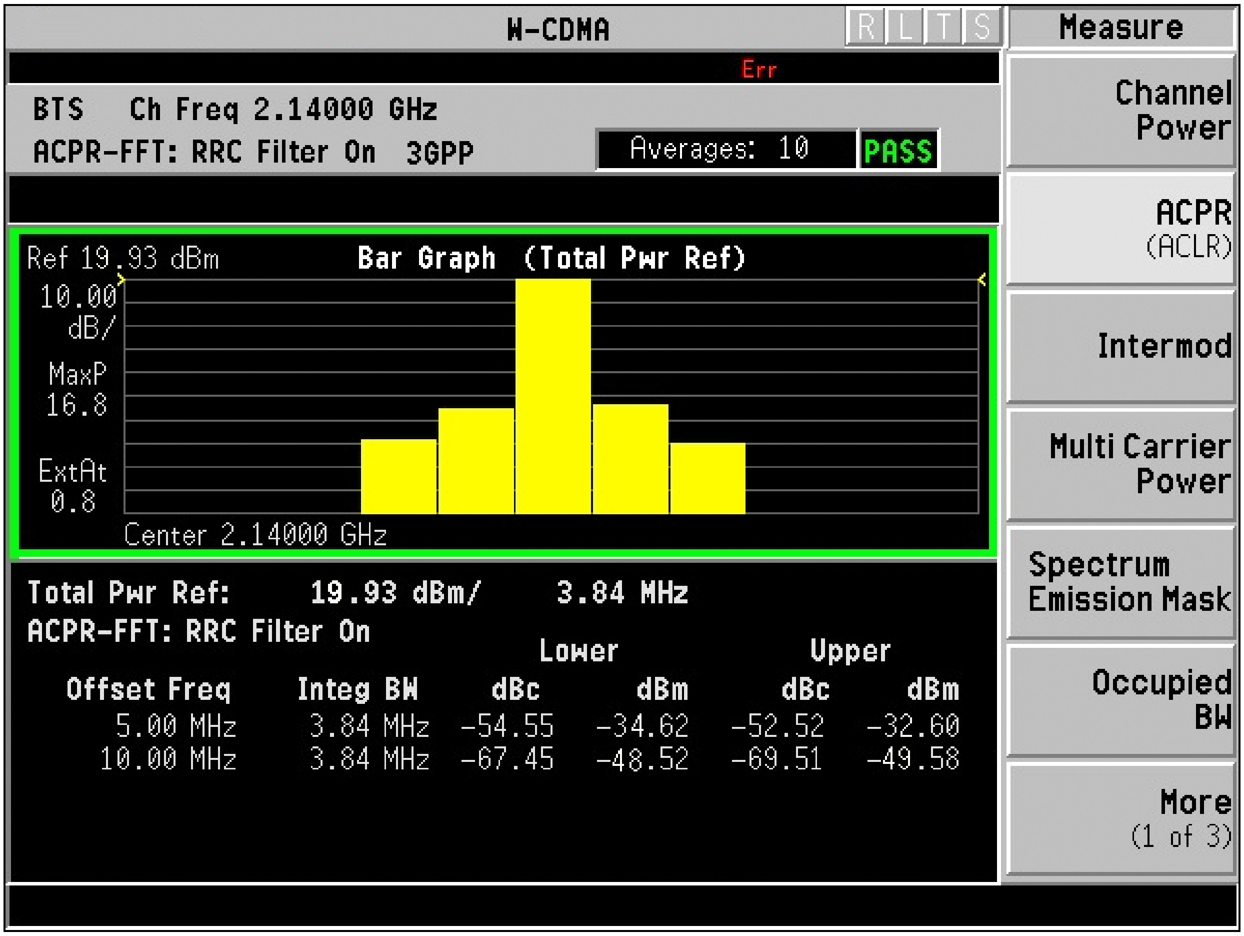


Figure 4. TM1 16DPCH signal ACLR at +20dBm output power level.

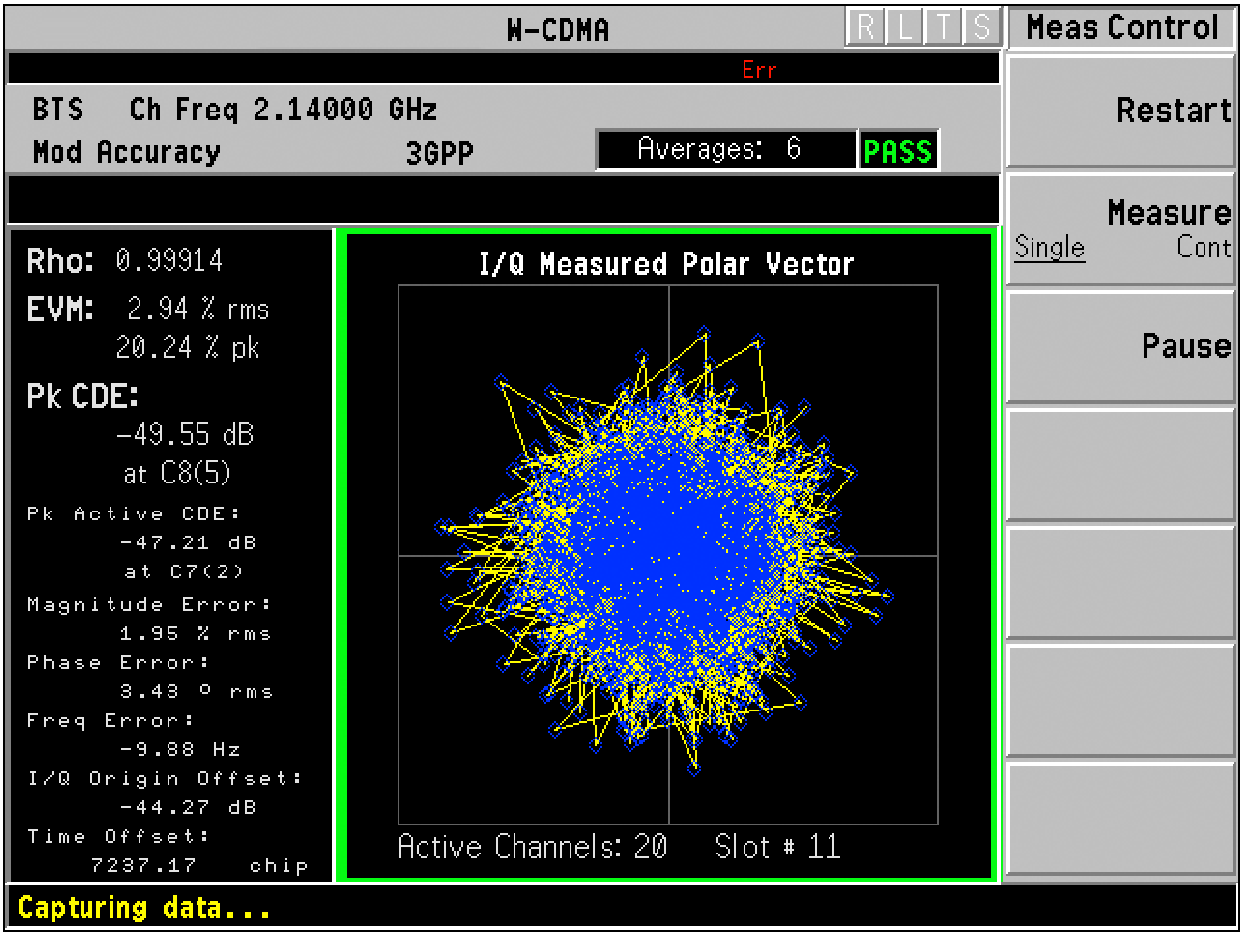


Figure 5. TM1 16DPCH signal EVM at +20dBm output power level.

Conclusion

Femtocell base stations will provide residential cell phone customers with a much-improved data network experience. Designing a femtocell base station circuit is difficult because it must meet stringent base station performance specifications, yet be low cost like a cellular handset. Maxim's femtocell base station transceiver successfully meets the 3GPP TS25.104 specification key requirements, and offers the smallest BOM parts count. Maxim's RD2550 UMTS band 1 radio reference design based on the MAX2550 femtocell RF transceiver achieves the optimal level of performance and cost for this market.

Related Parts		
MAX2550	Band I, V, and VIII WCDMA Femtocell Transceiver with	Free Samples

	GSM Monitoring	
MAX2551	Band II and V WCDMA Femtocell Transceiver with GSM Monitoring	Free Samples
MAX2552	Complete Single-Chip Femtocell Radio Transceiver for WCDMA Band 4	Free Samples
MAX2553	Band Class 0, 1, and 10 cdma2000 Femtocell Transceiver	Free Samples

More Information
For Technical Support: http://www.maximintegrated.com/support
For Samples: http://www.maximintegrated.com/samples
Other Questions and Comments: http://www.maximintegrated.com/contact

Application Note 5331: http://www.maximintegrated.com/an5331
APPLICATION NOTE 5331, AN5331, AN 5331, APP5331, Appnote5331, Appnote 5331