



APPLICATION NOTE 4063

Notes on Femto Base Station Application and a Radio Approach

Abstract: This application note discusses the development and deployment of 3G cellular femto base stations. The market position and the technical challenges for last-mile residential connectivity are discussed, and 3G femto base stations are proposed as a very good solution. Maxim's 3GPP TS25.104-compliant radio solution is presented.

Introduction to Deploying Femto Base Stations

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 remote areas and in residences.

One solution is the home base station, which provides in-home mobility with maximum user data rates, without loading the macro node-B cell sites. They are classified as "femto" power.

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

Femto home base stations access the network through the publicly-switched telephone network, which is typically available through a residential DSL line. The handset only communicates to the femto station in the home, and this completely offloads that user from the macrocell.

In the following paragraphs, we review the basis for femto home base-station deployment and show how Maxim's radio solution offers key advantages for this technology.

General Case for Improving Cellular Coverage Compared to Other Solutions

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 are in the works. 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 "metro area broadband wireless access" service.

Using OFDM instead of single-carrier modulation permits these broadband wireless systems to overcome urban multipaths, 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 first-world 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 femto base-station deployment, these services are complimentary and necessary as we will cover more in the next section.

Basic Femto Base-Station Implementation

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

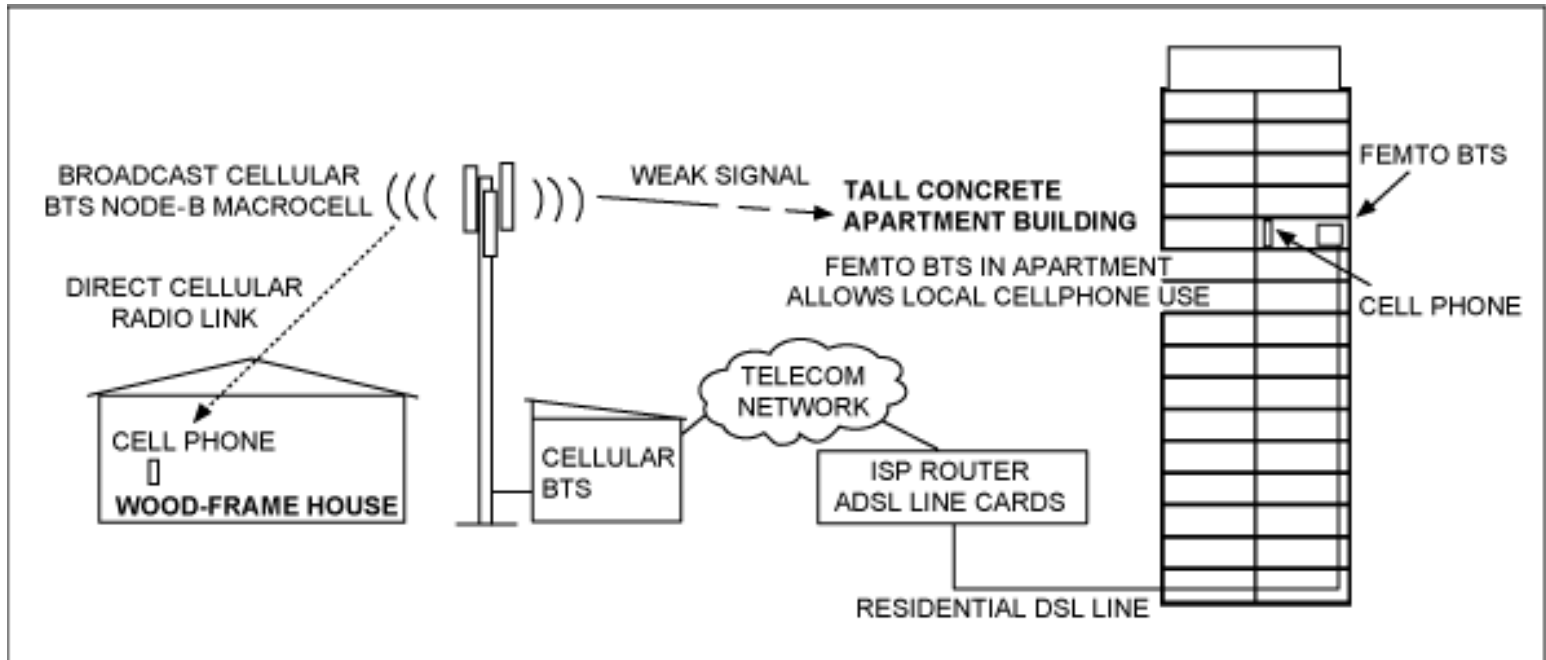


Figure 1. Traditional node-B macrocell cellular connection vs. femto base-station connection.

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 femto base station installed in the apartment. The network feed to the femto base station is through a residential DSL line. In this scenario, we show that the signal to the apartment building is weak. The femto 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 femto station to ignore macrocell and other femto cell transmissions is a

key design problem that has been overcome by several baseband DSP providers.

Cellular System Problems that Femto Base Stations Overcome

Key Capacity Limiters

Traditional macrocell base stations are typically caller-capacity-limited at peak loading hours when all the users try to call. 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**).

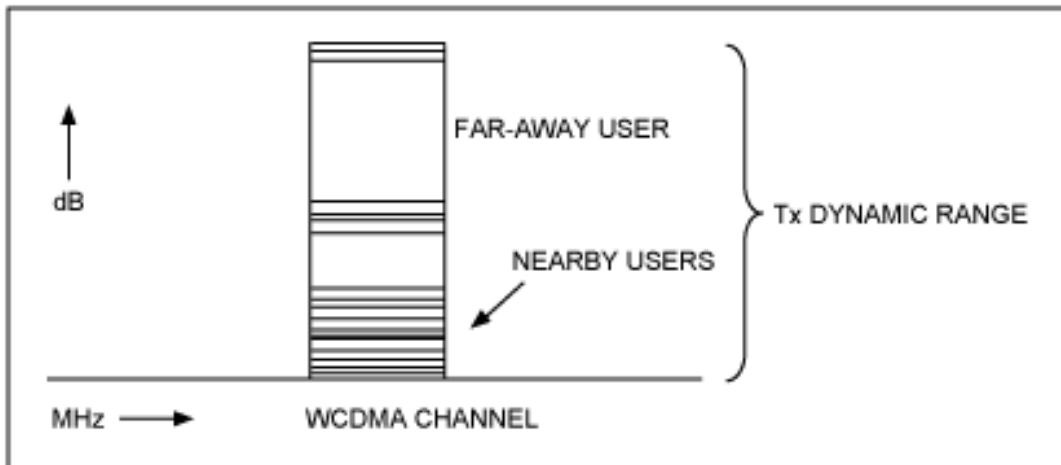


Figure 2. Conceptual caller power occupancy for a macrocell transmitter.

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

The Case for DSL-Served Home Base Stations

It is estimated that roughly half of cellular calls are made from inside a home, and many users complain of poor reception within concrete-construction apartment buildings.

Figure 3 shows path-loss estimates into two types of residences. Most 3G cell phones require approximately -110dBm received-traffic channel power or more for reliable IP data service. In the case of the concrete apartment, the receiver sensitivity shows that the user will not get data service.

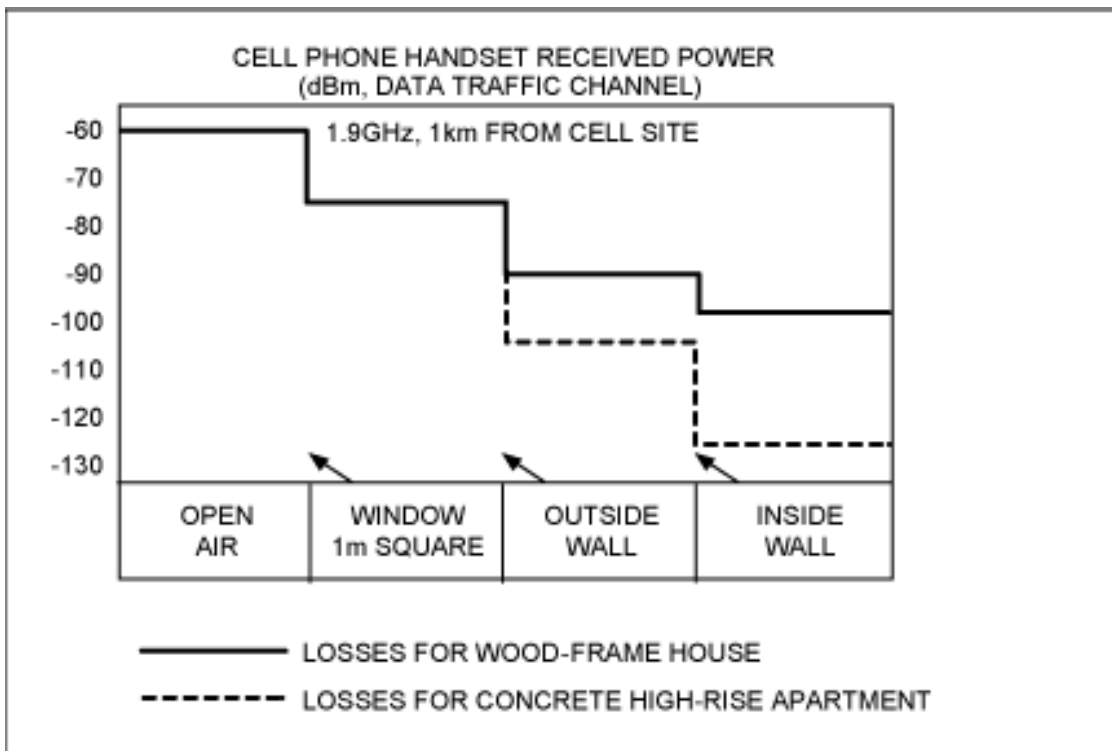


Figure 3. Path loss into two types of residences.

At the same time, it has been observed that DSL is being adopted in Europe, is very mature in the US, and is used widely in much of the Pacific Rim including China. New DSL modems will incorporate this service.

Many US and European cellular users have a cordless phone (POTS or IP phone), DSL or cable-modem computer internet, TV service, and Wi-Fi in their home. The 3G cellular carriers want to compete with these services and provide the ultimate in multimedia service.

Figure 4 shows how the femto base station coexists with an in-home Wi-Fi access point, and replaces cordless phones.

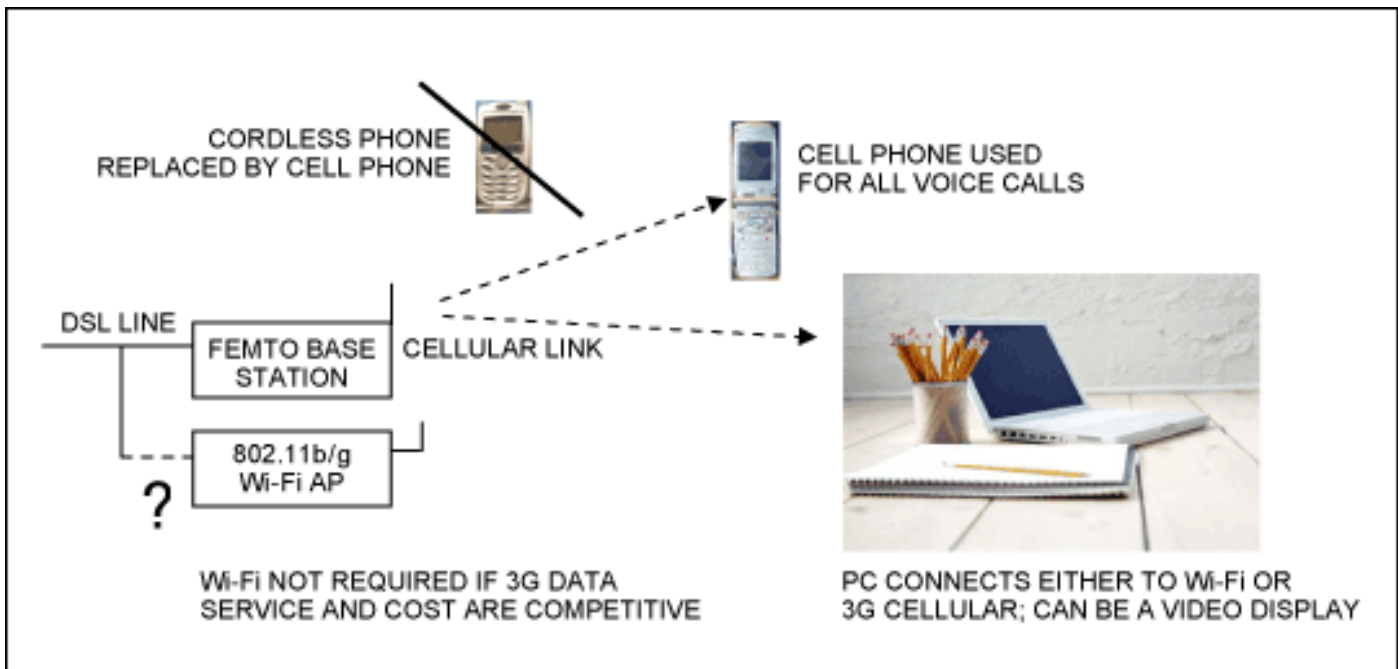


Figure 4. Femto base-station coexistence with in-home Wi-Fi access point.

Maxim's Femto Base-Station RF Transceiver Chipset

Maxim's V8.0 femto base-station reference design was designed to meet the TS25.104 requirements for WCDMA band class 1. This RF chipset consists of a two-chip RF transceiver with a sigma-delta 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 transmit-band monitor-mode using an integrated LNA in the receiver IC. A photograph of the reference board is shown in **Figure 5**.

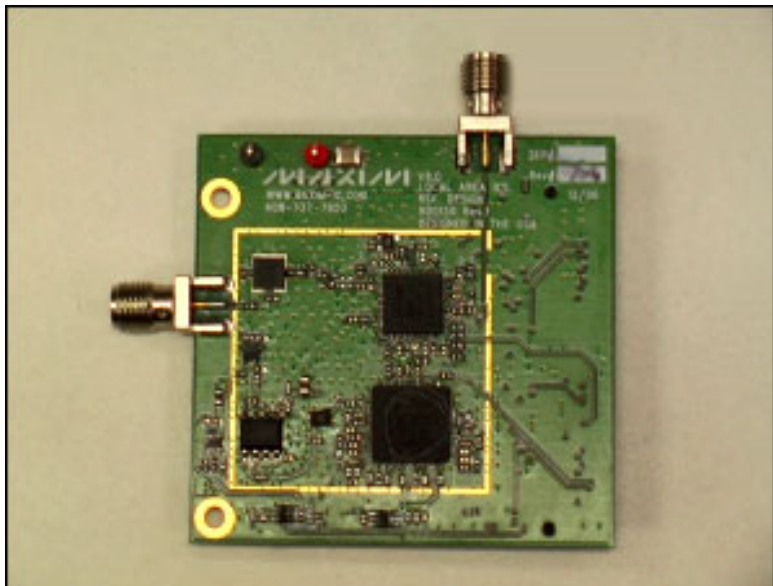


Figure 5. Maxim femto base-station reference design.

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

The main requirements of the femto base-station standard are shown in **Table 1**. For a WCDMA femto 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 0.001%
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 more harsh 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 femto base station to meet than it is for a handset. For a WCDMA handset, ACPR is specified at -33dBm, whereas for TS25.104 femto base station it is -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_0 to meet 0.001% BER for a QPSK signal (processed in the baseband demodulator). The sensitivity can be calculated as follows:

$$\text{Reference sensitivity} = \text{KTB} + \text{NF} + (E_b / N_0) - \text{PG}$$

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:

$$-108.13\text{dBm} + 10.5\text{dB} + 7.5\text{dB} - 25\text{dB} = -115.13\text{dBm}$$

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 performances are 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.

V8.0 UTRA Band 1 Femto Base-Station Reference Design Measured Performance

Table 2. V8.0 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	Passes
Blocking (1MHz to 12,750MHz, except 1900MHz to 2000MHz)	-101dBm	Passes
Intermodulation	-101dBm	Passes
Downlink Requirements		
Description	Specification	Measured Performance

Frequency band	2110MHz to 2170MHz	Band 1
Maximum output power	Less than +24dBm	Passes
ACLR	-45dB/-50dB	Exceeds
Error vector magnitude	17.5%/12.5%	Exceeds

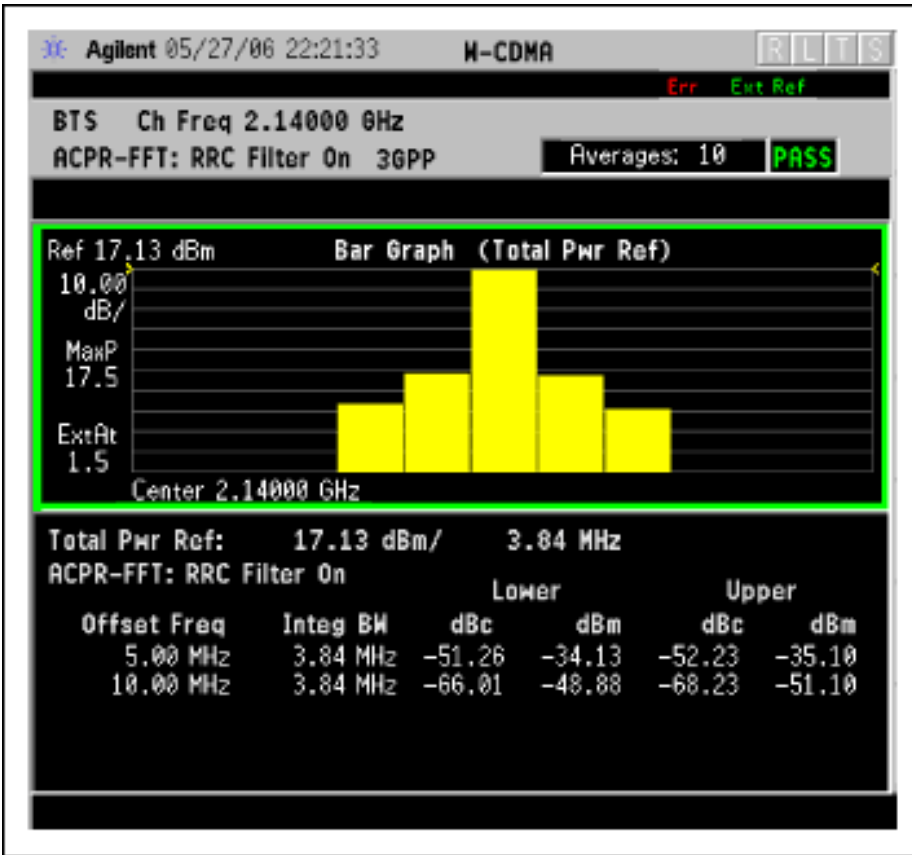


Figure 6. TM1 64DPCH signal ACLR at +17dBm output power level.

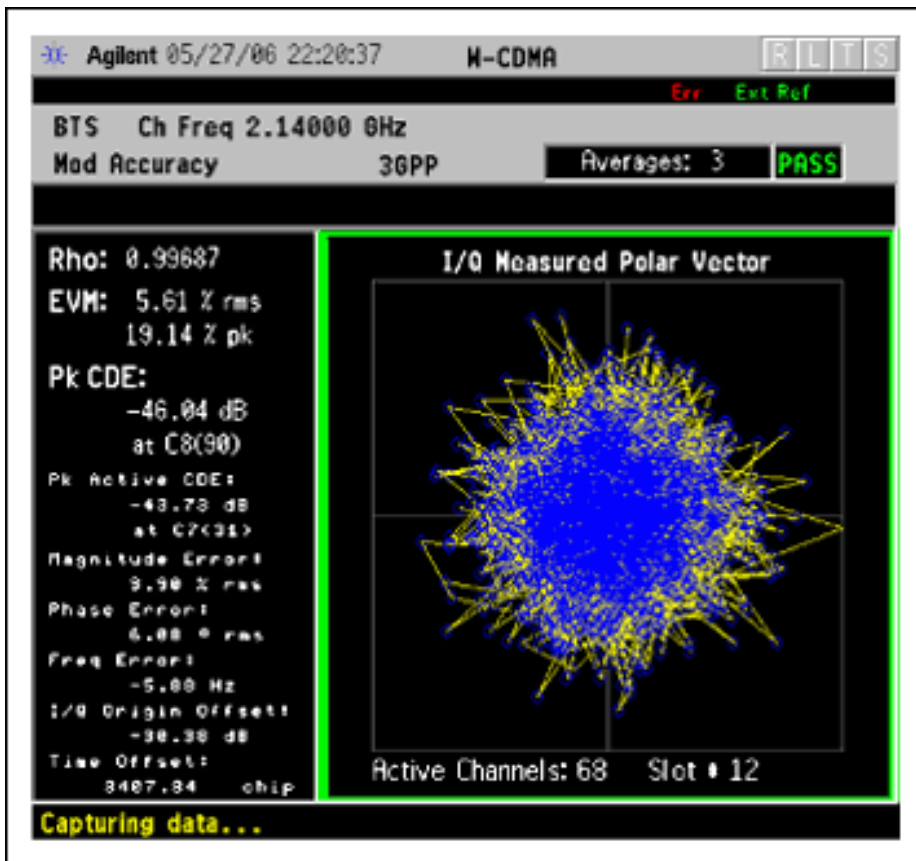


Figure 7. TM1 64DPCH signal EVM at +17dBm output power level.

Conclusion

Femto base stations will provide residential cell phone customers with a much-improved data network experience. The circuit design is difficult because it must meet stringent base-station performance specifications, yet be low-cost like a cellular handset. Maxim's femto base-station chipset successfully meets the 3GPP TS25.104 specification key requirements, and offers the smallest BOM parts count.

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