A SDR RFFE Reference Design for Femtocells

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ABSTRACT

Femtocells - small base stations deployed residentially and in the enterprise – present several challenges for RF designers. Femtocells must support the required uplink and downlink frequencies while also integrating downlink scanning capability which will be used by the network to identify neighboring femtocells and macro cells. The integration of this multi-band multi-mode functionality in a consumer electronics device presents cost and performance challenges. BitWave has developed a WCDMA femtocell reference design which supports WCDMA femtocell functionality as well as WCDMA and GSM downlink scanning using a single BitWave Softransceiver RFIC. Multi-band functionality, as implemented in BitWave's RFFE reference design, is and continues to be, extremely important to commercial radio design. BitWave will present performance data for BitWave's femtocell RFFE reference design including sensitivity, EVM and transmit mask.

1.0 INTRODUCTION

According to the Femto Forum, "Femtocells are low-power wireless access points that operate in licensed spectrum to connect standard mobile devices to a mobile operator's network using residential DSL or cable broadband connections." [1] Industry opinion expects femtocells will soon be deployed both in-building for enterprise use and residentially, and will offer carriers and customers multiple values. These benefits include:

Improved Data Throughput – by locating a small base station inside a residence or enterprise, where the base station signal is likely to be weakest (in-building), received signal strength (RSSI) in the handset may be significantly improved resulting in higher potential data throughput.

Better Coverage – similar to the preceding, locating the femtocell where the coverage from the macro station is most likely to break down can improve the overall coverage offered by a particular carrier

Capacity Management – Femtocells are designed to leverage pre-existing broadband backhauls, thus any traffic supported by the femtocell is offloaded from the macro network onto the broadband backbone.

Capex Management – Since Femtocells can be used to manage capacity on the network, careful deployment of Femtocells may minimize the need for additional macro base stations.

Femtocells offer both carriers and consumers many reasons to implement a Femtocell strategy, however successful growth in Femtocell deployments also presents a few problems to be solved.

Cost - Carriers today often license multiple spectrum bands. A Femtocell optimized for a particular carrier should therefore be designed to provide support across all of the carrier's licensed spectrum. Since each carrier may license a unique set of spectrum, each carrier will require a unique infrastructure configuration which reflects its unique use case. The economies of scale in the infrastructure business are dramatically different than that of the handset business; expected deployment volumes are an order of magnitude less than that of mobile terminals. Low volume results in higher cost (as compared to a mobile terminal), which presents carriers with a challenge; carriers higher upfront costs may make it riskier to grow their Femtocell business using the same type of subsidy driven model that's been successful for mobile terminals. Without a low cost point, it's difficult to drive a compelling business case, and femtocell deployments risk postponement. Today, even though femtocell trials have been ongoing at multiple carriers for several years, no carrier has yet purchased million+ quantities of femtocells for deployment in their networks.

Operational Requirements and Device Complexity – Network planning can be complicated by the addition of Femtocells. By design, Femtocells are portable and can be plugged into a router for broadband backhaul. However, until a customer installs the Femtocell, the network has no information of where the Femtocell is in its network; once powered up, one of the first tasks for a Femtocell is to identify where it is. To do this, the Femtocell uses either GPS (assuming adequate GPS RSSI) or it must be able to fix its location based on the surrounding macro cells in that carrier's network. This requires a Femtocell to operate using uplink and downlink frequencies as defined for both infrastructure and mobile devices. Since there's no

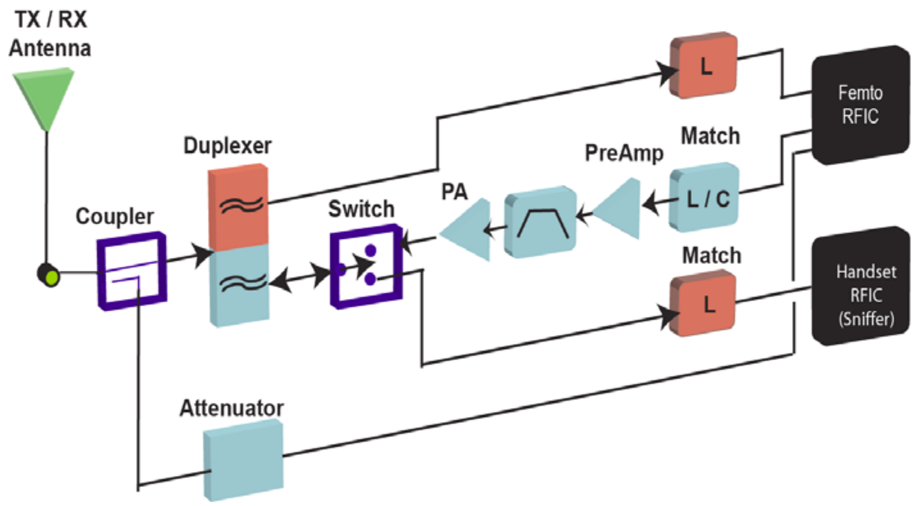

Figure 1 - Single Band Femtocell with Downlink Scanning (Multi-RFIC Solution)

guarantee that a consumer would locate a Femtocell in a room with sufficient view of the sky to guarantee that GPS would work, carriers must include "downlink scanning" in their requirements. Femtocells designed for a single band of coverage must actually work on multiple frequency bands of operation in order to ensure that they can localize their position.

2.0 INTEGRATION CHALLENGES IN A MULTI-BAND RADIO

Existing Femtocell designs are either comprised of discrete RF components or are based on multi-band chipsets. Each unique frequency band and protocol that a particular application must support may require a separate RF path and chipset. At a minimum, each femtocell must provide for the uplink and downlink of the primary band and protocol supported but must also provide band coverage as necessary for downlink scanning. A block diagram for a single band Femtocell reference design that includes downlink scanning capability is provided in figure 2. The challenge for Femtocell vendors is that these existing architectures don't offer a clear path for cost reduction since each carrier-specific solution would require different chips or chipset(s). Combined with the lower volumes associated with each carrier specific use case, Femtocell chipset are not clear targets for integration based cost reduction.

With regards to chipset cost reductions, typical RF transceivers are a starting point. However, each band combination required by an individual carrier may require multiple unique RFICs to support both the femtocell in its primary bands of operation as well as support channel sniffing. This presents a challenge in that as a carrier's network grows with the addition of disparate spectrum, multiband devices are needed. However developing a cost effective Femtocell capable of deployment on all of a carriers licensed spectrum becomes more expensive.

3.0 BITWAVE'S WCDMA RFFE FEMTOCELL REFERENCE DESIGN

Programmable RFICs have the power to enable multi-band multi-mode functionality for Femtocells at a reduced cost. In other words, programmable RF technology is available today which can be used as the foundation for a multi-band RFFE reference design. Based on BitWave's Softransceiver RFIC products, BitWave has created a programmable RFFE reference design for WCDMA applications, Figure 2.

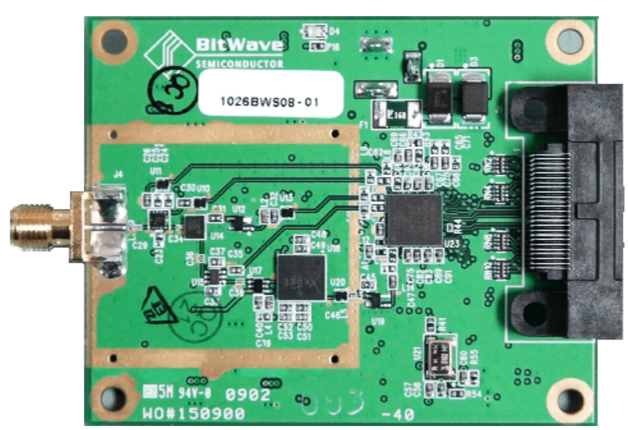

Figure 2 – BITWAVE WCDMA FEMTOCELL RFFE REFERENCE DESIGN

BitWave's Softransceiver was implemented with the same diligence as a designer would use for a fixed function ASIC. The design was completed with attention to

	Handset specs (dBm)	Femtocell spec (dBm)
Test Case	Signal	Signal
Ref Sensitivity	-106.7	-107
DPCH_Ec/Ior	-10.3 dB	-1.87 dB
Maximum Input	-25	NA
Dynamic Range	NA	-77
	NA	-57 *
Spurious Emissions	-57 dBm / 100 kHz	-57 dBm / 100 kHz
Max Power	+24 dBm (+1/-3 dB)	<+20
Frequency Error	+/-0.1 ppm	+/-0.25 ppm
OL Power Control Tolerance	+/-9 dB	+/-2 dB
CL Power Control Tolerance	+/-0.5 dB	NA
Min Power	<-50 dBm	<+6 dBm
Off Power	<-56 dBm	NA
Occupied BW (99%)	<5 MHz	<5 MHz
ACLR (adjacent channel)	>33	>45
ACLR (alternate channel)	>43	>50
EVM	<17.5%	<17.5% (QPSK) <12.5% (16QAM) (over the dynamic range of -3 to -28 dB CDP)
Peak Code Domain Power	<-15 dB (SF=4)	<-33 dB (SF=256)
Spurious Emissions into Rx band		
Low band	-79 dBm in 100 kHz	-82 dBm in 100 kHz
High band	-60 dBm in 3.84 MHz	-82 dBm in 100 kHz

Table 1 UE vs. Femtocell Spec Comparison

sensitivity as well as both total gain and blocker performance in the receiver and to max transmit power, transmit EVM, adjacent channel leakage ratio and transmit noise in the receive band in the transmitter. What is noteworthy is the fact that the choice and implementation of a software defined transceiver didn't affect the design of the femtocell RFFE any differently than any other fixed function transceiver would.

4.0 KEY DESIGN CONSIDERATIONS

Many proposals for Femtocells include the ability to support between 4 and 8 simultaneous connections. When located in building, the building floor plan will clearly impact the link budget associated with each user who attempts to connect to the femtocell and the femtocell may be required to support a wide dynamic range. Some of the more challenging considerations in a femtocell design may therefore include:

- ❑ Required Blocker Performance (Dynamic Range)
- ❑ RX Sensitivity / Full Duplex and Transmit Noise in RX Band
- ❑ Adjacent Channel Leakage Ration (ACLR)

Femtocell requirements are a little more challenging than handsets. For the reader's reference, Table 1 compares the requirements for UMTS handsets and femtocells as described in 25.101 and 25.104.

In a true SDR, dynamic range is achieved by specifying an appropriate ADC resolution. In the Softransceiver RFIC, the ADC may be configured as a pipelined or sigma delta ADC and can deliver up to 10 bits of resolution depending upon sample rate and power consumption. Initial software settings are applied upon Softransceiver initialization to set the clock trees (and ADC sample rates) and configure the ADC for the desired bits of resolution.

Higher receive sensitivity and EVM is achieved through good RF design for receive gain and noise figure but also through the implementation of automated calibration. The Softransceiver RFIC calibrates itself upon startup for DC offset and IQ balance in each protocol/frequency band combination that it is configured to support in the mode file.

The processor at the heart of the Softransceiver control block allows for the implementation of binary and seeded searches in order to rapidly complete calibration.

Sensitivity is also affected by transmit noise in the receive band. A combination of transmit SAW filters and improved transmit linearity combine to minimize transmit noise. In a software programmable RFIC, improved linearity can be also be improved through a combination of digital pre-distortion (leveraging the digital processing capability inherent the SDR RFIC) or through improved performance in the analog circuit blocks.

5.0 A MULTIBAND FUTURE

More and more functionality is being added in each device that is developed. Governments are continuing to auction and carriers are continuing to license many disjointed blocks of spectrum which, to provide seamless service to their customers, must be transparently supported by all the devices approved for deployment on the carriers network. As was mentioned earlier, the result is a trend towards smaller devices which must support more bands and protocols. SDR is one technology that provides an elegant solution to the multiband, multimode challenge yet can remain small in size and competitive in cost.

6.0 PERFORMANCE DATA

BitWave's BW1102 Femtocell RFFE Reference Design was completed and tested in early 2009. The reference was able to support frequency switching in less than 150 microseconds and offered EVM of about **12%.**

As shown in figure X, the reference design also met In Band Blocker specs with over 4dB of margin.

Transmit ACLR was sufficient up to Pout of about 18dBm. More work is required to achieve specification compliant performance at higher output powers.

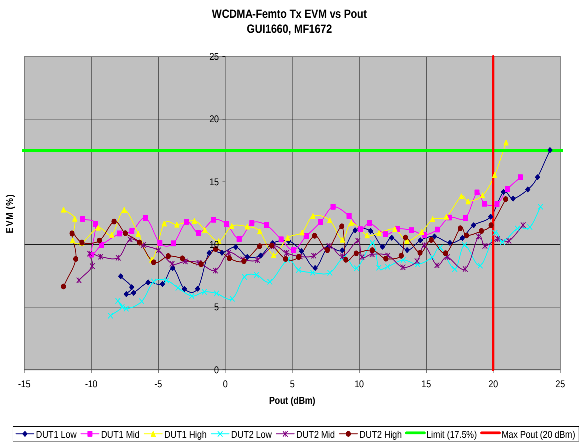

Figure 3 EVM vs. Pout

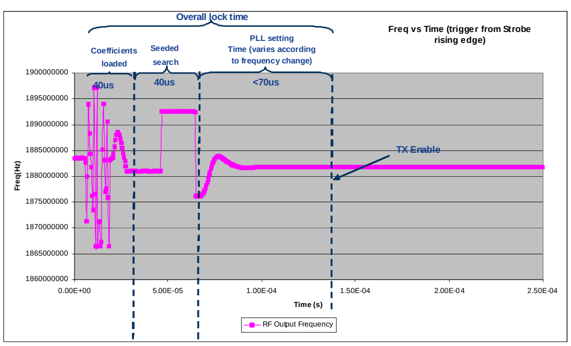

Figure 4 Frequency vs. Settling Time

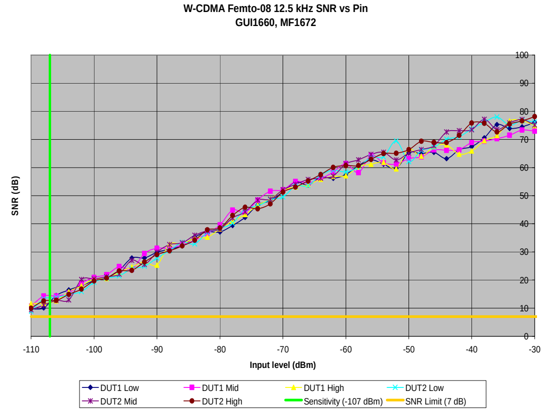

Figure 5 SNR vs. Pin

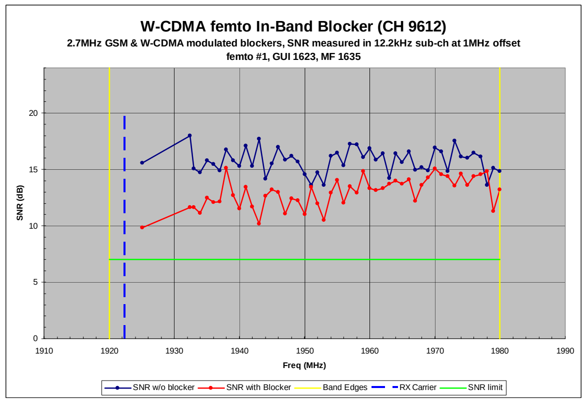

Figure 6 In Band Blocker Performance

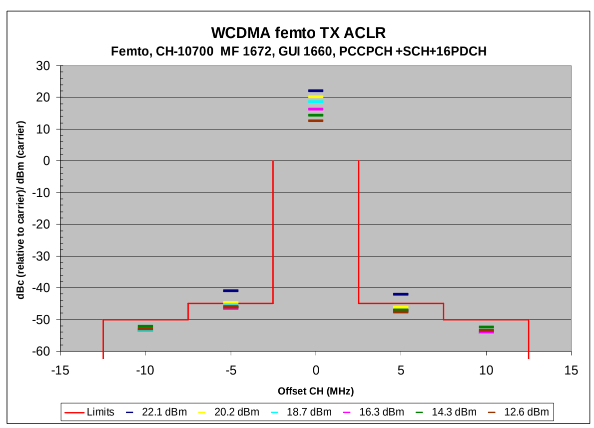

Figure 7 Transmit ACLR (Pout 18dBm)

7.0 SUMMARY

For Femtocells to become as ubiquitous in homes and businesses as cell phones, Femtocell vendors need to design and manufacture platforms which are high performance, low cost and adaptable to different frequency bands of operation and wireless protocols For Femtocells, the challenge to lower cost, provide flexibility in deployment, future proof designs, as well as offer turnkey solutions can be met with programmable RF architectures. In the Femtocell reference design described in this paper, it's shown that a single programmable RF architecture can meet the performance requirements of today's Femtocells designs. Supplying carriers with common platforms which can be reprogrammed with software to support multiple bands and protocols offers carriers an opportunity to streamline their supply chain and simplify their customer offering. These SDR solutions for Femtocells are available today.

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[1] FemtoForum,
www.femtoforum.org/femto/index.php?id=46