Multi mode wireless terminals –Key technical challenges

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***Abstract* — Increasing demand for seamless connectivity on mobile platforms is fueling phenomenal technological innovation in the wireless industry. In addition to second and third generation digital cellular standards striving to provide subscribers with higher data rates along with voice several competing standards like Wireless Local Area net works (WLAN) and Bluetooth are gaining consumer acceptance as viable solutions for data connectivity . Industry is rapidly moving towards convergence of radio technology to cater for multiple communication standards on single platform .Key technical challenges in implementation of radio architectures for multi mode radio are presented .**

***Index Terms* :--- Code division Multiple access (CDMA) direct Conversion , global system for mobile communication (GSM) Wide Band code division multiple access (WCDMA) , Wireless Local Area network (WLAN)**

I. INTRODUCTION

Phenomenal growth in wireless subscribers worldwide has fuelled evolution of multiple global technologies essentially addressing simple consumer need for voice data connectivity on mobile terminals . As the industry transitions from second generation (2G) to third generation (3G), subscriber terminals are becoming more and more application and feature rich. These multi mode platforms need to be small , portable and battery powered and also process signals in multiple frequency bands employing different modulation schemes and occupying different bandwidth . These terminals also need to support high speed data , multimedia applications , position location technology using Global positioning (GPS) technology and or compatibility to local and personal area networking standards like 802.11 and Bluetooth . Changes in wireless market from traditional voice centric hand phones to advanced feature rich personal digital assistant(PDA) smart phone and personal communicators pose stiff challenges to radio designer to come up with cost effective options for achieving small form factor multi mode radio architecture . Section II highlights process technology options while advanced packaging options are presented in section III Section lV and V focus on architecture options and key technical challenges in the implementation of Multi mode radio Receivers and Transmitters respectively .

II. PROCESS TECHNOLOGY OPTIONS

High performance RF requirements mandated by cellular standards have been traditionally addressed by radio design using proven and mature BiCMOS , SiGe semiconductor processes. Recent advances in Low cost RF CMOS technology offer attractive road map for large scale integration leading to System On Chip (SOC) .While reasonable RF performance has been achieved by < 0.18 μ geometry RF CMOS process, some of the classic issues of 1/f noise still pose challenges for implementing DCR solutions . Bi CMOS and SiGe processes with better RF performance and yield are dominating majority of the RF ASIC designs requiring high performance .

III. ADVANCED PACKAGE OPTIONS

While SOC still remains to be the ultimate design goal of ASIC designer , integrating high performance radio , mixed signal with DSP and controller in one device present significant challenges . Design methodologies for RF and digital subsystems are still far from optimum alignment. Substrate coupling and interference from high speed digital data / clocks are also critical issues that need to be addressed for providing viable SOC solution for multi mode platforms.

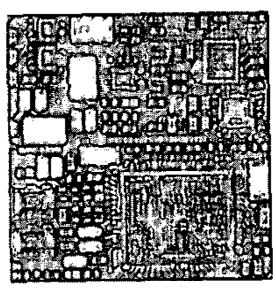

Figure 1 GSM/DCS Single Package Radio

Advances in packaging technology can effectively overcome some of the critical integration challenges and provide higher level of integration using optimum technologies for each of the functional block while

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meeting size , cost and performance goals of the radio designer. Single package radio (SPR) Fig.1 developed by Skyworks Solution Inc integrates entire receiver, Transmitter and Power amplifier functions including passives and Saw filters in a 13mmX13 mm package The SPR solution offers GSM/GPRS class 10 functionality in EGSM 900 and DCS bands.

TABLE I

Comparison of wireless standards

	Frequency Down Link	Multiple Access	Duplexing	Channel BW Mhz	Data Rate	Mobility
GSM	925-960 1805-1910 1930-1990	TDMA	FDD 45 MHz 95 MHz 80 MHz	0.2	12.2 Kbps	Cellular
GPRS (Class 12)					115Kbps Pk 25Kbps avg	
Edge					384Kbps Pk 150Kbps avg	
CDMA TIA/EIA 95	869-894 832-870 1930-1990 1840-1870	CDMA	FDD 45 MHz 55 MHz 80 MHz 90 MHz	1.23	14.4 Kbps	Cellular
CDMA 2000					307 Kbps pk 160 Kbps avg	
CDMA 1XDO					2Mbps pk 800 Kbps Avg	
WCDMA	2110-2170	CDMA	FDD 190 MHz	3.84	2.4 Mbps pk 1.2 Mbps Avg	Cellular
802.11a	2400-2497	CSMA / Collision Avoidance	TDD	20	11 Mbps pk	Local Area Adhoc, Hotspot
802,11b	5150-5350				54 Mbps pk	
802.11g	2400-2497				54 MBps pk	
Blue tooth	2400-2480	FHSS	TDD	1	434Kbps (pk Sym)	Personal area

IV Receiver Architecture

Table I summarizes some of the key performance of multiple cellular , WLAN and WPAN standards. While many combinations of the different modes of operation may be included in a wireless terminal let us consider a typical platform which supports GSM/GPRS /Edge in 900 , 1800 and 1900 MHz bands as well as , WCDMA in 2GHz band for voice and medium data rate in addition to 2.4 GHz WLAN for cheaper , higher data access in hot spot or corporate Intranet environment .

Multi mode radio of the above example needs to be designed for

1. Five different frequency bands
2. Full duplex , Time division Duplex (TDD) and Frequency division Duplex (FDD)
3. Processing signal band widths of 200 KHz , 3.84 MHz and 20 MHz
4. Receiving and transmitting GMSK/ 8 PSK, Hybrid PSK or OFSK signals of different crest factors

Super heterodyne architectures for such multi mode platforms are not economically viable due to number of factors like

- Number of IF filters needed to achieve signal filtering in each mode of operation
- Need large board space
- Higher overall bill of material

Direct conversion and or near zero IF receiver architectures are probably most optimal implementations for maximum reuse of circuits . Near zero IF architectures have been implemented successfully for GSM/GPRS receivers and may alleviate classic 1/f problems and Dc offset issues for narrow band signals while may not be optimal for wide band signals (WCDMA) with close in jammers. Some of the key technical challenges of designing RF and Base band functional blocks of DCR are presented in the following sections

A. RF front end section

Conceptual diagram of RF front end of direct conversion receiver is shown in Figure 1 below .

Wireless systems are required to operate in presence of unintentional jammers with in as well as out side desired frequency range of operation . Presence of large transmit signal can also cause receiver desensitization and distortion in full duplex systems like WCDMA. Duplex filters often large and bulky are unavoidable to achieve isolation between transmit and receiver sections. TDMA/TDD schemes used by GSM ,.WLAN / blue tooth receivers may use simple T/R switch followed by pre select filters as their transmitter , receiver are not active at the same time .

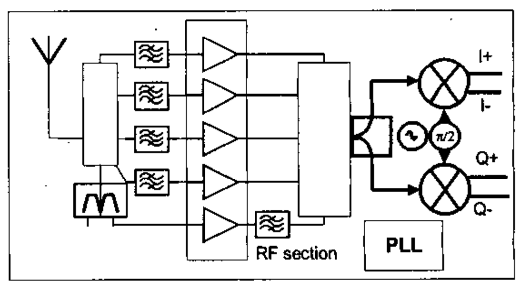

Figure 2 : Direct Conversion RF Front end

2^{nd} order non linearity in direct conversion mixer can cause DC or low frequency interference in presence of jammers [1] Transmit signal leakage through duplexer is significant in WCDMA signal path necessitating high linearity LNA and RF Saw filter between LNA and Down converter .

IIP2 in DCR can be improved by designing circuits with high common mode rejection, near perfect balance between differential arms of I/ Q signal paths., as well as accurate calibration techniques.

Rejection for intermodulation distortion is another important requirement specified based on interference scenario in which mobile terminals operate.

OFDM signals of WLAN(802 .11a,g) when subjected to non linearity can cause intermodulation between orthogonal carriers severely degrading Signal to noise performance. Since IIP3 requirements vary depending on respective performance standards, programmable linearity by dynamically optimizing the bias current is desirable to reuse down converter for multiple standards.

Multi mode terminals need different Local oscillators depending on operating mode [ref table 1] .Automatic tuning of on chip Voltage control oscillators is another key challenge in the radio design . Key performance metrics like phase noise, tuning range and power consumption could be traded judiciously for achieving stringent cellular system requirements as compared those of to l WLAN and Bluetooth.

1/f noise or flicker noise is a classic issue in DCR implementations especially for Narrow band signals like GSM with signal energy at DC . Choice of process with low flicker noise cut off frequency " f_α"or non zero IF receivers have effectively addressed this issue [1]

B. Base band section

Signals down converted to DC have distinctly different characteristics in a multi mode receiver . for example GSM/ Edge, WCDMA, WLAN signals have different crest factors , signal bandwidth ,jammer rejection requirements as well as fading profiles to list a few.

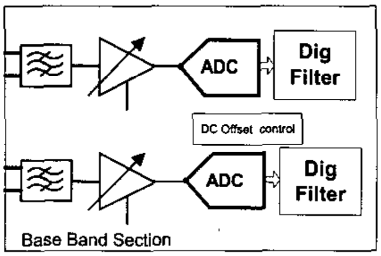

Figure 3 Base band I/ Q channel

Multi mode radio architectures are migrating towards digital implementation where AGC, Filtering and demodulation are done in digital domain offering increased flexibility and programmability This architecture provides significant advantage in size and component count.

Conceptual diagram of Base band shown fig. 3 has identical I/Q channels with a simple on chip tunable analog filter to reject far off jammers followed by AGC amplifier to reduce variation at the input of ADC . Jammer to signal ratio , fading depth ,crest factor, signal band width and required signal to noise ratio set the effective resolution of ADC . For example GSM signals may need relatively lower sampling rates but higher resolution as compared to WCDMA or WLAN which need much higher sampling rates . Programmability of sampling frequency and resolution is a critical requirement to address signal digitization. $\Sigma\Delta$ modulators have been effectively implemented addressing tradeoff between resolution , power consumption and sampling rate issues by choosing optimal over sampling rate(OSR) and order of the loop(L) Ref[2,3]

.SNR improvement in Low pass $\Sigma\Delta$ = (6L+3)*OSR dB (1)

Oversampled bit stream from $\Sigma\Delta$ ADC is filtered through decimation /digital filter to reject jammers and quantization noise . Digital processing of signals offers flexibility in optimal reconfiguration of sampling and filtering functions depending upon mode of operation.

V TRANSMITTER ARCHITECTURE

Traditional single conversion transmitters are not very attractive for implementation of multi mode transmitters due to larger die size and external component count requirement in addition to complex frequency planning to accommodate multiple operating frequencies.

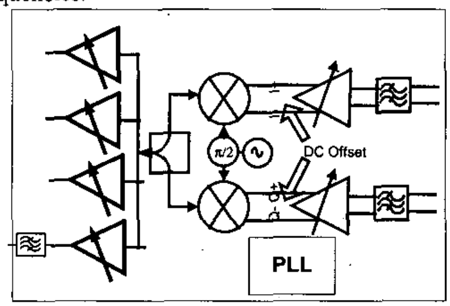

Figure 4 : Direct Conversion Transmitter

Some of the elegant transmitter architectures using ΣΔ modulators directly modulating VCOs are implemented up converter for blue tooth systems which have constant envelope (GFSK) signal waveform. [4]. Similar architectures are suitable for GSM /GPRS systems using GMSK waveform but may not be suitable for EDGE ,WCDMA or WLAN waveforms with large crest factors .

Direct conversion transmitters offer significant advantages and are more suitable for up-converting multi mode signals with different crest factors.

Fig 4. indicates conceptual block diagram of a direct conversion transmitter I/Q signals are filtered to suppress noise in the Rx band and amplified through Base band I, Q Variable Gain amplifiers designed for accurate gain match across gain control range.

WCDMA devices need accurate reverse link power control over 85 dB with linear gain slope characteristic .

Achieving entire power control in RF stages may not be power efficient and technically challenging. Part of the gain variation can be achieved in base band VGA stages .

Error Vector Magnitude of an I-Q modulator is an important metric that determines the transmit signal integrity. Residual side band (RSB) and inadequate carrier suppression in I-Q modulators are the main impairments that increase energy in the error vector.

Phase and Gain imbalance in the In-phase and Quadrature-phase arms of the modulator produce unwanted " Residual side band " (RSB). It is expressed as follows:

$$RSB\ (dB) = 20*\log_{10} \sqrt{[(K^2 - 2K\cos\Phi + 1)/(K^2 + 2K\cos\Phi + 1))]} \quad (2)$$

Where K = linear amplitude imbalance, between I and Q channels

Φ = Phase imbalance in degrees or deviation from perfect phase quadrature

The DC offset between I+ and I- or Q+ and Q- can result in undesired carrier component in the spectrum. For an rms signal " S" and DC offset of "v", the carrier suppression is expressed as

$$\text{Carrier suppression (dBc)} = 20*\log_{10} (v/S). \quad (3)$$

Gain control in the base band VGA can reduce v/S ratio causing degradation in the effective carrier suppression. Contemporary designs achieve > 50 dB carrier suppression at maximum VGA gain allowing for tolerable degradation at lower gains due to reduced Dc offset to Signal ratio.

WCDMA , EDGEand WLAN reverse link waveforms have crest factors of 3 dB – 10 dB requiring highly linear transmit chain . Power performance tradeoff need to be made to achieve optimal design achieving tolerable maintaining signal integrity . Programmable linearity of RF blocks by varying bias conditions for each mode and power output may be on way to conserve battery. Tunability and agility of Local oscillators is another key challenge in multimode transmitter architecture. Automatic tuning of on chip VCOs operating at harmonically related frequency is popular technique implemented in contemporary designs to address VCO pulling and carrier leakage issues. .

VI. Conclusion

Multi mode terminals are gaining increasing consumer acceptance necessitating need to explore cost effective small form factor radio solution. Radio architectures are required to be compatible to multiple cellular , WLAN , WPAN standards .

Advanced Process and package options addressing Multi mode RF design are presented .Programmable linearity , automatic on chip tuning of VCOs and filters is essential in realizing increased reuse of functional blocks between different modes of operation

Trend in Radio architecture is migrating towards more flexible Digital Radio design . Key technical challenges designing receiver transmitter ASIC solutions are presented.

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