

Software Defined Radio, the new reality

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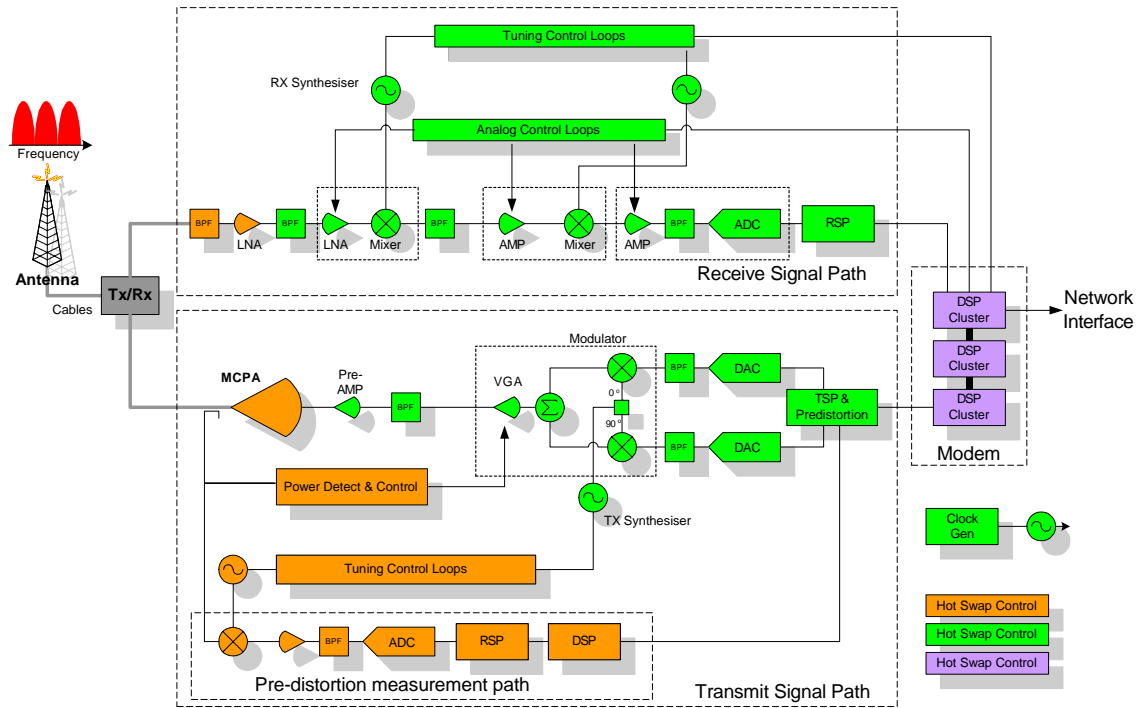
Abstract: As new 3G cellular standards begin to roll out across the globe, the demand for new infrastructure hardware is beginning to increase. However, with the recent downturn in the worldwide economy, many infrastructure providers lack the capital resources to develop multiple system platforms. Instead of developing independent platforms capable of only one air standard, they are now looking to develop a single platform capable of more than one standard. While traditional software radio has focused on interoperability and will continue to do so, this application seeks to streamline the development cycle, minimize product inventory and simplify deployment by offering one system capable of multiple deployments simply by 'reprogramming' the hardware. While this has been the goal for many years, only recently have circuit components been available that can realize this concept. With the devices now available, manufacturers can now seriously begin to investigate the possibilities of software defined radio. This paper will explore the latest possibilities of software-defined radio.

Although semiconductor technology continues to grow and improve, the worldwide economy continues to falter. Like other business sectors, the high tech industry has had to adjust its business model to the changing realities of reduced capital investment. Just as many companies are restructuring their organization, product design flows are also being streamlined. In many cases, old product lines are being eliminated; still others are working diligently to reduce the cost of manufacturing, both in terms of materials as well as factory overhead. One such area going through these changes are the cellular infrastructure industry.

Technology wise, cellular communications are going through some major changes in transitioning from 2G standards such as IS-95 to the 3G standards of CDMA2000 1x and UMTS. However, the worldwide economy has slowed both development and deployment of these standards. Many global equipment manufacturers have reduced their R&D efforts and in many cases are having to focus resources on one standard or the other for 3G. The problem is that by picking one standard or the other, the available market may be significantly limited since air standard deployment tends to be geographic in nature.

The good news is that software defined radio systems have again surfaced as a potential solution to this problem. A software-defined radio is a type of radio that has the ability to be configured through software to a particular air interface. To accomplish this, instead of using analog components for the entire signal chain, as much of the signal chain is converted to digital processing as possible. This means that the receiver is constructed using an ADC to convert the signals into digital as soon as possible and on the transmit end, using a DAC to convert to analog as late in the signal chain as possible. The benefits of this are that traditional analog components such as mixers, filters, detectors and other analog components may be replaced by their digital equivalent. These digital equivalents produce exactly the same results from one system to another, making a more robust and repeatable radio as compared to the traditional analog counterpart. Additionally, if the components that determine the air interface characteristics are programmable, the system can be reprogrammed or reconfigured for different standards. These characteristics include but are not limited to channel bandwidth, data rate and

coding. If the transceiver has the ability to manipulate these and other parameters, it is then possible to configure the system for the air interface needed.



Typical Software Defined Base Station

Figure 1: Typical Software Defined Base Station

With a transceiver design that has the ability to operate on a number of standards, the aggregate product design cycle can be reduced to the development of only a single piece of hardware. Different air standards can then be accomplished simply by loading different configuration programs. Not only does this simplify the design process, the manufacturing and inventory systems can be simplified as well. With only one piece of hardware to build and stock, the manufacturing costs associated with duplicate products can be eliminated.

From an end user point of view, deployment is also simplified. A single type hardware can be deployed across much of the network. This may be especially true where either multiple standards are deployed or where the systems are in transition. If the systems are reprogrammable a single piece of hardware can be used to cover multiple standards. While this may not be all at the same time, more importantly, a piece of hardware can be purchase for one standard and then at a later time as the network changes, be reconfigured for the new standard without have to change the hardware, allowing the preservation of the capital already invested.

While these are not novel concepts, there are several key factors that have enabled this type of system. First, 3G standards require a lower dynamic range than some of the earlier standards because of slightly reduced requirements and more coding or processing

gain. Therefore, there are some 'relaxations' in the anticipated performance in terms of blocking performance. Second, and more important is the continued advancement of a large range of semiconductor processes and devices.

In the area of linear devices that includes LNAs, mixers, modulators and IF amplifiers, much improvement in performance has been achieved in the area of processing including GaAs, SiGe and even standard bipolar. Designs and topology innovations have yielded significant improvements in performance over the last five years with a key focus on lowering the noise and improving the linearity.

In the area of data converters, continued progress has yielded data converters that operate at higher and higher analog input frequencies. While the bit precision and sample rates have not improved by the leaps and bounds that other technologies have, a focused effort on increasing performance at higher IF frequencies has finally reached a point where IF sampling signals is possible. So while bit precision has only improved two bits (12 to 14 bits) over the last 5 years, the linearity has significantly improved by 40 dB (60 to 100 dBc for harmonics) for IF sampling.

Digital processing to has seen large improvements. Digital technology more than any other has benefited from the reduction in feature sizes now possible in current lithography. This has simultaneously allowed more functions to be packaged into a die while at the same time allowing reducing the total cost of these chips. This technology has notably been used to increase the processing power of general purpose digital signal processors, but has also been used to create cost effective fixed function digital devices such as receive signal processors and even field programmable gate arrays, all key components used within a software defined radio system.

The end result is that now unlike any time in the past, the components are available that can enable software defined radio systems. Not only this, they are available at a price that allows construction of multi-channel, multi-mode (i.e. software defined) systems that can compete on a per carrier basis with traditional single channel fixed mode transceiver systems.

Of software defined radio systems, the most technically challenging aspects include the receive signal path and the power amplifier. The power amplifier is the focus of much research at this time and is best covered in a separate discussion. The remaining focus of this paper will be on the receive signal path. It is the authors opinion that although the transmit path of the software defined radio is challenging, the receive path is the most difficult and will now be covered.

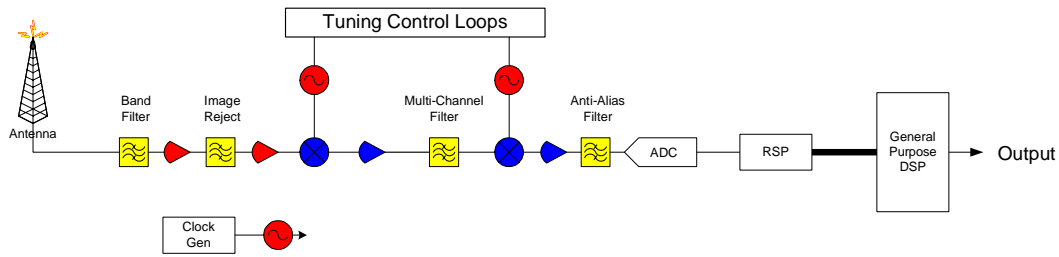


Figure 2: Typical Receive Signal Path

The key standards addressed are CDMA2000 and UMTS that is also known as WCDMA. CDMA2000 will largely be deployed in spectrally congested areas and requires tolerance of GSM, analog FM and IS-136 in the form of large blockers while UMTS is currently allocated to relatively quite spectrum just above 2 GHz. Due to the competitive nature of these standards and close attention to past history, it is probable that UMTS will eventually be deployed in spectrum currently used by CDMA2000 (and GSM, FM and IS-136) and therefore requires the same or similar blocking tolerance. It is also true that CDMA2000 will find deployment in UMTS spectrum. Since this is relatively quite, no additional constraints are to be expected for this deployment.

Summary studies of the requirements for these standards show that the following receiver performance is required. These numbers are aggregate and in some cases are based on cross band performance. However, since it is intended that one system be used for all deployment bands, the more difficult of the specifications is selected.

	CDMA2000	UMTS
Reference sensitivity	-117 dBm	-121 dBm
Narrowband blocker	-30 dBm	-30 dBm (1)
CDMA blocker	-52 dBm	-40 dBm
(1) not a requirement of the standard.		

From the block diagram of the receiver, the front-end conversion gain may be determined that would cause clipping in the ADC by the narrowband blocker. This becomes the minimal conversion gain required without saturating the receiver. The minimum gain required for maximum sensitivity can be determined by computing the noise spectral density of the ADC. It is desirable that the noise spectral density of the data converter be as much as 10 dB below the noise of the analog front end. The noise spectral density of the ADC may be computed by taking the same ADC fullscale used for the clipping calculation, subtracting the SNR and then distributing the noise over the Nyquist spectrum. The noise of the analog front end becomes available kT noise in 1 Hz plus the conversion gain plus the noise figure.

$$N_{ADC} = P_{fullscale} - SNR - 10 \log \left[\frac{samplerate}{2} \right]$$

$$N_{\text{frontend}} = 10 \log \left(\frac{kT1\text{Hz}}{0.001} \right) + \text{conversiongain}_{\text{dB}} + \text{noisefigure}_{\text{dB}}$$

k=Boltzmann's constant, T=absolute temperature

In reviewing state of the art ADC technology, the following table describes the ADC performance using typical data sheet numbers and the equations above to format performance in the proper manner.

ADC Fullscale	+4 dBm
ADC SNR	75 dBFS
ADC NSD @ 61.44 MSPS	-145.9 dBm/Hz
ADC NSD @ 92.16 MSPS	-147.6 dBm/Hz
Largest blocker	-30 dBm
Gain to clip	34 dB
Gain plus noise	36.5 dB

In looking at the blocking requirements, the narrowband blockers occur at -30 dBm at the antenna. In considering the wideband blockers, the peak to rms ratio is about 10 dB, therefore, the -40 dBm blocker peaks near -30 dBm so both conditions require about the same signal range. To figure the clipping gain, the blocker is subtracted from the ADC fullscale giving 34 dB of gain. In order that the ADC noise does not limit sensitivity, it is desirable for the noise from the analog front end to exceed that of the ADC by as much as 10 dB. From the table above, the ADC noise spectral density is approximately -146.5 dBm/Hz. This requires that the noise from the analog front end be -136.5 dBm/Hz. If the available noise from the antenna port is -174 dBm/Hz then the front-end noise figure plus gain needs to be 36.5 dB. Given an aggressive receiver noise figure of about 2.5 dB, the resulting gain is 34 dB which is consistent with the clip gain.

In review of the sensitivity, a CDMA2000 signal at -117 dBm presents a signal density of -177.9 dBm/Hz at the antenna which is below the noise floor. When gained by the antenna, this is presented to the ADC as -143.9 dBm/Hz. If the analog noise at the ADC is -136.5 dBm/Hz, a resulting SNR of -7.4 dB. The CDMA2000 despreading gain is 21 dB, therefore, the effective SNR after despreading is up to 13.6 dB. Since only about 5 dB of SNR is required, the excess SNR can be used to improve the sensitivity beyond what is required by the specification. Since both dynamic range and sensitivity can be met for a CDMA2000 system.

UMTS requires a reference sensitivity of -121 dBm, which gives a spectral density of -186.8 dBm/Hz over 3.84 MHz. After 34 dB of gain, this is -152.8 dBm/Hz resulting in an SNR of -13.6 dB. With a despreading and coding gain of about 24 dB, the resulting SNR is 7.7 dB, again sufficient to improve the sensitivity beyond that which is required. Likewise, the dynamic range is sufficient as well.

In summary it is possible to create a design that capable of working for both CDMA2000 and WCDMA. With a design that provides sufficient gain and linearity, the digitization process can be performed at the first IF and digital processing can be used extract either

standard by reconfiguring the digital filters and reprogramming the DSP according to the needs of the standards.