21st Century Radio Communications – Part 1

By Dr. John F. Catalano

The dawning of the new century has ushered us into a revolutionary era of radio communications. The first ten years of the 21st century will change radio communications more than it has changed since the invention of radio over 100 years ago.

We all have many questions and concerns about the radio communications in the 21st century. What type of radio signals will be invading the 21st century airwaves? How high is high frequency in the 21st century? How will the radio receivers of the 21st century look? What is a Digital Radio, Configurable Radio, DSP Radio, Software Definable Radio? Cognitive Radio? How are they different? Will we ever see one on the market? How and why did all this technology get developed? What's the driving force behind all of these changes? ... Important questions, especially to anyone who began their interest in radio communications in the last century … in other words, all of us!

Over the next few issues we will try to give some insight into the answers to these questions and more. Clues to the future can be found by looking at major developments in radio communications during the past few years. How these developments have been implemented in today's radio products is another indicator of the future technologies. The purpose of this series of articles is to introduce new radio and technology concepts, to stimulate thought as to how our radio world is evolving, and to make some predictions for the next five to twenty years.

We will cover just enough of the theory to give you some idea of the new technological methods. These discussions are not meant to be rigorously complete. Instead they are presented in general concept form as an introduction. Web sites will be included throughout the series for those of you (and I hope it is many) who wish to fully understand the science behind the concepts and perhaps join the development efforts as a career.

We'll start at the beginning of the digital radio revolution, which took place in the last quarter of the 20th century.

From a Spark to an Explosion

The historical beginnings of radio, from early spark gap communications to modern times was the topic of a 2001 *Monitoring Times* series feature articles entitled "The History and Future of Radio." I direct you to this series if you are interested in the how radio developed from its beginning through most of the 20th century. Also included in these articles is a brief overview and comparisons of analog and digital methods.

Software Every-ware

I'm sure most of you have heard the term "software radio," or something similar. Today the dream of radio designers for the past twenty years is becoming a reality. The Holy Grail of radio design is SDR, Software Defined Radio. SDR is as important to 21st century radio communications as superheterodyne once was to the 20th century radio. Simply put, SDR moves radio design from dedicated analog-based circuit hardware to software configurable digital data processing. The SDR will revolutionize radio communication. Clearly the words "software" and "digital" go hand-in-hand in SDR.

A quick review of the basic analog and digital worlds might be a good place to start our journey toward the SDR radio.

Analog and Digital Concepts

This is going to be a very quick and dirty overview of a complex subject. In the analog world, signals are modulated, or converted, in a manner *analogous* to the input signal. For example, let's look at recording of sound, which is a varying air pressure wave. In order to record it on an analog tape recorder, the sound is converted into a varying magnetic field and applied to the iron particles on the tape. To play back the analog recording, magnetic variations are converted into electrical variations. Detection of these small signal variations, which can be very small and difficult to detect, is the limiting factor of analog communications.

The digital world is quite different. Here, by using a circuit called an analog to digital converter (ADC), a sound wave is converted in a series of rapid "on" or "off" pulses. In the digital world these pulses are read as binary based numbers of "ones" and "zeros" respectively. The resulting on/off magnetic field is applied to the tape.

True, this digital conversion process is much more complex than in the analog world. Also the digital process of encoding must be fast enough so that little or no delay is noticeable.

To play back the digital recording, the process is reversed and the magnetic digital signal of "ons" and "offs" are converted into the original high fidelity analog sounds with crystal clarity. Only two variations, on and off, need be detected, instead of an almost infinite number of variations of an analog signal. Further, the signal amplitude between the two levels is relatively large. Clearly (pun intended) digital methods provide cleaner, clearer signals. Just look at the quality of a VHS tape and compare it to its big brother, DVD!

You can imagine that the digital processing speeds and computer power to accomplish these processes require some complex high-speed hardware. But the results can't be beat!

That's enough of background. What we covered we'll need later. Now let's get on with 21st century radio technology story.

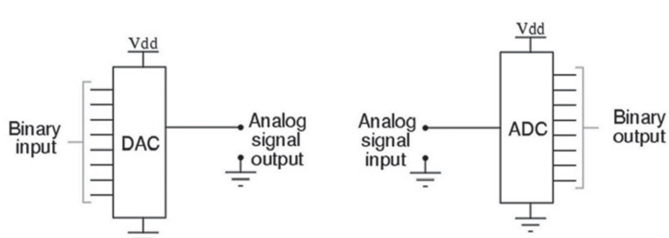

Figure 1-1 – Simple Analog to Digital (ADC) and Digital to Analog Converter (DAC) Circuits

Enter the Digital (Audio) Radio

What is a Digital Radio? Well, this term is evolving almost as fast as radio technology itself! In the last quarter of the 20th century the military communications market demanded digital radio systems for maximum receive-ability under adverse conditions and to provide a measure of security. Back then, the "digital" referred to a digitizing of the audio. This was accomplished via traditional analog circuitry with some new circuit twists called Analog to Digital (ADC) and Digital to Analog Converters (DAC), see Figure 1-1. These simple circuits, together with the semiconductor electronics technology of the day, were fast enough to cope with the audio frequency spectrum of 100 to 20,000 Hz.

In 1992, Collins Radio introduced into the consumer/professional markets the revolutionary model 926 communications receiver, which was PC controlled and utilized DSP in the audio section. See Figure 1-2. The performance of the DSP audio filtering really wowed the communications world with adjacent signal heterodynes becoming things of the past. The 926 was derived from a Collins receiver supplied to the military market, but the DSP audio concept was soon to become a feature on many ham and SWL receivers.

Perhaps it was about this time that radio designers began to dream of moving the digitalization from just the audio section to more of the radio circuits. But with limitations in speed and complexity of semiconductor technology of the early 1990s, it was just a dream.

Cell Phones Hit The Airwaves

The staggeringly huge cellphone market was exactly what the semiconductor companies needed to get out of the slump they found themselves in, in the closing years of the 20th century. The thought of everyone carrying around an analog two-way

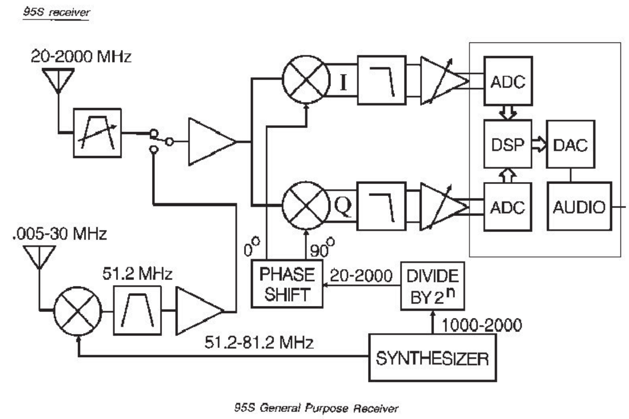

Figure 1-2 – DSP Audio Radio Collins 926 circa 1993

high frequency radio made the semiconductor industry's financial mouths water. Integrated circuit companies turned their massive and powerful attentions to the design of micro-miniature, silicon circuit, 800MHz radio blocks.

Once just the realm of high cost, low volume, military and professional markets, these companies used all their technical and manufacturing muscle to create low cost, commodity, circuit blocks to enable the introduction of a consumer priced 800 MHz portable transceiver – i.e., cellphone.

The NEED for Digital Grows!

Today, electronic technological advances are usually motivated by market need. The larger the market potential the more aggressively the electronics industry works to fulfilling the seemingly impossible market requirement. This was the case with digital audio as Philips Electronics was leading the charge to make their digitally encoded optical Compact Disk invention the replacement of the LP record. Digital encoding, and of course decoding, of audio was springing up in communication and entertainment markets and becoming the norm as the 20th century was ending.

At the same time, satellite TV was planning to grow from its hobby status to a full-fledged high volume consumer product. But the industry was demanding something better and more efficient than the analog signals that it had endured from birth. That meant a move to digitally encoded signals.

Cellphones Go Digital

As the demand for cellphones grew, the 800 MHz band was becoming very crowded, possibly limiting the cellphone companies' business. This fact, plus some issues of privacy from monitoring, gave the initial motivation to move to digitally modulated cellphones.

As the digital market has matured, a number of different digital encoding cellphone standards have been adopted by different countries and phone companies. This has become increasingly costly to cellphone companies who sell into many different encoding markets. Today they find it difficult and costly to balance their inventories of different types of cellphones using different digital standards.

One Radio – Many Uses

The thinking goes like this. Every radio receiver has the same basic block functions. However, manufacturers have to make changes to some circuits depending upon their frequency, digital encoding/decoding method, application, etc.

The military's "one radio" requirement came about as a result of a number of deadly incidents. Since each one of the USA's armed services are tasked with different mission objectives, their communications needs are also different. However, in joint operations, this leads to Army troops not being able to easily communicate with, say, Air Force aircraft. This inability to communicate has been the cause of an alarming, and growing, number of friendly fire casualties.

The military first experienced these communications problems in 1983 in Grenada and then in 1991 during the first Persian Gulf War. But the military's need would escalate with world events of the 21st century, and they knew it.

The Configurable Radio

Although their motivation was profit, cellphone manufacturers also had the need for a radio that could change itself to fit the situation, just like the US military.

Now, assuming all the required hardware building blocks for all different requirements were built-in to a radio. Then the signal path could be directed to the required circuit blocks and around other blocks by a programmable series of simple logic switches or gates. In this way, the radio's hardware circuits could be configured to the desired functions. This concept probably came from a radio designer who remembered his youth spent with Heathkit, Lafayette and Radio Shack electronic experimenter's labs.

Simple Beginnings

These "labs" consisted of a piece of wood or cardboard upon which a number of components, transistors, light bulbs, resistors etc, were mounted. On each connection of each component was a spring. The lab, with a fixed set of hardware components, could be rewired by connecting wires to the springs in different configurations to make many different electronic devices. Does that bring back childhood memories?

Imagine that instead of boards with large components we have a piece of silicon, or a number of pieces, with a much larger number of total micro-components. Instead of manually connecting, the connections are routed via logic gates, or switches, which can be programmed to be open (no connection) or closed (connected). You have just constructed a programmable array.

Let's take this one step further by making the micro-components into groups of components wired into circuits used in communications receivers, such as AM, FM, and digital audio decoders, stages of IF, RF and audio filters and amplifiers. Now, using user one-time controlled switches or gates we can "configure" the radio to whatever our need requires. And with that, we have a configurable function radio. Of course, all the added unused circuitry makes this hardware-intensive, programmable switched array approach very expensive, limiting its use to military and professional markets.

Wishful Thinking?

With the advent of commonly available digitized audio integrated circuits, radio designers began again to dream. The dream of making all signal manipulation from the antenna to the speaker into digital data and therefore controllable by mathematical algorithms was near. This would be the truly digital radio.

Let's go back to ones and zeros and see exactly what this means to users.

Digital's Real Edge!

As we saw earlier with digital audio radios, once we digitize a signal it is reduced to a mathematical representation of the signal in the form of ones and zeros. These binary words can be manipulated using mathematical formula, or, as software engineers like to call them, algorithms and transforms.

Let's look at an over-simplified example. During most of the 20th century, in order to demodulate a FM signal we would have to build an FM demodulator using hardware components such as diodes, resistors, and inductors.

Instead, in the digital world we can calculate what effect these components have on the signal using circuit theory. For example, a resistor-capacitor-inductor (RLC) combination would transform the signal using a time constant determined by their relative values. A transistor acting as a gain stage would impart a characteristic amplification to the signal. These very simple examples can be applied to complex multi-circuit functions.

In the digital world we can cause the same effects as the hardware by subjecting the digitized signal to the same set of signal conditioning mathematical transforms. The effect of the hardware LRC circuit can be defined mathematically by the same set of equations we used above, dependent on their component values. To demodulate a digitized FM signal all we need is a faster microprocessor that can take the formula equivalent of the RLC and run our input signal through it.

Flexible Hardware

The hardware required in the digital case is a complex, fast running processor and its equally fast "A to D" and "D to A" converters. In fact, in component count the digital circuit would take more than one hundred thousand more components to decode FM than its analog equivalent! However, in the 21st century, integrated circuit technology is routinely capable of producing circuits having a million devices on a small piece of silicon. So circuit complexity is not necessarily a limiting issue. But still, where is the savings?

The savings is that hardware – the digital signal-processing integrated circuit – need only be designed once and then can be mass-produced. These production stages are the most expensive and time-consuming steps required to bring a new integrated circuit-based product to market.

If we were designing a traditional analog circuit-based integrated circuit radio, a new design and manufacturing run would be needed *each* time we wanted to change a function, very costly in time and money.

With our digital signal-processing chip (within some limitations) the same integrated circuit can produce many different manipulations on the incoming signal just by programming the processor with different software algorithms. Meet the Software Definable Radio concept.

"Within Limitations"

Let's not forget that the frequencies which we can digitize, and the complexity of the programmed functions, are limited by the speed of our digital electronics, among other factors. The higher the speed of our input signals and the more complex signal manipulations we desire, the faster the required digital electronics must be.

If the direct conversion radio, which digitizes the signal right from the antenna, were possible, we could say goodbye to messy analog! Then all control, functions, and operating modes would be configuration via software. But in order to realize this dream, complex, inexpensive chips having low power consumption and very high speed processors (at least 1 GHz) would be needed. A very tall technical order during most of the 20th century. In fact, to some it seemed to border on science fiction.

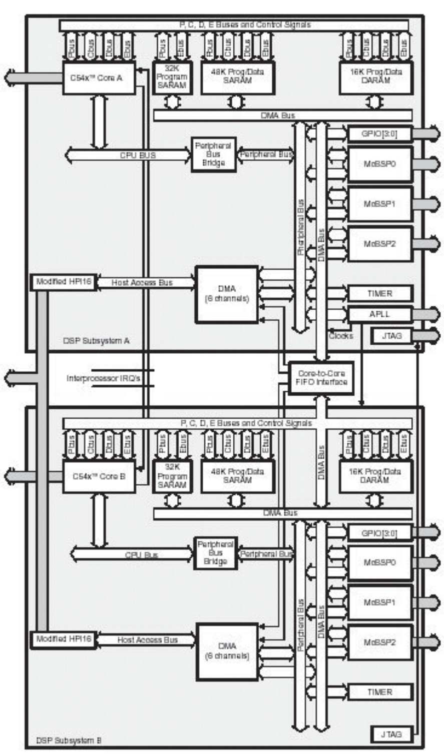

Figure 1-3 – Block Diagram of TI DSP Chip TMS320vc5420

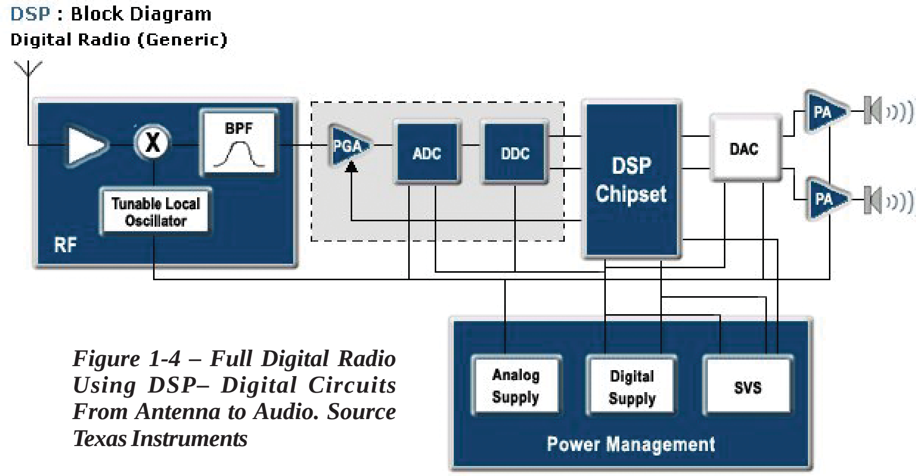

Figure 1-4 – Full Digital Radio Using DSP– Digital Circuits From Antenna to Audio. Source Texas Instruments

A Piece of the Puzzle

We can now begin to answer the first question we posed: What's the driving force behind these radical changes in radio communication? In part, it is the rapid development of high-speed digital integrated circuits and microprocessors for the huge and competitive personal computer market.

Wake Up, Silicon Guys!

Silicon manufacturers began to see the need to design and manufacture off-the-shelf, complex integrated circuits aimed squarely at communications applications. By combining fast processors, digital encoding/decoding control and digitally configurable filtering all on a single chip, the Digital Signal Processor, DSP, was born in the factories of Texas Instruments (TI) in the late 20th century. See Figure 1-3 for a block diagram of a TI DSP chip, vintage 1999.

DSP technology was a step in the direction toward the SDR, but the technology of the day lacked the microprocessor muscle required to handle the number of complex computations required to function as a complete receiver. And, of course, there was the processor's speed, which further limited the functions as well as the frequency of the input signal. DSP began to appear in communications products, replacing some functions of the receiver, usually in the audio section.

By the mid 1990s, DSP had proven the concept of a digital processor being able to configure and control signal processing methods, albeit in limited manner. Today, DSPs are so common that just about every PC sound card is built around one.

As faster digital electronics were developed, the digitized portion took a larger part of the radio receiver. The goal to convert the RF signal to digital form right from the antenna was moving from dream to reality. See Figure 1-4, the all digital radio.

Electron Speed Limits

In the 21st century, with 2.8 GHz personal computers being sold at under $800, gigahertz-processing speeds are common and relatively inexpensive. Where has all this processing speed come from?

To find the speed-limiting factor of circuits we have to take a little detour into semiconductor device physics. In order to make this a detour and not an odyssey, we'll take some literary liberties and keep it simple.

Electronics is all about moving electrons. The basic circuit element of a modern-day integrated circuit is the MOS (metal-oxide-semiconductor) field effect transistor. This device consists of two "electrodes," the source and drain, separated by a third. The electric field on the "separating electrode," called the gate, controls the flow of electrons from the drain to the source.

One factor that controls the transfer speed of the electrons is the gate width. The smaller the gate width, the faster the field can propagate and the shorter the distance the electrons have to traverse. The speed to gate width relationship is not linear but logarithmic. This means that speeds increase by a large amount with a small decrease in width.

Advances being made by the semiconductor companies are constantly reducing the minimum size structure that can be reliably manufactured in high volume. This minimum structure has been reduced from 5 microns (1 micron = 0.000000000001 meters) in 1985 to 0.1 microns in 2004.

Simultaneously, the size of the silicon area that can be reliably manufactured and the number of on-chip components have also been increasing at a rapid rate. In the 1980s the component count was in the hundred thousands. Today it is approaching tens of millions. This means that more devices can be placed on a single "chip," allowing for whole "Systems on Chip" (SoC) to be designed and manufactured.

Pieces In Place - Almost

As we have seen, required technological "pieces" to make a full digital software definable radio a reality are in place. Planning for the third generation of SDRs are in progress. Will it be an all software radio using a PC-type platform? What is a "cognitive" radio?

Remember, in order for a technology to transition from prototype development to production, it requires industrial "Godfathers" in a number of industries who are willing to risk their own career on the product's success. Next time we'll answer these questions and more. We'll also see if the industrial climate is right for SDR to become a real, high volume, commodity, 21st century product.

"software programmable and hardware configurable digital radio system."

Everything is "almost" in place for the complete digital software definable radio, although in 2002, a director of one of the major contractors predicted that "an actual physical JTRS radio is some years away." Let's look elsewhere for some real product activity and development efforts.

Digital Modular Radio - DMR

The US Navy's requirement for one radio to provide all fleet communications, which is essentially based on four different communications structures, was a prime candidate for early SDR designs. General Dynamics and Motorola both provided DMR four-channel product to the US Navy beginning in 2000 and are committed to the JTRS/SDR concept in future designs.

The Falcon Flies

In 2002, Harris Corporation's (**http://www.harris.com**) software-defined Falcon II radio was one of the first to demonstrate "voice waveform on a fielded, software-defined radio platform and successfully conducted on-air interoperability demonstrations of its capabilities." That mouthful says they have a working model SDR.

The RF-5800 series of software definable radios covers 30 to 512 MHz. It includes frequency bands and modulation modes for combat net, close air support, military and civilian air-to-ground, long-range patrol and government land mobile radio (LMR). Falcon II radios come in various configurations, including man-packs, portables, fixed station and tactical mobile. Signal encryption is, of course, a standard feature.

Harris' advertising slogan for the Falcon II radio is "Multiple bands. Multiple missions. One solution." That's pretty close to the fully Software Definable Radio, but not quite. A *total* SDR mission statement should read, "All Missions. One Radio." It is toward this end that many companies are diligently working.

SDR Developer's Kit

DRS Technologies claims to be the first company to offer a software definable receiver with a software developer's kit. The kit enables users to download DSP algorithms that employ IQ filtering, special demodulation, signal pre-processing, or signal post-processing techniques.

The DRS WJ-9104B multi-channel digital tuner is a software-defined receiver that allows the user to monitor up to eight RF channels, with a frequency range of 20 to 3000 MHz. It has some impressive operating specs:

- 20 to 3000 MHz frequency coverage
- 10-MHz instantaneous BW (2 MHz or 25 MHz also available)
- 80-dB Spur-Free Dynamic Range (SFDR) digital, 85-dB SFDR analog
- 60 millisecond tuning speed
- Up to 8 phase-coherent or independently tunable channels
- Digitized IF outputs from each channel at 14 bits of precision
- Supported by Spectrum Signal Processing's SDR Development System

DRS Technologies products, which are not priced for the consumer market, can be seen on their website at **http://www.drs.com**

Echotek

The Echotek Company (**http://www.echotek.com**) has a range of "receivers" which use high speed and high resolution A to D Converters and digital receiver processing. The result, ECDR-4814's block diagram, is seen in Figure 2-1. The ECDR is not a stand-alone full receiver. The input can be as high as 100 MHz; however, a relatively high level input signal of 100 mV (millivolts) is required, as compared to a modern receiver input which is around .001 µV (microvolts). The ECDR-4814 is actually a multi-input IF (intermediate frequency) block or down converter, that can then be defined by software to do just about anything.

Another Echotek product, ECDR-GC314-PCI, is a PCI card for use in a personal computer. It has three analog IF inputs that can be used up to 200 MHz and 12 digital channels that can be combined for wide band use. It also has impressive dynamic range specs. However, it also requires a high input level of 100 mV, since it is designed as an SDR function block, not an entire SDR.

Gray Who?

If you look at Figure 2-1 you will see that a large part of the functionality of the Echotek product is performed by GrayChip's GC4016 Quad Multi-Standard Digital Down converter. This device has some very impressive digital performance capabilities. In fact, it is critical to the receiver's operation. Figure 2-2 shows how the GC4016 fits into a receiver.

If you are wondering who GrayChip is, think back to the first producer of DSP chips – Texas Instruments (TI). In 2001, TI purchased GrayChip, a small fourteen-person company founded in 1989, to design reconfigurable digital down converters (DDC) and digital up converters (DUC) for high-speed communications. TI's acquisition of GrayChip clearly shows that it is committed to expanding the DSP concept to the entire radio.

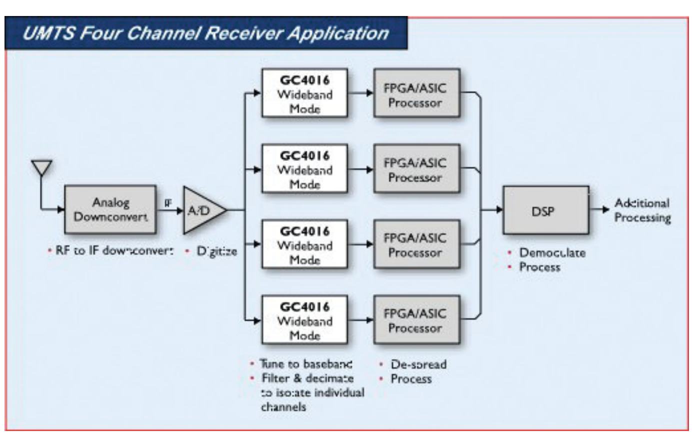

Figure 2-2 How GrayChip's GC-4016 Digital Down Converter "Fits" Into a Digital Receiver

"It's *Only* a Software Glitch"

In the 1980s a NASA spokesman used these ill-chosen words to explain a shuttle lunch delay. As a result of his glib, over-simplified comment, technical people around the world derided him. Anyone who has been involved in the development of a hardware/software product knows never to minimize the software's critical importance or to underestimate the required development resources.

Major software efforts directed toward SDR by a number of companies have produced the first generation of "middleware." Middleware has the difficult task of making operational software independent of the hardware. Hardware manufacturers have been co-operating with the SDR effort by producing hardware platforms which can accessed using this "common" language. This is another major step along the road to realizing the one radio SDR concept.

Where is SDR Today?

In January 2004 Cubic Corporation (**http://www.cubic.com),** a noted military communications systems company, and Spectrum Signal Processing (**http://www.spectrumsignal.com),** an SDR software company, joined forces. Together they have won an ambitious contract from the US Army. Under the 18-month contract, Cubic will develop waveform software that will help all branches of the military and multiple public agencies communicate with one another.

The software will be based on common Software Communications Architecture (SCA) that will guarantee interoperability, compatibility with current communications systems including APCO-25, and provide voice, data and video communications. This is a major step, or maybe even a leap, closer to the complete SDR concept.

One interesting fact is that although many companies are working on a true JTRS software, Cubic found that *only* Spectrum Signal's flexComm package could perform to JTRS signal processing requirements as laid out in the 1997 JTRS Request. Looks like the marketing mouth of some companies outpaces their technical capabilities! (SOS - Same Old Stuff!)

Other major international companies are proceeding along the development path to SDR. One interesting product providing a development link along the path to SDR is coming from Thales Communications Inc. They are working on defining an enhanced version of the JTRS radio called JTRS-JEM. JEM will provide enhanced multi-band inter/intra team communications, including cipher text. Version 2.2 of the JTRS software will be used on their current little SDR, AN/PRC-148, which weighs under two pounds.

As we have seen above, the software radios currently deployed in the field are really software *configurable* radios. They are the first step toward Software *Definable* Radios and the complete interoperability of the 1992 JTRS requirement.

When a radio is manufactured

which is capable of morphing itself, via downloads or internal programming, to communicate in any and all communications situations whether military or civilian, then we will have a full JTRS and an advanced software definable radio, SDR. Some are now defining this as the Universal Radio.

Strength in Numbers

A group called the SDR Forum (**http://www.sdrforum.org**) is steadily gaining membership among the hundred plus companies working on SDR. The forum's members include military communications, cellphone and professional communications companies. These include established companies with market muscle such as Harris, BAE Systems, General Dynamics, L-3 Communications, Intel and Motorola, as well as young companies such as Vanu Inc.

All are working to break down radio communications paradigms of the 20th century. The programs of interest have different names – JTRS for the military boys, SDR for the cellphone people, or Project25 for the public safety crowd – but the goals are the same: Total Interoperability.

3rd Generation SDR

Although the military applications for SDR are pretty tough, many feel that the cellphone industry presents the greater design challenge. First, they have to be backwards compatible with all existing formats: CDMA, CDMA-2000, GSM, D-AMPS, to name a few.

Then there is the issue of cost; very low cost is a prerequisite.

And, finally, the operational issues are far from easy to accomplish: 330 MHz to 2 GHZ frequency range, bandwidth in excess of 75 MHz, and dynamic range greater than 75 dB! Not easy operational parameters to achieve even without the economic constraints. To see the direction of SDR in the next five years, I suggest you carefully watch the cellphone industry for the real advances.

The Next Leap - Cognitive Radio

Cognition is defined by dictionary.com as, "The mental process of knowing, including aspects such as awareness, perception, reasoning, and judgment." The idea of the cognitive radio is a stretch of the SDR's downloadable reconfiguring capabilities.

Key to the SDR concept is its ability to be reconfigured through user initiated downloads. Okay, now let's say we build into the radio the ability to receive and then analyze any signal. Then, in theory, with this information and some very fancy internal software, the radio could *learn* how to reconfigure itself to communicate with any received signal. See Figure 2-3. Talk about artificial intelligence!

Cognitive Radio could handle all of today's modes: FDMA**,** TDMA, CDMA, TDD**,** AM, FM, MFSK, MPSK, MQAM, CPM, SSB, DSSS, DES, 3DES, AES, MeXe, Trunked Radio, APCO-25, GSM, Iridium, 802.11X, tone coded squelch, CVSD, LPC, VSELP, AMBE …and the list goes on. Let cognitive radio hear it, and it becomes it.

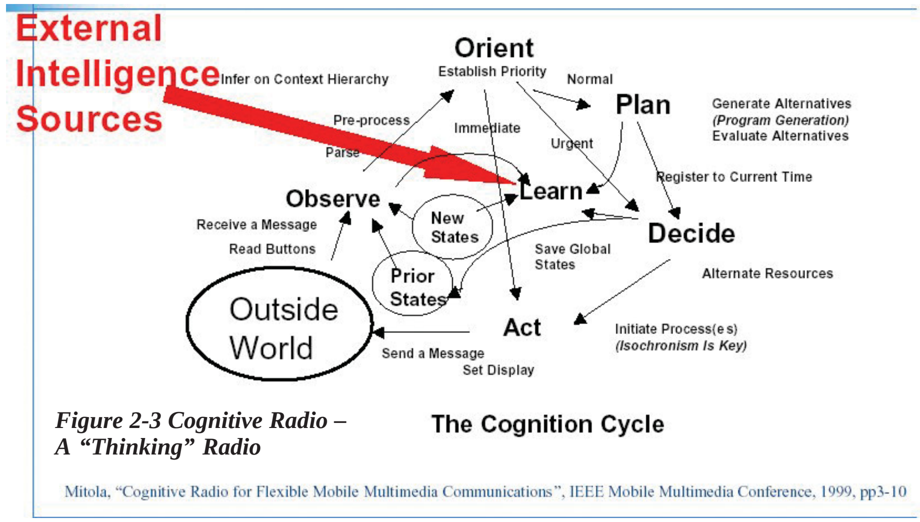

Figure 2-3 Cognitive Radio – A "Thinking" Radio

The potential is huge. It has been hypothesized that cognitive radios could perform many more tricks such as selecting the optimum frequency spectrum, mode and power levels for given use, propagation and radio traffic conditions. The possibilities are limitless. The military has funded a cognitive project called XG, Next Generation Communications.

For an SDR to perform as a cognitive radio it must have some "self worth." It must know its own capabilities and how to reconfigure them. In 2004 this is pure concept since no radio exists with this ability. There are many licensing, control, and interaction issues which must be considered However, many heavyweights such as Microsoft and Intel, are diligently working on cognitive radio. I have no doubt that it will be a technical reality by the end of the decade.

Currently there is lobbying going on to allow cognitive radio in the UHF TV band. A number of groups have expressed their opposition to the cognitive concept. They point out that due to cognitive radio's auto adaptability it could monitor almost any radio communications, including voice, video, trunked system, satellite and data such as wireless LANs and Bluetooth networks. Wow! And the 20th century thought it had a privacy problems with scanners!

SDR for the Hobbyist

The military, professional and cellphone industries are not the only ones interested in SDR communications. In their own words, "GNU Radio is a collection of software that when combined with minimal hardware, allows the construction of radios where the actual waveforms transmitted and received are defined by software."

The GNU radio's goal is transceiver operation in all ham bands – HF, VHF and UHF up to 2.4 GHz. Currently the hardware's maximum bandwidth is 6 MHz and it has a capability of extracting up to four separate channels simultaneously.

The minimal hardware referred to is not exactly a simple onechip printed circuit board. It is, as expected, a sophisticated collection of high speed Analog to Digital and Digital to Analog converters (ADCs and DACs) and programmable logic. See Figure 2-4.

The large chip in the center is the programmable array for math functions and control. The RF front ends (receiver antenna input) are not on the board. They are "daughter" circuit boards (nearing availability when this was written) which plug into the two connectors on the top of the board. Software downloads and hardware info and purchase details are available on the website **http://www.gnu.org/software/gnuradio**. It appears to be in the early beta-testing phase of the hardware/software interfacing of the main board. The RF modules are either being prototyped or are under development.

Since the SDR technology is evolving at a rapid pace and the available chips are trying to keep up, designing and making a piece of hardware at this time is like trying to hit a moving target. But the GNU project is a great SDR ground floor learning experience open to any one.

The Essential Antenna

Although we have only concentrated on the

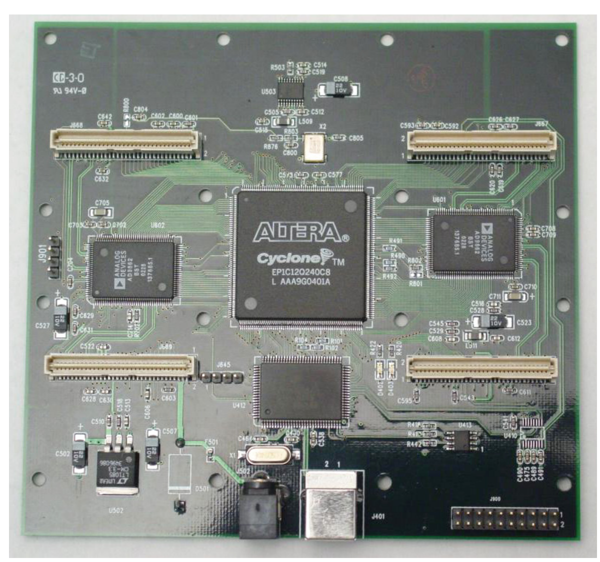

Figure 2-4 GNU's Universal Receiver Project PC Board. Note Four Horizontal Slots for Daughter Boards.

receiver of the 21st century another element in the receiving hardware chain will require equally revolutionary development. When we have these wildly frequency agile radios running all around the radio spectrum, fixed-tuned antennas are going to be as useless as a spark gap sphere!

The 21st century antenna must be capable of tuning itself on the fly as the radio runs around 2000 MHz of spectrum in different modes. Tuning and beam forming must be performed at very high speeds by the "antenna."

Watch for an explosion of adaptive antenna technology. This technology is not trivial. Although it has already been used in military applications, commercializing for consumer use it will be a major technical and manufacturing challenge.

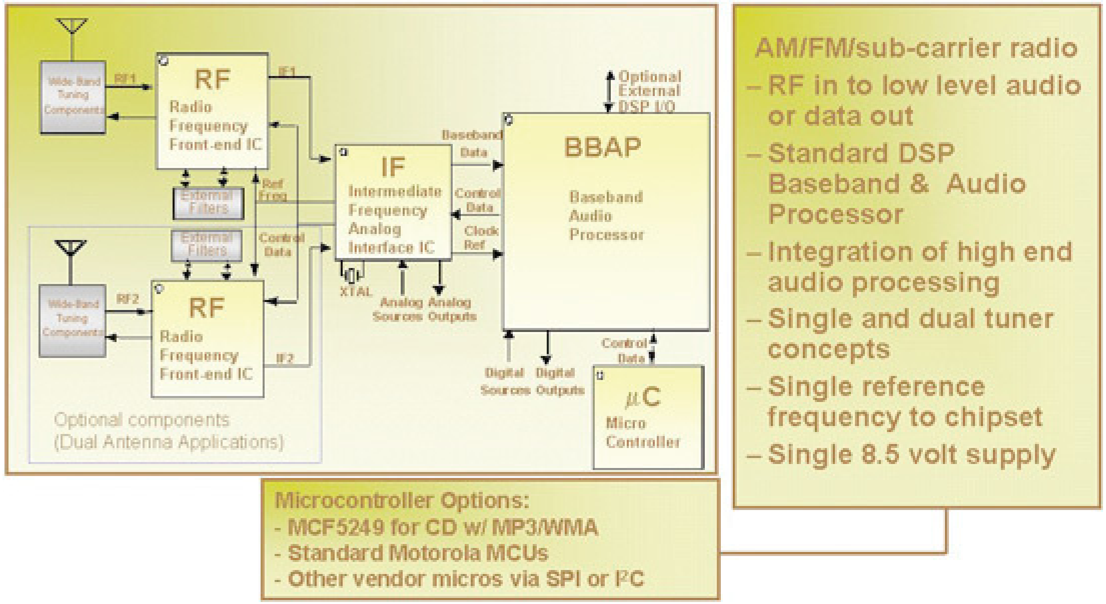

Figure 2-5 Motorola's Symphony Device: A Digital Treatment of Analog Broadcast Signals

Other Radio Systems Under Development

Although SDR promises to affect every facet of radio communications in the future, there are developments in other radio systems as well. Let's leave SDR and look at a few other major radio developments occurring in the 21st century

Digital Audio AM/FM Radio

The commercial radio bands are going through a new phase with the introduction of digital satellite and terrestrial radio services. Admittedly, satellite radio has not proven to be a commercial success as yet. And, after a number of false starts, digital terrestrial radio is trying to get off the ground again.

Texas Instruments, Philips Electronics, STMicroelectronics, and others are about to roll out their chips for demodulating commercial broadcast AM/FM digital audio. These are based on a software configurable approach.

Market predictions say that 2006-2007 will be the year that the digital radio makes its breakout and sells tens of millions of units. I predict that, without great pressure from the government to go digital, the acceptance period could be far greater.

Don't Discount Analog

If Motorola has its way, analog radio has a life yet! For the past few years Motorola has been working on improving analog radio using digital methods. Their latest chip effort is called Symphony™. According to a press announcement, Symphony is to the AM/FM radio what Compact Disk is to a cassette.

In actuality, it is a three chip set which is a complete digital Intermediate Frequency (IF) radio. See Figure 2-5. It is composed of combining a Digital Signal Processor (DSP) with a Radio Frequency (RF) front-end and IF analog interface.

Symphony was designed to improve radio static, fading, pops and hisses, tuning, adjacent station interference, limited listening range from existing signals, and audio clarity and volume. The digital methods that Motorola is employing should make a big difference in signal detection, bandwidth, distortion and resulting audio quality. The chipset is capable of AM/FM and weather band. I'm looking forward to hearing off air commercial radio using a Symphony based receiver. Will a wideband-monitoring receiver be next? Let's hope so.

Voice Activated Wireless Control

A low cost one-chip receiver and matching transmitter which uses FSK (frequency shift keying) promises to be the foundation of 21st century wireless applications. EZRadio by Integration Associates (**http://www.integration.com**) features user programmable frequencies in the ISM (Industrial Scientific and Medical) band of 315, 433, 868 and 915 MHz. Remote sensing, toy, vehicle monitoring, and control applications are immediately obvious. It has a range of between 100 and 40 meters and is capable of data rates of 256 kbps. It utilizes a patented antenna tuning method that is totally controlled on chip. All it requires for external parts is a 10 MHz crystal! Everything else is on-chip.

When EZRadio is coupled to the speech recognition technology of a company called RSC, via an EEPROM, we have a complete speech controlled remote system. Two chips and not much more which make a two-way wireless speech-controlled link.

21st Century Sat Com

As we saw in the first part of this series, digital satellite TV played a major part in the development of the digital signal technology and product base. But no industry can stand still and expect to survive. Broadband connectivity via satellite is the product being developed today. It is currently estimated that, using either wired T1 or DSL, only 60% of the business in the USA can be served. That translates to over 40% of broadband providers' potential business customers being lost due to their remote location. That is a lot of lost revenue. Satellite broadband may be the answer.

The technical challenges required to make a satellite broadband act like terrestrial broadband are not simple modifications. Both hardware and software are being developed to fit the role. Satellite links have lots of signal path variations. For TCP/IP the satellite link's unpredictable path timing events and signal strength variations require taming.

Whatever coding method is used, it has to be smarter and more robust than its constant propagation environment land-based brother.

Hughes Gives it a Try

Hughes has developed a whole new protocol for its Ka broadband satellite system, SPACEWAY. In Hughes' words, "Operating in globally assigned Ka-band spectrum, SPACEWAY employs high-performance, onboard digital processing, packet switching and spot-beam technology to offer single-hop connectivity, regardless of location." The move to the Ka band results in a higher bandwidth and, therefore, higher density data structure is possible.

It had better work as advertised if it is going to feel and act like a landline connection. Others trying to compete in this untapped, but risky market are iDirect and Aloha Networks.

What's Next

We have inhabited about the same 1000 or so MHz of frequency spectrum for the past 100 years. To what frequencies can the 21st century semiconductor technology take us?

Once there, it is unlikely that we will use radio in the same manner. What form will radio transmissions take? How will we use the expanded radio spectrum? When does a radio not act like radio? We'll attempt to gaze into the crystal ball to answer these questions and more in the next and final installment of radio in the 21st century.