A SOFTWARE DEFINED RADIO TRANSFORMATION

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May 17, 2009

ABSTRACT

A handheld software defined tactical VHF/ UHF radio used for AM/FM/PM line of sight communications is transformed into a single sideband HF band radio for HF 2G and 3G ALE networking. Military radio convergence presents real challenges to aggregation of widely variant narrowband waveforms. This paper discusses the hardware adaptations that allow a handheld VHF radio to act as the core radio of a HF band Manpack by simple software upgrade. This is an architectural discussion of how first generation software defined radios (SDR) are showing the promise that the SDR community has been promoting. Discussion covers baseband hardware architectures and the advantages and limitations of the current best practice software definable modem design. The addition of external frequency translation and PA design are used to transform the base radio. This paper discusses the mix of signal processing software and hardware filtering used to complete the radio transformation.

1. INTRODUCTION

The history of HF band radios that operate between 1.6MHz to 30MHz dates back over 100 years. Military HF radios often conjure up mental images of old WWII movies with the crazy radio operator surrounded by equipment and cables madly tuning through the HF spectrum to find a good channel. We also think of Ham operators Dxing (distance communications) across countries or even continents. Hams often participate in DX competitions based on the number or distance of contacts. These contests depend heavily on the skill and knowledge of the Ham and their understanding of ionospheric propagation and radio signal tuning and filtering. HF radios have long been used for naval ship to ship or ship to shore due communication due to excellent performance of HF over long distances. Even as satellites have gradually come to dominate distance communications, HF is still an important backup in naval operations. But the complication of radio operation in the military tactical environment for data communication has only seen limited use until recently. The evolving sophistication and robustness of algorithm and link layer protocols in 2G ALE and more so in 3G ALE has vastly improved the usability of HF radios in the tactical man portable arena for data communications. HF radio has seen a particular resurgence by the ground soldier especially as a backup or alternative to limited satellite availability. The value in HF for reliable beyond line of site data communications is especially useful in mountainous terrain where VHF line of sight radios can be very limited in range.

The evolution of digital hardware in the form of processors (GPP, DSP) and logic devices (FPGA) along with advances in software based radio waveforms has had a profound effect on the advances in military radio design and application. This evolution has enabled the advance of radios applied as modems for over the air data in an all IP packet based battlefield network. This seems like an odd place for HF radios to make a resurgence as a gateway modem for an all IP network. But the advances in processing and the development of 2G ALE protocol and more importantly 3G ALE HF digital waveform has made the practical use of HF radios for data applications like text messaging and IP based email applications possible.

The other evolution occurring over the last few decades has been the advance of the software defined radio (SDR). The promise of SDR to provide radio platforms that can transform from one waveform to another by simple software loads has materialized and exists through the Joint Tactical Radio System (JTRS) program. For example, the JTRS JEM (formerly Cluster 2) is shipping in volume production. It is a fully software defined radio that can support a wide range of radio waveforms and operating modes. The JEM radio is a Software Communications Architecture (SCA) compliant platform that operates from 30-512 MHz that runs various VHF and UHF band software defined waveforms such as SINCGARS, AM/FM, HAVEQUICK, ANDVT, MIL-STD-188-181C SATCOM IW and MANET.

Today's HF tactical radio communications solutions demand the capabilities and flexibility provided by Software Defined Radios (SDR) with their associated demand for processing power. The SDR digital baseband platforms that allow radios in the JTRS radio world to run a wide variety of waveforms is exactly the type of platform needed to host the modern HF 3G ALE waveform for advanced digital modulation, link layer protocol and networking. The next section introduces the Extended Band Man Pack (EBMP), a newly introduced radio that takes advantage of the JEM software defined radio as the host for an HF radio that runs the 3G ALE HF waveform.

2. EBMP SYSTEM

The EBMP radio consists of a core VHF/UHF radio (JEM) that hosts the HF 3G ALE waveform. This waveform is modulated into the JEM radio RF subsystem and is presented at the JEM side connector antenna port as a modulated VHF signal. The EBMP then does a simple frequency translation from VHF to the HF band The signal is then switched into a variable gain 20W amplifier on transmit or directly from the antenna port to the frequency translator during receive.

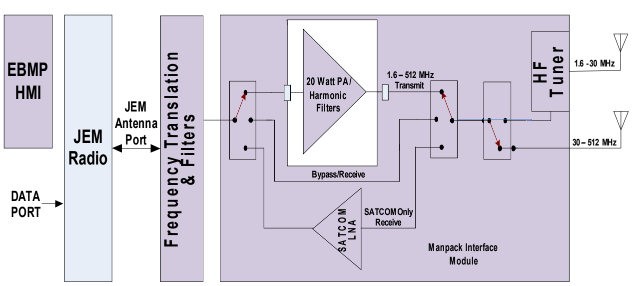

Figure 1: EBMP Diagram

As shown in Figure 1, there is also an HMI external to the JEM radio that is the HMI for the EBMP. This EBMP HMI interfaces directly to the hosted JEM radio and acts as a keypad input and display unit for the waveform HMI hosted on th JEM radio.

The advantage to this architecture is that the EBMP simply acts as a host to the JEM radio that is hosting the HF 3G ALE waveform.

For example, the JEM radio provides the audio IO for voice modes or a data interface for digital data modes of HF operation. The JEM radio provides the MELP audio vocoding for voice compression. It then hosts the modem side processing to generate a single side band modulation at a VHF frequency out of the JEM antenna port. This is necessary since the JEM cannot produce an HF band signal directly.

The advantage to this manpack architecture is that the host VHF radio already has an SCA environment and has an existing set of VHF/UHF waveforms. By extending the frequency range of the host VHF radio to the HF band we now have a radio platform that can host the entire HF 3G ALE waveform with the exception of the final frequency translation to the 1.6-30 MHz HF band.

The EBMP also provides two other essential functions to the HF band, amplification and antenna impedance matching. The HF band amplification is also necessary when using an high power amplifier (HPA) so the the output has enough power to optimally drive an HPA. Although amplification is necessary for HF band due to the primary applications of distance communication, the VHF and UHF band or the host radio also benefit from the wideband amplifier. It would be natural to think of setting up two EBMP radios in a retrans configuration using the VHF host radio existing retrans capability. In fact, the flexibility of hosting VHF and HF waveforms allows the possibility of using two EBMP radios to bridge between various VHF waveforms to an HF waveform like 3G ALE digital waveform.

The antenna tuner built into the EBMP is designed to match the impedance of the 50 ohm amplifier output to a broadband HF antenna. This is an essential function needed to maximize the power transferred to the antenna and thus radiated over the air. HF band is particularly susceptible to antenna mismatch due to the wide variety of antenna configurations depending on the application. For example, one might use a vertical antenna for line of sight communication. For beyond line of sight, one might use a Near Vertical Incident Skywave (NVIS) antenna that is directs the antenna signal near vertically from the ground. This is used to bounce the signal off of the ionosphere in a local radius of tens to hundreds of miles. This is one of the key advantages of HF over VHF band radio. The VHF signals travel straight through the atmosphere out to space whereas the HF band is reflected from layers of the atmosphere directly back down to the ground. This is the key value of HF band communication that allows beyond line of sight communication from many tens of miles to even thousands of miles. This is not possible with VHF and higher frequencies.

It is important to point out that the primary functions of frequency translation, amplification and tuner impedance matching are all directly controlled by the baseband modem processor of the host VHF radio. The control protocol is essentially the identical messaging or slightly modified messaging from that used internally to control the VHF radio's RF subsystem. In fact, there exists an external control interface that can connect to an external 125 Watt HF amplifier and external antenna tuner for use with the EBMP. The control interface sends information such as transmit or receive state and frequency band information for the amplifier and tuner to switch modes as a seamless part of the radio system.

Although not directly related to the HF 3G ALE data networking applications, the EBMP also supports an internal BA2590 rechargeable lithium ion battery and associated charging circuitry. There is an optional SAASM GPS or a (cheaper) commercial GPS. There is a front panel accessory connector to support various data and control interfaces for adding external devices.

As can be seen in Figure 2, the VHF host radio slides into a sleeve built into the EBMP chassis. Once installed, the JEM radio HMI is no longer visible or accessible. The EBMP front panel contains an HMI device with a full color LCD display and a numeric keypad. This operator interface is removable for use by a simple RF adapter cable that allows remote operation of the EBMP radio system.

This removable operator interface allows the user to control the EBMP and select operational modes and channels for the radio. But this sophisticated user interface communicates directly to the installed JEM radio where the actual application controls all of the radio states and modes. This is really a basic interface to the operating radio waveform.

Figure 2: EBMP Radio Set

3. EXTENDING THE FREQUENCY RANGE

As noted in the prior section, the EBMP acts as a frequency translator between VHF and HF bands. This is accomplished, as shown in Figure 3, by an added mixer stage that combines the VHF output of the host radio with a local oscillator generated signal to produce two image signals. The upper image signal is filtered out leaving the lower image signal that is in the HF band. By tuning either the modulated input VHF signal or the local reference oscillator appropriately, the HF band signal can be tuned anywhere in the 1.6-30 MHz frequency range.

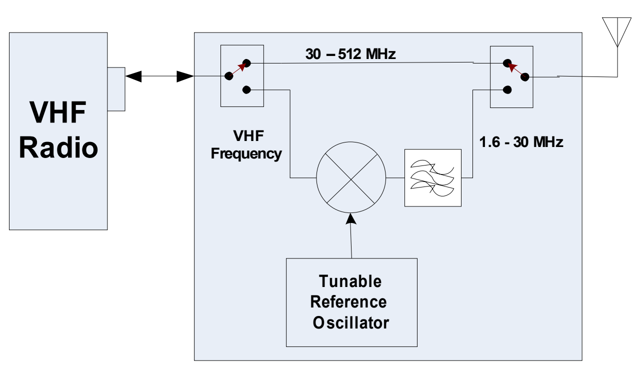

Figure 3: Frequency Translation

The addition of another mixer stage is merely and extension to what is already being done in the

RF section of the base VHF radio. The host radio provides a baseband of intermediate frequency signal into the RF subsystem. The RF subsystem mixes the signal up to the desired VHF or UHF output frequency in a number of stages depending on the RF performance characteristics needed. Adding another mixer stage to translate to HF is just an extension to the existing host radio RF functionality.

What does differ dramatically is the baseband modulation. Many of the current or legacy narrowband VHF/UHF military waveforms use mostly FM or possible AM modulation which is inherently double sideband with a fixed carrier. HF radio uses single side band (SSB) suppressed carrier in order to conserve precious bandwidth in the HF range. For simple analog voice, modulation is an upper or lower sideband (USB,LSB) AM modulation. The HF digital modulations are typically a form of phase modulation from simple FM to the complex 64 state quadrature amplitude modulation (64-QAM). What is significant in this EBMP radio is that the complete HF modulation of 64-QAM[4] single side band suppressed carrier modulation is generated entirely in software on the host VHF radio. The EBMP just adds the final mixer stage to convert this modulation signal from the VHF to HF band. This is the power of a software defined radio.

The digital data modulation types are defined in STANAG4285(PSK), STANAG4539(QAM) or in MIL-STD-188-110B(PSK/QAM). The 2G ALE also defines an 8 tone FSK modulation. All of these modulation types are defined to be baseband (low IF) single sideband (LSB,USB) with suppressed carrier. These are all realizable in software on the host VHF radio of the EBMP.

Here is a brief example of the software modulation process for a digital modulation in single sideband HF. In the transmit direction an HF mode digital bit stream is modulated with one of the above methods, say 16 QAM modulation. The 16 QAM signal has 16 distinct states of phase and amplitude. Each state represents a four bit binary symbol as shown in Figure 3 below.

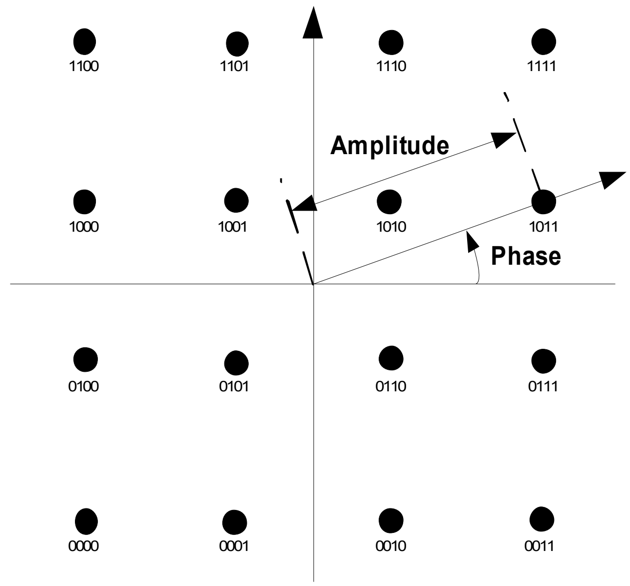

Figure 4: 16 QAM Constellation

The data bit stream 16 QAM modulation algorithm is a form of I&Q (real&imaginary) modulation to convert bits to a low IF amplitude and phase modulated signal. The 16 QAM signal produced at this stage is double side band signal with both upper and lower sideband and a carrier frequency.

This signal is then fed into another signal processing algorithm that converts the signal to a single sideband suppressed carrier signal. This may be either an upper or lower sideband as needed. The type of transform used is a Hilbert transform although there are other algorithms that can accomplish the same transformation (Weaver modulator). At this point, the signal still exists only as digital data representing the modulated signal in local DSP memory.

At this point it the digital modulation stream is sent to a Digital to Analog Converter (DAC). This low IF analog modulated signal is then mixed and up-converted to the VHF still within the VHF host radio. It is finally at this point that it enters the prior described VHF to HF down-conversion mixer, amplified and sent out the EBMP antenna port.

4. 3G ALE

The discussion thus far has not directly addressed the operation of HF 3G ALE. The acronym 3G ALE stands for Third Generation Automatic Link Establishment. The reference to 3G ALE also implies a whole suite of protocols that complement each other to provide an overall operational waveform. This is referred to in the NATA STANAG series of specifications as the HF House as shown in Figure 5.

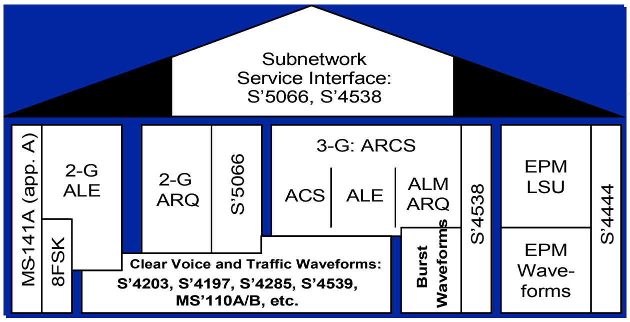

Figure 5: HF House

This diagram illustrates both the parallel existing HF protocols and also the vertical protocol relationship of protocols defined in the various STANAG specifications. This is a very helpful diagram in understanding at once the historical evolution of HF protocols and the interrelationship between them.

But for the case of a running 3G ALE in a data networking mode it is more useful to think of the particular relationship of the various parts of the overall 3G ALE HF and modulation modes in how they relate to each other to create a complete radio modem. For the instantiation of a specific waveform and mode of operation it is more useful to resort to the classic OSI layered networking model of protocol stacks.

The diagram in Figure 6 shows a more layered network model of the HF 3G ALE protocol stack. This is more reflective of how the overall waveform executes and interacts in the EBMP radio platform. The three layers highlighted on purple execute on processing hardware in the host VHF radio. The bottom box highlighted in blue is the physical layer of the communications channel and resides in the EBMP. The layer consists of the frequency translation circuitry, 20 Watt amplifier and antenna tuner hardware.

The upper two layers of the protocol stack, the network layer is classically shown to be hosted on personal computer interfaced to the radio set with the radio set serving as a classic modem. It should be noted that these two functions could easily be hosted in the removable user interface of the EBMP. This display unit has a powerful microprocessor of the same class as many PDA and data oriented cellular devices. This user interface could host a basic email application or tactical chat application and directly host these two upper layers of the HF House protocols.

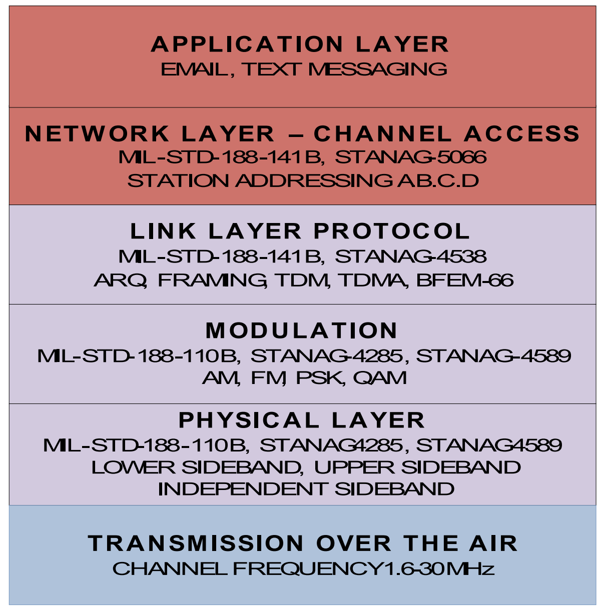

Figure 6: Waveform Protocol Stack

7. CONCLUSIONS

The recent success of first generation software defined radios is beginning to show the promise of waveform flexibility and adaptability to allow use of new waveforms. The initial concern that the RF domain could not be tamed by the pie in the sky notion of digitizing the radio signal directly at the antenna. But as this example shows, a second generation SCA compliant software defined radio can be applied in dramatically new waveform applications by simple software changes with a little creative hardware extension. Transforming a handheld tactical VHF/UHF radio into an 3G ALE digital single sideband HF band radio clearly demonstrates the possibilities and flexibility of software defined radio platforms.

8. REFERENCES

[1] Eric Johnson, "Third-generation technologies for HF radio networking", *Proceedings of MILCOM '00*, 2000.

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[4] STANAG 4539, "*Technical Standards For Non-Hopping HF Communications Waveforms* ", 2005.

[5] STANAG 4538, "*Technical Standards for an Automatic Radio Control System for HF Communications Links*", 2005.