SWaP Optimized RF Sensor Chain Innovation That Detects to Protect

Introduction

Protection on and off the battlefield is defined as the ability to constantly monitor, detect and translate the RF spectrum into actionable intelligence to alert personnel and secure vital assets. In a dynamic and constantly mobile environment, innovative methods and designs must be applied to create a size, weight, and power (SWaP) optimized system capable of being deployed in-place or stationary, in a vehicle, or even in a man-pack portable configuration. First, the optimal design must address and incorporate an entire RF sensor chain into a small light-weight package and at the same time, maintain RF signal integrity with a high probability of intercept (HPOI) of signal detection by rapidly scanning over a wide band of frequencies starting with a continuous scanning coverage, for example, from DC up to 10GHz. The ability to select and stare at a dynamically determined narrow band of signals must also be included in the system design. Secondly, the combination of several of these base units with phase coherent timing operation provides advanced direction finding functionality adding more detail to the situational awareness picture. Finally, the system must provide a network interface for the dissemination of the derived and analyzed data using a real time spectral waterfall or a constantly updated wideband spectrum display format.
Defining the RF Sensor Chain

Figure 1 below visualizes the dataflow of a complete RF sensor chain, from the first steps of sensor acquisition and data conversion through digitization, filtering and formatting of the data. This is followed by the steps to ready data for the next stage of processing combined with data storage operations and on-board close to the sensor exploitation. The final step of transferring the data to the network for dissemination concludes the RF sensor chain and places the requirement on the subsystem design to provide best in class network connectivity. To accomplish the task of designing a subsystem that will meet the size, weight and power requirements and at the same time, incorporate an entire RF sensor chain capable of providing the ability to constantly scan the RF spectrum for signals over an extremely wide broadband of continuous frequencies poses a great challenge especially when considering a range spanning from DC to 10 GHz for this example. Balancing the SWaP and the signal integrity without adding digital noise that impacts the sensitivity of the system is critical to the success of the unit design.

The constantly changing emerging threat detection requirements demand a portable autonomous design with optimized SWaP characteristics that include exceptional frequency agility, ultra-wide bandwidth and advanced on-board processing. The SIGINT receiver must detect, isolate, filter, amplify, digitize and process signals of interest starting with the antenna apertures as shown in Figure 2. The need for innovation that detects to protect necessitates exceptionally high probability of intercept of fleeting signals to produce in a very short duration actionable intelligence using ultra-fast scanning technology and high probability of intercept techniques over the ultra-wide broadband continuum of frequencies from DC to 10 GHz and implementation using an advanced digital backend for signal digitization and processing.

The transition from the mixed RF analog frontend that receives/detects/filters and amplifies to the digitizer that begins the implementation of the digital portion of the system is a critical juncture in the sensor chain system design implementation as shown in Figure 3 in the yellow blocks.

As shown in Figure 4, the following characteristics of the selected analog-to-digital converter (ADC) are very important measurements of the effective performance of the digitizing process in the sensor chain.

The optimal balances of the effective number of bits (ENOB), signal-to-noise ratio (SNR), spur free dynamic range (SFDR) and signal-to-noise ratio and distortion ratio (SINAD) of the ADC must be the best possible in each category to minimize and eliminate the possibility of injecting digital noise into the received signal. By minimizing the system induced noise factors in the analog and digital portions of the IMA, the SIGINT subsystem provides a very accurate representation of the detected signal for additional digital filtering and processing.
Understanding the Phase Coherent Requirements for Direction Finding

As shown in Figure 5, Phase coherency across the antenna apertures is the key to a system that can receive signals and determine the direction and location of the emitter with great accuracy. As the electromagnetic wavefront of the signal of interest travels towards the multiple antenna apertures in Figure 6, the angle of incidence will be different for each antenna element in the array and therefore, the phase of the signal will also be different. The signals must be sampled at each aperture in synchronization using the same clock with very fine timing granularity and minimal error throughout the system.

Figure 5

Direction finding system antenna aperture elements receive the carrier frequency signals and convert them to a pre-determined intermediate frequency (IF). The system as a whole is synchronized in all of the receive sections using one synthesizer and this allows for each section as shown in Figure 8 to convert the received carrier frequency to the designed-in system intermediate frequency (IF) with equal amplitude and phase, which is critical to accurately determining the bearing of the emitter. The multi-channel receiver must be able to distribute with minimal system induced noise the local oscillator (LO), sample clock and trigger distribution signals across the receive sections to enable the accurate measurements of phase and signal emitter direction. Coherent and independent local oscillator (LO) distribution in Figure 8 is critical to optimized and accurate direction finding system performance. The typical GHz sample clock must maintain alignment throughout the receiver sections with minimal error and noise. The direction finding system must be designed to process the signals at a high throughput rate with low latency and be deterministic in order to sample and detect the fleeting signals. A sophisticated agile local oscillator (LO) and coherent clock distribution with fine granularity is key to the design of a direction finding system based on mixed analog, RF microwave and digital IMA building blocks.

Figure 6

The bearing of the signal emitter can be determined from the amplitude and phases of the intermediate frequency (IF) of the signals received. Figure 7 shows a basic system diagram with multiple receive antenna apertures feeding a receiver that detects a signal based on the amplitude and power parameters while measuring the phase of the signal over multiple apertures and combining all of the signal characteristics in the processing unit to calculate and determine the direction of the emitter.

Figure 7
In Figure 9, the direction finding configuration makes use of sensor array processing techniques throughout the mixed analog, RF microwave and digital domains that comprise the baseline integrated microwave assembly (IMA) design. The synthesizer in the system is a key element to synchronize across the channels in the system. The analog signals are received by the multiple apertures and ultra-fast tuners of the system in Figure 9. The signals are amplified, frequency translated, filtered using preselected filters and converted to the intermediate frequency (IF) that matches the sampling rate of the analog-to-digital converter as the entry point of the signals into the digital processing domain. Additionally, the digital down converters (DDCs) in the field programmable gate array (FPGAs) are applied prior to the bearing processing to perform data reduction and convert the signals to baseband. The I and Q complex data set representing the signals at baseband can then be filtered to render the bandwidth of interest and calculate the direction of the signal of interest emitter.

**Figure 9**

**Creating Integrated Microwave Assemblies (IMAs) Is the Key to Optimizing System SWaP**

The general characteristics of Integrated Microwave Assemblies (IMAs) include high speed switching, high linearity, high isolation, low harmonic and spurious signals, low noise figure, hermetic ruggedized packaging, amplitude and phase matching, and digitally enhanced control components. As shown in Figure 10, a SIGINT receiver is a balanced design where analog and digital processing and signal manipulation functions must coexist in tight proximity to implement a mixed analog, RF/Microwave and digital broadband IMA. The primary discrete components required to configure a SIGINT receiver subsystem include analog tuning, amplification, frequency translation, filtering, digitizing and processing and those sequences may be used in a variety of innovative ways. The key to elevated subsystem performance across a broad frequency spectrum is the ability to blend analog and digital components without introducing digital noise. The design must properly define and balance the RF backend and digital frontend; while at the same time, the system must effectively isolate the RF and digital portions of the architecture. Homogeneous integration is required to optimize SWaP and maintain a high probability of intercept of fleeting signals of interest.

In the beginning of the subsystem design phase, RF design simulators can be used to properly sequence and align the logical components and isolate them along the analog and digital boundaries. RF simulation is critical to optimizing the sequence and geometries of the RF filters allowing the designer to choose the best design after simulating and test the results of all of the RF filter options. Complex design features can be rapidly prototyped and verified through experimentation. Simulators also drive design creativity enabling insights into the cause and effect of dense SWaP based subsystems that leverage highly-integrated vertical and multi-layered RF microwave component packaging in close proximity to the digital device and processing boundaries including FPGAs and microprocessor CPUs. Finally, the simulations provide predictive RF performance and also feedback on SWaP constrained design parameters to include heat dissipation measurements. Following this type of design process allows one to choose already existing IMAs like those in Figure 10 or determine the need to create new ones that can be assembled, sequenced and properly aligned to create a finely integrated homogeneous mixed analog and digital SIGINT receiver.

The use of integrated RF microwave assemblies optimizes the receiver subsystem design in the following critical performance areas of detection, signal isolation, amplification, digitization and processing. The output of the sequence described above results in digital data outputs that are demodulated and ready to be disseminated as actionable intelligence.

**Figure 10**
Combining Multiple Integrated Microwave Assemblies (IMA) with Phase Coherent Operations

The creation of a software defined radio (SDR) preemptive threat detection and direction finding receiver begins with a small device footprint optimized for superior SWaP implementation that can be incorporated into fixed, mobile or man-pack based applications such as SIGINT, force protection, TEMPEST and IED detection. The basic building blocks of the monitoring network are multiple receivers synchronized with precision timing and the appropriate local oscillator (LO) frequencies to determine the IF from one of the base units acting as the master control unit of the system as shown in Figure 12. The use of multiple integrated RF/microwave assemblies within a SWaP optimized enclosure as shown in Figure 11 or a network of the base unit IMAs connected by Ethernet at the GigE or even higher speeds can provide the 360 degree ability to detect fleeting signals with the highest probability of intercept (HPOI) and determine the direction of the emitter through ultra-fast scanning rates greater than 200 GHz/second and advanced on-board data processing to derive actionable intelligence closer to the sensor.

The resulting homogeneous integration of the right balanced mix of analog and digital IMAs is shown below in Figure 11 and the resulting sub-system design includes extensive I/O and EMC secure enclosure packaging as part of meeting the environmental and heat dissipation requirements for in-place, mobile and man-pack configurations. This autonomous SIGINT sub-system is a high-density, high-fidelity, highly-isolated, highly-integrated application-ready self-contained IMA. The agile receiver subsystem delivers the highest probability of intercept over an extremely wide broadband of frequencies with continuous coverage from DC to 10 GHz. The SIGINT receiver IMA implements a RF topology with optimized RF microwave building blocks providing the highest probability of receiving fleeting signals in an extremely wide broadband detection scenario using a scanning rate greater than 200 GHz/second and advanced on-board data processing to derive actionable intelligence closer to the sensor.

The specific characteristics of the SWaP optimized IMA in Figure 11 include application-specific PLL-based local oscillators with ultra-fast tuning speed and low phase noise plus processing of the analog-to-digital converter 16 bit output via a Virtex6 XC6VLX240T with digital-down conversion, FIR filtering and FFT processing for spectral outputs to the graphical control interface display software. The Linux operating system is running on the Freescale MPC8536 control processor supported by 512 MB of DDR2 SDRAM as capture memory and a 32 GB SATA drive providing secondary signals of interest capture as the advanced processing and on-board storage functionality. I/O connectivity to the SIGINT IMA is via USB, Micro SD card, and two GigE Ethernet communication ports with the host using SCPI commands (Standard Commands for Programming Instruments). The ultimate optimized SWaP of the SIGINT IMA base unit is a weight of 5 lbs., power consumption of 39 Watts and a dimension of 7x9x3 inches.

Defining the Data Display and Software Interface

The SIGINT receiver IMA is capable of being programmed and processed data results displayed using one of two GigE Ethernet communication ports with the internal host controller via SCPI commands (Standard Commands for Programming Instruments). In addition, the X-MIDAS standard interface software can configured and integrated with the mixed analog, RF microwave and digital IMA to provide spectral waterfall and spectrum analyzer displays of the wide broadband and narrowband processing output results as shown in Figure 13. The display interface allows the operator to use the innovative ultra-scanning and narrowband stare features of the receiver to detect fleeting signals of interest and gain the actionable intelligence needed to detect and protect. The SCPI programming interface allows the operator to program the pre-selection filters and tap into different outputs and display the digital down conversion, broadband/narrowband and demodulated signal data as waterfall or spectral operator displays.
interest over an extreme wide broadband of continuous frequencies in a package that measures 7x9x3 inches with a weight of 5 lbs. and a power consumption of 39 Watts. The phase coherent operation of several of the IMA units together provides advanced direction finding functionality with the highest probability of intercept (HPOI) and detection of fleeting signals resulting in near-instantaneous persistent actionable intelligence and protection on and off the battlefield in vehicles, man-packs or in-place. The IMA design provides the network interfaces necessary to disseminate and display the operational results in a waterfall or power spectrum format with the ease of use to change between a broadband view from DC to 10 GHz and a narrowband view of selected signals of interest. The SIGINT subsystem IMA also includes the ability to store the selected results on-board or over the network. The mixed analog/digital IMA SIGINT receiver is a powerful innovative design that detects to protect.

References


FM 34-40-9: Chapter 3 Technology, pages 3-1 to 3-12, U.S. Army Field Manual on Direction Finding history.


Conclusion

The innovative combined use of three or more SWaP optimized units based on a high fidelity IMA design provides constant situational alert and awareness with an unprecedented high probability of intercept and direction finding performance that results in a blanket of detection and protection over a broadband spectrum from DC to 10 GHz. With an ultra-fast scanning rate of greater than 200 GHz/s, the highly integrated mixed analog, RF microwave and digital assembly in Figure 11 demonstrates that a SWaP optimized environmentally hardened and application-ready highly-effective IMA can be designed that tightly integrates and highly isolates the mixed analog RF microwave front end from the advanced digital backend. In addition, the IMA based sub-system maintains the highest signal integrity with a high probability of intercept (HPOI) of signals of...