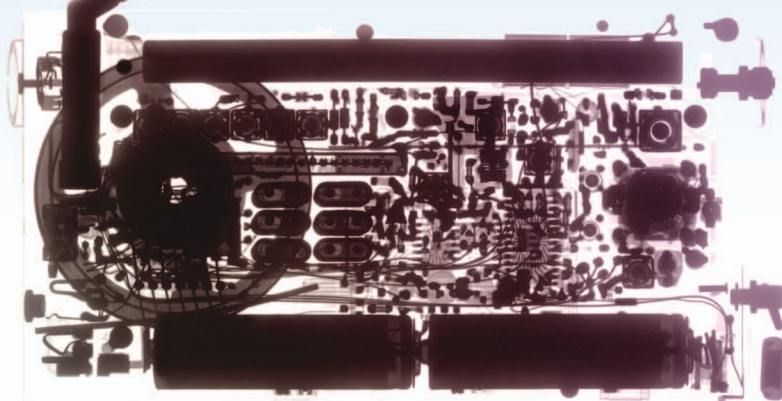# The VITA 49 Analog RF-Digital Interface

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Abstract

Over the last several years, the interface between the digital and analog RF subsystems of a radio (the analog RF-digital interface) has become increasingly important. This article first discusses the different technology alternatives that exist for this interface and the rationale behind them. The emergence of cognitive radio technology is identified as a trend that increases the importance of the analog RF-digital interface. Then the article discusses in detail the VME bus International Trade Association (VITA) 49 standard. VITA 49 is a packet-based protocol to convey digitized signal data and metadata (or context data) pertaining to different reference points within a radio receiver. The metadata includes analog front-end parameters such as RF center frequency, bandwidth, IF center frequency, sampling rate, gain, location, etc. This standard allows all information about the spectrum as seen by a radio at its antenna to be described, stored, and transported to other systems. VITA 49 is identified as a hierarchical radio description language that is a new paradigm for radio architectures.

I. Introduction

Most wireless communication systems consist of a digital hardware section (digital back-end) and an analog RF section (analog front-end) located between the digital section and the antenna. This article is focused on the *interface* between the digital and the analog RF sections of a radio, the RF-digital interface. Our perspective is from the viewpoint of software-defined radios (SDRs)—radios for which the physical-layer parameters can be set or altered by software [1]. SDRs require reconfigurable hardware and hardware modularity—the ability to change portions of the system.

Before examining the analog RF-digital interface, let us briefly examine the analog RF and digital sections of a radio. The digital section implements the digital signal processing at the physical layer (coding, digital modulation) and some higher-layer protocols such as access protocols, encryption, etc. There is no universal design approach for the digital section of a radio—there is only a set of technology alternatives. In general, the available methods to implement the digital hardware are specialized processors such as Digital Signal

Processors (DSPs), general-purpose processors (GPPs), various multiprocessors, and field-programmable gate arrays (FPGAs) [2]. Application-specific integrated circuits (ASICs), which otherwise achieve the lowest cost and lowest power consumption, are not reconfigurable and therefore, in principle, are not applicable to SDRs. These technologies are well-known and each is characterized by a different design approach. The digital subsection of a radio may consist of multiple types of reconfigurable hardware. For example, a DSP, a GPP, and an FPGA might all be present in one radio.

The basic functions of the analog RF section are frequency band selection, amplification, and up/down conversion. Certain key radio parameters such as RF center frequency and power are determined entirely by the RF section. Like the digital section, the RF section is similarly characterized by the lack of general design approaches. Older designs were often implemented with a large number of discrete components located between the antenna and the digital hardware. Modern implementations have far fewer external parts and, in most cases, use CMOS integrated circuit (IC) technology which has become the least expensive alternative, due to high volume use by the computer industry. It is much more challenging to build reconfigurable analog RF components; nevertheless, certain solutions are available [3]. Overall, the design of the analog RF and the digital subsections of a radio have been the subject of considerable research over the years [3, 4], while much less attention has been paid to the interface between them.

Digital and analog RF are different technologies that have different evolution paths. As a result, they have become increasingly encapsulated in separate modules. These separate modules are, in most cases, ICs. In some systems, these separate modules are boards, or even chassis. Because these technologies have different evolution paths, it has become desirable to be able to replace them separately. This can be accomplished only if there is interoperability. Therefore, the interface between them has become a design problem with importance for both sides.

Since the focus here is a standard open interface for wireless devices, it is well worth clarifying that there are multiple different types of standards that affect the cellular, and more generally, wireless industries. The best known cellular standards are Radio Access Technologies (RATs), such as GSM, and the more recent Long-Term Evolution (LTE), and LTE-Advanced [5]. Other well-known physical layers are Wireless Local Area Networking (WLAN) technologies such as IEEE 802.11n, Worldwide Interoperability for Microwave Access (WiMAX) or IEEE 802.16, etc. [6]. These access technologies have been making steady progress and continue to do so. On the other hand, the development of what can be called infrastructure standards has been markedly slower. These infrastructure standards aim to develop open interfaces between various components of wireless systems.

These infrastructure standards have been significantly affected by the state of the wireless industry. Traditionally, the wireless industry has been dominated by a relatively small number of big companies. These dominating companies considered proprietary interfaces as a sustainable competitive advantage. They could develop all enabling technologies on their own, while smaller companies could develop only some enabling technologies. Anytime new entrants sought to develop open interface standards, the dominant suppliers worked just as hard to prevent, or at least delay, the development of such interfaces. Since standardization requires some consensus, until the last ten years there was little progress.

Over the last ten or so years, the evolution of the wireless industry has been especially fast. This evolution has been shaped up by several factors. The time to market for wireless products has been getting much shorter. The time interval between standardizing one mobile communication system and standardizing the follow-up system has been getting shorter too. Another trend that has affected the industry at the same time is the success of WLAN technology, offering very high data rates over unlicensed (and therefore low-cost) spectrum. Consumers demand personal portable devices that integrate computing and communications functionalities. These systems require multiple RATs, while state-of-the-art analog RF and digital ICs are optimized for a single RAT. Communication devices started

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to be built with multiple pairs of digital baseband ICs and RF ICs, one pair for every RAT that is supported. Because it is very easy to add and remove a pair of ICs supporting one RAT, the resulting architecture can be called a "Velcro" architecture, illustrated in Fig. 1. Note that, in the Velcro architecture, there is a separate analog RF-digital interface between every pair of digital and analog RF ICs.

To the extent that they can offer complete solutions, the large vendors can be expected to resist open standards. However, because of this rapid technological change and short time-to-market, the large vendors have been increasingly able to develop on their own only some, but not all, of the enabling technologies. In this environment, these companies have become interested in "open innovation" intellectual property models that would allow them to acquire those pieces of the solution that they do not have, and also sell portions of their technology to any other vendor as long as it is for a profit. Since any company can acquire all the enabling technologies, competition is based on who is first to market with a complete solution. Short time-to-market requires maximum flexibility and reusability of modules. The standards development process has become another area of competition, since companies are trying to impact the standards process in a direction that maximizes the value of their technology offering.

Overall, the environment today is more receptive to open infrastructure standards and several standard technologies have emerged.

In this article, we first discuss the evolution of the analog RF-digital interface in Section II. Then we describe the American National Standards Institute (ANSI)-approved VME bus International Trade Association (VITA) 49 standard in Section III. Section IV is devoted to both established and promising emerging applications of this standard. Section V contains the concluding discussion.

II. Evolution of the Analog RF-Digital Interface

The analog RF-digital interface is significantly affected by the placement of the analog-to-digital converter (ADC)/digital-to-analog converter (DAC) pair. For most of the wireless systems designed in the 1990s, the ADC/DACs were implemented separately or placed on the baseband chip. This meant that the interface between the baseband and the analog RF ICs had to be analog or mixed-signal. In a mixed-signal interface the transmit and receive I and Q signals are analog, but the control signals (typically clock, Tx/Rx enable) are digital. More recently, it became apparent that there are benefits to a completely digital interface, meaning that the ADC/
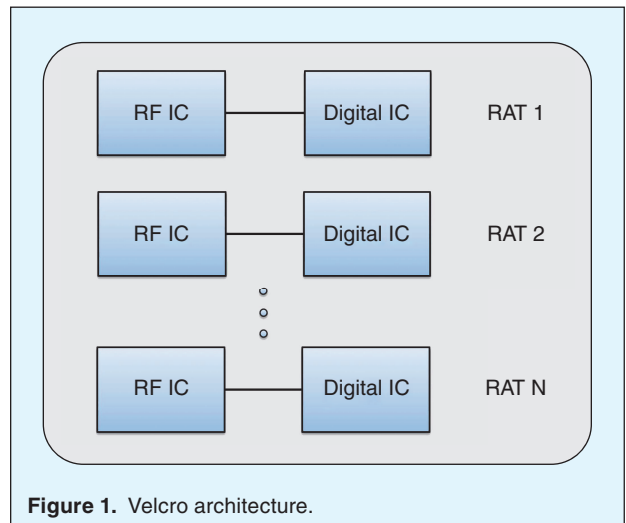

Figure 1. Velcro architecture.

DACs are placed on the RF IC. In this way, the digital chip can be changed to accommodate different wireless standards independently of the radio front-end. Placing the ADC/DAC on the RF IC is more appropriate for complex physical layers such as multiple-input multiple-output (MIMO), where the number of spatial streams may be different from the number of antennas (and RF front-end chains).

Over the past few years, several specifications have been developed defining the interface between the RF front-end and the digital baseband processing sub-system. These interfaces include the Reference Point 3 specification developed under the Open Base Station Architecture Initiative (OBSAI) [7], the DigRF interface specification from the Mobile Industry Processor Interface (MIPI) alliance [8, 9], and the Common Public Radio Interface (CPRI) [10]. There are technical and business reasons that several specifications exist. The OBSAI and CPRI specifications are for base stations, while the DigRF is for handsets. These standards have allowed an ecosystem of vendors to appear, offering interoperable RF and baseband processing modules.

To avoid confusion, we note that, in some system implementations, there is a finer granularity of interface definitions including such interfaces as the baseband/network interface, and baseband/application processor interface. While these interfaces can also be important, they are not discussed here. From a radio architecture perspective the RF-Digital interface is much more critical.

As mentioned above, CPRI and OBSAI are major industry standards in place for cellular radio base stations. Both standards allow splitting a base station into further sub-units, particularly into a system unit and

into a remote radio head. CPRI is an interface between blocks referred to as Radio Equipment Control (REC) and Radio Equipment (RE). The parties behind the CPRI Specification are Ericsson AB, Huawei Technologies Co. Ltd, NEC Corporation, and Siemens AG.

The OBSAI standard is broader in scope than the CPRI specification. It specifies the electrical and mechanical characteristics of multiple interfaces inside a base station, developed within the Technical Working Group of the Open Base Station Architecture Initiative Special Interest Group (OBSAI SIG). The OBSAI interface specifications covering the radio base station interfaces for Transport, Clock/Control, Base Band and Radio, together with hardware connection specifications. OBSAI includes also test specifications. OBSAI specifications define a mapping of the base station functionalities onto Control and Clock, Transport, Baseband, RF, and General Purpose blocks for all air interface standards, but the internal structure of the blocks is not in the scope of OBSAI specifications.

Another related work is the IQ interface developed at the Fraunhofer Institute in Germany [11]. The interface enables the bidirectional transmission of digital IQ baseband signals as well as the transmission of control and management information. The digital interface allows a transmission of IQ samples with rates between 1.2 and 72 MSamples per second. Thus, waveforms with a bandwidth of approximately 57 MHz can be transmitted. Moreover, the specification supports a division of the IQ samples into up to eight transmitters or receivers in the transceiver module, for example in multiple antenna systems. Thus, the maximum sample rate per transmitter or receiver is reduced, and also the maximum bandwidth for the waveform is reduced in proportion to the number of addressed transmitters and receivers. This IQ interface is developed on the basis of the CPRI and OBSAI specifications and is also point-to-point.

DigRF is a series of specifications for the interface between the baseband and analog RF chips for mobile handsets. These interfaces generally consist of two differential digital paths, one for transmit and one for receive, which are capable of handling several prioritized local channels for configuration, timing control and data. These interfaces are software-defined to some extent, since they allow some software control over parameters such as RF center frequency, bandwidth, and power. The main limitation of the DigRF series of interfaces is that they are designed only for specific air interface standards, with specific clock speeds, etc. They are even not backwards compatible among themselves. The latest version 4 is for devices that implement air interfaces such as LTE and mobile WiMAX and is not backwards compatible with DigRF v3 developed for 3G cellular [9], which in turn is not backwards compatible with DigRF 1.12 developed for 2G [8]. Backwards compatibility is not even a design requirement because both the analog RF IC and the digital hardware IC (which is an ASIC) used in handsets are not reconfigurable and are designed for specific air interfaces. If one is replaced, it is very likely that the other one will be replaced as well. Therefore the DigRF specifications are close to a coupled interface. They are appropriate only for handsets supporting specific wireless standards, but not appropriate as an interface between the analog front-end and the digital hardware for software-defined radios. The interface design developed in [12] is improved compared to the DigRF specifications, but it is also not intended for SDRs. The main conclusion is that there was no RF-digital interface for software-defined radios prior to the development of VITA 49, although some have recognized the importance of the RF-digital interface and have observed that a solution is notably missing [13].

Recently, other technological trends have emerged such as Distributed Antenna Systems (DAS) and cognitive radio, which require re-evaluation of the analog RF-digital interface.

According to DAS there is a central digital signal processing facility (a DSP fabric) and a set of distributed antennas and analog front-ends connected to the central facility by a high-bandwidth network such as optical fiber. DAS is now being considered as a base station technology. One advantage of DAS is that it may be cheaper to have one central site for digital signal processing. Another advantage is that an antenna (with an analog front-end) may be provided at a location where it may be difficult to put an entire base station. The DAS is, in fact an SDR cloud, where all the digital signal processing is done remotely in a "cloud," much like the processing in cloud computing [14].

The connection between the analog front-end and the distributed facility may be analog or digital. The first implementations have been analog with proprietary schemes (a familiar evolution path!). Unfortunately analog transmission over fiber suffers from various drawbacks such as attenuation, etc. It is also difficult to make multiple signals share the same cable. If there are multiple antennas, analog DAS will require multiple fibers, while digital DAS can multiplex all the signals onto one link.

The other powerful technological trend is the advent of cognitive radio. In turn, cognitive radio requires complete reconfigurability, provided only by software-defined platforms [1]. Solutions built using the Velcro architecture, sometimes referred to as multi-mode and multi-band, are software-defined to some extent. They can switch between bands and modes, but once the device is built, the bands and modes cannot be changed. Cognitive radios require seamless switching among RATs, reconfigurability and upgradability. Cognitive radios have a functional block that can be called a cognitive engine (CE) [1]. The CE must be aware of all communication parameters, such as RF center frequency, bandwidth, etc. Some of these parameters pertain only to the baseband subsystem, some parameters pertain to the analog RF subsystem, and some pertain to both the analog RF and the digital subsystems. It is best if the analog RF-digital interface is completely independent from any RAT and from any particular analog RF or digital hardware technology. In this way the interface can support any wireless physical layer, including all currently deployed and future RATs, as well as real time switching between them. None of the specifications considered so far satisfies this requirement. Note that even though these interfaces may include various "control" circuitry, this does not make a radio implementing such interfaces software-defined.

A software-defined radio (SDR) is a radio in which the physical layer functions are software-defined [1]. One of the keys to enabling SDR technology is having RF front-end that is software-defined, i.e. whose main characteristics are software-controlled or programmable.

The analog RF-digital interface in Fig. 2 consists of two types of signals: high-speed and low-speed. The IF and baseband signals use high-speed connections. The software control of the analog front-end provided by the digital hardware uses a low-speed connection. It is clear why this connection is low-speed: the parameters of the analog RF change at a much lower rate than the IF or baseband signal.

In most cases, even when the interface is said to be "open," only the signal data interface is specified and
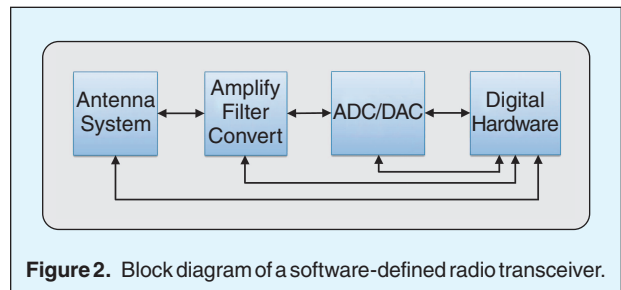

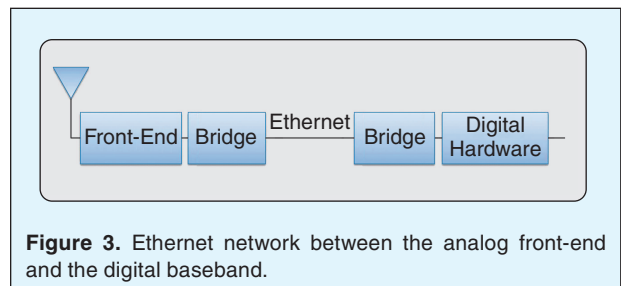**Figure 2.** Block diagram of a software-defined radio transceiver.

Figure 3. Ethernet network between the analog front-end and the digital baseband.

the control interface is left proprietary. Such interface definitions also do not achieve hardware modularity. If one component on either side of the interface changes, the entire interface to it has to be redesigned. Therefore, the low-speed connection must also be included in the interface definition, and this inclusion should be in a way that is completely independent of any radio access technology and any particular analog RF or digital hardware technology.

It is possible to connect the analog RF and digital hardware subsections with gigabit Ethernet [15], as illustrated in Fig. 3. Note that this is just Ethernet, without a higher-layer protocol such as TCP/IP on top of it. Ethernet packets are used to carry digital signal packets (at IF or baseband level). The use of Ethernet, while low in cost, has significant disadvantages including lack of clock synchronization. It is difficult to keep the radio front-end and the baseband processors synchronized. One solution to this problem is to use an extra wire for clock distribution, but this largely defeats the original idea of using Ethernet. An even bigger disadvantage is that this solution is only appropriate for digital radios that do not need the low-speed control connection and therefore are not fully software-defined.

III. Overview of Vita 49

VITA 49 is a new standard [16], and is not the result of the evolution of a previously existing standard. The VME bus International Trade Association (VITA) develops interface standards. It was felt that what
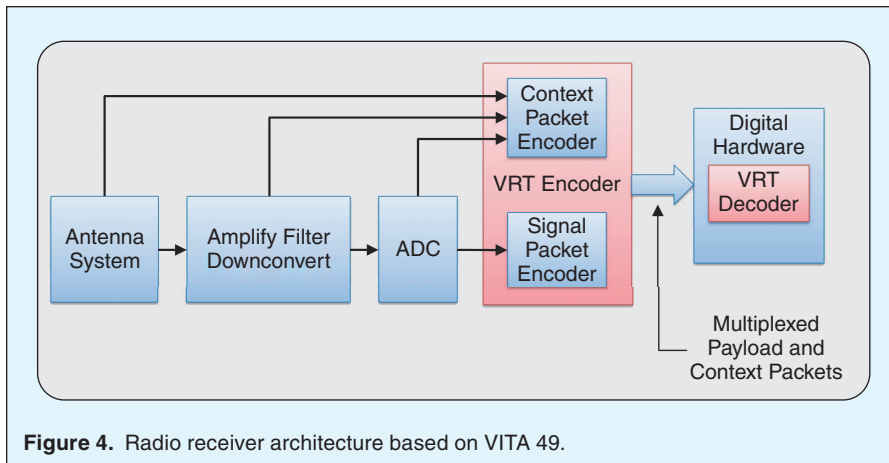
Figure 4. Radio receiver architecture based on VITA 49.

The data are the ADC samples that carry the downconverted RF signal. These data samples are time-stamped. The metadata is data about these samples, therefore justifying the name metadata (data about data). The metadata is defined to convey information about the radio, its location and the processing done on the signal prior to generating the signal data packet. The list of metadata parameters is given in Table 1.

eventually became the ANSI-approved VITA 49 standard would be best developed under the umbrella of VITA. This effort initially was targeted at the defense commercial off-the-shelf (COTS) industry with an emphasis on the needs of the signal intelligence (SIGINT) community.

III.1. Data and Metadata

A block diagram of a receiver using VITA Radio Transport (or VRT) is illustrated in Figure 4. VRT defines separate packets for signal data and context information. Note that the digital interface between the baseband and the ADC includes both data and metadata.

Table 1.
Standard metadata in VITA 49.

Reference Point Identifier
Bandwidth
IF Reference Frequency
RF Reference Frequency
RF Reference Frequency Offset
Band Frequency Offset
Reference Level
Gain
Over-Range Count
Sample Rate
Timestamp Adjustment
Timestamp Calibration Time
Temperature
Device Identifier
State and Event Indicators
IF Data Packet Payload Format
Formatted GPS (Global Positioning System) Geolocation
Formatted INS (Intertial Navigation System) Geolocation
ECFF (Earth-Centered, Earth-Fixed) Ephemeris
Relative Ephemeris
Ephemeris Reference Identifier
GPS ASCII

The Context Packets convey information about how the signal was processed by the radio. It contains information to represent the modifications to the signal that is represented by a physical transform, such as frequency translation, gain, time delay. The data and context packet types are mandatory. There are optional extension packet types for data and context. If a VRT decoder that does not support extension packet types receives an extension packet, it will only identify the packets as being of extension type and simply ignore its content.
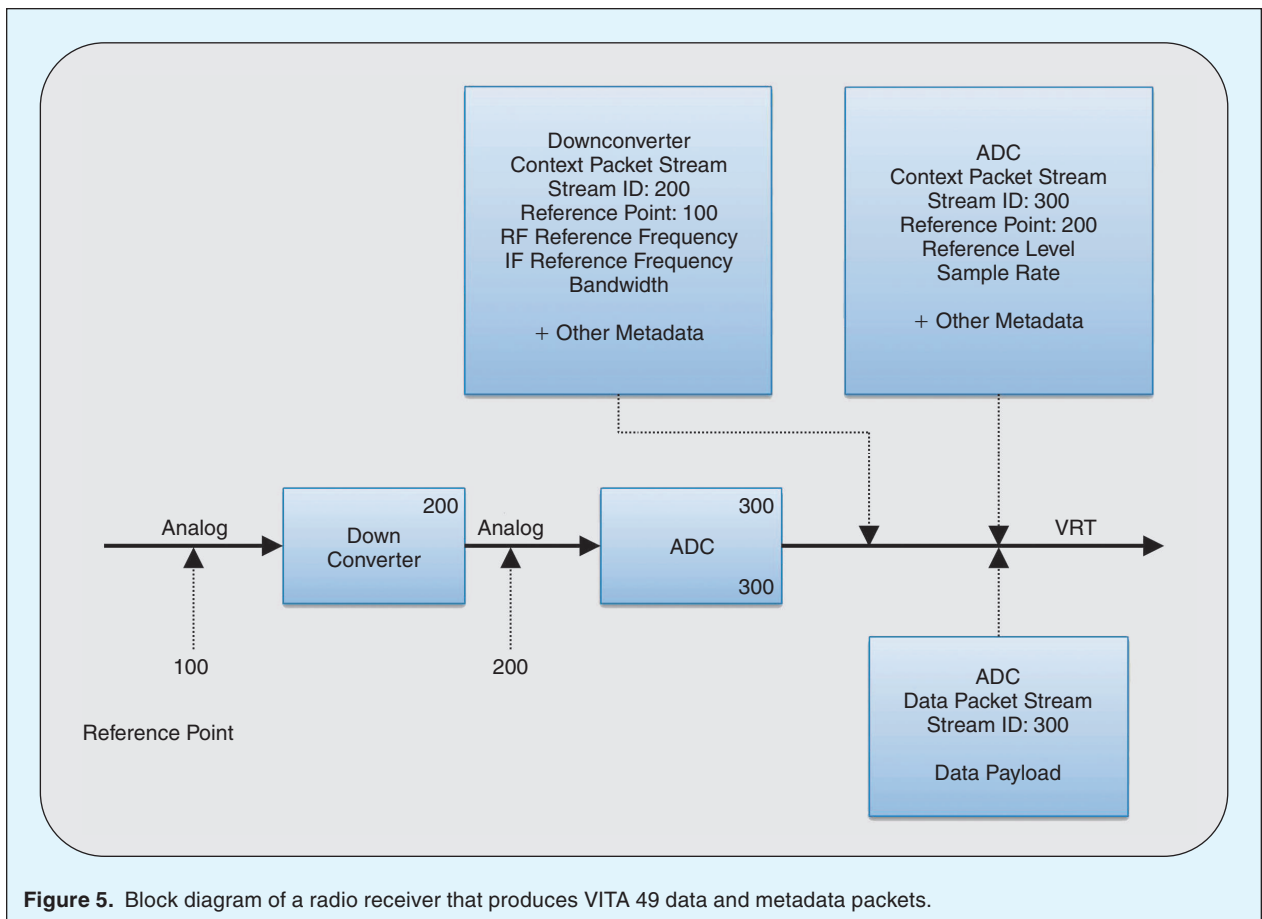
The metadata packets are multiplexed on the digital connection to the baseband and need only to be sent when the relevant metadata changes. The metadata is understood to be persistent between updates. The overhead due to the context packets is proportional to how often parameters such as the RF center frequency and bandwidth change. Since parameters such as frequency and bandwidth change at a much lower rate than the IF signal, the metadata packets will be a small percentage of all packets.

A set of constituent data and context packet streams is called an information class. Different types of radios will produce different data and context packet streams and will be separated according to the information class. A VRT Packet Class is the specification of the name, structure, and function of the packets in a VRT Packet Stream.

A device may have multiple RF chains. In this case, there would be multiple signal packet streams and multiple context packet streams, which may have to be multiplexed, i.e. transmitted over a single shared link. There must be a way to associate each data packet stream with its corresponding context packet stream. This is accomplished with stream identifiers. Data and context packets that share a stream identifier can be identified as paired. Pairing establishes a one-to-one

Figure 5. Block diagram of a radio receiver that produces VITA 49 data and metadata packets.

relationship between a data packet and a context packet stream. Pairing is the only instance in which it is allowable to use the same Stream Identifier for two packet streams. There are other associations that allow additional context to be associated with the data packet stream.

For example, bit error rates, spectral occupancy information (FFT values), power supply voltages, etc., can be associated with signal data packets.

III.2. Reference Points and Time-Stamps

A primary reason VITA 49 is useful for spectrum sensing is because it uses reference points and time-stamps. It is important to specify a point in the system where the metadata applies, referred to as a reference point. For instance, the center frequency or power level characteristics are ambiguous without knowing if the reference point is the input RF signal or the IF signal.

Figure 5 illustrates the concept of a reference point. The downconverter converts the analog RF signal from an antenna to IF or baseband. There are three reference points in the figure—the RF signal, the IF signal, and the output of the ADC, which are assigned IDs 100, 200, and 300, correspondingly. For the downconverter the reference point is the RF signal. For the ADC the reference point is the ADC input, while the data packet contains samples from the ADC output. After the ADC, a VRT-compliant packet stream is produced, consisting of data packets and metadata packets. There are two metadata packets, one for the downconverter, and one for the ADC, each one containing the parameters of the respective block. The downconverter is described by RF reference frequency, IF reference frequency and bandwidth, and these parameters are included in the downconverter context packet.

The values of the IF reference frequency and RF reference frequency are equal to the center of the corresponding band. Downconversion to baseband can be indicated by IF frequency of zero. The ADC can be described by sample rate and reference level. The Reference Level field allows associating signal values to power values and is equal to the power (in dBm) of a sinewave at the reference point (the ADC input) that results in a digitized sinewave of amplitude 1.
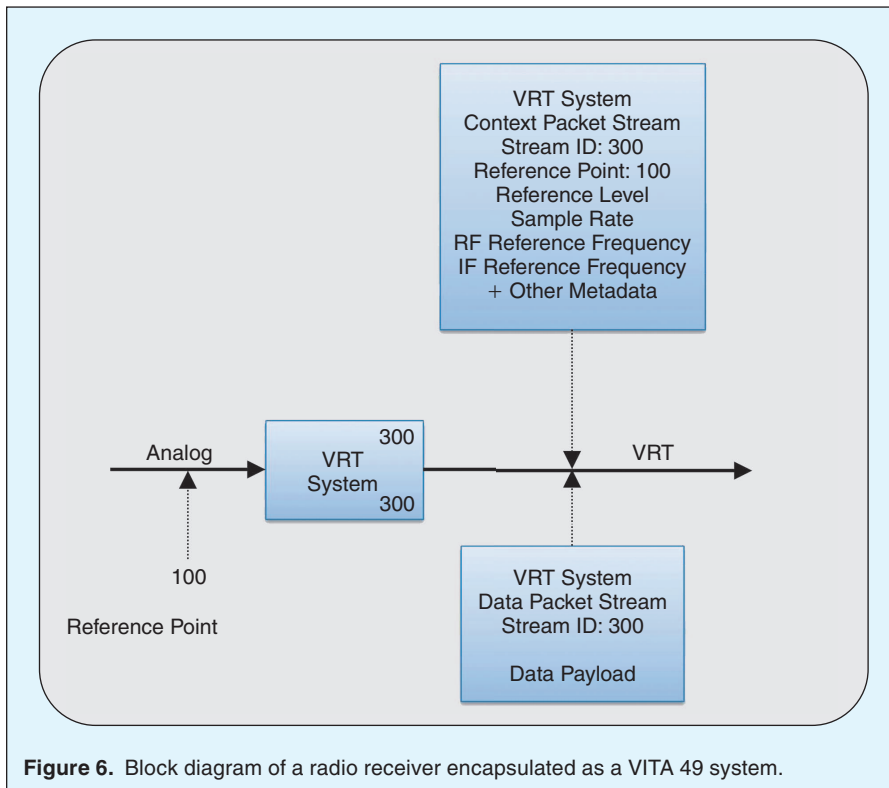
Figure 6. Block diagram of a radio receiver encapsulated as a VITA 49 system.

Note that nonlinearities are not taken into account when specifying the Reference Level.

If the downconverter and ADC were considered components encapsulated in a single receiver module then the same system could be described with the block diagram shown in Figure 6.

One may aggregate the context from each component and generate a summary context packet stream for the entire system to be sent along with the system's final data packet stream. This aggregate context packet describes the entire system with the reference point being the antenna.

These examples illustrate that VRT can be viewed as a hierarchical system description language. Each component through which the signal flows can be described with respect to how it modifies the signal in a way that is independent of the actual hardware architecture. Details such as the specific way downconversion has been implemented, etc. remain hidden from VRT.

There may be a delay between the time a signal is received by a spectrum sensor and the time it is analyzed, particularly if the analysis is done remotely and/or collaboratively. To make VRT packets convey accurately the instant a signal is impinging on the antenna, VRT packets included timestamps. The timestamps convey the timing of data and events at the specified reference point in the system. The timestamp of signal data is also valuable when information from multiple channels or multiple radios at different locations needs to be processed.

It should be noted that the timestamp attached at digitization reflects all delays prior to digitization. The timestamp is adjusted taking into account the group delay of the analog filter, the sampling delay of the ADC, the digital downconverter (DDC), any other group delay due to other components (a cable, for example) that may be present. It should be noted that while in general group delay varies with frequency, the timestamp adjustment is constant. Therefore an implicit assumption is made that the group delay will be constant in the frequency band of interest.

Context information is also time-stamped, but the time-stamp has slightly different interpretation. When the timestamp mode is fine resolution, the context packet timestamp conveys the precise timing of events related to the described signal. When the timestamp mode used is coarse resolution, the context packet contains events that occurred sometime within the data packet. In this way the VRT-compliant radio would know the exact time instant when parameters such as RF center frequency, bandwidth, power, etc. have been changed. Time-stamping enables algorithms such as beamforming, direction of arrival, etc.

An example of a multi-radio device is shown in Figure 7. The IF data packet stream from the VRT packet encoder includes context from the combiner and from each of the four upstream modules. It is important that the two RF chains can be different and can produce data and context packets at different rates. In Fig. 7 the tuner modules emit VRT packet streams conveying only IF Data to the DDC module. The connection between the tuner and the combiner may be hardware-dependent, over which the tuner can send its parameters, such as tuning frequency, bandwidth, etc., so that the combiner can properly produce VRT context packets. The DDC modules further downconvert the IF Data they receive and emit VRT packet streams consisting of data and context packets. The packet encoder

combines the tuner context with the VRT streams from the DDC blocks to create a new VRT-compliant stream. The architecture in Fig. 7 is in the middle between the Velcro architecture in Fig. 1 and the SDR architecture in Fig. 2. The architecture in Fig. 7 includes multiple RF sections, connected with a single VRT link to the digital hardware section.

III.3. Properties of VITA 49

As was discussed in Section II, the ADC/DAC must digitize downconverted RF signals, and it is appropriate to be placed on the RF IC. Another reason to put the ADC/DAC pair on the RF IC is that there could be additional digital signal processing between the ADC/DAC and the interface, as illustrated in Fig. 7. This additional digital signal processing could be digital decimation/interpolation to adjust the sampling rate. One benefit of this is reduced interconnection bandwidth. VITA 49 is very flexible and can readily accommodate additional digital signal processing.

VITA 49 is sometimes referred to as a "digital IF" standard, because in most cases the ADC and the DAC are at the IF level and the signal packets carried by VRT contain digital IF samples [17]. However, the standard in principle can be used to carry not only digital IF, but also digital baseband or digital RF samples. Inserting the ADC at the RF level would represent the ultimate SDR device, but leads to higher cost and higher power consumption. The current frontier in SDR technology is inserting the ADC at the IF level. In some cases inserting the data converters at the RF level is becoming possible. Since VITA 49 also specifies context packets, calling it a digital IF standard does not convey the full capabilities of the technology. More accurately VRT is a description technique for the radio front-end and an interface between the analog subsection and the digital subsection of a spatial stream.

VITA 49 is a packet-based interface. A packet-based connection provides the framework to separate signal packets on one side, and control or context packets on
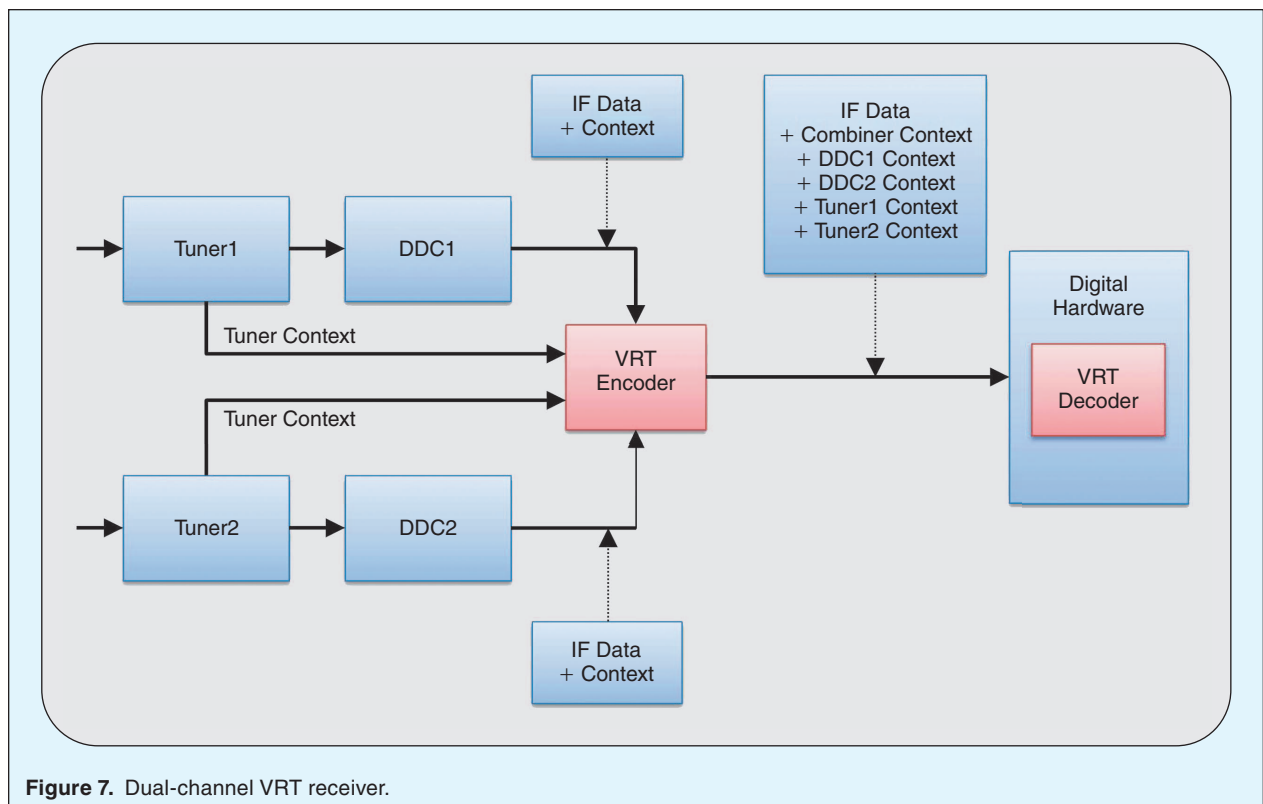

Figure 7. Dual-channel VRT receiver.

In the future a plethora of different wireless devices, used by the military, many different public safety entities and commercial users will share the spectrum. There are many technical problems that will have to be addressed before this vision becomes a reality.

the other, and for multiple different types of radio systems. The DAS/ SDR clouds are examples of architectures that require a packet-based connection.

In most current implementations VRT packets are transmitted over Ethernet. However, VRT is independent of the specific technique to carry VRT packets. VRT can be considered as an application and VRT-compliant packet streams may be carried over well-known protocols such as TCP, UDP, etc. Note that VRT does not provide error checking. If Ethernet or TCP are used to carry the VRT packets, then any errors are left to these protocols to handle. Furthermore, it should be completely clear that VRT is also completely independent of the specific wireless physical (PHY) and medium-access control (MAC) layers. The PHY layer determines the signal data samples carried in the VITA 49 packets and the MAC layer determines metadata parameters such as RF center frequency, bandwidth, and time instant. VITA 49 can be used with all current and future radio access technologies such as WLAN, WiMAX, LTE, etc.

IV. Applications of Vita 49

The first application of VITA 49 was in radios that perform only spectrum sensing. These radios do not transmit; they only listen for transmissions by other radios. Spectrum-sensing radios are used by military and government organizations in signal intelligence and in monitoring the spectrum for compliance with relevant regulations. For example, in a signal intelligence application, multiple VITA-49-compliant radios are deployed to cover a certain area. Because they do not transmit, these radios are sometimes referred to as spectrum-sensors. The results of spectrum sensing from each individual module are usually transmitted to a central site for further processing. The benefits of VRT are that not only the digital and the analog sub-systems can be changed independently, but that the results of the spectrum sensing are interoperable. By describing all the processing done on the signal prior to digitization and packetization, VRT allows the signal at the antenna of each spectrum sensor to be described completely, and the description to be stored and transmitted. At the central site various algorithms in the spatial and temporal domains become possible.

However, recently spectrum-sensing has become important beyond signal intelligence and regulatory compliance. The reason is that cognitive radios require spectrum sensing [18]. In a cognitive radio network, the results of spectrum sensing are used to adjust in a coordinated fashion the frequency, bandwidth, and power of the different radios.

Spectrum sensing can be independent, where every radio performs spectrum sensing independently. The results of spectrum sensing are not shared and decisions are also made independently. In cooperative spectrum sensing the results are shared. Most such algorithms assume that spectrum sensing is done by multiple identical radios with identical parameters such as bandwidth, resolution, sensitivity, etc.

It is easier to achieve spectrum sharing among government systems (initially only within military systems, and later also involving public safety), because common goals and order are easier to establish. Even among government systems, there are many different radio platforms, with different capabilities, etc.

In the future a plethora of different wireless devices, used by the military, many different public safety entities and commercial users will share the spectrum. There are many technical problems that will have to be addressed before this vision becomes a reality. One of these problems is interoperable RF spectrum sensing not only among the government systems, but also involving commercial wireless systems.

The information classes defined in VRT are a mechanism to allow the proper interpretation of system functionality from vendor to vendor. It helps interpret the results of spectrum sensing performed by different radio platforms, with different parameters. VRT is like a common language that can help achieve wide-scale interoperability.

Some companies such as DRS-SS, formerly Watkins-Johnston, has developed products that provide spectrum sensing capability for mobile radio devices operating in the HF, VHF and UHF bands. Furthermore, the interoperability among VITA-49 compliant products from different vendors has been demonstrated.

DASs are an emerging application for VRT. There is a strong synergy between VITA 49 and DAS. As a packet-based protocol VRT can readily handle multiple-antenna systems, for which analog DAS would require

The interface between the analog RF and the digital subsystems has repeated the evolution path of radio technology: first analog, then mixed-signal, and finally all-digital. VITA 49 takes it further by making it packet-based.

a separate cable. A point-to-point digital DAS also has to be re-designed to introduce multiple-antenna systems. Furthermore VRT readily supports the multiplexing of multiple sample streams that may have otherwise unrelated data rates, which is required for multi-standard systems. Therefore VRT increases the feasibility of DAS systems.

V. Summary and Conclusions

The analog and the digital subsystems of a radio are very different technologies for which there are no universal design approaches. There are only sets of design alternatives, from which designers can choose. Neither of these areas addresses adequately the question about the interface between them.

Several interface specifications have been developed in the past ten or so years. Although many designs claim to be "open" and "software-defined," in reality they are not suitable for software-defined radios. These interfaces are for specific RATs. On the other hand VITA 49 is an interface that is aimed at software-defined radios. VITA 49 defines mainly signal data and metadata packets. The metadata packets contain information about the RF center frequency, bandwidth, etc. An open analog RF-digital interface is a new aspect of radio design. The metadata has always existed, but in the history of radio has never been explicitly defined and shared. For example, for every radio the RF frequency of operation is known, but only implicitly. VITA 49 requires this metadata to be defined explicitly. One result of this is awareness about all explicitly defined parameters; awareness is the first step in cognitive radio algorithms.

We can come to the following conclusion: the interface between the analog RF and digital subsystems has repeated the evolution path of radio technology: first analog, then mixed-signal, and finally all-digital. VITA 49 takes it further by making it packet-based.

In this paper we present an overview of the standard and its applications. We also discuss some misconceptions about this technology.

VITA 49 began as a standard interface between the analog and the digital subsystems of a radio used in RF spectrum sensing. It has been used in applications such as spectrum signal intelligence, where it satisfies the requirements for open and modular wireless

architecture. The initial goal was to ensure that each subsystem can be replaced separately, which for developers means reduced development risk. But the significance of the technology extends beyond the system developer. For the network operator maintenance costs are reduced. Users also benefit as they have increased ability to upgrade portions of their systems.

Beyond interoperability and signal intelligence, recently other benefits and applications of VRT have been identified. One such application is spectrum sensing in cognitive radio networks. VRT leads to other important advantages such as allowing multiple different platforms to use identical formats and definitions for parameters such as RF center frequency, bandwidth, and transmit power.

Finally, it is worth noting that VITA-49 changes the definition of a "radio transceiver." A radio transceiver is traditionally meant to include filters, amplifiers, mixers, ADCs, etc. The term "transceiver" now encapsulates the entire set of hardware and software components within a radio necessary to convert a low-power RF signal to digital baseband on the receive side, and reciprocally to convert digital baseband signals to RF signals with appropriate power levels on the transmit side. The VITA 49 encoder and decoder now become parts of the transceiver. Therefore it can be said that VITA 49 is a new paradigm in radio architectures.

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