The Deep Space Network in the Common Platform Era:
A Prototype Implementation at DSS-13

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Abstract

To enhance NASA's Deep Space Network (DSN), an effort is underway to improve network performance and simplify its operation and maintenance. This endeavor, known as the "Common Platform," has both short- and long-term objectives. The long-term work has not begun yet; however, the activity to realize the short-term goals has started.

There are three goals for the long-term objective:

1. Convert the DSN into a digital network where signals are digitized at the output of the down converters at the antennas and are distributed via a digital IF switch to the processing platforms.
2. Employ a set of common hardware for signal processing applications, e.g., telemetry, tracking, radio science and Very Long Baseline Interferometry (VLBI).
3. Minimize in-house developments in favor of purchasing commercial off-the-shelf (COTS) equipment.

The short-term goal is to develop a prototype of the above at NASA's experimental station known as DSS-13. This station consists of a 34m beam waveguide antenna with cryogenically cooled amplifiers capable of handling deep space research frequencies at S-, X-, and Ka-bands. Without the effort at DSS-13, the implementation of the long-term goal can potentially be risky because embarking on the modification of an operational network without prior preparations can, among other things, result in unwanted service interruptions. Not only are there technical challenges to address, full network implementation of the *Common Platform* concept includes significant cost uncertainties. Therefore, a limited implementation at DSS-13 will contribute to risk reduction.

The benefits of employing common platforms for the DSN are lower cost and improved operations resulting from ease of maintenance and reduced number of spare parts. Increased flexibility for the user is another potential benefit.

This paper will present the plans for DSS-13 implementation. It will discuss key issues such as the *Common Platform* architecture, choice of COTS equipment, and the standard for radio frequency (RF) to digital interface.

1. Introduction

The Space Communications and Navigation (SCaN) Office of the National Aeronautics and Space Administration (NASA) provides communications and tracking services to all NASA space assets. These services are provided via three networks known as the Space Network (SN), the DSN, and the Near Earth Network (NEN). These networks dedicate hardware and software tools to ground antennas within their respective domains. Within each network, resources allocated to an application (or service), for the most part, are not used by another application. Furthermore, many of the resources have been developed specifically for each network, particularly in the cases of the SN and DSN. A new paradigm at SCaN calls for improved intra- and inter-network commonality as well as increased use of COTS products. Presently, SN is undergoing a major upgrade that, among other things, will also address the above concerns [1]. That activity is known as the Space Network Ground Segment Sustainment (SGSS) project.

The DSN is also investigating means of addressing the above issues. The subject of this paper is a pilot program that will develop and demonstrate a model of the future DSN, with mostly COTS equipment, offering increased commonality among different applications (services). The resulting prototype will be demonstrated using DSN's experimental 34m antenna at Goldstone, California. This activity is known as the *Common Platform* task.

The DSN, managed by the Jet Propulsion Laboratory (JPL), mainly consists of three complexes (Goldstone, Madrid, and Canberra). Each complex is equipped with a 70m antenna, two or more 34m antennas, and a Signal Processing Center (SPC). Signals received (or transmitted) by the operational antennas are processed at the corresponding SPC. Whereas at Goldstone some antenna distances to the SPC can exceed 20 km, Madrid and Canberra complexes are much more compact with distances in the order of 1 km or less. Figure 1 shows the data flow between the user and a deep spacecraft.

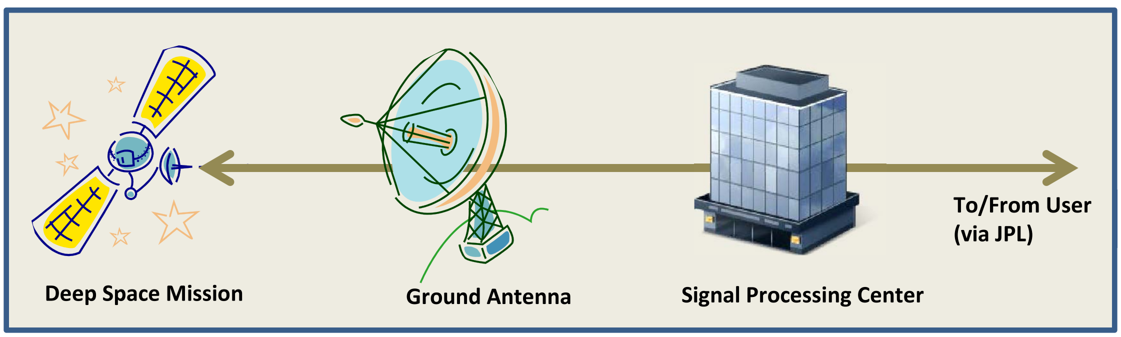

Figure 1. Deep Space Mission Data Flow through the DSN

The Goldstone complex is the host to an experimental station with a 34m beam waveguide antenna known as DSS-13. This station will be used as a test bed for the *Common Platform* activity.

DSN ground stations provide tracking, telemetry, and command (TT&C) services to NASA and international deep space missions (in some cases closer missions, such as moon orbiting satellites, may also be served). This paper will only discuss the downlink (return link).

Presently, DSN ground stations employ an architecture where analog signals are routed to the processing platforms that are each configured for a certain application. For example, the signal processing platform for telemetry is different from the one used for delta-DOR, a form of VLBI. Most, if not all, platforms are developed in-house. The current approach demands maintenance and sparing of a number of diverse platforms, hence resulting in a sub-efficient operation.

Figure 2 shows the generalized architecture of current DSN ground stations where signal processing hardware are dedicated to different applications rather than being shared among services that the DSN provides.

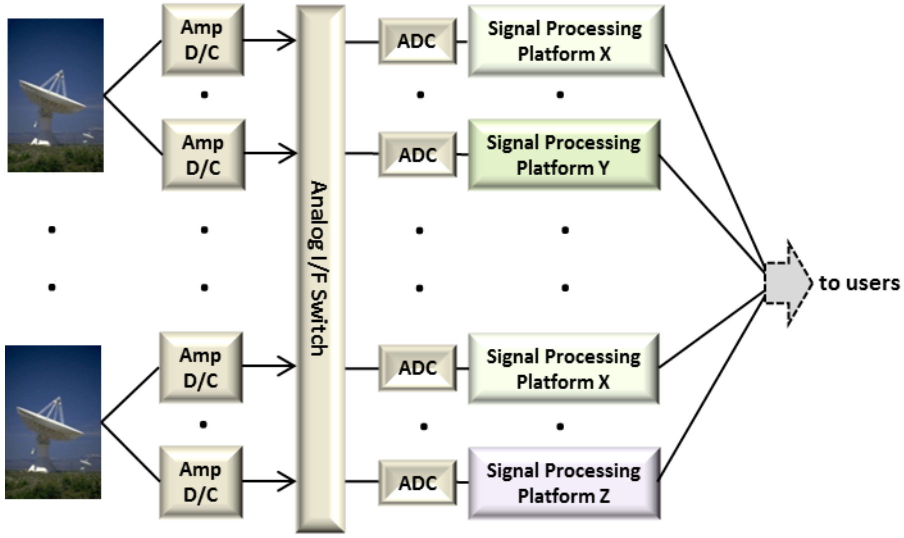

Figure 2. The Generalized Architecture of the Ground Stations Using Mostly In-House-Developed Equipment (Current System)

2. DSS-13

DSS-13 is an experimental station used for developing and demonstrating innovative concepts and technology as well as testing new hardware before infusion into the operational network. This station is easily accessible to experimenters and offers much flexibility to the user. It consists of a 34m beam waveguide antenna, multiple feeds at different frequency bands, cryogenically cooled amplifiers, and a 20kW X-band high-power transmitter. Its frequency range is from 2 GHz to 38 GHz. DSS-13 is operated independently of the operational network at Goldstone from a control room near the antenna. Figure 3a shows the antenna and Figure 3b shows the hardware in the antenna pedestal. The large RF mirror in the center of the picture can turn to align with one of the six feed positions, as shown in Figure 3c.

Figure 4 shows signal distribution at DSS-13. At the antenna pedestal, 16 lines carrying analog intermediate frequency (IF) signals from different antenna feeds enter a switch. A maximum of four signals are modulated on fiber optic lines and sent to the control room; note that a maximum of four signals are output from the antenna at any given moment in time. At the control room the signals are demodulated from the fiber optic lines and enter an IF distribution box. This box has also lines connecting it to the SPC. This box is followed by another switch (6×24) where the signals are sent to the user equipment of interest. There are several kinds of user equipment throughout the DSN as well as DSS-13. For example, in Figure 4, RSR stands for “Radio Science Receiver” and VSR stands for “VLBI Science Receiver.” RSR is used for radio science observations and VSR is used for VLBI observations.

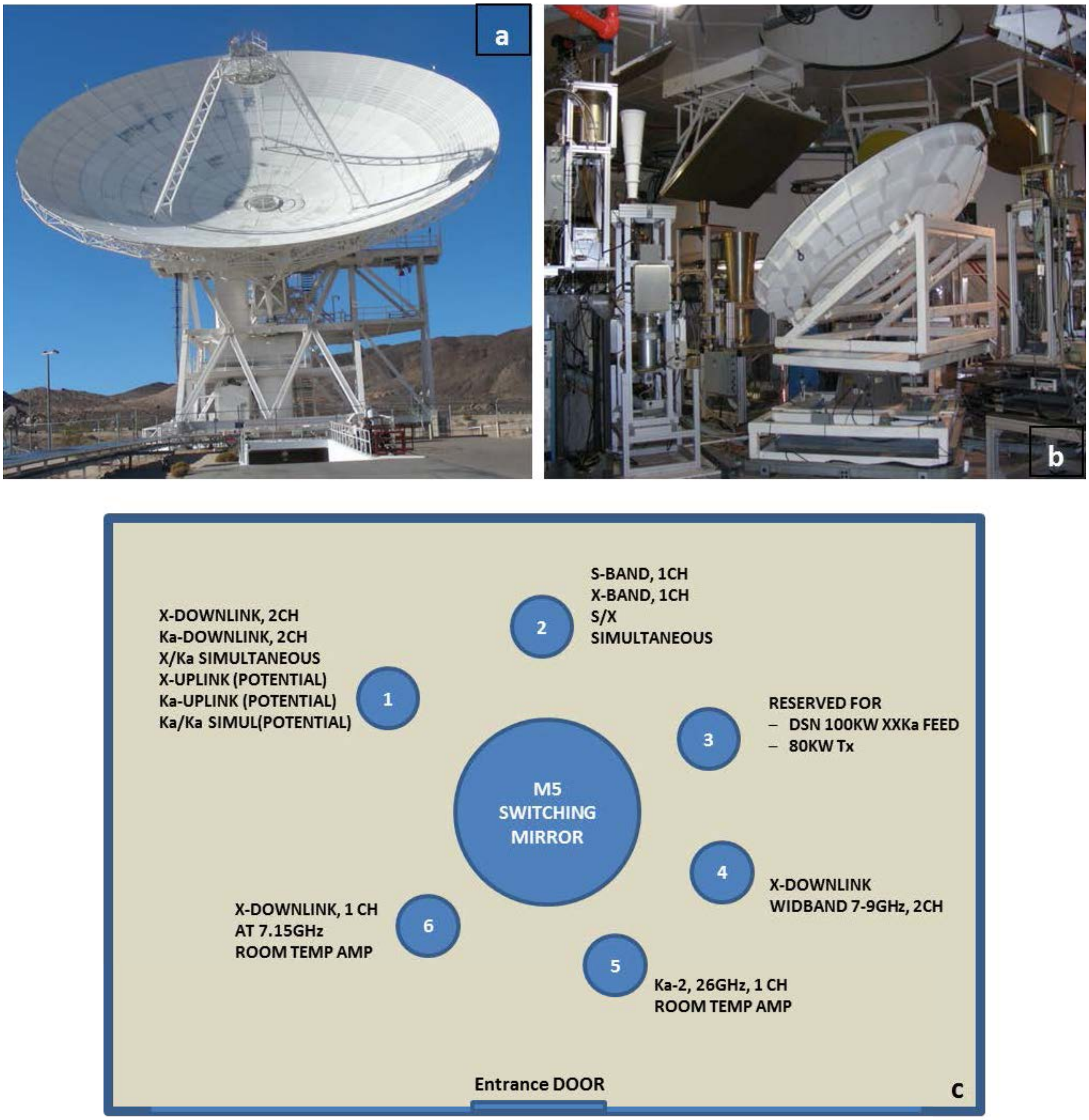

Figure 3. a) DSS-13 Antenna; b) Pedestal; c) Feed Positions

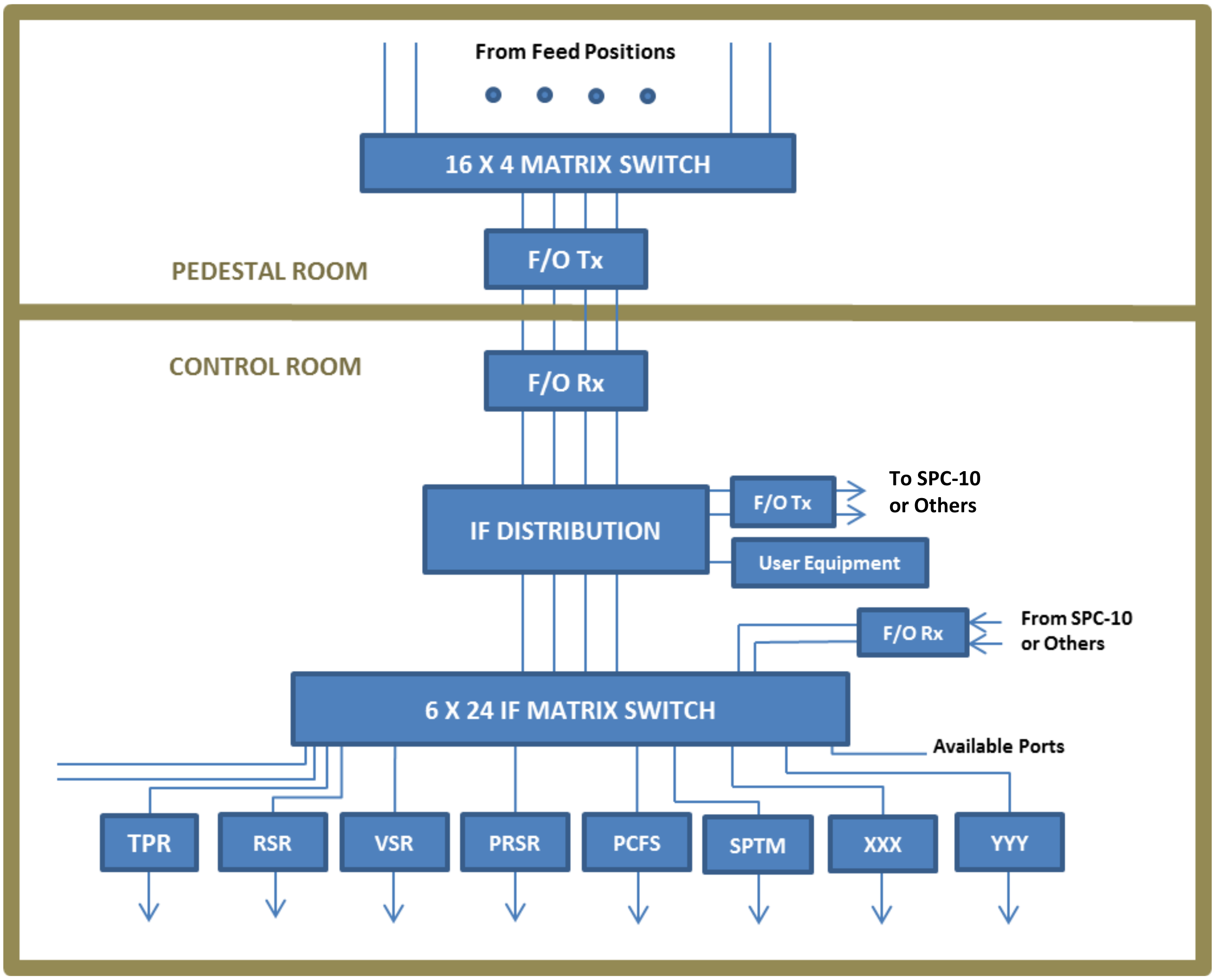

Figure 4. DSS-13 Signal Flow from Antenna Pedestal Room to the Control Room

3. The Common Platform Concept and Architecture

The *Common Platform* activity at JPL has two goals, long-term and short-term (all these goals are being pursued mainly in the interest of simplifying development, maintenance and operations in order to reduce costs). The long-term goal strives for the following achievements:

a) Convert the DSN into an all-digital network where signals are digitized at the output of the down converters at the antennas and are distributed via a digital IF switch at the corresponding SPC.

b) Employ a set of common hardware for signal processing needs, e.g., telemetry, radio science, VLBI.

c) Minimize in-house developments in favor of purchasing COTS equipment.

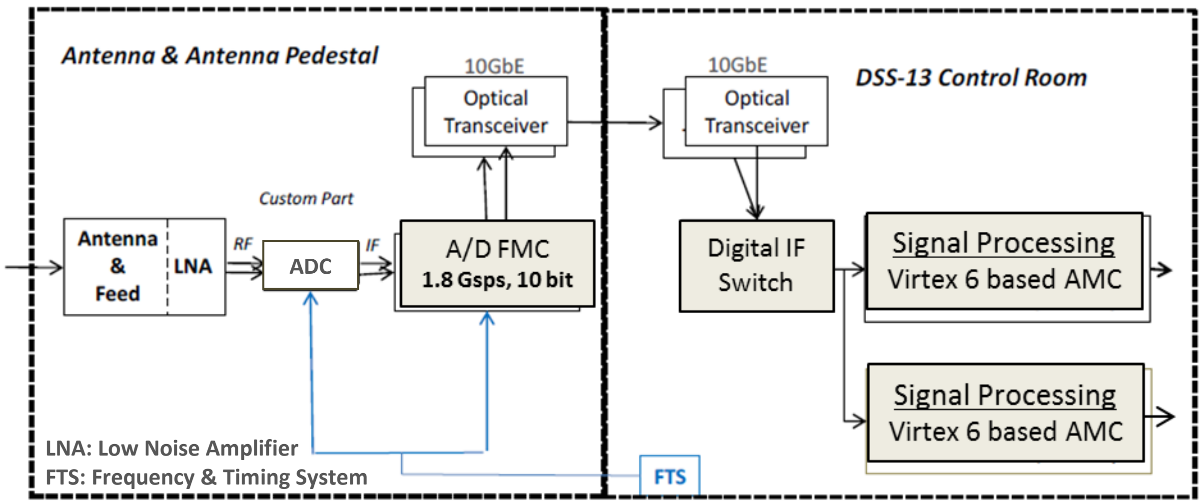

Figure 5. Conceptual *Common Platform* Implementation at DSS-13

The short-term goal is to develop a prototype of the above objectives at DSS-13. Other short term goals are to develop initial set of requirements for the common platform, test available COTS technologies, develop an architecture for the DSN common hardware platform, and test key and challenging aspects of the proposed architecture. Clearly the implementation at DSS-13 will benefit the long-term goal by addressing technical challenges, reducing cost uncertainties, and avoiding potential service interruptions. Presently, we are working on the short-term goals.

Once the *Common Platform* approach is developed and infused into the DSN, lower cost and ease of operations (maintenance and upgrades) will result. It will be easier to maintain only one kind of hardware platform. And being commercially obtained, future evolutions of the platform will be readily available from commercial vendors.

Figure 5 shows the concept as it may be implemented at DSS-13. Note that the majority of hardware modules are COTS. These parts are mostly the same brand as the ones selected by SGSS to ensure parts compatibility among NASA networks, as much as feasible.

It is constructive to compare the two architectures presented by Figures 4 and 5 to appreciate the difference between the pre-common-platform station and the post-common-platform station:

1. Whereas in Figure 4 IF distribution is analog, in Figure 5 signals are digitized before transmission to the control room.
2. Whereas in Figure 4 fiber optic lines carry analog signals, in Figure 5 the lines carry digital signals.
3. The IF switch at the control room of Figure 4 is analog and in Figure 5 is digital.
4. All user equipment in Figure 5 use the same hardware platform; however, in Figure 4 a variety of hardware platforms are used.
5. In Figure 4 most equipment were developed in-house, whereas most equipment in Figure 5 are COTS.

Therefore, after a full implementation of the *Common Platform* concept, most user equipment will use one kind of platform. Hence most if not all of the boxes at the lowest row of Figure 4 will be implemented using Virtex 6-based Advanced Mezzanine Cards (AMC), and each analog to digital converter (ADC) will be implemented in a FPGA Mezzanine Card (FMC). In rare occasions, non-COTS equipment may be used for special applications.

3.1 Analog-to-Digital Interface

An important consideration with the *Common Platform* development is the interface between the analog and digital segments of the signal paths. Among options, a standard known as VITA 49 has recently gained popularity and has been adopted by SGSS. Due to its many salient features, and also the fact that SGSS is going to use it, the *Common Platform* task will adopt the VITA 49 standard as the transport-layer protocol. VITA 49 is a packet-based standard that promotes interoperability between radio receivers and signal processing equipment in a wide range of applications [2].

According to *ANSI/VITA 49.0, VRT Standard* [3], the benefits of this radio transport protocol include:

- Transport-layer interoperability between equipment providers, which reduces integration time and effort. Hence, equipment from multiple vendors can be combined so that technology insertion is simplified. Interoperability is accomplished by:
    1. Standardizing signal data transport between receivers and signal processors.
    2. Standardizing metadata transport between receivers and signal processors, and standardizing metadata types. (Note: Metadata may or may not be implemented for DSN use; however, if implemented, metadata that may be conveyed can include a variety of equipment settings pertinent to signal processing applications, antenna weather station data, auxiliary sensor data, etc.).
- Efficient packet structures.
- Transport layer multiplexing of many signal channels onto one link interface.
- Flexible data routing to any number of signal processors or FPGAs in the same chassis, between multiple chassis, or to any destination without degradation of the signal. This makes VRT [VITA 49 Radio Transport] ideal for distributed antenna applications.
- Coherency between multiple receiver channels for both real-time and recorded-data applications via the use of high-precision time stamping.

The primary focus of this standard is on RF signals and equipment. A packet-based interface between the analog RF and the digital subsystems is conceptually illustrated in Figure 6. Analog RF is digitized via a number of receivers (amplifier, filter, down converter, analog-to-digital converter [ADC]) and the output digital signals are passed on to a number of signal processors. In this topology, any receiver can be connected to any signal processing or recording platform.

Figure 7 shows a simple VITA 49 application in RF communications. Figure 8 shows a design option where two X-band signals are multiplexed on a single 10 GbE fiber line. Note that X-band allocation for deep space research is 50 MHz. Each signal has to be sampled at 100 MHz or higher. Using 10-bit samplers, the total number of bits per second is $50x2\times2\times10 = 2$ Gb/s. The signals are processed digitally to reduce the number of bits per sample to 7. Hence the input to the fiber line is a 1.4 Gb/s stream, which is well below the line capacity of 10 Gb/s. The salient feature of this approach is that a single Ka-band signal with a 500 MHz bandwidth can also be placed on a 10 GbE line, hence providing the commonality that is an important objective. Presently, the suitable number of effective quantization bits for DSN applications is being investigated.

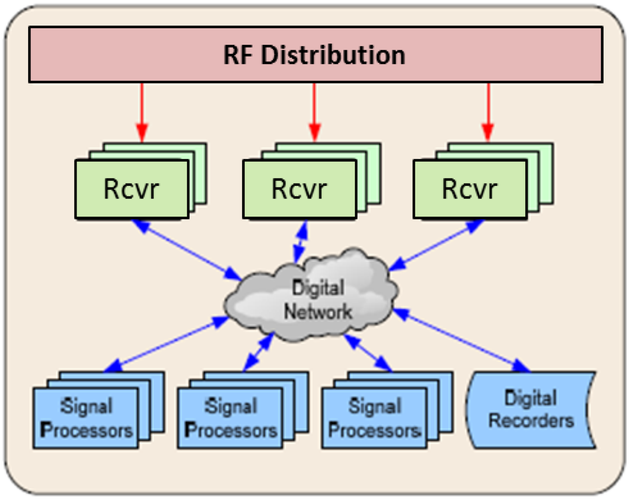

Figure 6. Conceptual Representation of an Open Architecture Interface over COTS Digital Networks

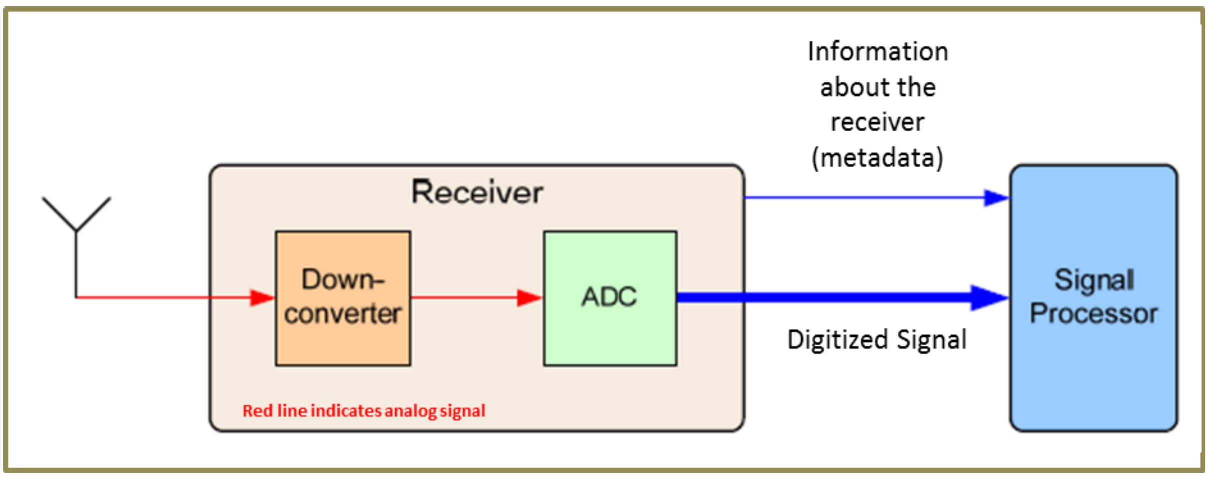

Figure 7. A Simple VITA 49 Application in RF Communications

3.2 Topics to Be Considered

The design and implementation of the *Common Platform* concept at DSS-13 has to consider the bigger picture, which includes the entire network. Therefore, as much as feasible, the current development should be pertinent to the operational antennas and the greater user community. Hence, a number of issues need to be considered:

a) The *Common Platform* implementation should be cost effective for a network that consists of many antennas and many user platforms.
b) Large distances between the user spacecraft and the ground station result in weak received signals. Many DSN users require stringent stability and accuracy levels for processing the observed signal.
c) It is desired to keep the system architecture simple while addressing the needs of a diverse set of users, present and future.
d) The implementation of the interface between the analog segment and the digital segment (VITA 49) should meet the needs of the science community.

e) Should the full spectral band be delivered to the SPC, or should only sub-bands be delivered to the SPC to reduce data flow bandwidth?

f) Would the placement of samplers (ADCs) in the antenna pedestal result in harmful interference to the low-noise amplifiers (LNA)? How should the LNAs be protected?

g) There is a mix of antenna types within the network. Should all these antennas be upgraded to the *Common Platform* format? For example, the 34m beam waveguide antennas are more amenable to such an upgrade than the 70m antennas because of availability of space at the 34m pedestal room.

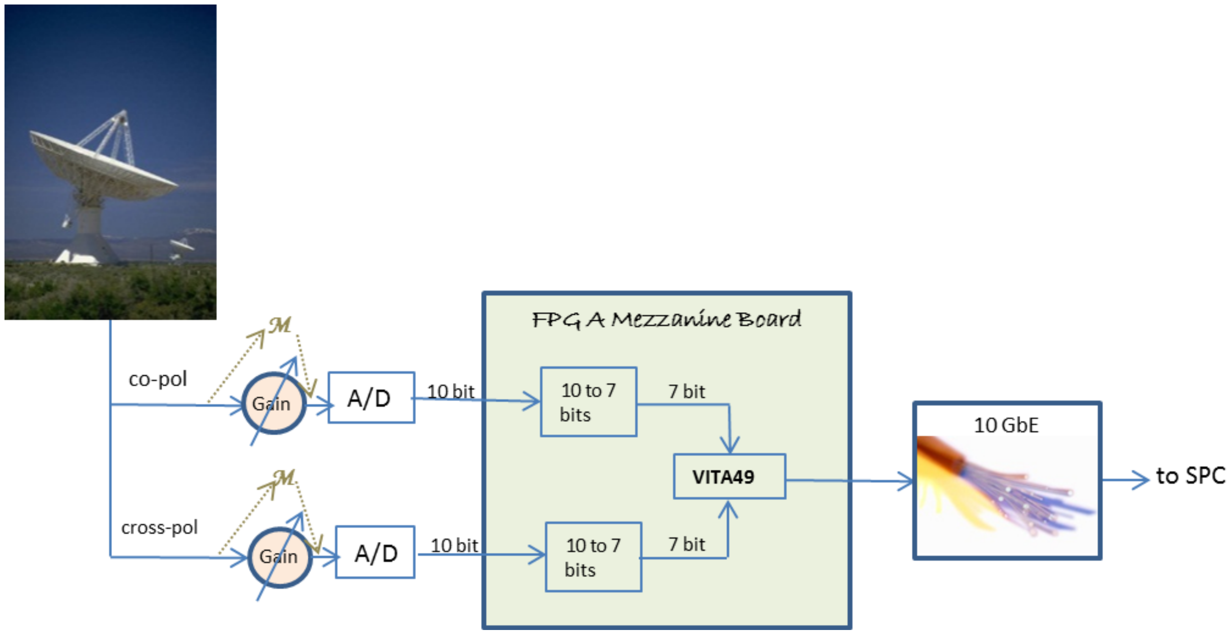

Figure 8. An Example of VITA 49 Application to a DSN Station Where Two X-band Signals Are Multiplexed at Full Bandwidth to Fit on a 10 GbE Fiber Line

Item (a) recognizes the fact that many antennas and many users are involved. Several user platforms and multiple fiber links will have to be obtained and configured. Item (b) recognizes the uniqueness of deep space communications and the fact that faint signals are often observed. This may require, among other things, stringent linearity characteristic from analog-to-digital converters as well as low quantization noise. Item (c) calls for simplicity of the architecture while serving a diverse user community. Item (d) recognizes the fact that the digital-to-analog interface (VITA 49) can be implemented fully with all the features (bells and whistles) provided in the standard, or it can be implemented in a limited fashion to reduce cost and that a reasonable compromise should be considered. Item (e) is concerned with the amount of bandwidth delivered to the SPC. For example, at Ka-band, deep space research has 500 MHz of downlink bandwidth allocation. Delivery of the whole 500 MHz will provide flexibility; however, it may demand large fiber bandwidth. The question asked is "What should be the architecture of digital IF distribution throughout the network to minimize cost while meeting user requirements and leaving room for growth?" Item (f) recognizes the fact that cryogenically cooled amplifiers are employed to pick up signals transmitted from deep space. These low noise amplifiers may be sensitive to small levels of spurious interference from ADCs. Item (g) recognizes the fact that the beam waveguide antennas are easier to convert to the *Common Platform* because of the presence of the pedestal room. Antennas that do not have a pedestal may pose a greater challenge for conversion to the *Common Platform* because of practical reasons.

From the above list of issues, it is evident that the following three topics are critical to the *Common Platform* endeavor:

1. Serve a diverse user community.
2. Leave room for growth.
3. Strive for a simple and low-cost implementation.

One final note is that, at some point, a road map will have to be developed for the infusion of the common platform architecture into the existing DSN.

4. Summary

NASA's SCaN Office is in the process of upgrading its space communications and tracking networks where IF signals will be distributed digitally and users will employ COTS processing platforms. For the SN, the above goals are being realized under the auspices of the SGSS program. For the DSN, a new effort has recently begun that will realize the above goals in two phases. First, a prototype of the system will be demonstrated at the experimental station DSS-13, and next the infusion of the developed system will take place into the operational network.

To this end, the prototype activity has begun investigating the requirements and making plans. The progress so far includes the following achievements:

- Gathering a group of experts to form the *Common Platform* team at JPL. The team's expertise includes systems engineering, communications, signal processing, and hardware and software engineering.
- Putting together a laboratory consisting of COTS equipment to be used at DSS-13. These tools include MicroTCA chasses, digital IF switches, ADCs, FPGAs, fiber optic transceivers, and more.
- Drafting a number of straw man designs and alternatives.

It is expected that by the end of this year (2013) hardware can be transferred from the laboratory to DSS-13 pedestal room for field tests.

References

[1] T. Gitlin and K. Walyus, "NASA's Space Network Ground Segment Sustainment Project: Preparing for the Future," SpaceOps 2012, Stockholm, Sweden, June 11-15, 2012

[2] T. Cooklev, et al., "The VITA 49 Analog RF-Digital Interface," IEEE Circuits and Systems Magazine, Fourth Quarter 2012, pp. 21-32.

[3] *ANSI/VITA 49.0: VITA Radio Transport (VRT) Standard*, American National Standards Institute, Inc., Approved May 2009.

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