

THE F-22 RADAR INSTRUMENTATION SYSTEM

Louis Natale, F-22, Senior Staff Engineer
Lockheed Martin Aeronautics
Marietta, GA USA

John Roach, Vice President, Network Products Division
Teletronics Technology Corporation
Newtown, PA USA

ABSTRACT

Radar is a critical element of the avionics system package in today's fighters, but often remains the least instrumented component of a test aircraft. The complexity and high-output data rates associated with a modern radar system usually precludes in-flight testing as part of a typical flight test program; often a specialized system is designed that can be flown in a conventional (non-fighter) aircraft. While such testing in isolation provides useful information, today's fighters rely on radar in conjunction with many highly-integrated systems; the absence of radar data as part of the instrumentation package provides at best an incomplete view of the operation of the aircraft. As part of a modernization task within the F-22 instrumentation program, a radar recording system has been designed which allows for real-time instrumentation of the existing F-22 radar system as part of the conventional instrumentation installation in the jet. This system is designed to support the acquisition of I and Q data from the on-board radar processor and the radar display maps generated by the pilot during normal mission activities. This paper describes the design requirements of the instrumentation package and how those requirements were met using a networked data acquisition system.

KEYWORDS

Radar, Instrumentation, F-22, Recording, Networking

INTRODUCTION

Radar is a critical element of the avionics system package in today's fighters, but often remains the least instrumented component of a test aircraft. The complexity and high-output data rates associated with a modern radar system usually precludes in-flight testing as part of a typical flight test program; often a specialized system is designed that can be flown in a conventional (non-fighter) aircraft. While such testing in isolation provides useful information, today's fighters rely on radar in conjunction with many highly-integrated systems; the absence of radar data as part of the instrumentation package

provides at best an incomplete view of the operation of the aircraft. As part of a modernization task within the F-22 instrumentation program, a radar recording system was designed that allows for real-time instrumentation of the existing F-22 radar system as part of the conventional instrumentation installation in the jet. This system is designed to support the acquisition of I and Q data from the on-board radar processor and to store the radar display maps generated by the pilot during normal mission activities. The top-level requirements on the data acquisition system for the F-22 Radar Processor (RP) are as follows:

- Record all I and Q data from the RP
 - 3 out of 4 active transmit channel link interfaces from the RP
 - 128 MBps worst-case sustained transfer rate from all four channel link interfaces, however, the bandwidth per channel would dynamically change during flight.
- Record Data Pump messages from the RP Instrumentation Processor
 - 1 RP dedicated copper Fibre Channel interface
 - 30 MBps worst-case sustained transfer rate for all messages
 - Controlled by an external IP command protocol coming from instrumentation
- Timestamp all recorded radar I and Q data
- Allow all recorded data to be processed using existing Northrop Grumman data analysis software.

SYSTEM DESCRIPTION

The system architecture proposed for the F-22 Radar IQ data acquisition requirement is based on the AIM-2004 hardware that is already in use as part of the JSF Instrumentation Data Acquisition System (IDAS) and also within the F-22 DO-0007 IDAS system. Both of these applications require a sustained data throughput rate of greater than 50 MBps to a recorder with a minimum recording capacity of 160 Gigabytes. The F-22 Radar IQ data acquisition mission requires the availability of data throughput rates of 120 MBps to the recorder with a minimum recording capacity of 512 Gigabytes.

To meet these mission requirements, TTC developed a new high-performance architecture that maintains backward compatibility with existing AIM/HSAVDAU I/O cards and power supply modules. The heart of this system is a new system overhead card, the OVH-350, which is designed to efficiently transport data from an I/O card across a customized compact PCI backplane to two 1 Gigabit Ethernet ports. Because the Ethernet controllers are an integrated part of the overhead card's processor circuitry, acquired data is transferred only once over the backplane. This differs from the existing AIM and HSAVDAU architecture, in which data passes from the overhead card across the backplane to an I/O card that interfaces to the recorder. This results in the acquisition data having to cross the system backplane twice, which reduces the maximum system performance. The other key element of the architecture is a new IP network recorder, the nREC-6000. This device receives the acquired data from the two 1 Gigabit Ethernet ports of the OVH-350 and records it on a cartridge that uses RAID (Redundant Array of Inexpensive Disks) technology to support both higher throughput rates and large capacities.

In order to fit in the limited mounting space available on the F-22 airframes for the Radar IQ system, a new AIM-4004 chassis was designed. An AIM-4004 contains two independent high speed data

acquisition systems, each with its own OVH-350 card, a CAIS bus remote interface card, and a single slot for a dedicated high speed data acquisition card. The two systems share a common power supply and motherboard for more efficient space utilization. A custom data acquisition card, the RDR-302, was developed for the F-22 program to connect to the LVDS interfaces of the Radar Processor. Each card supports two input channels which allows a single AIM chassis to house 4 inputs and meets the total I and Q input requirements.

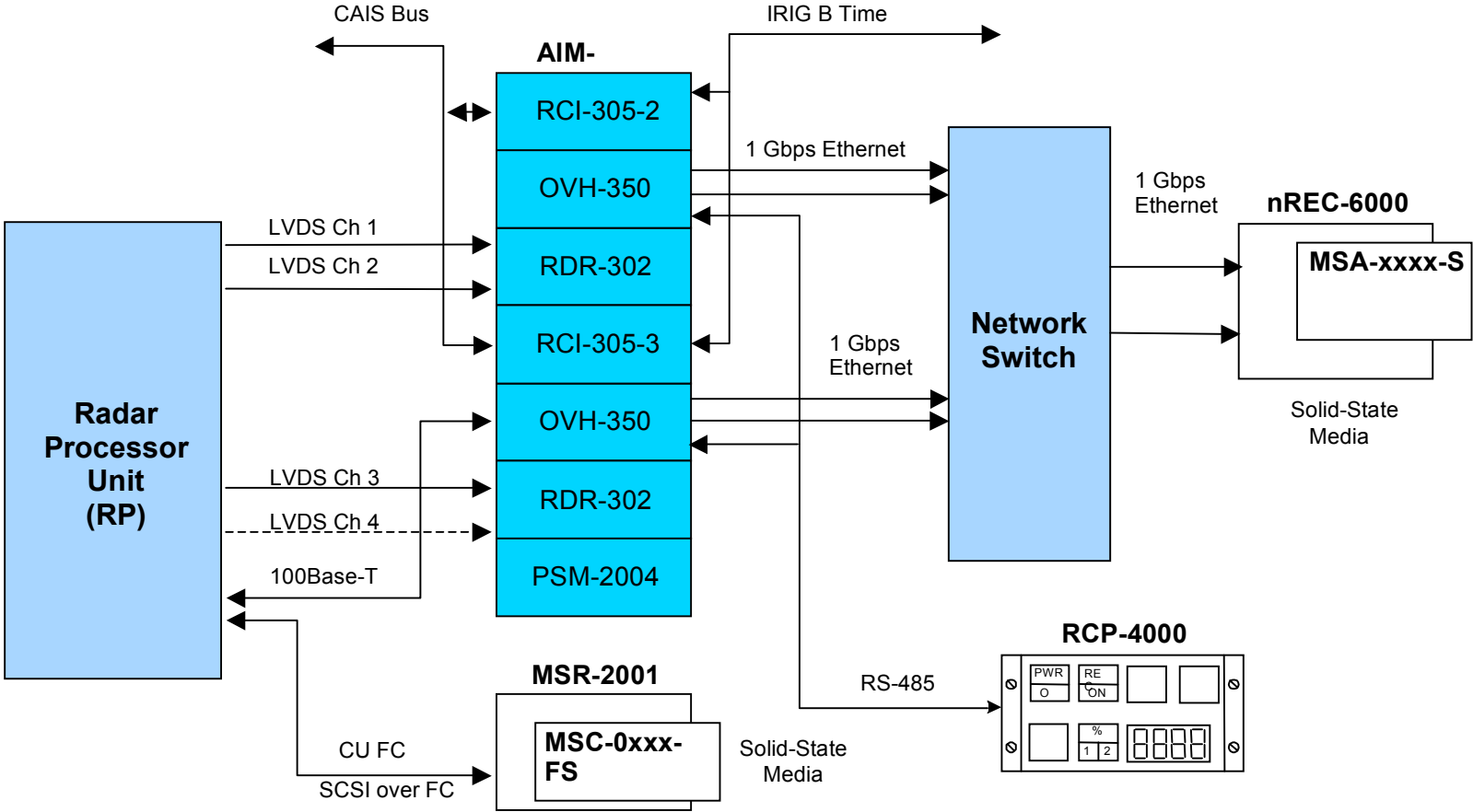
One of the more difficult requirements for the acquisition system resulted from the dynamic bandwidth behavior of the Radar Processor. While the total output data rate of the RP is 128 MBps, the distribution of this bandwidth across the 4 channels varies depending upon the particular operating mode that the RP is currently executing. The bandwidth can be equally distributed across the channels, or all of the bandwidth could come from a single input channel. Because a data rate of 128 MBps exceeds the practical rate of a single gigabit Ethernet interface, it requires that both gigabit interfaces on the OVH-350 must be connected to the nREC-6000. Since a single AIM-4004 contains two OVH-350 cards, a total of four gigabit Ethernet interfaces must be connected to the nREC-6000, which only has two interfaces. Using two nREC-6000s was deemed unnecessary, as a single nREC-6000 is capable of recording greater than 200 MBps and can store greater than a terabyte of data. Therefore, a switch was inserted between the AIM-4004 and the nREC-6000, which provides load balancing by distributing the packets from the two OVH-350 cards equally between the two input interfaces of the nREC-6000. This is accomplished by having each OVH-350 card distribute the output packets between the two gigabit Ethernet interfaces in a round-robin fashion. Therefore, a single Ethernet interface on the OVH-350 sees a maximum of 60 MBps and a single Ethernet interface on the nREC-6000 sees the same traffic level.

A second function of the Radar acquisition system is to obtain the Radar maps generated by the RP. These maps are written directly to a Fibre Channel solid-state drive by the RP during diagnostic operation. This procedure is controlled externally by sending IP command packets to the RP instructing it to operate in this manner. Additionally, the RP continues to send status packets to the command source, to verify that it should continue to operate in this mode. In addition to the 2 gigabit Ethernet interfaces on the OVH-350, it supports a third Ethernet interface primarily for diagnostic purposes. In this application, the firmware on the OVH-350 was modified to make use of this 10/100 Ethernet interface as a communication port for controlling the RP. The AIM/HS-AVDAU products are capable of controlling up to 4 external recorders, the RP Ethernet interface and its command protocol were defined in the system firmware as another “external recorder” and were slaved to the primary recorder (the nREC-6000) such that data from both RP interfaces are managed and recorded as a single entity.

Finally, a RCP-4000 unit was attached to both OVH-350 cards using RS-485 for pilot command and control of the entire system using each card’s built-in Chapter 10 console.

A block diagram of the proposed F-22 Radar IQ system is shown in Figure 1. Each individual hardware component in this block is discussed in the following paragraphs.

Figure 1: F-22 Radar IQ System Block Diagram



DATA ACQUISITION UNIT

The AIM-4004 is a modified Airborne Instrumentation Multiplexer (AIM) that is based on the design of the AIM-2004. The AIM-4004 uses a single backplane with two separate PCI bus segments. Each bus segment supports 64-bit PCI at 66.67 MHz or 533 MBps peak bandwidth. Each bus segment provides an independent AIM card set consisting of an OVH-350 overhead card, an RCI-305 remote CAIS interface card, and a high speed I/O card. The AIM-4004 chassis, as illustrated in Figure 2, is very similar mechanically to the AIM-2004. It uses the identical PSM-2004 power supply that is used in the AIM-2004.

Figure 2: AIM-4004



OVH-350 Overhead Card

The OVH-350 card is a new design that provides major enhancements over the OVH-300 used in the existing AIM/HSAVDAU-200X systems. The OVH-350 uses an embedded processor capable of up to 1600 Dhrystone 2.1 MIPS at a clock rate of 800 MHz. This card contains 256 MB of double data rate SDRAM with a memory bandwidth of about 2.1 GBps peak. The card also provides 64 MB non-volatile memory storage for the operating system and configuration data. In addition to higher processor performance, the major improvement to the card over the OVH-300 is the incorporation of two 1000BASE-T Ethernet interfaces and one 10/100BASE-T Ethernet interface.

The OVH-350 executes an embedded real-time Linux operating system, various hardware-specific drivers, and application software. It stores software executables and AIM programming information in its Flash file system. It terminates an IP stack to support standard Ethernet protocols and TCP and UDP, and communicates with the nREC-6000 IP recorder via one or two Gigabit Ethernet (GbE) ports. It formats the data acquired by the Radar LVDS data acquisition card for transmission to the IP recorder.

RCI-305 Remote CAIS Interface Card

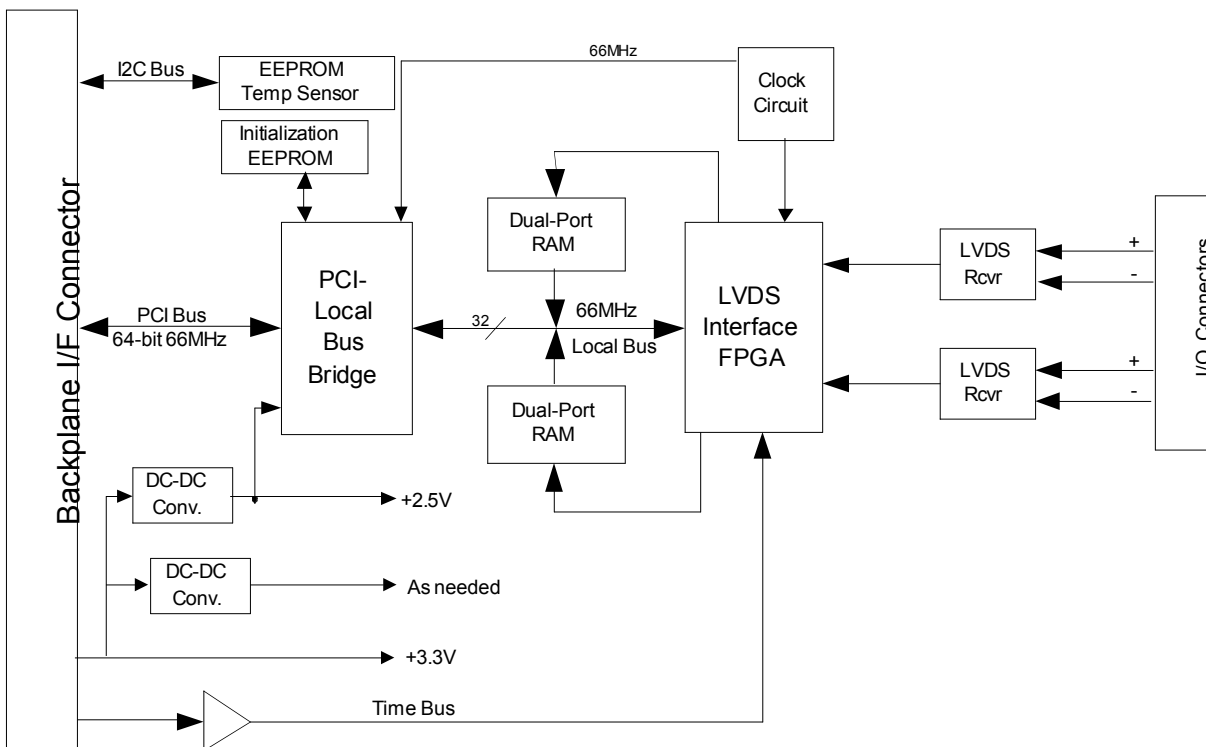
The RCI-305-2 provides a remote CAIS bus interface and a time code reader/generator. It is a mezzanine card that connects to the mezzanine port on the OVH-350 and is functionally identical to the existing RCI-305 card. A new layout is required to mate to the OVH-350. Two versions are required for the AIM-4004: the RCI-305-2 with a notched faceplate for mounting in the end position and the RCI-305-3 with a rectangular faceplate for mounting in the center position.

RDR-302 Two-Channel LVDS Receiver Card

The RDR-302 is a newly designed data acquisition card for the F-22 Radar IQ system. The card contains two independent LVDS receivers and acquires data from two LVDS channels at a 128 MBps maximum rate for each channel. It also timestamps the incoming data using the IRIG time code signal that is distributed on the AIM-4004 motherboard. A custom FPGA was designed based on specifications from Northrop Grumman to accept I and Q messages from the RP and forward them to the OVH-350 for processing.

A block diagram of the RDR-302 is shown in Figure 3.

Figure 3: RDR-302 Block Diagram



NSW-8GT-TG-D-1

The NSW-8GT-TG-D-1 is an 8-port non-blocking 1588-capable gigabit switch. Its normal purpose is to provide packet switching and the IEEE 1588 time distribution necessary to support networked data acquisition components. The switch supports managed operation, allowing for both static and dynamic configuration, statistics gathering and health monitoring using SNMP (Simple Network Management Protocol).

In the F-22 Radar data acquisition application, the primary role of the switch is to provide dynamic bandwidth load balancing for I and Q Radar data from the RDR-302.

nREC-6000 IP Recorder

The nREC-6000 is an Internet Protocol capable, high-rate, high-capacity recorder that is able to record over 200 MBps depending on the quantity and the type of media that is installed in the removable cartridge. It supports simultaneous read and write operations, and provides support for RAID level 0. The removable cartridge accepts one to eight solid-state drives. The nRec-6000 supports both IEEE 1588 and IRIG-B Time Codes. Input is received by two 1000Base-T Ethernet interfaces for data recording and one 100Base-T port for configuration and management of the unit. It includes built-in intelligence for health monitoring, statistics reporting and other intelligent actions.

Figure 4: nREC-6000



MSA-0512-S Media Storage Array

An MSA-0512-S is the nREC-6000 cartridge for the F-22 Radar IQ program. For this application, the MSA-0512-S provides 512 GB of solid-state storage, using eight 64 GB Serial Advanced Technology Attachment (SATA) solid-state drives. Solid-state media like these SATA drives offer numerous advantages over hard-disk drives for airborne applications: a wide operating temperature range of -40 to $+85^{\circ}\text{C}$; high altitude operation without pressure sealing; and excellent shock and vibration performance.

MSR-2001-PSB Recorder

The MSR-2001-PSB is a ruggedized airborne recorder receptacle. It supports an electrical Fibre Channel interface that connects directly to an F-22 Radar Processor Data Pump diagnostic output port. It accepts a single solid-state cartridge, the MSC-0080-FS, which is an 80 GB capacity device. This configuration provides a sustained recording rate of 30 MBps for up to 40 minutes.

RCP-4000 Recorder Control Panel

The RCP-4000 is a cockpit control and display panel for recorders. It provides the following functions in this application:

- A nine-switch matrix for pilot and external system control
- A four-digit seven-segment display for recorder “% Remaining” of either the nREC-6000 or the MSR-2001.
- A two-digit seven-segment display for the recorder number being accessed
- An RS-232/RS-422 serial port for RCP-4000 setup and programming
- A two-wire, half-duplex multi-drop RS-485 port for recorder communications (supports up to 16 recorders). Both OVH-350 cards are connected to the unit.

DATA TRANSLATION SOFTWARE

One of the key requirements of this application is to allow for continued use of the existing NGC Radar processing software. This requirement dictates the organization and format of the Radar data as multiple 4 gigabyte files in a Windows FAT32 file system. Due to performance requirements, the hardware system is unable to record the full bandwidth of the incoming radar data directly on the media in the Northrop Grumman format. To overcome this problem, TTC used its network packet-based data format for the media which allows for real-time recording at the necessary data rates. TTC then provided a software-based translation tool to extract the recorded data from the RAID cartridge and reformat the data to meet the Northrop Grumman specification for processing on an external computer system.

An example processing sequence follows:

dar32ngc version 1.2.4

Processing DAR file: 080101001651-0.dr2

Converted files located in: ./ConvertedFiles/Mission/Sessn001

First time packet = 2008 221 14:13:06.000000

<<< PROCESSING SUMMARY REPORT >>>

```
Total DAR packets received      : 557571
Total DAR segments received      : 765953
Total segment bytes received     : 742070832
Total unknown type received      : 0
Total LossOfFileSync             : 0
Total GainedFileSync             : 1

Time packets received            : 90
  Time A packets                  : 45
  Time B packets                  : 45
  Time unknown DSID packets      : 0
  Time segment length errors     : 0
Total Radar packets received     : 557481
Total Radar packet length errors : 0
Total Radar packet sequence jumps: 0
Total Radar packet segment jumps : 0
Total Radar packet time jumps    : 0
Total Radar segments received    : 765863
Total Radar seg. length errors   : 0
Total Radar seg. errors          : 0
Total Radar seg. truncate errors : 0
Total Radar seg. data errors     : 0
Total Radar seg. framing errors  : 0
<< IQ 1 >>
Packets received                  : 147120
Segments received                 : 294240
Radar simulated segments         : 294240
Complete segments                 : 73560
First segments                   : 110340
Middle segments                  : 0
Last segments                    : 110340
Sequence errors                  : 0
Aborted messages                 : 0
<< IQ 2 >>
Packets received                  : 127946
Segments received                 : 127946
Radar simulated segments         : 127946
Complete segments                 : 0
First segments                   : 1406
Middle segments                  : 125134
Last segments                    : 1406
Sequence errors                  : 0
Aborted messages                 : 0
<< IQ 3 >>
Packets received                  : 153155
```

```
Segments received           : 214417
Radar simulated segments   : 214417
Complete segments         : 0
First segments            : 91893
Middle segments           : 30631
Last segments             : 91893
Sequence errors           : 0
Aborted messages          : 0
<< IQ 4 >>
Packets received           : 129260
Segments received         : 129260
Radar simulated segments   : 129260
Complete segments         : 0
First segments            : 2810
Middle segments           : 123640
Last segments             : 2810
Sequence errors           : 0
Aborted messages          : 0
```

Received data source ID (DSID) values:

```
0x00000020 = IQ1
0x00000820 = IQ3
0x00000821 = IQ4
0x00000021 = IQ2
0x00000812 = Time B
0x00000012 = Time A
```

PROCESSED ALL PRESENT IQ SOURCES

```
Peak throughput A:          8.09 MB/s
Peak throughput B:          8.10 MB/s
```

<<< END SUMMARY REPORT >>>

CONCLUSION

A system has been developed for the F-22 flight test program which allows for the acquisition and recording of Radar data along with conventional instrumentation data. The system was developed using the existing instrumentation system architecture as a starting point and was expanded and refined to meet the unique requirements of this particular application. This approach allowed for the development of a package that was able to maximize the customer's existing experience with pre-installed instrumentation hardware and software and accommodate the challenges of acquiring radar data.