Software Reconfigurable State-of-the-Art Communication Suite for Fighter Aircraft

Conference Paper · July 2011

DOI: 10.1109/CSNT.2011.155 · Source: IEEE Xplore

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Software Reconfigurable State-of-the-art Communication Suite for Fighter Aircraft

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***Abstract* - Communication systems are considered as one of the major requirements for the current and next generation fighter aircrafts to complete a mission successfully. Efficient net-centric warfare and situational awareness can be achieved with modernized communication system and high-end sensors. The conventional communication systems available consist of individual systems for each functionality. In such cases, the failure of one system leads to failure of the functionality of that system and the mission has to be completed without that system. Hence there is an urge to develop a state-of-the-art on-flight software reconfigurable communication system to provide better redundancy, successful completion of mission and efficient utilization of systems on-board for fighter aircraft. In this paper, the functionality of all the on-board communication systems is explained and the design of a state-of-the-art software re-configurable communication suite is proposed for fighter aircrafts. The highlight of this architecture is that the hardware resources are shared between the systems and incase of failure of one system, the other system shall be reconfigured on-flight to take up the functionality of the failed system. The software architecture employs software code reusability for easy debugging and code verification. The proposed system is based on the concept of Software Defined Radio (SDR) and the functionality is extended from hand-held radio to entire communication system of the aircraft.**

Keywords - Reconfigurable Systems; Communication Systems; Aerospace

I. INTRODUCTION

On-board communication systems possess a vital role of establishing the link between the aircraft and the ground stations and between aircrafts themselves. It also enables the pilot to identify other aircrafts to take safety measures in case of emergencies. Hence communication systems are considered as one of the major requirements for the current and next generation fighter aircrafts to complete a mission successfully. Fig. 1 shows the conventional architecture of all the on-board communication systems. Details about the communication systems mentioned in Fig.1 are described in Section II. In the conventional architecture, the signal processing units, amplifier section and antennas for each communication system is separate. In such cases, the failure of one system leads to failure of the functionality of that system and the mission has to be completed without that system. Hence there is an urge to develop a state-of-the-art on-flight software reconfigurable communication system to provide better redundancy, successful completion of mission and efficient utilization of systems on-board for the present and next generation fighter aircrafts.

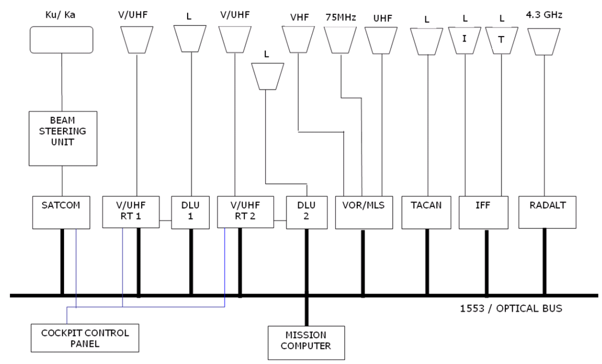

Figure 1. Conventional Architecture of On-board Communication System

MIL-STD-1553B [1] and Fiber Optic interface [2] are the two different approaches employed for interaction between various on-board communication systems and the Mission Computer on aircraft. All the on-board communication systems have varied functionality and operate at different frequency bands. Also these communication systems use different types of antennas mounted at various locations on the aircraft as shown in Fig.2. Research is still under progress towards development of body conformal antennas for all the on-board communication systems to achieve low observability and better body conformance.

The structure of the paper is as follows. An overview of all the communication systems on-board and their functionalities are explained in Section II. Section III describes the hardware architecture of the proposed state-of-the-art reconfigurable communication system. Section IV describes the software architecture of the proposed reconfigurable system, followed by conclusion and references.

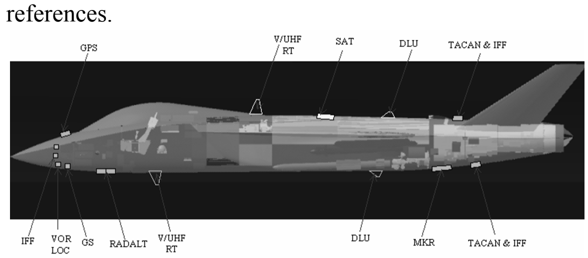

Figure 2. Antenna Locations for On-board Communication Suite

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DOI 10.1109/CSNT.2011.155

II. On-Board Communication Systems

This section describes the functionality of all the on-board communication systems of a fighter aircraft mentioned in Fig.1. Each communication system consists of the following subsystems - signal processing unit, power amplifiers for signal transmission, RF switching units and finally the antennas mounted on the aircraft.

A. Radio Altimeter (RADALT)

Radio Altimeter gives the information about present altitude of the aircraft above the terrain. This system operates in C band, centered at 4.3GHz with RADALT antennas mounted on the bottom of the aircraft.

The major functionality of radio altimeter is usually Frequency-Modulated Continuous Wave (FM-CW) transmission and demodulation of the receiver signals. Radio altimeter sends a modulated pulse downwards and computes the turn-round trip time to calculate the height and displays the value onto cockpit display. The signal transmitted is represented as

$$x_T(t)=\exp(j(2\pi f_c t + nat^2)), \quad -Ts/2 < t < Ts/2 \qquad (1)$$

where f_c is the carrier frequency, a is the sweep rate and Ts is the sweep partition period. The received signal is a delayed (time t_d) and scaled (factor A) replica of the transmitted signal given as

$$x_R(t)=A\bullet\exp(j(2\pi f_c(t - t_d))+ na(t - t_d)^2)) \qquad (2)$$

The time delay t_d can be extracted from $x_T(t)$ and $x_R(t)$ by the demodulation given as

$$x(t)= x_R(t) \otimes x_T(t) \qquad (3)$$

which is a simple function of the aircraft altitude and velocity. More details about working of RADALT can be had from [3].

B. Microwave Landing System (MLS)

Microwave Landing System (MLS) is an instrument approach system for landing under various meteorological conditions and its purpose is to align aircraft to the runway's center and provide a safe angle of descent. The aircraft derives its angular position within the coverage volume by measuring the time difference between two pulses received by its MLS receiver. For a given scanning speed and pause time, the elevation angle θ can be calculated as

$$\theta = (t_0 - t)\, V/2 \qquad (4)$$

where θ is the angular position of aircraft in degrees, V is the angular speed of the scanning beam, t is the actual time interval between pulses received from to and fro scans and t_0 is the value of t for $\theta = 0$.

MLS operates in C Band, marker frequency is 75MHz and the glidescope operates in UHF band. Localizer and glidescope antennas are mounted in the front radome, whereas marker antennas are mounted in the belly of the aircraft. Glidescope antenna receives information about the angle of descent, localizer antenna receives information about the offset from center of the runway and marker antennas receive pulse modulated tones and are used as landmarks before landing. Table I

Table I. Details of Marker Beacon Signal

Marker Type	Light	Sound
Outer (4-7 miles from runway)	Blue with O	dash-dash-dash
Middle (3500 feet from runway)	Amber with M	dash-dot-dash-dot
Inner (Between marker and runway)	White with I	dot-dot-dot

lists the light and sound signals and placement for each type of marker beacon. More details about working of MLS can be had from [4].

C. VHF Omni directional Range (VOR) Finder

VHF Omni directional Range finder is a type of radio navigation or "radio-compass" unit, broadcasting a directional signal that not only acts as a beacon but also provides coded information that gives the compass angle of the signal between the aircraft and the ground station.

A detailed study is made to conclude that VOR antenna can be shared with the localizer antenna of the instrument landing system and it is mounted either on the front radome or on the tail fin of the aircraft. It is also observed that the Glidescope(GS) of MLS system works in the UHF band and a single antenna can be used as VOR/GS antenna using an RF switch to switch between VOR and MLS systems. This is possible because the functionality of GS is required only during landing; whereas VOR is required during the flight path and hence a mutually shareable single antenna can be used for both the systems.

The ground VORs feed combined AM and FM modulated signals to an array of four omnidirectional antennas, which rotates the signal at 30 times a second. VOR systems on-board fighter aircraft uses AM and FM demodulation and are purely receiving systems. Amplitude demodulation for an AM signal $s(t) = A_c f[m(t)]\cos(2\pi f_c t)$ is obtained by using a product detector with recovered carrier $c(t) = A_r\cos(2\pi f_c t)$ to obtain the message signal as

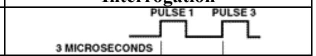
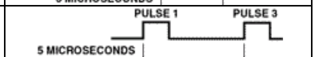
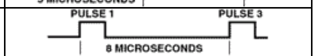
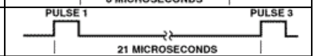
$$m(t) = s(t)c(t) = A_c A_r\, f[m(t)](1+\cos(2\pi(2f_c)t)) \qquad (5)$$

For FM demodulation, phase-locked loops (PLL) are used to "phase-lock" onto a carrier frequency and extract the modulating signal. More details about working of VOR finder can be had from [5].

D. Identification Friend or Foe (IFF)

IFF identifies friend or foe of aircraft and ground forces using IFF for Air-to-Air and Air-to-Ground respectively. IFF consists of two functionalities – interrogator and transponder. The functionality of interrogator is to continuously interrogate the targets entering its scanning range and recognize the target as friend, foe or neutral. The functionality of transponder is to transmit the acknowledgement signals to the received interrogated signal. IFF operates in mode 1, 2, 3A, C, 4 and the details about each mode is reported in Table II. The operating frequency of all the modes is L band. Interrogator antennas are mounted on the front radome whereas the transponder antennas are mounted on the top and bottom of the aircraft, near the rear fuselage.

TABLE II. IFF OPERATING MODES

Mode	Purpose	Interrogation
1	Military – Aircraft Mission	
2	Military – Personal Identification	
3A	Military / Civilian ATC	
C	Altitude Reporting	
4	Secure Military IFF	

TACAN and IFF transponder functionalities are mutually exclusive and hence both share a common antenna.

E. Tactical Aid to Navigation (TACAN)

Tactical Aid to Navigtion (TACAN) provides the position/range and bearing information of the aircraft with respect to a TACAN ground beacon, and to measure the distance, either to a Distance Measuring Equipment (DME) beacon or to another airborne TACAN unit. The signal s(t) sent by TACAN beacon is given as

$$s(t) = s_m[1+m_1 \mathrm{sing}(\Omega t - \theta)+m_2\sin(9\Omega - 9\theta)] \sum_{i=0}^{\infty}[\delta(t-t_i)\, G(t)]\cos(\omega t) \quad (6)$$

where s_m is the amplitude of carrier wave signal, m_1 and m_2 are modulation degree of approximate and exact measurement signals, θ is the azimuth, $\Omega = 2\pi f$, f=15Hz, ω is the angular frequency of carrier wave. G(t) is bell-shaped modulation signal and t is the time of arrival impulse. It may be observed from (6) that the signal s(t) is a series of impulse code train.

The major functionality of airborne TACAN involves demodulation of the received beacon signal and phase comparison. Interrogation or transmission by pilot is only during air re-fuelling and aircraft carrier and it operates in the L-band. TACAN antennas are mounted on the top as well as on the bottom of the aircraft. More details about working of TACAN can be had from [6]

F. V/UHF Radio Transmitter (V/UHF RT)

V/UHF RT is a secure, jam resistant airborne radio communication set for simplex two-way communication in the VHF and UHF frequency bands. It also provides voice and data communication with the associated sets in the airborne environment. The data is encrypted, modulated and transmitted onto ground station as well as between pilots. In order to provide maximum coverage, one antenna is mounted on the top of aircraft and other on the belly of the aircraft and both operate in V/UHF frequency band. Same antenna is used for transmission as well as reception and an RF switching is provided between antenna and Tx/Rx modules. V/UHF radio communication is a very important system in fighter aircraft and hence a standalone redundant V/UHF radio system is provided to take over in case the primary fails.

The major signal processing requirements in this system include echo cancellation, voice processing, data compression, signal modulation and demodulation (AM, FM,MSK,FSK,PSK etc.), data encryption/decryption and communication security (Spread-Spectrum). This system currently uses software defined concept to some extent in the sense that the same hardware is used for data transmission in a smaller range of frequency band. Frequency or channel selection is performed by the pilot using push-buttons on the display modules.

G. Data Link Unit (DLU)

Data Link Unit provides the pilot with secured data communication (voice, video, sensor inputs, net-centric data) among the fighter, ground control intersection stations, other fighters and forward air controllers on ground, to establish a true situational awareness and net-centric information by making available the data of air targets, ground targets, friendly ground forces and surface to air missile threats in real-time. In order to provide maximum coverage, one antenna is mounted on the top of aircraft and other on the belly of the aircraft and it operates in L band. Laser data link [7] is the latest technology that can be employed for next generation aircraft. NATO approved data links are Link 16, Link 14, Link 22 and can be referred from [8]

H. Satellite Communication (SATCOM)

SATCOM provides the pilot with secured data communication among the fighter, ground control intersection stations, other fighters, to establish a true situational awareness by making available the data of air targets, ground targets, friendly ground forces and surface to air missile threats in real-time through satellite link in Ku/Ka Band depending on the satellite band allocated for the application.

The major functionality of SATCOM system includes the modulation and demodulation of processed signals (voice, video, data etc) from data link or V/UHF transmitter systems and transmission of the same at higher frequency through satellite link. This system uses a single body conformal antenna on top of the aircraft along with an electronic beam steering unit.

III. PROPOSED HARDWARE ARCHITECTURE

In this section, the transition of on-board communication system from the conventional architecture to the proposed state-of-the-art software reconfigurable architecture is described. Fig. 3 shows proposed hardware architecture for the software reconfigurable communication system. The architecture is divided into two sections with each section comprising of signal processing stage and the sections are classified on the basis of their operating frequency bands. The signal processing section includes a cluster of high-end digital signal processors (DSP) and Field Programmable Gate Arrays (FPGA). The software reconfigurable architecture shares the hardware resources between the systems and incase of failure of one system, the other system shall be reconfigured to take up the functionality of the failed system. Antennas for all these functionalities are located on the aircraft at different locations, as it was for the conventional architecture. The architecture has the flexibility to share antennas with redundant RF amplifier sections. In case of failure of RF amplifier, antenna

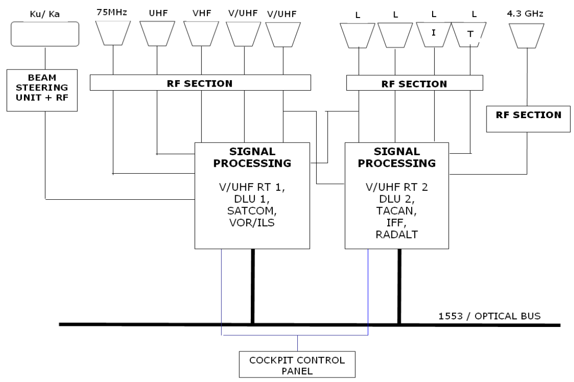


Figure 3. Proposed Architecture for
Software Re-configurable Communication System

switching at the RF section shall solve the problem. When signal-processing functionality fails, any other signal processor can be reconfigured to perform the functionality of the failed unit and shall lead towards the successful completion of the mission. The software reconfiguration does cater for the antenna switching too.

The RF hardware consists of one or more conversion stages where an intermediate frequency (IF) signal is converted to or from an RF frequency. The IF signals is converted to or from the digital domain by wideband analog-to-digital converters or digital-to-analog converters, respectively. With Field Programmable Gate Arrays (FPGA), high-end Digital Signal Processors and data converter technology continuously evolving, software defined re-configuring concepts are increasingly becoming a reality [9]. Baseband processing often requires both processors and FPGAs, where the processor handles system control and configuration functions while the FPGA implements the computationally intensive signal processing data path and control, minimizing the latency in the system. To go between configurations, the processor can switch dynamically between major sections of software while the FPGA can be completely reconfigured, as necessary, to implement the data path for the particular configuration.

IV. Software Architecture

The software architecture for the proposed state-of-the-art software reconfigurable communication system is described in this section. The functionalities of all the on-board communication systems are studied, analyzed and proposed as function modules or blocks. The major functionalities of the on-board communication system are – modulation (where type of modulation, frequency of operation etc. are the arguments/variables changing for each system), demodulation (type of demodulation, frequency of operation, sensitivity etc. are the arguments/variables in this case), ECCM features (Various spread spectrum techniques), speech processing, data compression, data encryption and decryption. By providing such functions, software reusability is achieved with a systematic development of reusable components and thus reducing the storage of program code. Software reusability enables easy debugging and faster independent verification and validation of code.

During analysis, it is noticed that most of the functions are common to all the on-board communication systems with variations in parameters like frequency, voltage, sensitivity etc. This feature is employed to generate call-by-value functions for various functionalities. Software running on a high end digital signal processor manipulates the sampled IF signal, performing multiple steps that either prepare a signal for transmission or extract useful information from a received signal. The high-end signal processors receive the digital input from a high speed ADC of Analog front end section. The proposed architecture is characterized by its flexibility: Simply modifying or replacing software programs can completely change its functionality and thus the entire Communication suite is software defined. This allows easy upgrade to new modes and improved performance without the need to replace hardware. This Software defined convergence is occurring because of advances in software and silicon that allow digital processing of radio-frequency signals.

The software architecture of the proposed re-configurable communication suite for fighter aircraft is shown in Fig. 4. The software functionalities involve the signal processing functions of RADALT, IFF, TACAN, MLS, VOR, V/UHF Radio, DLU and SATCOM and these functions can run in any of the signal processor of the system. Mission computer monitors data and Built-in-Test (BIT) status. In case of failure of any functionality, spare processing capability can take over the failed functionality and control commands are sent for required antenna switching. Facility for sharing antennas between both the signal processors is achieved by providing direct access to antenna switching functionality wherein data transfer and antenna switching is achieved, thus providing better reliability. The functions required at the transmitter end include source coding, channel coding, modulation, up-conversion to an intermediate frequency, digital-to-analog conversion, and up-conversion to an RF frequency. The functions that are required at the receiver end include down-conversion, demodulation, channel decoding, and source decoding.

The software load on the signal processors may be reduced after thorough analysis and study of all the communication systems functionalities on-board. During research, it was also noticed that not all systems operate for the entire duration of flight or mission and following are the observations. MLS is required only during landing for beacon detection from localizer, glidescope and marker. Similarly RADALT functionality is limited to low-level flight, landing and during terrain flights. It is sometimes used for weapon aiming algorithm on non-terrain battleground. TACAN and IFF transponder functionalities are mutually exclusive and thus share a common antenna and hence their software functionality is also mutually exclusive. DLU and SATCOM are used

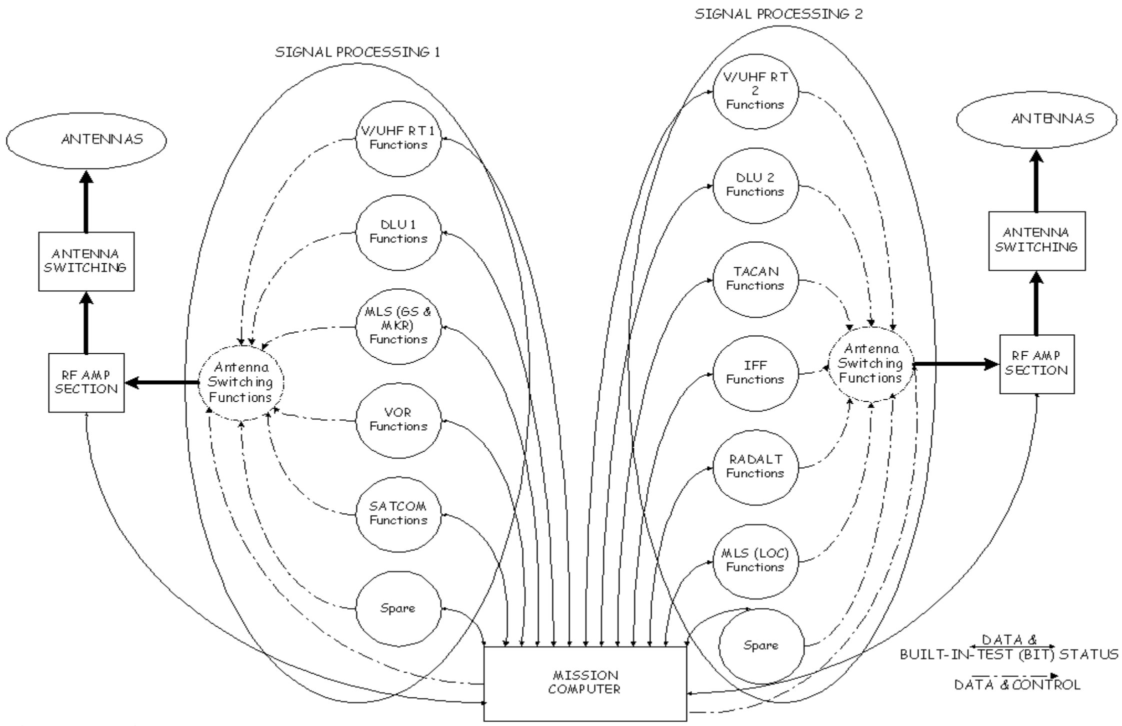


Figure 4. Software Architecture for the Re-configurable Communication Suite

mainly for net-centric warfare. SATCOM is recommended and used as redundant for V/UHF radio, when the later goes out of communication range with ground station. Hence the proposed software reconfigurable communication suite would save a lot of hardware, power dissipation including antennas and also performs software processing efficiently.

V. Conclusion

In this paper, a viable software reconfigurable communication suite enabling seamless, real-time flexibility and communication across the military services, coalition forces and allies is proposed. The proposed scheme provides flexibility for any changes in configuration, reduces hardware including antennas, plug-in type of faulty module replacements, incorporates software reusability, controlled emission of signals by transmitting signals when required, efficient utilization of power for systems. Hence the proposed software reconfigurable system proves to be more advantageous and sophisticated over the conventional communication system. The proposed software reconfigurable communication system with all body conformal antennas is best suited for the next generation fighter aircrafts.

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