Receiver G/T Ratio Improvement for Space Communications Missions

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Abstract— Space satellite system design trade-offs increase with the complexity of the payload requirements. For reliable and dynamic in-orbit satellite operations, the front-end receiver of the payload must have the capability to adapt to emergent mission and post-mission reapplication requirements. This paper presents a novel payload receiver front-end topology(s) for maintaining a reliable and stable gain-to-noise (G/T) ratio of the satellite network; the G/T ratio defines the uplink performance of a satellite network. The use of adaptive reconfigurable low-noise amplifiers is proposed. The underlying transponder architecture enables the integration of device-level technologies with inherent reliability and radiation tolerance. Furthermore, a system engineering case study for a satellite communications mission is presented. Adopting this design philosophy in future space satellite payload module promises stable, economical, optimal, broadband and adaptive space operations.

Index Terms **gain-to-noise temperature, highly adaptive small satellite, payload receiver, space communication.**

I. Introduction

A communications spacecraft consists of two generic subsystems: the communications payload subsystem and spacecraft bus subsystem [1, 2]. The payload subsystem houses the transponder equipment used for the reception and transmission of communication signals. A key element of the payload subsystem of a communications satellite system is the wideband receiver [1 – 8]. This follows the antenna subsystem at the input of the transponder equipment. The uplink performance of the satellite communication network depends on the receive antenna gain and noise temperature of the satellite receiver. Mathematically, the system noise temperature of the satellite receiver, T_{sys}, is given by: [1, 2]

$$T_{sys} = (T_a/L) + (1 - 1/L)*290 + T_{rec} \quad (1)$$

where,

T_a is satellite antenna temperature equivalent to the Earth's brightness temperature of 290 K, L is the input cable loss factor and T_{rec} is the equivalent noise temperature of the payload receiver.

The ratio of the receive antenna gain, G, to the effective wideband receiver noise temperature, T_{sys}, defines the uplink operation and service metrics of a satellite network. Furthermore, the G/T (dB/K) ratio is a figure of merit that indicates how reliable the uplink performance is for a radio signal transmission. For a given antenna gain, operating frequency and waveguide loss factor, the effective receiver noise determines the G/T ratio. The G/T of a satellite network is used in link budget calculations. Hence, to improve the uplink performance of a satellite network, the underlying receiver technology should support adaptive low noise amplifier configuration. This promises to ensure adequate downlink power for satellite systems with low-powered user terminals and networks of low-cost very small aperture terminals.

In this paper, novel satellite wideband receiver circuit topologies for device- and circuit-levels implementations are presented. Section II covers the integrated adaptive technology system that enables adaptive low noise amplifier design. An adaptive receiver front-end architecture is explained in section III. A case study analysis of a communication mission concludes this paper in section IV.

II. Integrated Adaptive Technology System

Adaptive and solid-state device technologies are realised on layered structures and architectures. For instance, a field programmable gate array (FPGA) architecture places routing and interconnect resources above a logic grid; this transforms a channelled architecture into a "sea-of-modules architecture." Interconnection between logic modules is achieved using programmable interconnect elements embedded between the substrate/metal layers. Furthermore, III – IV semiconductor technologies devices are implemented on layered architectures that can be integrated with the FPGA system. The implementation of this novel design prommises to ensure real-time reconfiguration of subsystems (such as the satellite wideband receiver) to achive a desired in-orbit performance [9 – 18].

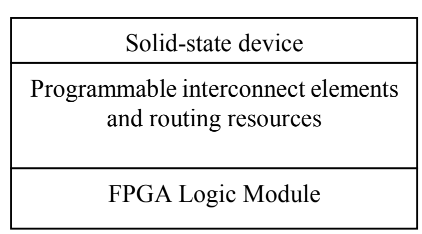

Fig. 1 Adaptive Device-level Configuration

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Figs. 1 and 2 show the device- and circuit-levels configurations of the adaptive receiver elements. It is obvious from Fig. 1 that a solid-state RF/microwave device can be integrated on the same module platform as an adaptive device (such as FPGA) with programmable interconnects and routing resources. In this configuration, the RF device can be remotely reconfigured in real-time to realise a desired circuit-level performance [9 – 14]. This adaptive RF/microwave device-level module can be replicated and organised into clusters and superclusters for increased design efficiency and device performance.

An adaptive low noise amplifier (ALNA) and local oscillator (ALO) circuits integration configuration is shown in Fig. 2. The FPGA logic module traverses the LNA and LO circuits via a layer of programmable interconnect elements and routing resources. This forms a module grid network that enables and enhances remote and deterministic circuit-level reconfiguration. Thus, the LO frequency can be adaptively mapped to the incoming RF signal to achieve a desired IF for the next stage of the transponder chain. For GaAs-based RF/microwave LNAs and LOs, a key merit of this configuration is the provision of a radiation shield to underlying electronics. This greatly enhances the reliability, availability and operability of the satellite receiver subsystem. The architecture can also be used to implement any LNA circuit topology.

LNA Module	Local Oscillator Module
Programmable interconnect elements and routing resources	
FPGA Logic Module	

Fig. 2 Adaptive Circuit-level Configuraton

III. Adaptive Receiver Front-end Architecture

Fig. 3 gives a complete architecture of an adaptive wideband receiver. The input RF signal is received via the LNA module interface and adaptively mapped to a corresponding LO frequency. The outputs from the LNA and LO are then routed to the mixer module via a network of programmable interconnect elements and routing resources. The elimination of associated cabling and wire harnesses implies reduced interface bandwidth requirement (FPGA constraint) and coupling and signal losses (due to electrical circuit parasitics).

Mixer Module	
LNA Module	Local Oscillator Module
Programmable interconnect elements and routing resources	
FPGA Logic Module	

Fig. 3 Adaptive Wideband Receiver Architecture

IV. G/T Ratio Analysis And Results

The gain-to- noise temperature ratio is the vital parameter for qualifying the uplink operation of a given satellite network; this is akin to the effective isotropic radiated power for the downlink. Figs. 4 and 5 show the effect of noise figure drifts on the G/T ratio of a space satellite employing a 5.3 dB receive antenna system at 2.116 GHz for its radio communication. Generally, the satellite system engineering reveals that G/T ratio decreases as the effective receiver system noise temperature increases. For a given antenna gain and waveguide loss factor, the governing parameter in the wideband receiver noise performance is the noise figure of the LNA. Though this reduces with the gain of the succeeding amplifier stages, the noise of the first stage still dominates. In Fig. 4, a 0.5 K increase in the receiver system noise temperature results in over 0.002 dB/K decrease in the G/T ratio. This has the effect of lowering the carrier and data links margins of the satellite network. Furthermore, Fig. 4 shows a steeper gradient compared with Fig. 5 due to the wider noise temperature drift. Hence, adaptive wideband receivers are required onboard space satellites to improve their in-orbit G/T ratios.

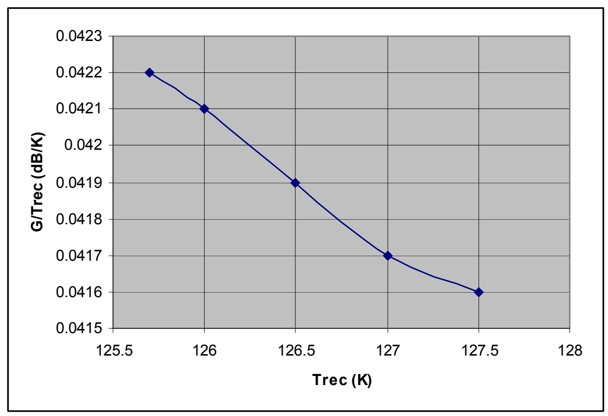

Fig. 4 G/T Ratio versus Receiver Noise Temperature (0.5 K drift)

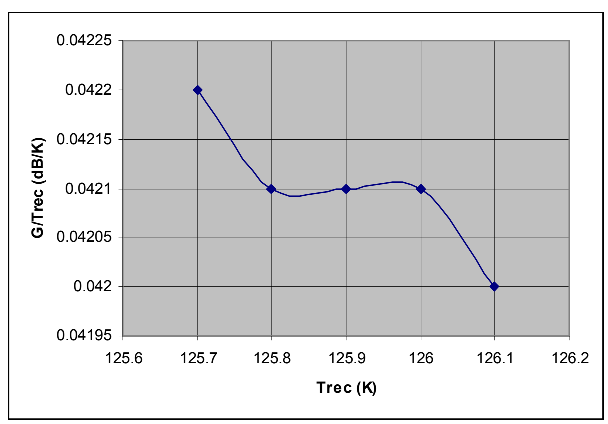

Fig. 5 G/T Ratio versus Receiver Noise Temperature (0.1 K drift)

The G/T ratio of Fig. 5 shows a flat-profile response with an average value of 0.042 dB/K. To achieve this performance, the satellite receiving system must be adaptive to enable in-orbit reconfiguration of its architecture for the desired mission requirement/objective. The process can involve a code transmission to activate LNA cooling or complete/partial circuit-level reconfiguration. The overall objective is to increase the sensitivity of the satellite receiver; a lower system noise means a higher G/T ratio.

V. CONCLUSION

This paper has presented novel device- and circuit-levels configurations and wideband receiver architecture for improving the G/T ratio of communications satellite networks. The underlying adaptive and RF/microwave technologies are integrated together within modules to form clusters. Programmable interconnects and routing resources constitute the layer for logic transfer to all the modules of the architecture. An analysis of the G/T ratio of a space satellite reveals that adaptive wideband receiver is required to ensure a less than 0.1 K drift in the system noise temperature for optimal carrier and data links performances. Hence, implementing the proposed receiver architecture design promises to enable ultrasensitive satellite receiver design for reliable, broadband, optimal, cost-effective and sustainable space communication operations.

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