High-Speed Data Transmission Subsystem of the SEOSAR/PAZ Satellite

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Abstract. *This paper analyzes a digital interface and bus system modeling and optimization of the SEOSAR/PAZ Earth Observation satellite. The important part of the satellite is an X–band Synthetic Aperture Radar instrument that integrates 384 Transmit/Receive Modules located in 12 antenna panels 7.5 m away from the central processor and controlled by a synchronous 10 Mbps bidirectional serial protocol. This type of mid–range point–to–multipoint transmission is affected by bit errors due to crosstalk, transmission line attenuation and impedance mismatches. The high–speed data communication network has been designed to optimize the transmission by using a simulation model of the data distribution system which takes into account the worst–case scenario and by developing a lab–scaled prototype which exhibits BER of 10^{-11} for an interfering signal of 10 V_{pp}. The result is a point–to–multipoint bidirectional transmission network optimized in both directions with optimal values of loads and equalization resistors. This high–speed data transmission subsystem provides a compact design through a simple solution.*

Keywords

Crosstalk, data buses, high-speed communications, SAR, satellite, SEOSAR/PAZ.

1. Introduction

A number of airborne Synthetic Aperture Radar (SAR) systems are designed nowadays to be utilized by research institutions, government agencies and private companies. SAR technology has a number of current and potential applications. Launched in April 2010, CryoSat-2 measures the thickness of sea ice in order to understand how climate change mechanism works [1]. SAOCOM satellites (Satellites for Observation and Communications) carry an L-band full polarimetric SAR on board for monitoring and managing natural disasters [2], [3]. SEOSAR/PAZ X-band instrument is comprised of an active front end with 384 active Transmit/Receive Modules (TR–Modules) [4], [5]. TR-Modules are arranged in a 12 x 32 matrix. An Antenna Control Unit forms the command and monitoring interfaces between the central electronics and the panels. Panel Control Units are in charge of controlling and monitoring all TR–Modules.

In this paper, a data transmission subsystem which connects Panel Control Unit to 16 TR-modules is modeled, simulated and optimized. The aim of the modeling, simulation and optimization is overall improvement of the network signal integrity: crosstalk and distortion reduction. Simulation results are validated on a lab-scaled prototype.

2. Modeling and Simulation of the 10 Mbps Data Transmission Network

A simplified interface scheme of SEOSAR/PAZ front end, which consists of the Antenna Control Unit, 12 Panel Control Units and 384 TR–Modules, is shown in Fig. 1. The Antenna Control Unit, Panel Control Units and TR-modules are composed of a number of drivers and receivers and synchronized with a RS422 interface at 10 Mbps. Panel Control Units and TR–Modules establish discrete timing signals for the bus traffic control, transfer command data and receive telemetry data from each of the TR-Modules during the Pulse Repetition Interval (PRI) of the satellite's radar. Antenna Control Unit, Panel Control Unit and TR–Modules are connected to each other by twinax cable with a maximum length of 7.5 m.

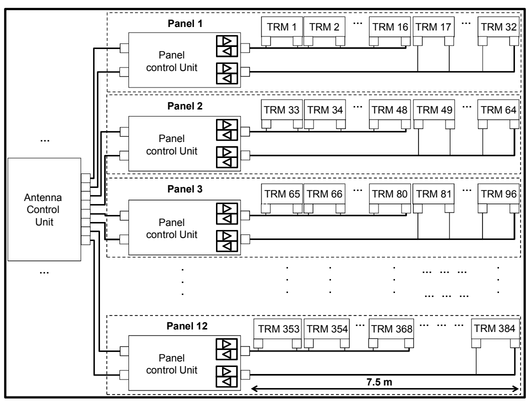

Fig. 1. Interface scheme of SEOSAR/PAZ front end.

This architecture requires very careful design in order to equalize signals in both directions, reduce crosstalk and bit error rate (BER), to ensure correct operation. The asymmetric bidirectional transmission subsystem, which consists of a Panel Control Unit (PCU), 16 TR-Modules (TRMs) and their connections, is the most complex part of the satellite. The worst-case scenario occurs when RS422 buses transfer 16 Command and Control Messages during one PRI. In this case the network reaches the limit imposed by the RS422 standard [6]. Once the complete network was modeled and simulated, the simulation results were compared with the results obtained from a tested lab-scaled prototype.

The subsystem architecture and the signal transmission in both directions were modeled using a standard time domain software simulator, AWR Microwave Office® (AWR MWO) [7]. The simplified circuit of the data transmission network is shown in Fig. 2.

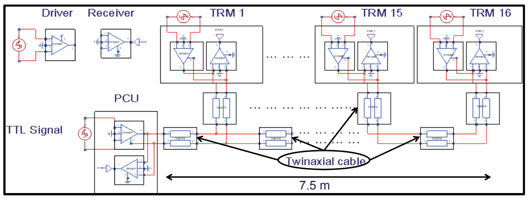

Fig. 2. Simplified circuit of the data transmission subsystem.

This asymmetric bidirectional transmission subsystem is composed of 20 HS–26CLV31RH quad differential line drivers, which convert the transmitted LVTTL signals at 10 Mbps to RS422 signal, and 20 HS–26CLV32RH quad differential line receivers, which convert RS422 signal back to LVTTL. Therefore, 4 drivers of the PCU transmit to 16 receivers of TRMs, and 16 drivers of TRMs transmit only to 4 receivers of the PCU.

Some aspects have to be taken into account for carrying out precise simulations. First, it is necessary to accurately model drivers and transmission lines of the network. Then, the crosstalk effect between adjacent wires needs to be considered in the data transmission network modeling. A capacitive model was fitted for this purpose. Finally, optimization of termination loads and serial resistors was performed to equalize transmission in both directions.

2.1 Simulation of the RS422 Drivers

The driver HS–26CLV31RH was modeled as operational amplifier due to the inherently differential nature of the circuit. The principal parameters of the driver are gain, input impedance, output impedance, cut-off frequency and delay. The simulation model was validated by measurements in the laboratory. The model was obtained by measuring the response of the HS–26CLV31RH device which was excited with LVTTL/TTL input signal at several frequencies up to 100 MHz and by loading it with a segment of twinax transmission line terminated with different resistive loads (Z_L): 27 Ω, 56 Ω, 120 Ω and 220 Ω. The length and characteristic impedance (Z_0) of the transmission line are 2.75 m and 120 Ω, respectively. The measurement process was focused on getting the data for building an accurate simulation model of the driver. Both simulated and measured results are shown in Fig. 3.

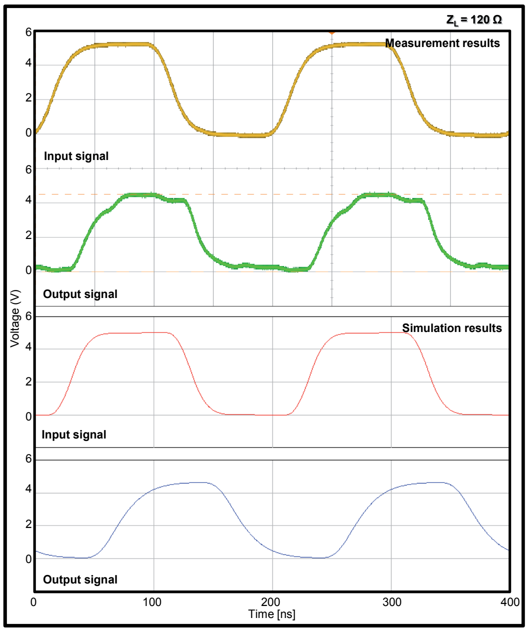

Fig. 3. Measurement vs. simulation results (Z_L = 120 Ω).

2.2 Modeling the Behavior of the Transmission Line

The connections between active elements (drivers and receivers) are realized by using 30 AWG twinax cables, whose features are most suitable for this particular application. This type of cable is less susceptible to interference, it has lower internal resistance and therefore, it supports higher electrical current over longer distances than other types of twinax cables with the same characteristic impedance, Z_0 = 120 Ω [8].

The cables were modeled as transmission lines in AWR MWO [7] by using the model of balanced line with isolated ground terminals [9]. The model parameters are characteristic impedance (Z), physical length of the line (L), dielectric constant (K), loss (A [dB/m]), and frequency for scaling losses (F).

Main features of the transmission line, both for the twinax cable and the AWR MWO model, are summarized in Tab. 1. The total length of the data distribution network is about 7.5 m.

Balanced shielded line (from the datasheet)						
Variant	Z_0	AWG	ε_r	Attenuation (dB/100 m)		
				10 MHz	50 MHz	100 MHz
22	120 Ω	30	2.29	15	35	48
AWR Microwave Office® model						
Z	L	K		A	F	
120 Ω	7.5 m	2.29		0.15 dB/m	10 MHz	

Tab. 1. Main parameters of the transmission line.

2.3 Modeling and Analysis of the Crosstalk

Crosstalk is one of the most important effects that causes transmission errors. Therefore, it is very important to have accurate models to study its behavior and mitigate its impact. Crosstalk was modeled by using a parallel *Coupled Circuit*, since in this scenario the effect of coupling capacitance dominates (different twinax cable segments are packed close to each other) and neglecting, thereupon the magnetic coupling [10]. It is composed of two parallel transmission lines (adjacent buses constituted by twinaxial cable) and a capacitive model, $C_{coupling}$, connected between the buses, that takes coupling effects into consideration [11]. Thus, it is possible to define a coupling coefficient, $Coeff_{coupling}$, between the direct voltage, V_{direct}, and the crosstalk voltage, $V_{crosstalk}$, as:

$$Coeff_{coupling} = \frac{V_{direct}}{V_{crosstalk}}. \tag{1}$$

In this manner, the value of the above mentioned capacitor is tuned using measurements of the transmitted signal level, V_{direct}, as well as coupled signal level, $V_{crosstalk}$, from the lab–scaled prototype. The appropriate capacitance is 8.2 pF.

The simplified electrical model (by using the AWR MWO) of the subsystem where termination loads and serial resistors are included, is shown in Fig. 4. This simulation model is used to optimize data transmission.

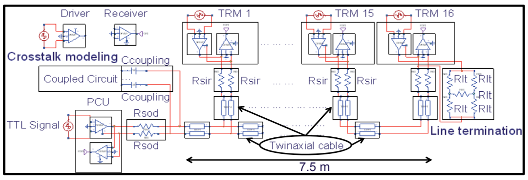

Fig. 4. Simplified electrical model which includes termination loads and serial resistors.

2.4 Equalization in Data Transmission

Another important aspect of the design is to equalize signal in both directions, from PCU to TRMs and back, from each TRM to PCU [12]. For this purpose, serial resistors, R_{sod} and R_{sir} are used for achieving an optimal data transmission in both directions, as well as for protecting drivers and receivers against short–circuits.

The back termination network *Line Termination*, composed of R_{lt} resistors, serves to achieve the correct impedance matching in the system where $R_{lt} = Z_L = Z_0 = 120\ \Omega$.

2.5 Analysis of Serial Resistors

Serial resistors, R_{sod} and R_{sir}, attenuate the received signals in both directions, from the PCU to TRMs and from each TRM to PCU. The effect of serial resistors on received and crosstalk voltage level in both directions is shown in Fig. 5 and Fig. 6, respectively. As it can be seen in these figures, serial resistors also equalize both signals and reduce the level of crosstalk signal. Fig. 5 shows the digital signal received by the TRM 16 and Fig. 6 the digital signal received by the PCU, as well as the crosstalk existing in adjacent lines in each case.

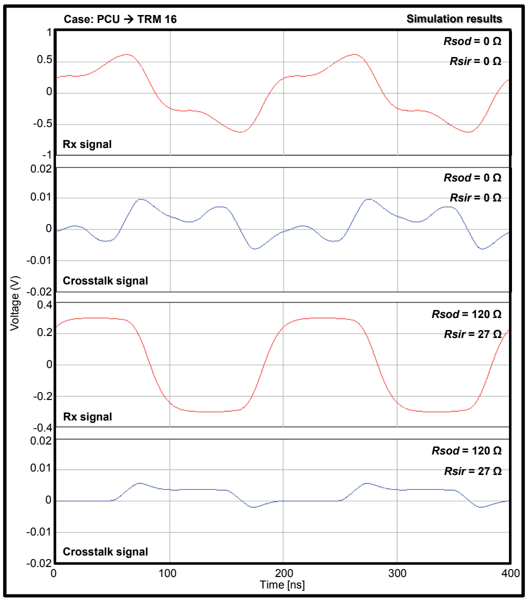

Fig. 5. Effect of serial resistors, R_{sod} and R_{sir}, on received and crosstalk voltage level (PCU → TRM 16).

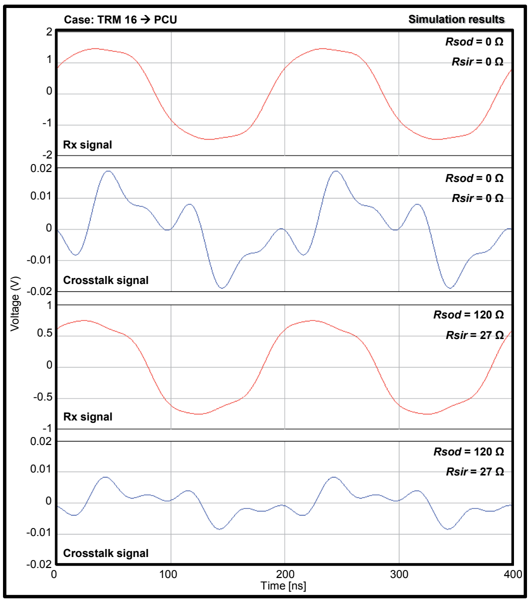

Fig. 6. Effect of serial resistors, R_{sod} and R_{sir}, on received and crosstalk voltage level (TRM 16 → PCU).

Crosstalk is a very important factor because it is a source of error that affects the data transmission of X–band SAR. There is no general approach for crosstalk reduction. It will depend on the vulnerability of the transmitted and received signals to this phenomenon, without forgetting voltage thresholds of used multipoint data transmission protocols. In the worst case scenario according to the considerations made before, crosstalk was diminished about 50 % both PCU → TRM and TRM → PCU. The useful signal was attenuated around 6 dB in both directions until it was equalized taking into account RS422 threshold. Receiver input threshold is ±200 mV for RS422.

Each type of serial resistor is more or less relevant which depends on the direction of the data transmission. The R_{sod}'s effect is greater in the PCU → TRM direction, while the R_{sir}'s effect is greater in the TRM → PCU direction. The graphical representation of this analysis is shown in Fig. 7. The first graph shows the crosstalk reduction (%) in the PCU → TRM direction, while the second graph shows the crosstalk reduction (%) in the TRM → PCU direction. The crosstalk was reduced around 50 % as it was considered. Optimal values are R_{sod} = 120 Ω and R_{sir} = 27 Ω, which are extracted from the first and the second graph, respectively.

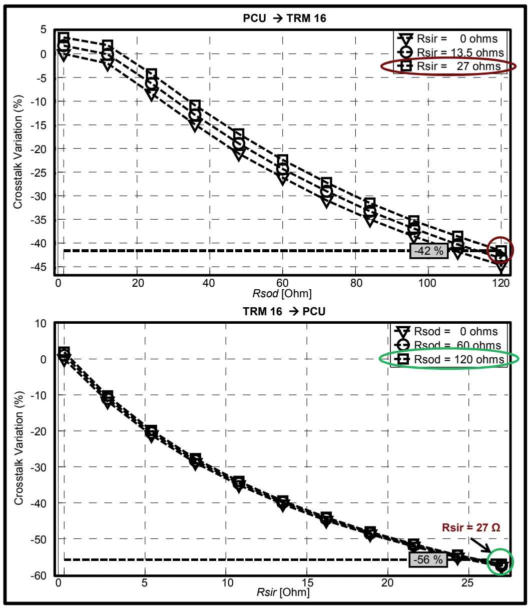

Fig. 7. Effect of serial resistors on crosstalk voltage level.

3. The Prototype in Test

The advanced prototype system was mounted to verify simulation results. Moreover, it allowed us to make additional tests with more accuracy as well as crosstalk analysis in presence of serial resistors and jitter and BER measurements by using noise injection.

The photo of the lab–scaled prototype is shown in Fig. 8.

3.1 Analysis of Serial Resistors

As the lab–scaled prototype consists of 4 TRMs and a PCU driver, optimal values of resistors are different from those calculated in section 2.5, although their values are estimated in the same way. Optimal values calculated in this case are R_{sod} = 44 Ω and R_{sir} = 27 Ω.

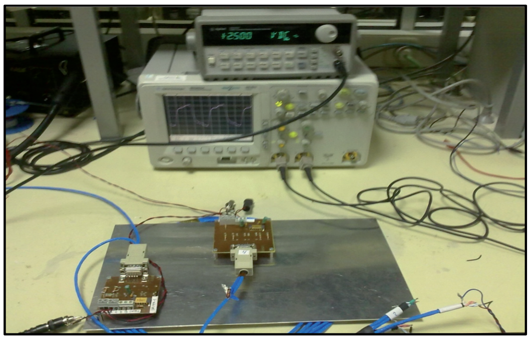

Fig. 8. Photo of the lab–scaled prototype.

As it was demonstrated in the simulation model, serial resistors reduce the crosstalk signal level on average by around 50 %. This reduction can be seen in Fig. 9 (in the PCU → TRM direction).

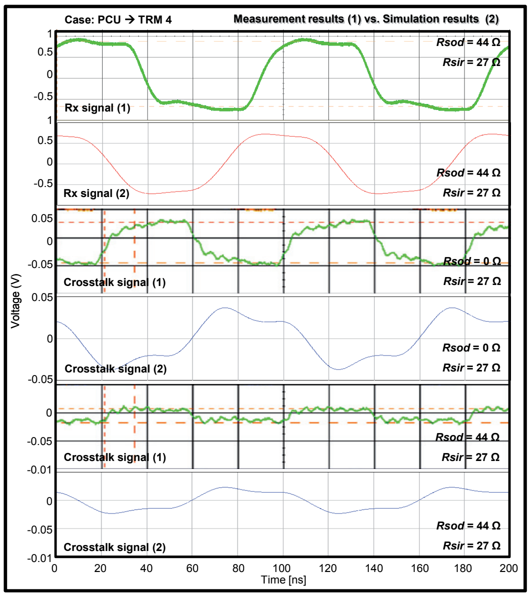

Fig. 9. Comparison of measurement and simulation results (PCU → TRM 4).

These resistors protect module against an accidental short-circuit during the assembly process of the different blocks, PCU and TRMs. These modules are sealed since the short–circuit would result in malfunction of the entire module. As the drivers and receivers have low output and input impedance, 8 Ω in both cases, it is needed to increase the impedance by means of the serial resistors, R_{sod} and R_{sir}. The measurements are compared with simulation results in Fig. 9 and Tab. 2.

PCU → TRM 4		
Results	Rx signal (Vpp)	Crosstalk signal (mVpp)
Measurement	1.55	25
Simulation	1.38	30

Tab. 2. Measurement results vs. simulation results.

Main parameters of the high–speed data transmission network (HSDTN) and lab–scaled prototype (LSP) are shown in Tab. 3.

Driver				
Gain	Z_{in}	Z_{out}	$f_{cut-off}$	Delay
1	1 K Ω	8 Ω	100 MHz	10 ns
Receiver				
Gain	Z_{in}	Z_{out}	$f_{cut-off}$	Delay
1	8 Ω	8 Ω	100 MHz	10 ns
Twinaxial cable segment parameters				
Z_0	ε_r	Losses	Scaling Frequency	Length
120 Ω	2.29	0.15 dB/m	10 MHz	7.5 m
Protection/equalization/impedance matching resistors				
	R_{sod}	R_{sir}	R_{lt}	
HSDTN	120 Ω	27 Ω	120 Ω	
LSP	44 Ω	27 Ω		

Tab. 3. Main parameters of the building blocks of the network.

3.2 Jitter and BER Measurements

The purpose of this test is to analyze the effect of the presence of common mode noise/interference in different points of the high–speed data transmission network. It makes it possible to detect the interference threshold which produces errors in data transmission and reception and besides, it allows us to measure jitter level in this situation. In this section, two cases have been evaluated:

When a strong interfering signal (I) of 1.5 Vpp is injected directly into the PCU driver input of the lab–scaled prototype, BER is degraded. At the receiver output, at the TRM furthest from the PCU (TRM 4) – 7.5 m away from the central processor, the jitter measured in this circumstance is 145 ns as shown in the first graph of Fig. 10.

When an interfering signal (I) of 10 Vpp was injected at the *Line termination*, BER was deteriorated to 10^{-11}. The variation of BER as a function of jitter in this state is shown in the second graph of Fig. 10.

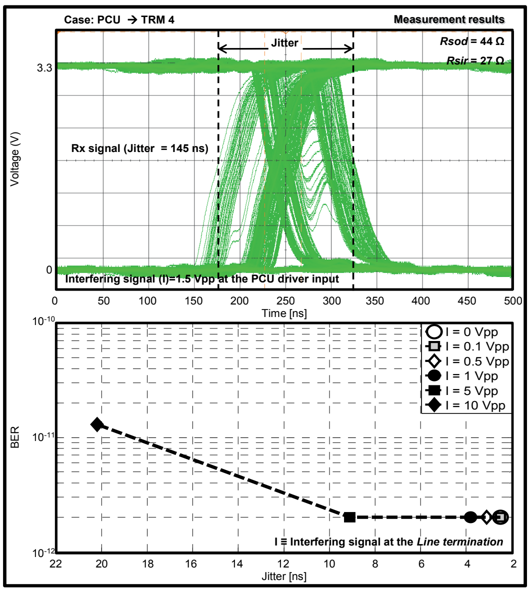

Fig. 10. Rx signal + interfering signal (PCU→TRM 4). BER vs. Jitter at the *Line termination*.

4. Conclusion

The transmission of high speed data in a SAR satellite with large planar arrays requires the use of a complex data distribution network between the Panel Control Unit and the large number of TR–Modules located in the panels. This network must be carefully designed and must have high reliability to avoid transmission errors. In this paper, we have presented the architecture and a solution of the problems of data transmission between the Panel Control Unit and TR-Modules of the satellite. The principal problems are the equalization of the asymmetric transmission between PCU and TRMs and the effect of crosstalk between different lines. To improve the system several resistors have been added to equalize and optimize transmissions in both directions. The process of optimization and calculation of these resistors has been accurately described providing a method for equalizing signals in both directions. These resistors have been designed to reduce crosstalk and the effect of other critical parameters in the transmission network and to protect modules against short–circuits. A scaled prototype has been used to compare measurement and simulation results and to evaluate the effect of the equalization resistors. Finally, the analysis of the effect of jitter on BER has been included. The final outcome of the modeling and optimization is an asymmetric bidirectional high-speed data transmission network with ameliorated signal integrity: crosstalk and distortion reduction, impedance-matching and BER performance improvement. This network provides a compact design through a simple solution and has been implemented in the SEOSAR/PAZ satellite whose launch is scheduled for late 2012.

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