C-Band Reconfiguration Matrix Employing MMIC Switched Amplifiers

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Abstract

This paper presents the design, packaging and measured performance of a redundant 8x8 Reconfiguration Switch Matrix (RSM) at 5.5 GHz for use on board the Data Relay Satellite Systems (DRSS). The RSM includes the RF Switch Matrix (RFSM), a Switch Matrix Controller (SMC) and a Telecommand/Telemetry Interface (TTI). Miniaturization of the RFSM has been achieved by using custom designed MMIC switched amplifiers. The ON-state insertion loss and ON-to-OFF isolation for all the 64 RSM paths are measured to be 8 dB and 60 dB (minimum) over 5.3 to 5.7 GHz frequency range, respectively. The gain tracking between the 64 pathes is within 1 dBpp. This design allows for modular 8x8 RFSM expansion or redundant contraction.

Introduction

The increasing Low Earth Orbit (LEO) spacecraft traffic and mission data communication requirements necessitates an increase in the real-time ground segment communication capability per orbit.

The European Space Agency (ESA) Data Relay Satellite Systems (DRSS), consists of three geostationary satellites, in thus seen to improve LEO spacecraft ground segment communications. In order to achieve the required frequency flexibility and interconnectivity in the DRSS, reconfiguration switch matrices are required to switch incoming IF signals (from downconverters) to the appropriate upconverters and transmitters.

RF switch matrix development, of late, has concentrated on development of the INTELSAT satellites for TDMA applications, with numerous publications on this subject [1] - [6]. RFSM development thus far have been limited to one-off applications of 8x8 size or smaller (e.g. 4x4 size), although a 20x20 size proof of concept was reported [3]. The disadvantage of the larger 8x8 matrices is their size and mechanical complexity. The physical size is approximately a square function of the matrix order. In addition, RF-performances are degraded considerably with the increase in RFSM size. There is an evident trend to planar architectures, using MIC passive and MMIC active circuits.

RSM Requirements

The purpose of this study was to identify by analysis, design, manufacture and test a redundant 8x8 RSM with on board telecommand, control and telemetry, using an architecture and structure that would allow for flexible implementation of larger or smaller matrices, in the DRSS.

The operating frequency band of the RSM is from 5.3 to 5.7 GHz and must provide a non-interruptable reconfiguration, with a path-to-path isolation of 60dB. The SMC & TTI unit receives the telecommand data for the desired RFSM configuration and monitors the power consumption and switch status of the RSM.

As preparation for these requirements, ESA has placed a contract on ANT Nachrichtentechnik GmbH together with Plessey to study, design, manufacture and test one engineering model redundant 8x8 RSM for the DRSS.

Fig. 1 shows the principle block diagram of the RSM required.

RFSM Design

The variable time assignment requirements can only be satisfied using one of the following architectures:

- Divider/Combiner Matrix
- Coupled Crossbar Matrix
- Single-Pole-Multi-Throw Matrix (SPMT)

The SPMT matrix, however, is limited in the maximum isolation achievable.

Coupled crossbar matrices are suited to matrix expansion but require couplers of varying coupling ratios (3 dB to 9 dB for an 8x8 RFSM) which is difficult in the production. In addition, the additive losses and VSWR's in such an architecture limit its RF-performance , e.g. gain tracking, at 8x8 RFSM level.

Therefore, a planar form of the power divider/combiner matrix was selected, because it provides the optimum RF-perfomance, mechanical and structural simplicity with simple control requirements, using one switch per node or path.

The 8x8 matrix is based on a corporate structure of binary couplers. The Wilkinson coupler provides an optimum performance in "coupling balance", insertion loss, bandwidth and coupling variation. It is easy to fabricate, although it suffers from poor Input VSWR's, (see [2]).

In order to overcome this problem, a **Lange** coupler is used as the level of binary coupler, thus providing a good input/output VSWR to the ports of the RFSM for any balanced port terminations. For the 8x8 RFSM 16 eight-way corporate structures are required. They are designed using 15 mils Alumina substrate for the **Lange** coupler and 10 mils 5880 RT-Duroid for the **Wilkinson** couplers and 50 Ω interconnect lines. The 8 input corporate dividers differ in size and layout from the 8 output corporate combiners.

Since each of the 8 input corporate dividers include 8 packaged MMIC switches, the layouts were designed for a minimum size determined by the switch package size ($1cm^2$). The 8 input corporate dividers and switches and the 8 output corporate combiners are arranged in mechanical channels which suppress wave guide mode propagation. These input channels are arranged orthogonally to the output channels on either side of a common base which forms a planar architecture. The RF connection between the created input and output channels is managed by means of custom designed RF-feedthroughs.

For a redundant 8x8 RSM, two modular 8x8 RFSM's paralled provide the optimum redundancy and modularity for further expansion.

The MMIC Switched Amplifier

The MMIC switch concept consists of a 3-stage self-biased FET amplifier, straddled by two SPDT FET switches, which in the ON-state connect the RF-path through the amplifier and in the OFF-state terminate both RF ports in on-chip 50Ω resistors. The switched amplifier has a gain of about 15 dB in order to achieve an ON-to-OFF isolation of 60 dB.The switch has the following main characteristics:

- Gain of approximately 15 dB in the ON-state
- ON-to-OFF isolation of 60 dB
- Low power consumption in ON-state (< 250 mw)
- No power consumption in OFF-state
- Two DC-lines, one for power supply and one for direct digital control
- Non-reflective

This novel design utilizes a single 5V supply (50 ma in ON-state) and a single control voltage (0V = ON-state , -5V = OFF-state). This simplifies the DC wiring and the digital control circuitry.
The MMIC has been designed and processed on the standard Plessey (GEC-MARCONI) F20 GaAs Foundry line. All components are realized on a single chip, measuring 4 mm x 1.5 mm. The MMIC is packaged as shown in Fig. 2. It has the bias and control lines brought to both sides of the chip to facilitate assembly and use of packaged device in both left- and right-handed configuration. Fig. 2 shows also the on-wafer RF measurements.

SMC & TTI

The Switch Matrix Controler (SMC) and Telecommand/ Telemetry Interface (TTI) unit is required to perform the following functions:

- Provide an interface for Telecommand reception
- Subsequent TC decoding and configuration setting
- Provide a temperature Telemetry signal
- Provide a Telemetry of the RSM power consumption
- Provide a Telemetry of the current switch status
- Provide a TC-Memory-load-Command-Read-Back in the form of Telemetry signal (TM of the last TC configuration before execution)

A block diagram of the SMC & TTI unit is given in Fig. 3. These functions provide the necessary RSM control and monitoring without overcomplication with on board diagnostics. The considerable digital circuitry required in this unit requires a consideration of the technology to be used. Modern trends emphasize the use of ASIC's for their size and weight advantage.

The TC signal is a 16 bit serial data word which adresses and configures one RSM input row of eight switches. Thus a total of eight TC's are required to completely reconfigure the RSM. The Telemetry Read Back (TMrb) and switch configuration Telemetry (TMsw) are both 16 bit serial data words. These telemetry signals can be adressed by means of an ENABLE bit for each. The 16 bit word provides three spare bits for future expansion and includes a priority RESET bit, (this sets all switches to OFF, after the EXECUTE signal, when activated). Row-by-row addressing reduces the data word length to a minimum and significantly simplifies the SMC & TTI unit circuitry. The system application do not require any severe constraints on switching and configuration speed, such as those required for TDMA.

RSM Performance

The integrated RSM is shown in Fig. 4. Key performance characteristics are summarized in Table 1. The RSM provides any N inputs to any or all M outputs including broadcast mode. The measured transmission loss performance for all 64 paths (Fig. 5) shows ON-state insertion loss of about 8 dB and a path-to-path insertion loss variation of less than 1 dBpp over the frequency range

5.3 to 5.7 GHz. The ON-to-OFF isolation is greater than 60 dB (Fig. 6). The power consumption of the matrix is less than 3 watts.

Table 1. RSM Performance Chracteristics

* Frequency Range	5.3 -5.7	GHz
* Bandwidth	400	MHz
* Nom. Input Power	-20	dBm
* Gain	>-8	dB
* Gain Flatness	<0.8	dBpp
* Gain Tracking	< 1.0	dBpp
* 3rd Order Intermod.	<-65	dBc
* Crosstalk	<-60	dBc
* Input/Output Return Loss	>20	dB
* DC Power Consumption	< 3	watt

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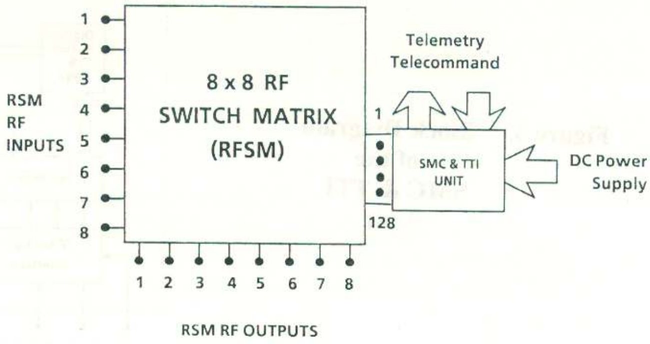

Figure 1. A Simplified Block Diagram of the RSM

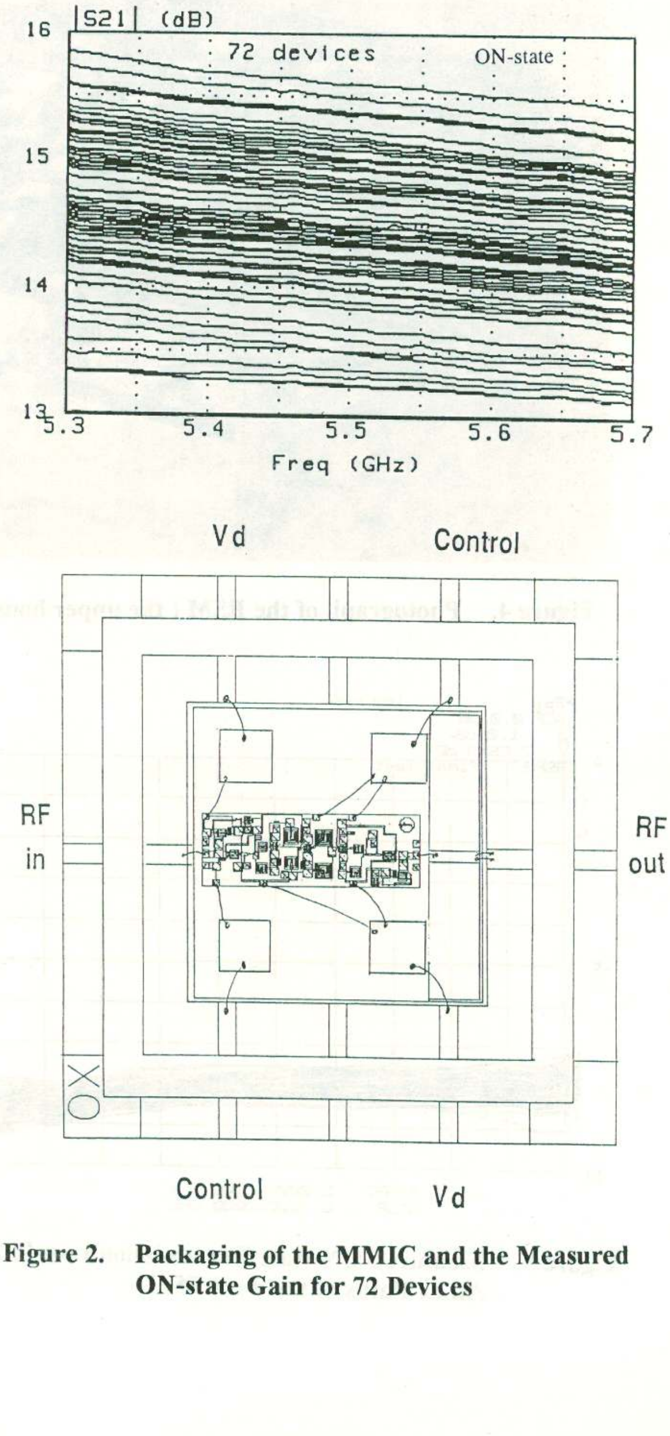

Figure 2. Packaging of the MMIC and the Measured ON-state Gain for 72 Devices

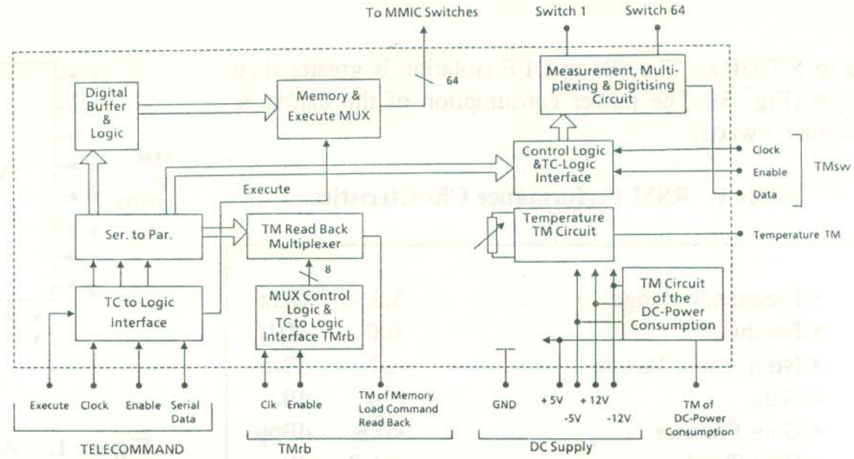

Figure 3. Block Diagram of the SMC & TTI Unit

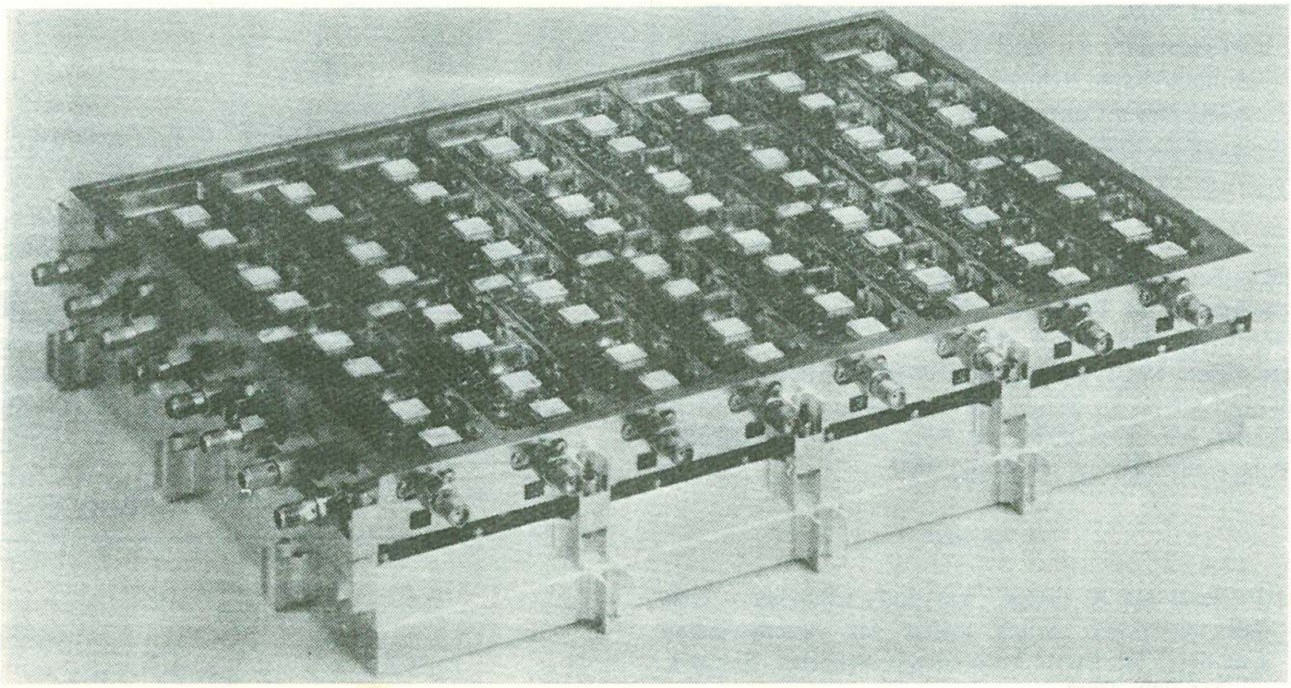

Figure 4. Photograph of the RSM (the upper housing is the RFSM the lower one is the SMC & TTI unit)

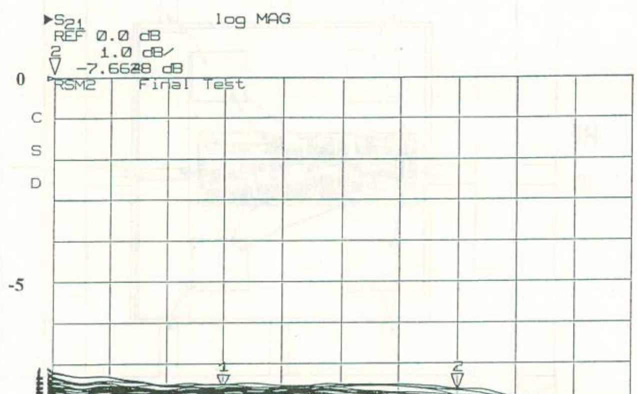

Figure 5. Measured ON-state Transmission Loss for All 64 Paths of the 8 x 8 RSM

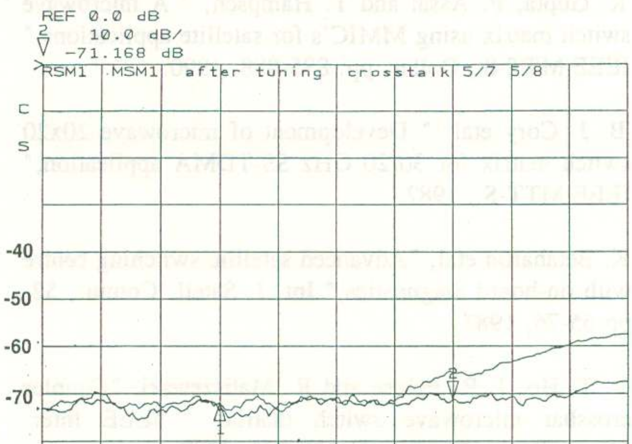

Figure 6. Measured Crosstalk between adjacent Paths of the 8 x 8 RSM