SOLID STATE COMPACT AND SCALABLE KA-BAND SWITCH MATRIX IN LTCC PACKAGE

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1. Abstract

The latest results of a project aimed at design of a novel Solid State Switch Matrix are reported in this paper. The object of the study, which is founded by the Italian Space Agency (ASI) and under supervision of ESA (Contract Nr.5.1-5C.171 A0/1-7369), is to design and fabricate a Ka-band (27.5 to 30 GHz) 4x4 switch matrix, as a building block for higher order switch matrices. The intent is to prove the feasibility of an advanced highly integrated, low mass and cost effective Switch Matrix for use in future Ka-band multi-beam payloads for application either in low level redundancy rings or in flexible on-board channel to beam connectivity.

2. Switch Matrix Design

The basic 4x4 switch matrix (see the block diagram in Fig.1) has four by-4 splitters blocks followed by SPST's switches at the input, four SP4T's at the outputs and suitable 50 ohm lines and crossings to realize a point-to-multipoint connectivity, which may be used in flexible payload to process the signal coming from a single beam with more than one transponder, in case of traffic increase.

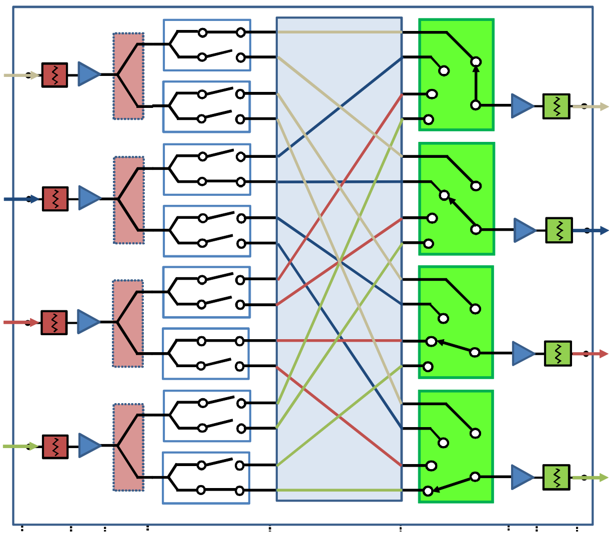


Figure 1: 4x4 Switch Matrix module

The design also includes MMIC amplifiers to restore the losses and input/output attenuator to improve matching. Input and output I/F are coaxial *blind mate* connectors.
The design is conceived to be implemented on a single tile of multilayer LTCC substrate, which is the proper choice to reduce fabrication cost.
As the design is rather complex in that the RF signal paths go thru several items such as coaxial connectors, MMIC switches and amplifiers, routing and crossing etc., a special care must be paid on the study of the transitions among such different types of transmission lines and components. The target is to reduce the insertion loss and the undesired coupling among not connected RF paths. With the aim to reduce the number of transitions as much as possible, the Matrix has been developed using a 22-layer LTCC substrate. In this way, the strip lines can run on different layers without interfering

each other. In Fig.2 the various sections of the LTCC board are shown. **Sect. A** includes transitions between coaxial connectors and strip lines. Any of the four strip lines runs on a different layer of the LTCC board.

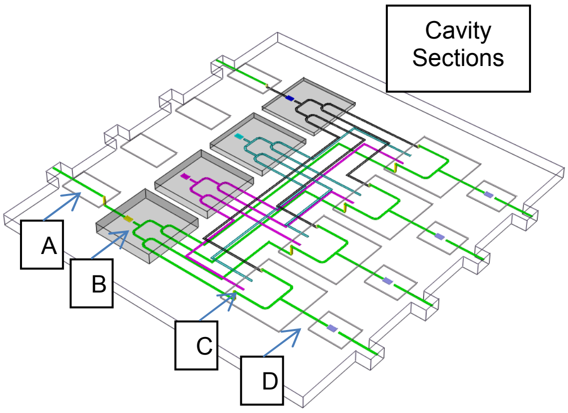


Figure 2: Conceptual Switch Matrix Scheme

Sect. B has cavities on different layers. Each cavity includes a MMIC amplifier (UMS-CHA2190), a by-two Wilkinson divider and two SPDT MMICs, specifically designed for this project. Both input and outputs are strip lines. As the strip lines leaving these cavities have different routes with different losses, suitable attenuators are necessary to equalize the losses of any path. Each cavity of **Sect. C,** in which the SP4T MMIC switch is assembled, collects the signals arriving from the four Matrix inputs to one of the possible outputs. The four inputs are at different levels, in this case, while the output is at the same level for any of the four output. Finally, **Sect. D** has cavities all at on the same layer, which contain a second MMIC Amplifier (UMS-CHA2190).
All the cavities and signal path have been analyzed and optimized by using a full 3D Electromagnetic Simulator (CST Microwave Studio), as well as any transition, in order to reduce the insertion loss and get the best 50 ohm matching. To enhance RF isolation among transmission lines, absorptive walls have been widely used, as shown in Fig. 3.

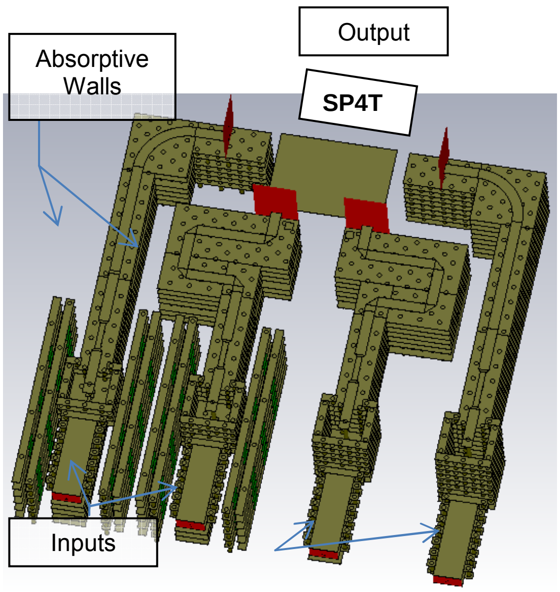


Figure 3: Absorptive walls in Section C of the LTCC board

The 3D drawing of the internal layout of the 4x4 Switch Matrix module is presented in Fig.4. The LTCC board (in blue) including the RF section of the matrix is assembled in a cavity of the module, while the digital circuitry needed to process the commands for the setting of the matrix and drive the switches is implemented on a second LTCC board, which is assembled in a separate cavity of the module. DC connections between the two boards are realized by using EMI-filters to improve isolation. The mechanical box is composed by a baseplate made of AlSi material, a Kovar frame and a top lid in Aluminum. These metallic items are gold plated. The Kovar frame is brazed onto the AlSi. The use of AlSi as a material for the baseplate has been chosen to better dissipate the thermal heat produced by the MMIC amplifiers and prevent their junction temperature to go higher than 115°C.

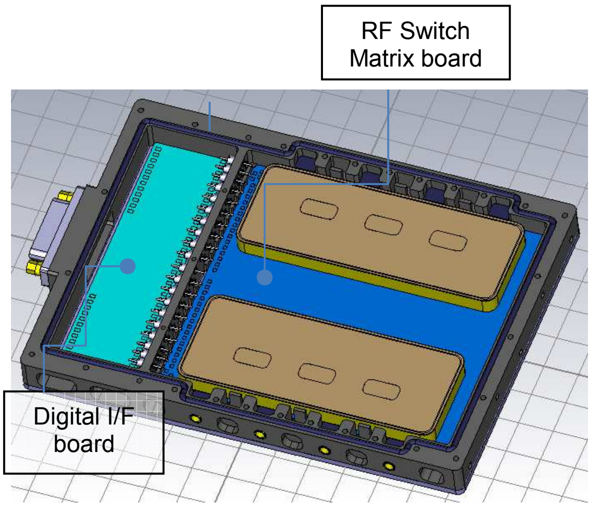


Figure 4: Mechanics lodging RF and digital parts of the switch matrix

In order to meet the demanding performance of 50dB of isolation, the undesired coupling among the RF paths must be reduced as much as possible. The most problematic has been found to be the coupling between adjacent connector pins. Due to the fabrication tolerances of both LTCC board and mechanical box, a small gap between the board and the frame is unavoidable. This realizes a channel (like a sort of waveguide) running all around the structure, which can sustain an electromagnetic field propagation. To reduce the associated coupling, the gap is filled with conductive glue; this tends to rise the cut-off frequency of the pseudo-waveguide. A further coupling effect is between connector pins of opposite sides (input to output) by EM field radiation inside the mechanical box. This is highly reduced by properly machining the top cover of the mechanical box. As shown in Fig. 5, a series of posts are realized acting like a periodic filtering structure.

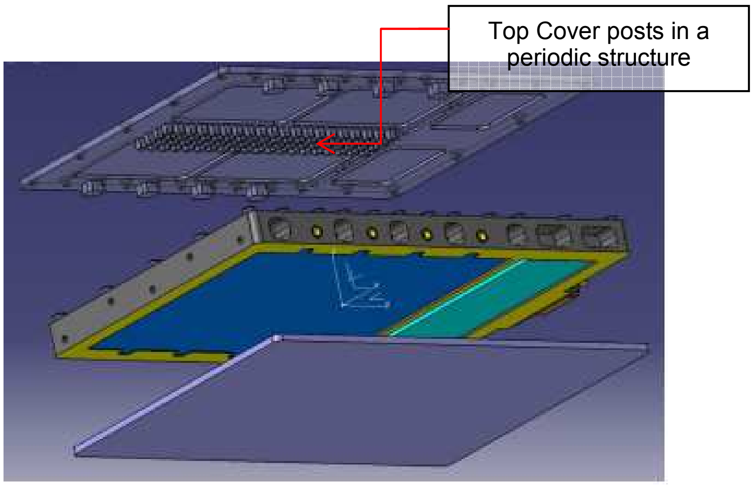


Figure 5: Final assembling of the switch matrix

In Fig. 6 all the analyzed sources of coupling are plotted together, as simulated with CST Studio. The worst case is still the coupling between adjacent pins (red curve), which goes over 50dB in the range 29 to 30 GHz.

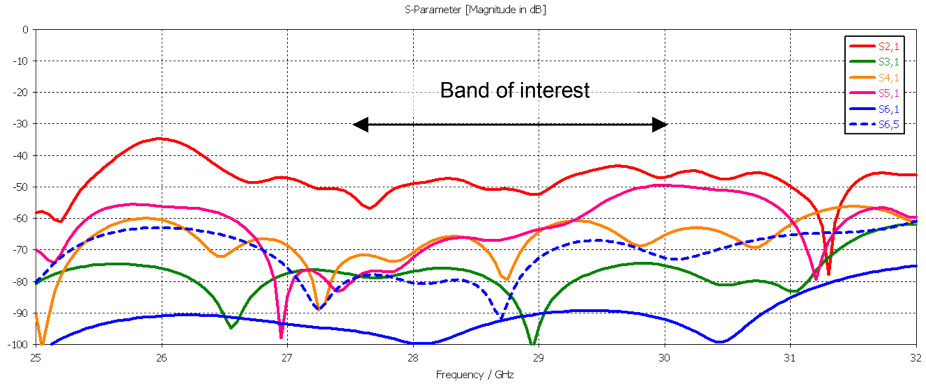


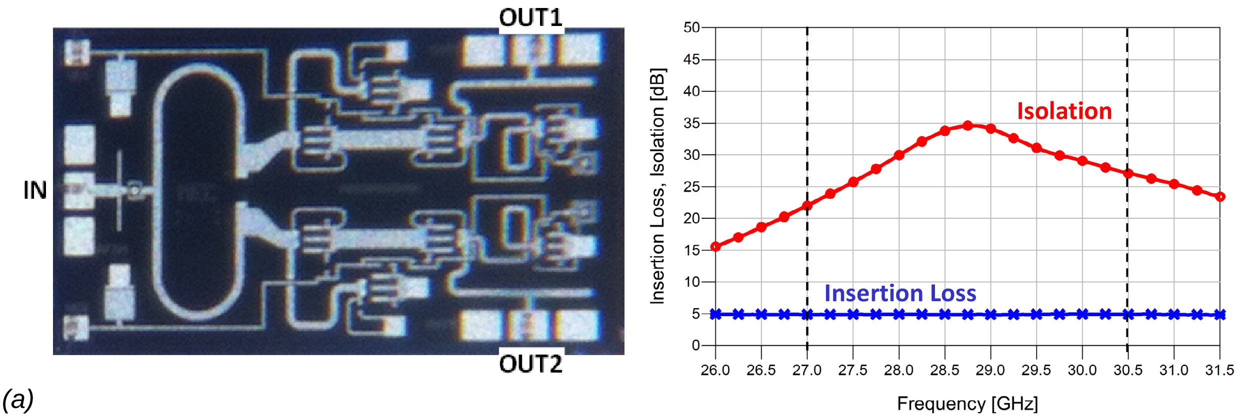
Figure 6: Behavior of different coupling sources in the Switch Matrix

3. MMIC's Building Block Test Results

Two custom MMICs have been specifically designed for this project: a *Reconfigurable SPDT* and a *SP4T switch*, to be used at the input and output of the 4x4 building block, respectively. Their topology and configuration are based on three fundamental requirements:

a) to provide high Isolation between each path
b) to present an absorptive load at the inputs and outputs in any operating condition (*Reconfigurable SPDT*)
c) to exploit one single control voltage for each branch to set the required configuration.

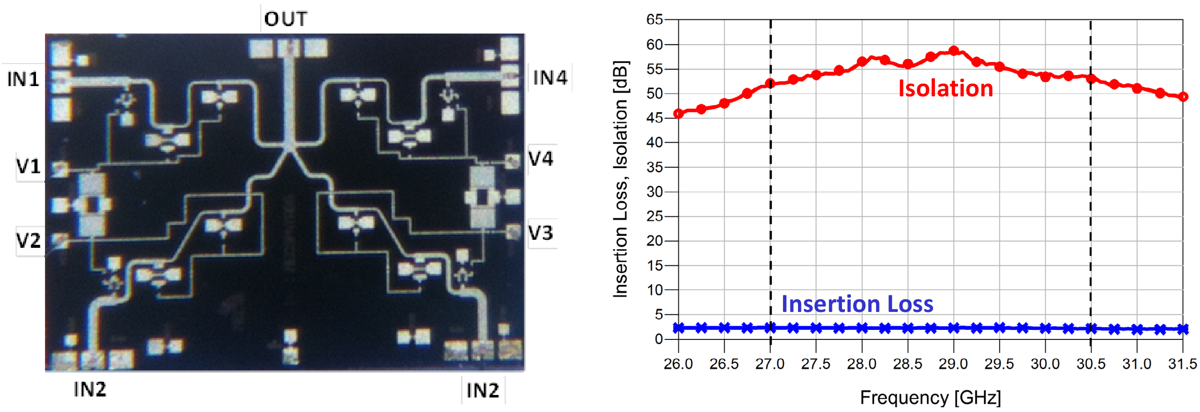
The MMICs have been realized exploiting the space-qualified PH25 process, from United Monolithic Semiconductor (UMS). It is a 0.25 µm gate-width GaAs/InGaAs/AlGaAs pHEMT technology featuring a T-shape aluminium gate obtained by double electron-beam lithography.
Compared to the usual schemes, the *Reconfigurable SPDT* allows routing the input signal to either, both or none of the outputs, properly loading the power splitter at the input, whichever the selected configuration is. As shown in Fig. 7a, the MMIC consists of an integrated microstrip power divider and two absorptive SPST. The latter exploits four switching transistors, two series and two shunt, which are switched On and Off to enable and disable the channel, respectively. Aiming at obtaining the best trade-off between insertion loss and isolation, both transmission lines characteristics and transistors dimensions have been carafully optimized to minimize the losses and to guarantee a good isolation when the specific path is turned Off (transistor in Off mode). Besides, a proper dimensioned resistor in parallel with the shunt transistors ensures the absorptive characteristic at the output of the integrated combiner and at the output of the MMIC when the SPST is operated in Off mode. Fig. 7b shows the measured performances in terms of insertion loss and isolation: they are respectively nearly 5 dB and better than 20 dB over the operating bandwidth. It is worth noticing that, due to the specific application, the isolation has been defined as the difference between the insertion loss of the connected and the disconnected paths. The MMIC can be set in Off mode by applying a control voltage between -2V and -1.3V; while the On mode corresponds to a voltage range between -0.2V and +0.6V. The MMIC has dimensions 2.4x1.4 mm^2.



(a) *(b)*

Figure 7: Reconfigurable SPDT photo (a), Insertion Loss and Isolation (b)

In the 4x4 matrix configuration, each of the four SP4T MMICs can receive signals from all the inputs, but only one path can be activated and routed to the output. The activated path exploits the transistors in their Off mode, while the remaining paths are deactivated by switching their transistor On. When activated, each of the four branches has a low-pass filtering response. This has been obtained by carefully design the series transmission lines and the shunt parasitic capacitance of the transistor in Off mode (i.e. the size of the shunt transitor). Once the best configuration for the single path has been designed, a final circuit optimization was required to adjust the desired performance by taking into account the unavoidable interaction between the active path and the other ones. This MMIC is reflective so it doesn't have any absorptive path at the not-connected inputs. Fig. 8a shows the photograph of the SP4T MMIC. Its expected insertion loss and isolation are about 2.3 dB and better than 50 dB (sostituire grafico con misure), respectively. In the SP4T the Off state can be set by applying a control voltage between -0.2V and +0.6V; while the On state corresponds to a voltage range between -2V and -1.3V. The MMIC has dimensions 2.4x3.4 mm^2.



(a) *(b)*

Figure 8: SP4T layout (a), Insertion Loss and Isolation (b)

With reference to the block diagram, the RF budget of the 4x4 switch matrix is presented in Table 1, which includes all components and interconnecting structures along each channel. Table 1a, summarizes the main contribution to the RF Budget for the building block, which achieves a Gain of about 0.1 dB and a Power consumption of 1.4 W. Likewise, Table 1b shows the budget for the whole 32x32 Switching Matrix, obtained by the combination of 40 4x4 elementary cell, with an estimated Gain of about -1.9 dB and a Power consumption of 56 W.

4x4 BUILDING BLOCK

#	Qty	ITEM	GAIN (dB)	P1dB (dBm) (Input)	PDC (W)
			INDIVIDUAL COMP. PERFORMANCES		
1	4	CONN/TRANSITIONS	-2.8	40.0	0.00
2	4	Attenuator1	0.0	40.0	0.00
3	4	PA - CHA2190	14.5	-1.0	0.18
4	4	Power Divider	-5.0	40.0	0.00
5	8	MMIC2 - SPDT ABS	-5.0	10.0	0.00
6	1	Interconnection 16X	-11.2	40.0	0.00
7	4	MMIC1 - SP4T REF	-2.5	10.0	0.00
8	4	PA - CHA2190	14.5	-1.0	0.18
9	4	TRANSITIONS/CONN	-2.4	40.0	0.00
		TOTAL	0.1	1.8	1.40

(a)

32X32 SWITCHING MATRIX

#	Qty	ITEM	GAIN (dB)	P1dB (dBm) (Input)	PDC (W)
			INDIVIDUAL COMP. PERFORMANCES		
1	8	4X4 BB	0.1	1.8	1.40
2	32	Blind Mate SMP Pair	-0.1	40.0	0.00
3	8	4X4 BB	0.1	1.8	1.40
4	4	Interconnection 8X	-1.1	40.0	0.00
5	8	4X4 BB	0.1	1.8	1.40
6	4	Interconnection 8X	-1.1	40.0	0.00
7	8	4X4 BB	0.1	1.8	1.40
8	32	Blind Mate SMP Pair	-0.1	40.0	0.00
9	8	4X4 BB	0.1	1.8	1.40
		TOTAL	-1.90	1.8	56.00

(b)

Table 1 : RF Budget for the 4x4 (a) and for the 32x32 (b) Switch Matrices

4. Packaging

The packaging approach is based on the 3D LTCC technology and solderless connectors advanced packaging techniques is used (SMP). All the MMICs are assembled on a single multi-layer LTTC board (85x85cm), designed and manufactured by the Thales Alenia Space Italia in-house facility.
By exploiting the available 22 internal layers for RF signal routing, DC power lines and commands, the overall size and cost is dramatically reduced (h=3 mm). The crossings of the paths in the 4x4 matrix are realized by using different stripline layers, which have the additional advantage to minimize the couplings and control the isolation performance. One internal layer is exclusively devoted to the routing of the DC lines used for commanding the switches, while the DC I/F are be placed on the top layer.
The TASI LTCC technology allows designing fences realized with via holes, which improve the isolation between adjacent paths even further.

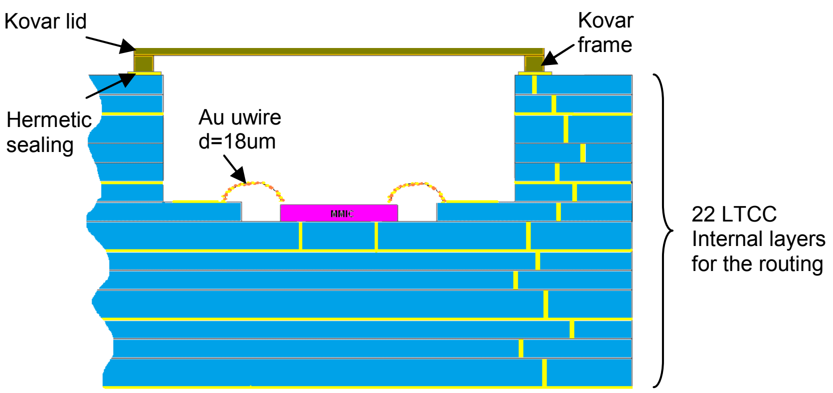


Figure 9: LTCC board for switch matrix RF section

The LTCC board is also used to hermetically package the MMICs, as shown in Figure 9. The dices are glued into suitable cavities realized in the LTCC and connected to the RF striplines and DC lines by using bond wires. The cavities are hermetically closed by means of gold-plated metal rings, soldered onto the LTCC and suitable metals caps, which are soldered onto the metal rings by using the seam sealing technique. This procedure also improves the isolation, as the cavities are shielded each other.
The LTCC board is glued on a baseplate of AlSi alloy, while the upper part will be realized in aluminium in the order to reduce the weight of the overall matrix.
The mechanical assembly (see Fig.10) also includes GPPO RF connectors, DC connector, EMI gasket and Eccosorb.

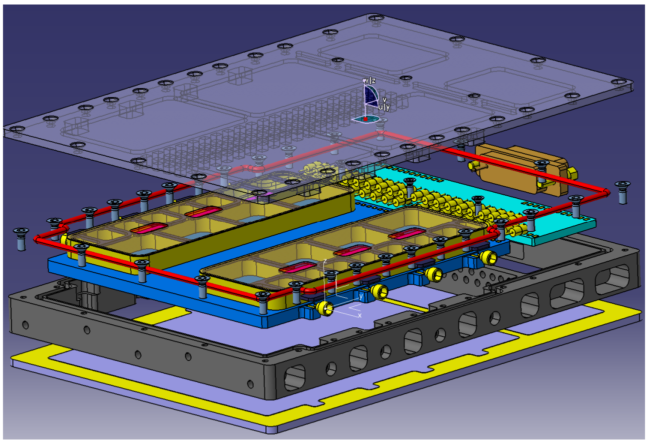


Figure 10: Assembling of the switch matrix

A thermal analysis has been carried out by using the commercial software Strauss 7 with the following assumptions:

Environmental temperature [K]	Thermal load on the lateral walls	Load on the bottom wall	Load on the base wall	Load on the head wall	Supporting plane	Entire case with elements
333.15	Conduction Radiation	Conduction	Conduction	Conduction radiation	Conduction Radiation	Conduction

In Fig. 11, the modelled elements of the switch matrix are represented. The bottom of the case is represented in pink (AlSi), the lateral walls of the case is represented in purple (Kovar), the LTCC is reported in light blue, the MMICs are reported in blue and the mounting plane is represented in azure. Several via's are placed below each MMIC to properly drain the heat.

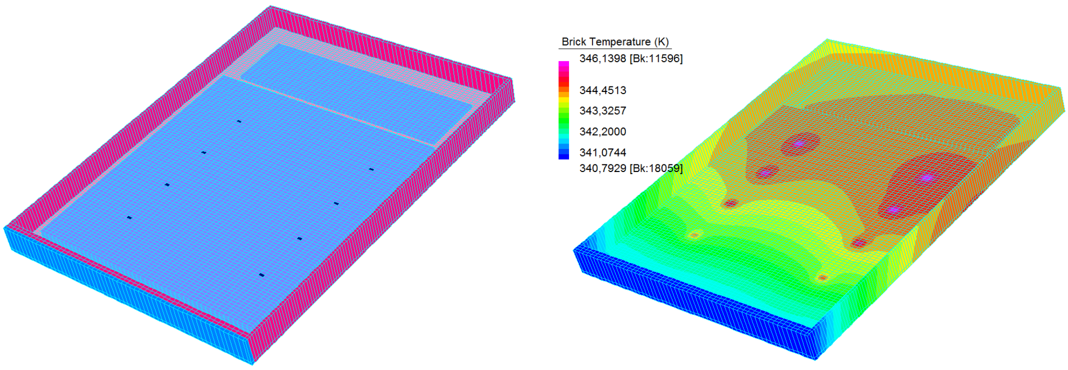


Figure 11: Thermal Analysis of the 4x4 Switch Matrix

The temperature below the MMIC's, which is the hottest point, is about 347°K (74°C). The junction temperature of the MMIC's is calculated by adding 44°C, which are given by multiplying the mounting thermal resistance (bonding with H20E plus silver) and junction to case of the MMIC's by their power dissipation (200mW). The hottest MMIC is at 118°C junction temperature, which is within the maximum allowed derated temperature of 125°C, according to the space quality rules.

Conclusions

The ongoing development of a 4x4 switch matrix module operating in the frequency range 27.5-30 GHz module has been presented in this paper. The 4x4 module is conceived as a building block for high order switch matrices (32x32) to be used on future flexible payload for satellite communication. Key design choice to reduce size and mass, preserving the electrical performance at the same time is the advanced use of multilayer LTCC technology, combined with the development of custom switching MMIC's manufactured by UMS foundry. By the end of 2015 the switch matrix will be fully tested.

REFERENCE

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[2] L. Devlin, "Design of RFICs and MMICs" (Ref. No. 1999/158), IEE Tutorial Colloquium