High Power Ka-band Waveguide (WR51) Isolator for Space Applications

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INTRODUCTION

Recent advancement in Ka-band satellite payloads and equipments drive the power level requirements to several hundred Watts per transponder. Travelling Wave Tube Amplifiers (TWTAs) delivering more than 200 Watt are under development and channel filters for 250 to 500 Watt power handling are also needed for Output Multiplexers (OMUX).
Isolators, based on biased ferrites, consist of a circulator connected to a high power load in order to protect amplifiers from high external VSWR conditions. Current classical Y-junction isolators in the Ka-band are limited for high power applications and cannot handle more than 150-200 Watt because of the very high power density in the centre of the junction. Yet, the major design driver for isolators is the peak power handling and the thermal limitations for the circulator in case that the output of the isolator is short-circuited (failure mode).
For power levels higher than 150 Watt, the temperatures reached by standard designs easily approach the material limitations. In order to support the increased power level requests of payload equipments, novel isolators able to handle at least 300 Watt RF power are necessary.
Therefore, Cobham Microwave, based on a heritage of more than 30 years of space experience in high power circulators and isolators, is designing a novel high power Ka-band waveguide isolator capable to handle a minimum power level of 350W-CW.
This design, unlike standard designs e.g. classical Y-junction and resonance isolator, is based on an innovative technology in order to reduce the power density travelling in the centre of the junction. The proposed isolator will cover the band 17.3-20.2 GHz. The typical electrical performances are 0.15dB for insertion loss, 23dB for isolation and 23dB for return loss at input and output ports in the operating temperatures (from -20°C to +85°C).

HIGH POWER ISOLATOR TECHNOLOGY

Functioning Principle

A 3-port circulator is the basic model which can be used to explain how circulator operates. If a signal is applied at port#1, it will emerge from port#2 with a loss characteristic called “Insertion loss”. Typical values of insertion loss are 0.15 to 0.5 dB. In the reverse direction, there will be leakage at port #3 from the incoming signal at port #1. This leakage called isolation is typically 20dB below incoming power at port #1.
Due to the “3rd order symmetry” of the Y-junction, the behavior is the same for the other ports, with respect to port #1 to port #2, port #2 to port #3 and port #3 to port #1. The function of the circulator is to transmit RF power to the antenna, for instance in the RF head of a radar, with minimized insertion loss and ensuring high isolation between the high power transmitter and the sensitive low power receiver as shown in Fig.1.a.

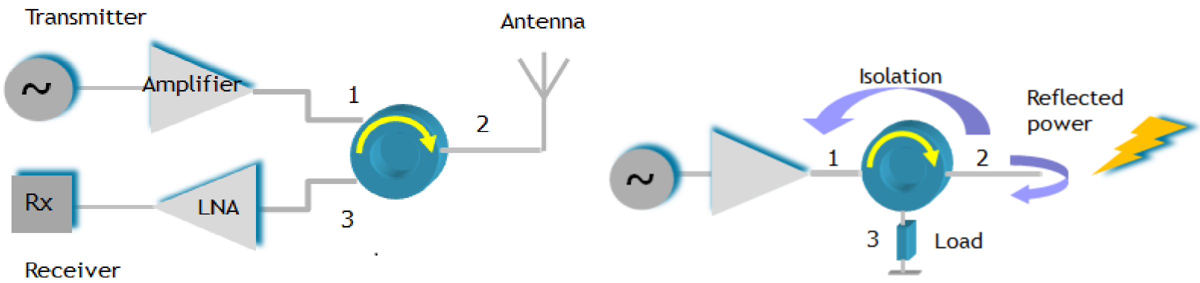


Fig.1. Typical Applications for
(a) Circulators (b) Isolators

A Y-junction circulator can be made into an isolator by adding a termination on port #3 for example. The device transmits signals with low loss (from port #1 to port #2) and with high isolation in the opposite direction (from port #2 to port #3). It is used to "isolate" one microwave device from another. For example, Fig. 1.b shows how an isolator can protect expensive high-power RF sources from variations due to bad matching.
Table 1 shows the types of application where this type of RF components is extensively used for (radar, medical, scientific, military and Telecommunications).

Table 1. Typical Applications

Ferrite Devices	Main Functions	Typical Applications
Circulator	Duplexer Transmission(Tx)/Reception (Rx) In order to use one unique antenna for transmission and reception	Radars
Isolator (circulator + load)	Protection and matching	Microwave Tx, Rx Radio links Space Imux/Omux Etc.

Isolator Design: Cobham Multilayer Gyrator Design

Due to the high frequency of the device, around 20 GHz, the waveguide dimensions of WR51 are rather small: 12.95 x 6.48 mm. Therefore, the power density in the device becomes very large. As a comparison, a level of 350W in WR51 waveguide induces the same power densities than 758W in Ku-band (WR75). Additionally, with a short-circuit in output, average power densities are equivalent to 700W in WR51 in normal conditions and local RF fields can be as high as fields obtained with 1400W in WR51, or 3000W in WR75.These comparisons are to point out the difficulty of the product needed on thermal aspects and power handling in general.
In order to develop such an isolator capable to handle high power at Ka band, one should review all possible designs available for circulators. As for the termination, it is composed with parallel loads connected by a magic T. This termination is under development and should handle the maximum possible reflected power in fault condition (Reverse power 350W-CW): Each unit basic load has lower power to handle which is equivalent of the half reverse power ~175W.
Among possible designs for circulators, there are:

- Classical Y-junction: this design is the classical one. It is limited for high power applications. The matter of power handling capabilities and the thermal effect resulting is discussed later in this paper.
- Parallel Y-junction Assembly: the design consists on an assembly of two Y-junctions with waveguide power dividers that have the same functions of the magic tees. Each circulator should handle half to the input power. The main constraint concerns its volume and mass.
- Classical 4-port waveguide differential phase shift circulator. This is a typical very high power isolator with two loads, widely used and developed by Cobham Microwave. This design is not used for space applications due to the mass and the volume requested by two waveguides partially filled with ferrite material. This design consists of a RF recombination of a magic T and a 3dB-coupler and a load to operate.
- Resonance Isolator, also known as "Uniline". This old design has the advantage that the reflected power from the antenna is directly absorbed in the device without the need of an additional termination due to the absorbing behavior of the ferrite at the ferromagnetic resonance. This solution is not compatible with the present need due to its very large mass and the limited capability of reflected power absorption of the ferrite.
- Faraday–effect circulator that consists on a ferrite needle which is placed in the center of a circular waveguide. A thermal drain is also needed in order to evacuate heat. Farday-effect circulator is rather an old design and commonly used for quasi-optic applications. It is also reported as low power handling capability and lossy, more than 0.5 dB.

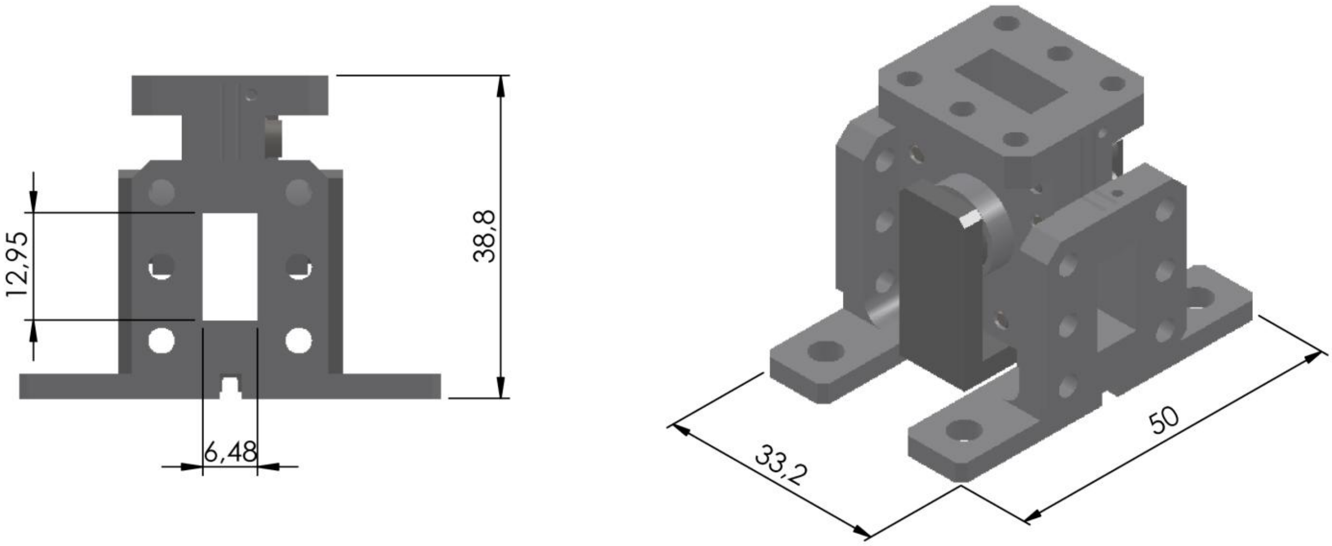


Fig.2. Interface drawing of the "Cobham Multilayer Gyrator Design"

All these designs are eliminated due to volume or mass constraints for some of them or because of power handling limitations for others. Our alternative design is an innovative one that we will call for confident reasons the "Cobham Multilayer Gyrator Design". Fig.2 shows external dimensions of this design.

RF ELECTRICAL PERFORMANCES

Optimizing the performance of this complex design requires an accurate modelling of electromagnetic fields. Therefore, we have chosen the full-wave 3D EM simulator CST Microwave Studio © [1]. Fig.3 shows the circulator design modelled with the transit solver that is based on the *Finite Integral Technique* (FIT).

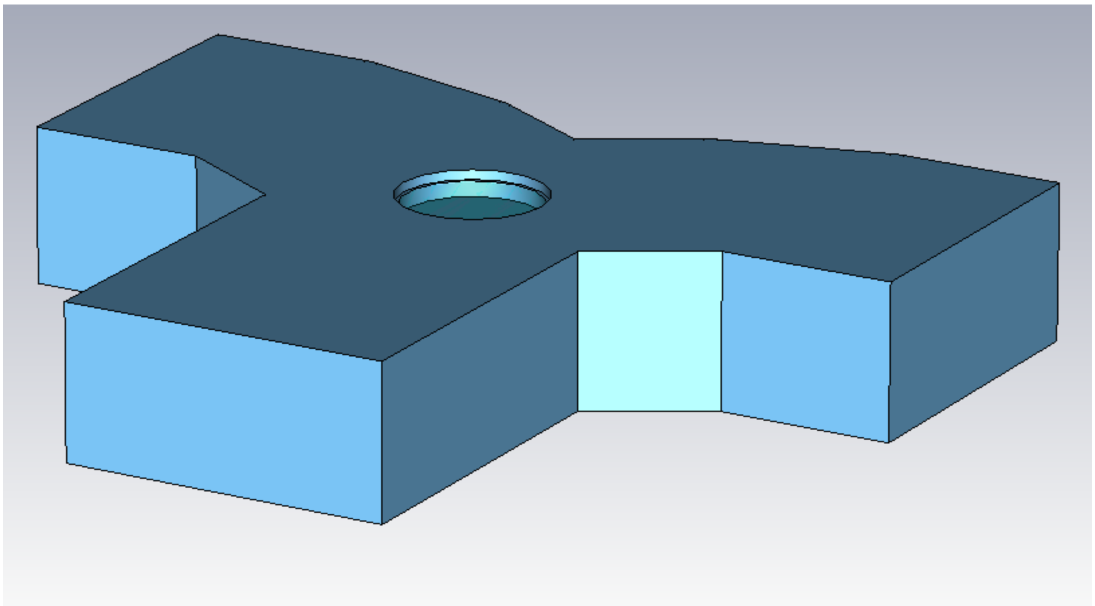


Fig.3. "Cobham Multilayer Gyrator Design" modelled using CST MS.

Electromagnetic simulations show a resonance in the insertion loss parameter in the operating band 17.3-20.2GHz. Fig.4 shows the measurement results that confirm the existence of this resonance around the frequency 19.5 GHz. Therefore the band is split into two equal narrow bands: the low narrow band 17.3-19GHz and the high narrow band 18.5-20.2GHz, with respectively 9.3% and 8.7% bandwidth for each device.

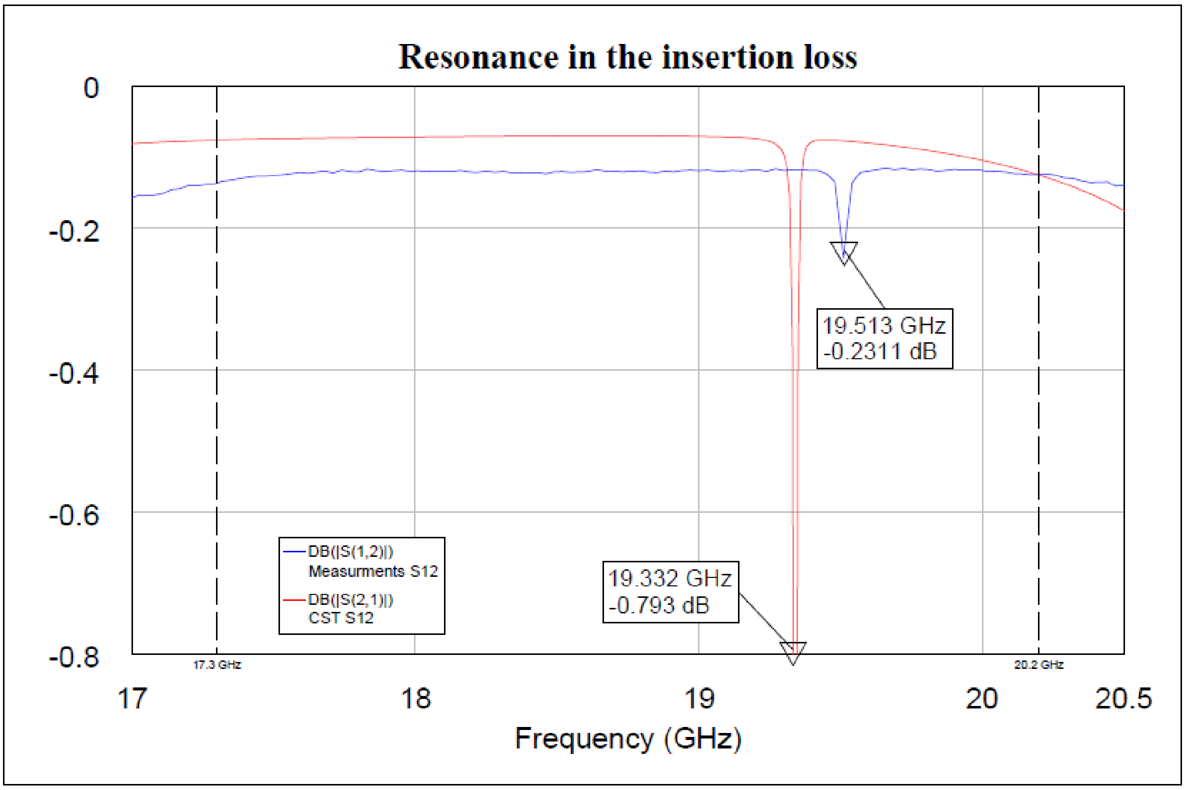
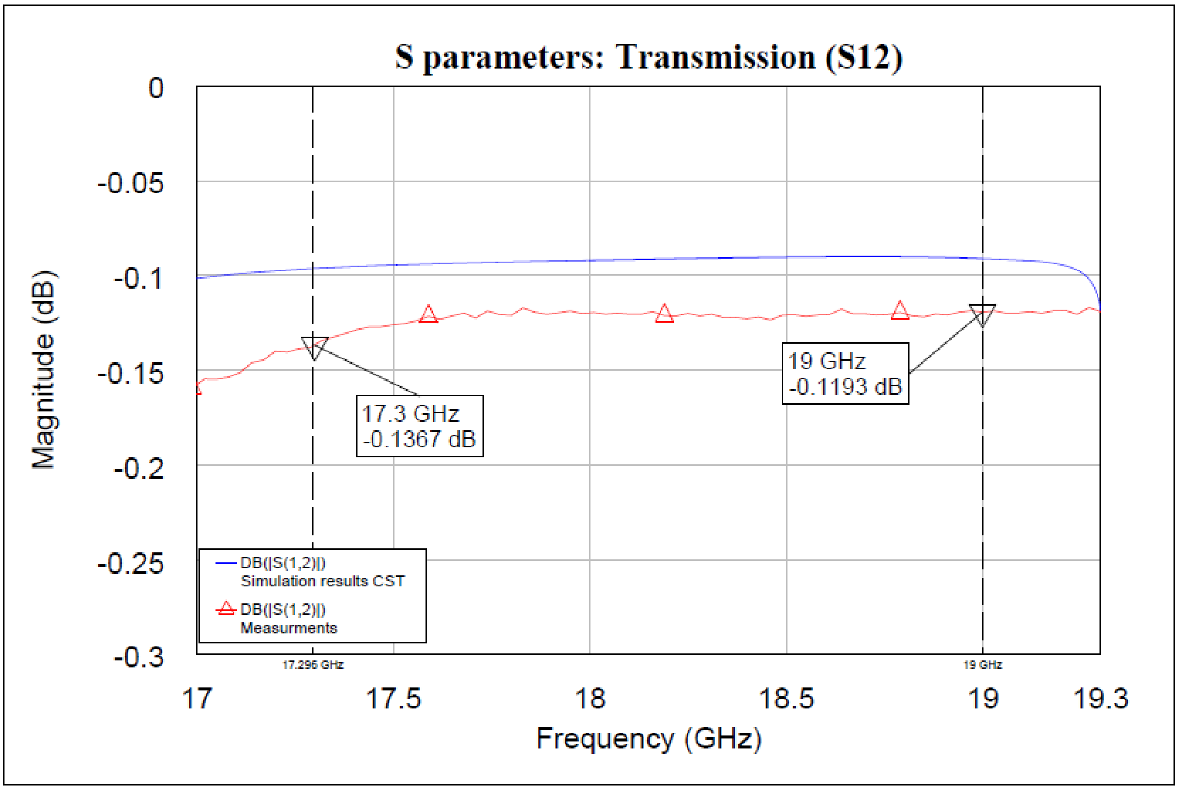
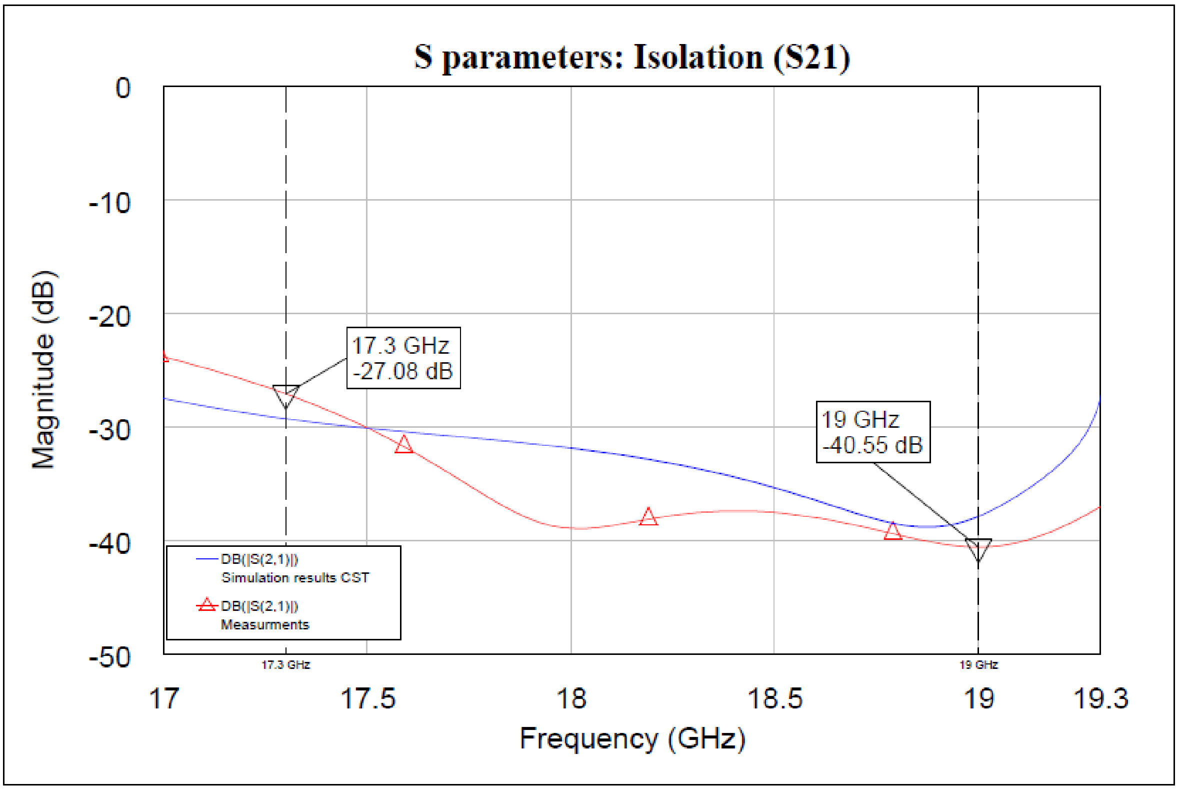


Fig.4. Comparison between simulation and measurement results points a resonance in the operating band.

Optimizing the structure allows to get good performances in order to fit specification for the low narrow band 17.3-19GHz.





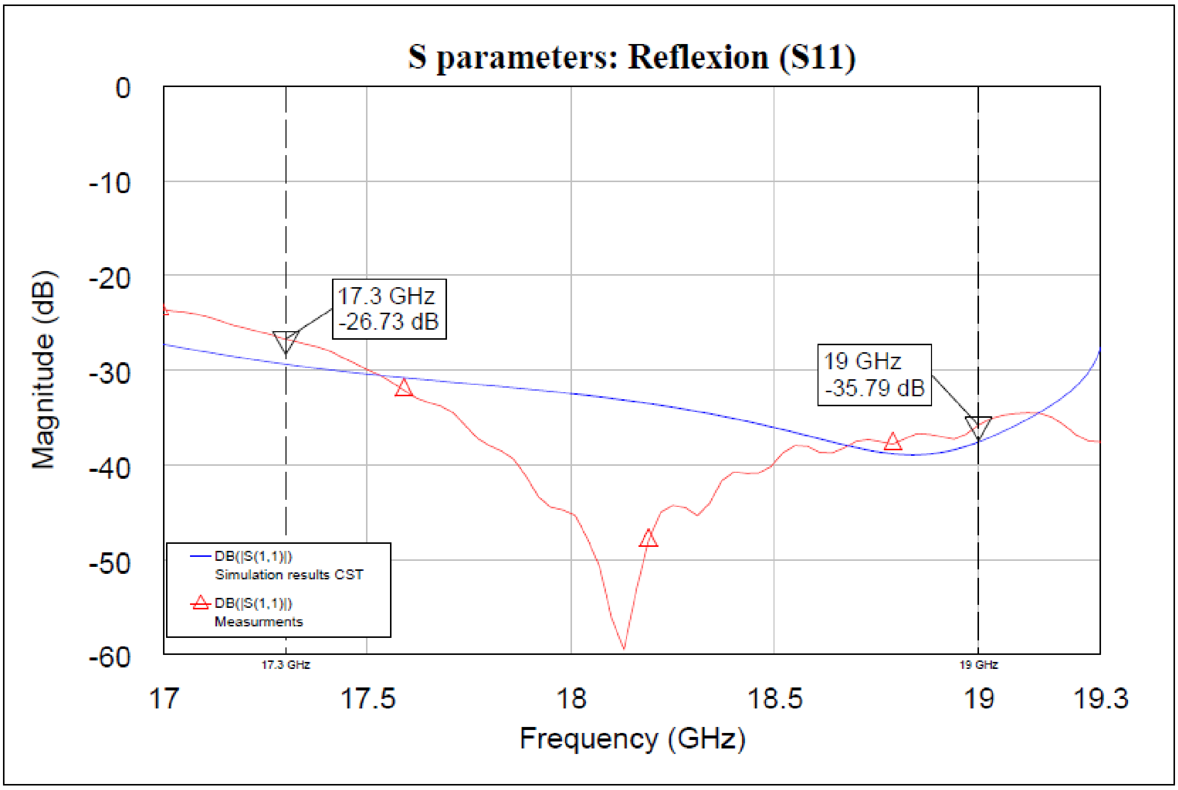


Fig.5. Comparison between simulated and measured scattering parameters (transmission S12, isolation S21 and reflexion S11)

Comparison between the simulated scattering parameters (insertion loss, isolation and return loss) and the measured parameters yields very good matching for the low narrow band. Typical electrical performances are less than 0.15dB for insertion loss, and higher than 23dB for isolation and for return loss at input and output ports at the ambient temperature. The specification electrical performances should be guaranteed at the minimum and high operating temperatures (-20°C and +85°C). Electrical measurements at extreme operating temperatures will be presented at the conference.

THERMAL ANALYSIS

In this section, we performed thermal simulations for both design: the classical Y-junction design and the Cobham Multilayer Gyrator design in order to compare the maximum temperature in the ferrites in the worst case condition at maximum operating temperature (85°C) , in vacuum and in fault mode (350W-CW incident power + 350W-CW reflected power). These results help to evaluate the limitations and risks of the classical design and show that the Cobham design can handle high power levels unlike the classical one.

We use Solidworks [2] to design RF devices. This software also includes a thermal simulator that allows calculation of conduction, radiation and convection phenomena. Thermal calculations can be directly performed without the need of specific interface. This software provides all necessary tools to calculate the impact of RF losses on temperatures in the structure and to calculate heat fluxes and gradients.
A global view of the waveguide WR51 circulator is presented in the following figure:

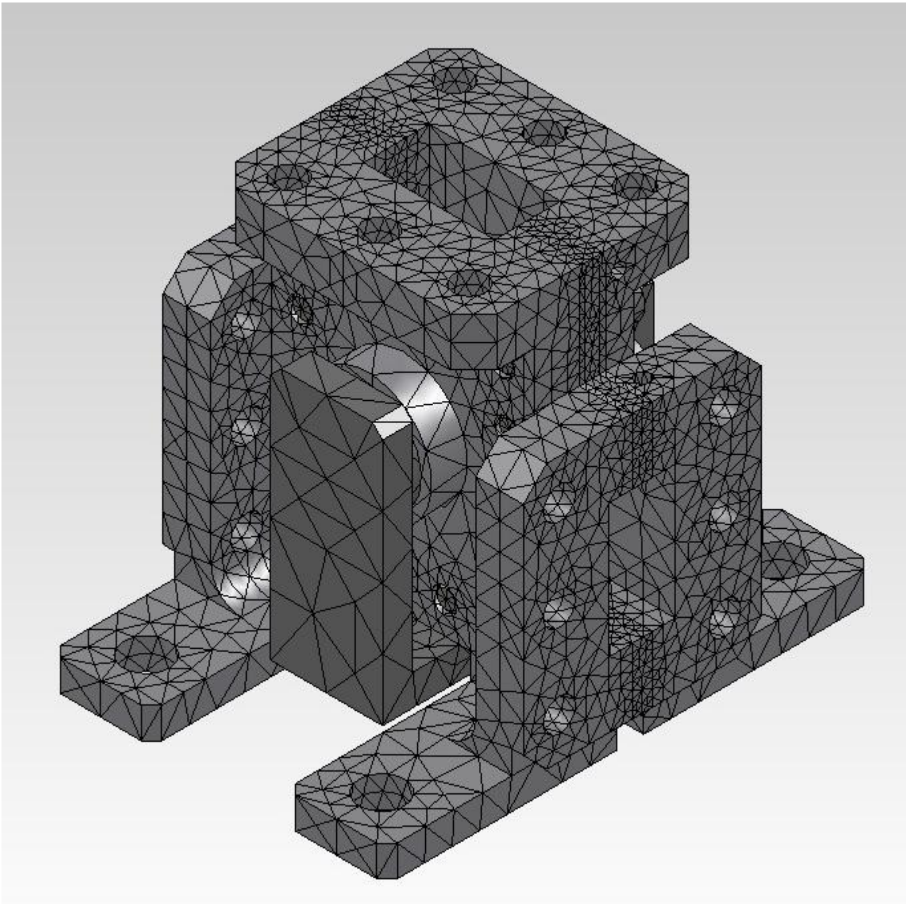


Fig.6. Waveguide WR51 circulator mesh.

Comparison between the classical design and the Cobham design shows that our solution can handle high power levels unlike the classical Y-junction where ferrite and glues temperatures reach too high values, around 257°C, higher than the qualification maximum temperatures (Fig.7).
The temperature distribution in fault mode for the Cobham design, unlike the classical design, indicates a maximum temperature around 161°C (Fig.8). All critical temperatures (glues and ferrites) are below the specification given for the various components.

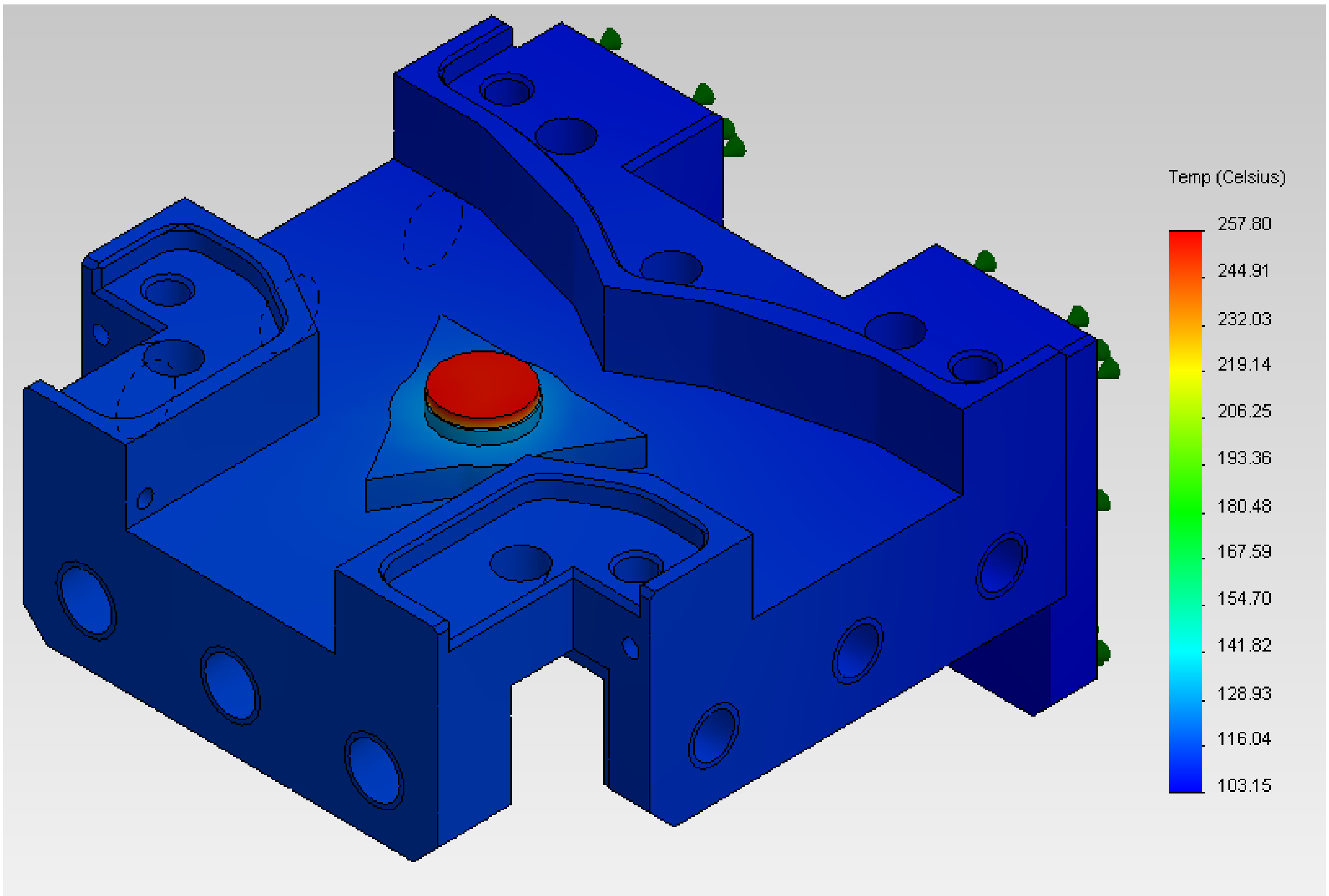


Fig.7. Temperature distribution in the classical design in the fault case.

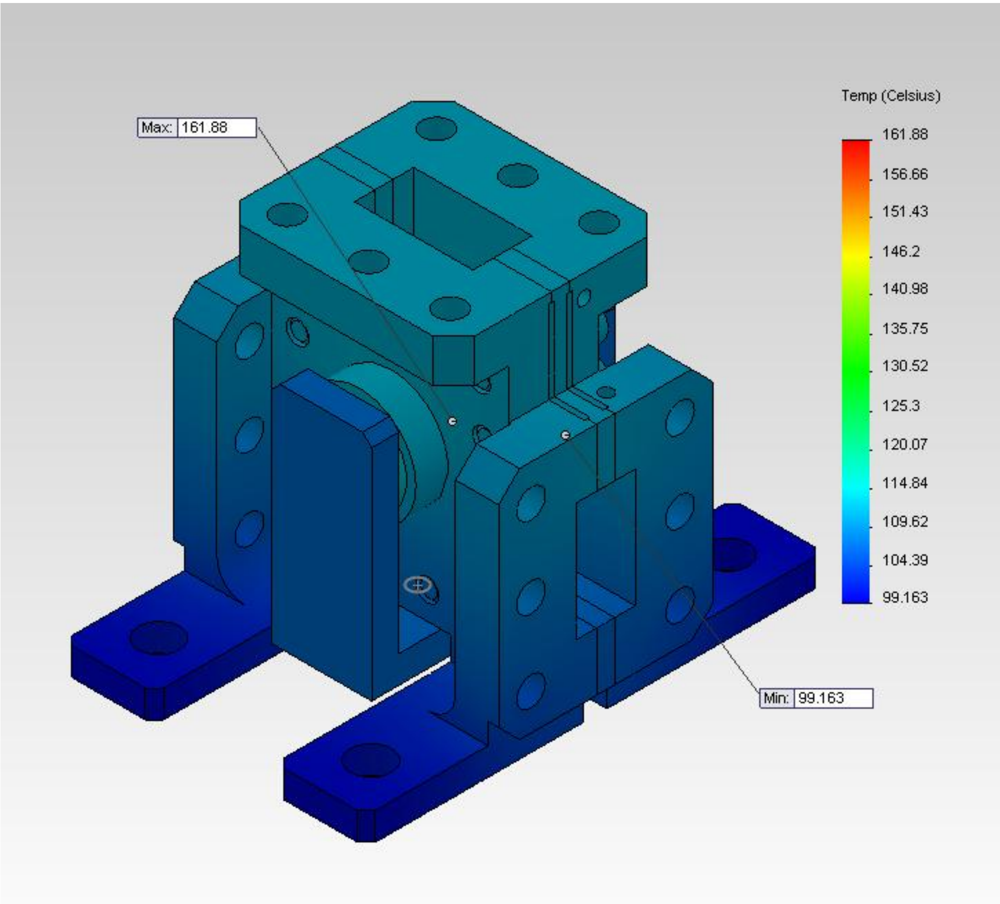


Fig.8. Temperature distribution in the Cobham design in the fault case.

Thermal analysis shows that our solution can reduce the power density travelling in the center of the junction, inside ferrites and critical gaps. Also, a multiplication analysis is planned to demonstrate that the device has a sufficient margin according to ESA rules, with no detection of multipaction over the maximum power specified.

CONCLUSION AND FUTUR WORK

Comparison between simulation and measurements results yields some good matching. This means that the modeling of the isolator design is rather accurate. Also, preliminary measurement results at ambient temperature in the case of the lower narrow band (17.3-19GHz) of the high power isolator show that the design‘s performances fit the specification of the project. Measurements results at minimum and maximum operating temperatures (-20°C and +85°C) for both bands will be presented during the conference.
Thermal analysis demonstrated that even in the case of full short circuit in output, at maximum operating temperature and power level, all critical temperatures are below the specifications for the various components. Power test results that prove that this design can handle these power levels will be also presented.
The ultimate objective of this ESA project is the design, manufacturing and test of a Ka-Band 350 Watt class isolator EM capable to operate in full reverse power.

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