Design and measurement of waveguide transitions for Ka and Q band cryogenic amplifiers.

I. Malo, J.D. Gallego, C. Jarufe, J.L. Cano.

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Centro Astronómico de Yebes
Apdo. 148 19080 Guadalajara
SPAIN
Phone: +34 949 29 03 11 ext.208
Fax: +34 949 29 00 63

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1. Introduction

Ka and Q band cryogenic amplifiers chassis were designed with the possibility of a dual configuration (coaxial or waveguide) in the input and output ports. Coaxial is more convenient during the development because it allows measurements down to DC, but waveguide is often preferred at the input side in the final receivers because of its lower loss.

For Ka band (26.5-40 GHz) the connector used is the Wiltron (now Anritsu) K type (2.92 mm), which can be directly mated to 3.5 mm and SMA and has a cutoff frequency well over 40 GHz. Note that the Ka band waveguide transition **was optimized for 25-35 GHz** and not for the standard 26.5-40 GHz range. For Q band (33-50 GHz) it is necessary to use 2.4 mm connectors which cannot be mated to the 3.5 mm family. In this case, the waveguide transition was optimized for full coverage of the standard waveguide band.

The amplifiers are fitted with a standard hermetic glass beads which can be used either to attach a field-replaceable type connector or to hold a small cylinder which is used as an antenna in the waveguide. The large or K bead (12 mil pin dia.) is of the type originally used for Wiltron K connectors and it is not clear whether it can be used up to 50 GHz without higher order modes. The smaller or V bead (9 mil pin dia.) was originally developed for Wiltron V connectors and its cutoff frequency is well above 65 GHz. Both bead types were tried for the Q band transition. The concept of the waveguide to coaxial transition is illustrated in Figure 1.

The transitions have been optimized with HFSS. The parameters involved in the optimization were:

- Distance from the axis of the cylinder to the waveguide short ("H" in Fig. 1).
- Distance from the base of the cylinder to the glass bead ("d" in Fig. 1).
- Cylinder radius ("R2" in Fig. 1).
- Cylinder length ("L2" in Fig. 1).

In the case of the Q band transition with V-glass bead the optimization did not converge to a solution good enough for full band coverage and it was decided to add a tuning screw (see Figure 5) to improve the performance. An alternative solution is using a machined square protrusion in the waveguide wall (see Figure 7.)

In this case, the additional parameters introduced in the optimization were:

- Distance from the axis of the screw to the axis of the glass bead ("Hp" in Figure 5)
- Screw diameter (2x"Rp" in Figure 5).
- Height of the screw inside the waveguide ("Lp" in Figure 5).

The characteristics of the prototype transitions designed are summarized in the Table 1:

Amplifier Band	*Waveguide*	*Glass Bead*	*Tuning*	*Coaxial Connector*
Ka	WR28	Large (K)	no	2.9 mm
Q	WR22	Large (K)	no	2.4 mm
Q	WR22	Small (V)	screw	2.4 mm
Q	WR22	Small (V)	square protrusion	2.4 mm

Table 1. Characteristics of the prototype transitions designed.

The dielectric used in the K and V glass bead is Corning 7070[1] (dielectric permittivity of 4.1 @ 1 MHz and a loss tangent of 0.06 @ 1 MHz).

[1] *http://www.corning.com/docs/specialtymaterials/pisheets/wafersht.pdf*

2. Ka band (25-35 GHz): WR28 to coaxial K (2.92 mm) connector (with K-glass bead).

The design is based in a perforated cylinder (“hat”) inserted at the end of the longest pin of the K-glass bead (large).

The relevant parameters of the transition are outlined in Figure 1 and their nominal values are presented in the Table 2.

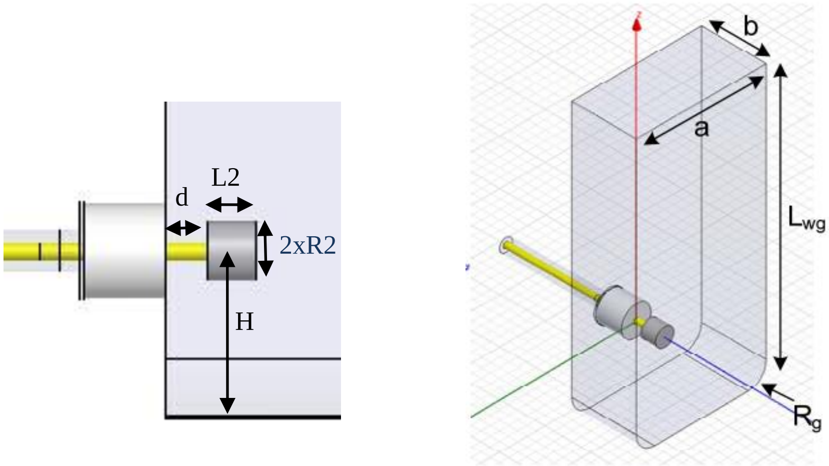


Figure 1. Transition WR28 to 2.9 mm coaxial connector with K-glass bead.

Parameter		*Value*	*Unit*
d	Glass bead to hat gap	0.74	mm
R2	Hat radius	0.503	mm
L2	Hat length	0.81	mm
H	Hat to short-circuit distance	2.85	mm
a	WR28 waveguide dimension	7.11	mm
b	WR28 waveguide dimension	3.56	mm
Lwg	Waveguide length	15	mm
Rg	Milling tool radius	1	mm

Table 2. Nominal value of the parameters of the transition WR28 to 2.9 mm coaxial connector with K-glass bead.

The HFSS simulation uses ε_r= 4.00 for Corning 7070. The internal radius of the bead is 0.813 mm, the bead length is 1.4 mm, the pin radius of the bead is 0.1525 mm and the lengths of the bead pins are 1.04 mm (to insert the “hat”) and 0.74 mm.

The waveguide was milled with a tool of 1 mm of radius. This is the reason why the value of Rg is 1 mm. Rg is1 mm for all transitions presented in this report.

The simulation doesn’t include the effect of the coaxial connector (taken into account in the measurement). Simulated and measured S-parameters are presented in Figure 3.

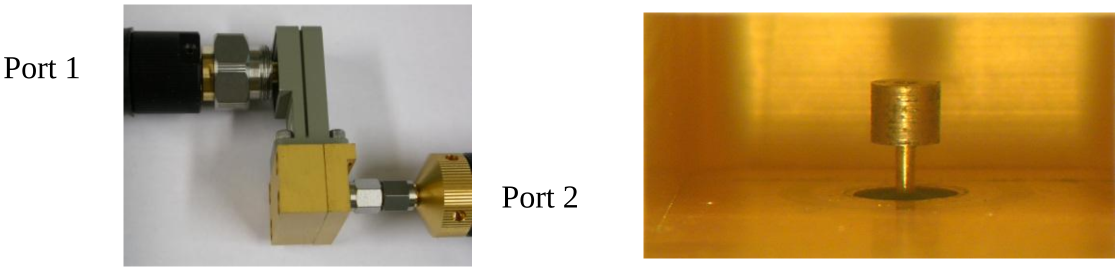


Figure 2. Left: The gold plated block is the prototype waveguide (WR28) to coaxial (2.92 mm) transition built for testing the performance. It is shown connected to the Vector Network Analyzer cables. Right: A view inside the waveguide showing the glass bead and the cylinder ("hat") used as antenna.

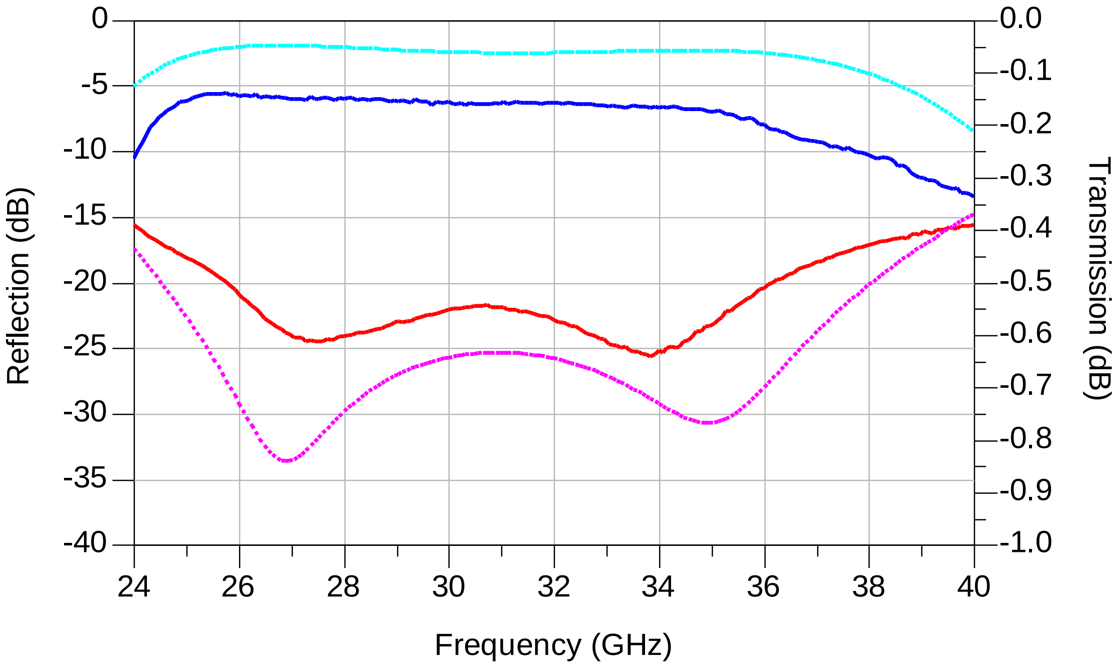


Figure 3. HFSS simulation of the transition WR28 to 2.92 mm coaxial connector with K-glass bead (doted line) vs. measured transition (solid lines). The transition was measured in VNA Agilent E8364B using a "Full 2 Port" calibration with "unknown thru". Port 1 is WR28 port and Port 2 is 2.92mm (female) connector. The HFSS simulation does not include the effect of the coaxial connector.

3. Q band (33-50 GHz): WR22 to coaxial (2.4 mm) connector (with K-glass bead).

The design is based in a perforated cylinder (“hat”) inserted at the end of the longest pin of the K-glass bead.

The relevant parameters of the transition are outlined in Figure 1 and their nominal values are presented in the Table 3.

Parameter	*Value*	*Unit*
d	0.5	mm
R2	0.43	mm
L2	0.85	mm
H	2.13	mm
a	5.689	mm
b	2.845	mm
Lwg	10	mm

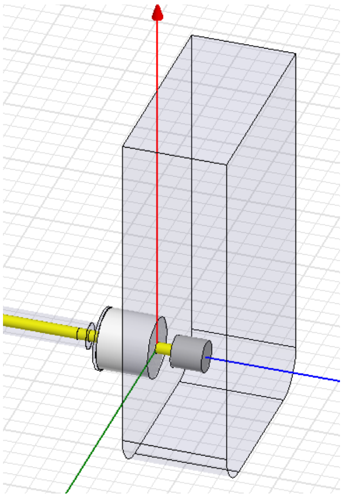


Table 3. Value of the parameters of the transition WR22 to 2.4 mm coaxial connector with K-glass bead.

The HFSS simulation uses ε_r= 4.035 for Corning 7070 to get a 50 Ω for the K-glass bead impedance with the internal radius of the bead of 0.813 mm. The bead length is 1.4 mm, the pin radius of the bead is 0.1525 mm and the lengths of the bead pins are 1.04 mm (to insert the “hat”) and 0.74 mm.

The simulation does not include the effect of the coaxial connector (taken into account in the measurement). The transition made in Yebes uses a Southwest Microwave 2.4 mm connector for K-glass bead (p/n: 1420-01SF). Simulated and measured S-parameters are presented in Figure 4.

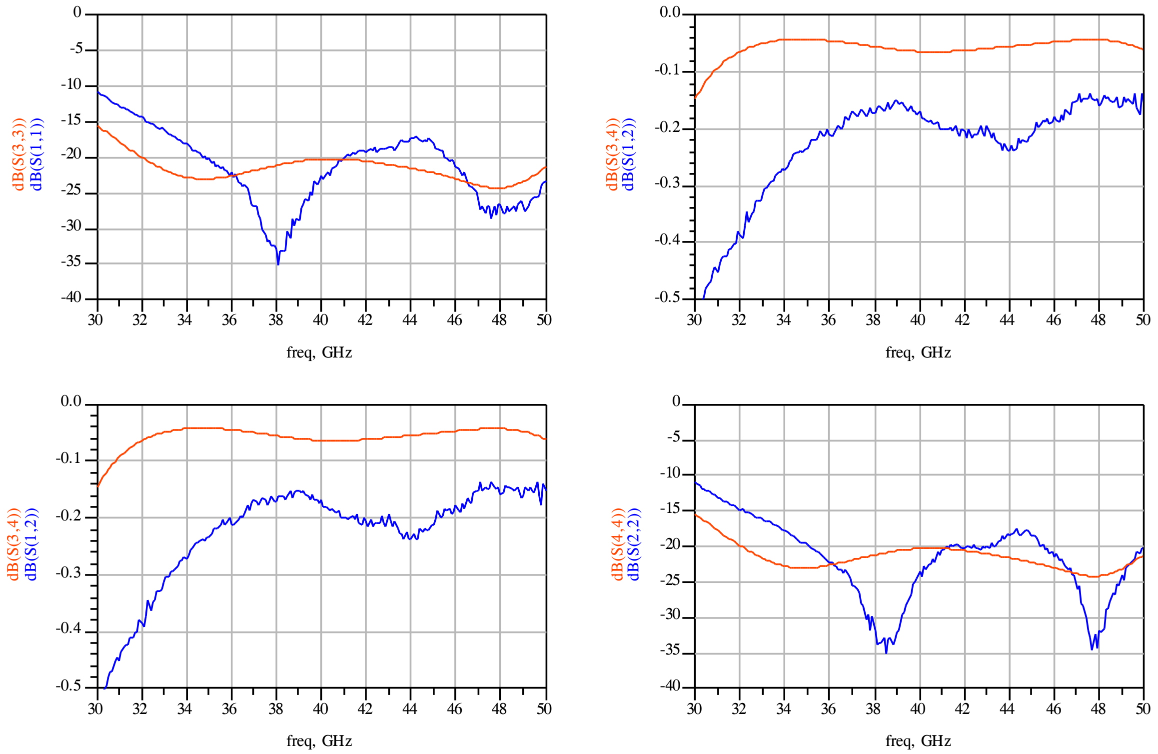


Figure 4. HFSS simulation of the transition WR22 to 2.4 mm coaxial connector with K-glass bead (red line) vs. measured transition (blue line). The transition was measured in VNA Agilent E8364B using a "Full 2 Port" calibration with "unknown thru". Port 1 is 2.4mm (female) connector and Port 2 is WR22. The HFSS simulation does not include the effect of the coaxial connector.

4. Q band (30-50 GHz): WR22 to coaxial (2.4 mm) connector (with V-glass bead), using a tuning screw.

The design based in a perforated cylinder ("hat") inserted at the end of the longest pin of the V-glass bead (small) is not enough to adapt the entire band (30-50 GHz) with a simulated reflection loss better than -20 dB. That reflection is achieved adding a M2 screw in the center of the E plane, in the wall opposite to the bead, at a z-distance of 1.8 mm from the center of the V-glass bead.

The relevant parameters of the transition are outlined in the Figure 1 and the new parameters related to the screw are shown in the Figure 5. The nominal values of the transition are presented in the Table 4.

Parameter	*Value*	*Unit*
d	0.5	mm
R2	0.35	mm
L2	0.85	mm
H	2.15	mm
a	5.689	mm
b	2.845	mm
Lwg	10	mm
Rp	0.96	mm
Hp	1.8	mm
Lp	0.15	mm

Table 4. Value of the parameters of the transition WR22 to 2.4 mm coaxial connector with V-glass bead and a tuning screw.

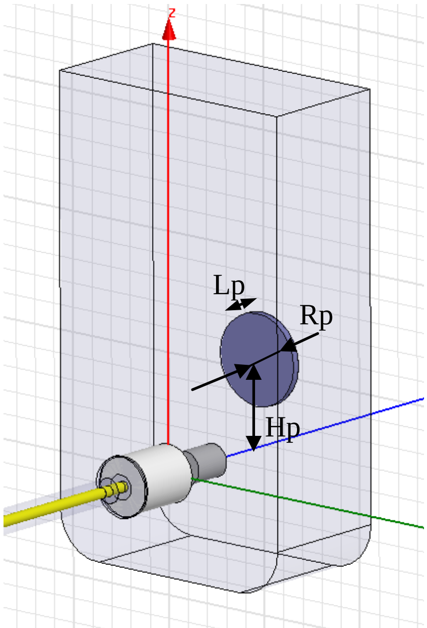


Figure 5. Value of the parameters of the transition WR22 to 2.4 mm coaxial connector with V-glass bead and a tuning screw.

The HFSS simulation uses ε_r= 4.05 for Corning 7070 to get a 50 Ω for the V-glass bead impedance with the internal radius of the bead of 0.60975 mm (Advanced Technology Group, INC. datasheet). The V-glass bead length is 1.397 mm, the pin radius of the bead is 0.114 mm and the lengths of the bead pins are 0.8128 mm (to insert the "hat") and 0.6604 mm.

The HFSS simulation doesn't include the effect of the coaxial connector (taken into account in the measurement). The transition made in Yebes uses a Southwest Microwave 2.4 mm connector for V-glass bead (p/n: 1420-03SF). Simulated and measured S-parameters are presented in Figure 6.

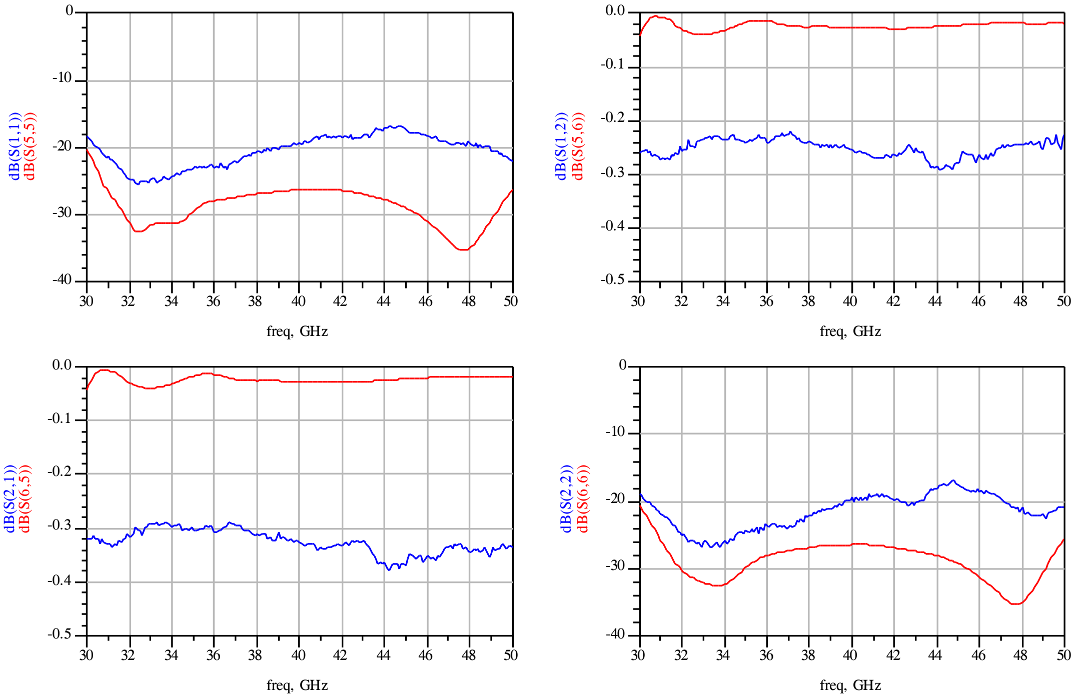


Figure 6. HFSS simulation of the transition WR22 to 2.4 mm coaxial connector with V-glass bead and a tuning screw (red line) vs. measured transition (blue line). The transition was measured in VNA Agilent E8364B using a "Full 2 Port" calibration with "unknown thru". Port 1 is 2.4mm (female) connector and Port 2 is WR22. The HFSS simulation does not include the effect of the coaxial connector.

5. Q band (30-50 GHz): WR22 to coaxial (2.4 mm) connector (with V-glass bead), using a square protrusion for tuning.

The design based in a perforated cylinder (“hat”) inserted in the longest pin of the V-glass bead is not enough to adapt the entire band (33-50 GHz) with a simulated reflection loss better than -20 dB. That reflection is achieved adding a square protrusion in the center of the E plane, as it was shown in the previous point. The effect of the square protrusion is same as the effect of a screw with similar metal volume inside the waveguide. The advantages of the square protrusion vs. screw are avoiding screw turning and the simplicity of the manufacturing.
The values of the transition parameters are presented in the Table 5 and the new parameters are shown in the Figure 7.

Parameter	*Value*	*Unit*
d	0.5	mm
R2	0.35	mm
L2	0.85	mm
H	2.15	mm
a	5.689	mm
b	2.845	mm
Lwg	10	mm
Xp	0.8	mm
Zp	0.9	mm
Hp	1.8	mm
Lp	0.15	mm

Table 5. Value of the parameters of the transition WR22 to 2.4 mm coaxial connector with V-glass bead and a square protrusion for tuning.

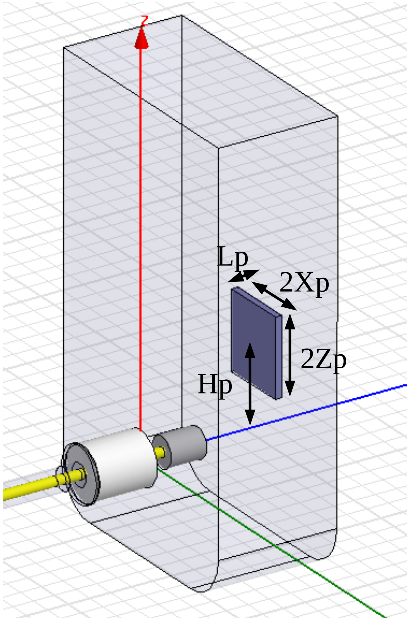


Figure 7. Value of the parameters of the transition WR22 to 2.4 mm coaxial connector with V-glass bead and a square protrusion for tuning.

The HFSS simulation uses ε_r= 4.05 for Corning 7070 to get a 50 Ω for the V-glass bead impedance with the internal radius of the bead of 0.60975 mm (Advanced Technology Group, INC. datasheet). The V-glass bead length is 1.397 mm, the pin radius of the bead is 0.114 mm and the lengths of the bead pins are 0.8128 mm (to insert the “hat”) and 0.6604 mm.

The HFSS simulation does not include the effect of the coaxial connector (taken into account in the measurement). The transition made in Yebes uses a Southwest Microwave 2.4 mm connector for V-glass bead (p/n: 1420-03SF). Simulated and measured S-parameters are presented in Figure 8.

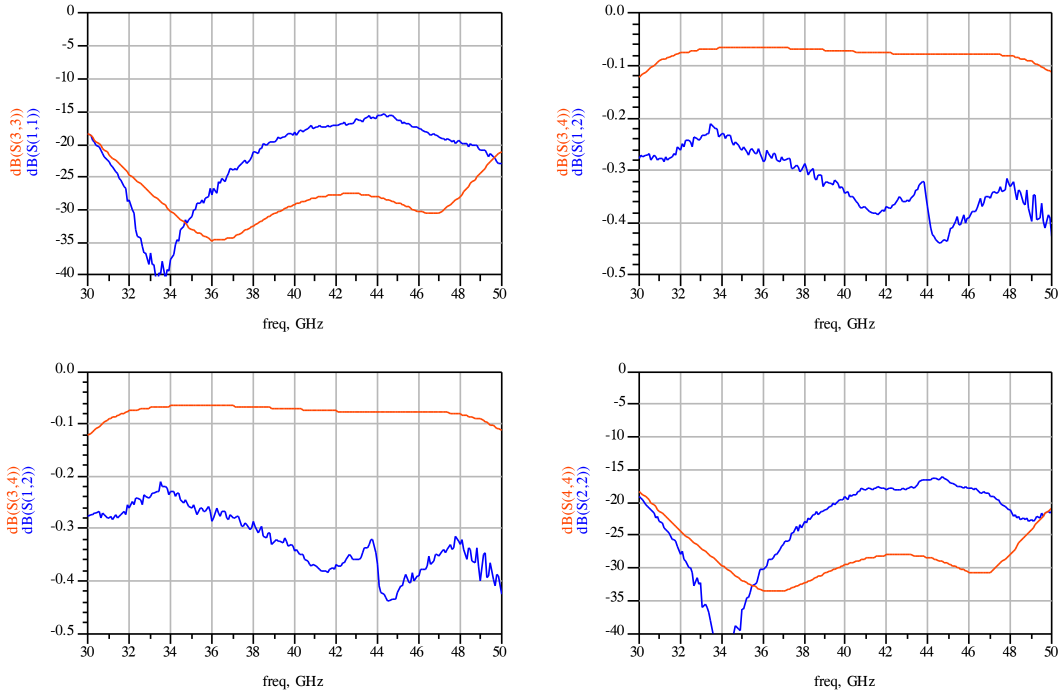


Figure 8. HFSS simulation of the transition WR22 to 2.4 mm coaxial connector with V-glass bead and a square protrusion for tuning (red line) vs. measured transition (blue line). The transition was measured in VNA Agilent E8364B using a "Full 2 Port" calibration with "unknown thru". Port 1 is 2.4mm (female) connector and Port 2 is WR22. The HFSS simulation doesn't include the effect of the coaxial connector.

6. Conclusions

The comparison between the measurements of the Q band transitions made in Yebes is presented in Figure 9. The chosen design for the Q band transition was presented in the section 4. It is based in a perforated cylinder ("hat") inserted at the end of the longest pin of the V-glass bead, with a M2 screw in the center of the E plane, in the wall opposite to the bead, at a z-distance of 1.8 mm from the center of the V-glass bead.

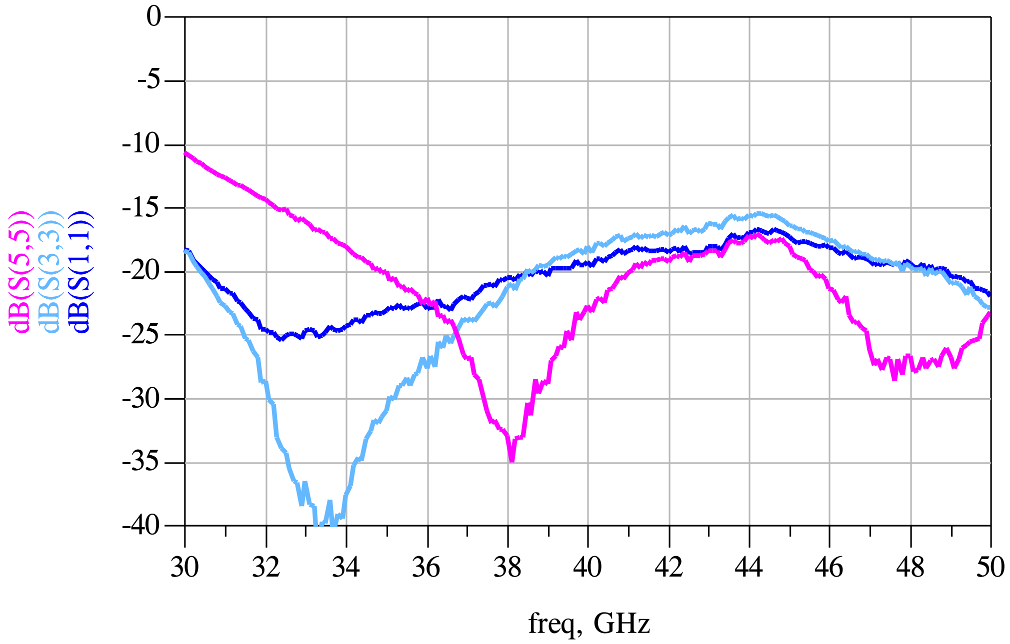


Figure 9.Measurements of the Q band transitions made in Yebes: a) WR22 to 2.4 mm coaxial connector (with K-glass bead) (pink), b) WR22 to 2.4 mm coaxial connector (with V-glass bead) using a tuning screw (blue) and c) WR22 to 2.4 mm coaxial connector (with V-glass bead) using a square protrusion for tuning (cyan).

All measurements of the S_{11} of the transitions made in Yebes present a broad peak at 44 GHz. In addition, the measurements are between 5 and 10 dB worse than the HFSS simulation results. Note that HFSS simulation does not include the non-ideal 2.4 mm coaxial connector and the glass bead is modeled as a perfect 50 Ω impedance coaxial line. These differences are probably the causes of the differences observed between the simulations and the measurements.

7. Annex:

8. Effect of non-ideal models for the 2.4 mm coaxial connectors.

Problem: The s_{11} measurement of the WR22 to coaxial (2.4 mm) transitions made in Yebes is more pessimistic than the HFSS simulation (Figure 10).

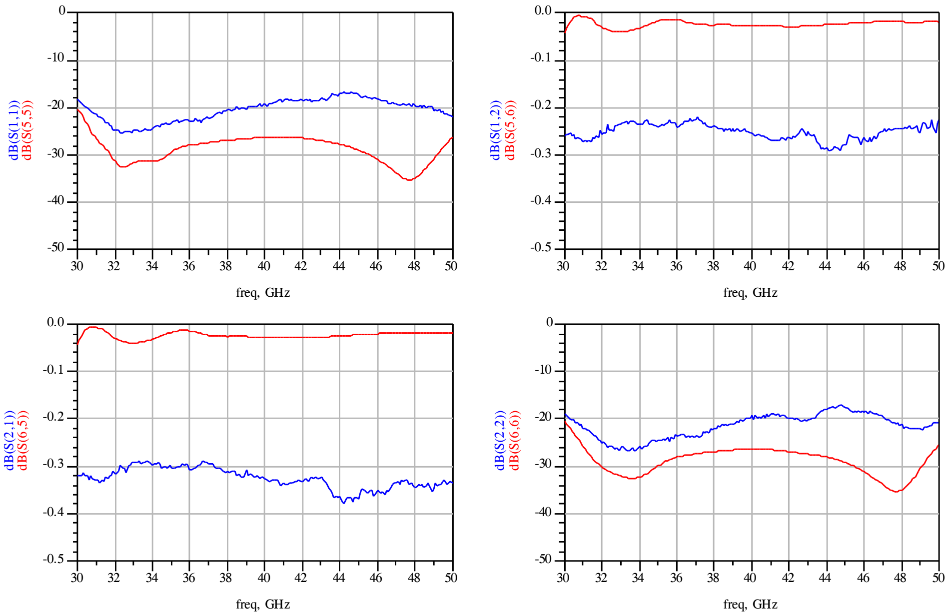


Figure 10. Comparison of the HFSS simulation of the Q band transition using a tuning screw (red line) and the measurement of the Q band transition made in Yebes.

The HFSS simulation does not include the non-ideal 2.4 mm coaxial connector and the glass bead is modeled as a perfect 50 Ω impedance coaxial line. These differences could probably explain the discrepancy between simulation and measurement.

The aim of this work is to determine a more realistic model of the coaxial connectors and of the glass beads based on experimental time and frequency domain measurements of back to back connectors. The non-ideal connector and bead models could be used to compute the expected degradation of the ideal HFSS model due to this effect.

The models and the measurements performed are:

1) Heat block with two back to back 2.4 mm coaxial connectors directly connected.
2) Heat block with two back to back 2.4mm coaxial connectors connected by a V-glass bead.
3) Model of the Q band transition WR22 to coaxial (2.4 mm) connector (with V-glass bead) using a tuning screw.
4) Heat block with two back to back 2.4 mm coaxial connectors connected by a K-glass bead.
5) Model of the Q band transition WR22 to coaxial (2.4 mm) connector (with K-glass bead).

Performance comparisons:

a) Heat block with two back to back SRI 2.4 mm coaxial connectors connected by a K-glass bead.
b) Comparison of the performance of a SRI 2.4 mm coaxial connector vs. a Southwest connector, measured in a heat block using two identical connectors connected by a K-glass bead.
c) Comparison of the performance of a K-glass bead connector vs. a V-glass bead connector from Southwest, measured in a heat block using two identical connectors connected by the suitable glass bead.

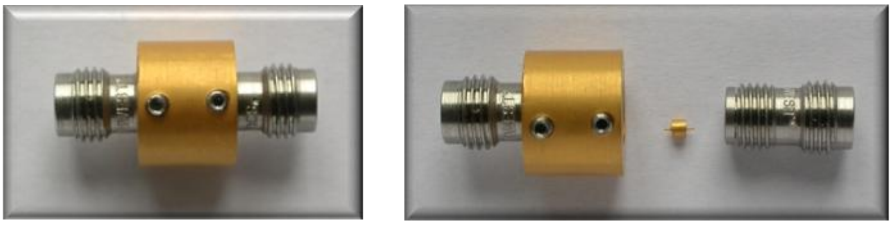


Figure 11. Photography of the heat block with two back to back Southwest 2.4 mm coaxial connectors connected by a V-glass bead.

1) Heat block with two back to back 2.4 mm coaxial connectors directly connected.

2.4 mm coaxial connectors: Southwest Microwave, p/n: 1420-03SF
Cable diameter: 0.23 – 0.24 mm.
Measurement file: “Heat_Blk_2c4mm_cable_1.s2p”.

The aim of this measurement is to find the electrical length of the connector which is 9.5 mm. The physical length of the connector is 8.5 mm.

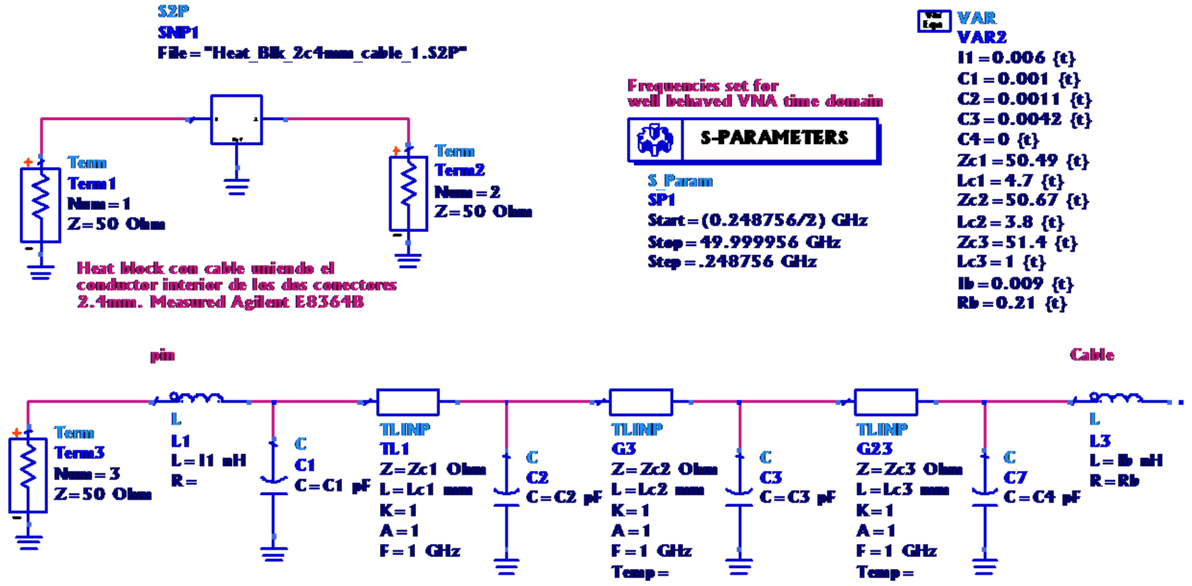


Figure 12. Zoom of the ADS model of the heat block with two back to back 2.4 mm coaxial connectors directly connected. An additional transmission line is added to improve the fit in the time domain

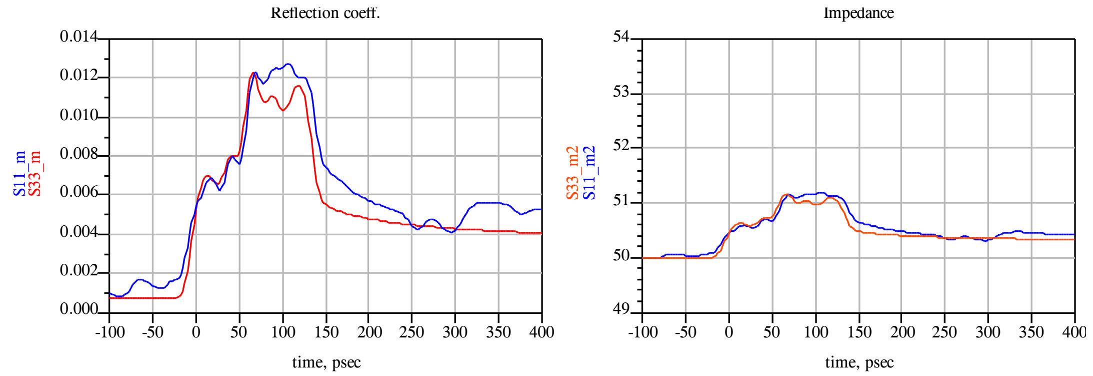


Figure 13. Measurement (blue) vs. ADS model (red) of the heat block with two back to back 2.4 mm coaxial connectors directly connected, in time domain.

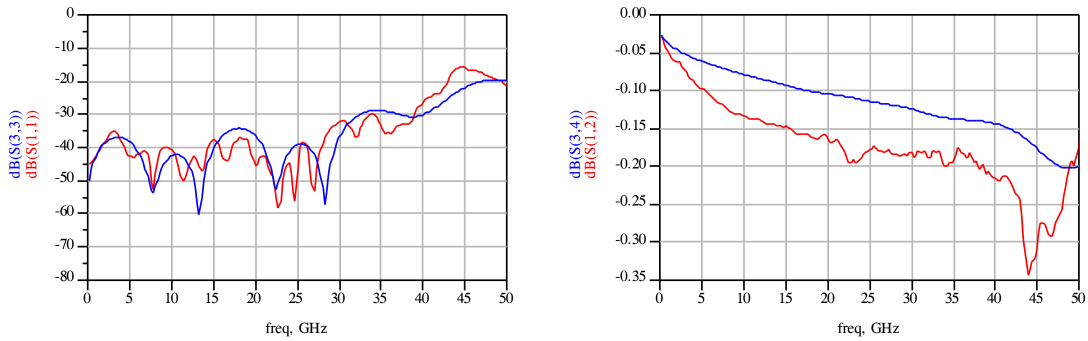


Figure 14. Measurement (blue) vs. ADS model (red) of the heat block with two back to back 2.4 mm coaxial connectors directly connected, in frequency domain.

2) Heat block with two back to back 2.4mm coaxial connectors connected by a V-glass bead.

2.4 mm coaxial connectors, p/n: 1420-03SF.
Manufacturer: Southwest Microwave.
Measurement file: "Heat_Blk_2c4_small_bead_1.s2p".

The initial attempt of modeling this structure using only a set of cascaded elements (as obtained from the time domain data) did not provided a good fitting in the high frequency end (30 to 50 GHz) (Figure 18). A high frequency effect, not easily visible in the time domain and not included in the initial model should also be present. An improvement in the fitting could be achieved including in the model a capacitor (C16) between two discontinuities of the connectors. This capacitor could be considered an attempt to include in the model the coupling between higher order evanescent modes. This improves the fitting to some of the general features but still fails to model all the subtle details of the high frequency end of the frequency domain data.

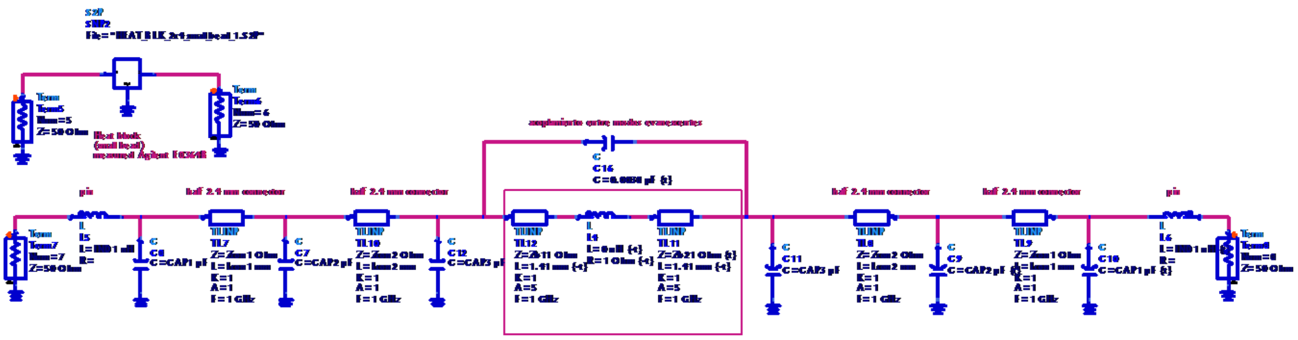


Figure 15. ADS model of the heat block with two back to back 2.4mm coaxial connectors connected by a V-glass bead.

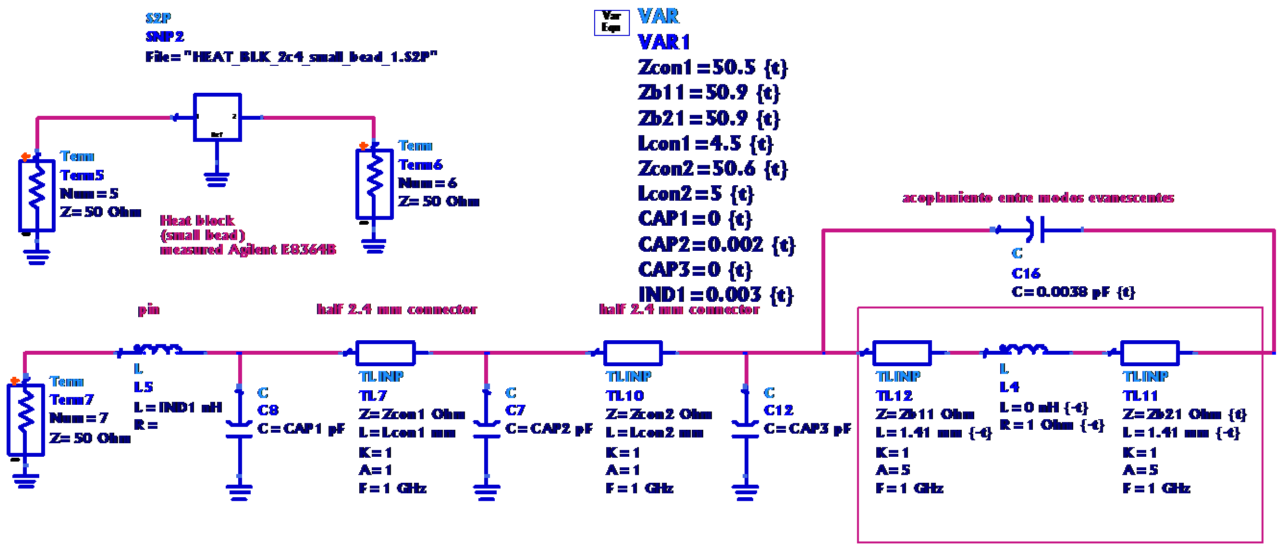


Figure 16. Zoom of the ADS model of the heat block with two back to back 2.4mm coaxial connectors connected by a V-glass bead.

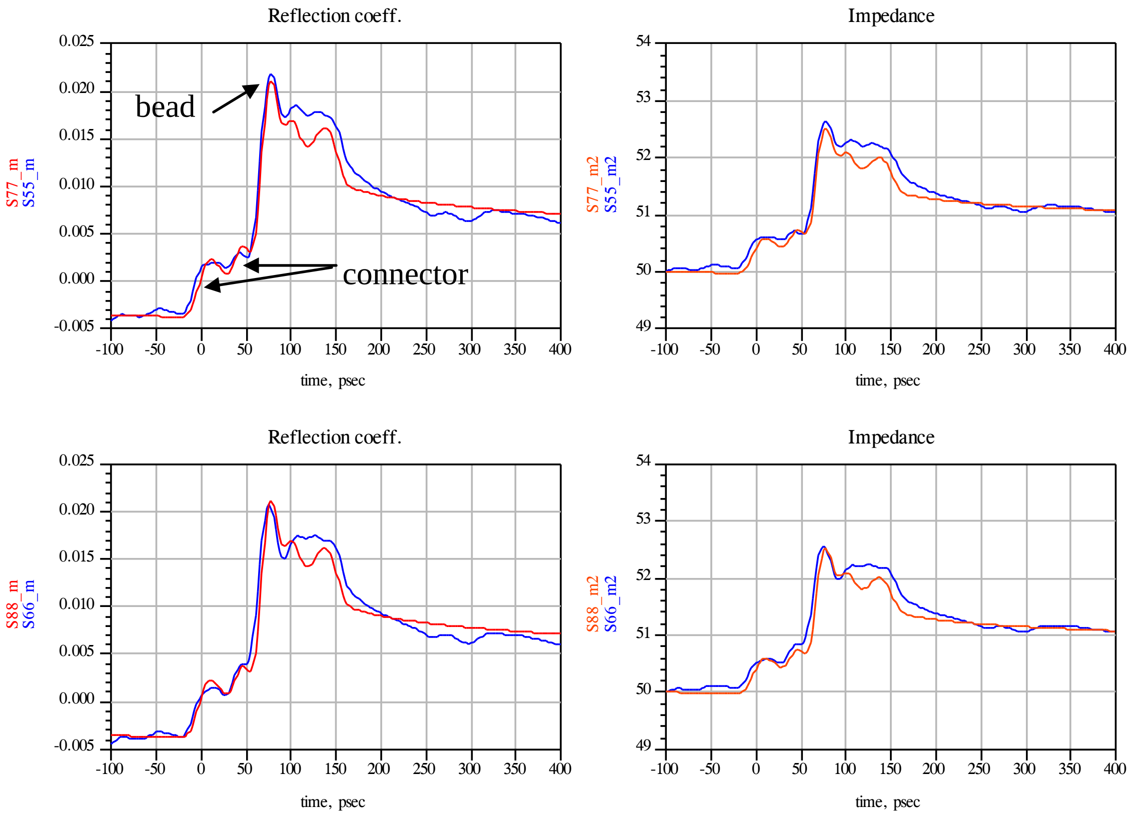


Figure 17. Measurement (blue) vs. ADS model (red) of the heat block with two back to back 2.4mm coaxial connectors connected by a V-glass bead, in time domain.

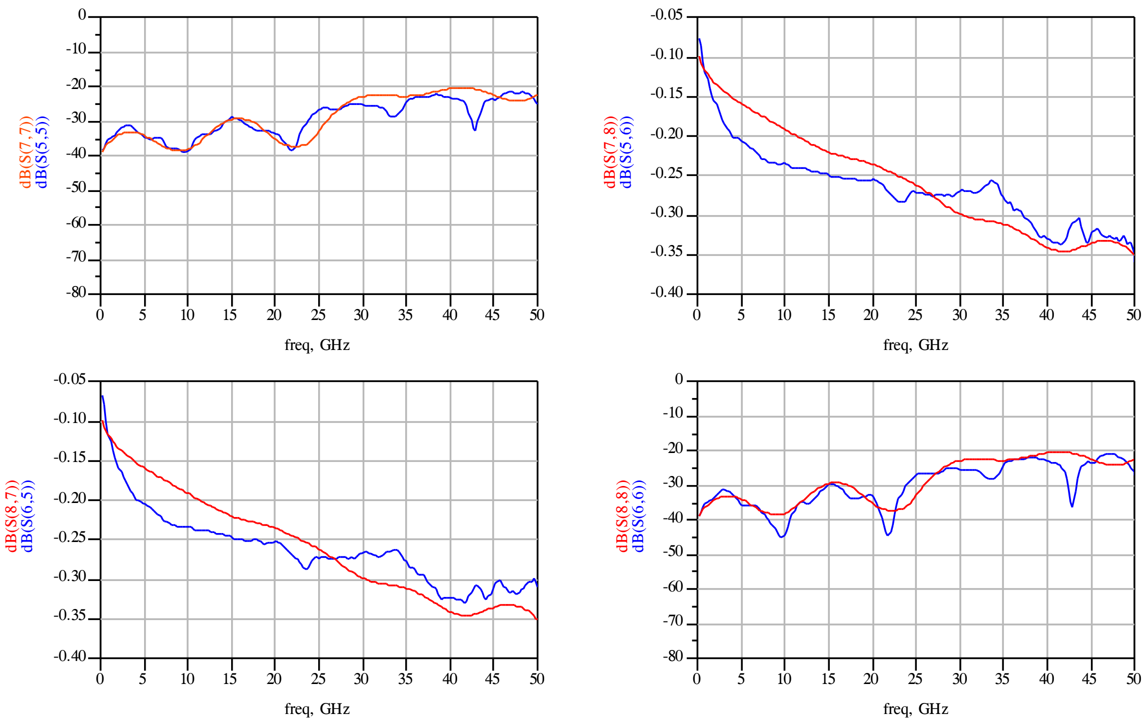


Figure 18. Measurement (blue) vs. ADS model (red) of the heat block with two back to back 2.4mm coaxial connectors connected by a V-glass bead, in frequency domain.

3) Model of the Q band transition WR22 to coaxial (2.4 mm) connector (with V-glass bead) using a tuning screw.

The new model of the Q band transition is obtained by adding the model obtained in the section 2 to the HFSS simulation of the transition (with the reference plane of the input port set at the beginning of the bead).

2.4 mm coaxial connectors: Southwest Microwave, p/n: 1420-03SF
Measurement file: “Qc_WG_to_24_1.s2p” (blue line).
HFSS file: “Transic_WR22_VBead_Bead_HFSS.s2p”.

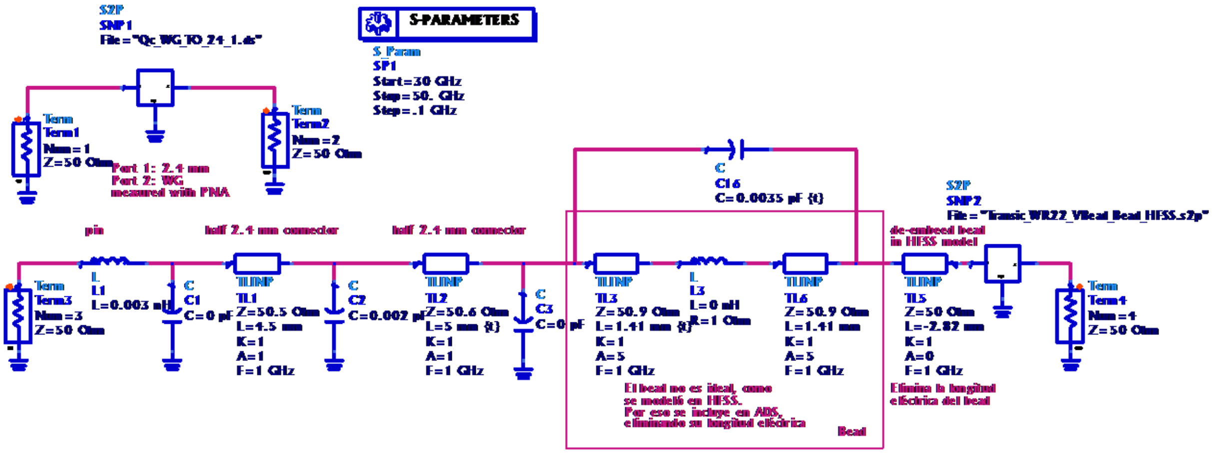


Figure 19. ADS model of the Q band transition WR22 to coaxial (2.4 mm) connector (with V-glass bead) using a tuning screw.

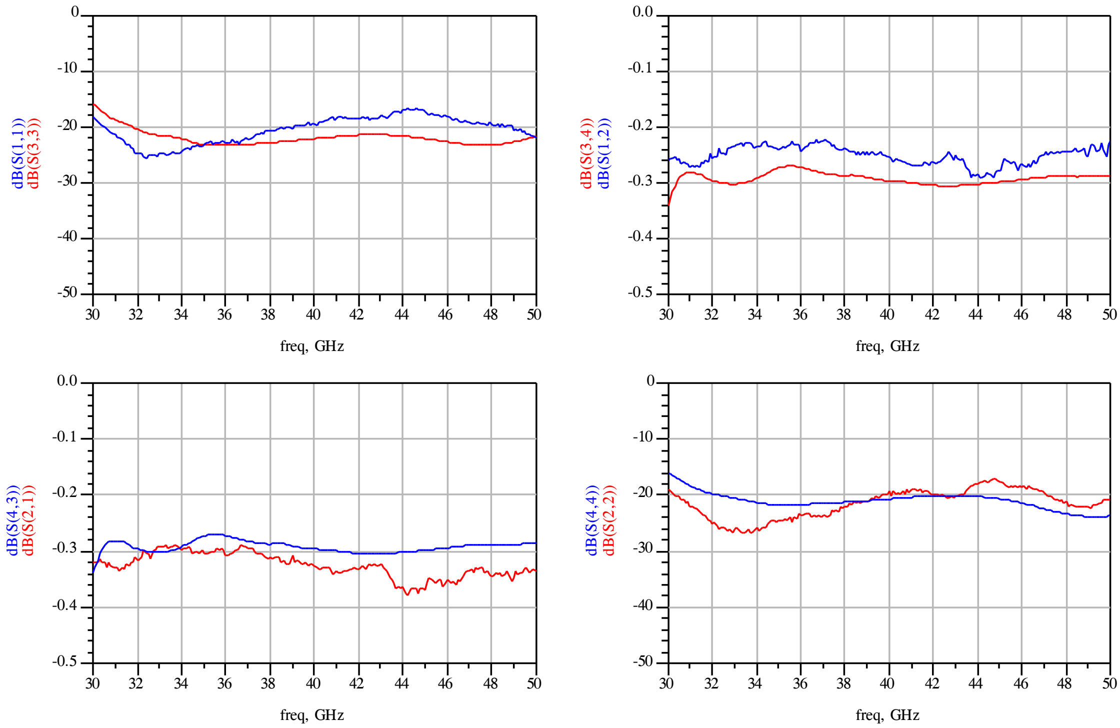


Figure 20. Measurement (blue) vs. ADS modeled (red) of the Q band transition WR22 to coaxial (2.4 mm) connector (with V-glass bead) using a tuning screw.

4) Heat block with two back to back 2.4 mm coaxial connectors connected by a K-glass bead.

2.4 mm coaxial connectors, p/n: 1420-01SF.
Manufacturer: Southwest Microwave.
Measurement file: "Heat_Blk_2c4_big_bead_1.s2p".

The initial attempt of modeling this structure using only a set of cascaded elements (as obtained from the time domain data) did not provided a good fitting in the high frequency end (30 to 50 GHz) (remarked in the Figure 24). A high frequency effect, not easily visible in the time domain and not included in the initial model should also be present. An improvement in the fitting could be achieved including in the model a capacitor (C15) between two discontinuities of the connectors. This capacitor could be considered an attempt to include in the model the coupling between higher order evanescent modes. This improves the fitting to some of the general features but still fails to model all the subtle details of the high frequency end of the frequency domain data.

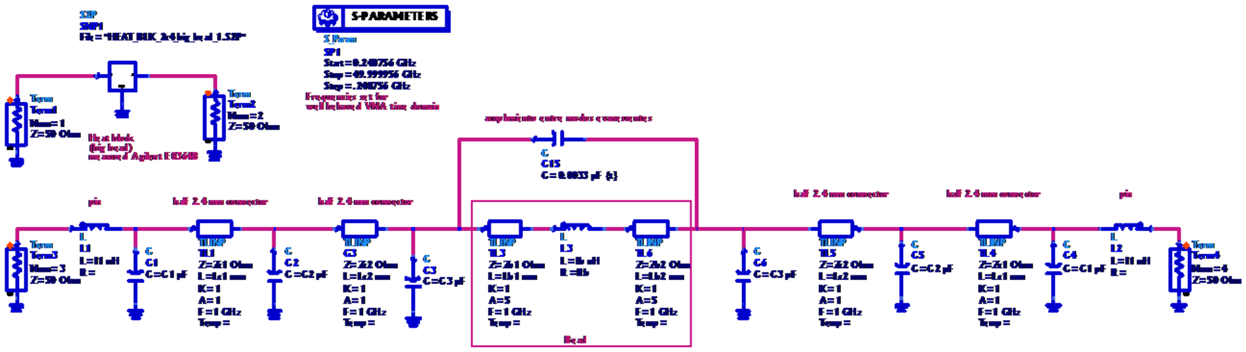


Figure 21. ADS model of the heat block with two back to back 2.4 mm coaxial connectors connected by a K-glass bead.

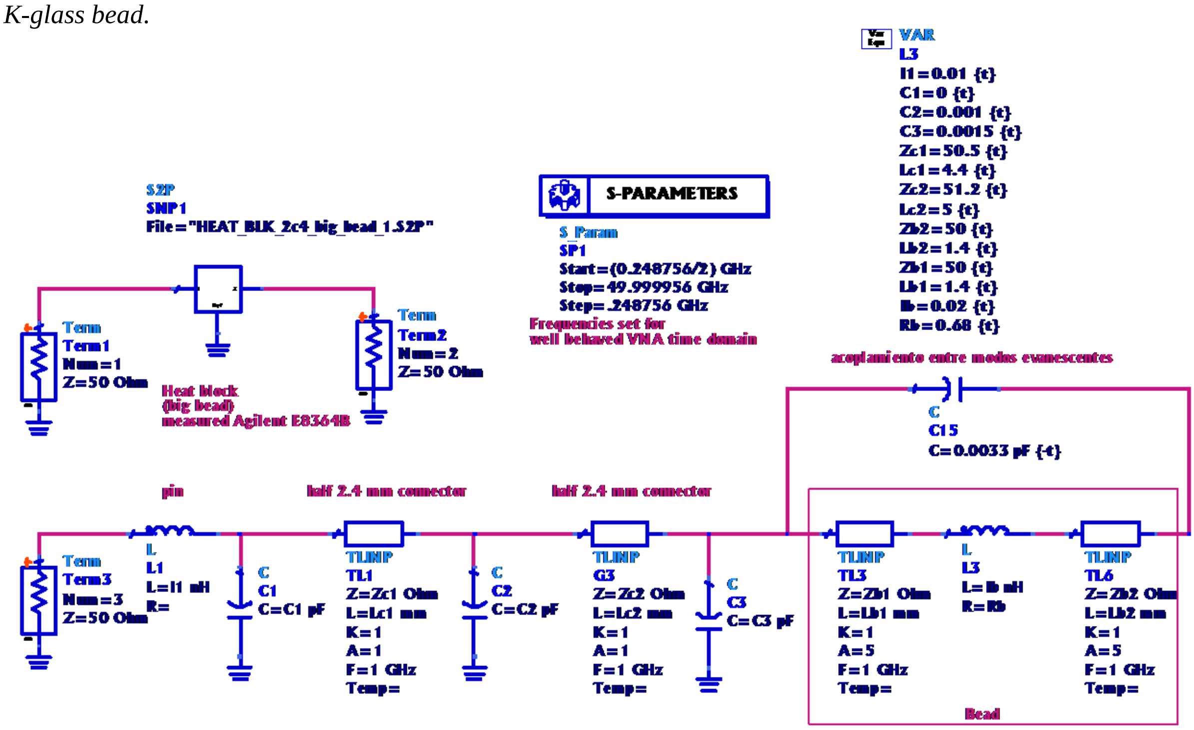


Figure 22. Zoom of the ADS model of the heat block with two back to back 2.4 mm coaxial connectors connected by a K-glass bead.

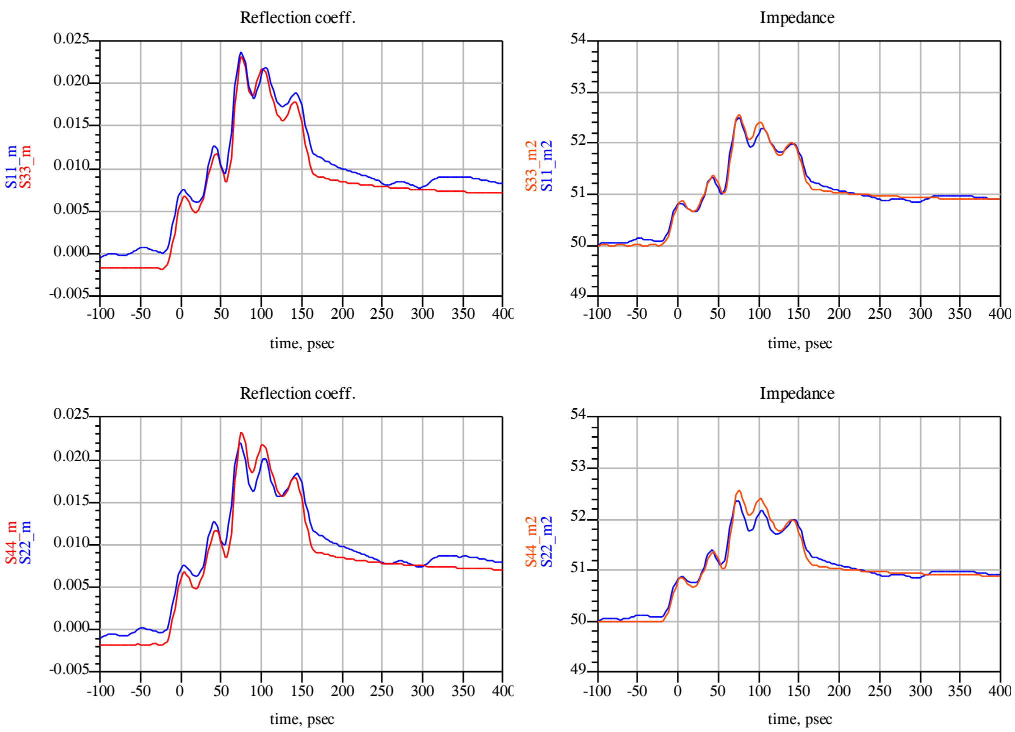


Figure 23. Measurement (blue) vs. ADS model (red) of the heat block with two back to back 2.4 mm coaxial connectors connected by a K-glass bead, in time domain.

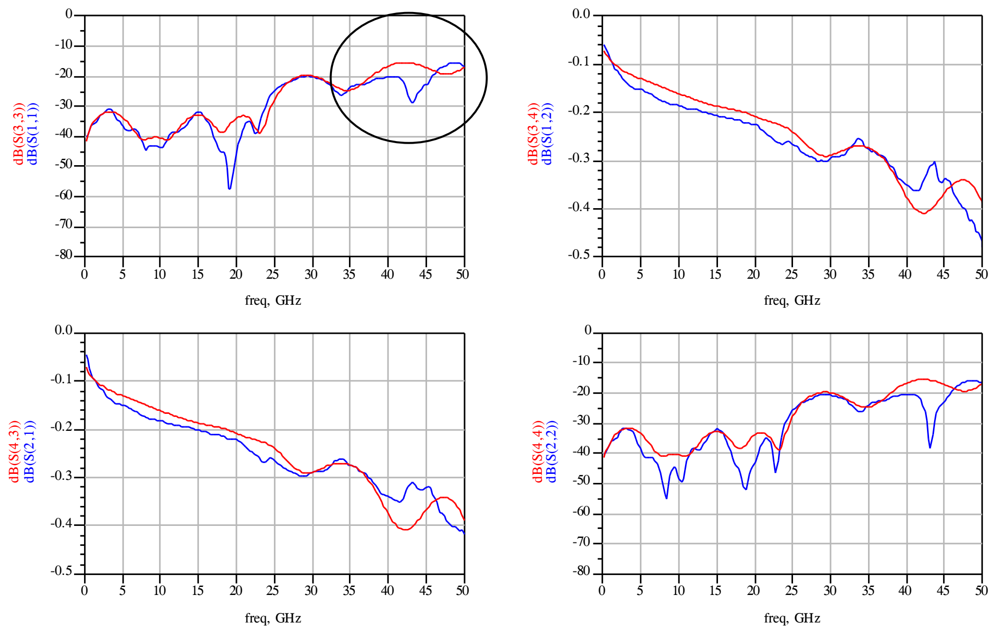
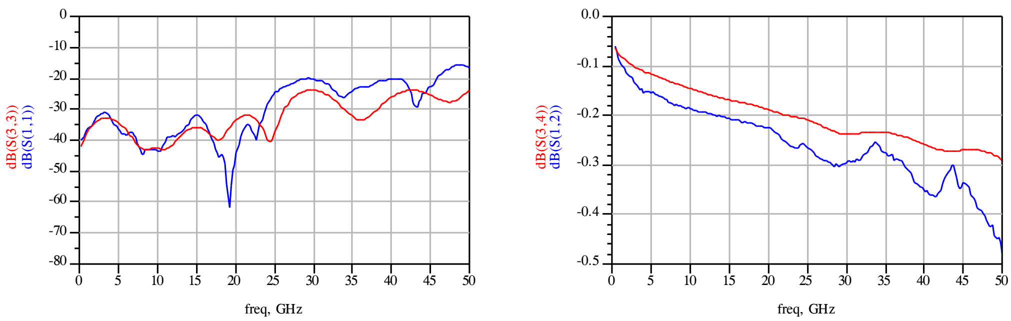


Figure 24. Measurement (blue) vs. ADS model (red) of the heat block with two back to back 2.4 mm coaxial connectors connected by a K-glass bead, in the frequency domain.

If the C15 capacitor is eliminated from the ADS model, the s_{11} parameter would be:



5) Model of the Q band transition WR22 to coaxial (2.4 mm) connector (with K-glass bead).

The new model of the Q band transition is obtained by adding the model obtained in the section 2 to the HFSS simulation of the transition (with the reference plane of the input port set at the beginning of the bead). The fitting is not good (Figure 26).

2.4 mm coaxial connectors: Southwest Microwave, p/n: 1420-01SF
Measurement file: “Q_WG_to_24_6.s2p”.
HFSS file: “Transic_WR22_ Coax2c4_beadK_d0c45.s2p”.

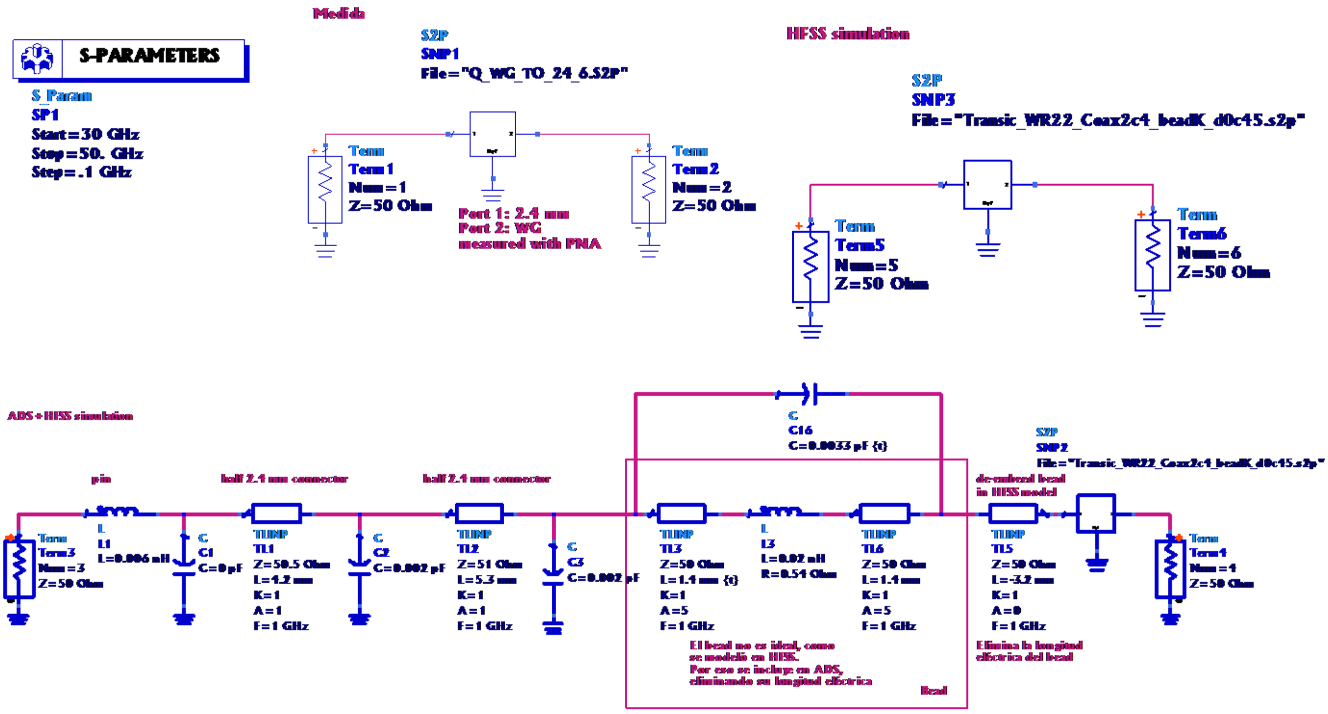


Figure 25. ADS model of the Q band transition WR22 to coaxial (2.4 mm) connector (with K-glass bead).

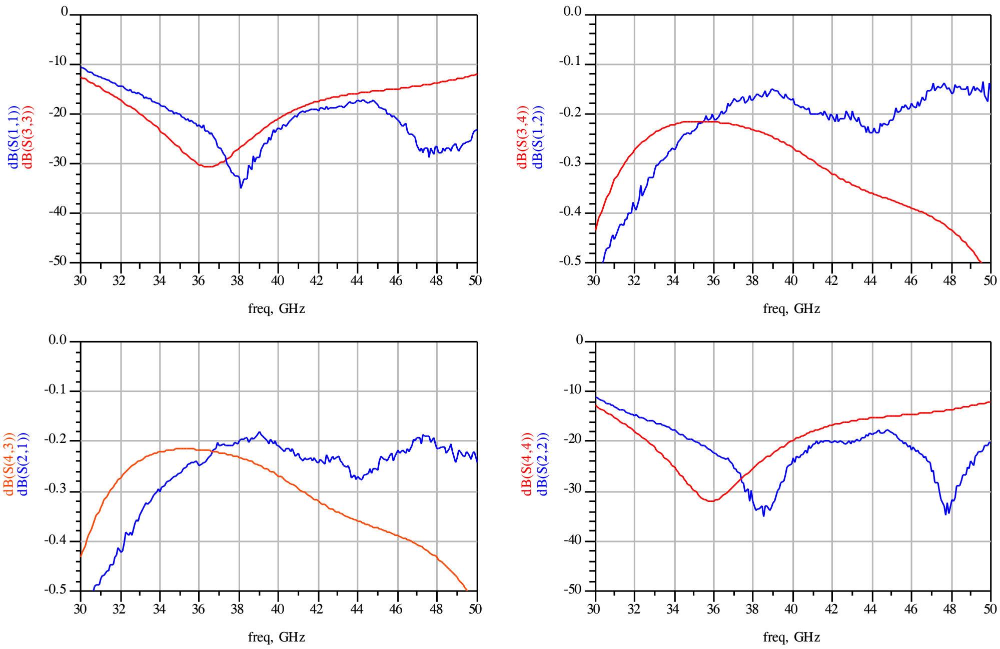


Figure 26. Measurement (blue) vs. ADS model (red) of the Q band transition WR22 to coaxial (2.4 mm) connector (with K-glass bead), in the frequency domain.

If the C16 capacitor is eliminated from the ADS model, the modeled s_{11} parameter fits better to the measurement (Figure 27).

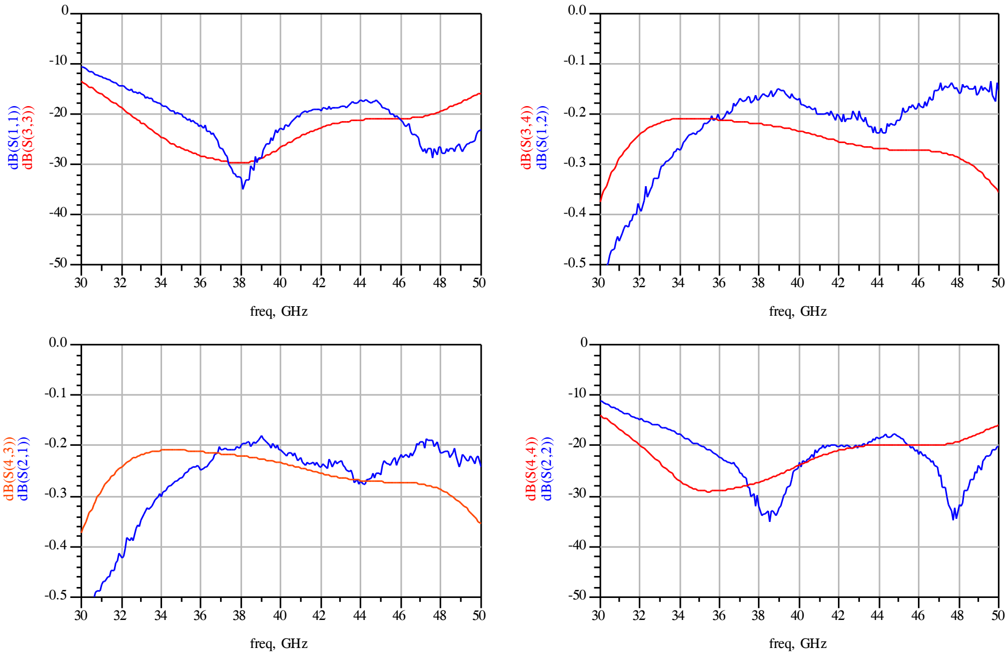


Figure 27. Q band transition: Measurement (blue) vs simulation without C16 capacitor (red).

a) Heat block with two back to back SRI 2.4 mm coaxial connectors connected by a K-glass bead.

2.4 mm coaxial connectors: SRI, p/n: 27-150-1500-40.
Measurement file: “Heat_Blk_ SRI_2c4mm_beadK_1.s2p”.

The estimated electrical length of the connector is 9.2 mm, using the electrical length of 2.8 mm for the K-glass bead (estimated in the section 4) of the Annex). The physical length of the connector is 8.6 mm.

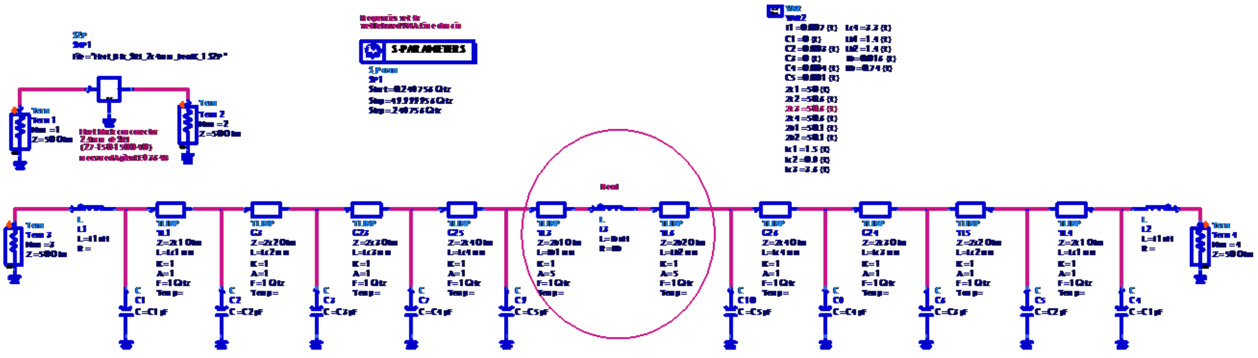


Figure 28. ADS model of the heat block with two back to back SRI 2.4 mm coaxial connectors connected by a K-glass bead.

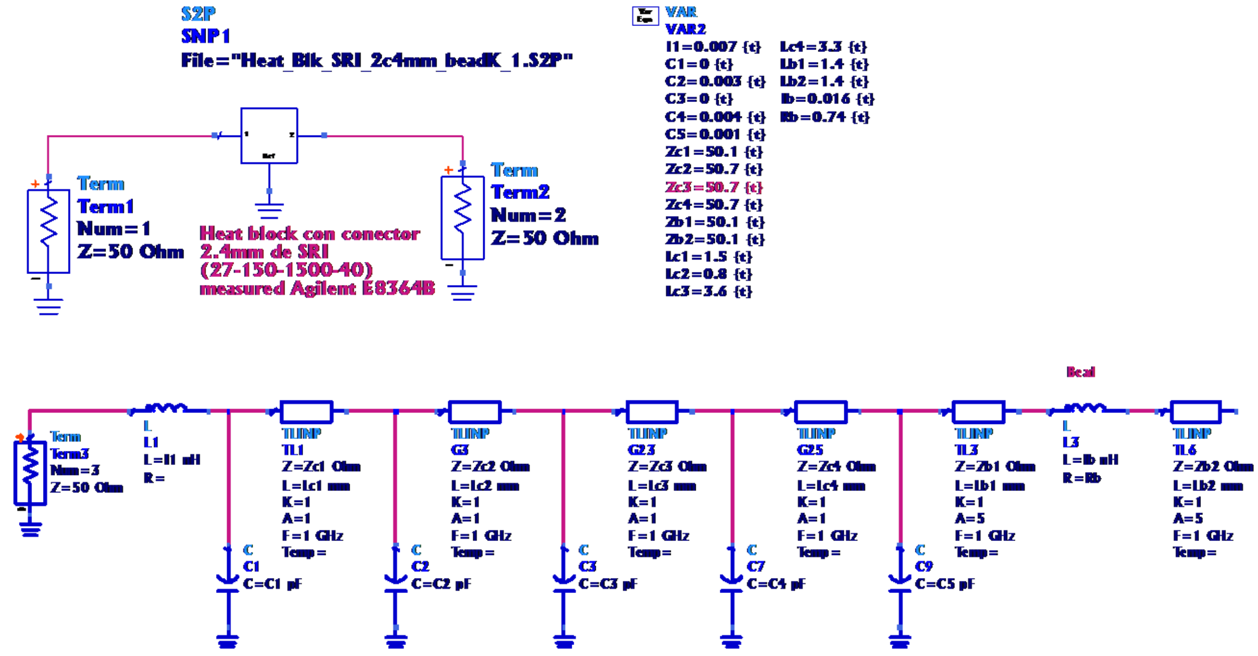


Figure 29. Zoom of the ADS model of the heat block with two back to back SRI 2.4 mm coaxial connectors connected by a K-glass bead.

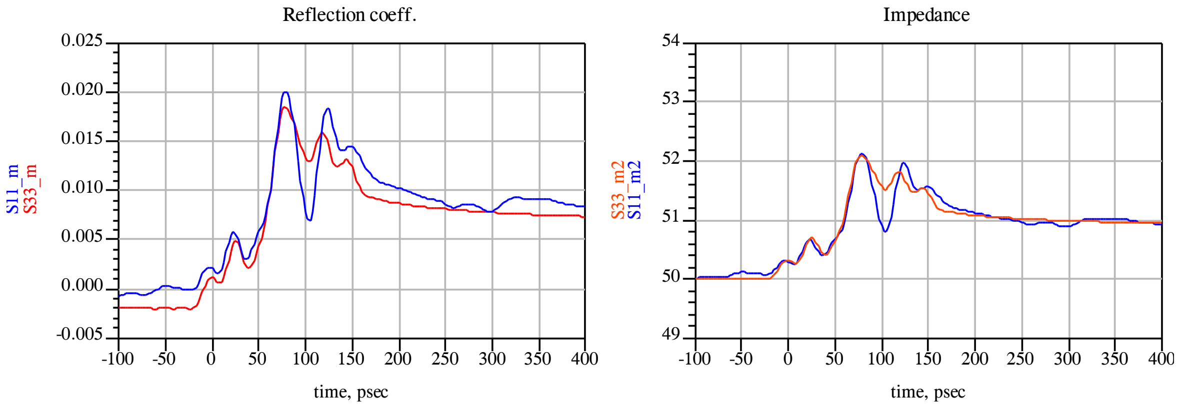


Figure 30. Time domain of the measurement (blue line) vs. ADS model (red line) of the heat block with two back to back SRI 2.4 mm coaxial connectors connected by a K-glass bead.

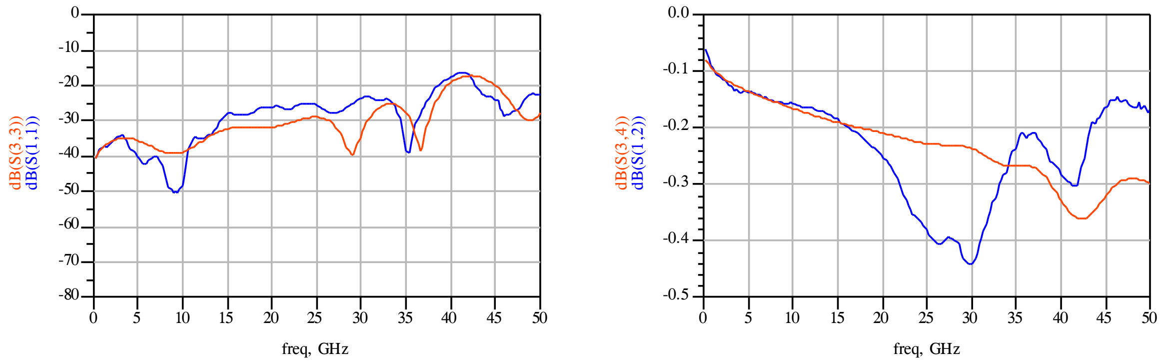


Figure 31. Frequency domain of the measurement (blue line) vs. ADS model (red line) of the heat block with two back to back SRI 2.4 mm coaxial connectors connected by a K-glass bead

b) Comparison of the performance of a SRI 2.4 mm coaxial connector vs. a Southwest connector, measured in a heat block using two identical connectors connected by a K-glass bead.

2.4 mm coaxial connectors, SRI: 27-150-1500-40.
2.4 mm coaxial connectors, Southwest Microwave: 1420-01SF.
Measurement files: "Heat_Blk_SRI_2c4mm_beadK_1.s2p"
"Heat_Blk_2c4_big_bead_1.s2p".

The s_{11} parameter for SRI and Southwest connector is similar in the 30-50 GHz band. Up to 40 GHz, southwest connector is better than SRI connector. In the time domain, the discontinuities of the SRI connector (Figure 33) are lower than the discontinuities of the Southwest connector.

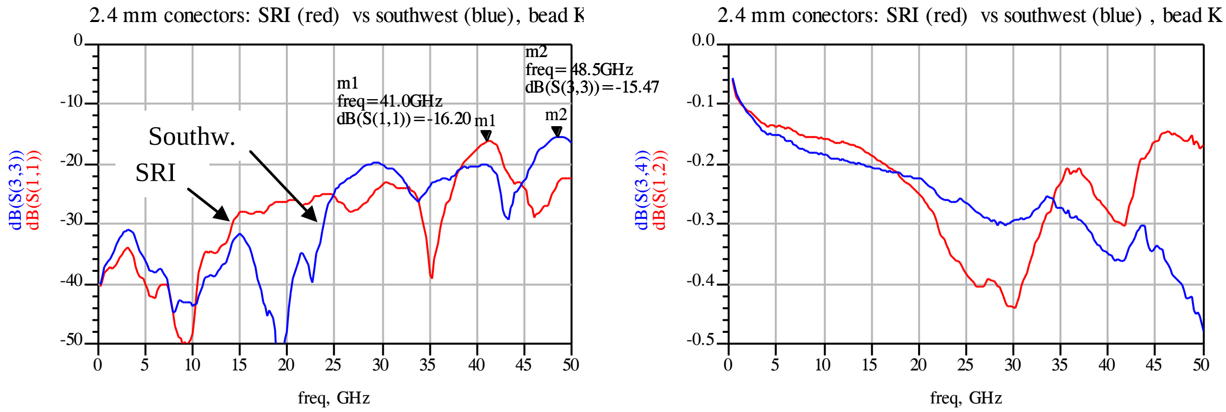


Figure 32. Comparison of the heat block measurements in the frequency domain.

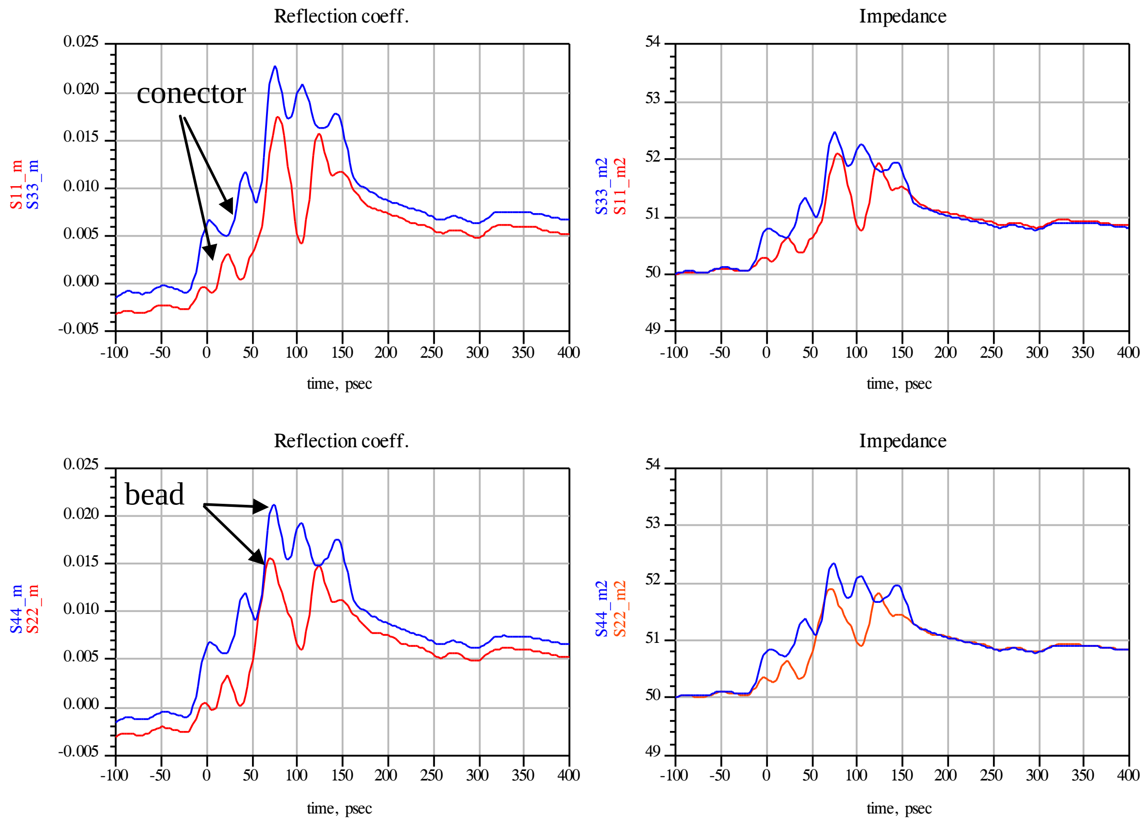


Figure 33. Comparison of the heat block measurements in the time domain.

c) Comparison of the performance of a K-glass bead connector vs. a V-glass bead connector from Southwest, measured in a heat block using two identical connectors connected by the suitable glass bead.

2.4 mm coaxial connectors for K-glass bead (big bead), Southwest Microwave: 1420-01SF.
2.4 mm coaxial connectors for V-glass bead (small bead), Southwest Microwave: 1420-03SF.
Measurement files: "Heat_Blk_2c4_big_bead_1.s2p".
"Heat_Blk_2c4_small_bead_1.s2p"

The glass bead introduces the largest discontinuity, and it is similar for both beads. However the connector for V-glass bead produces lower discontinuities than the connector for K-glass bead (Figure 35). In the frequency dominion, the S_{11} is lower for the V-glass bead connector (Figure 34). Therefore, the ***V-glass bead connector must be used for the 30-50 GHz band.***

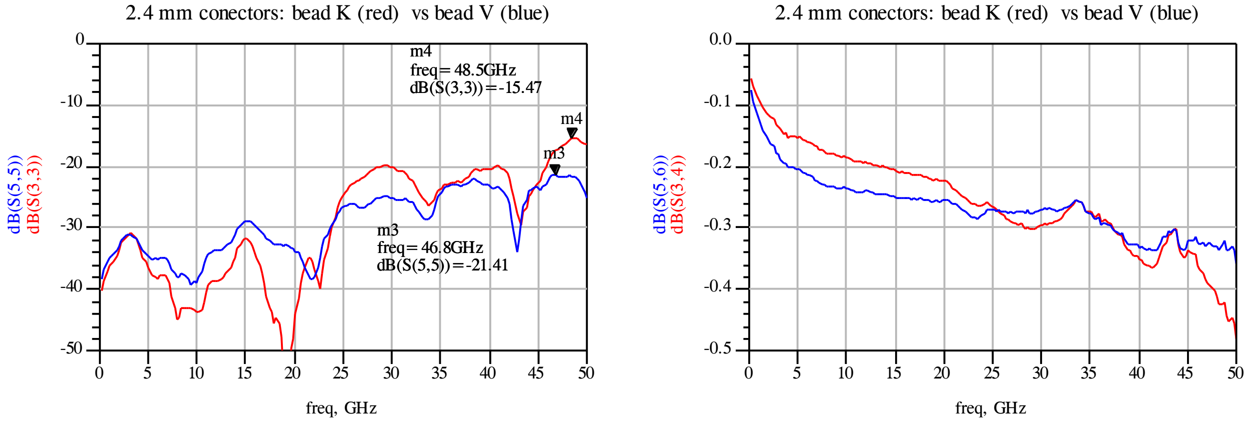


Figure 34. Comparison of the heat block measurements with K-bead connector (red line) and with V-bead connector (blue line) in the frequency domain.

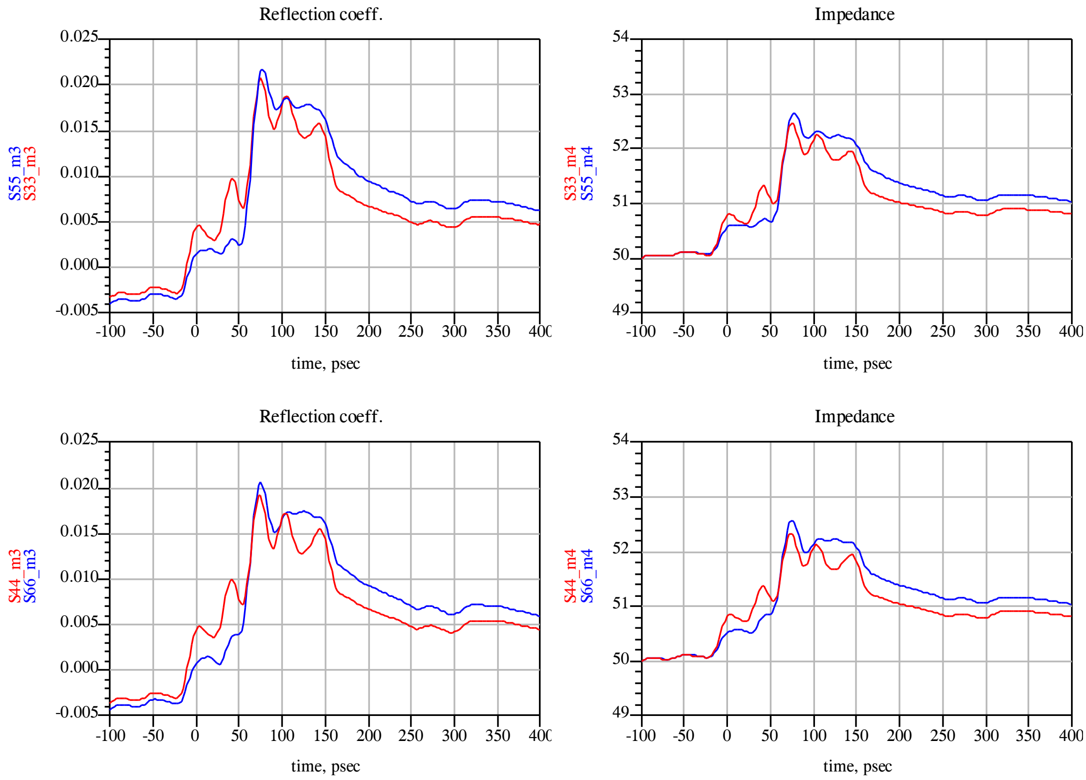


Figure 35. Comparison of the heat block measurements with K-bead connector (red line) and with V-bead connector (blue line) in the time domain.

The high frequency variations are reduced when a gate (0-200 ps, approximate connector length) in the time domain measurement is set.

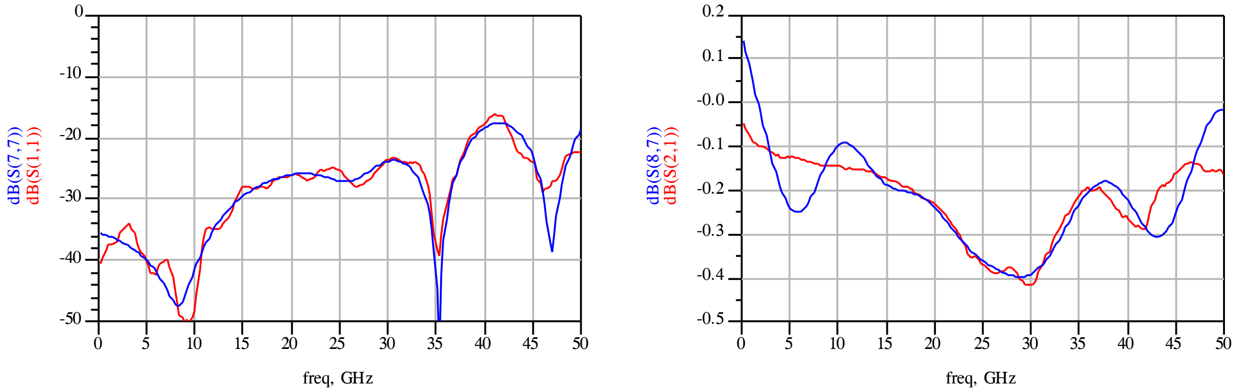


Figure 36. Measurements of the heat block without (red line) and with (blue line) a gate in the time domain.

Annex conclusions:

The fitting of the theoretical non-ideal models of the connectors to the measurements is not very good in the high end of the band (from 30 to 50 GHz). There are high frequency effects not taken into account by these simple models. One of them could be related to coupling between evanescent modes created in the discontinuities of the connector.

The physical / electrical length of the SRI 27-150-1500-40 2.4 mm coaxial connector is:
8.6 mm / 9.2 mm.

The physical / electrical length of the Southwest 1420-03SF 2.4 mm coaxial connector is:
8.5 mm / 9.5 mm.

The SRI and Southwest 2.4 mm connectors for K-glass beads perform quite similarly in the 30 to 50 GHz frequency range. Up to 40 GHz, the Southwest connector appears to perform slightly better than the SRI connector. However, in the time domain, the discontinuities of the SRI connector appear to be lower than the discontinuities of the Southwest connector.

Southwest 2.4 mm connector for V-glass bead performs better than the Southwest 2.4 mm connector for K-glass bead in the 30 to 50 GHz band.