Design and measurement of a waveguide to coaxial transition for 18 to 32.3GHz band (ASTROREC Project).

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1. Abstract

A transition from a not standard WR36 waveguide to 2.92mm coaxial connector has been designed and manufactured covering the 18-32.3 GHz band for the ASTROREC project. The developed transition addresses two goals: a) allowing a dual configuration –coaxial and waveguide – for the input port of the LNA and b) the manufacturing of a compact WR36-coax transition for the calibration kit used in the S-par measurements with the VNA of components in WR36.

The design, similar to [1], is based on a cylindrical radiating element attached to the bead fixed at a wide wall of the waveguide. There is also a protrusion machined on the wall placed in front of the bead to help achieve good return loss in such a wide bandwidth. However it introduces a new element, a clamp, used to insert the radiating element to the bead pin. The clamp avoids degradation of the grip of the radiating element every time the port of the amplifier is changed between waveguide or coaxial.

Return loss of the designed transition is better than -25 dB in the whole band. However the machined sample shows a minimum of -14.5 dB in the return loss at 18 GHz that improves with frequency to be better than -20 dB from 19.2 GHz onwards. The reason for the degradation of the return loss in the lower part of the band is unknown. Several possible manufacturing errors have been considered but none of them explained the degradation.

2. Introduction.

ASTROREC is a project of the Observatorio de Yebes (OY) for the design, construction, measurement, installation and commissioning of a high sensitivity cryogenic receiver for Radio Astronomy with an instantaneous bandwidth between 18 and 32.3 GHz. This receiver will be mainly used for the detection of heavy molecules in the interstellar medium. Partly funded by Spanish *Plan Nacional de I-D+I*, the receiver will be installed in the 40m radio telescope of the OY.

The most critical input components of the frontend of that receiver will be designed with waveguide interfaces (instead of coaxial) to reduce the loss of the connecting lines and thus the thermal noise added. However there is no standard waveguide covering the complete 18-32.3 GHz band required. The closest standards are WR42 (18-26.5 GHz), WR34 (22-33 GHz) and WR28 (26-40 GHz) but they only partially cover the ASTROREC band. It was therefore decided to use a custom rectangular waveguide with dimensions of 9.2 x 4.6 mm, with a 16.245 GHz cut-off frequency for the fundamental mode (TE_{10}) and a 32.49 GHz for the cut-off of the first higher mode. The adopted flange is based on standard flange for WR42 (MIL-F-3922/54-001[1], compatible with UBR 220 and UG-595/U flange types) and detailed in Annex B. From now on, this particular waveguide for ASTROREC will be named WR36[2].

In this framework, the design and fabrication of a transition from the WR36 waveguide to 2.92 mm coaxial (K-connector) is required to satisfy these conditions:

a) Two transitions are needed to enable the measurement of the S-parameters of some of the frontend components (horn, OMT, directional coupler and the input port of the Low Noise Amplifier) with the VNA. For that purpose two transitions will be manufactured: one from WR36 waveguide to female 2.92 mm coaxial and the other one from waveguide to male 2.92 mm coaxial, together with a short and a λ/4 long waveguide needed for the VNA calibration process.

b) The developed transition should be adequate to allow having a dual configuration – coaxial and waveguide – for the LNA input port. A coaxial port is more convenient during the development of the LNA because it allows measurements down to DC. However, a waveguide input port will be needed in the final receiver configuration to interface with the other front-end components.

1 A. Kerr et al, “Waveguide Flanges for ALMA Instrumentation”, ALMA Memo nº 278.

2 Following the WR naming convention (from US), because the long side of the waveguide has a width of 9.2 mm or 0.36 inches.

3. Design

The WR36 waveguide to coaxial transition will be designed based on a radiating element (hereinafter referred as antenna), easily removable, attached to a glass bead, in a similar way as it was done for Ka and Q band amplifiers [1] but introducing any modifications to the design in order to address to issues found:

- The [1] design had a mechanical problem: the antenna was only held in the glass bead's pin by a friction fit i.e. it was not glued or soldered because it must be removed every time the port of the amplifier has to be switched between waveguide and coaxial. Each change causes a slight increase of the diameter of the antenna hole, worseing the grip of the antenna. The antenna was made from a copper cylinder cut lengthwise in one side only to allow it to be opened and clamped, similar to how a connector clamp works. The wear of the antenna hole is due to the low hardness of its material.

- It is not possible to scale the [1] design to the ASTROREC frequency band because the radius of the 0.012" pin (called R1 in [1]) accepted by some 2.92 mm connectors[3] leads to an antenna length more than four times longer than the piece of the pin available to grip the antenna, which jeopardizes the mechanical strength of the design.

A diagram of the new transition proposed is shown in Figure 1. In order to address the two drawbacks outlined before, a new piece, a clamp, is added, as shown in Fig. 1. A photo of the clamp is presented in Fig. 6.

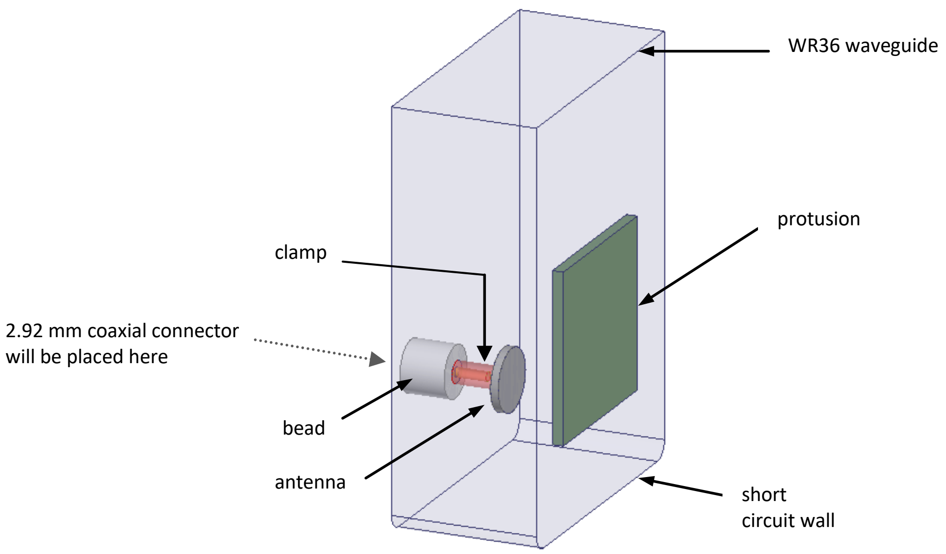


Figure 1. Diagram of the WR36 waveguide to coaxial transition, showing its main components. The coaxial 2.92mm connector, not included in this graph, will be attached to the bead placed outside of the waveguide.

The antenna will be inserted in the clamp and the clamp will be then fitted in the bead pin. When the antenna has to be removed, it is not the antenna but the clamp what is pulled out. So the antenna

[3] From Wiltron (now Anritsu), part numbers: K-102F (female), K-102M (male)

is inserted on the clamp only one time ensuring it remains properly placed without gluing or soldering. And most importantly, the clamp fitted in the pin causes an increase of the effective radius of the pin (called R1 in Fig.2) allowing dimensions of the transition suitable to obtain a robust mechanical design. Furthermore the clamp adds an additional parameter named "d" (as shown in Fig.2) to the optimization process.

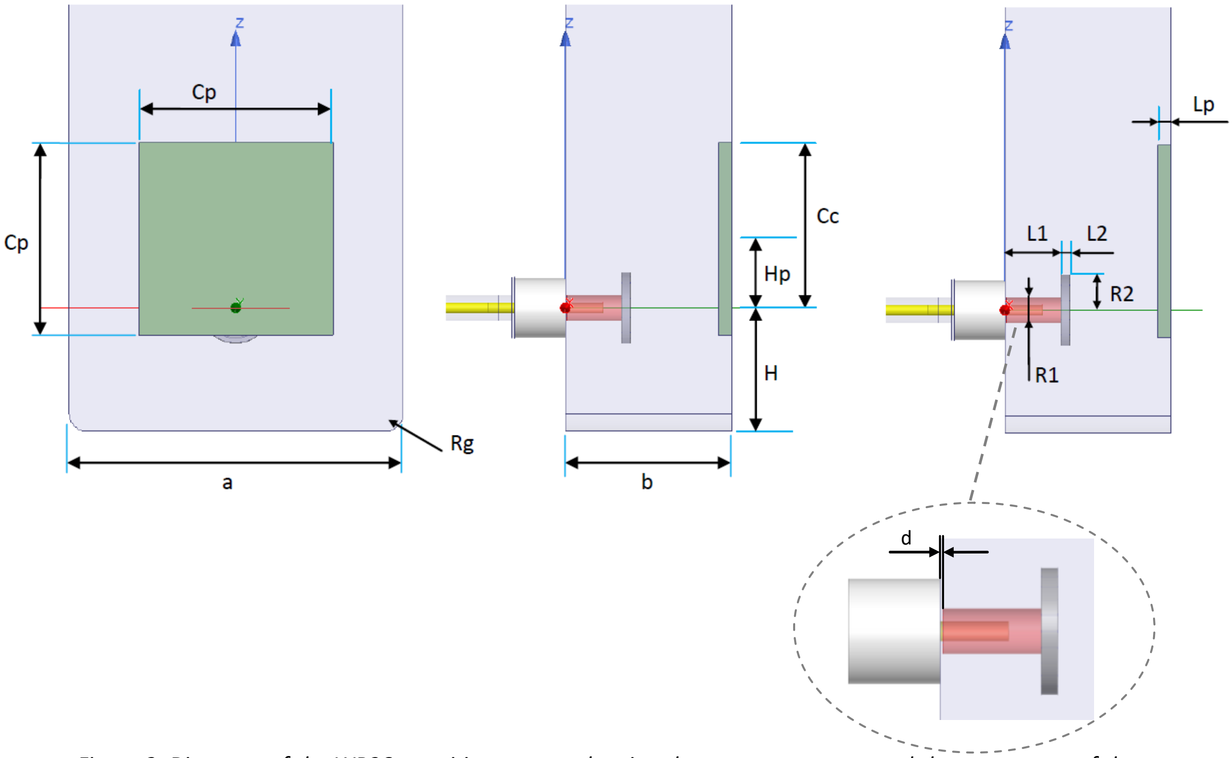


Figure 2. Diagrams of the WR36 transition to coax showing the component parts and the parameters of the transition. On the left side is the front view of the transition. In the middle and right side is the lateral view. The component parts of the transition are colored in the diagrams: The protrusion is shown in green color, the clamp in pink, the antenna in dark grey, the waveguide in pale grey and the bead pin in yellow color.

In summary, the concept of the WR36 waveguide to coaxial transition for ASTROREC is illustrated in Figure 2. The parameters involved are:

- H: Distance from the axis of the bead to the waveguide short.
- R2: Antenna cylinder radius.
- L2: Antenna cylinder length.
- R1: Clamp radius measured when the bead pin is inserted in the clamp.
- L1: Distance from the base of the antenna to the wall of the waveguide where the bead is located.
- d: Distance from the clamp to the wall of the waveguide where the bead is located.

All these parameters except the clamp radius (that is fixed) were included in the optimization process done using HFSS (ANSYS) software. Because of the wide bandwidth, a protrusion was introduced in the design to achieve a return loss of around -25 dB for the whole band. The protrusion is machined in the wide wall of the waveguide placed in front of the bead. The parameters added by the protrusion to the optimization are (see Fig. 2):

- Cp: The length of the square protrusion side.
- Hp: Distance from the protrusion centre to the axis of the glass bead.
- Lp: Thickness of the protrusion.

The milling tool radius used to machine the waveguide is also taken into account (called "Rg") in the simulated model.

Following the design presented in Fig. 2, the value of the optimized parameters is presented in Table 1 (shaded in grey color), followed by the fixed dimensions of the transition. The simulated return loss is presented in Fig. 2.

Parameter		*Value*
d	Distance from the clamp to the wall	0.04
R2	Antenna radius	0.98
L2	Antenna length	0.25
H	Distance from the axis of the bead to the waveguide short-circuit	3.41
L1	Distance from the base of the antenna to the wall of the waveguide where the bead is located.	1.50
Hp	Distance from the protrusion centre to the axis of the glass bead	1.90
Lp	Thickness of the protrusion	0.35
Cp	Length of the square protrusion side	5.32
a	WR36 waveguide widest dimension	9.20
b	WR36 waveguide shortest dimension	4.60
R1	Clamp radius measured when the clamp was inserted in the glass bead 0.012" pin	0.35
Rg	Milling tool radius	0.60
Cc		4.56
bead		0.012"

Table 1. Nominal value of the parameters used to manufacture the WR36 to 2.92 mm transition. Note that Cc+H is the minimum length of the waveguide needed for the transition. All dimensions are in mm.

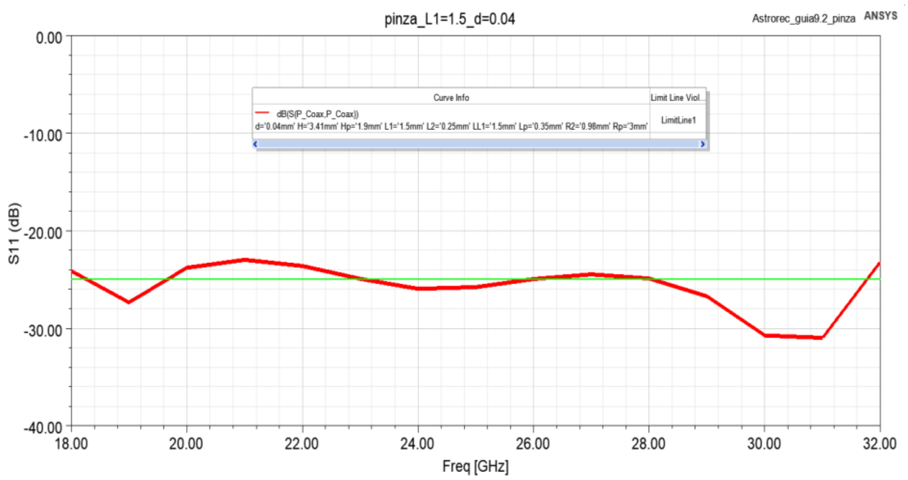


Figure 3. Return loss of the WR36 waveguide to coaxial transition with the value of the parameters presented in Table 1, simulated with HFSS (ANSYS).

4. Manufacture

A description of the elements used for manufacturing the transition together with some construction details are presented below:

- The selected K type (2.92 mm)[3] connector, can be directly mated to 3.5 mm and SMA connectors. Its cutoff frequency is well over 40 GHz.

- The 0.012" glass bead[4] is of the type originally used for Wiltron K connectors. The dielectric used in the bead is Corning 7070[5] (dielectric permittivity of 4.05 @ 1 MHz and a loss tangent of 0.06 @ 1 MHz). It is glued with conductor-epoxy[6] and it was held in place for assembly with the help of an aluminum plate with a hole for the bead pin screwed to the inside wall of the waveguide. The bead, impregnated with epoxy, is inserted from the outer wall of the waveguide.

    - In the case of the waveguide to K connector transition manufacture, the glass bead is fitted to the wall of the waveguide where the connector will be placed. The bead's longest pin will be placed towards the waveguide where the radiating element will be placed. A field-replaceable type connector will be attached to the shortest pin.

    - For the amplifier manufacture, the glass bead is fitted in its input port with the shortest pin placed towards inside of the amplifier. To let the dual configuration of its input port, the longest pin can be used both to attach a field-replaceable type connector when a coaxial port is used and to hold the antenna when the waveguide port is required.

- The clamp, used to insert the antenna into the bead pin, has been made using one of the two K-102F connector component parts, marked as "(1)" in Fig. 4. The center conductor was extracted from the plastic encapsulation of "(1)" and it is shown in Fig. 5. It is made of five parts distinguished and marked as "Ti" in Figure 5. The useful parts for us are the bead-clamp, marked as T5, together with

[4] 12 mil pin diameter bead, part number 290-07G from Southwest

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

[6] EPOTECK H20E

part of T4 (“L2” length) that will be used to fit the antenna. The set is marked in Figure 5 by the blue dashed rectangle.

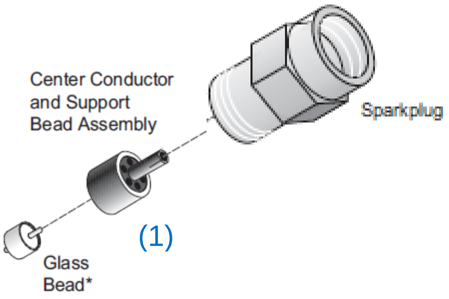


Figure 4. This figure shows a glass bead and the two component parts of a K102-M connector.

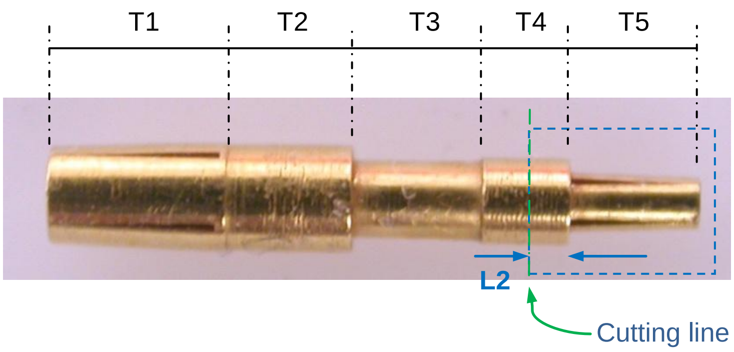


Figure 5. This photo shows the center conductor removed from the plastic encapsulation marked as “(1)” in Figure 4. Five different parts can be identified: T1 is the clamp for matting connectors. T5 is the bead clamp (1.5 mm long with a diameter of 0.7 mm). T4 is 1 mm long and has a diameter of 1.02 mm. The center conductor was cut by the “cutting line” (marked in green color). A clamp composed by a L2 length of the T4 (where the antenna will be placed) together with T5 (which will be the clamp for the bead) is obtained. The resultant part is shown in Figure 6 with its final dimensions.

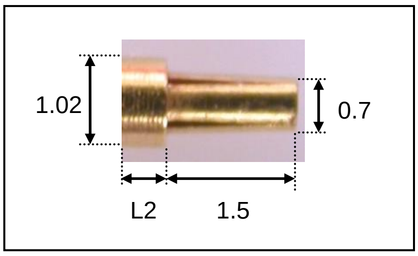


Figure 6. Clamp dimensions (all values are in mm).

- The antenna was made out of brass and plated with hard gold around 1 µm thick.

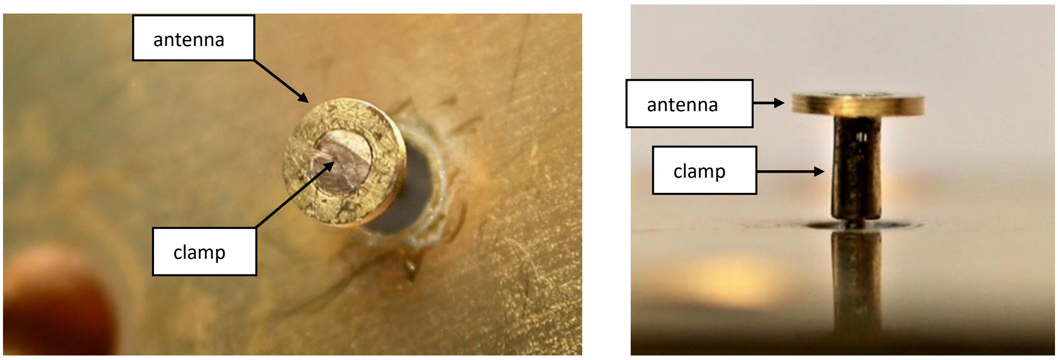


Figure 7. Antenna and clamp placed inside the waveguide inserted in the bead-pin.

- The waveguide housing the transition is made of two parts as shown in Figure 8. Four pins are carefully placed in order to ensure correct alignment. Five screws keep the two pieces together. The plane chosen to split the waveguide is not the best according to the current distribution in the walls, but there are three reasons to do it in this way: a) To let CNC tool machine the waveguide housing avoiding rounded edges (with the exception of the edges at the short circuit wall end) b) Easy placement and alignment of the clamp with the antenna in the bead-pin and c) It is the only way for the transition to be attached to the amplifier when an interchangeable coaxial-waveguide port is required. The material used is 6082 Aluminum plated with 1 µm thick hard gold to reduce loss and to protect the surface from corrosion.

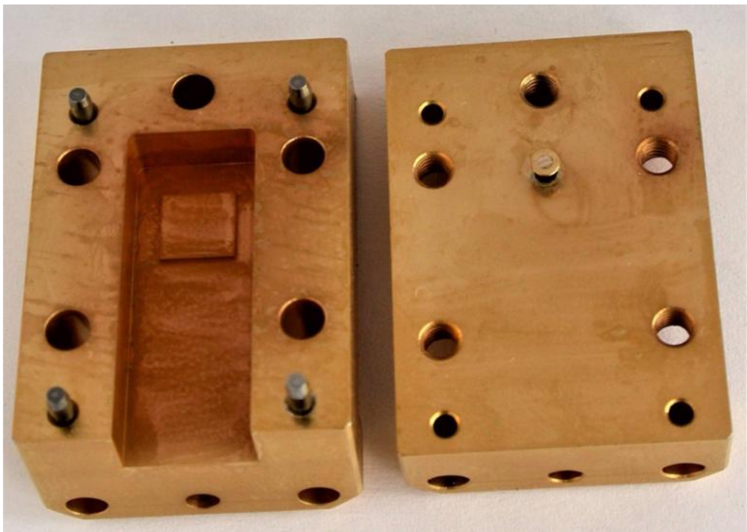


Figure 8. Photo of the two blocks which form the waveguide transition shown by the internal side. On the left is the block with the protrusion; on the right is the block with the antenna.

Two male-female sets of transitions, together with a short and a λ/4 in waveguide have been made (see Fig. 9) according to drawings (see Annex A for details). Each transition weights around 25 g. The transition for the input port of the Astrorec-LNA will be manufactured together with the LNA due to their external geometry depends on the LNA design. Some considerations have been taken into account in the 6th section of this report.

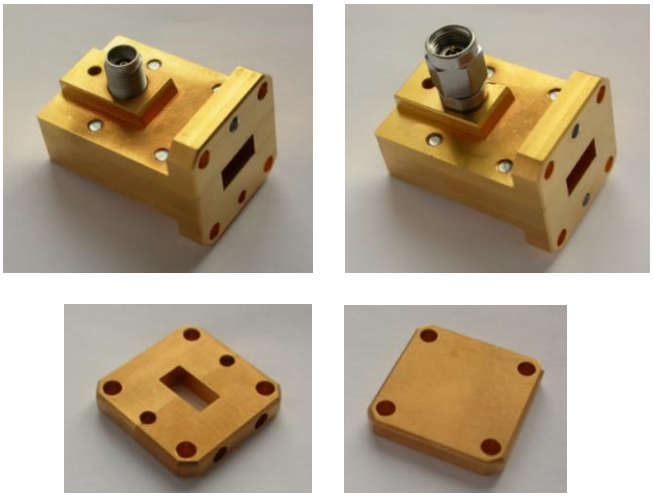
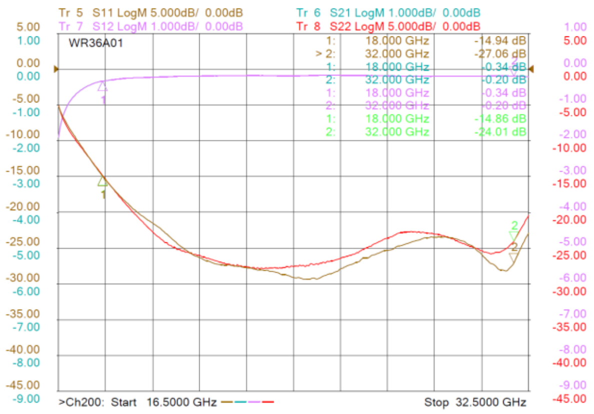


Figure 9. WR36 waveguide to coaxial transition photos: on the top left, transition with female coaxial (marked as WR36A); on the top right, transition with male coaxial (marked as WR36B); on the bottom left, the λ/4 line in WR36; on the bottom right, the waveguide short.

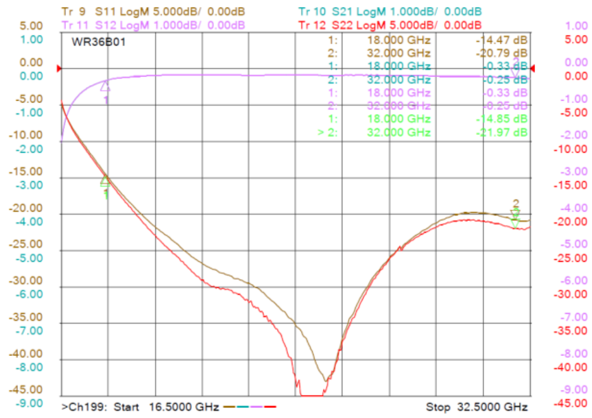
5. Measurement.

S-parameters have been measured with a VNA and are presented in Figure 10 and in the following table:

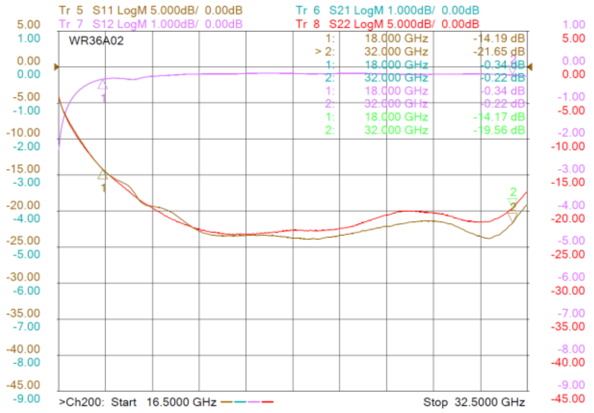
	Return loss (dB), better than:	
SET 01	*-14.5 dB from 18 GHz*	*-20 dB from 19.2 GHz*
SET 02	*-14 dB from 18 GHz*	*-20 dB from 20 GHz*



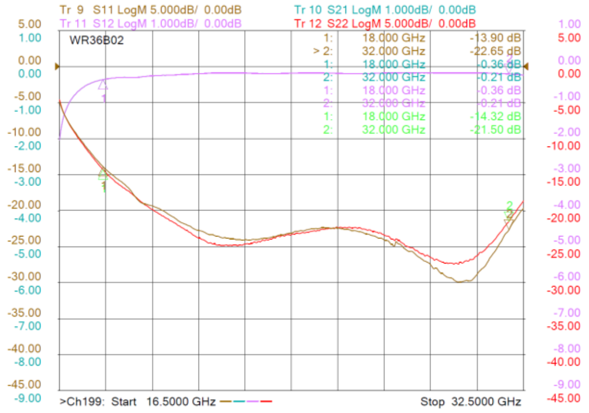
SET 01. WR36A01 is the WR36-K(Female) transition.



SET 01. WR36B01 is the WR36-K(Male) transition.



SET 02. WR36A02 is the WR36-K(Female) transition.



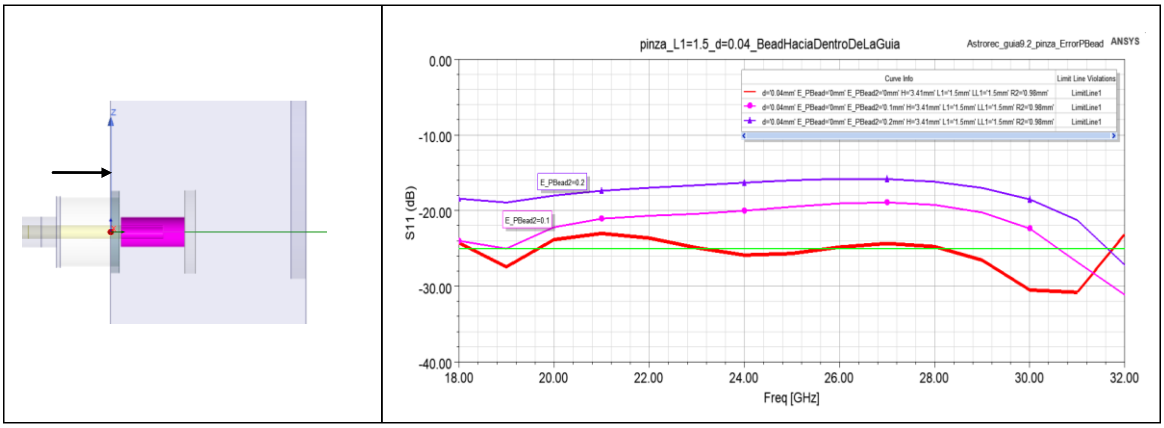
SET 02. WR36B02 is the WR36-K(Male) transition.

Figure 10. S-parameters of the two sets (numbered 01 and 02) of WR36 to female (A) of male (B) coax transitions manufactured.

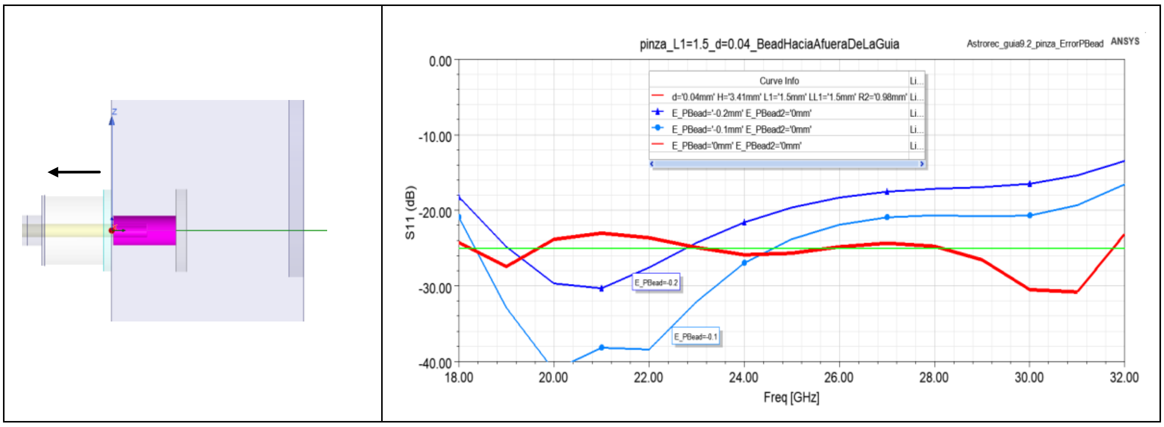
The reasons for the degradation of the return loss in the lower part of the band are unknown. Several possible manufacturing errors have been considered as detailed below but none of them explained the degradation.

1. Wrong placement of the bead.

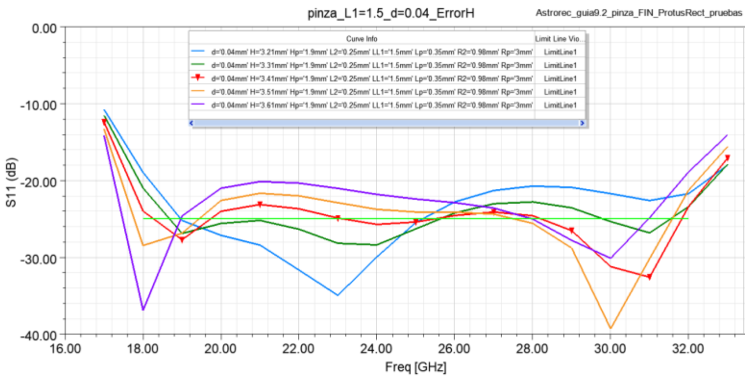
   a. Bead displacement into the waveguide: Bellow, a diagram of the transition with the displacement is presented on the left. On the right, HFSS simulations show the performance of the transition with parameters in Table 1 with the red line as reference (referred as “nominal transition” from now on) versus a transition with a bead displacement of 0.1 or 0.2 mm into the waveguide. The simulation does not match to observed degradation. Besides, in all the manufactured transitions, the bead showed a displacement out of (instead of into) the waveguide.



   b. Bead displacement outward of the waveguide. The displacement measured in the manufactured transitions is between 0.02 and 0.05 mm. Looking at the HFSS simulation (shown in the right graph below), it is not large enough to explain the low frequency degradation .

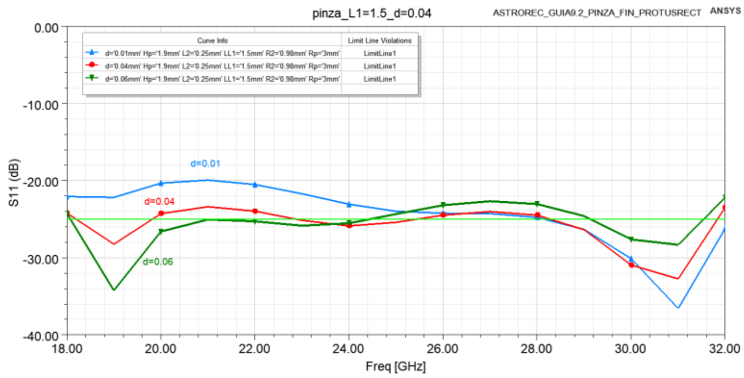


2. Distance from the center of the antenna to the short (H in Table 1). HFSS simulation presented below shows a return loss improvement in the low band when H increases (purple line is H=3.61 mm, red line is the nominal value H=3.41 mm). In order to improve the performance of the transition, new protrusion-blocks were made one with H = 3.61 mm and the another one with H= 3.81 mm, which were attached to the same antenna-block. Although the band moves towards low frequency when H increases, improving the return loss at 18 GHz, the return loss beyond 27 GHz degrades to a larger extent. Therefore increasing the H parameter (see Table 1) is not the way to tune the transition.



3. Higher "d":

   The antenna-clamp is fitted with the aid of a 0.04 mm gauge. An error in the placement of the clamp, shown in the HFSS simulation below for d=0.01 mm (cyan line) and d=0.06 mm (green line), cannot explain the low frequency degradation.



   Transition return loss has been measured placing the clamp from d=0.01 mm to d=0.06 mm, as next figure shows, but the slightly improvement at 18 GHz does not compensate the degradation which appears in the high part of the band.

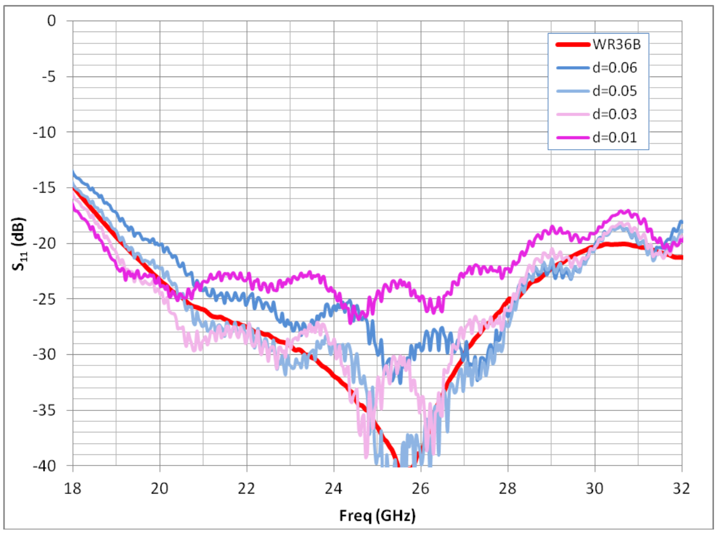
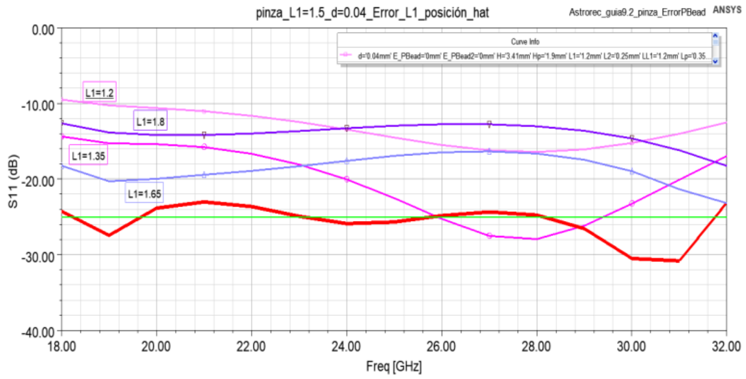
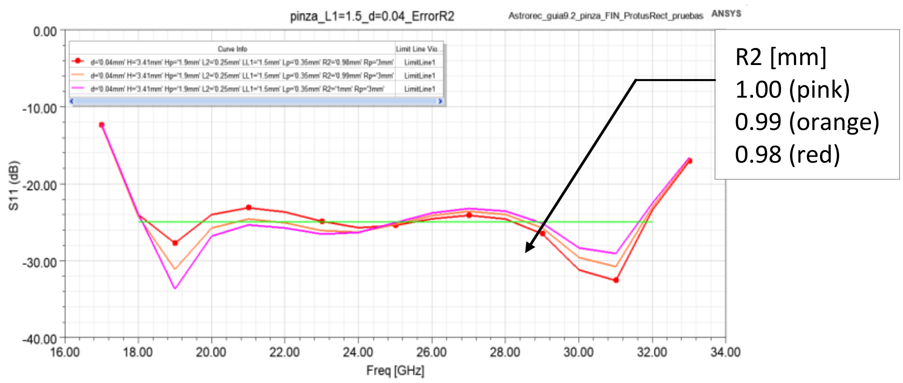


Figure 11. Measurements of the transition for different values of parameter "d" (described in Table 1). Red line is the nominal transition, magenta line is the transition with d=0.01 mm and blue line with d=0.06 mm.

4. Error in the placement of the antenna in the clamp (L1 in Table 1). The plot presented below shows the simulation of the transition for different values of L1 (from 1.2 to 1.8 mm, with nominal value 1.5 mm). It does not explain the low frequency degradation.

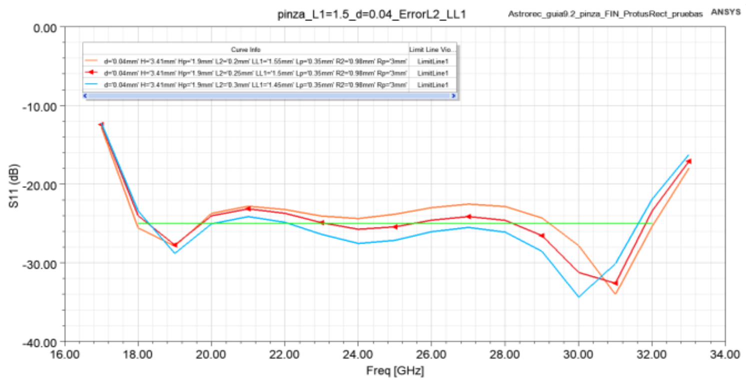


5. Error in the radius of the antenna (R2 in Table 1). The radii of the manufactured antennas are between 0.98 and 1 mm (nominal value is 0.98 mm). According to the simulation presented below, this error is too small to explain the low frequency degradation.



Besides, the excentricity of the antenna was included in the simulation with HFSS. The antenna is a cilinder of radius R2 with a hole inside. Errors in antenna-machining could result in differences between the centers of the hole and the cilinder. Measured center position errors are smaller than ±0.03 mm. This has very little impact on the return loss.

6. Antenna thickness (L2 in Table 1). Nominal value of L2 is 0.25 mm, manufactured antennas have thicknesses between 0.24-0.28 mm. Next graph shows the simulation of the transition when L2 is 0.2 mm (in orange color), 0.25 mm (in red) and 0.3 mm (in cyan). This manufacturing error has a very small impact on the low band performance of the transition.



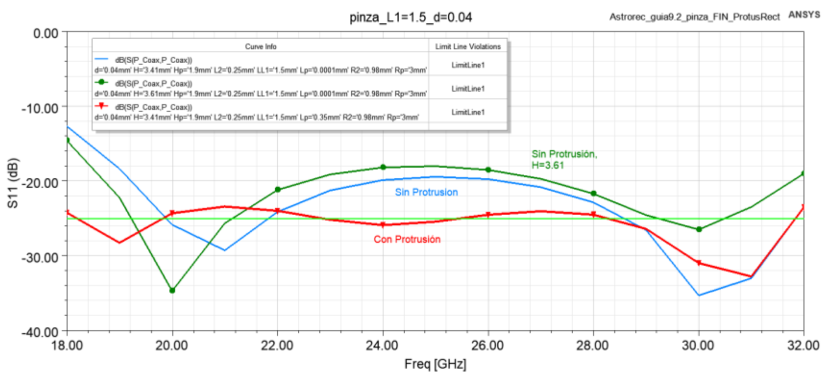
7. Antenna could not be placed perpendicular to the clamp. A tilt of 25 degrees has been simulated but it has a negligible impact on the performance.

6. Transition for the LNA.

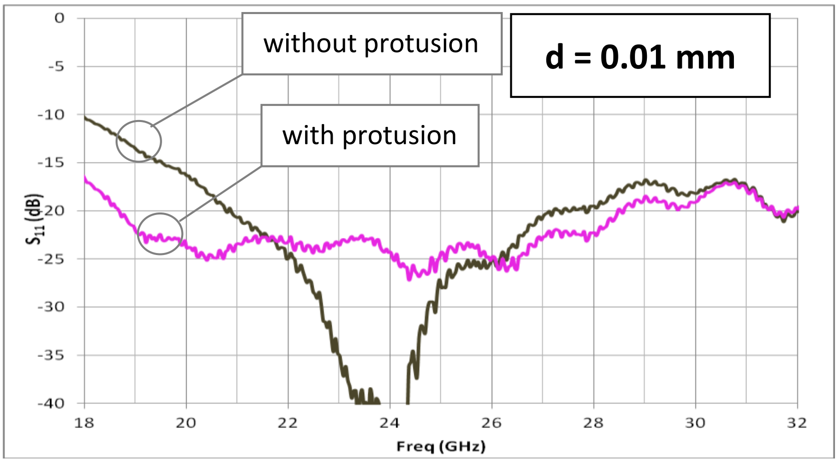
In order to use the waveguide transition at the input port of the LNA some issues have to be taken into account. One of them is the distance from the center of the bead to the end of the protrusion. It is 4.56 mm (Cc in Figure 2 and Table 1), plus a guard space to the flange, if desired. This means that the wall of the LNA input port above the microstrip plane could be too high, hindering the assembly of the components.

One solution could be placing the waveguide flange towards the bottom side of the LNA. This will reduce the size of the wall from 4.56 + guard to 3.41 mm (“H” parameter in Table 1).

Other possibility could be removing the protrusion from the design. HFSS simulation of the nominal transition (red line in next figure) versus a transition without protrusion (cyan line) shows a significant degradation in the low and middle part of the band. Simulation also shows that increasing distance to the short, H (green line), improves the performance at low frequency but degrades it at middle and high frequency.



A transition without protrusion has been manufactured and measured. The figure below shows a comparison with/without protrusion when d=0.01 mm. This value for “d” parameter, different from the nominal one, was selected in order to reduce the degradation in the lower part of the band (as shown in Figure 11). However, the degradation is still significant.



7. Conclusion.

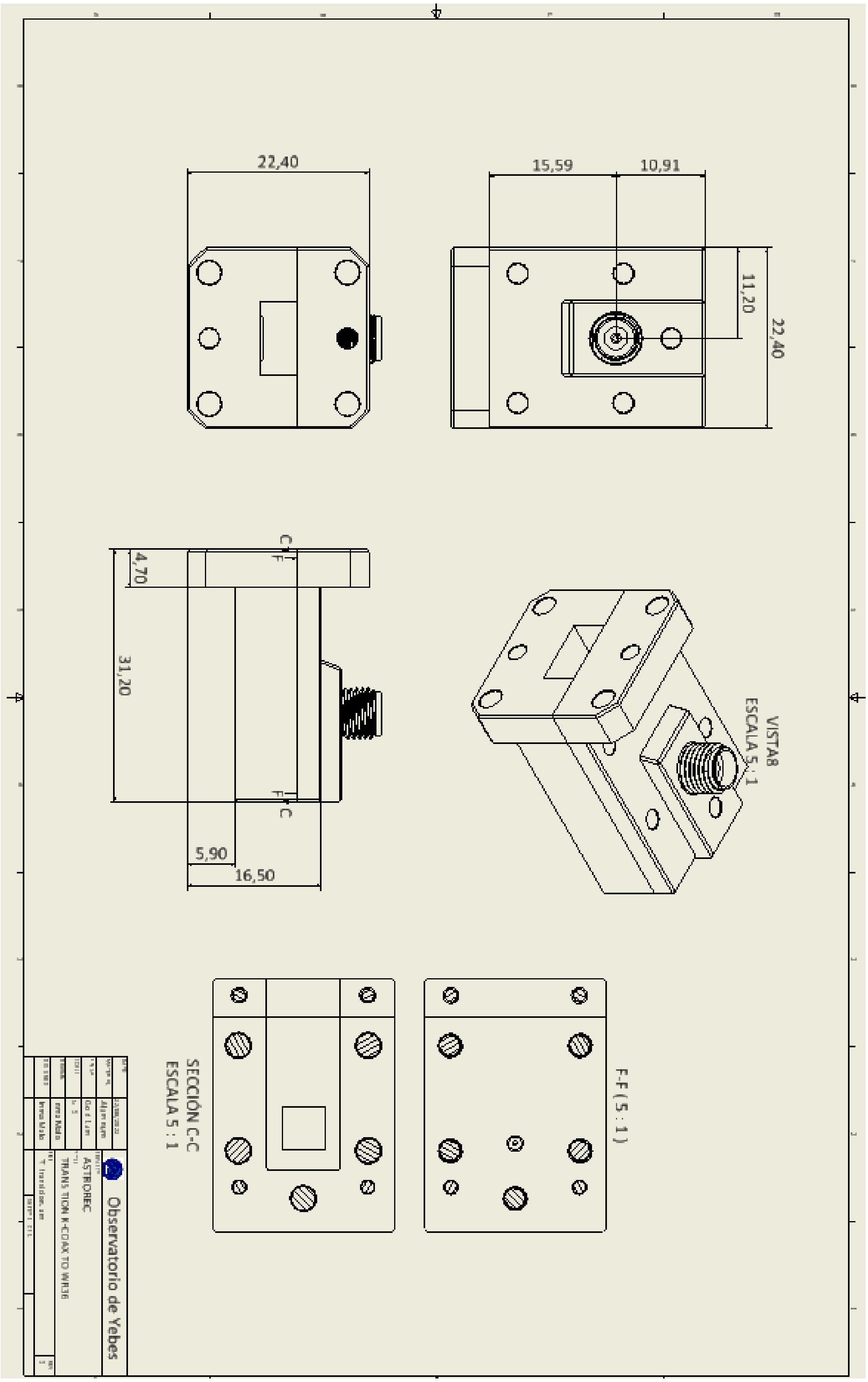
A transition from a not standard not WR36 waveguide to 2.92mm coaxial connector has been designed and manufactured covering the 18 to 32.3 GHz band. Two measurement-sets made up of two transitions (one with male and the other one with female connector) together with a short and a λ/4 long waveguide have been manufactured for the WR36 cal kit of the VNA. Return loss of the designed transition is better than -25 dB in the whole band. However in the machined sample the worst value of the return loss is -14.5 dB at 18 GHz, improving with frequency to be better than -20 dB from 19.2 GHz onwards. The reason for this degradation in the lower part of the band is unknown. Several possible manufacturing errors have been considered but none of them offer a satisfactory explanation.

The designed transition is also adequate to allow having a dual configuration – coaxial and waveguide – for the LNA input port. The mechanical design introducing a clamp is more robust than previous attempts (see [1]) allowing any number of changes of the LNA port from waveguide to coaxial without degradation. The high wall of the LNA input port forced by the transition was addressed and two possible solutions were suggested.

8. References.

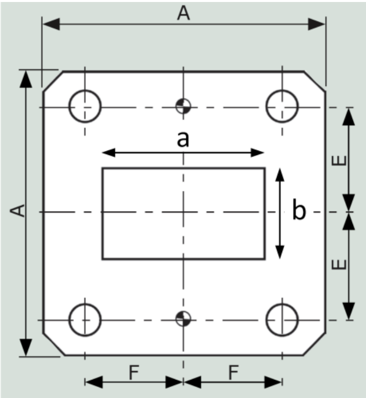
[1] I. Malo, J.D. Gallego, C. Jarufe, J.L. Cano; *"Design and measurement of waveguide transitions for Ka and Q band cryogenic amplifiers"*. *IT-CDT 2013-2.*

9. Annex A: Drawings of the transition.



10. Annex B: Flange

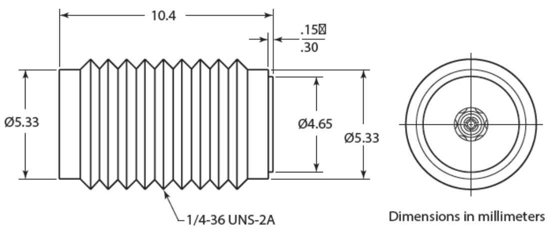
Based on WR42 standard flange (mate with Flann-UBR 220, UG-595/U o equivalents), dimensions of the flange used in the WR36 transition are presented below.



a	9.2 mm
b	4.6 mm
A	22.40 mm
E	8.51 mm
F	8.13 mm
Screw through hole	4x Ø2.95 mm (# 4-40 screws)
Pin through hole	2x Ø2.42 mm (# 3/32'' pin)

11. Annex C: 2.92 mm coaxial connectors.

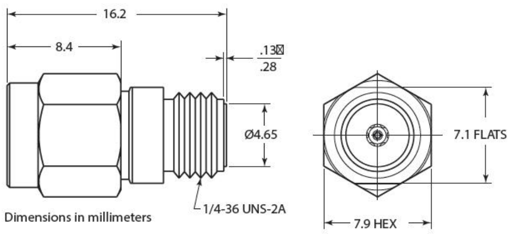
K Female Sparkplug
Launcher Connector
K102F-R
DC-40 GHz
EK102F-R
DC-43.5 GHz



Web site:

https://www.anritsu.com/en-us/components-accessories/products/k102f-r

K Male Sparkplug
Launcher Connector
K102M-R
DC-40 GHz
EK102M-R
DC-43.5 GHz



Web site:

https://www.anritsu.com/en-us/components-accessories/products/k102m-r

Instructions sheets:

https://dl.cdn-anritsu.com/en-us/test-measurement/files/Manuals/Instruction-Sheet/10100-00046C.pdf