Atacama
Large
Millimeter
Array

Band 5 Beam Scanner Test Source design description and test results

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1 INTRODUCTION

1.1 Purpose

This document provides the design description and test results of the Beam Scanner Test Source (BeaSTS) for Band 5.

1.2 Scope

The information given in this document provides a summary of the tests performed to the main devices that form the RF source and tests performed to verify the performance of the entire BeaSTS. There is also a description of the mechanical design.

1.3 Applicable Documents List (ADL)

The following documents are part of this document to the extent specified herein. If not explicitly stated differently, the latest issue of the document is valid.

Reference	*Document title*	*Document ID*

In the event of a conflict between one of the before mentioned applicable documents and the contents of this document, the contents of this document shall be considered as a superseding.

1.4 Reference Documents List (RDL)

The following documents contain additional information and are referenced in this document.

Reference	*Document title*	*Document ID*
[RD1]	Beam Scanner Test Source Technical Specifications	FEND-40.09.03.00-182-A-SPE
[RD2]	Band 5 LO Design Report	FEND-40.10.05.00-027-B-DSN
[RD3]	LabView Control Software for the Cartridge Test M&C Module	FEND-40.04.03.01-001-A-MAN

1.5 Acronyms

A limited set of basic acronyms used in this document is given below.

AD	Applicable Document
ALMA	Atacama Large MillimeterArray
AMC	Active Multiplier Chain
BeaSTS	Beam Scanner Test Source
CAN	Controller Area Network
DAS	Departamento de Astronomía, Universidad de Chile
FE	Front End
FLOOG	First Local Oscillator Offset Generator
GUI	Graphical User Interface
ICD	Interface ControlDocument
IF	Intermediate Frequency
IR	Infra Red
LO	Local Oscillator
M&C	Monitor &Control
MMIC	Monolithic Microwave Integrated Circuit
PLL	Phase-Locked Loop
RAL	Rutherford Appleton Laboratory
RD	Reference Document
RF	Radio Frequency
SIF	Sample Intermediate Frequency
YTO	YIG Tuned Oscillator

1.6 Verb Convention

"Shall" is used whenever a specification expresses a provision that is binding. The verbs "should" and "may" express non-mandatory provisions.
"Will" is used to express a declaration of purpose on the part of the design activity.

2 DESCRIPTION

2.1 Equipment Definition

The Band 5 BeaSTS is based in the Front End Local Oscillator configuration used by ALMA receivers but using only one of the two available channels. It consists of a YIG tuned oscillator (YTO) followed by a chain of frequency multipliers (x2 - x3 - x2) that ends in an open ended waveguide probe. To phase lock the local oscillator chain a fraction of the LO power is split off and mixed with a microwave reference provided by a photo-mixer (provided by others). The resulting IF signal and a 20-45 MHz signal from the FLOOG are compared in a digital PLL. The PLL correction signal is sent to the YTO, closing the phase-locked loop.
The control and power signals to the YTO, PLL and photo-mixer come from the LO monitor and control module which resides in a box shared with the PLL (MCDPLL assembly). The MCDPLL is connected to the Front End Monitor and Control Module, which controls the different subsystems in the FE. The bias and monitor signals to the multipliers come from an interface manufactured by RAL which communicates with the MCDPLL. The desired frequency is set by applying the appropriate reference signal (via the photonic reference) and then sweeping the YTO under software control using a LabView GUI [1] and a CAN bus for the interaction between the computer and the FE M&C module. The unit phase-lock is acquired to the desired sideband above or below the reference by a frequency offset controlled by the FLOOG setting.

2.2 Block Diagram

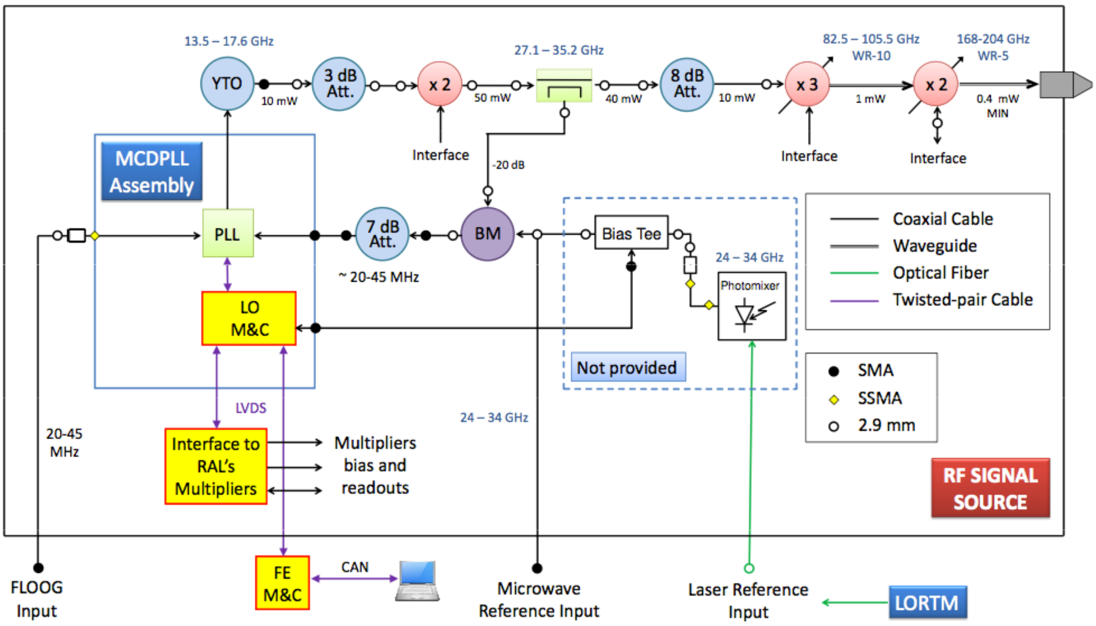

Figure 1: Band 5 BeaSTS block diagram

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[1] The software used for this purpose is the *Cartridge M&C v1.3.1.vi*, and is available in:

http://edm.alma.cl/forums/alma/dispatch.cgi/iptfedocs/docProfile/104362/d20071102152600

3 MECHANICAL DESIGN

For the construction of the RF source assembly, several mechanical parts were built: the bulk panel, base plate, a counter weight and it supporting structure, the RAL's interface casing (figure 2) and the open ended waveguide probe (figure 3).

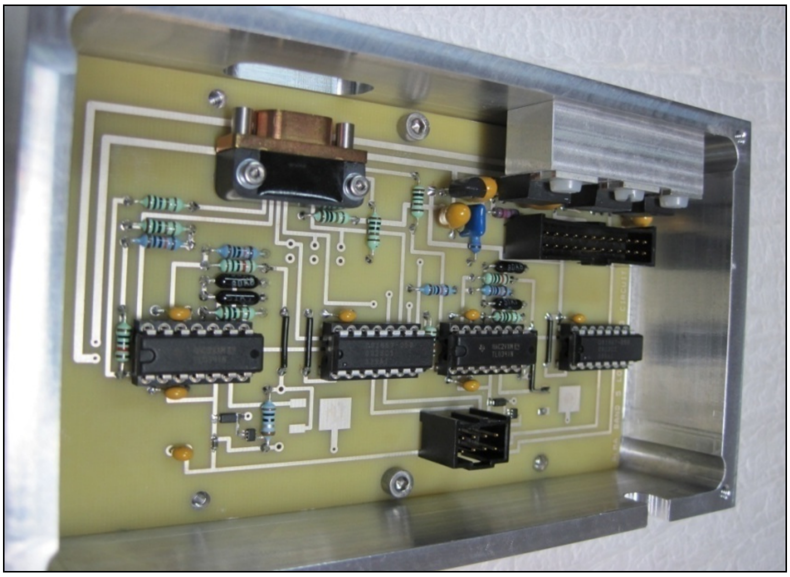
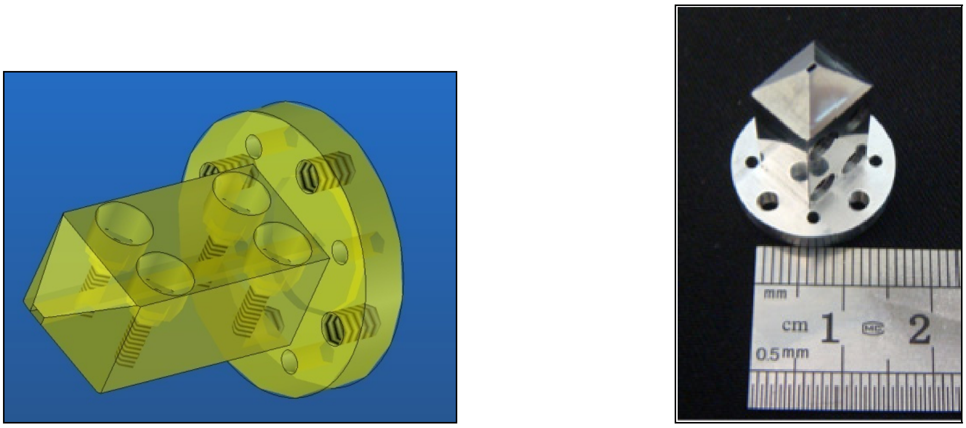


Figure 2: RAL's interface in its casing.



(a) **(b)**

Figure 3: Open ended waveguide probe (WR-5). (a) 3D model. (b) Picture.

The distribution of the different devices was an important topic in order to achieve an organized layout. For the RF probe the accuracy was critical. The 3D model was developed in Top Solid 2009 v6.10. In figure 4 there is an overview of the entire assembly (cables and some connectors not shown). In figure 5 there is a picture of the real assembly, including all the components and cabling. The Photo-mixer is not present, but the microwave plate is designed to host it in case is needed. Figure 6 shows the assembly covered with microwave absorber.

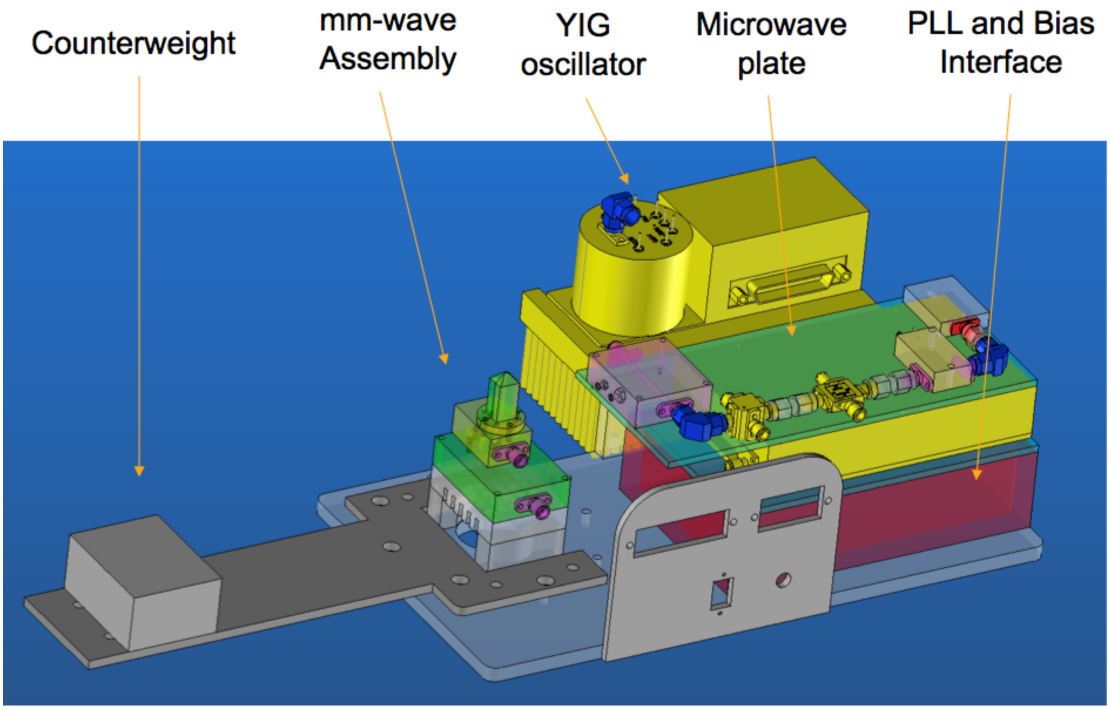


Figure 4: Band 5 BeaSTS 3D model

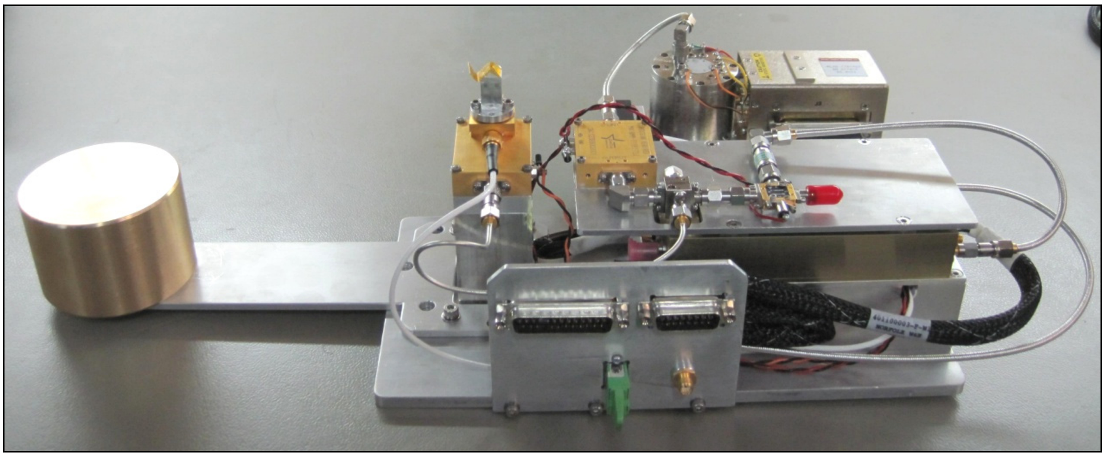


Figure 5: Band 5 BeaSTS assembly

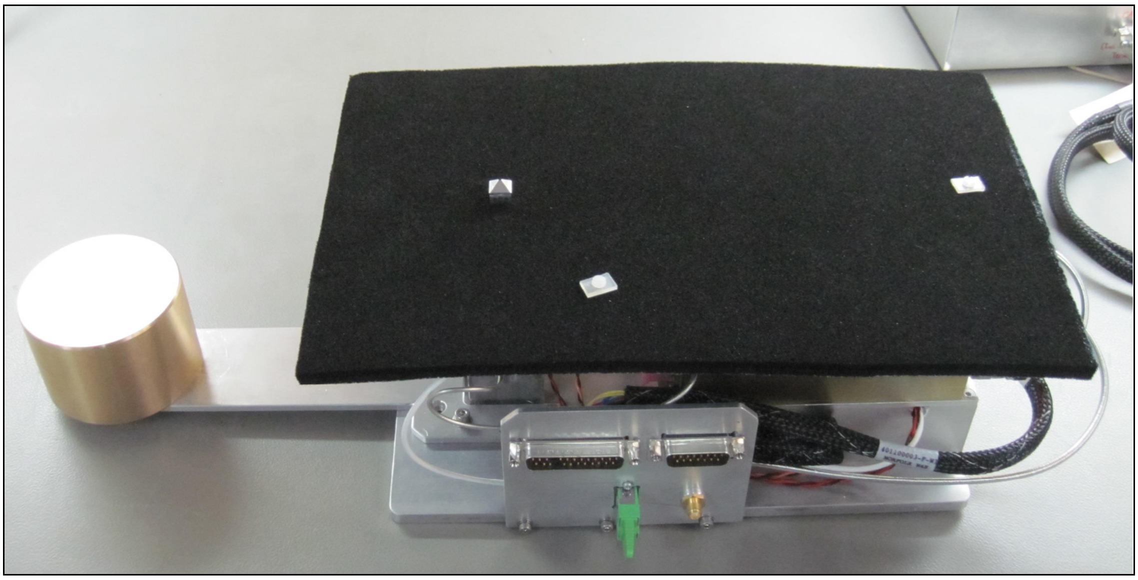


Figure 6: Band 5 BeaSTS assembly covered with absorber.

4 PERFORMANCE TESTS

4.1 Single devices tests

Before to assembly the source every device was tested separately. Results are shown in this chapter.

4.1.1 YIG

Originally, the YIG oscillator was set for operation between 14 and 17 GHz (for the B5 LO). In order to drive all the B5 RF band it was extended to 13.5 - 17.6 GHz. This extension was performed by the YTO manufacturer (Microlambda, Inc), through a modification of the YIG driver.

For this test the YTO was controlled by software with a LabView GUI named *Write YIG Port.vi*, which receives a hexadecimal word between 000 and FFF and sets the coarse frequency to the device. Results are detailed in table 1.

Table 1: YIG frequency sweep

Control	Expected frequency	Measured frequency	Power	Frequency offset	$\Delta P = P_{Max} - P_{Freq}$
Hexadecimal	GHz	GHz	dBm	MHz	dBm
0	13.500	13.466	10.9	34	0.6
199	13.909	13.876	11.2	33	0.3
333	14.320	14.287	10.8	33	0.7
4CC	14.729	14.698	10.1	31	1.4
666	15.140	15.109	10.9	31	0.6
7FF	15.549	15.519	10.3	30	1.2
999	15.960	15.930	11.5	30	0
B32	16.369	16.339	10.6	30	0.9
CCC	16.780	16.750	11.0	30	0.5
E65	17.189	17.159	10.8	30	0.7
FFF	17.600	17.570	9.9	30	1.6

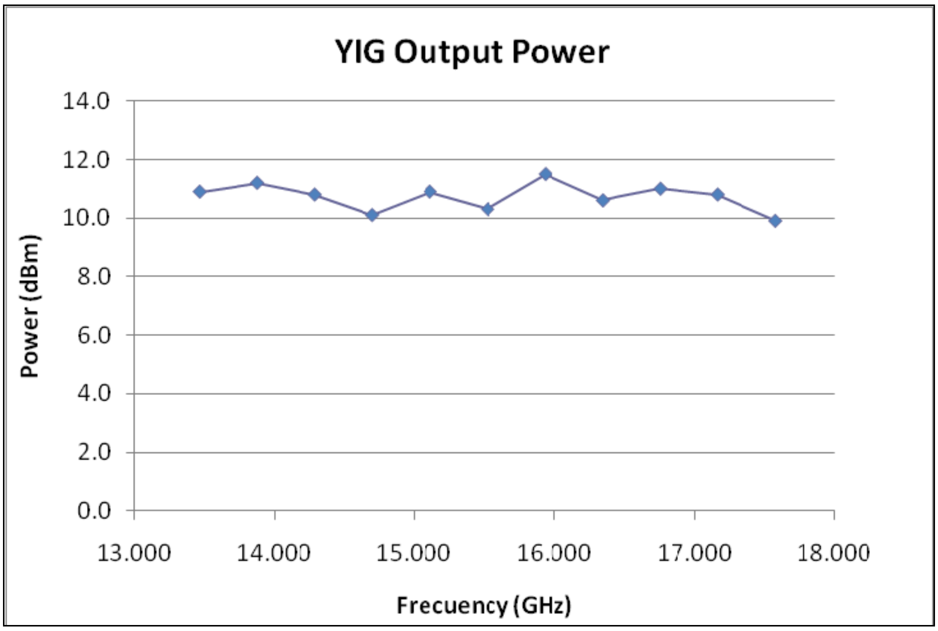


Figure 7: YTO Output power

4.1.2 Quinstar Doubler

A 10 dBm input signal was supplied to the Quinstar doubler and the output was measured for different frequencies. The instrument was an Agilent E4418B power meter. Results are detailed in table 2.

Table 2: Quinstar doubler output at 10 dB input

Input Frequency	Doubler input power	Doubler output power
GHz	dBm	dBm
13.50	10.10	20.50
13.91	10.00	21.00
14.32	10.00	20.00
14.73	10.00	20.90
15.14	10.00	20.00
15.55	10.00	19.90
15.96	9.90	20.10
16.37	10.00	>21
16.78	10.10	>21
17.19	10.00	>21
17.60	10.00	>21

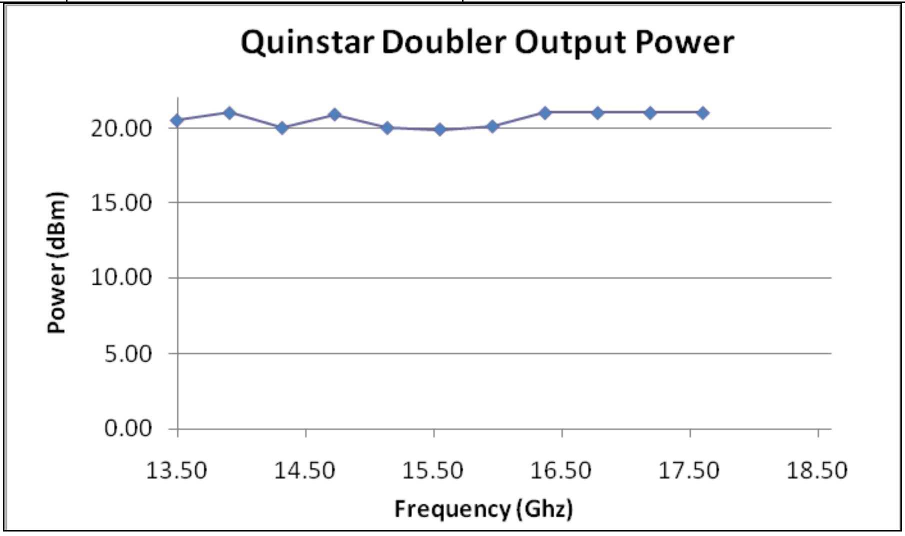


Figure 8: Quinstar doubler output power

4.1.3 Quinstar Tripler

A 10 dBm input signal was supplied to the Quinstar tripler and the total output was measured for different frequencies. Results are detailed in table 3. The instrument was an Erikson PM3millimeter-submillimeter power meter.

Table 3: Quinstar tripler output at 10 dBm input

Input Frequency	Tripler input power	Tripler output power
GHz	dBm	dBm
27.00	10.00	7.48
27.82	10.00	7.32
28.64	10.00	7.32
29.46	9.90	7.19
30.28	10.10	6.48
31.10	10.00	4.90
31.92	10.00	4.01
32.74	10.00	4.13
33.56	10.10	5.19
34.38	10.00	5.72
35.20	10.00	4.61

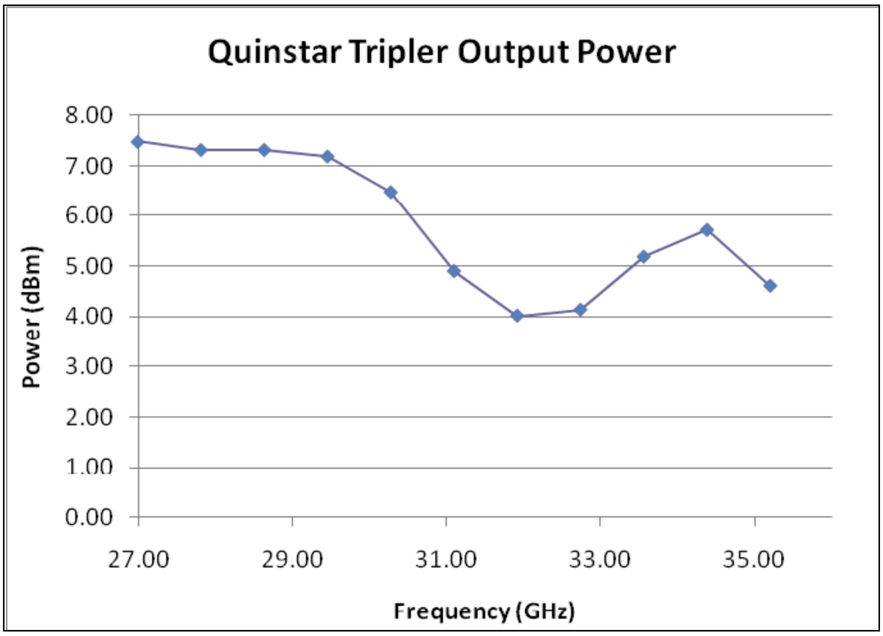


Figure 9: Quinstar Tripler output power

4.1.4 Quinstar Tripler + mm-wave doubler (RAL)

A 10 dBm input signal was supplied to the Quinstar tripler. In its output the mm-wave doubler was connected. The doubler output power was measured for different frequencies. Results are detailed in table 4. The instrument was an Erikson PM3 mm-submm power meter.

Table 4: mm-wave doubler output power at 10 dBm tripler input power

Tripler input frequency	Tripler input power	mm-wave doubler input frequency	mm-wave doubler output power
GHz	dBm	GHz	dBm
27.00	10.00	81.00	-22.22
27.82	10.00	83.46	-23.98
28.64	10.00	85.92	-8.27
29.46	9.90	88.38	-14.81
30.28	10.10	90.84	-15.69
31.10	10.00	93.30	-11.80
31.92	10.00	95.76	-13.19
32.74	10.00	98.22	-18.24
33.56	10.10	100.68	-26.99
34.38	10.00	103.14	-30.00
35.20	10.00	105.60	-30.00

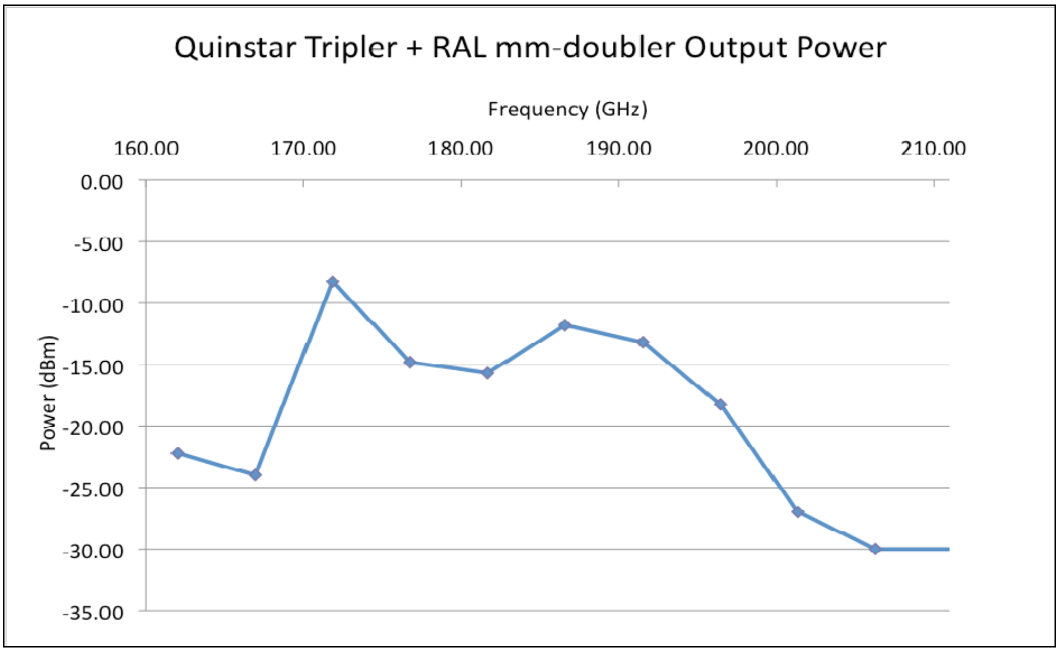


Figure 10: Quinstar Tripler + RAL mm-doubler output power

4.1.5 Multiplier chain (Quinstar Doubler + Quinstar Tripler + RAL mm-wave doubler)

The whole chain was tested with an input power low enough to not to deliver more than 15dBm to the Quinstar tripler (manufacturer recommendation). The maximum output power was detected at 14.32 GHz (input), so that was the chosen frequency to perform the beam pattern test (section 4.1.6). Results are detailed in table 5.

Table 5: Multiplier chain total output power

Q. doubler input frequency	Doubler input power	Tripler input power	mm-doubler input frequency	mm-doubler output power	
GHz	dBm	dBm	GHz	uW	dBm
13.50	7.7	10.30	81.00	8	-20.97
13.91	7.9	11.00	83.46	7	-21.55
14.32	7.7	10.50	85.92	197	-7.06
14.73	7.5	9.50	88.38	45	-13.47
15.14	7.6	9.60	90.84	34	-14.69
15.55	7.3	9.40	93.30	64	-11.94
15.96	7.3	10.10	95.76	10	-20.00
16.37	7.4	11.10	98.22	29	-15.38
16.78	7.3	12.50	100.68	8	-20.97
17.19	7.4	13.50	103.14	7	-21.55
17.60	6.9	9.70	105.60	7	-21.55

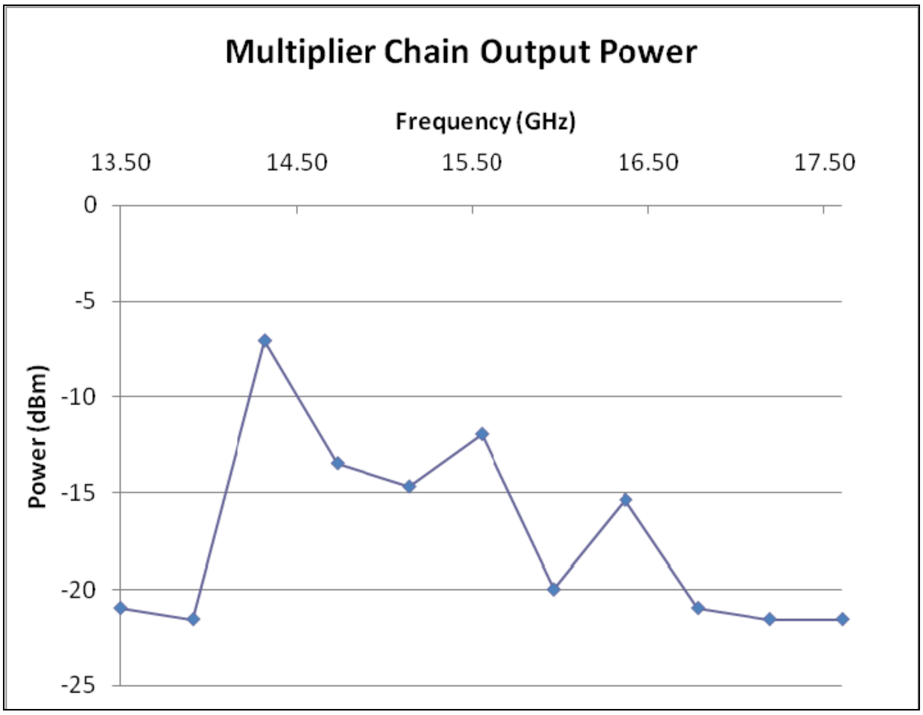


Figure 11: Multiplier chain output power

4.1.6 Waveguide Probe Beam Pattern

The multiplier chain was mounted on an aluminium structure bolted to a rotary stage. In front of it, a standard gain horn connected to a power meter was used. The complete setup lies on an optic table. The setup is shown in figure 12.

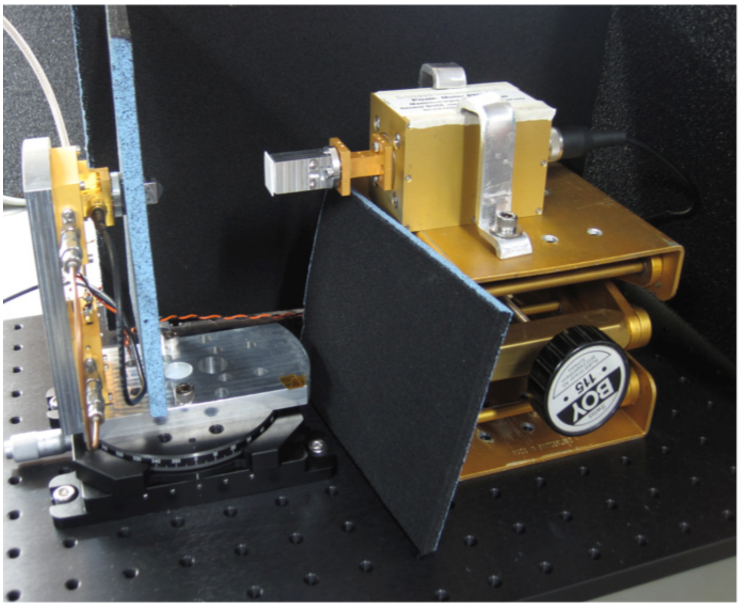
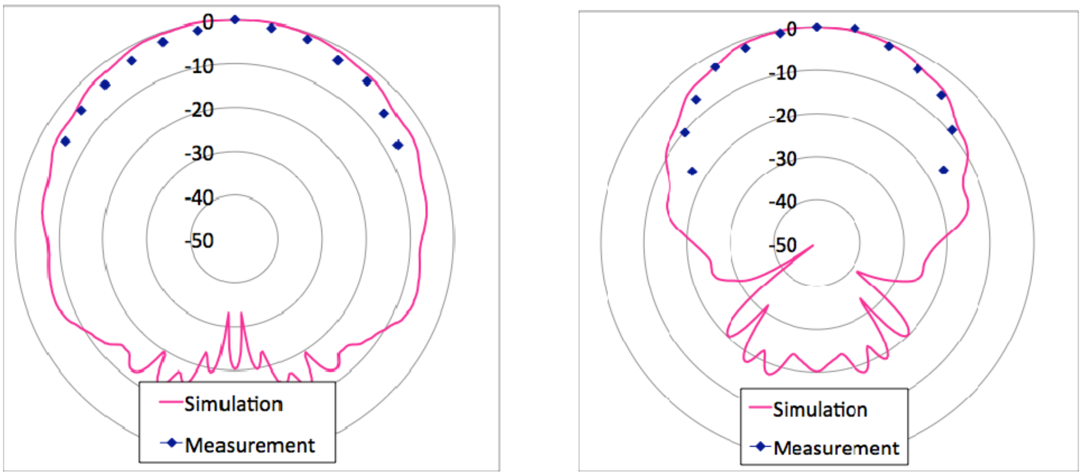


Figure 12: Experimental setup for beam pattern measurement

The test was performed with an input frequency of 14.32 GHz (output frequency of 171.84 GHz) for both elevation and azimuth. The measurement results and previous simulations (HFSS) are shown in figure 13.



(a) **(b)**

Figure 13: Beam gain pattern (dB) results. (a) Elevation. (b) Azimuth.

4.1.7 YIG Phase-Locking Test

A microwave reference of 34 GHz was supplied to the balanced mixer emulating the photomixer output. With a second synthesizer, phase-locked to the first one, a 30 MHz signal was supplied to the REF (FLOOG) port of the BeaSTS. Figure 14 shows the IF signal (at the SIF output from the MCDPLL). In figure 15 a picture of the software screen can be seen. The 'LO Lock' led is in green, confirming that the system is phase-locked, at 17 GHz + 30 MHz. The software used for this test was the "cartridge M&C 1.3.1" available in: http://edm.alma.cl/forums/alma/dispatch.cgi/iptfedocs/docProfile/104362/

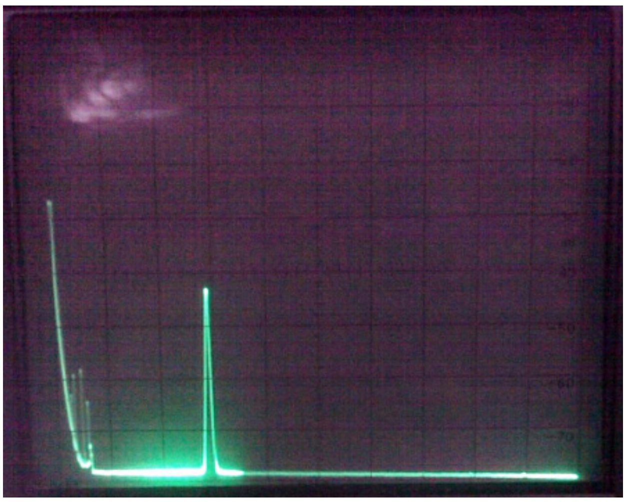


Figure 14: SIF signal in 30 MHz. The span is 10 MHz per division

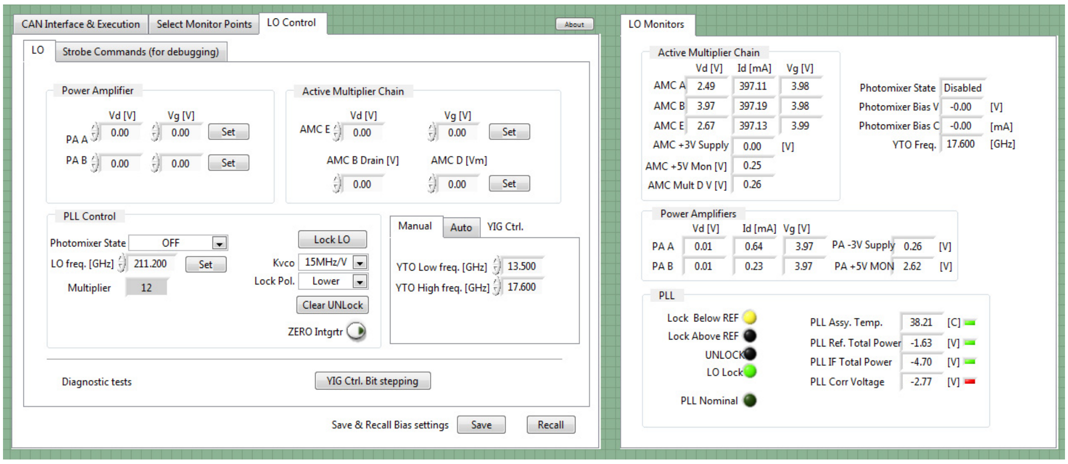


Figure 15: Control software screen shot

4.1.8 RAL mm-doubler Bias Voltage

The RAL mm-doubler has a bias voltage range of 0 to -6V. To set this voltage the PA B Vd port is used. The software (originally design for NRAO's PA) presents a scaling issue. The Bias interface sets a voltage equal to aprox. -2.6 times the voltage commanded at the software. The voltage output is limited by hardware by the bias interface so no danger for overvoltage is present. The bias voltage delivered to the mm-wave doubler was characterized for different set voltages on the software. Results are detailed in table 6.

Table 6: RAL mm-doubler bias voltage

Set Voltage	Monitor Voltage	Measured Voltage
V	V	V
0.0	0.01	0.00
0.1	-0.29	-0.29
0.2	-0.57	-0.57
0.3	-0.85	-0.86
0.4	-1.11	-1.11
0.5	-1.35	-1.35
0.6	-1.59	-1.59
0.7	-1.82	-1.83
0.8	-2.08	-2.08
0.9	-2.31	-2.31
1.0	-2.54	-2.55
1.1	-2.78	-2.79
1.2	-3.02	-3.03
1.3	-3.29	-3.29
1.4	-3.55	-3.55
1.5	-3.81	-3.82
1.6	-4.09	-4.10
1.7	-4.39	-4.40
1.8	-4.73	-4.74
1.9	-4.98	-5.07
2.0	-4.98	-5.42
2.1	-4.98	-5.81
2.2	-4.98	-5.99
2.3	-4.98	-6.00
2.4	-4.98	-6.00
2.5	-4.98	-6.00

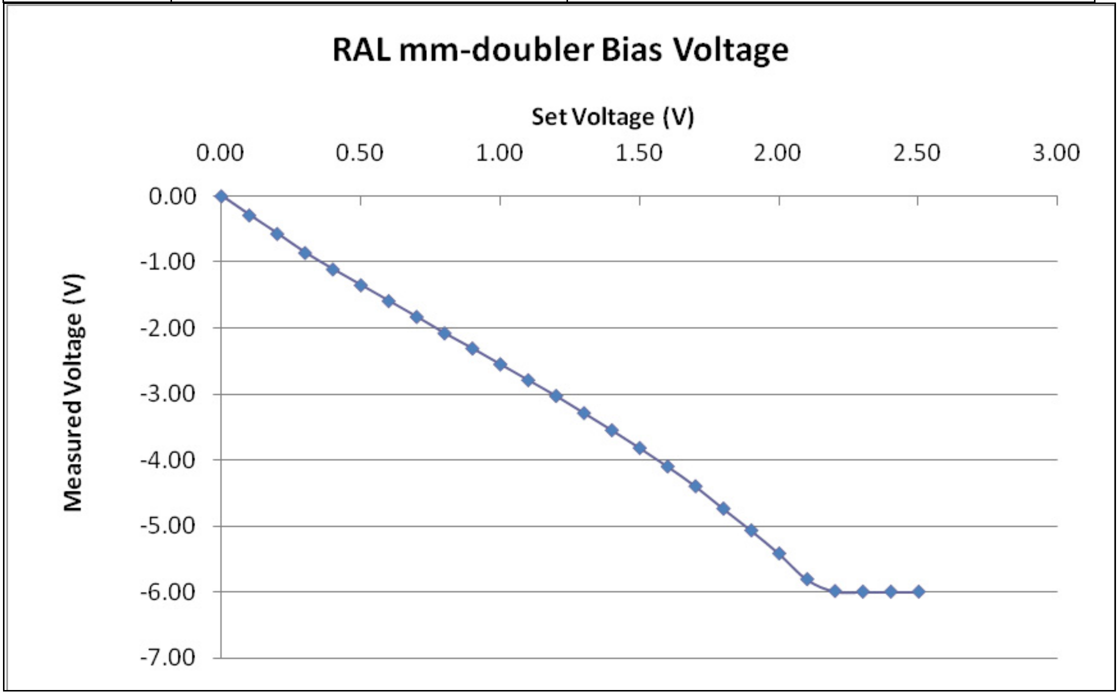


Figure 16: RAL mm-doubler bias voltage

4.1.9 Mixer IF output

The MCDPLL IF nominal input power is -30 dBm. To deliver a power within specifications a 7 dB attenuator was used after the balanced mixer at its IF output port. Results of the IF output power (before the 7dB attenuation) are detailed in table 7 and figure 17.

Table 7: RAL mm-doubler bias voltage

Frequency	Mixer IF output
GHz	dBm
27.00	-20.0
27.82	-32.0
28.64	-18.0
29.46	-18.8
30.28	-17.0
31.10	-18.0
31.92	-17.5
32.74	-16.6
33.56	-22.0
34.38	-26.0
35.20	-14.6

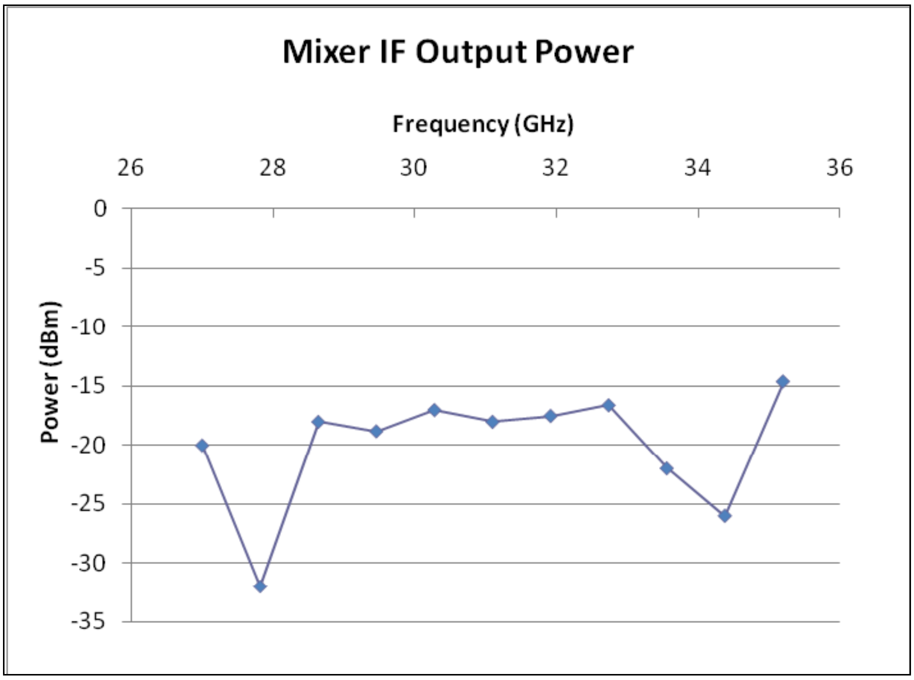


Figure 17: Mixer IF output power

4.2 Overall source tests

4.2.1 Total Output Power

Using the configuration shown in figure 1, with the BeaSTS totally assembled, the total output power was measured using an Erickson mm-submm power meter (figure 19). The source was phase-locked for each frequency. For that purpose the photo-mixer input was connected to an Agilent E8257D synthesizer, which provided a 27 to 35.2 GHz signal to the balanced mixer. The 30 MHz FLOOG reference was provided by an Agilent N5181 signal generator phase-locked to the later. Total output power was measured at each frequency for different values of RAL's mm-wave doubler bias voltage, which gives different levels of attenuation. Blank fields represent levels below the instrument detection threshold. Results are shown table 8 and figure 18.

Table 8: BeaSTS total output power (locked)

	PA B V_d = 0 V	PA B V_d = 0.5	PA B V_d = 1.0 V	PA B V_d = 1.5 V	PA B V_d = 2.0 V	PA B V_d = 2.5 V
Frequency	**Output Power**					
GHz	**uW**	**uW**	**uW**	**uW**	**uW**	**uW**
162.00	6.60	1.07	0.31			
166.92	4.20	0.60	0.10			
171.84	147.00	38.00	17.50	7.50	2.50	2.00
176.76	39.00	10.50	4.60			
181.68	39.40	14.90	7.90	4.00	2.15	1.80
186.60	84.50	23.70	10.65	4.32	1.66	1.35
191.52	5.30	0.75	0.20			
196.44	24.80	9.50	4.70	2.30	1.20	1.00
201.36	1.75	0.40				
206.28						
211.20						

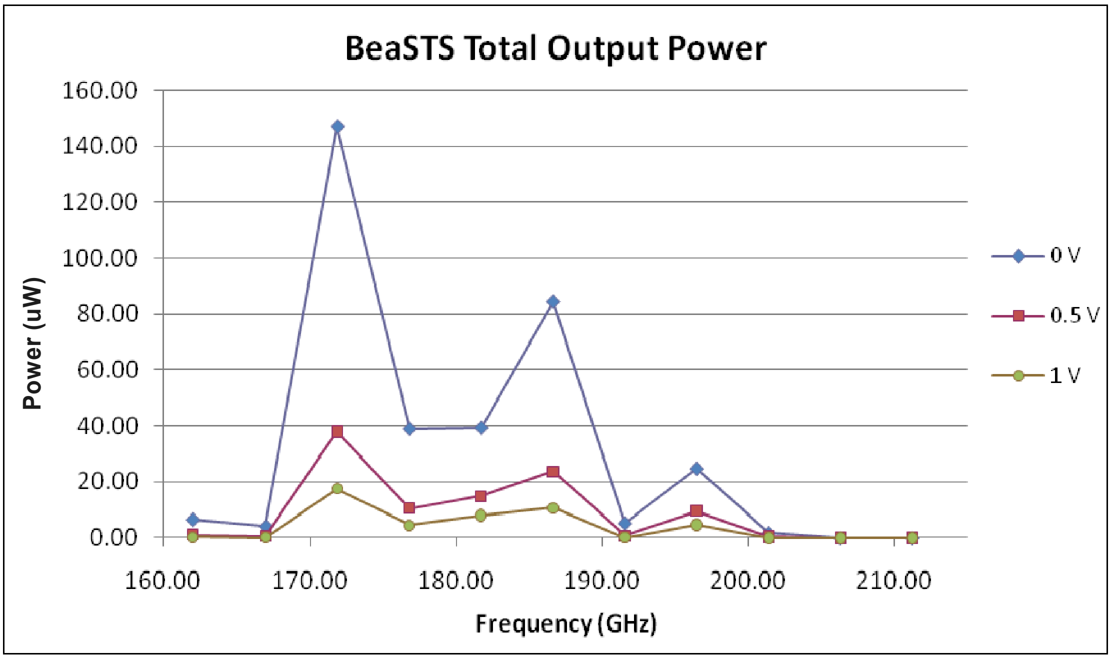


Figure 18: BeaSTS total output power for 3 different attenuation levels (PA B Vd)

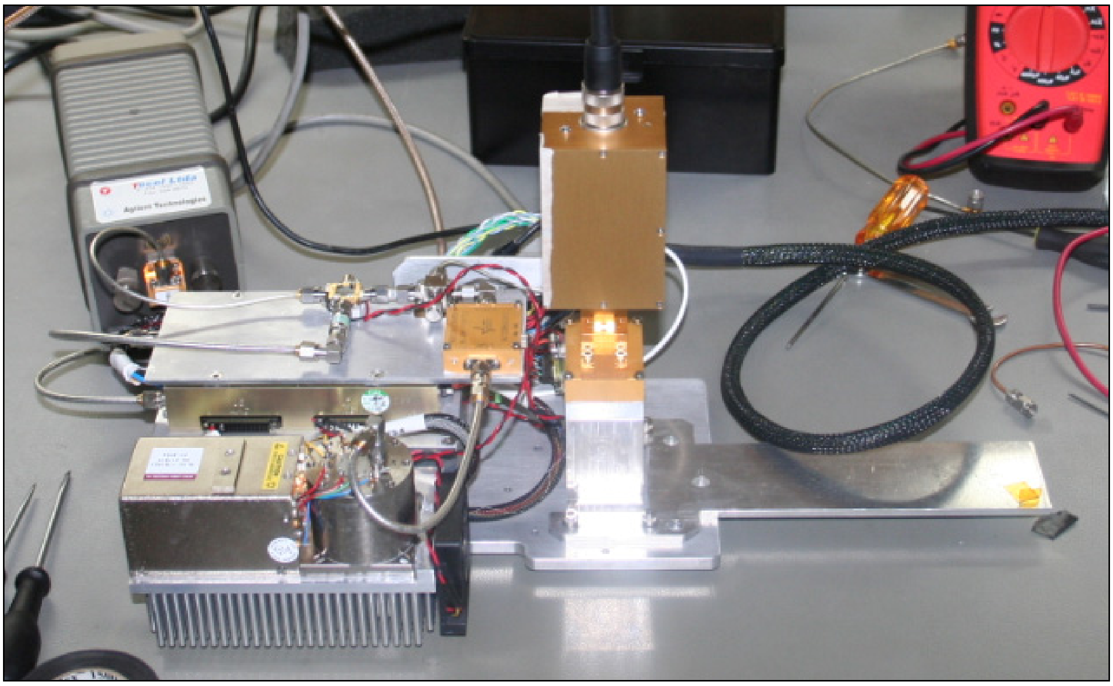


Figure 19: Total power measurement. Power meter connected to the output of the BeaSTS