IF MATRIX SWITCH FOR THE 40 METER RADIO TELESCOPE

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1. Introduction

This report shows the design, construction and characterization of a matrix switch for the IF signal distribution in the patch panel of the 40 m radiotelescope receiver room.

1.1 Current system

Currently, all IF signals from the receiver outputs are sent to a patch panel in a rack located in the receiver room through *Andrew FSJ4-50B* coaxial cable. From this rack (figure 1), the IF signals are sent down to the backend room through *Andrew FSJ4-50B* coaxial cables, too. Once in the backend room, the signals are manually distributed to the backends through their corresponding patch panels. Figure 2 show the patch panels and the rack in the backend room.

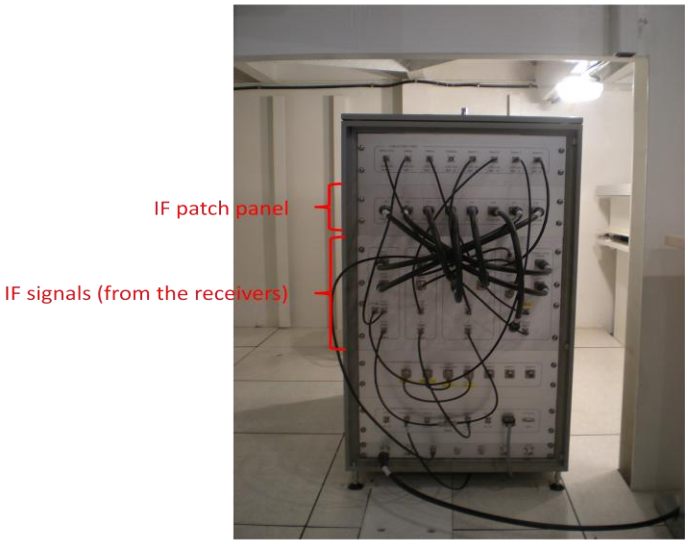


Figure 1: IF signals rack (receiver room).

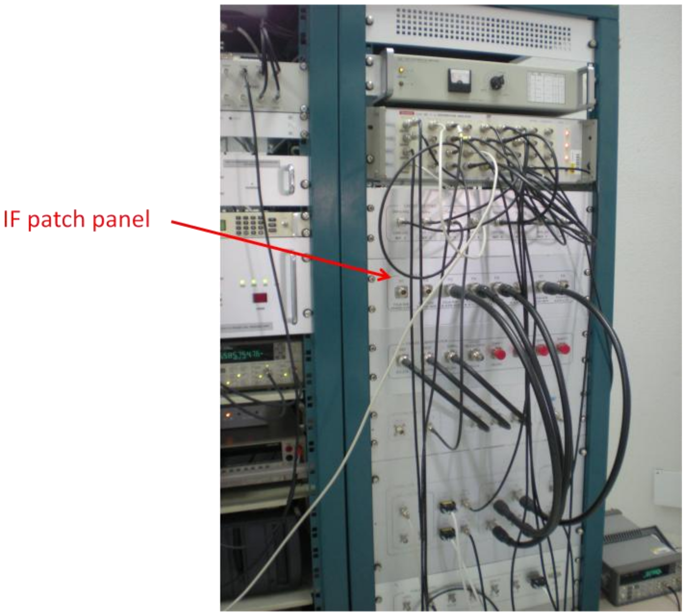


Figure 2: IF patch panel (back-end room).

1.2 Justification of the matrix switch

The CAY 40m radio telescope has 5 receivers already installed (S/CH, C, X, 22GHz and 3mm bands) and one receiver (45GHz band) which will be installed by the end of 2011.

The X band receiver has two simultaneous output bands: the standard and the expanded one. In addition, all the receivers, except the 3mm one, have double circular polarization reception, so each one needs two inputs in the patch panel. At present, there are only 8 IF *Andrew FSJ4-50B* cables connecting the receiver room and the backend room. According to the number of receivers 13 cables would be needed so a matrix switch is requested to select the receiver's signals that will be routed through the IF cables.

Manual patching can degrade the quality of coaxial connectors in the patch panels so a remotely controlled RF matrix switch avoids this problem. In addition, the switching time to change the operating frequency band of the 40 meter radiotelescope is reduced significantly, due to the automation of the patching process.

The 13 signals which might be sent to the backend room are the following:

- S/CH LCP and RCP.
- C LCP and RCP.
- X STD RCP and LCP.
- X EXP RCP and LCP.
- 22GHz RCP and LCP.
- 3mm H and V.
- 45GHz RCP and LCP.

The inputs to the matrix switch will come from the receivers that can't operate simultaneously due to the different configuration of the receiver room optics (mirrors M5, M6...). The selected ones are:

- C LCP and RCP.
- 22GHz RCP and LCP.
- 45GHz RCP and LCP.
- 3mm H and V

Therefore, a dual 4:1 RF matrix with RS-232 remote control in the range from DC to 2.5 GHz has been developed.

1.3 Matrix switch: a brief description.

The matrix will consist of two SP4T modules (one for each polarization sense), that will select one IF signal out of four possible inputs, and two amplifiers (one for each polarization, too) that will compensate for the insertion loss of the solid-state SP4T PIN switches and cables. In principle, the amplifiers might not be needed because the IF units provide enough output power to the back-ends and the insertion losses of the SP4T are low. However, it is considered that it might be useful to have some additional gain.

The matrix switch module will have a PIC microcontroller that will enable the radio telescope operator to perform remote monitor and control via a RS-232 serial port.

With the construction of this matrix, the CAY 40m radio telescope will be provided with the capability to select remotely the IF signals to be sent down to the backend room.

2. Block diagram

The matrix switch consists of two chains (one for LCP and the other for RCP). These two chains are identical and each one is composed of a SP4T module followed by an amplifier module as shown in figure 3.

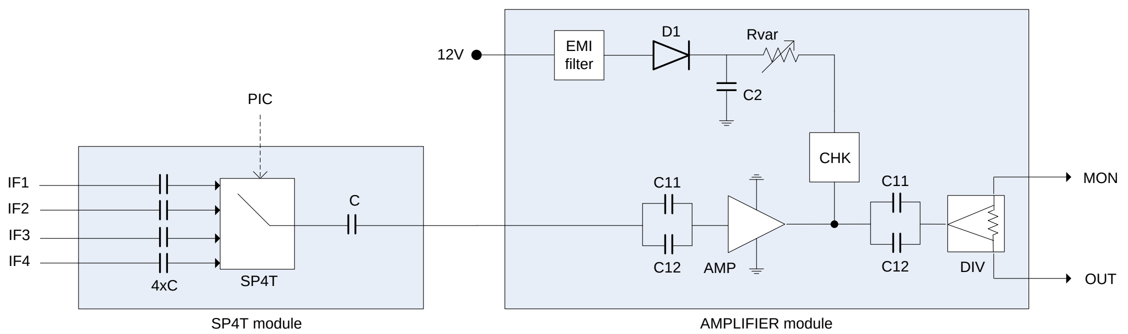


Figure 3: Matrix switch block diagram.

The following table shows the selected components for both modules. The datasheets are included in appendix B.

COMPONENT	Description
SP4T	Hittite HMC241QS16 DC-3.5GHz
AMP	Mini-Circuits ERA-3SM+
CHK	Mini-Circuits ADCH-80
Rvar	1KΩ
C	330 pF
C11	470pF C0G 0603 (AVX ref. 06035A471JAT2A)
C12	68pF C0G 0603 (YAGEO ref. CC0603JRNPO9BN680)
C2	100nF X7R 0805
D1	BAS16
EMI filter	muRata NFE61P 4700pF
DIV	Resistive splitter with R=16 Ohm

Table 1: Matrix switch part list.

3. SP4T module

3.1 Description

The SP4T module is a board from Hittite (p.n. 102809-2) which allows the evaluation of the Hittite HMC241QS16 solid-state SP4T switch.

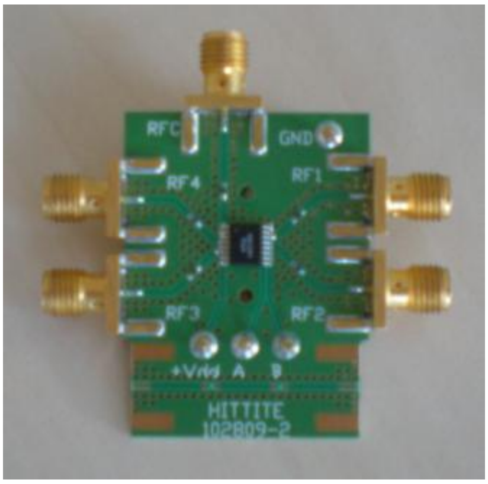


Figure 4: Evaluation board (Hittite p.n.102809-2)

3.2 Measurements

Figures 5 to 10 show the main properties of the evaluation board: insertion loss, return loss and isolation. These graphs have been obtained in Yebes laboratories using the Rohde & Schwarz ZVK Network Analyzer that operates from 10MHz to 40GHz.

According to figures 5 and 6, the SP4T module can operate from DC to 3.5GHz with insertion loss inferior to 2dB and with return loss higher than 20dB. However, if only isolation was considered as in figures from 7 to 10, the frequency range would be less restrictive and the device would be able to operate from DC to 5GHz with an isolation value better than 25dB.

According to the insertion and return losses, which are the most restrictive properties of the SP4T module, the frequency range of the evaluation board spans from DC to 3.5GHz. This span is higher than the one needed for this application because the IF signals from current receivers range from 500 - 1000 MHz, except the Q-band which will span from DC - 2 GHz.

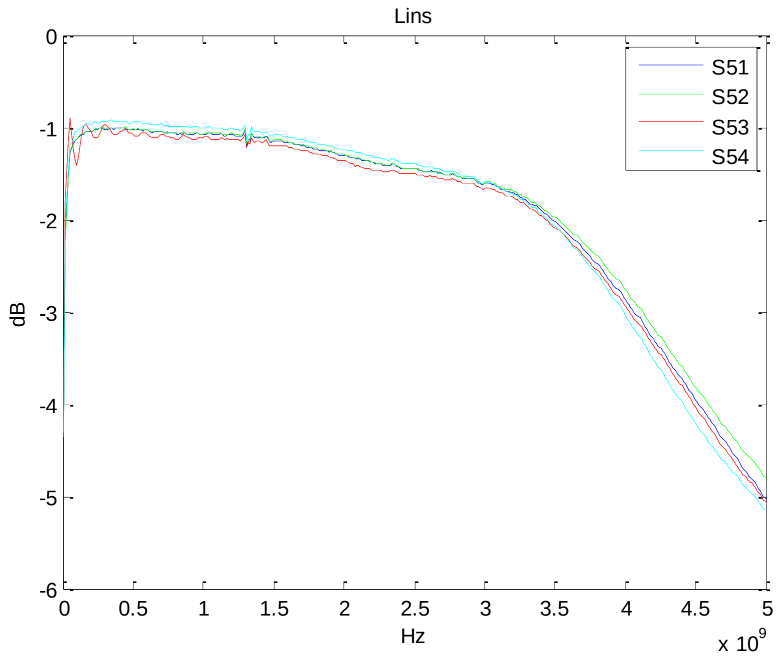


Figure 5: Insertion loss.

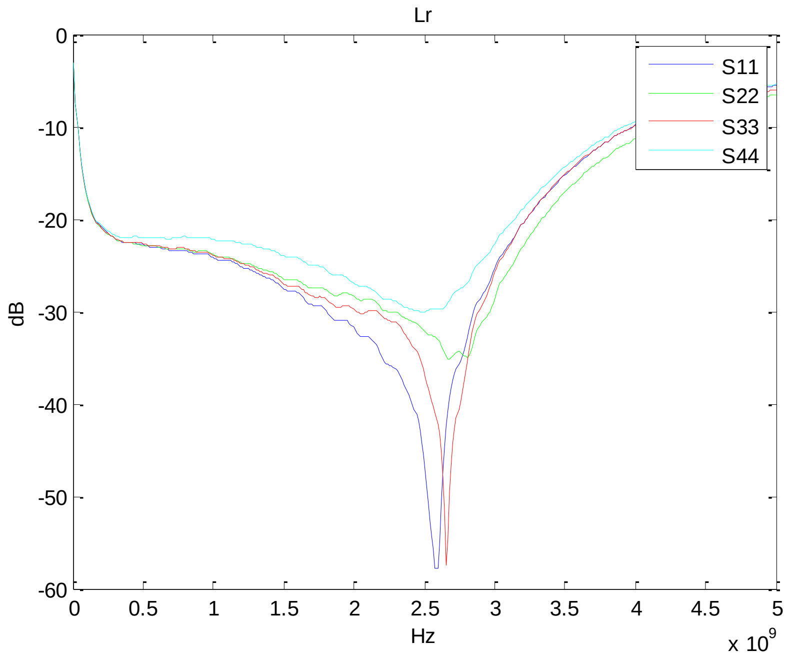


Figure 6: Return loss.

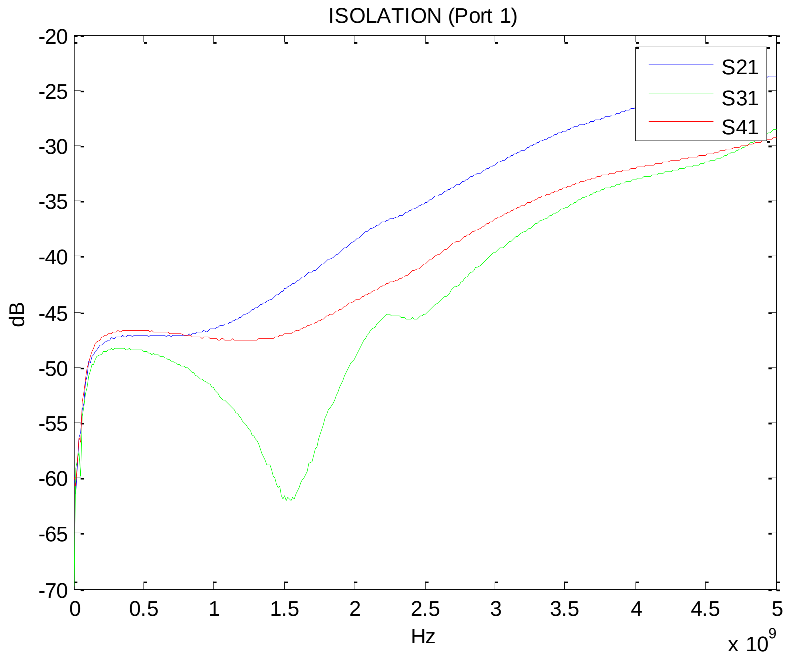


Figure 7: Isolation (port 1)

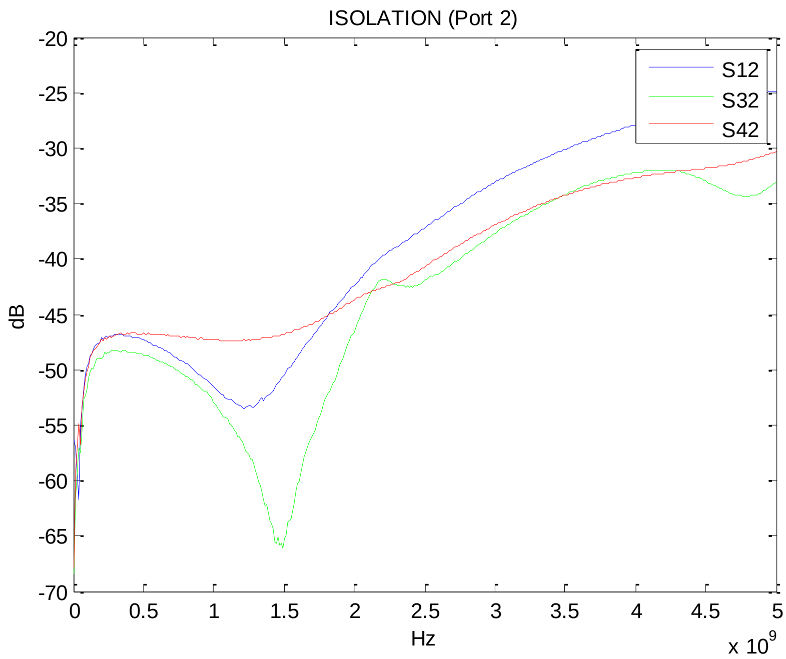


Figure 8: Isolation (port 2)

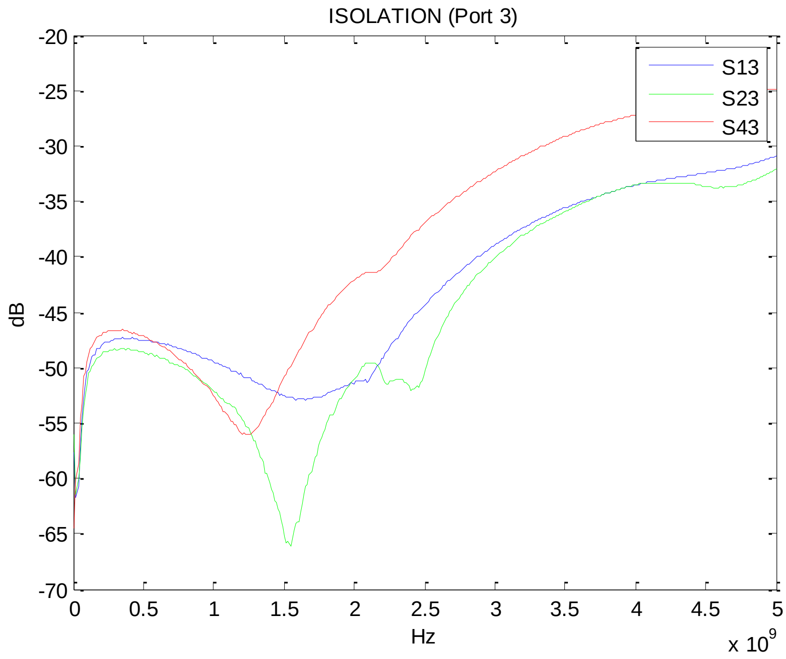


Figure 9: Isolation (port 3)

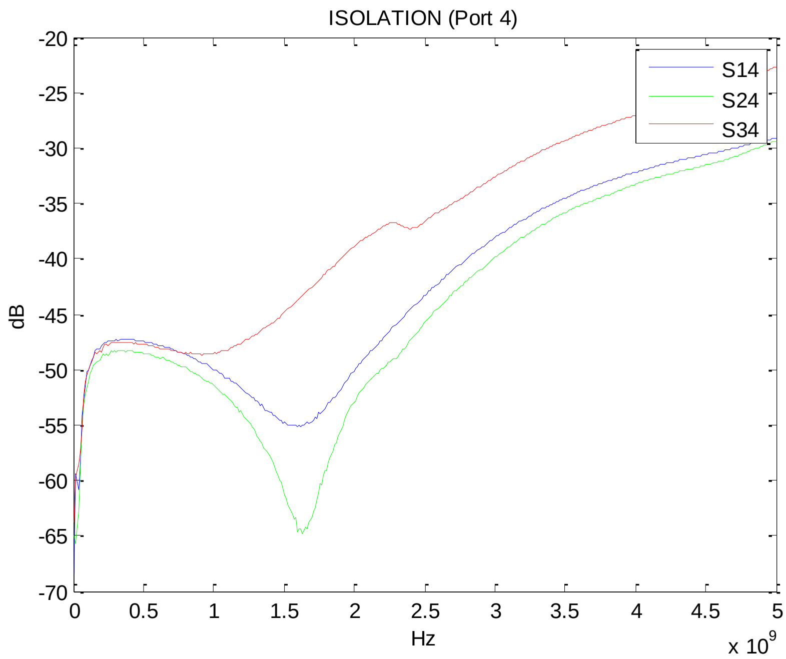


Figure 10: Isolation (port 4)

4. Amplifier module

4.1 Amplifier module design

The amplifier module was designed, integrated and characterized in Yebes laboratories. Figure 11 shows the design of the amplifier PCB circuit and figure 12 shows its final implementation:

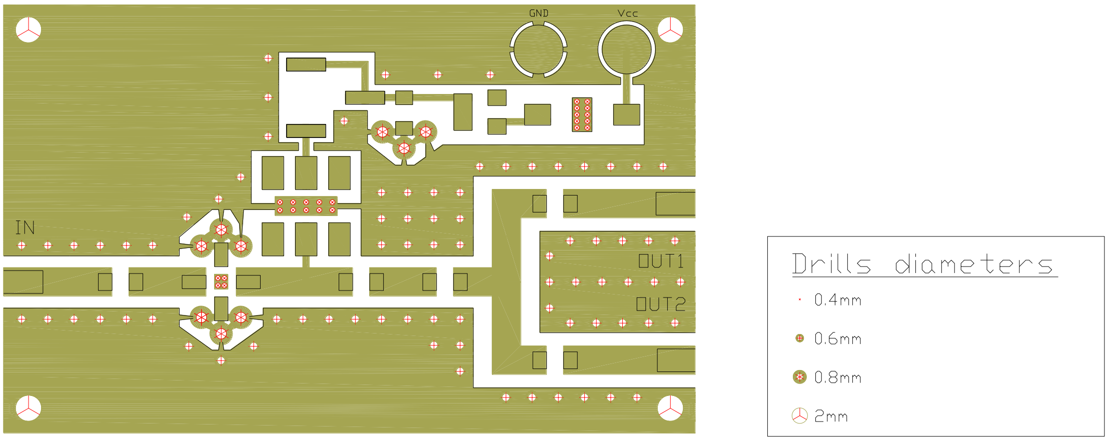


Figure 11: Amplifier PCB circuit design.

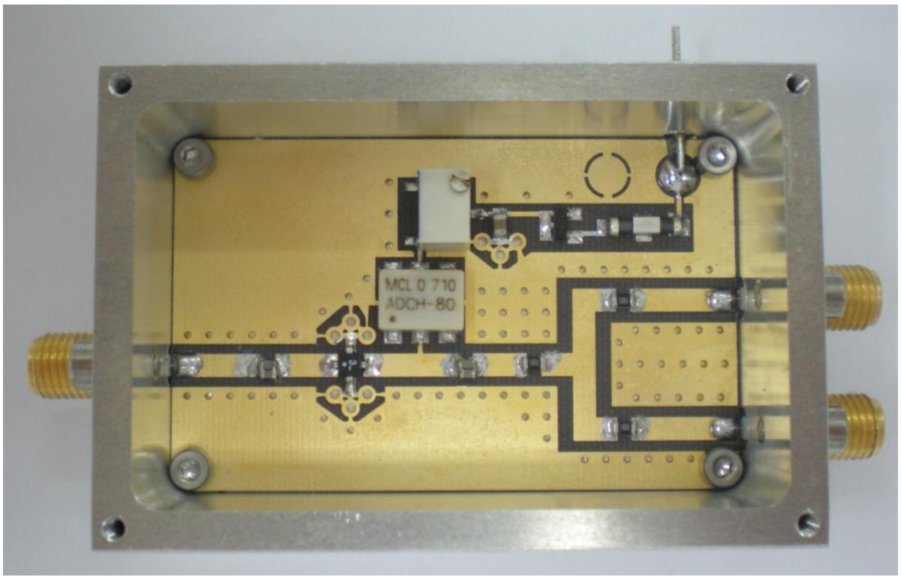


Figure 12: Amplifier PCB circuit implementation.

The microstrip line substrate used for this design was Taconic TLX-8. It has the following properties:

Dielectric constant	2.55 +/- .04
Dielectric thickness	0.78 mm
Copper thickness	35 µm

Table 2: Microstrip substrate properties.

To achieve an impedance of 50 ohms, the width of the microstrip line must be 2.1851 millimeters. It has also been necessary to design an enclosure box for each PCB circuit. The design and drawings of the boxes are shown in Appendix B.

4.2 Amplifier module polarization

According to the design, the amplifier module must be polarized with a source of 5V and the operating current of the amplifier must be 35mA. Hence, the variable resistor must be adjusted to achieve this polarization.

4.3 Measurements

Figure 13 shows the main properties of the amplifier module: insertion loss, return loss and isolation. These graphs have been obtained in Yebes laboratories using the Rohde & Schwarz ZVK Network Analyzer that operates from 10MHz to 40GHz. For each parameter there are two traces, one corresponds to the output and the other corresponds to the monitoring port. As the behaviour of the two output ports is the same, it's indifferent which one is used for monitoring.

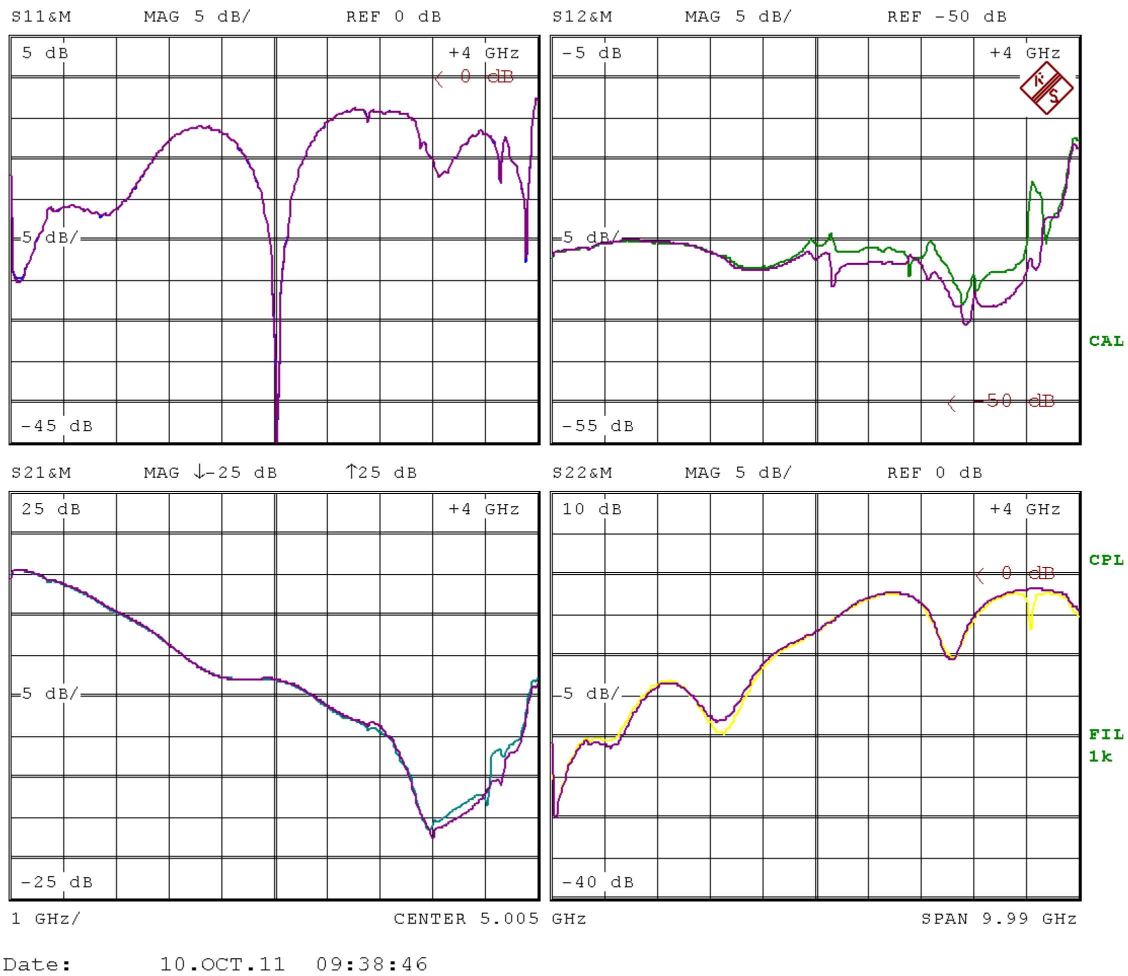


Figure 13: S parameters of the amplifier module.

According to figure 13, the amplifier module is good for operation from DC to 2.5GHz, approximately, where a minimum gain of 10 dB and return loss of 15dB are achieved. This span is higher than the one needed for the application, again.

5. Laboratory measurements

All measurements have been performed using the following instrumentation:

- Rodhe & Schwarz ZVK Network Analyzer (10MHz – 40GHz).
- Agilent E8257D Signal Generator (250kHz – 67GHz).
- Tektronix 494AP Spectrum Analyzer (10kHz – 21GHz).

Figures 14 and 15 show the testbenchs used to obtain the S parameters and the gain curves respectively.

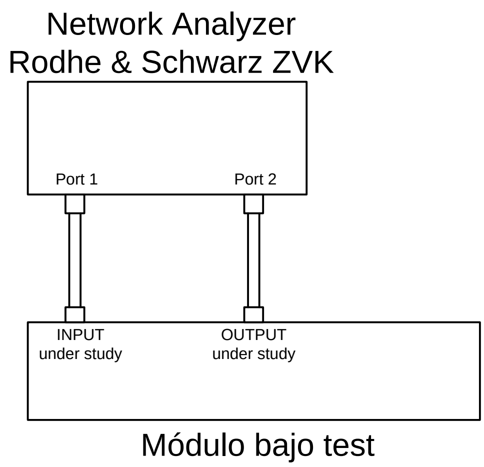


Figure 14: testbench for matching measures.

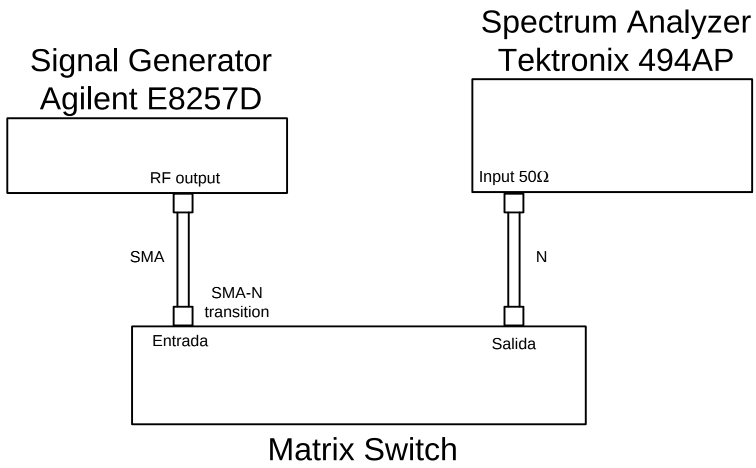


Figure 15: testbench for gain measures.

5.1 *Return loss measurements*

➢ **Input ports' return loss**

Figures 16 to 19 show the S11 parameter of ports 1 to 4 respectively. On each graph, the channel with left circular polarization is displayed in purple while the channel with right circular polarization is represented in blue.

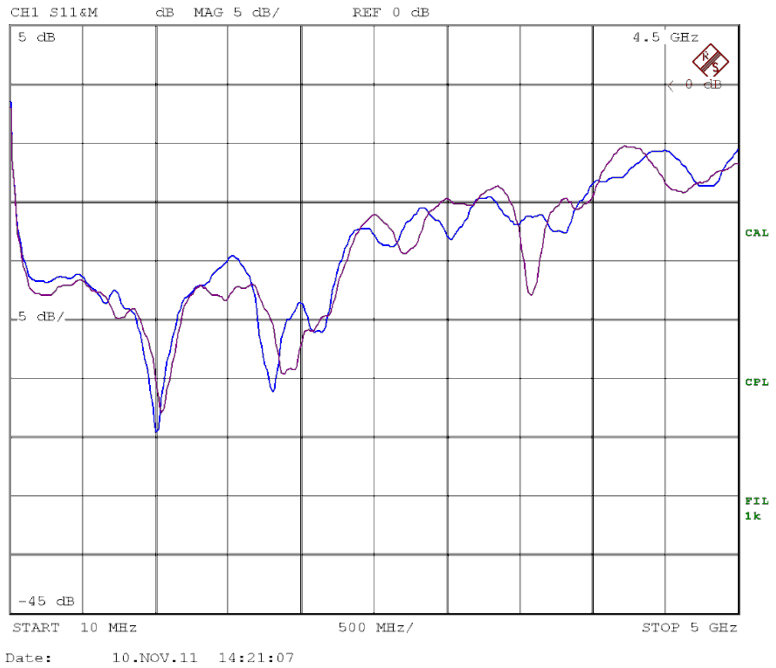


Figure 16: S11 of port 1 (L1 in purple and R1 in blue).

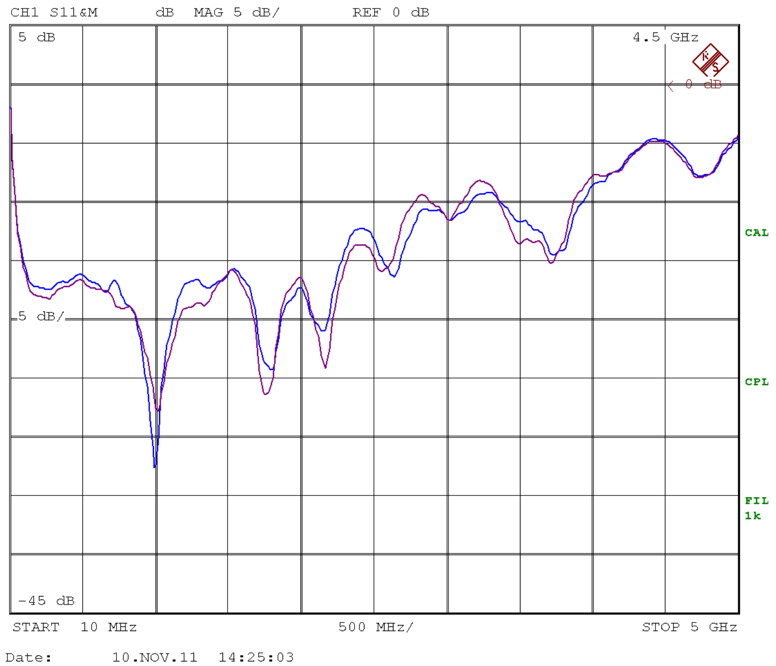


Figure 17: S11 of port 2 (L2 in purple and R2 in blue).

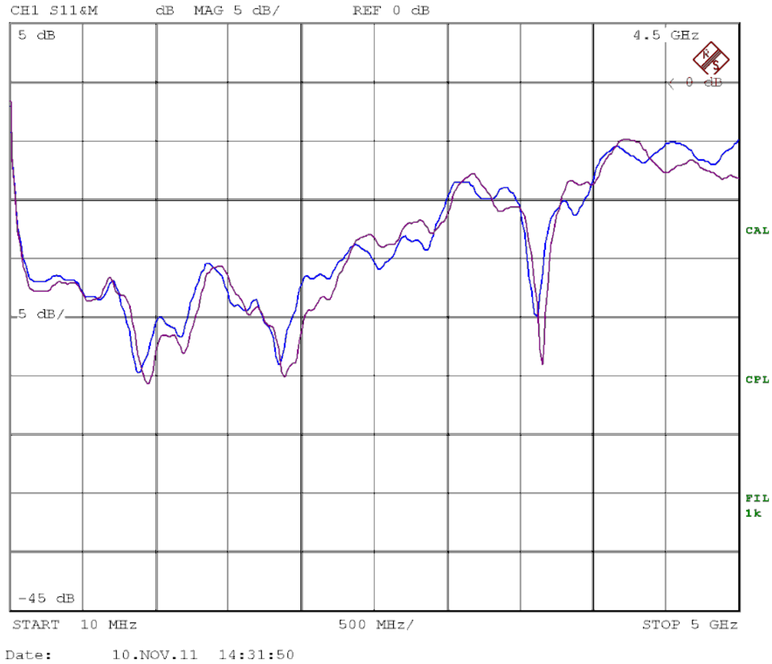


Figure 17: S11 of port 3 (L3 in purple and R3 in blue).

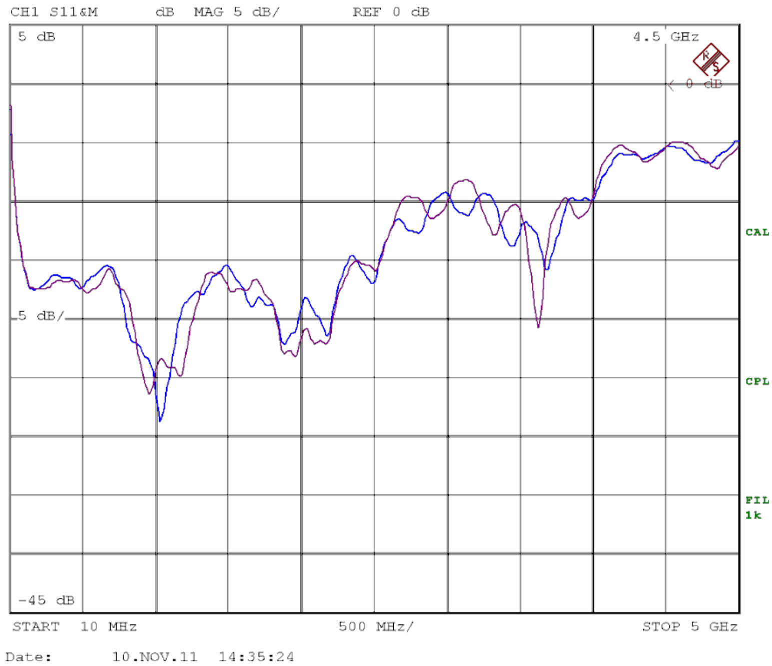


Figure 17: S11 of port 4 (L4 in purple and R4 in blue).

➢ Output ports' return loss

Figure 18 represents the return loss of the output ports and figure 19 shows the return loss of the monitoring ports.

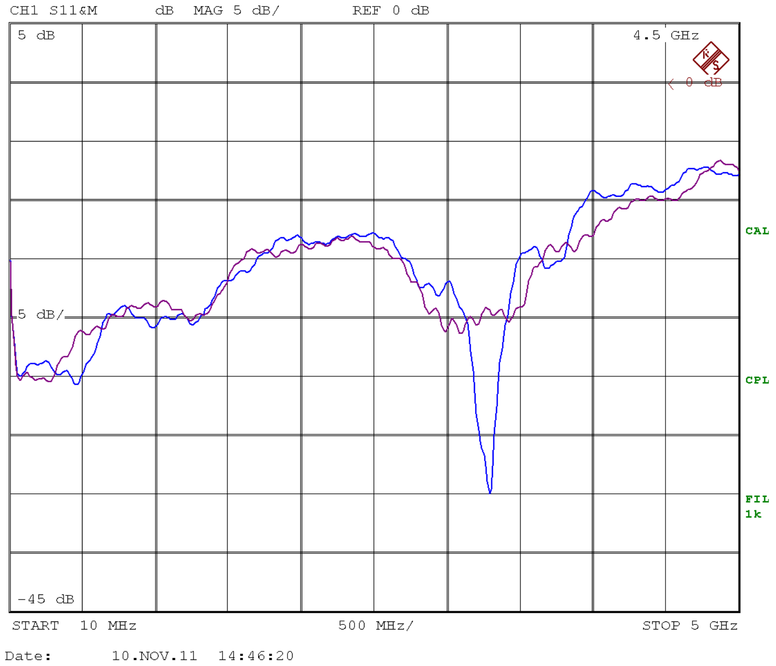


Figure 18: Return loss of the outputs (Lout in purple and Rout in blue).

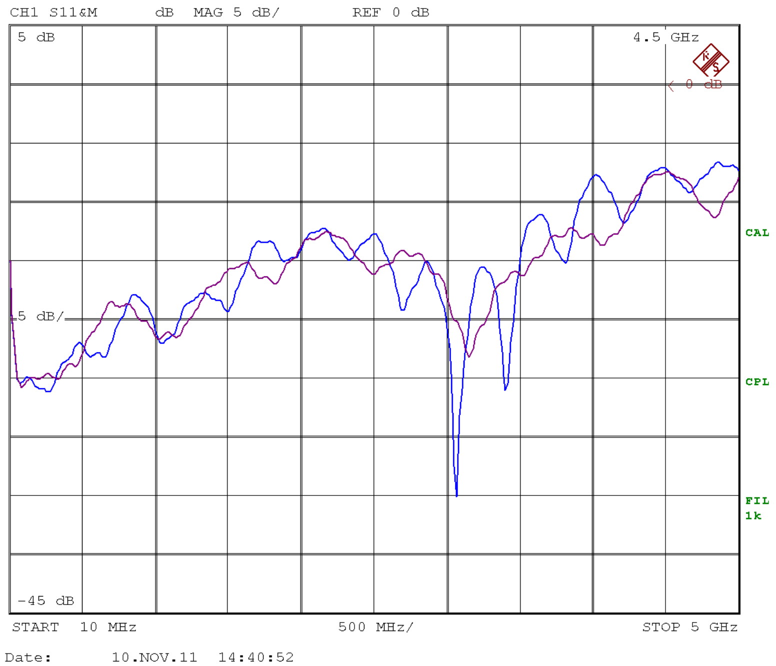


Figure 19: Return loss of the monitoring ports (Lout in purple and Rout in blue).

If a return loss higher than 13 or 14dB is desired, the module can operate properly from 10MHz to 2GHz.

5.2 Insertion loss measurements

Figures 20 to 23 show the insertion loss of the four channels of the matrix switch.

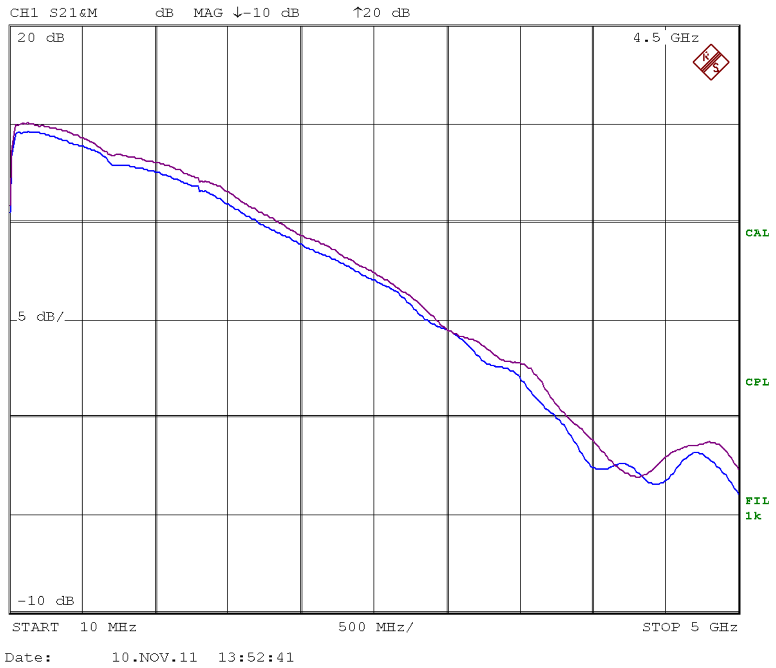


Figure 20: Return loss of channel 1 (L1 in purple and R1 in blue).

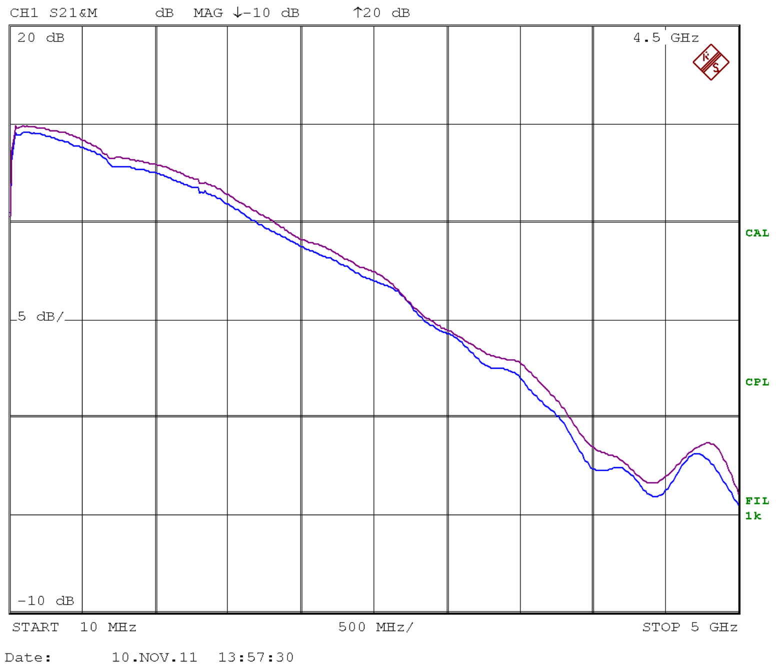


Figure 21: Return loss of channel 2 (L2 in purple and R2 in blue).

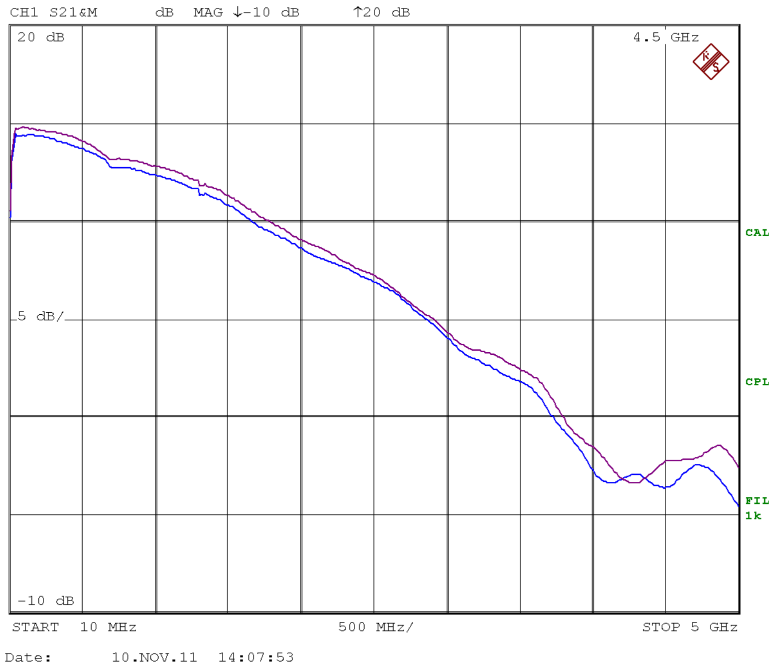


Figure 22: Return loss of channel 3 (L3 in purple and R3 in blue).

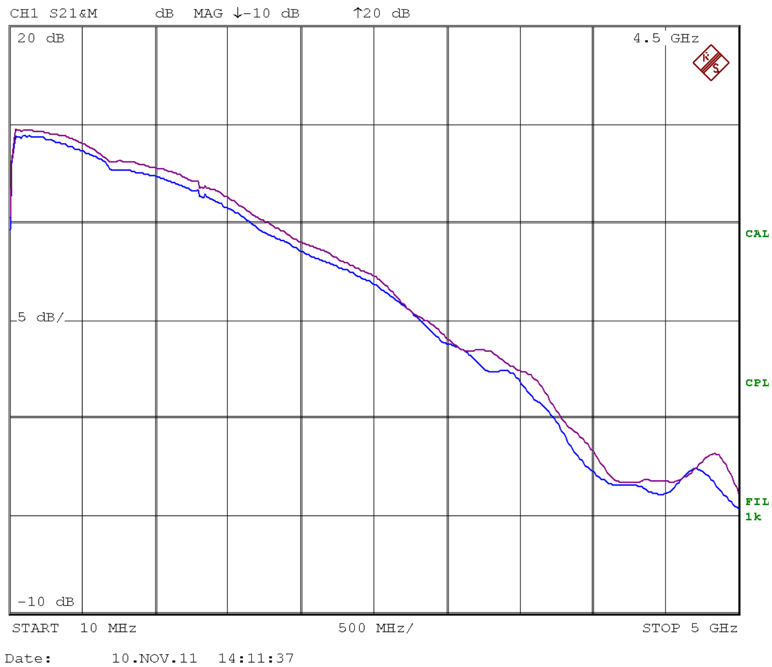


Figure 23: Return loss of channel 4 (L4 in purple and R4 in blue).

5.3 Gain curves

To obtain the gain curves of the four channels and determine the saturation point of the module, several measurements have been carried out for several frequency and power values. These measurements are shown in tables 3 to 6 and figures 24 to 31.

- **Channel 1**

Port L1						
P_{IN} (dBm)	**10 (MHz)**	**500 (MHz)**	**1000 (MHz)**	**1500 (MHz)**	**2000 (MHz)**	**2500 (MHz)**
-33	-21,6	-18,4	-20,2	-22	-23	-27,4
-30	-18,4	-15,4	-17,6	-18,8	-20	-24,4
-27	-15,6	-12,4	-14,8	-16	-17,6	-21,2
-24	-12,8	-9,2	-12	-12,8	-14,8	-18,8
-21	-10	-6,6	-8,8	-9,6	-11,2	-16
-18	-6,4	-3,6	-6	-6,8	-8	-13,6
-15	-3,6	-0,8	-3,2	-4	-5,2	-10
-12	-0,8	2,2	0	-0,8	-2,4	-7
-9	1,6	4,8	3,6	2	0,4	-4
-6	4,8	6,8	5,6	4,6	3,2	-1,2
-3	6,8	7,2	6,4	6,4	5,2	1,2
0	7,6	8	7	6,8	6,4	3,2
3	8	8,4	7,6	7,6	6,8	3,6

Port R1						
P_{IN} (dBm)	**10 (MHz)**	**500 (MHz)**	**1000 (MHz)**	**1500 (MHz)**	**2000 (MHz)**	**2500 (MHz)**
-33	-22	-19,6	-20,8	-22,4	-24	-27,2
-30	-18,8	-16,4	-18	-19,2	-20,8	-24
-27	-16	-13,2	-15	-16,4	-17,6	-20,8
-24	-12,8	-10,4	-12	-13,6	-14,8	-18
-21	-10	-7,2	-8,8	-10,4	-12	-15,2
-18	-6,8	-4,4	-6	-7,6	-8,8	-12,8
-15	-3,6	-1,2	-3,2	-4,8	-6	-9,2
-12	-0,8	1,6	0	-2	-3,2	-6,4
-9	2	4,4	2,4	1,2	0	-3,2
-6	4,8	6	4,4	3,6	2,4	0
-3	6,4	6,8	5,2	5,2	4,8	2,4
0	6,8	7,2	5,8	6	5,6	4
3	7,2	7,6	6,4	6,8	6,4	4,4

Table 3: Gain calibration of channel 1.

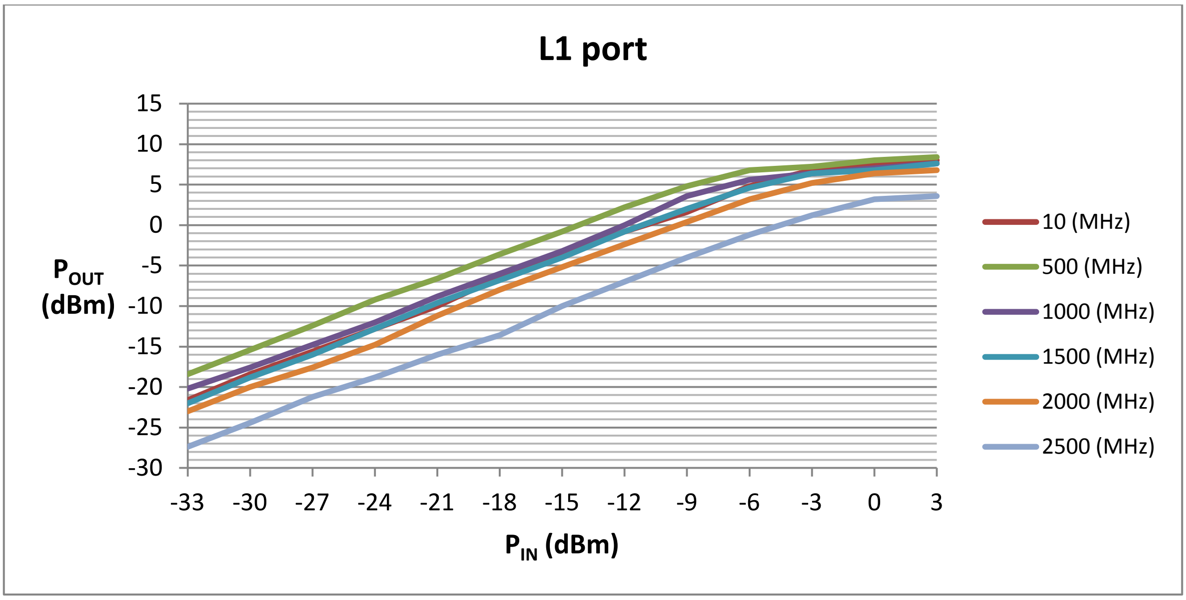


Figure 24: Gain curves of L1 port.

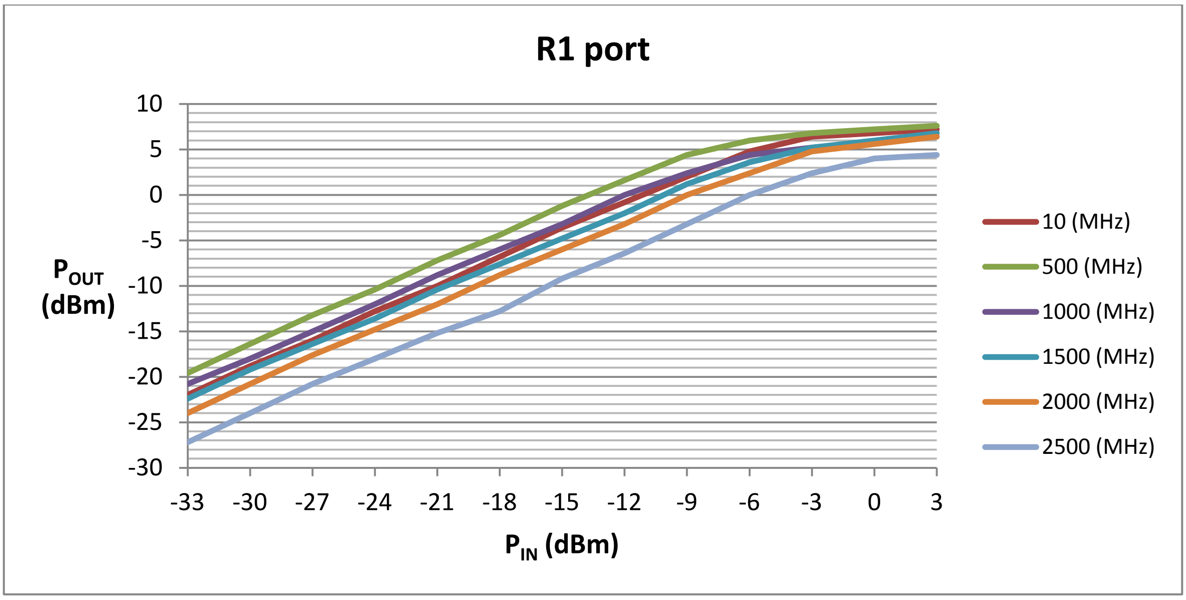


Figure 25: Gain curves of R1 port.

➢ Channel 2

Port L2						
P_{IN} (dBm)	10 (MHz)	500 (MHz)	1000 (MHz)	1500 (MHz)	2000 (MHz)	2500 (MHz)
-33	-21,6	-18,8	-20,4	-22	-24,8	-26,2
-30	-18,8	-16	-17,6	-19,2	-21,6	-23,2
-27	-15,6	-12,8	-14,4	-16,4	-18,4	-20
-24	-12,8	-9,6	-11,6	-13,6	-15,6	-17,2
-21	-9,6	-6,8	-8,4	-10,8	-12,4	-14,4
-18	-6,4	-4	-5,6	-8	-9,2	-11,2
-15	-3,2	-0,8	-2,8	-5,2	-6,4	-8,2
-12	-0,4	2	0,4	-2,8	-3,2	-5,4
-9	2,4	4,8	3,2	0	0	-2,4
-6	5,2	6,4	5,2	2,8	2,8	0,4
-3	6,8	7,2	6,8	6	4,8	3,2
0	7,6	7,6	7,2	6,8	6,4	4,8
3	8	8	7,6	7,2	6,8	5,2

Port R2						
P_{IN} (dBm)	10 (MHz)	500 (MHz)	1000 (MHz)	1500 (MHz)	2000 (MHz)	2500 (MHz)
-33	-22	-19,2	-20,8	-22,4	-24	-26,4
-30	-19	-16,4	-18	-19,2	-21	-23,6
-27	-16	-13,2	-15	-16,4	-18	-20,4
-24	-13,2	-10	-12	-13,6	-15,2	-17,6
-21	-10	-7	-8,8	-10,4	-12	-15
-18	-7,6	-4,4	-6	-7,2	-9,2	-13,2
-15	-4,8	-0,8	-3,2	-4,8	-6,4	-9,2
-12	-1,6	1,8	0	-1,6	-3,2	-6,4
-9	1,2	3,6	2,8	1,2	-0,4	-3,2
-6	4	5,6	4,8	3,6	2,4	0
-3	5,6	6,4	6	5,2	4,8	2,4
0	6,4	6,8	6,4	6,4	5,6	4
3	6,8	7,6	6,8	6,8	6,4	4,4

Table 4: Gain calibration of channel 2.

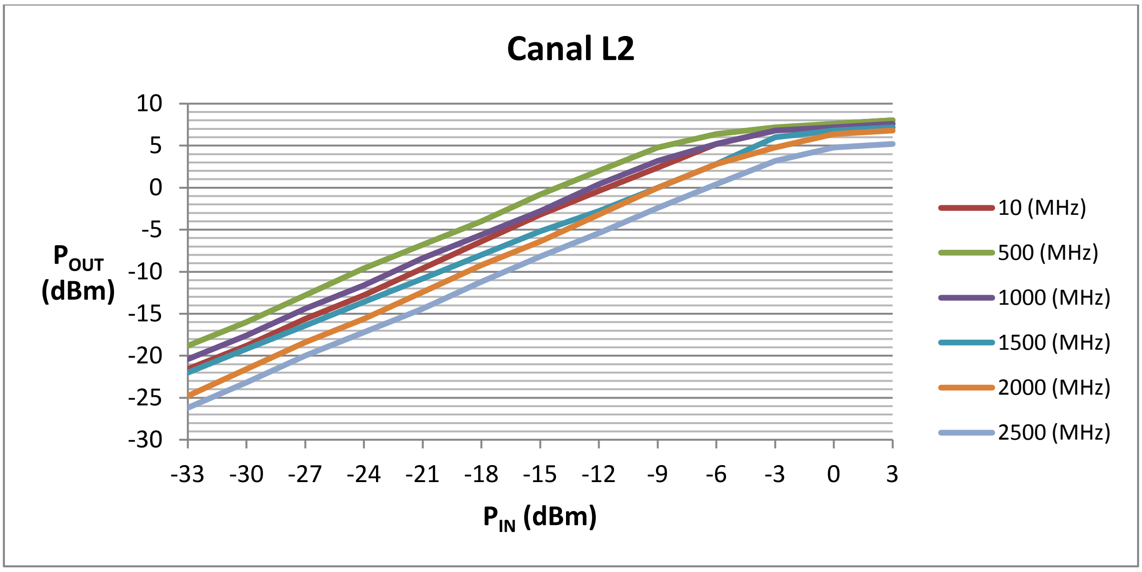


Figure 26: Gain curves of L2 port.

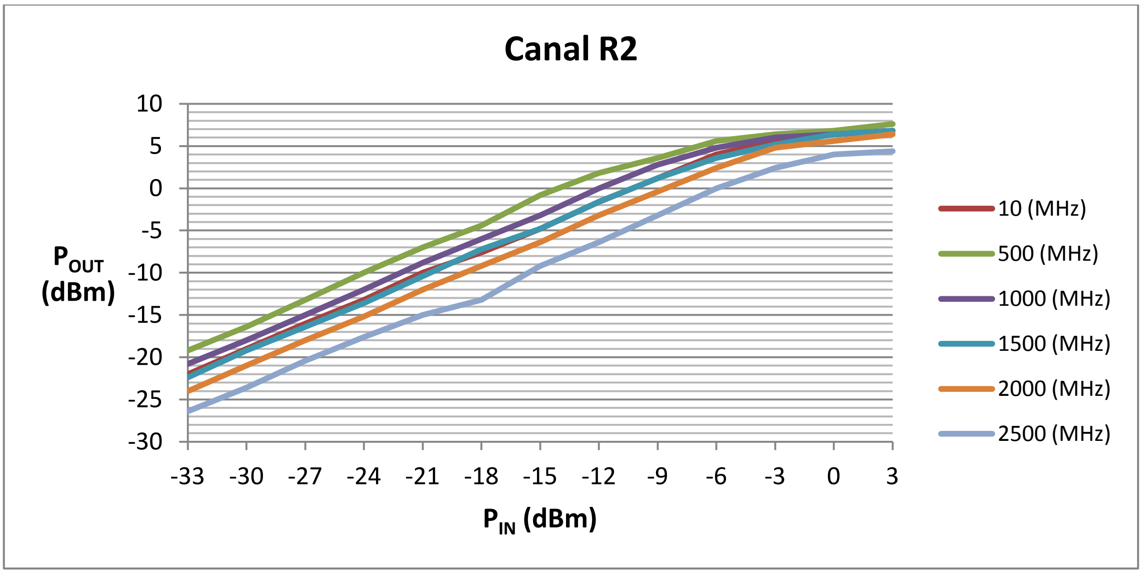


Figure 27: Gain curves of R2 port.

➢ Channel 3

Port L3						
P_{IN} (dBm)	10 (MHz)	500 (MHz)	1000 (MHz)	1500 (MHz)	2000 (MHz)	2500 (MHz)
-33	-22	-18,4	-20,4	-22	-23,8	-26
-30	-18,8	-15,6	-17,6	-19	-20,6	-22,8
-27	-16	-12,8	-14,6	-16	-17,6	-19,8
-24	-12,8	-9,2	-11,6	-13	-14,8	-17,2
-21	-9,6	-6,4	-8,4	-10	-11,6	-14
-18	-6,8	-3,6	-5,6	-6,8	-8,8	-11,8
-15	-3,6	-0,4	-2,8	-4	-6	-8
-12	-0,8	2	0,4	-1,6	-2,8	-5,2
-9	2	4,8	3,2	1,2	0	-2
-6	4,8	6,8	5,2	4	2,8	0,8
-3	6,8	6,8	6,8	6	5,2	3,2
0	7,2	7,6	7,2	6,8	6,4	5,2
3	7,6	8	7,6	7,6	6,8	5,6

Port R3						
P_{IN} (dBm)	10 (MHz)	500 (MHz)	1000 (MHz)	1500 (MHz)	2000 (MHz)	2500 (MHz)
-33	-22	-19	-20,8	-22,8	-24	-26,4
-30	-19,2	-16	-18	-19,6	-20,8	-23,6
-27	-16	-13,2	-15,2	-16,6	-18	-20,4
-24	-13,2	-10	-12	-13,6	-15,2	-17,6
-21	-10	-7,2	-8,8	-10,4	-12	-14,4
-18	-7,2	-4,4	-6	-7,6	-9	-12,4
-15	-4	-1,2	-3,2	-4,8	-6,4	-8,4
-12	-1,2	1,6	0	-1,6	-3,2	-5,6
-9	1,6	4	2,8	1,2	0	-2,8
-6	4,4	6	4,8	3,6	2	0,4
-3	6	6,8	6	5,2	4,8	2,8
0	6,8	6,8	6,4	6,4	5,6	4,4
3	6,8	7,6	6,8	6,8	6,4	5,2

Table 5: Gain calibration of channel 3.

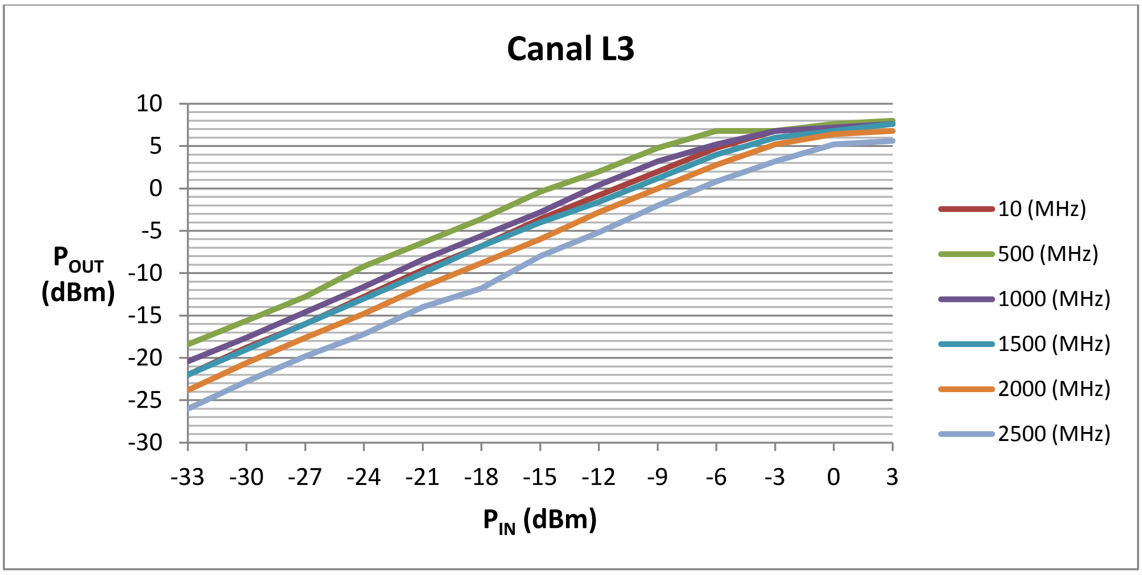


Figure 28: Gain curves of L3 port.

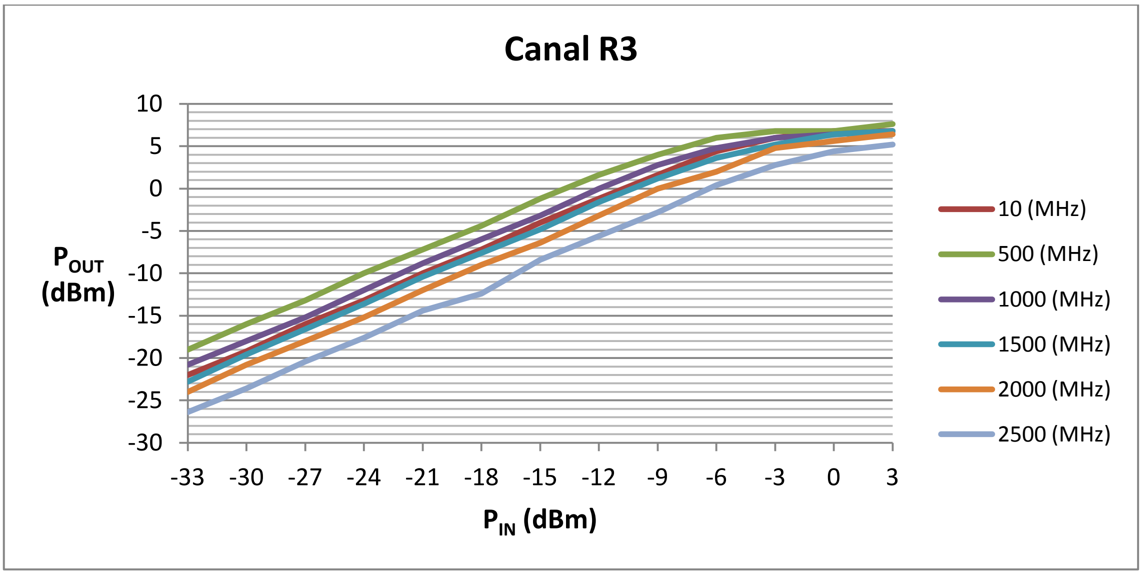


Figure 29: Gain curves of R3 port.

- ## Channel 4

Port L4							Port R4						
P_{IN} (dBm)	**10 (MHz)**	**500 (MHz)**	**1000 (MHz)**	**1500 (MHz)**	**2000 (MHz)**	**2500 (MHz)**	**P_{IN} (dBm)**	**10 (MHz)**	**500 (MHz)**	**1000 (MHz)**	**1500 (MHz)**	**2000 (MHz)**	**2500 (MHz)**
-33	-22	-18,8	-21,2	-22	-23,6	-26	**-33**	-22,2	-18,8	-20,8	-22,4	-24,4	-26,4
-30	-19,2	-16	-18	-19,2	-20,6	-23	**-30**	-19,2	-16	-18	-19,6	-21,2	-23,2
-27	-16,4	-12,8	-15,2	-16	-17,8	-20	**-27**	-16	-12,8	-15,2	-16,4	-18,4	-20,4
-24	-13,2	-9,4	-12	-12,8	-14,8	-17,2	**-24**	-13,2	-9,6	-12	-13,6	-15,6	-17,6
-21	-10	-6,8	-8,8	-10	-11,6	-14	**-21**	-10	-6,8	-9	-10,8	-12	-14,4
-18	-7,2	-3,8	-6	-6,8	-8,8	-11,8	**-18**	-7,2	-4	-6	-7,6	-9,2	-11,4
-15	-4	-0,6	-3,2	-4	-6	-8	**-15**	-4	-1,2	-3,2	-4,8	-6,8	-8,4
-12	-1,2	2	0,4	-1,2	-2,8	-5,2	**-12**	-1,2	1,6	0	-2	-3,6	-5,6
-9	2	4,8	3,2	2	0,4	-2	**-9**	1,6	4,4	2,8	0,8	-0,8	-2,4
-6	4,8	6,4	5,2	4,4	3,2	0,8	**-6**	4,4	6	4,8	3,6	2	0,4
-3	6,4	7,2	6,4	6,4	5,2	3,6	**-3**	6	6,8	5,6	4,8	4,4	3,2
0	6,8	7,6	7,2	6,8	6,4	5,2	**0**	6,8	6,8	6,4	5,8	5,6	4,8
3	7,4	8	7,6	8	6,8	5,6	**3**	6,8	7,6	6,8	6,4	6,4	5,2

Table 6: Gain calibration of channel 4.

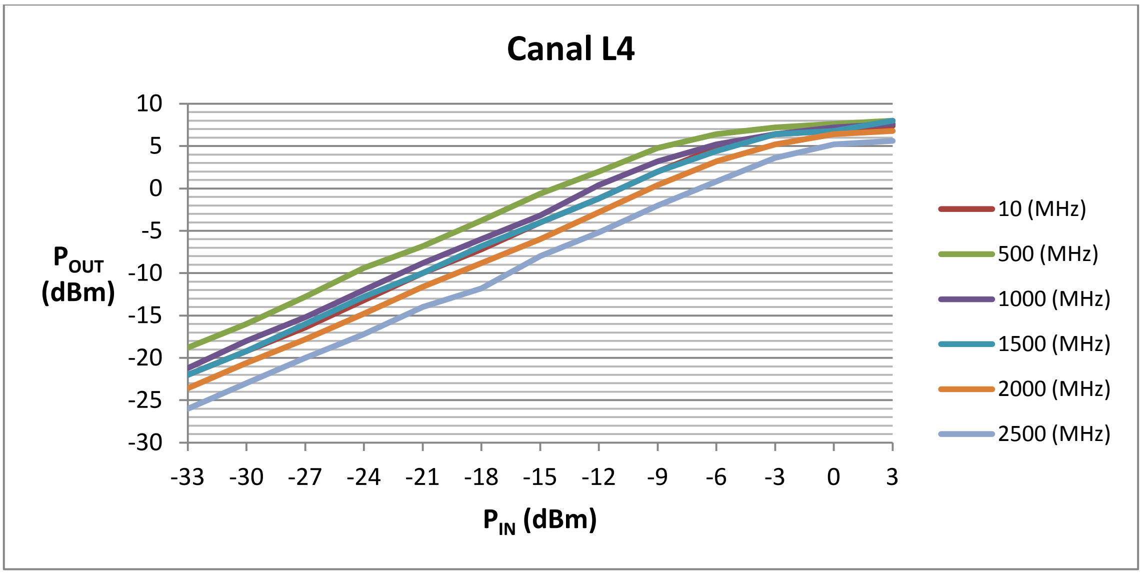


Figure 30: Gain curves of L4 port.

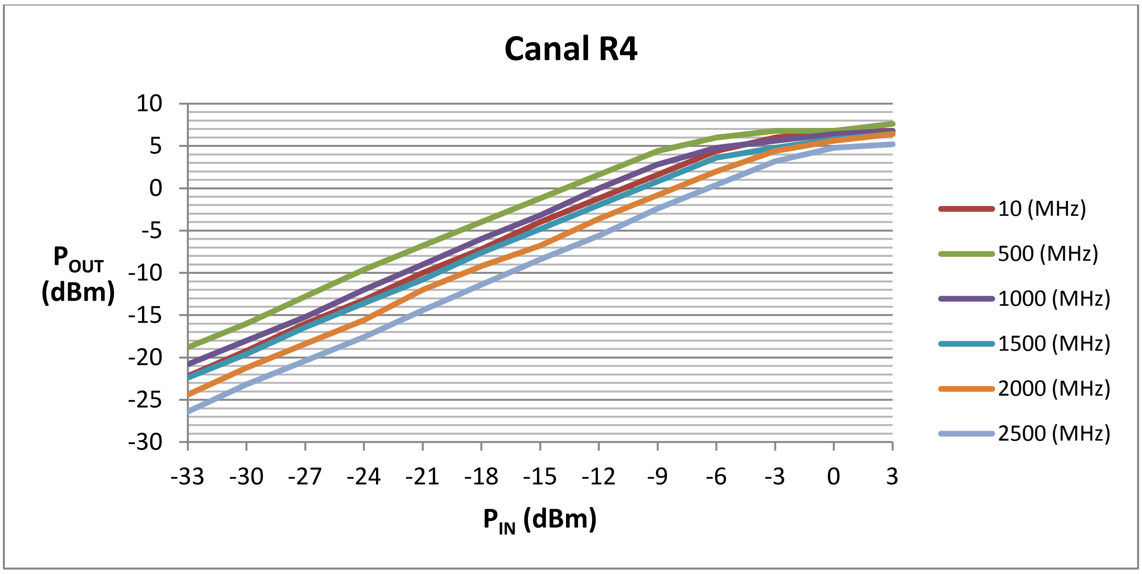


Figure 31: Gain curves of R4 port.

As it was shown on figures 14 and 15, all these measurements have been obtained using two cables and a SMA to N transition. These elements introduce losses that haven't been taking into acount. Furthermore, the signal generator and the spectrum analyzer have an uncertainty which also contribute to the inaccuracy of the measurements.

Table 7 is given to enable the matrix user to find out the inaccuracy due to the cables, the SMA to N transition and the uncertainty of the instrumentation. The testbench used to obtain this table consists on the signal generator connected to the spectrum analyzer via a cable with SMA connectors, a SMA to N transition and a cable with N connectors.

P$_{IN}$ (dBm)	10 (MHz)	500 (MHz)	1000 (MHz)	1500 (MHz)	2000 (MHz)	2500 (MHz)
-33	-32	-32,8	-33,6	-33,8	-33,4	-34,2
-30	-29,2	-30	-30,4	-30,8	-29,6	-30,8
-27	-26,4	-27,2	-27,6	-27,6	-27,2	-28,4
-24	-23,2	-24	-24,8	-24,8	-24	-25,2
-21	-20	-21,2	-21,6	-22	-21,2	-22,4
-18	-17,2	-17,6	-18,4	-18,8	-18	-20
-15	-14,4	-14,8	-16	-15,6	-15,2	-16,4
-12	-11,6	-12	-12,8	-13,2	-12,4	-13,2
-9	-8,8	-9,2	-9,6	-10	-9,2	-10,4
-6	-5,6	-6,4	-6,8	-7,2	-6,4	-7,2
-3	-2,4	-3,6	-4	-4	-3,2	-4,8
0	0,4	-1,2	-1,2	-1,6	-0,4	-2
3	3,2	2	1,6	1,6	2,4	-0,8

Table 7: Calibration of the cables and the transition

Finally, figure 32 has been obtained substracting the spectrum analyzer values (white columns in table 7) from the signal generator values (left colum in table 7). It represents the fluctuation of the measurement inaccuracy.

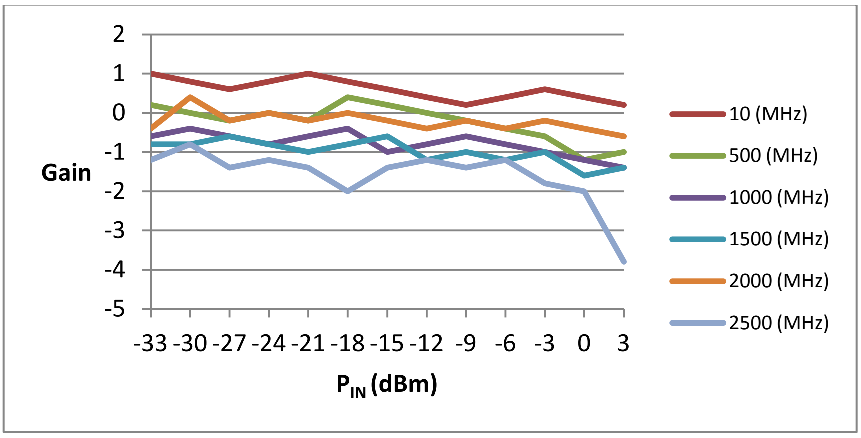


Figure 32: Fluctuation of the measurement uncertainty.

5.4 Saturation

Acording to the previous graphs and taking the 1000 MHz curves as reference, it can be concluded that the output power at 1dB compresion of the module is between 4 dBm and 6 dBm depending on the selected port.

6. Control module

The control of the matrix switch module is performed via an RS-232 serial port connected to a PIC model 16F84A. This PIC is integrated into a PCB circuit designed at CAY Laboratories to provide the PIC with the necessary signals and connections. Figure 14 shows the schematic of this circuit and figure 15 shows a photograph of its implementation:

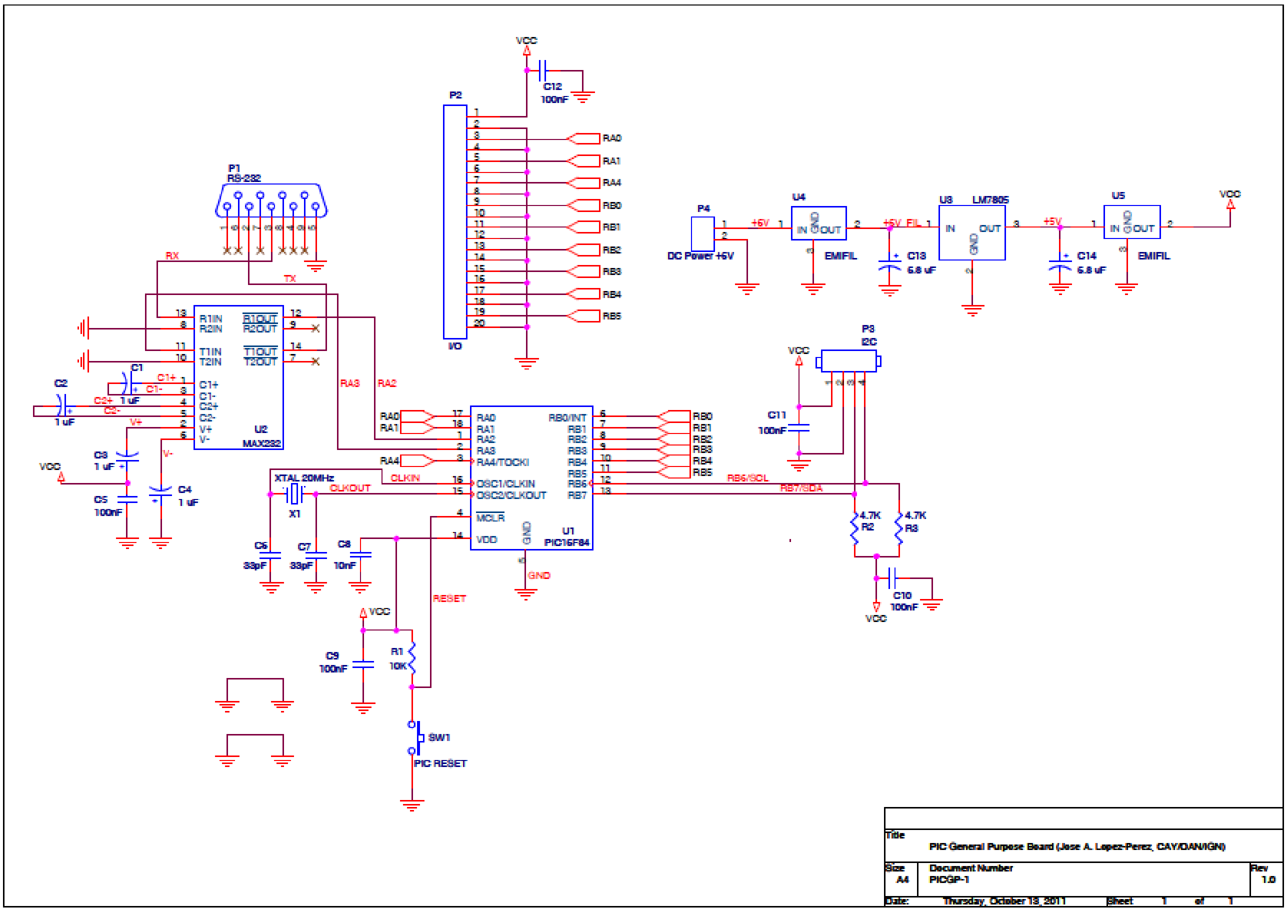


Figure 14: PIC's controller schematic.

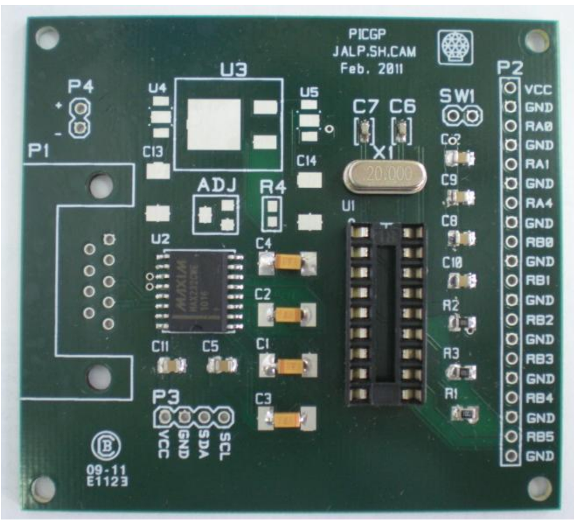


Figure 15: PIC's controller circuit.

This way, the board receives the commands transmitted from the PC. Then these signals from the PC are converted to 5V in the MAX232 adapter and finally they are processed by the PIC in order to select the desired output in the SP4T module. Table 3 represents the truth table of the system and the commands that must be introduced in order to activate one output or another:

Command introduced in the PC	PIC outputs		SP4T		Selected outputs
	RB0	RB2	A	B	
1	1	0	1	0	L1 and R1 (*RF2 of SP4Ts*)
2	0	0	0	0	L2 and R2 (*RF1 of SP4Ts*)
3	0	1	0	1	L3 and R3 (*RF3 of SP4Ts*)
4	1	1	1	1	L4 and R4 (*RF4 of SP4Ts*)

Table 3: Truth table of the control module

It is also possible for the operator to find out which output is already selected by sending the command '?'.

The code employed to program the PIC is shown in Appendix A.

7. Assembly and integration

The matrix switch will be integrated inside a 1U 19'' rack as shown in figure 16. This rack will be installed in the receiver room patch panel rack.

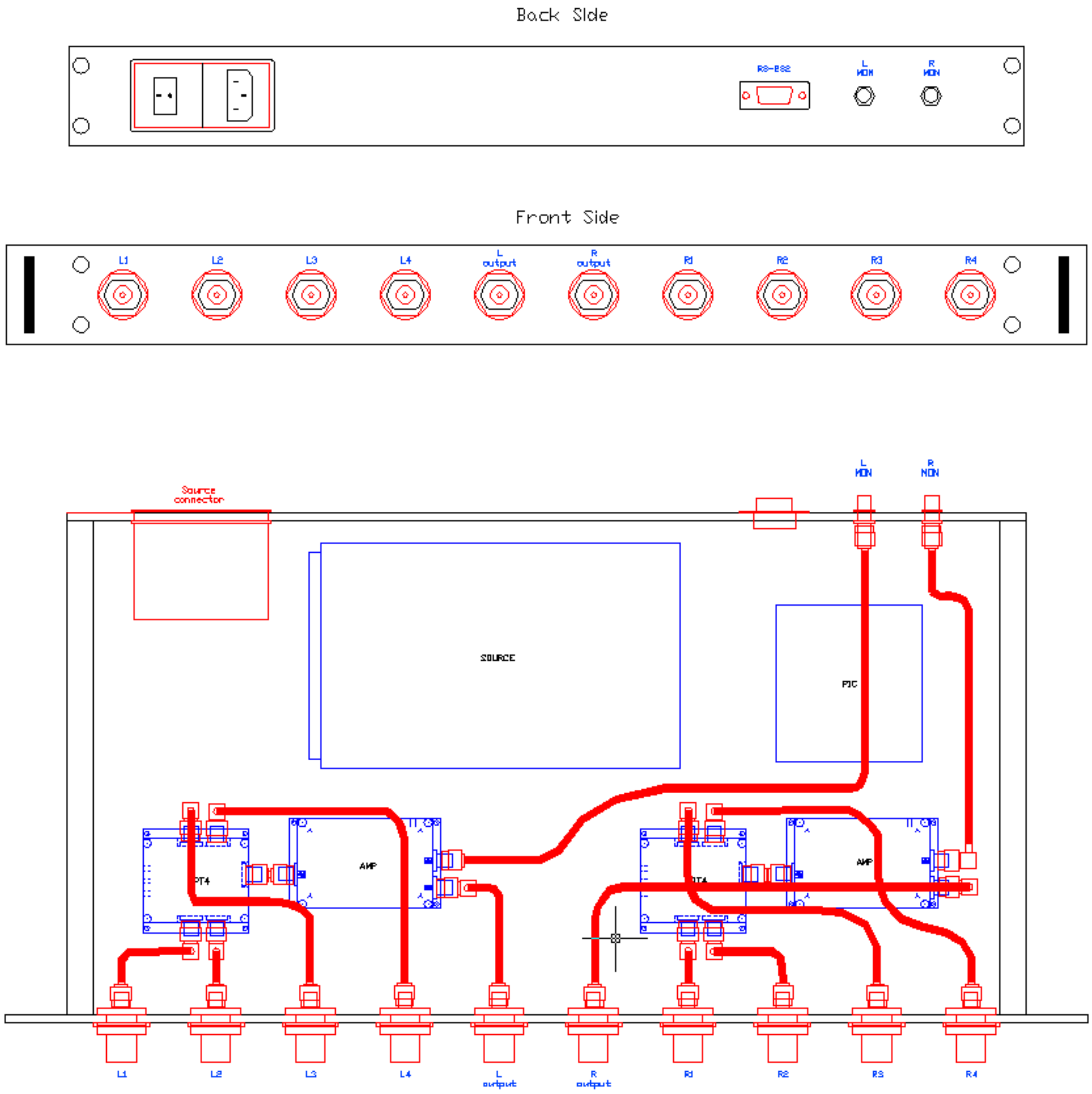


Figure 16: Matrix switch rack.

The semi-rigid cable connections (red lines) between components are preliminary. The final cable paths/shapes might be different from what's shown in figure 16.

8. Conclusions

A simple IF matrix switch has been designed and integrated in Yebes laboratories. It will provide the 40m radio telescope with the capability to automatically select which IF signals are sent down to the backend room, without the need of manual intervention of the operator in the patch panels.

The operation of the matrix switch will be remotely controlled via an RS-232 serial port according to the next table:

Command introduced in the PC	SP4T control pins		Selected output
	A	B	
1	1	0	L1 and R1 (*RF2 of SP4Ts*)
2	0	0	L2 and R2 (*RF1 of SP4Ts*)
3	0	1	L3 and R3 (*RF3 of SP4Ts*)
4	1	1	L4 and R4 (*RF4 of SP4Ts*)
?	Returns the active outputs' number		

Technical specifications:

- For frequencies below 2GHz, the module's return loss is always higher than 14 dB.
- In the band of interest between 0 and 2GHz the gain of the matrix is above 10 dB.
- The 1dB compression point of the module is around 5dBm (depending on the port) for a frequency of 1 GHz.

9. Acknowledgements

The authors wish to thank the help provided by Carlos Almendros and Sergio Henche for the soldering of the PCB circuits and the assembly of the matrix and Rubén Bolaño for the integration of the matrix into the antenna's control system.

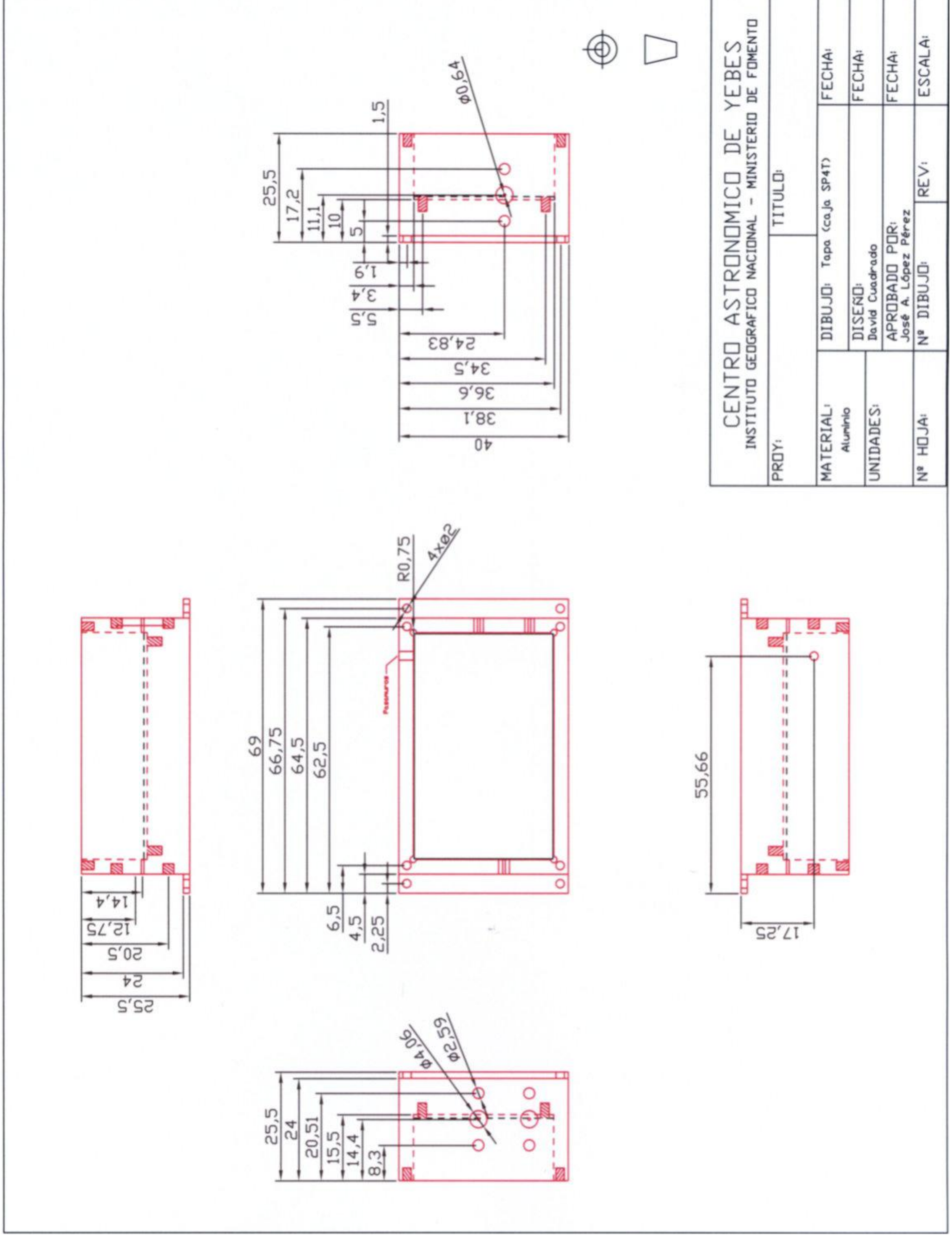
APPENDIX A: PIC’s programming code.

```
////////////////////////////////////////////////////////////////////////
////
//// Copyright (C) 2011
//// Instituto Geogrï¿½fico Nacional, Spain
////
//// This library is free software; you can redistribute it and/or modify
//// it under the terms of the GNU Library General Public License as
//// published by the Free Software Foundation; either version 2 of the
//// License, or (at your opinion) any later version.
////
//// This library is distributed in the hope that it will be useful, but
//// WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY
//// FITNESS FOR A PARTICULAR PURPOSE. See the GNU Library General Public
//// License for mor details.
////
//// You should have received a copy of the GNU Library General Public License
//// along with this library; if not, write to the Free Software Foundation,
//// Inc., 675 Massachusetts Ave, Cambridge, MA 02139, USA. Correspondence
//// concerning APEX should be addressed as follows:
////
//// who      when         what
//// --------  ---------     ---------
//// DCC&JALP   26-10-2011     Created
////
////////////////////////////////////////////////////////////////////////


#include<16F84A.h>
#include <stdlib.h>
#include <string.h>

#fuses NOWDT,HS,PUT,NOPROTECT

#use delay(clock=20000000)
#use rs232(baud=9600,xmit=PIN_A3,rcv=PIN_A2)

#define RB0 PIN_B0  //pinA (evaluation board HITTITE 102809)
#define RB2 PIN_B2  //pinB (evaluation board HITTITE 102809)

//#define wait 100;  //Value in msec (to be adjusted)

int selected_output=0;

void RF1()
{
  printf("1\r\n");
  output_high(RB0);
  delay_ms(100);
  output_low(RB2);
  selected_output=1;
  delay_ms(100);
}

void RF2()
{
  printf("2\r\n");
```

```
  output_low(RB0);
  delay_ms(100);
  output_low(RB2);
  selected_output=2;
  delay_ms(100);
}

void RF3()
{
  printf("3\r\n");
  output_low(RB0);
  delay_ms(100);
  output_high(RB2);
  selected_output=3;
  delay_ms(100);
}

void RF4()
{
  printf("4\r\n");
  output_high(RB0);
  delay_ms(100);
  output_high(RB2);
  selected_output=4;
  delay_ms(100);
}

void ID()  //This functions returns the selected output
{
  switch(selected_output)
  {
    case(0):
      printf("N\r\n"); //No output selected
      break;
    case(1):
      printf("1\r\n");
      break;
    case(2):
      printf("2\r\n");
      break;
    case(3):
      printf("3\r\n");
      break;
    case(4):
      printf("4\r\n");
      break;
  }
}

void Error()
{
  printf("E\r\n");
}

void main()
{
```

```
  char command;
  port_b_pullups(0b00000101); //para activar resistencias pullups 1 activado, 0 desactivado
  set_tris_a(0b10111);
  set_tris_b(0b00000000);//0 si se utilizan como salidas, 1 como entradas

  do
  {
    command=getc();
    delay_ms(200);

    switch(command)
    {
      case('1'):
      RF1();
      break;

      case('2'):
      RF2();
      break;

      case('3'):
      RF3();
      break;

      case('4'):
      RF4();
      break;

      case('?'):
      ID();
      break;

      default:
      Error();
      break;
    }


  } while (TRUE);

}
```

APPENDIX B: boxes for the PCB circuits


CENTRO ASTRONOMICO DE YEBES
INSTITUTO GEOGRAFICO NACIONAL - MINISTERIO DE FOMENTO
PROY:
TITULO:
MATERIAL: Aluminio
DIBUJO: Tapa (caja SP4T)
FECHA:
DISEÑO: David Cuadrado
FECHA:
UNIDADES:
APROBADO POR: José A. López Pérez
FECHA:
Nº HOJA:
Nº DIBUJO:
REV:
ESCALA:
25,5
17,2
11,1
10
5
1,5
1,9
3,4
5,5
24,83
34,5
36,6
38,1
40
Ø0,64
R0,75
4xØ2
69
66,75
64,5
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4,5
2,25
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25,5
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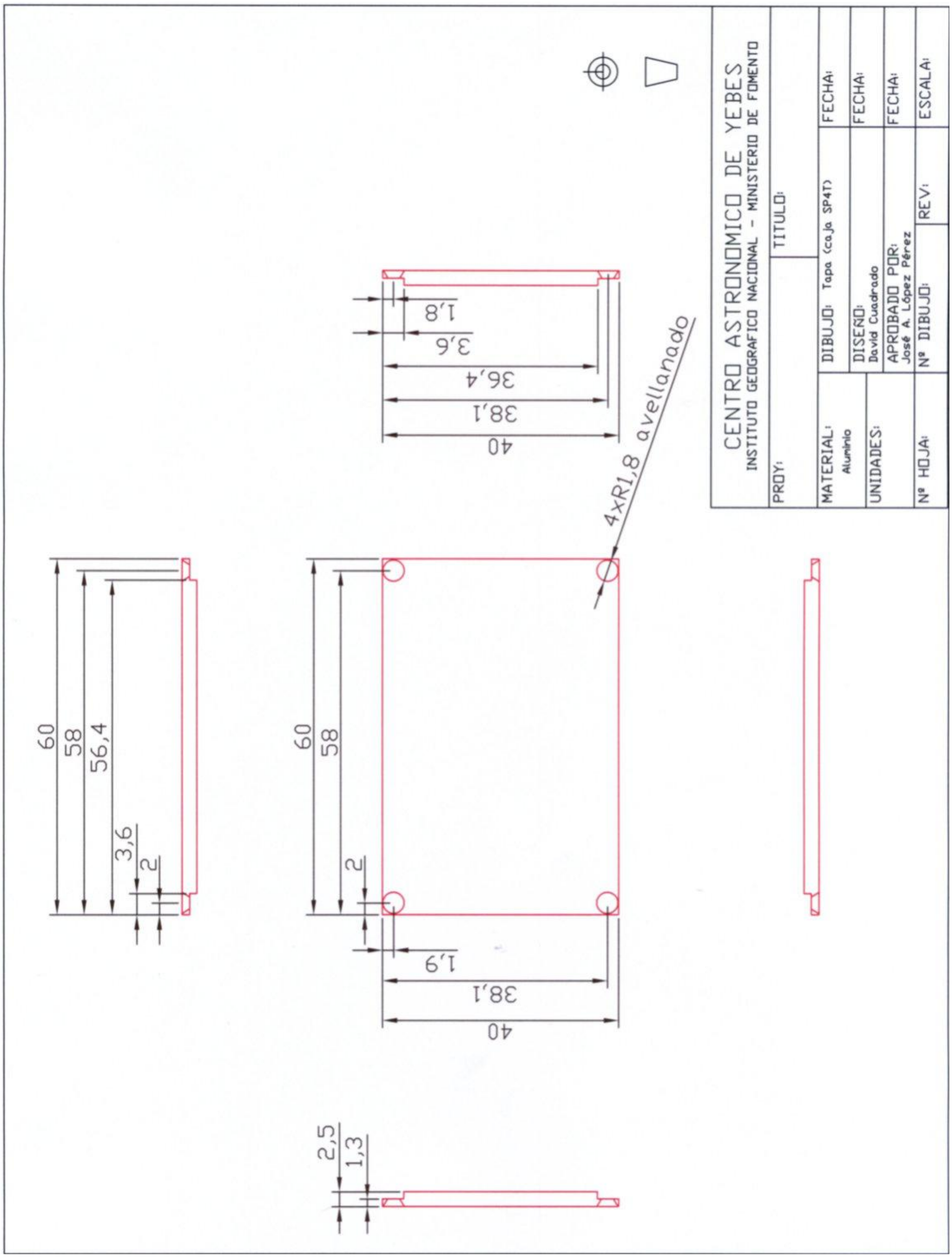
20,51
15,5
14,4
8,3


CENTRO ASTRONOMICO DE YEBES
INSTITUTO GEOGRAFICO NACIONAL - MINISTERIO DE FOMENTO
PROY:
TITULO:
MATERIAL: Aluminio
DIBUJO: Tapa (caja SP4T)
FECHA:
UNIDADES:
DISEÑO: David Cuadrado
FECHA:
APROBADO POR: José A. López Pérez
FECHA:
Nº HOJA:
Nº DIBUJO:
REV:
ESCALA:
4xR1,8 avellanado
60
58
56,4
3,6
2
40
38,1
36,4
1,8
1,9
2,5
1,3