Characterization and Measurements of VLBI2010 Tri-Band S Band Downconverter

David Álvarez Carrillo
Andrea Martínez Parra
María Patino Esteban

August, 2025

Observatorio de Yebes
Apdo. 148, E-19080
Guadalajara, Spain

GOBIERNO DE ESPAÑA
MINISTERIO DE TRANSPORTES Y MOVILIDAD SOSTENIBLE
INSTITUTO GEOGRÁFICO NACIONAL
YEBES

Table of Contents

1 Introduction **2**

2 Complete characterization of the RF Downconverter **2**

2.1 Module views . . . 3

2.2 Measurements . . . 4

2.2.1 *S* parameters and Gain . . . 4

2.2.2 Noise Figure . . . 6

2.2.3 P1dB . . . 7

2.2.4 Harmonics and Spurious Emisions . . . 9

2.3 Conclusions . . . 9

Appendices **10**

A Harmonics at Different Frequencies **11**

B Noise Figure at Different Attenuations **16**

List of Figures

1.1 Block Diagram of the Downconverter . . . 2

2.1 Front and Rear View of the RF Downconverter . . . 3

2.2 Internal View of the RF Downconverter . . . 3

2.3 External Full View of the RF Downconverter . . . 3

2.4 *S* - Parameters of the RF Downconverter . . . 5

2.5 Gain Linearity with different Attenuations of the S Band Downconverter . . . 5

2.6 Noise Figure of the RF Downconverter at 0 dB attenuation . . . 6

2.7 Pi1dB of the RF Downconverter at different Frequencies . . . 8

A.1 IF Outputs for 2.20 GHz RF Input . . . 11

A.2 IF Outputs for 2.26 GHz RF Input . . . 11

A.3 IF Outputs for 2.32 GHz RF Input . . . 12

A.4 IF Outputs for 2.38 GHz RF Input . . . 12

A.5 IF Outputs for 2.45 GHz RF Input . . . 13

A.6 IF Outputs for 2.51 GHz RF Input . . . 13

A.7 IF Outputs for 2.57 GHz RF Input . . . 14

A.8 IF Outputs for 2.63 GHz RF Input . . . 14

A.9 IF Outputs for 2.70 GHz RF Input . . . 15

B.1 Noise Figure of the RF Downconverter at 15 dB attenuation . . . 16

B.2 Noise Figure of the RF Downconverter at 31 dB attenuation . . . 16

List of Tables

2.1 Points of Compression of RF Downconverter . . . 7

2.2 Downconverter Harmonics and Spurious Emissions for RCP Polarization . . . 9

1 Introduction

The VLBI2010 converter module, originally developed for the VGOS tri-band receiver at Yebes Observatory, is currently being evaluated for its potential reuse in the planned upgrade of the 40 m telescope S-band receiver. Its role within the new system would be to provide the frequency conversion stage, converting the incoming RF signals to the IF band for subsequent backend processing.

From a technical standpoint, the module operates with an RF input range of 2.2–2.7 GHz and generates an IF output in the 0.5–1.0 GHz band. It provides a nominal conversion gain of 50 dB and incorporates a programmable attenuator with a dynamic range of 0–31 dB, allowing precise adjustment of the signal level across the IF chain. If its measured performance in terms of gain stability, linearity, and noise contribution is found to be adequate, the module will be integrated as part of the upgraded S-band receiver.

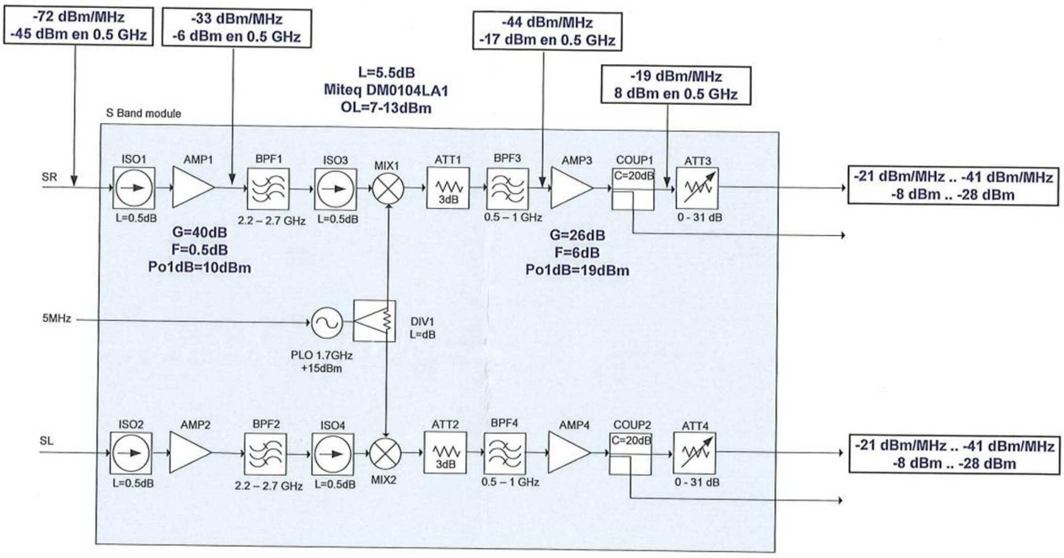


Figure 1.1: Block Diagram of the Downconverter

2 Complete characterization of the RF Downconverter

The measurement setup along with the necessary instrumentation for such purposes will be described. Following this, laboratory measurements will be presented, demonstrating the performance of these devices in terms of output power versus input power. Additionally, other parameters specified in the technical datasheets, such as gain (G), the 1dB compression point (P1dB), noise figure (NF), and spurious emissions will also be evaluated.

2.1 Module views

The following figures show the Downconverter module from different perspectives:

Figure 2.1: Front and Rear View of the RF Downconverter

Figure 2.2: Internal View of the RF Downconverter

Figure 2.3: External Full View of the RF Downconverter

2.2 Measurements

These measurements were carried out during August, 2025. The instrumentation used consisted of the following elements:

- 3 Hz - 50 GHz PXA signal analyzer from Keysight, model N9030A.
- 10 MHz - 67 GHz PNA vector network analyzer from Keysight, model N5277A.
- 250 kHz - 67 GHz PSG Analog Signal Generator.
- Low loss K coaxial cables.
- K adapters.
- 1 - 50 GHz noise source from Keysight, model 346CK01.
- 28 Vdc BNC power cable.
- RF Converter under test.

2.2.1 *S* parameters and Gain

To measure the S-parameters and determine the converter's gain, a network analyzer configured in mixer mode was employed. A 5 MHz signal was used to provide the PLO with the external reference in order to generate the LO at the frequency (1.7 GHz) and power (0 dBm) necessary for the mixter to function correctly and generate the intermediate frequency (IF). To avoid system saturation, the RF and IF power levels were set at -55 dBm. In this setup, ports 1 and 2 were used for RF-IF connections with low-loss cables.

With this configuration in place, the analyzer was calibrated, using an electronic and power calibrators, to then perform the measurements of the S-parameters and the converter's gain.

Figure 2.4 shows the S-parameters of the converted system, with an intermediate frequency range between 0.5 and 1 GHz, as illustrated in the S_{21} (gain) plot. Input return losses are approximately 44 dB (defined as $-20\log_{10}|S_{11}|$), with certain frequencies exceeding this value.

The output return losses remain above 20 dB ($-20\log_{10}|S_{22}|$) and exceed 40 dB in some parts of the IF band. The reverse transmission from port 2 to port 1 is below –35 dB, indicating that signal propagation occurs only in the forward direction (from port 1 to port 2).

The S_{21} parameter (gain) plot demonstrates nonlinear behavior across the IF band, which introduces some amplitude distortion. However, the gain remains within a ±2 dB tolerance, thereby mitigating the detrimental impact of the distortion. However, this effect must still be taken into account.

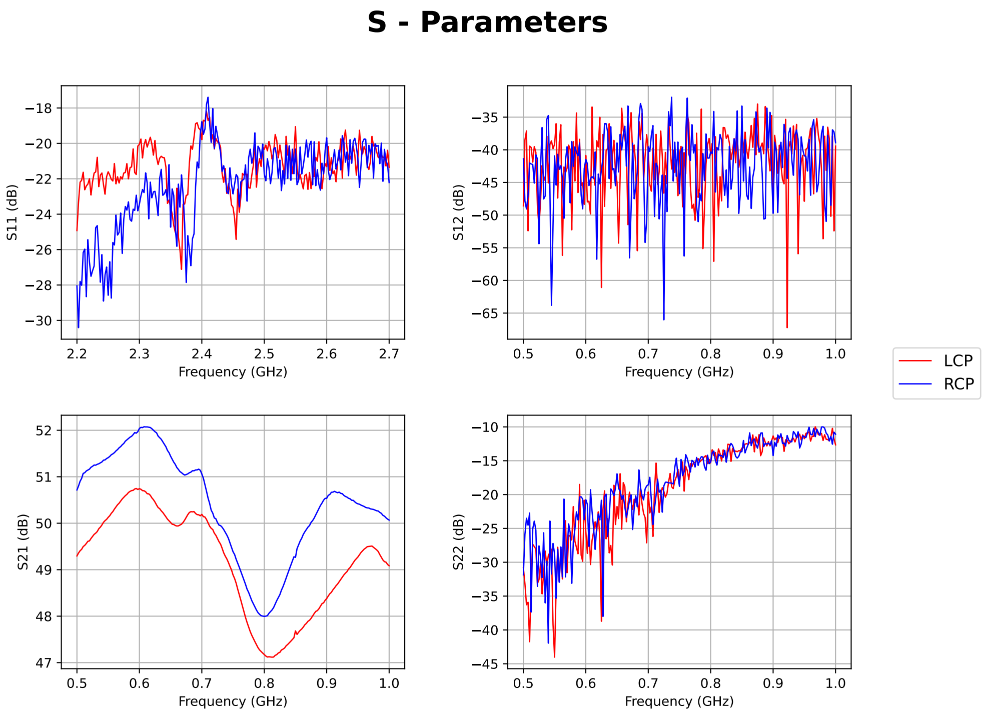


Figure 2.4: S - Parameters of the RF Downconverter

Another parameter of particular importance is the linearity of the variable attenuator, since this component should ideally not introduce amplitude distortion into the output signal. The attenuator can be considered linear if it applies the same attenuation factor to all frequency components.

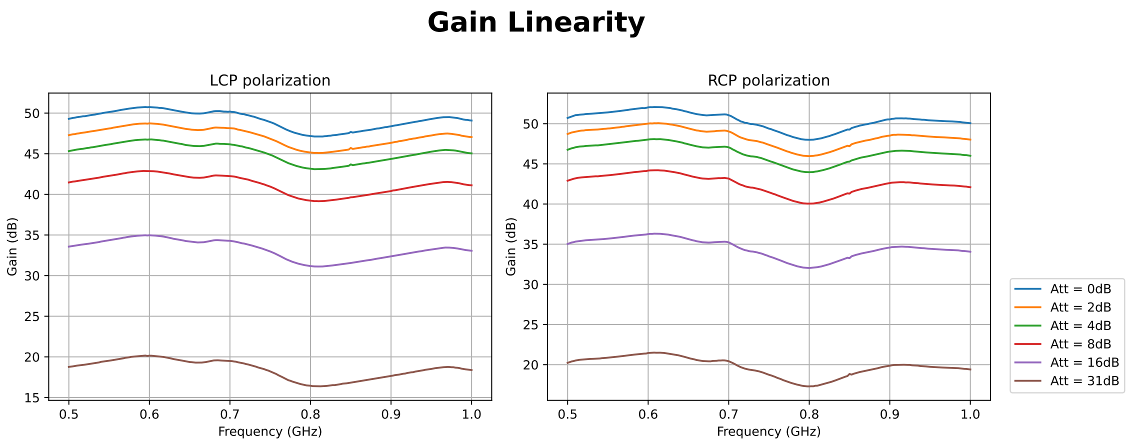


Figure 2.5: Gain Linearity with different Attenuations of the S Band Downconverter

Figure 2.5 shows that the converter's variable attenuator maintains high linearity across the full IF bandwidth for both polarizations, confirming its proper functionality.

2.2.2 Noise Figure

The noise figure was measured at different attenuation levels for comparison. The equipment used included a spectrum analyzer and a signal generator, which provided a 5 MHz and 0 dBm tone as an external reference for the local oscillator (LO), which emitted a 1.7 GHz tone. The spectrum analyzer measured the noise figure in the entire band. The RF input of the converter is connected to a noise source, prior to connecting a K adapter, which is powered with a 28 Vdc BNC cable from the back of the spectrum analyzer. The IF output is connected to the spectrum analyzer, previously calibrated up to 1 GHz (IF frequencies), via a low loss K cable.

Figures 2.6, B.1, and B.2 show the noise figure values across the frequency band for different attenuation levels. As observed, the values remain below 3.5 dB, with typical levels around 1.3 dB, which is consistent with the expected performance of the converter.

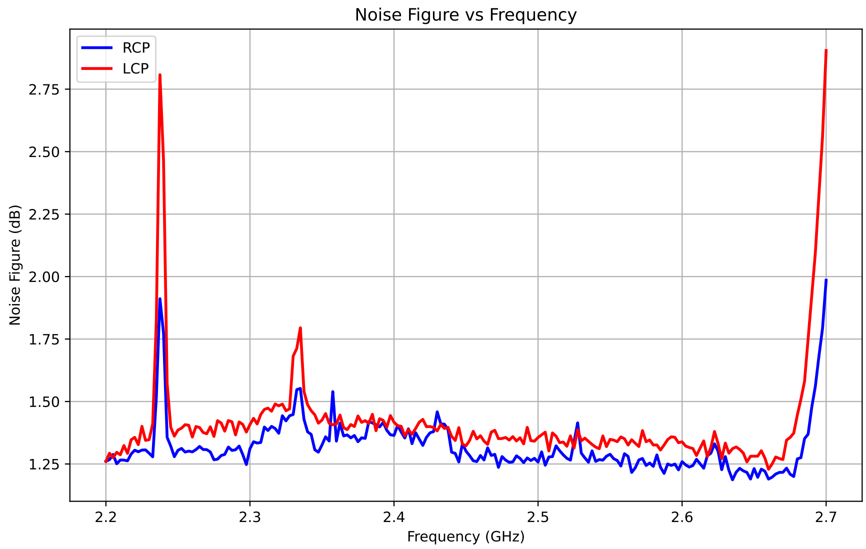


Figure 2.6: Noise Figure of the RF Downconverter at 0 dB attenuation

The remaining figures are provided in Appendix B.

2.2.3 P1dB

The measurement of the 1 dB input compression point (Pi1dB) was carried out using the Keysight PXA Signal Analyzer N9030A (3 Hz–50 GHz). Measurements were taken at the start frequency (2.2 GHz), the end frequency (2.7 GHz), and seven additional equispaced frequencies within the band. Table 2.1 summarizes the 1 dB input compression point for each measured frequency and polarization.

Table 2.1: Points of Compression of RF Downconverter

Frequency (GHz)	Polarization	Pi1dB (dBm)
2.20	LCP	-39.4
	RCP	-41.0
2.26	LCP	-39.4
	RCP	-41.2
2.33	LCP	-38.4
	RCP	-40.2
2.39	LCP	-36.6
	RCP	-37.6
2.45	LCP	-35.4
	RCP	-36.0
2.51	LCP	-33.2
	RCP	-34.6
2.58	LCP	-39.6
	RCP	**-43.2**
2.64	LCP	-39.6
	RCP	-41.4
2.70	LCP	-38.0
	RCP	-39.0

It is important to note that the most restrictive in-band input power level is –43.2 dBm, which requires operation at least 10 dB below this value (–53.2 dBm). A study was conducted using the measurement data to determine the input power level at which the gain departs from linear behavior. The results, shown in Figure 2.7, indicate the points at which these limits occur.

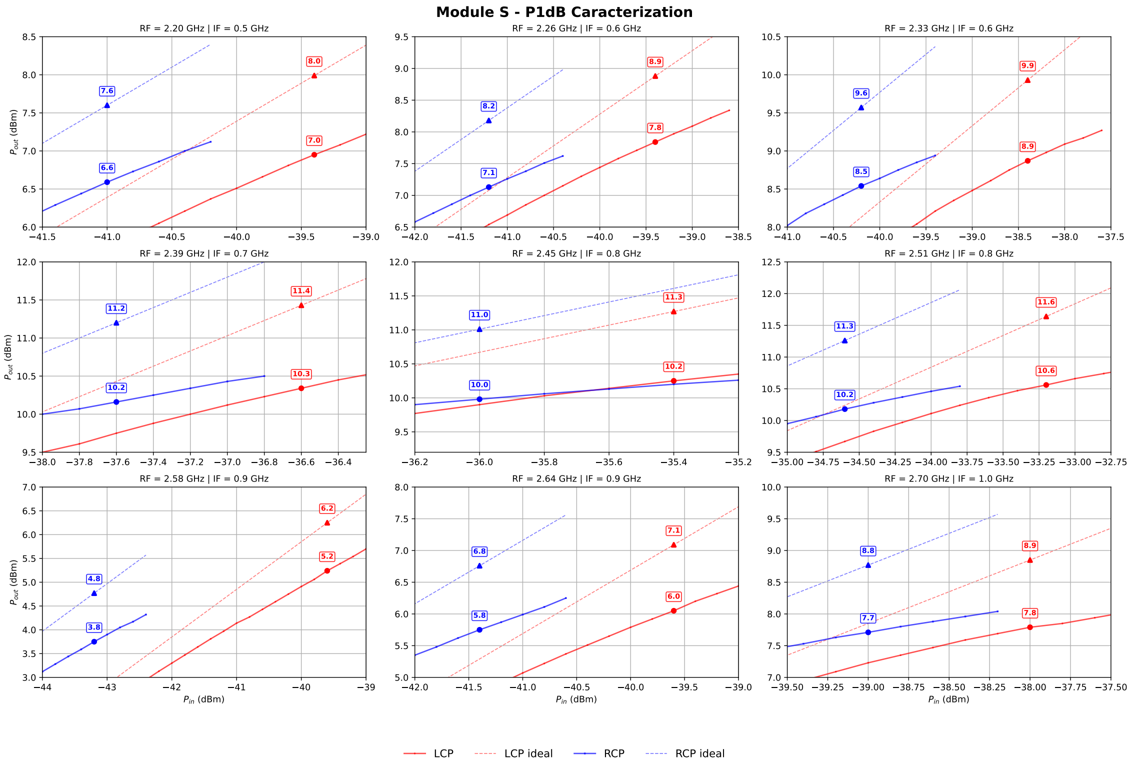


Figure 2.7: Pi1dB of the RF Downconverter at different Frequencies

Since the most restrictive value is -43.2 dBm, it has been decided to operate with an input power below -53.2 dBm.

2.2.4 Harmonics and Spurious Emisions

A mixer typically produces spurious signals at frequencies of the form $\pm m \cdot LO \pm n \cdot RF$, where $m, n \in \mathbb{Z}$. For this specific downconverter, the most critical spurious components and harmonics are those that fall within the band of interest (0.5–1 GHz).

As observed in Table 2.1, the limiting polarization is RCP. Consequently, harmonic and spurious emission measurements were performed specifically on this polarization. These measurements were conducted with an RF input signal of –55 dBm.

Table 2.2: Downconverter Harmonics and Spurious Emissions for RCP Polarization

RFin (GHz)	IF (MHz)	LHC [1](dBm)	RL [2] (dBc)	MLC [3] (dBm)	CHC [4]
2.20	500	-47.93	42.72	-49.28	$2f_{LO} - 2f_{RF}$
2.26	562	-52.00	47.56	-52.00	$3f_{LO} - 2f_{RF}$
2.32	625	-40.55	36.27	-40.55	$2f_{LO} - f_{RF}$
2.38	687	-34.14	29.03	-34.14	$2f_{LO} - f_{RF}$
2.45	750	-34.53	27.49	-34.53	$2f_{LO} - f_{RF}$
2.51	812	-36.06	27.97	-38.81	$2f_{LO} - f_{RF}$
2.57	875	-39.01	33.11	-41.95	$2f_{LO} - f_{RF}$
2.63	937	-45.22	39.22	-45.22	$2f_{LO} - f_{RF}$
2.70	1000	-41.07	34.78	-41.07	$2f_{LO} - f_{RF}$

At certain frequencies, spurious components located outside the IF range were considered due to their proximity to the band and their substantial power level.

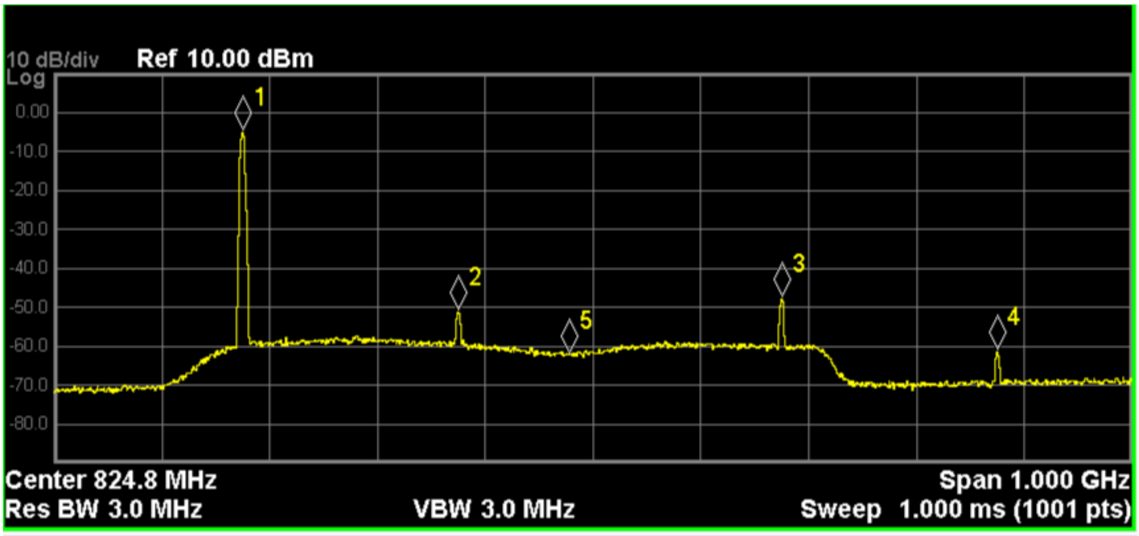
2.3 Conclusions

The VLBI2010 Downconverter operates within an RF frequency range of 2.2–2.7 GHz and an IF frequency range of 0.5–1 GHz, providing an average gain of 50 dB with a variation of ±2 dB across the band. The most restrictive P1dB, measured at –43.2 dBm input power, defines the operational limit; accordingly, input levels are set around –55 dBm to ensure safe operation. Noise figure measurements are sufficiently low to guarantee reliable system performance. Overall, the VLBI2010 Downconverter is fully operational and meets the specifications for deployment in the 40 m VLBI2010 receiver at Yebes Observatory.

[1]Level of the Highest Component in the IF band (without $f_{in} - f_{ol}$)
[2]Rejection Level
[3]Mean Level of the Components
[4]Combinations of the Highest Component

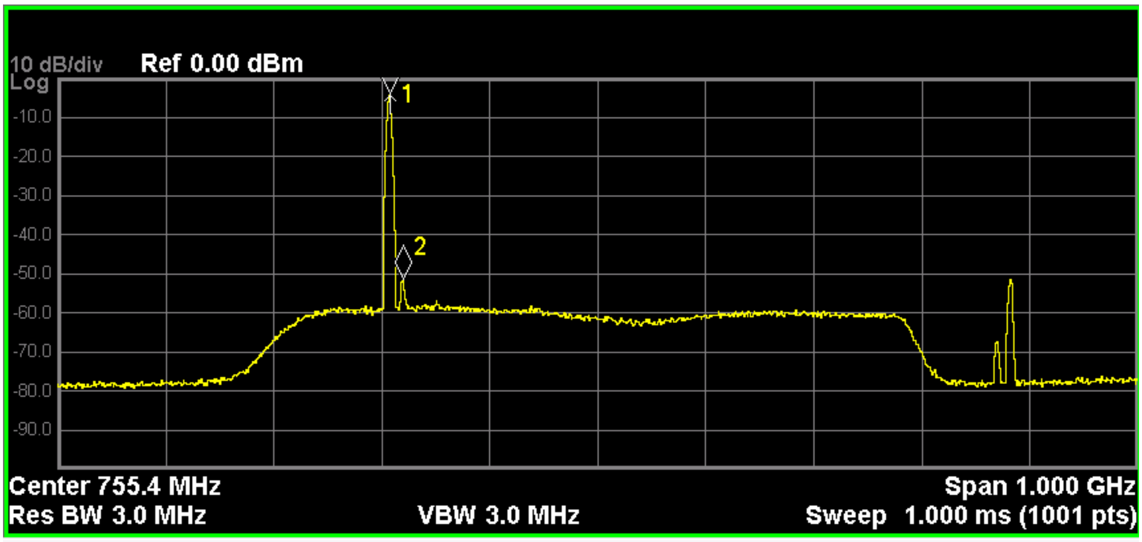
APPENDIX

A Harmonics at Different Frequencies



MKR	MODE	TRC	SCL	X	Y	FUNCTION	FUNCTION WIDTH	FUNCTION VALUE
1	N	1	f	500 MHz	-5.212 dBm			
2	N	1	f	700 MHz	-51.245 dBm			
3	N	1	f	1.00 GHz	-47.936 dBm			
4	N	1	f	1.200 GHz	-61.413 dBm			
5	N	1	f	803 MHz	-62.370 dBm			

Figure A.1: IF Outputs for 2.20 GHz RF Input



MKR	MODE	TRC	SCL	X	Y	FUNCTION	FUNCTION WIDTH	FUNCTION VALUE
1	N	1	f	563 MHz	-4.447 dBm			
2	N	1	f	575 MHz	-52.005 dBm			

Figure A.2: IF Outputs for 2.26 GHz RF Input

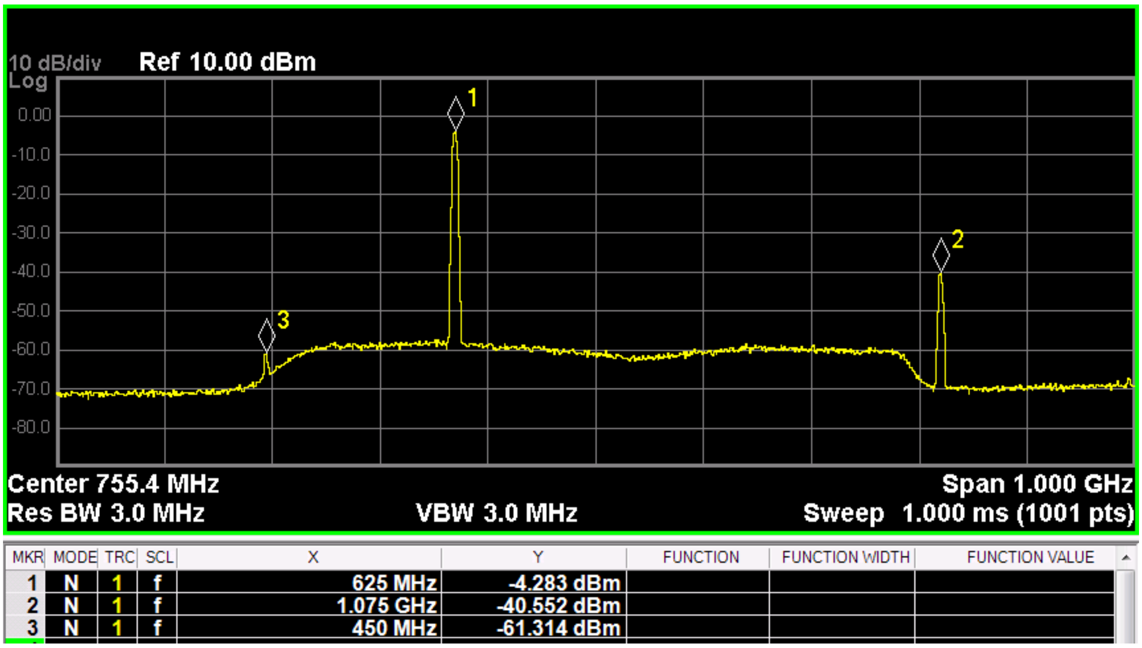


Figure A.3: IF Outputs for 2.32 GHz RF Input

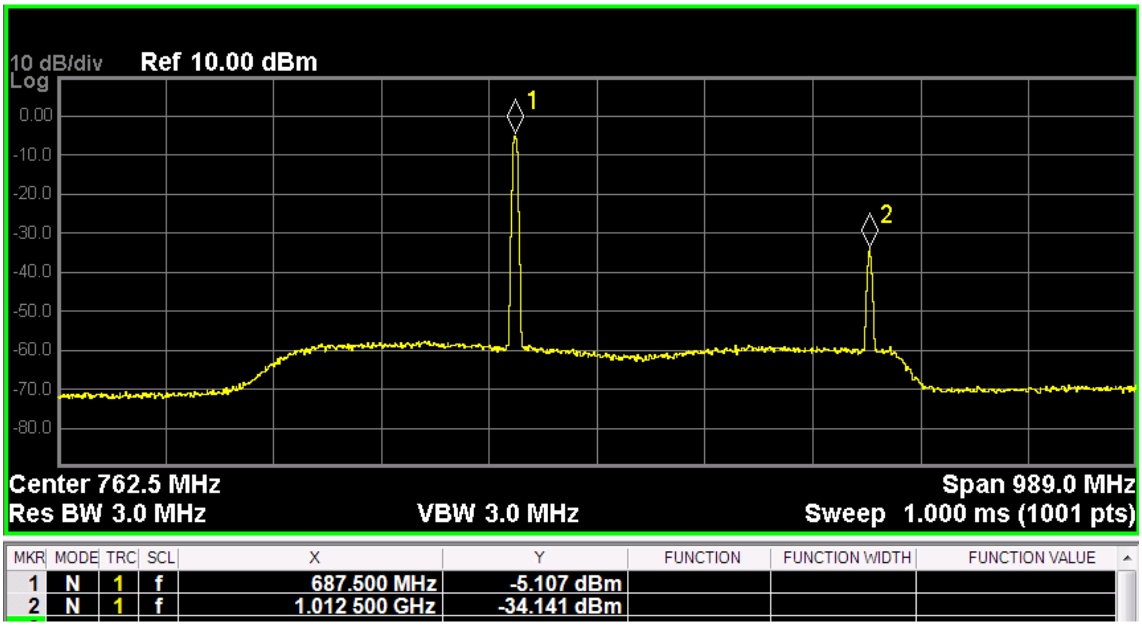


Figure A.4: IF Outputs for 2.38 GHz RF Input

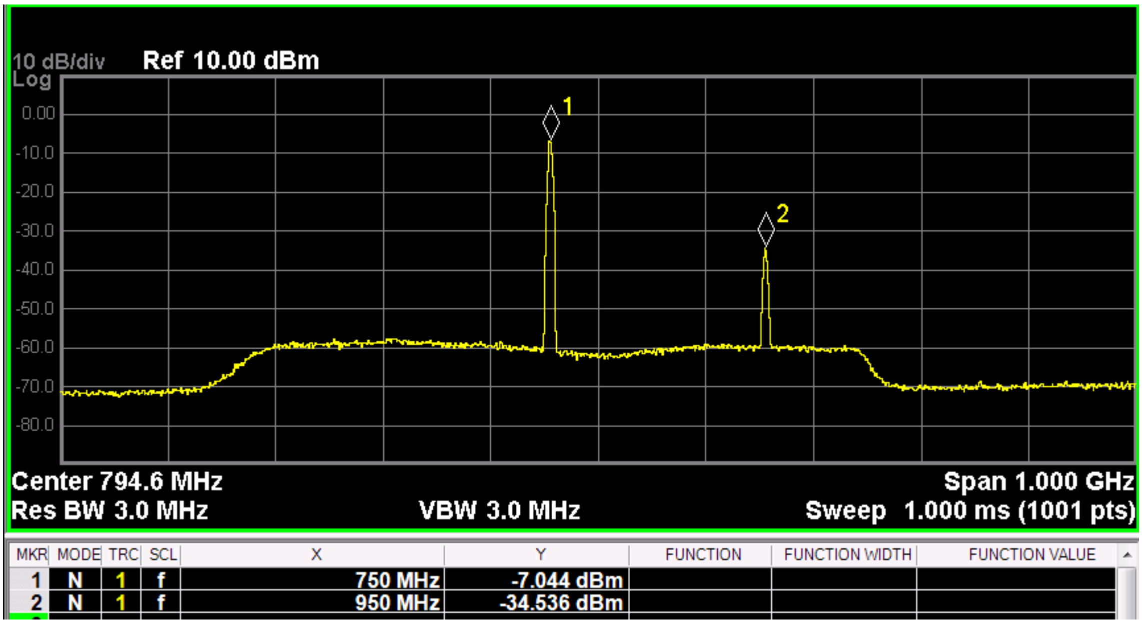


Figure A.5: IF Outputs for 2.45 GHz RF Input

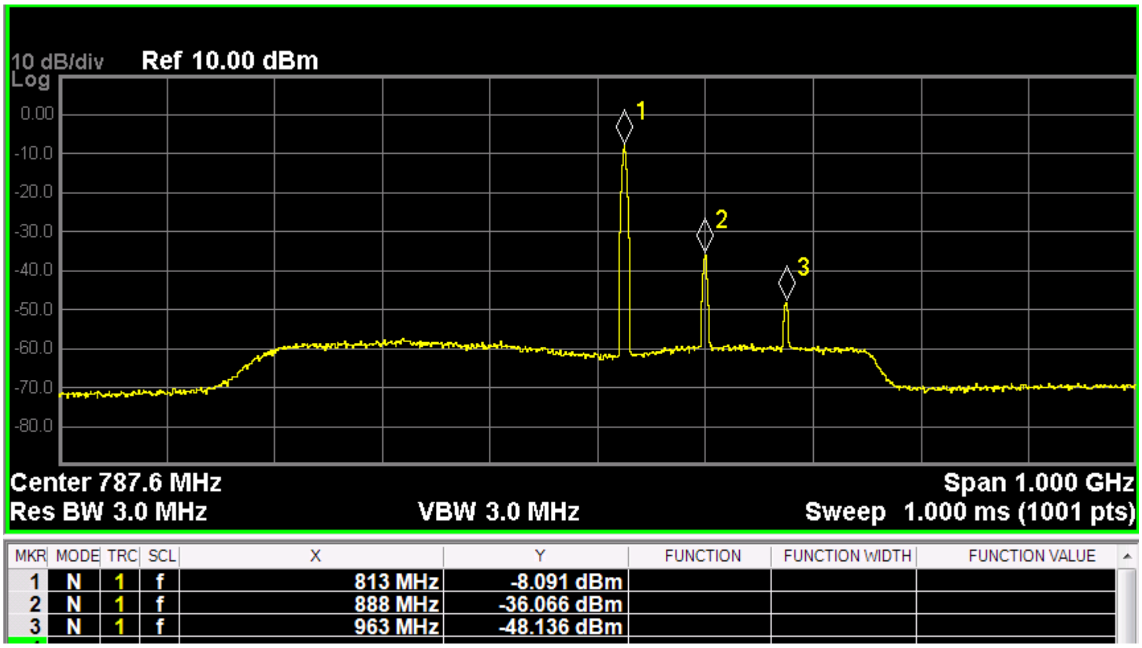


Figure A.6: IF Outputs for 2.51 GHz RF Input

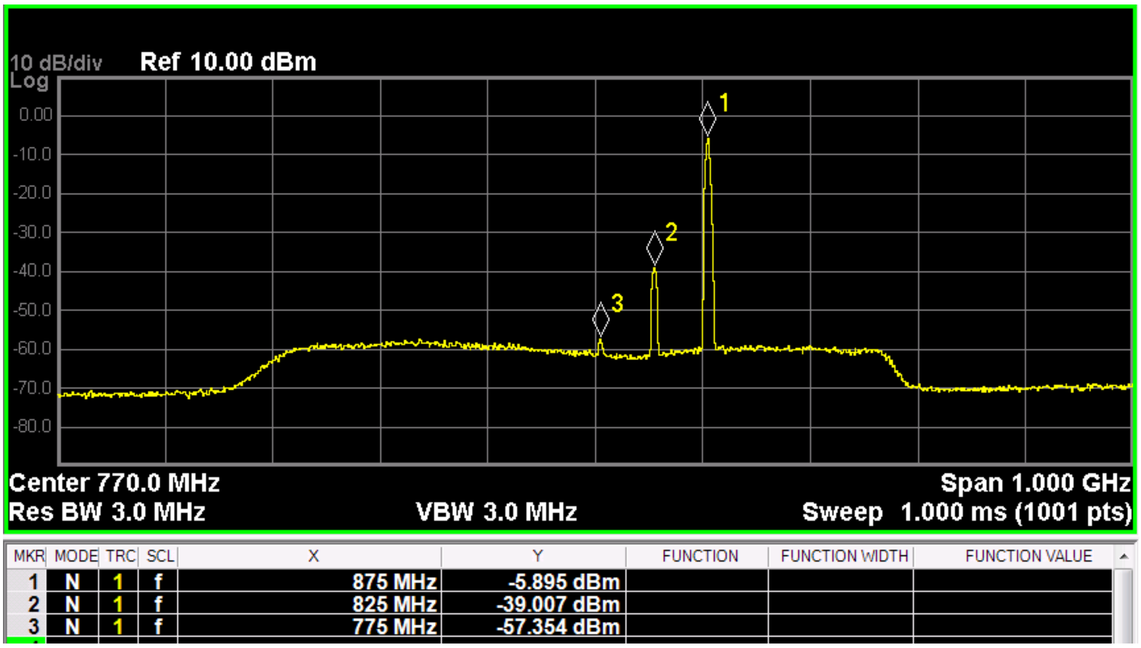


Figure A.7: IF Outputs for 2.57 GHz RF Input

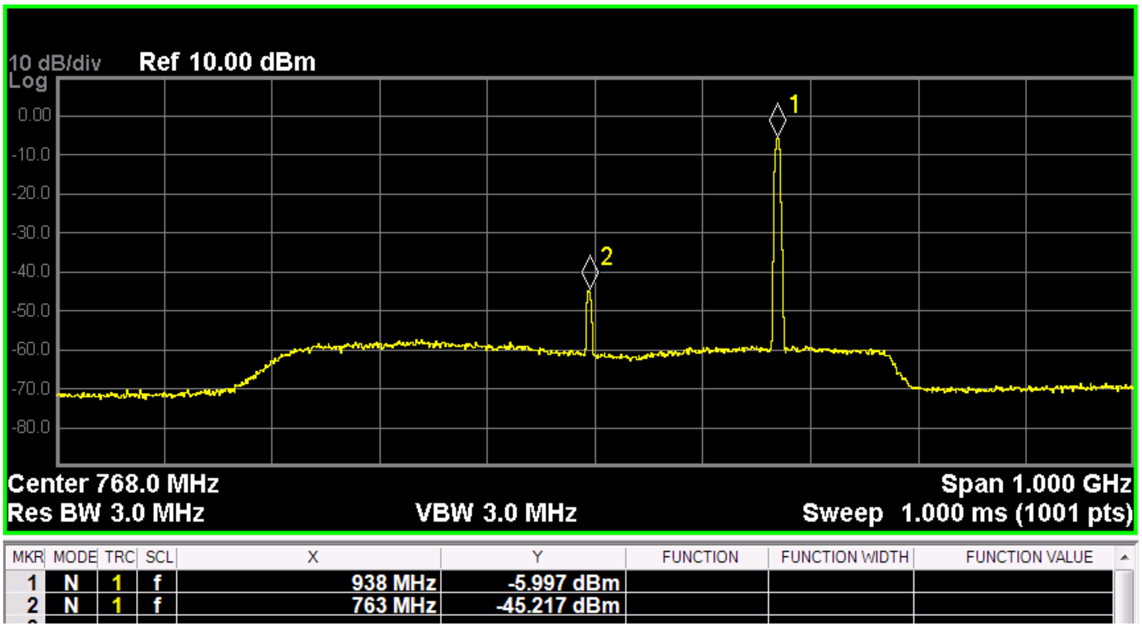
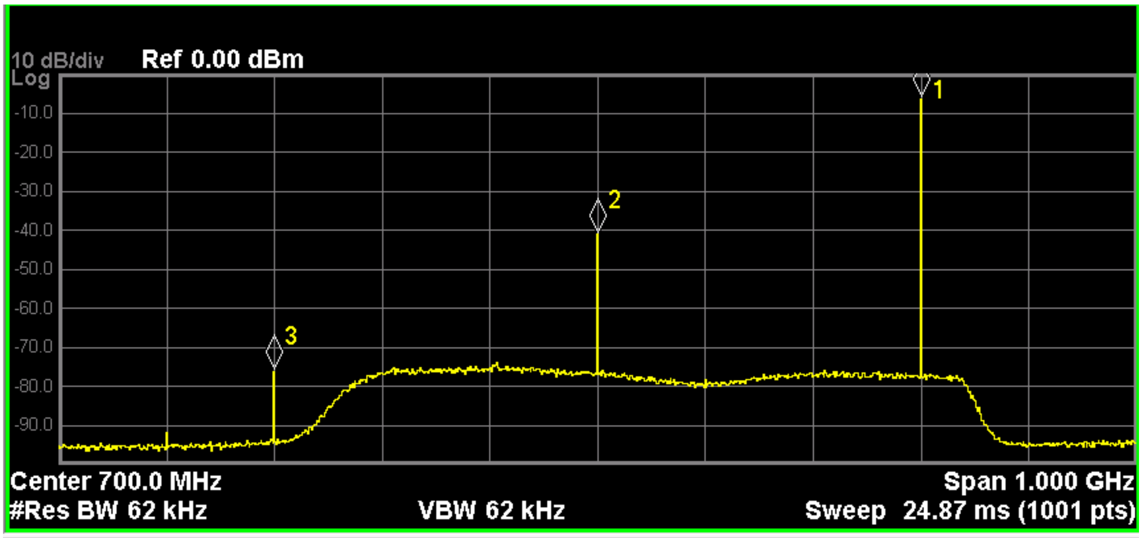


Figure A.8: IF Outputs for 2.63 GHz RF Input



MKR	MODE	TRC	SCL	X	Y	FUNCTION	FUNCTION WIDTH	FUNCTION VALUE
1	N	1	f	1.000 GHz	-6.286 dBm			
2	N	1	f	700 MHz	-41.067 dBm			
3	N	1	f	400 MHz	-76.132 dBm			

Figure A.9: IF Outputs for 2.70 GHz RF Input

B Noise Figure at Different Attenuations

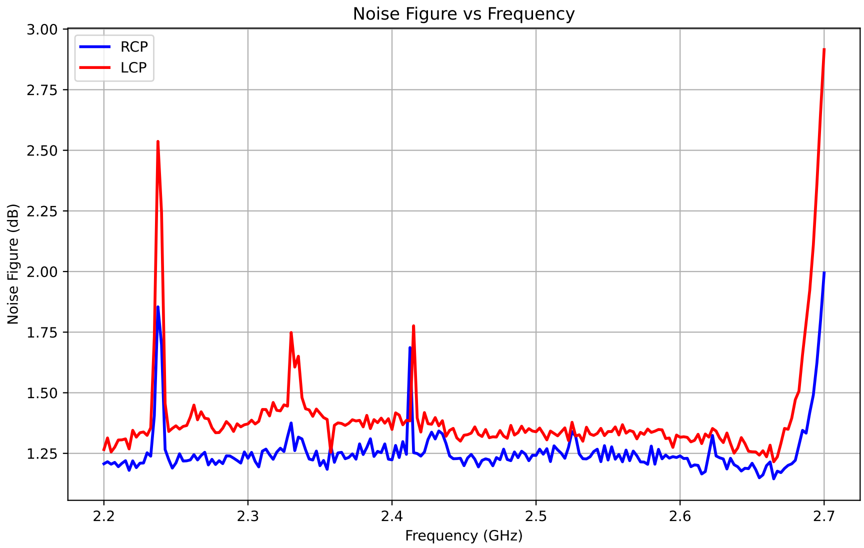


Figure B.1: Noise Figure of the RF Downconverter at 15 dB attenuation

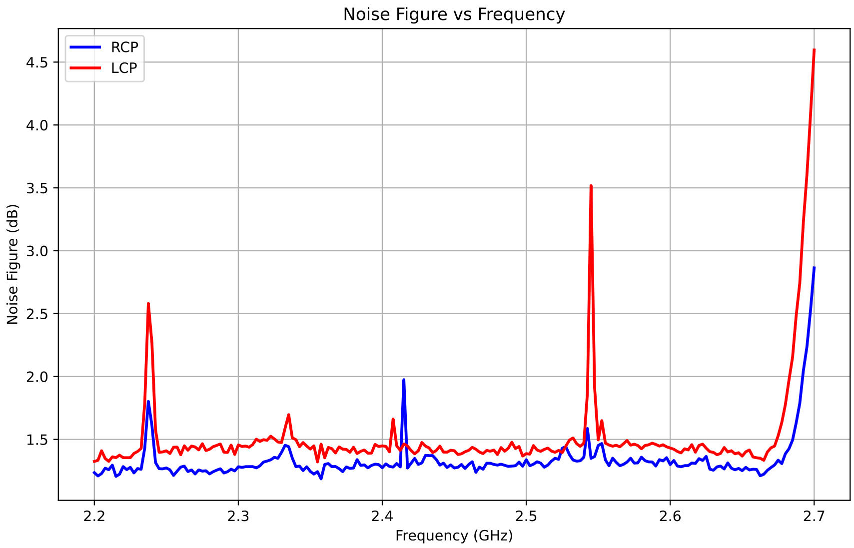


Figure B.2: Noise Figure of the RF Downconverter at 31 dB attenuation