Characterization of the YNART Baseband Conversion Modules

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1 Introduction

This report aims to analyze several parameters of six YNART baseband downconverter modules in order to verify their compliance with the specifications required for their intended function. Those parameters are:

- S parameters
- P_i1dB
- Noise Figure
- Intermodulation Products

The modules comprise an initial preamplification stage, whose block diagram is depicted in Figure 1.1.

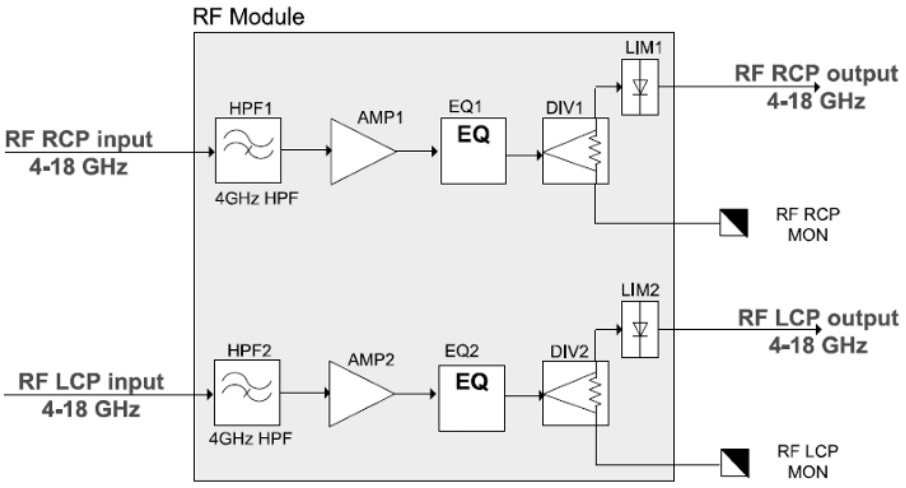


Figure 1.1: Preamplifier Stage Block Diagram

All YNART modules share the same block diagram. The only variation lies in the constituent components, which are adapted to the specific frequency band of each module. This block diagram is illustrated in Figure 1.2.

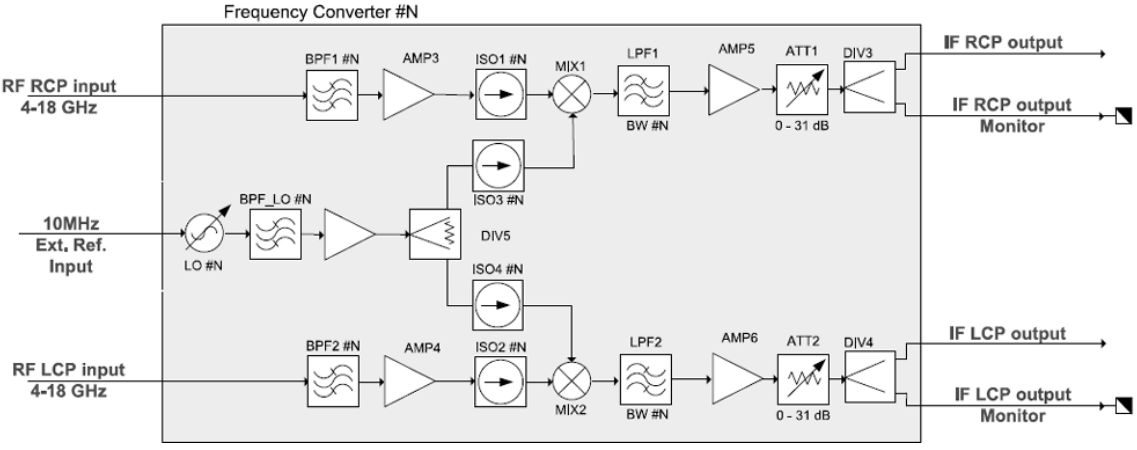


Figure 1.2: Generic Block Diagram of a YNART Baseband Downconverter Module

Table 1.1 outlines the operational requirements for the modules to ensure proper functionality.

Table 1.1: Specific Requirements of the Downconverters

Parameter	**Value**	**Comment**
$\|S_{11}\|$	$\leq -12\ dB$	RF input range
$\|S_{22}\|$	$\leq -12\ dB$	IF output range
$\|S_{21}\|$	23 dB	Nominal
Gain Ripple	$\pm\ 2\ dB$	Maximum
P_i1dB	$\geq\ -20\ dB$	-
Noise Figure	$\leq\ 5\ dB$	Input
Spurious Level	$\leq\ -50\ dBc$	-
Harmonics Level	$\leq\ -15\ dBc$	-

Table 1.2 provides a summary of the most relevant frequencies associated with the modules.

Table 1.2: General Specifications of the Downconverters

Module	**RF input**	**LO**	**IF output**
BBC1	4.6–8.5 GHz	4.5 GHz	0.1–4 GHz
BBC2	8.6–12.5 GHz	8.5 GHz	
BBC3	12.6–16.5 GHz	12.5 GHz	
BBC4	14.1–18 GHz	14 GHz	
BBC5	6.2–7.1 GHz	6.1 GHz	0.1–1 GHz
BBC6	11.8–12.7 GHz	11.7 GHz	

2 Module views and measurement instruments

Figures of the downconverter modules from different perspectives are provided in Appendix A.

Measurements were carried out during July and 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.

3 *S* - parameters and gain

To measure the S-parameters and determine the downconverters' gain, a network analyzer configured in mixer mode was employed. A 10 MHz signal was used to provide the PLO with the external

reference in order to generate the LO at the frequency 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 -30 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 electronic and power calibrators, to then perform the measurements of the S-parameters and the downconverters' gain.

Appendix B presents the S-parameters for the various modules. As can be observed, the input reflection coefficient (S_{11}) remains below -14 dB, and the output reflection coefficient (S_{22}) remains below -17 dB. Regarding transmission, the forward gain (S_{21}) is approximately 23 dB, while the reverse isolation (S_{12}) remains below -50 dB, demonstrating excellent isolation in the undesired direction.

3.1 Attenuation linearity

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 3.1 shows the gain of the BBC1 module for different variable attenuator settings, illustrating its linearity. The remaining results are provided in Appendix C.

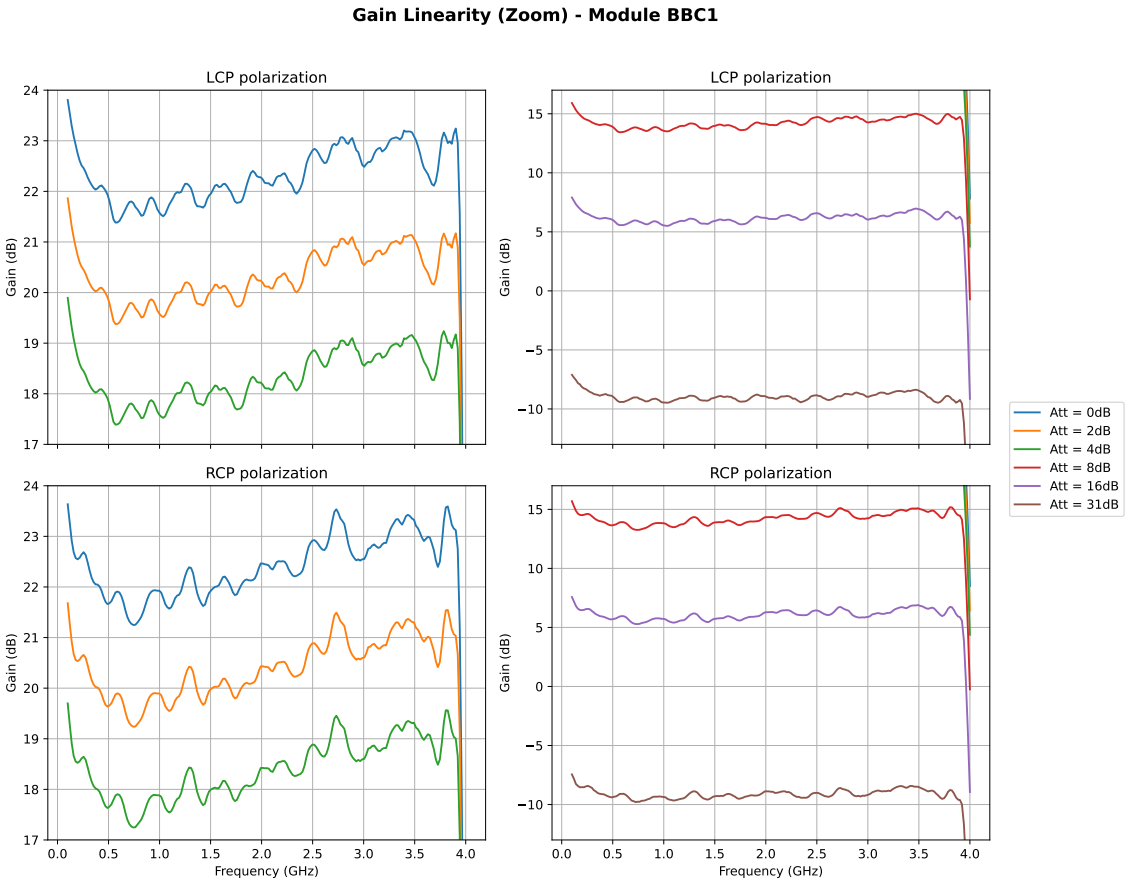


Figure 3.1: Linearity of the BBC1 Variable Attenuator with Zoom

Figure 3.1 and Appendix C show that the variable attenuators of the downconverters maintain a high linearity throughout the entire IF bandwidth for both polarizations, confirming their proper

functionality.

3.2 Comparison between modules

Figure 3.2 illustrates the gain performance of the various RF downconverter modules.

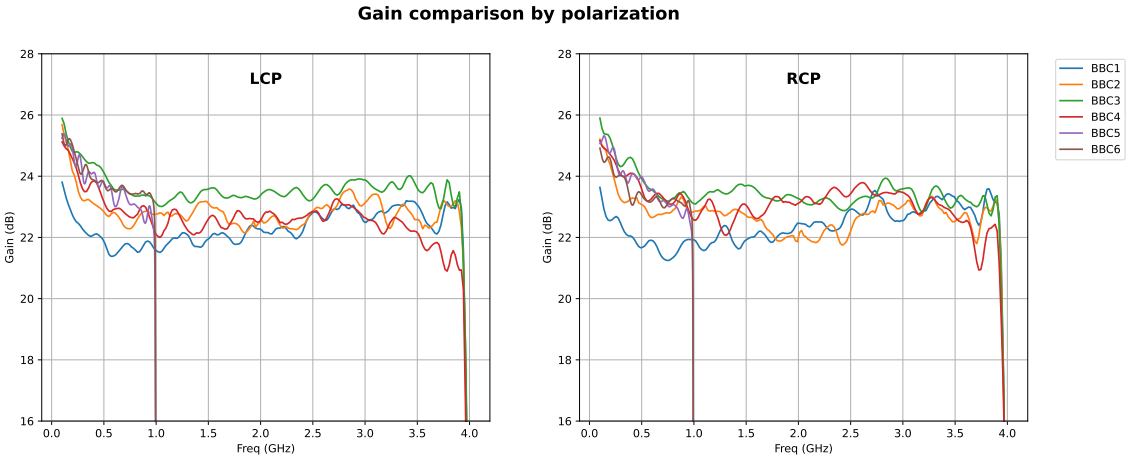


Figure 3.2: Gain Comparison Between Modules

4 P1dB

The measurement of the 1 dB input compression point (P_i1dB) was performed using the KEYSIGHT PXA Signal Analyzer N9030A (3 Hz- 50 GHz), setting the frequency values for the start, end, and another seven intermediate values of the band. Table D.1 and Appendix D summarize the 1dB input compression point for each of the measured frequencies and polarizations for each downconverter module.

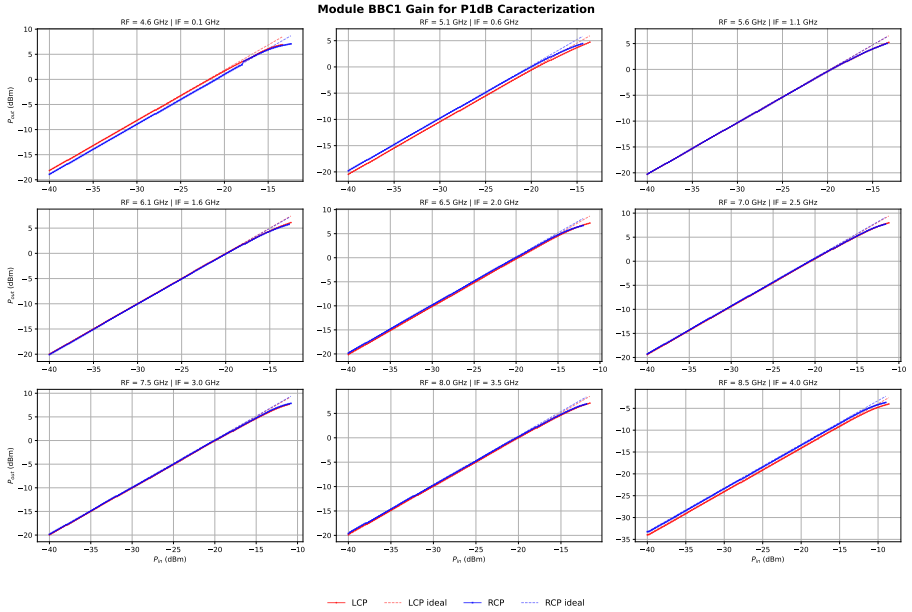


Figure 4.1: Actual and Ideal Gain Curves by Frequency for BBC1 module

Table D.1 presents the P_i1dB values of the BBC1 module for different frequencies and polarizations, where a minimum value of -15.2 dBm is observed. As this is the limiting value, it will be adopted as the module's reference P1dB. For the remaining modules, although only three frequencies are displayed, the same analysis performed for the BBC1 module has been conducted.

Although the 1dB compression point (P1dB) values for the various modules are presented in Appendix D, a practical operating point 10 dB below these values has been adopted. This ensures operation within the amplifiers' linear region, minimizing undesired effects such as distortion, harmonic generation, and intermodulation products. The final operating point for each module is summarized in Table 4.1.

Table 4.1: Maximum Required Input Power by Module

Module	Input Power (dBm)
BBC1	-25.2
BBC2	-21.8
BBC3	-22.6
BBC4	-22.8
BBC5	-27.8
BBC6	-24.2

5 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 10 MHz and 0 dBm tone as an external reference for the local oscillators (LO). The spectrum analyzer measured the noise figure in the entire band. The RF input of the downconverter 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 the IF frequencies, via a low loss K cable.

Figure 5.1 shows the noise figure of the BBC1 module for two different attenuation settings.

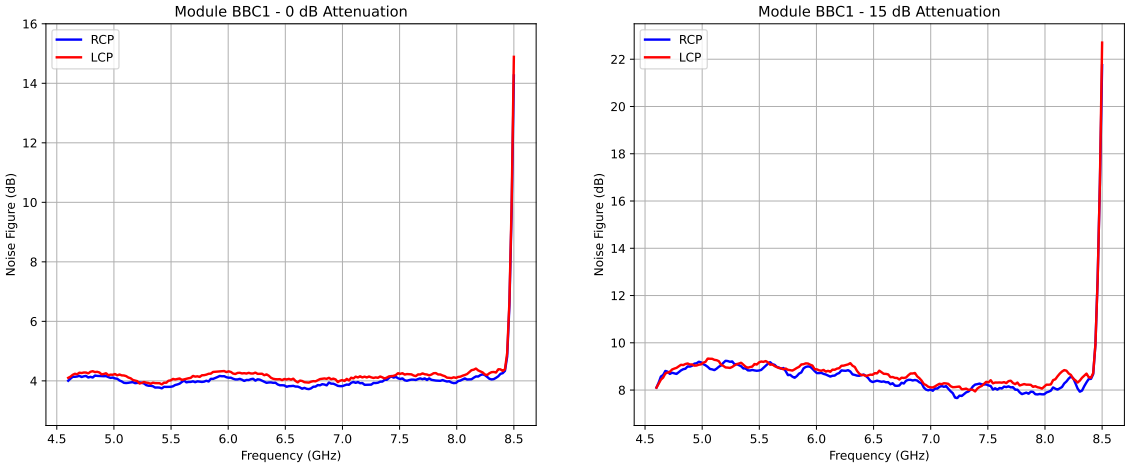
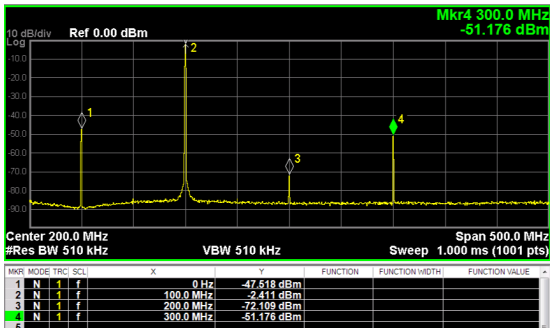


Figure 5.1: Noise Figure of the BBC1 Module at 0 dB and 15 dB Attenuation

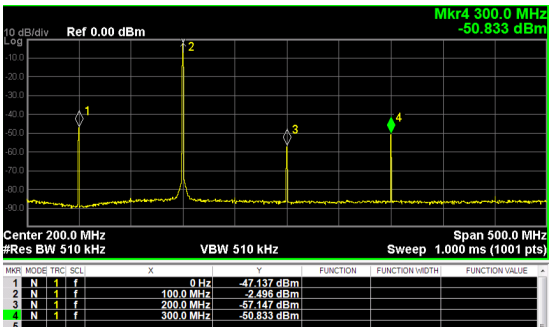
The noise figure for the various modules, under these two attenuation settings, can be found in Appendix E.

6 Harmonics and Spurious Emissions

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 every downconverter, the most critical spurious components and harmonics are those that fall within the IF band.



(a) LCP



(b) RCP

Figure 6.1: BBC1 - Intermodulation Products for LCP and RCP Polarization

The following tables display the various intermodulation products observed in each module across different frequencies. It is important to note that only those corresponding to the polarization containing the most limiting P1dB are shown, though the alternate polarization was also measured in the laboratory.

Table 6.1: BBC1 Harmonics and Spurious Emissions for RCP Polarization at -25.5 dBm Input Power

RFin (GHz)	IF (GHz)	LHC [1](dBm)	RL [2] (dBc)	MLC [3] (dBm)	CHC [4]
4.600	0.100	-50.833	48.337	-52.931	$3f_{RF} - 3f_{LO}$
5.087	0.587	-40.304	32.618	-43.580	$3f_{RF} - 2f_{LO}$
5.575	1.075	-43.167	38.390	-48.803	$3f_{LO} - 2f_{RF}$
6.062	1.562	-35.442	27.875	-39.793	$2f_{RF} - 2f_{LO}$
6.550	2.050	-39.539	35.356	-44.487	$2f_{LO} - f_{RF}$
7.037	2.537	-43.914	39.390	-48.252	$2f_{LO} - f_{RF}$
7.525	3.025	-37.725	32.944	-40.695	$2f_{LO} - f_{RF}$
8.012	3.512	-44.371	30.950	-48.611	$2f_{LO} - f_{RF}$
8.500	4.000	-31.992	13.908	-37.982	$2f_{LO} - f_{RF}$

Table 6.2: BBC2 Harmonics and Spurious Emissions for LCP Polarization at -22 dBm Input Power

RFin (GHz)	IF (GHz)	LHC (dBm)	RL (dBc)	MLC (dBm)	CHC
8.600	0.100	-54.640	57.206	-57.203	$2f_{RF} - 2f_{LO}$
10.550	2.050	-	-	-	-
12.500	4.000	-44.462	26.846	-44.462	$3f_{LO} - 2f_{RF}$

[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

Table 6.3: BBC3 Harmonics and Spurious Emissions for RCP Polarization at -22.5 dBm Input Power

RFin (GHz)	**IF (GHz)**	**LHC (dBm)**	**RL (dBc)**	**MLC (dBm)**	**CHC**
12.600	0.100	-49.238	50.824	-51.607	$2f_{RF} - 2f_{LO}$
14.550	2.050	-	-	-	-
16.500	4.000	-	-	-	-

Table 6.4: BBC4 Harmonics and Spurious Emissions for LCP Polarization at -23 dBm Input Power

RFin (GHz)	**IF (GHz)**	**LHC (dBm)**	**RL (dBc)**	**MLC (dBm)**	**CHC**
14.100	0.100	-56.994	57.069	-60.216	$2f_{RF} - 2f_{LO}$
16.050	2.050	-	-	-	-
18.000	4.000	-	-	-	-

Table 6.5: BBC5 Harmonics and Spurious Emissions for RCP Polarization at -28 dBm Input Power

RFin (GHz)	**IF (GHz)**	**LHC (dBm)**	**RL (dBc)**	**MLC (dBm)**	**CHC**
6.200	0.100	-61.374	55.027	-63.763	$2f_{RF} - f_{LO}$
6.650	0.550	-	-	-	-
7.100	1.000	-	-	-	-

Table 6.6: BBC6 Harmonics and Spurious Emissions for RCP Polarization at -25 dBm Input Power

RFin (GHz)	**IF (GHz)**	**LHC (dBm)**	**RL (dBc)**	**MLC (dBm)**	**CHC**
11.800	0.100	-59.919	58.060	-60.229	$3f_{RF} - 3f_{LO}$
12.250	2.050	-	-	-	-
12.700	4.000	-	-	-	-

Beginning with module BBC3, the absence of unwanted emissions is observed. This is attributed to the fact that, for the given input RF and local oscillator frequencies, the most critical mixing product ($2f_{LO} - f_{RF}$) falls outside the passband of the IF filter.

7 Conclusions

This section evaluates whether the parameters assessed for the modules comply with the requirements specified in Table 1.1.

As shown in Appendix B, the input reflection coefficient ($|S_{11}|$) remains below -14 dB, while the output reflection coefficient ($|S_{22}|$) remains below -17 dB. The forward gain ($|S_{21}|$) is approximately 23 dB, with a ripple of roughly $\pm$ 2 dB, except at the lower end of the IF band where the gain is higher, as illustrated in Figure 3.2. Overall, these results confirm that the modules comply with the S-parameter requirements.

Regarding the 1 dB input compression point, Table 4.1 specifies that all modules require an input power below -21.8 dBm, accounting for the 10 dB back-off implemented to ensure active components operate within their linear region. Without this back-off, the modules' actual 1 dB input compression point is greater than -20 dBm, specifically, it exceeds -11.8 dBm.

Regarding noise figure, Appendix E shows that with the variable attenuator set to 0 dB, all modules remain below 5 dB, except for module BBC4, which slightly exceeds this value (by 1 dB) at the upper end of the RF band. It can therefore be concluded that all modules meet the noise figure requirements.

Finally, Section 6 demonstrates that all modules comply with the harmonic and spurious emission power limits.

Thus, it has been demonstrated that the YNART downconverter modules meet the basic requirements to perform their intended functions at the Yebes Observatory.

APPENDICES

A Module Views

Figure A.1: Front and Rear view of the RF Downconverters

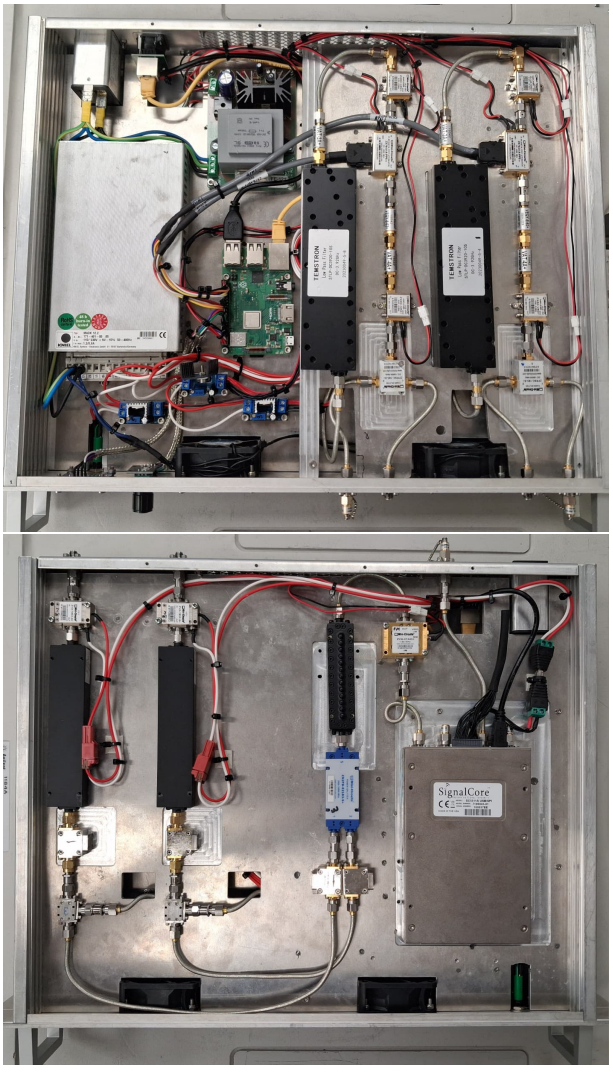


Figure A.2: Inside views of the RF Downconverters

B *S* - Parameters Comparison

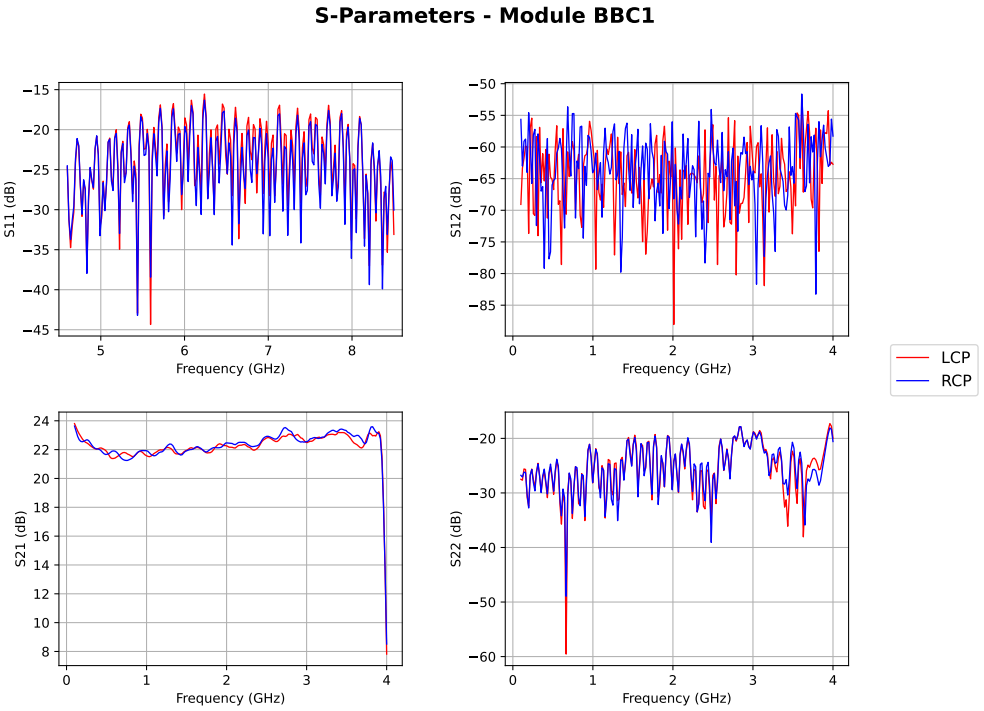


Figure B.1: BBC1 *S* - Parameters

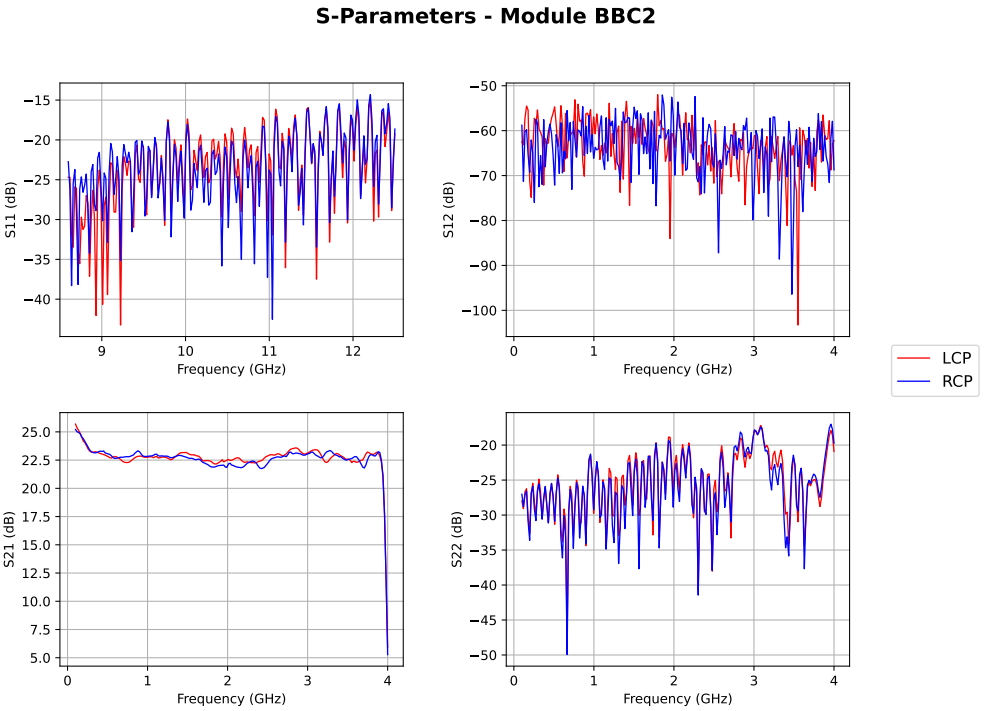


Figure B.2: BBC2 *S* - Parameters

Figure B.3: BBC3 S - Parameters

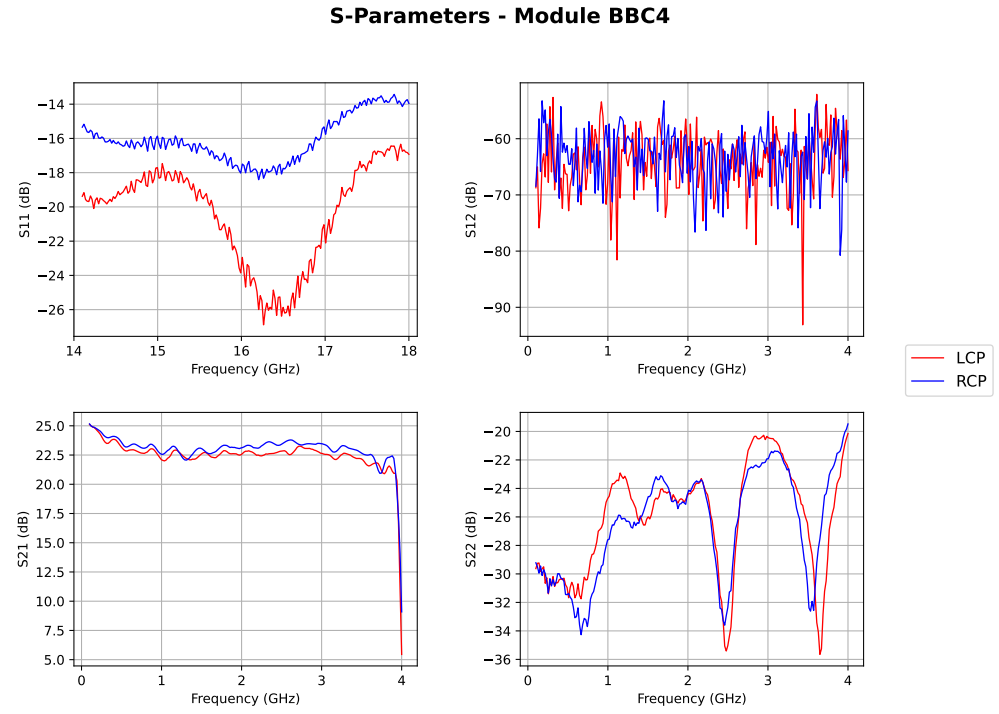


Figure B.4: BBC4 S - Parameters

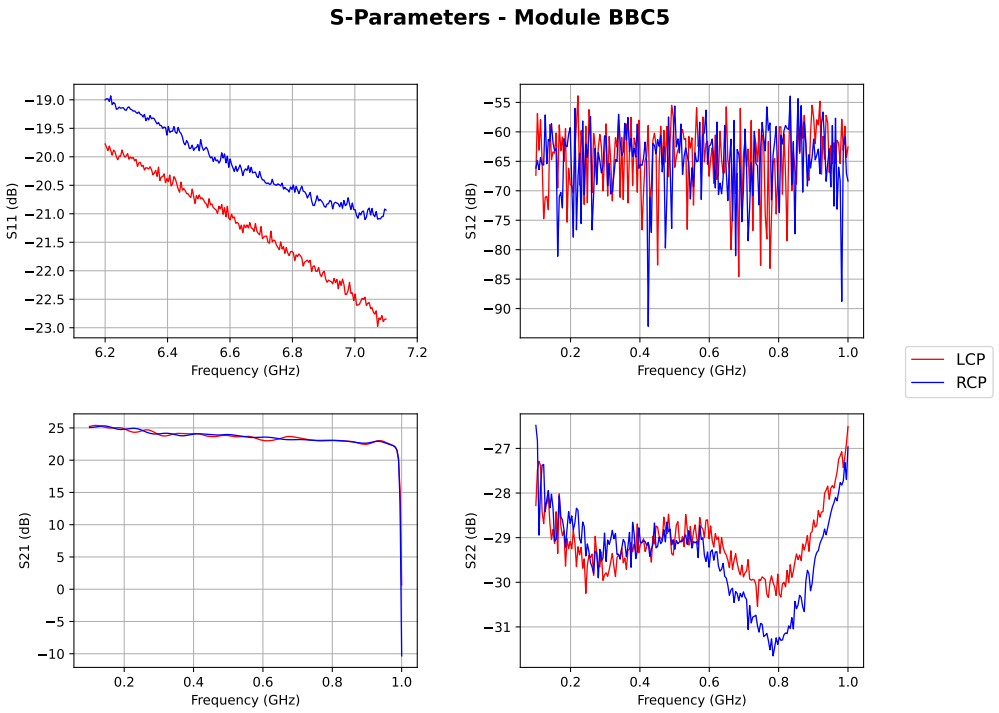


Figure B.5: BBC5 S - Parameters

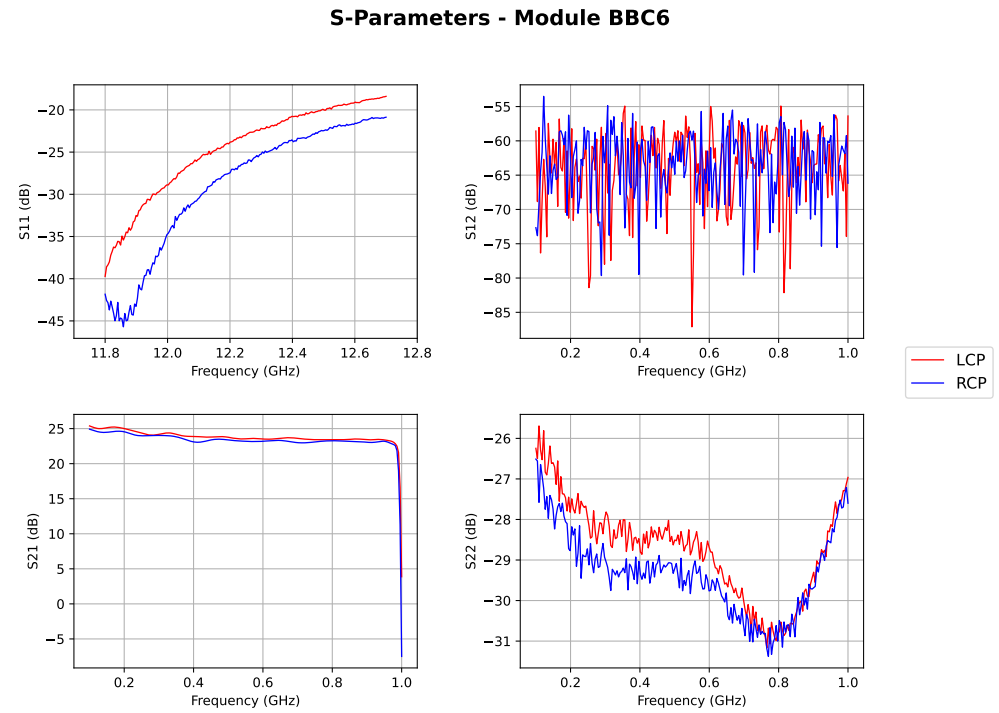


Figure B.6: BBC6 S - Parameters

C Gain Linearity with Different Attenuations

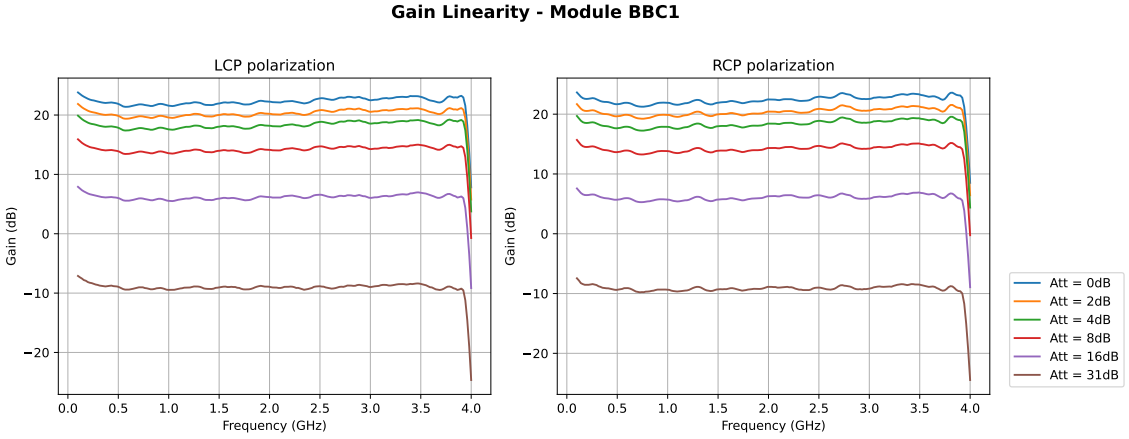


Figure C.1: Linearity of the BBC1 Variable Attenuator

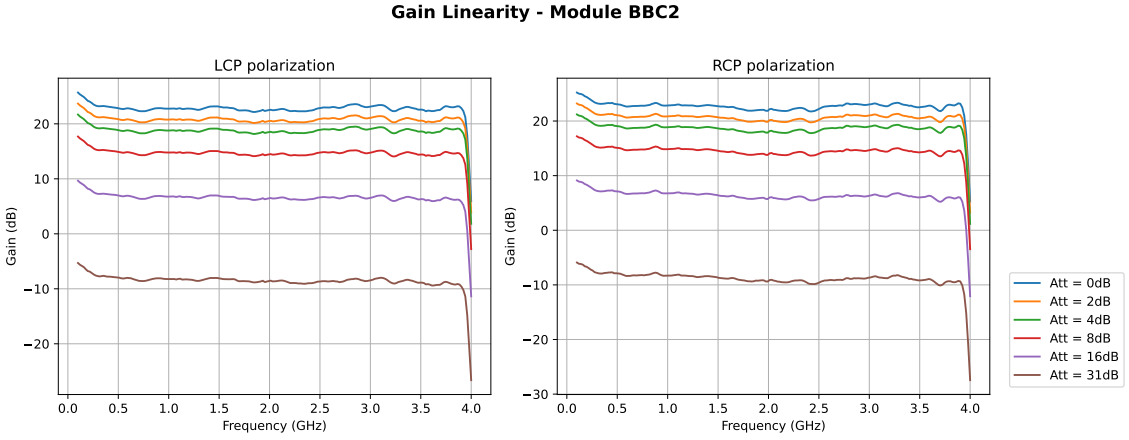


Figure C.2: Linearity of the BBC3 Variable Attenuator

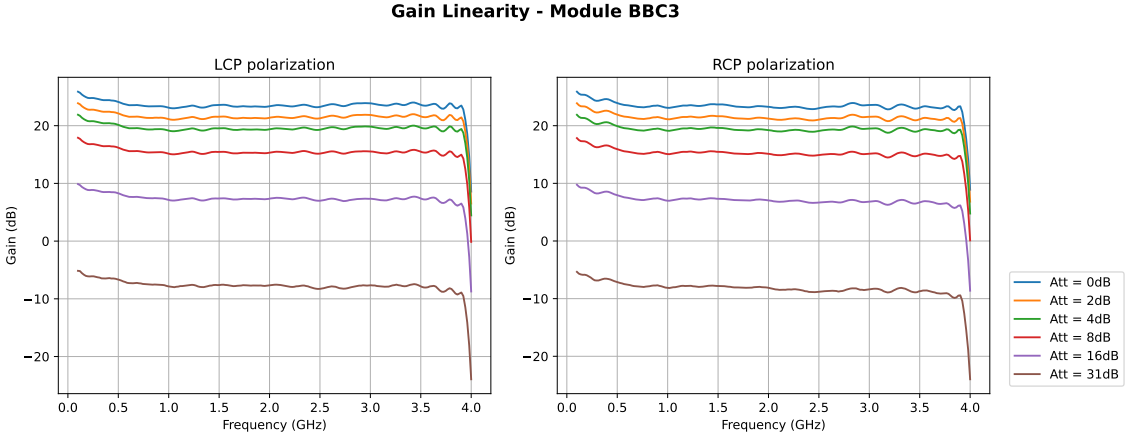


Figure C.3: Linearity of the BBC3 Variable Attenuator

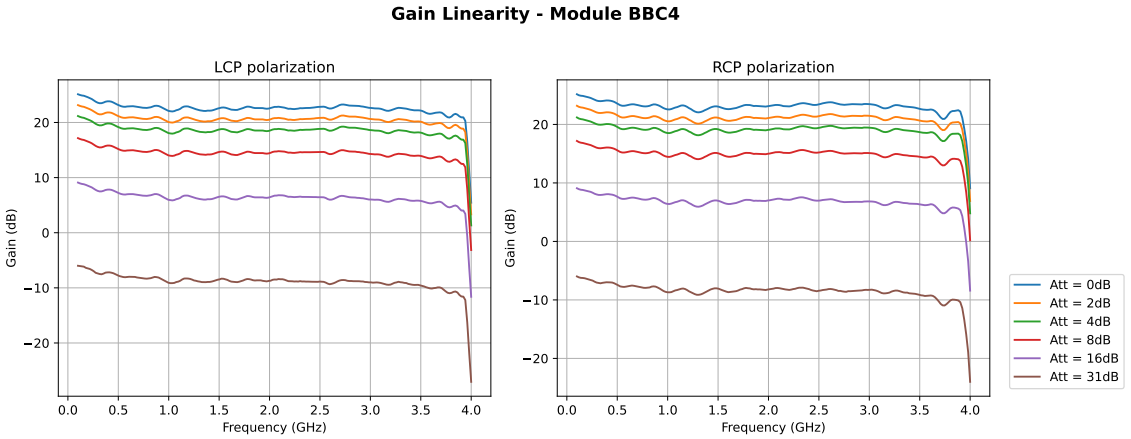


Figure C.4: Linearity of the BBC4 Variable Attenuator

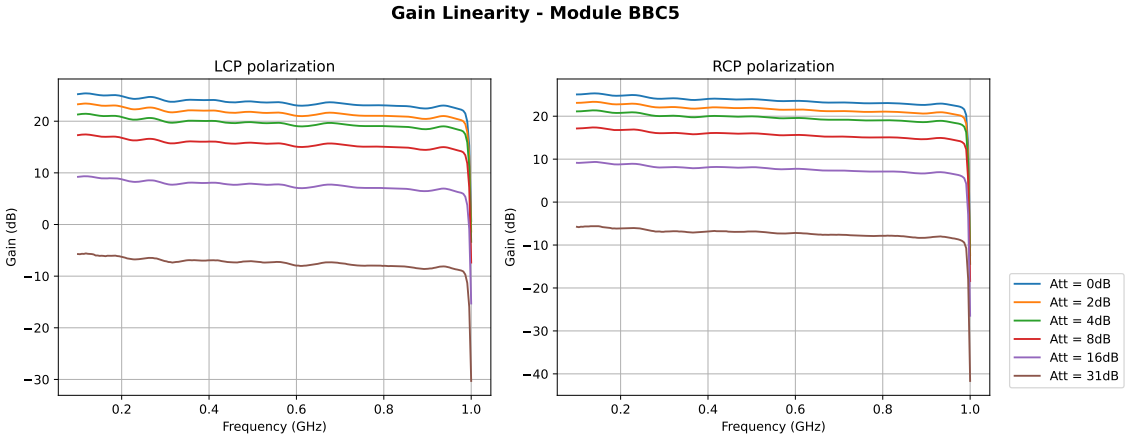


Figure C.5: Linearity of the BBC5 Variable Attenuator

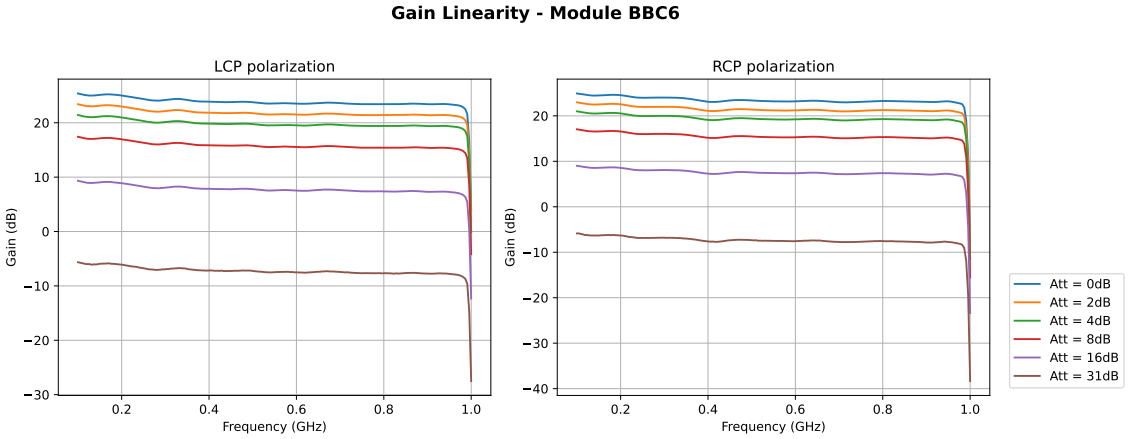


Figure C.6: Linearity of the BBC6 Variable Attenuator

D P1dB Comparison

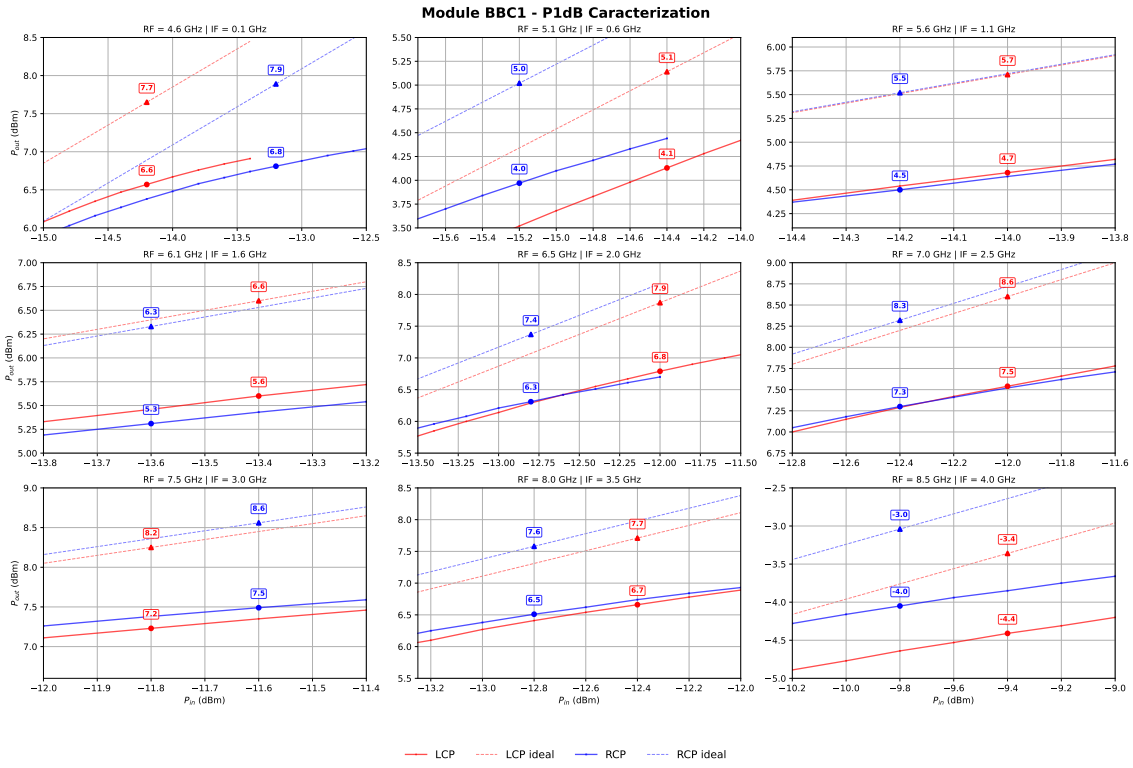


Figure D.1: BBC1 - P1dB

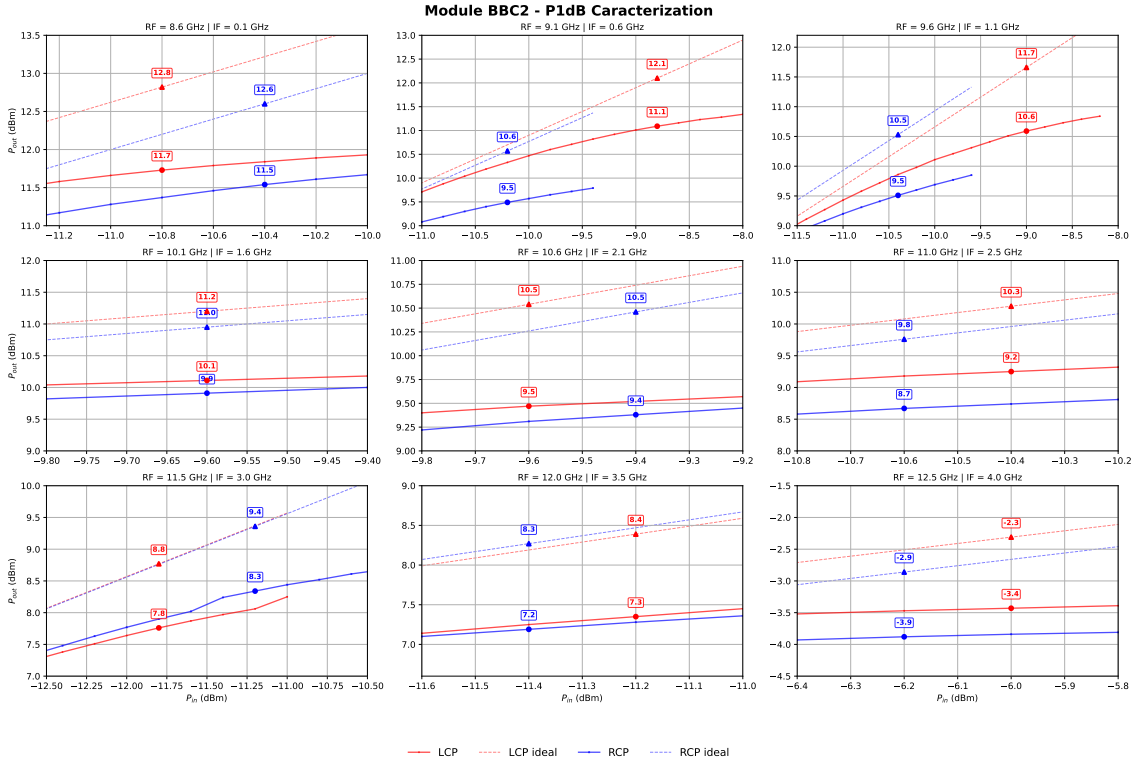


Figure D.2: BBC2 - P1dB

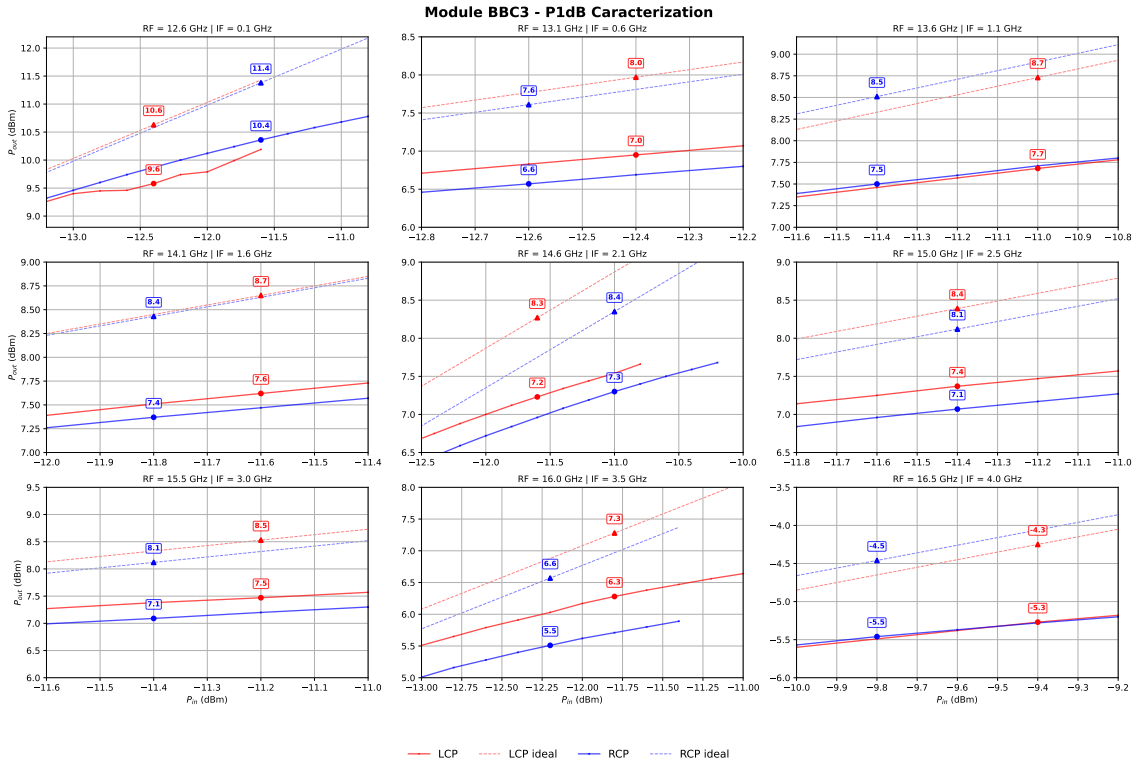


Figure D.3: BBC3 - P1dB

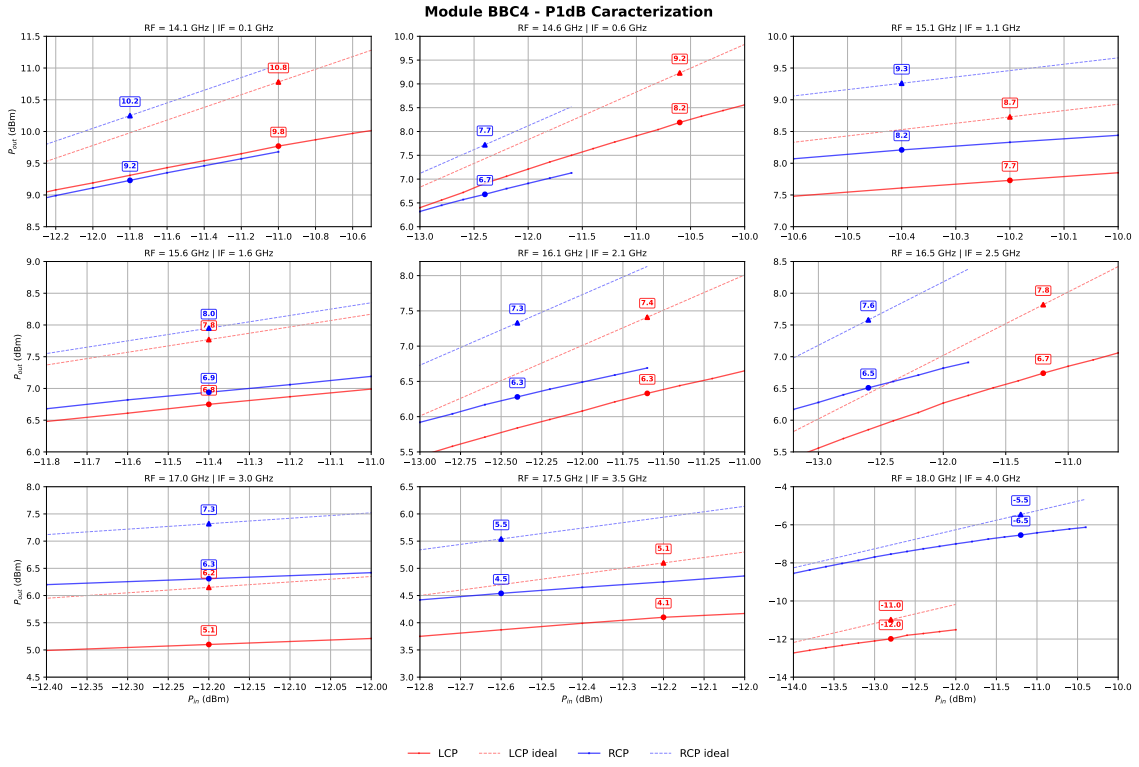


Figure D.4: BBC4 - P1dB

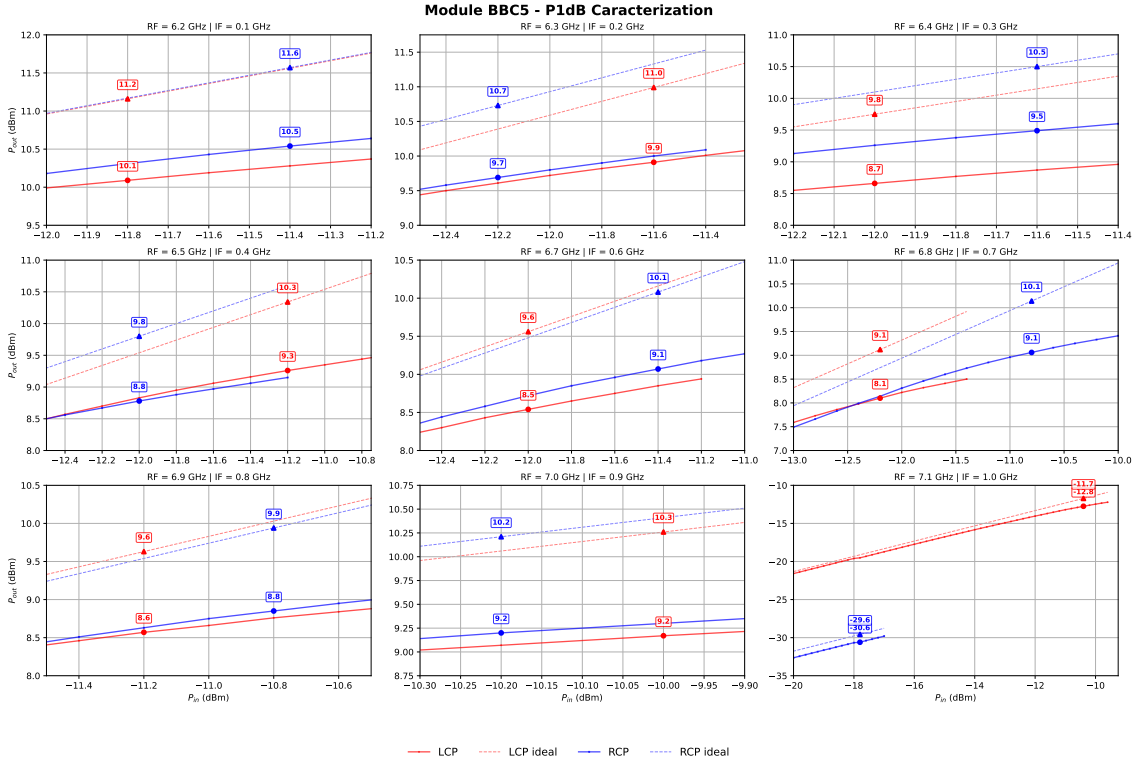


Figure D.5: BBC5 - P1dB

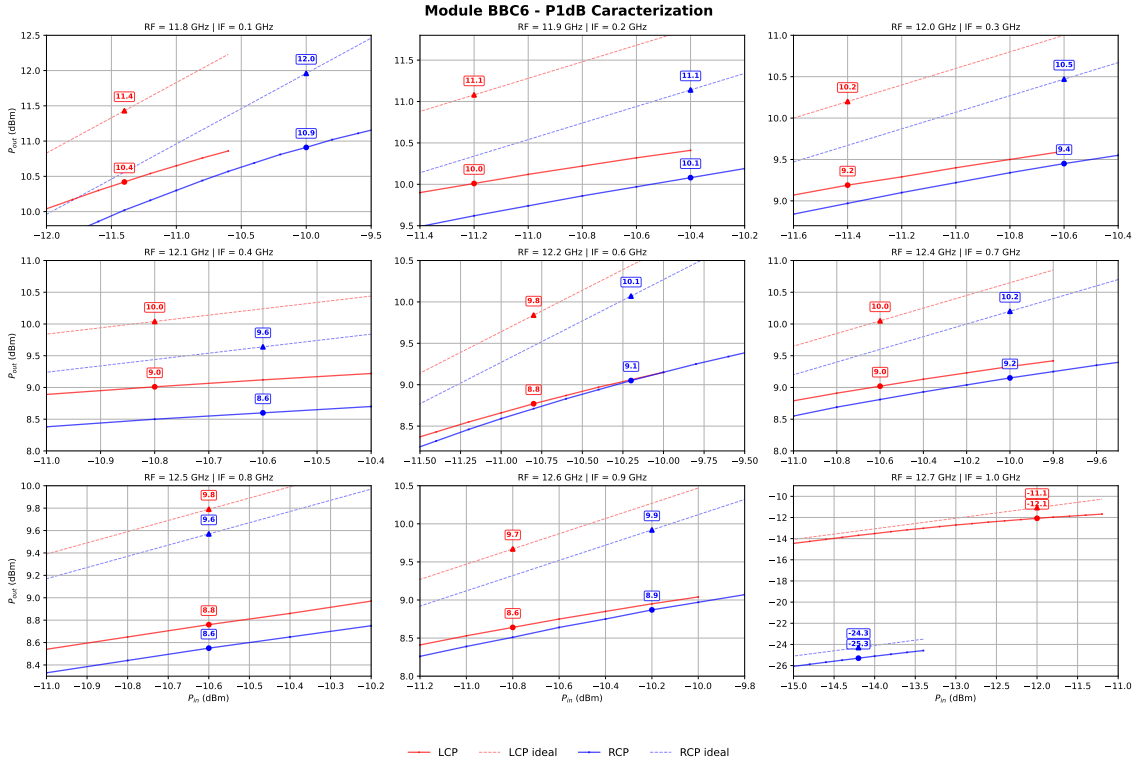


Figure D.6: BBC6 - P1dB

Table D.1: BBC1 P1dB Values by Frequency

Frequency (GHz)	**Polarization**	P_i1dB **(dBm)**
4.6	LCP	-14.2
	RCP	-13.2
5.1	LCP	-14.4
	RCP	**-15.2**
5.6	LCP	-14.0
	RCP	-14.2
6.1	LCP	-13.4
	RCP	-13.6
6.5	LCP	-12.0
	RCP	-12.8
7.0	LCP	-12.0
	RCP	-12.4
7.5	LCP	-11.8
	RCP	-11.6
8.0	LCP	-12.4
	RCP	-12.8
8.5	LCP	-9.4
	RCP	-9.8

Table D.2: BBC2 P1dB Values by Frequency

Frequency (GHz)	**Polarization**	P_i1dB **(dBm)**
8.6	LCP	-10.8
	RCP	-10.4
10.6	LCP	-9.6
	RCP	-9.4
12.5	LCP	-6.0
	RCP	-6.2

Table D.3: BBC3 P1dB Values by Frequency

Frequency (GHz)	**Polarization**	P_i1dB **(dBm)**
12.6	LCP	-12.4
	RCP	-11.6
14.6	LCP	-11.6
	RCP	-11.0
16.5	LCP	-9.4
	RCP	-9.8

Table D.4: BBC4 P1dB Values by Frequency

Frequency (GHz)	**Polarization**	P_i1dB **(dBm)**
14.1	LCP	-11.0
	RCP	-11.8
16.1	LCP	-11.6
	RCP	-12.4
18.0	LCP	-12.8
	RCP	-12.2

Table D.5: BBC5 P1dB Values by Frequency

Frequency (GHz)	**Polarization**	P_i1dB **(dBm)**
6.2	LCP	-11.8
	RCP	-11.4
6.7	LCP	-12.0
	RCP	-11.4
7.1	LCP	-10.4
	RCP	-17.8

Table D.6: BBC6 P1dB Values by Frequency

Frequency (GHz)	**Polarization**	P_i1dB **(dBm)**
11.8	LCP	-11.4
	RCP	-10.0
12.2	LCP	-10.8
	RCP	-10.2
12.7	LCP	-12.0
	RCP	-14.2

E Noise Figure Comparison

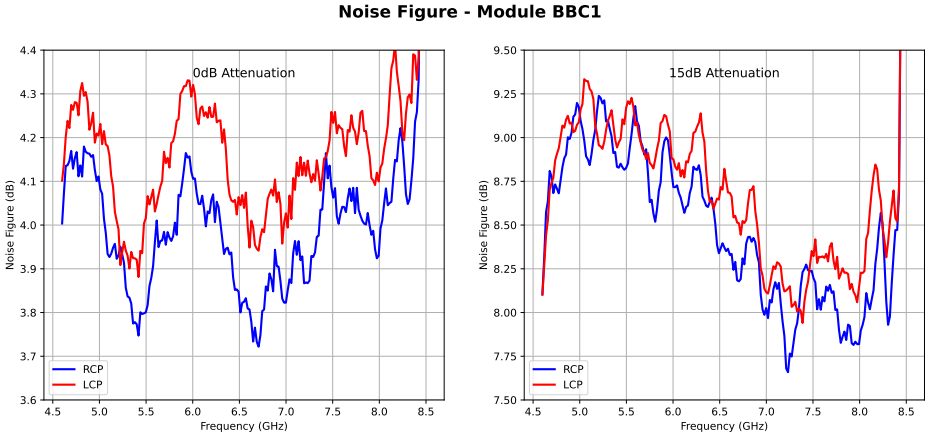


Figure E.1: Noise Figure of the BBC1 at Two Different Attenuations

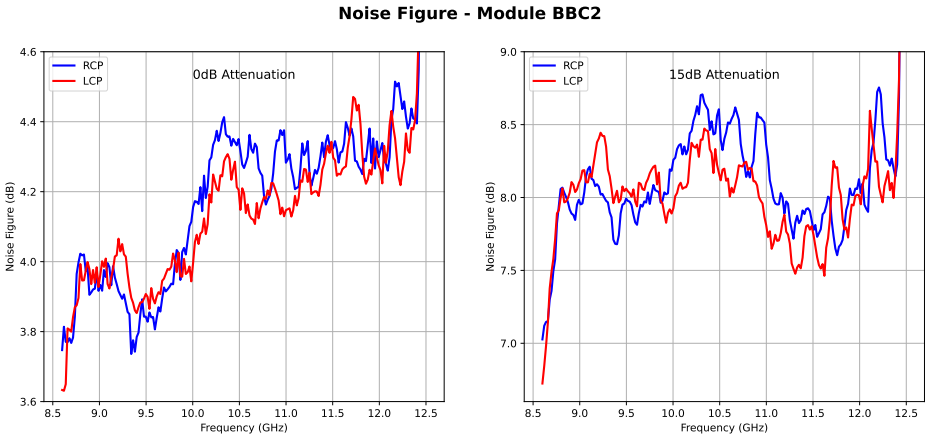


Figure E.2: Noise Figure of the BBC2 at Two Different Attenuations

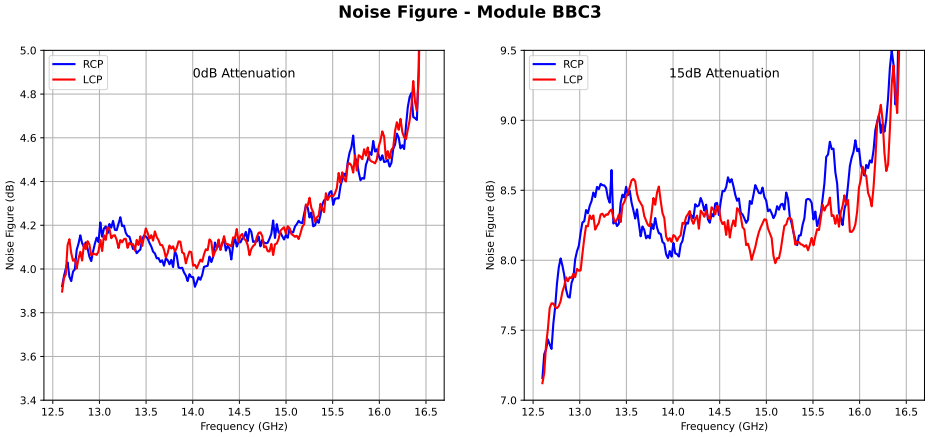


Figure E.3: Noise Figure of the BBC3 at Two Different Attenuations

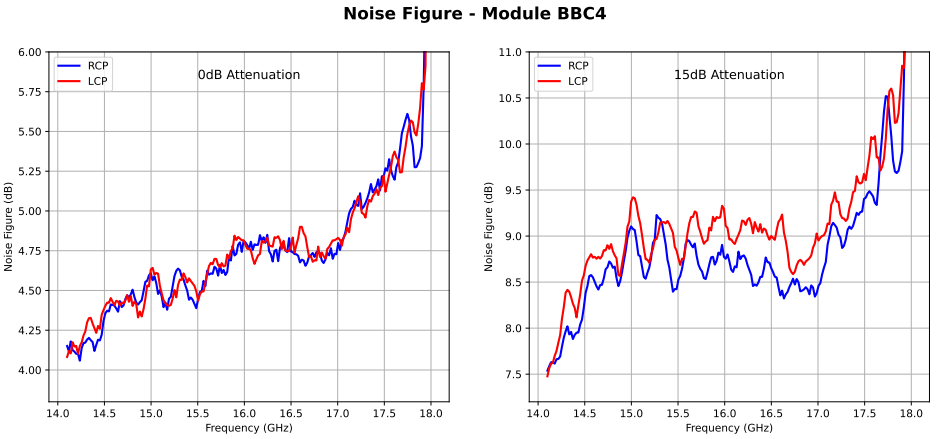


Figure E.4: Noise Figure of the BBC4 at Two Different Attenuations

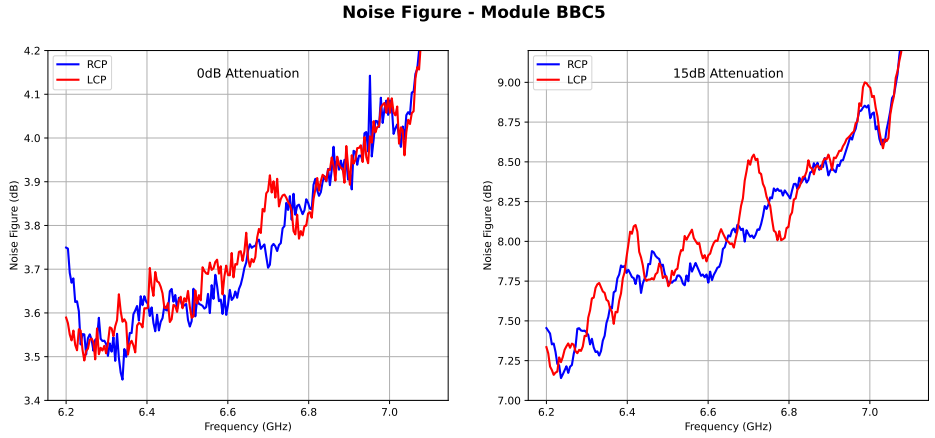


Figure E.5: Noise Figure of the BBC5 at Two Different Attenuations

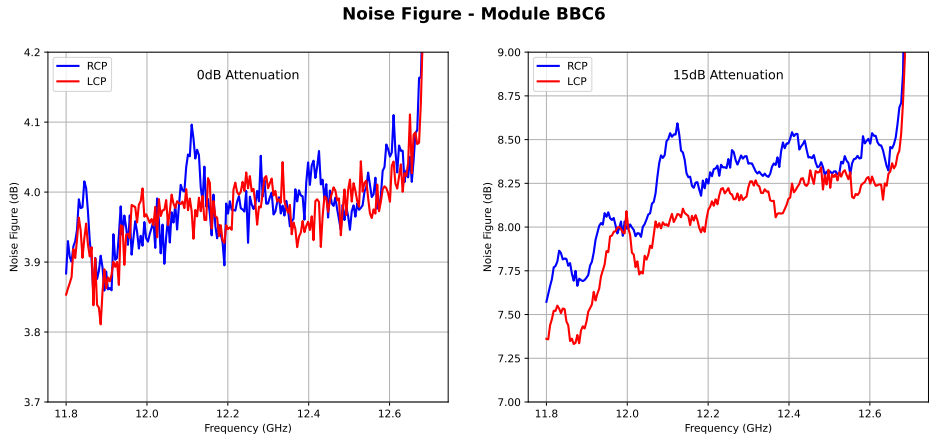


Figure E.6: Noise Figure of the BBC6 at Two Different Attenuations