EVLA Memo 111

2 – 4 GHz End-to-End Signal Path Tests

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July 19, 2007

1 Abstract

The complete EVLA 2 – 4 GHz (2.048 – 4.096 GHz) signal path has been tested in the laboratory. The test was designed to exercise the system consisting of the Gain Slope Equalizer, the 2.048 – 4.096 GHz anti-aliasing filter, and the prototype 3-bit digitizer. Tests included signal continuity, passband gain slope correction, and the effect of the Gain Slope Equalizer on system noise figure (Y-factor).

2 Introduction

The Gain Slope Equalizer ("equalizer") is intended to correct for excessive variation in output power spectral density, for which the EVLA specification in the 2 – 4GHz path is given as +/- 1.5dBm (EVLA Project Book, Chapter 6). Provided that passband ripple is within specification, the Gain Slope Equalizer allows removal of any amplitude variation in the passband. The details of the equalizer are discussed fully in EVLA Memo 80, "A Gain Slope Correction Scheme for the EVLA Receiver System" (R. Hayward, M. Morgan and K. Saini). The science requirements that motivate the need for and equalizer are detailed in EVLA Memo 83, "Quantization Loss for a Sloped Passband" (Brent Carlson, Rick Perley)

Although the Gain Slope Equalizer, 2-4GHz anti-aliasing filter, and 3-bit digitizer had each been tested in isolation and found to meet specification, the full 2-4 GHz signal path has now been tested as a system. A warm K-Band receiver provided an 18 – 26 GHz "sky" signal to the LO/IF system. Several 2 GHz-wide sub-bands of this were downconverted and presented to the 3-bit digitizer, ostensibly to test the performance of the Gain Slope Equalizer. This experiment was designed to test for (a) slope correction, and (b) contribution of the Gain Slope Equalizer to system noise figure.

3 Slope Correction

Figure 1 shows the output spectrum of the warm K-Band receiver, SN 6. Two regions of this spectrum, 20 – 22 GHz and 22 – 24GHz, show significant (greater than 5dB over the 2 GHz bandwidth) inherent slope, and were ideal candidate bands for slope correction.

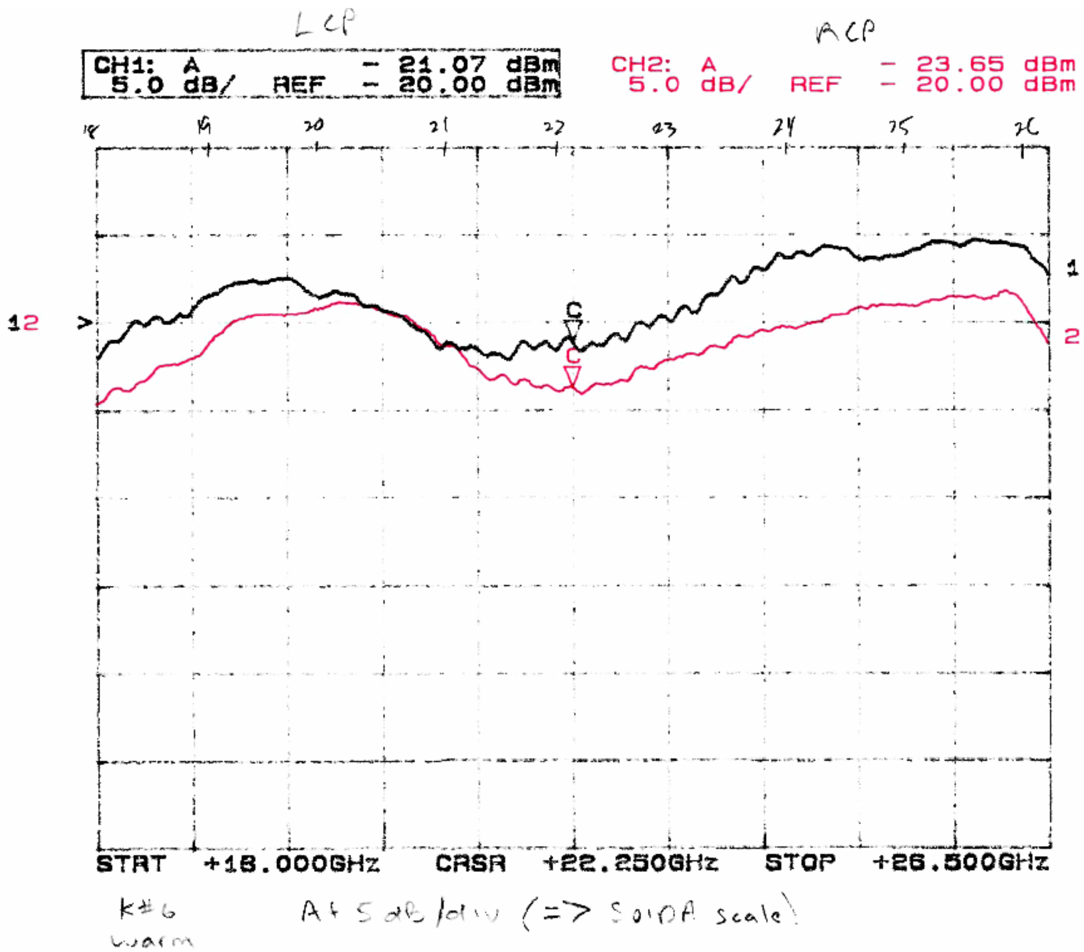

Figure 1: Normalized receiver output spectrum. Vertical scale is 5dB per division.
Courtesy Robert Hayward

The UX Converter will pass signal in the range of 7.5 - 12.5 GHz to the input of the T304 Baseband Converter. Since the direct path of the UX Converter is being used, the first LO frequency conversion occurs in the receiver itself. Table 1 shows first and second LO settings for particular 2 GHz regions of receiver spectrum.

2 GHz band (GHz)	Fc (MHz)	IF1 (MHz)	L301		L302	
			Lo Ref (MHz)	LO1 (MHz)	LO2 (MHz)	IF2 (MHz)
18-20	19000	9928	14464	28928	12928	3000
19-21	20000	9952	14976	29952	12952	3000
20-22	21000	9976	15488	30976	12976	3000
21-23	22000	10000	16000	32000	13000	3000
22-24	23000	10024	16512	33024	13024	3000
23-25	24000	10048	17024	34048	13048	3000
24-26	25000	10072	17536	35072	13072	3000

Table 1: Frequency map that simplifies the selection of L301 (LO Ref) and L302 (LO2) synthesizer frequency settings to obtain a given 2GHz region of the receiver output spectrum.

This first LO, which is supplied by the L301 synthesizer, centers the appropriate spectral region on the UX Converter output/T304 input band. The second LO, supplied by the L302 synthesizer, centers a 2.048 GHz region of this input spectrum on the 2.0480–4.096 GHz output of the T304. It is here that the slope is to be corrected.

The first and second LO frequencies were chosen such that a residual slope was clearly discernible in the T304 output spectrum, thereby visibly exaggerating the effect of the slope correction. LO1 was set to 15488 MHz, so that the receiver output from 18.5 GHz to 23.5 GHz appeared at the input to the T304. LO2 was set at 12976 MHz, so that the band center, 9976 MHz, was mapped to the output band center of 3000 MHz. Figure 2 shows the T304 output at two equalizer settings: no correction and maximally flat passband.

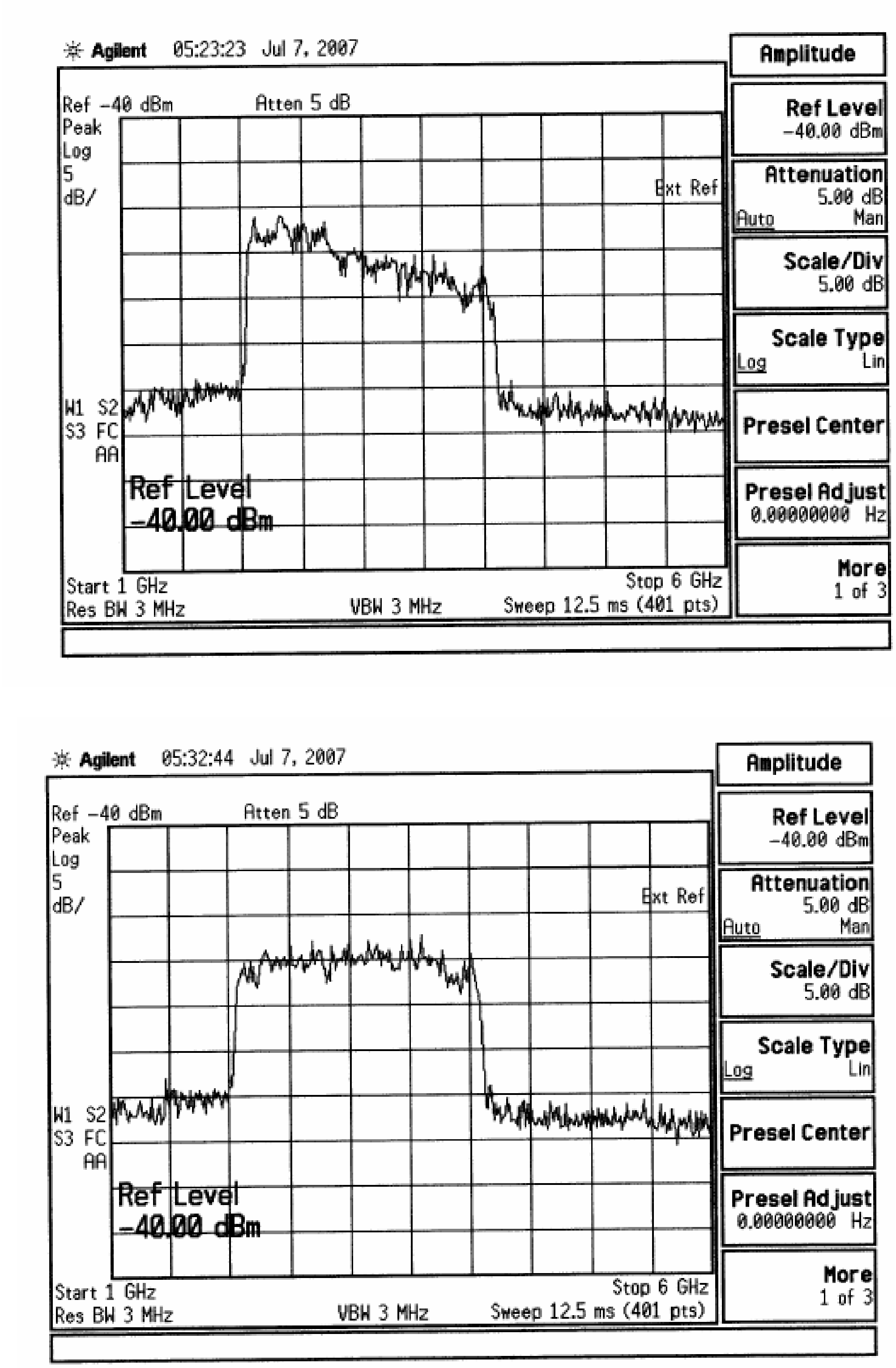

Figure 2: Spectrum analyzer display showing the output passband with no equalizer correction (top), and equalizer correction that yields a maximally flat passband (bottom).

In each case, the signal was sampled by a modified D30X digitizer using the prototype 3-bit sampler chip. Data was captured and displayed using the DTS real-time spectral display tool. Figure 3 shows the digitized spectrum for a single setting of the equalizer: maximally flat. The vertical display resolution of this display tool is optimized for the 8-bit sampler, and does not sufficiently indicate the effect of slope correction. It is included here primarily as evidence of its inclusion in the test.

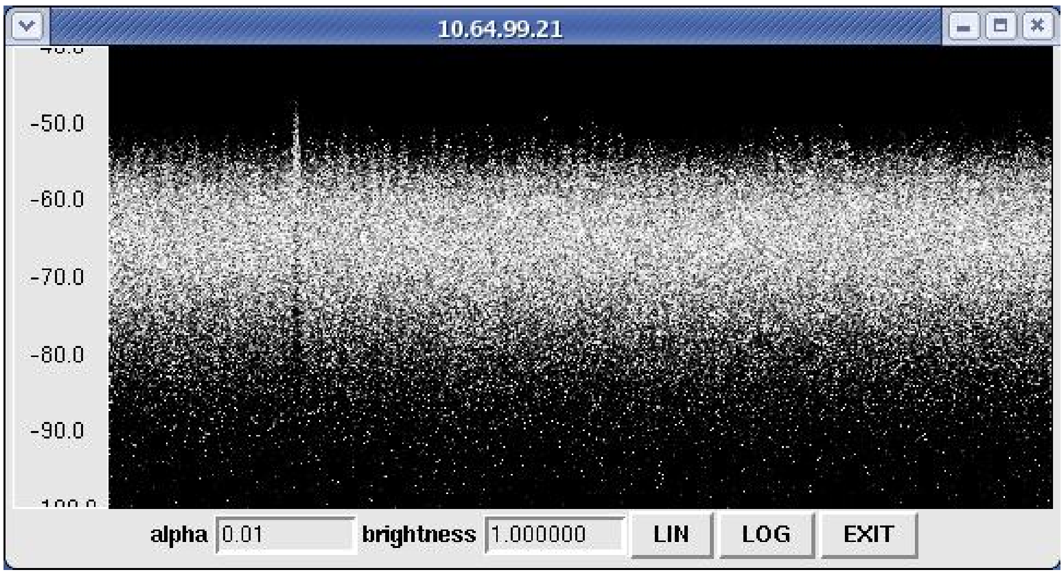

Figure 3: Digitizer spectral display tool showing sampled 2.048 - 4.096GHz output of T304 with gain slope correction applied. Courtesy: Mike Revnell

The optimal input level to the 3-bit sampler was determined experimentally during the course of this test, and found to lie between -32dBm, where sampler underflow occurred, and -27dBm, where MSB saturation occurred. Another phenomenon became evident also; the integrated band power varied with the equalizer setting. This is unremarkable in and of itself; because of the slope of the input signal, power was not distributed uniformly across the output band. For a signal with a negative slope, integrated band power will increase with increasingly negative slope correction, and decrease for increasingly positive slope correction.

4 Effect on Integrated Band Power

The integrated band power of a signal spectrum with a non-zero passband slope will change as the equalizer is engaged. Figure 4 shows the integrated band power for the selected spectral region versus equalizer setting. Note that since the input signal showed a concentration of power towards the low end of the frequency band, negative slope settings of the equalizer will pass more power than will positive slope settings.

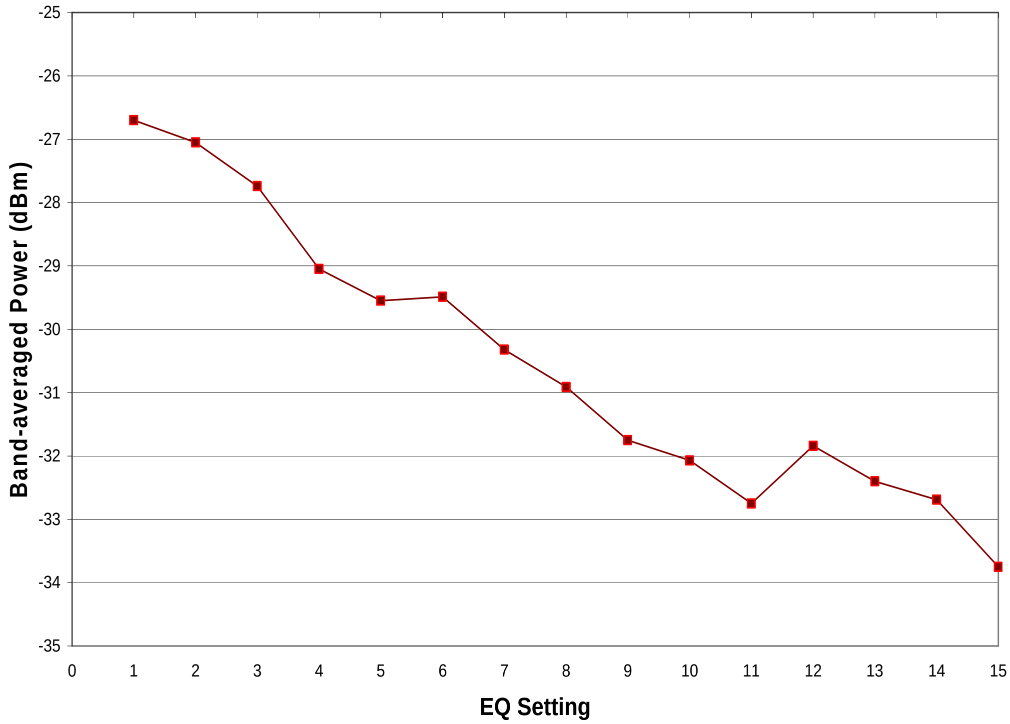

Figure 4: Band-averaged power versus equalizer setting for the output passband shown in Figure 2. Decreasing power with increasingly positive slope correction indicates that the input signal power was concentrated at the lower end of the spectrum.

This can be treated in the limiting case by applying a continuous wave signal at different frequencies to the input of the equalizer and measuring the output power that results from different equalizer settings. Figure 5 shows the response of the equalizer to sinusoidal inputs at three frequencies. Effective bypass of the equalizer occurs at EQ =7 or 8. Note that the 3072 MHz signal experiences a 0.8dB RMS deviation for all settings of the equalizer. This is the mid-band frequency to which the gain of all equalizer paths is normalized.

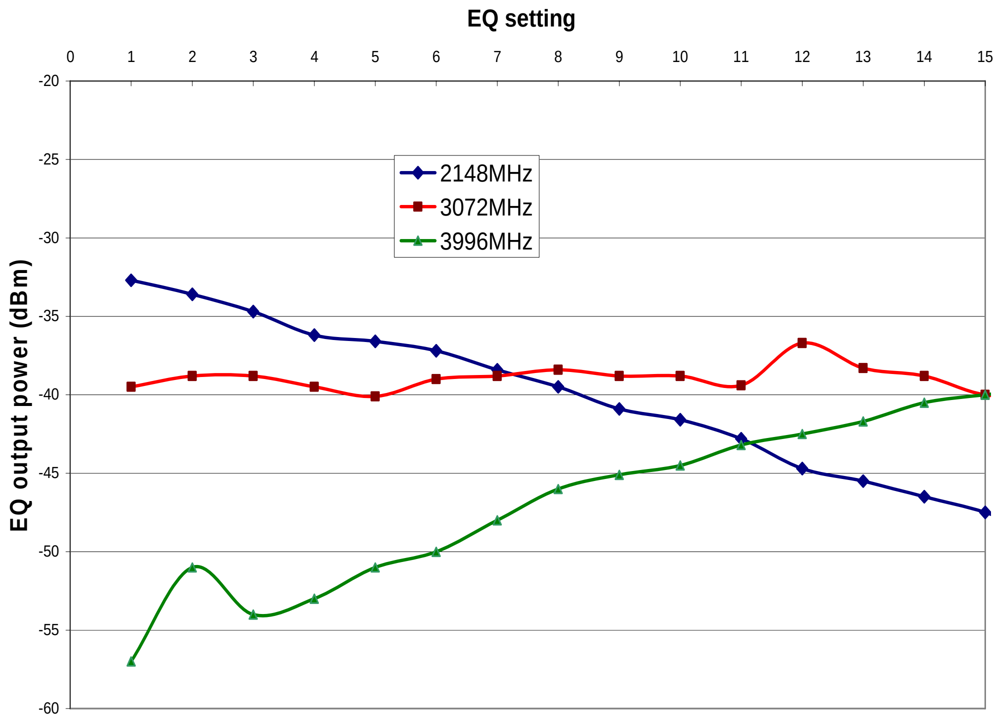

Figure 5: Equalizer response for three sinusoidal signals: 2148MHz, 3072MHz, and 3996MHz.

Because the band-averaged passband gain is not constant for all settings of the equalizer, the optimal Gain Slope Equalizer setting must be determined and set before any meaningful automated level control is possible.

5 Noise Figure

The effect of the Gain Slope Equalizer on system noise figure was measured by the Y-factor method. The noise-injection circuit of the K-Band receiver was modified with additional amplification such that the difference between noise on and noise off states was approximately 5dB with the equalizer set to “no correction”. The equalizer was then stepped through its full range, and the Y-factor and integrated band power measured for each step. These results are shown in Figure 6. Wideband Y-factor was measured using a band-limited input to an Agilent 4418 Power Meter.

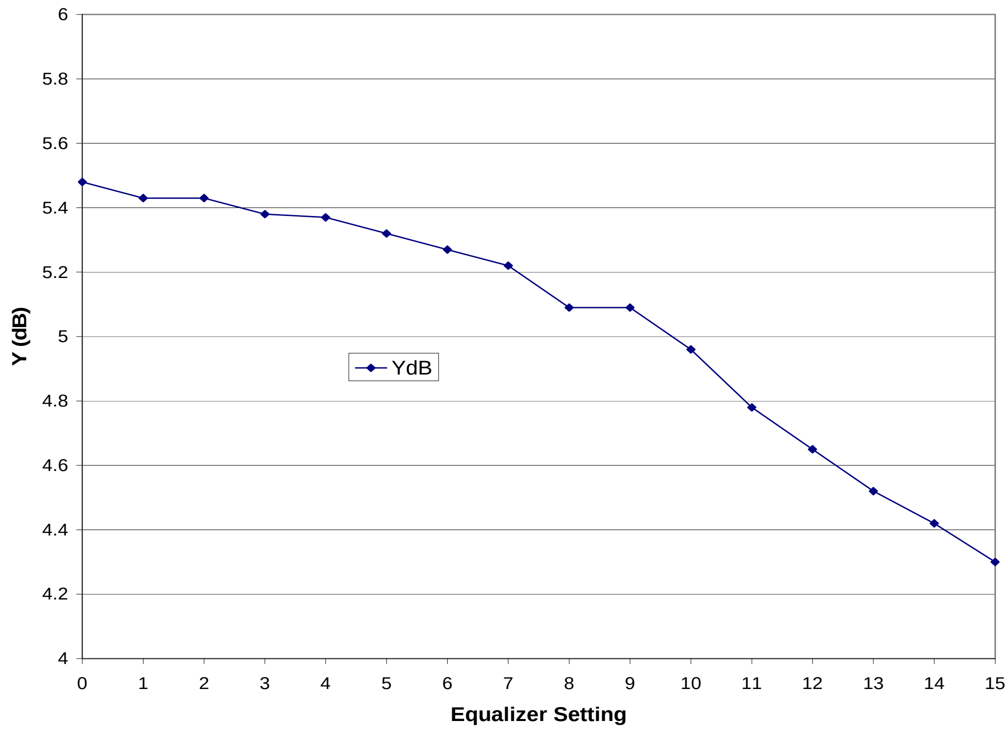

Figure 6: Wideband system Y-factor versus frequency for the region corresponding to the receiver output from 18.5GHz to 23.5GHz.

The T304 with Gain Slope Equalization preserved the input SNR for all settings of the equalizer. Figure 7 shows the instantaneous Y-factor versus frequency for the UX Converter output. The band under test in the previous section is centered on 9976 MHz, which is the transition region in Figure 7, where the Y-factor changes from roughly 4 to slightly greater than 5.

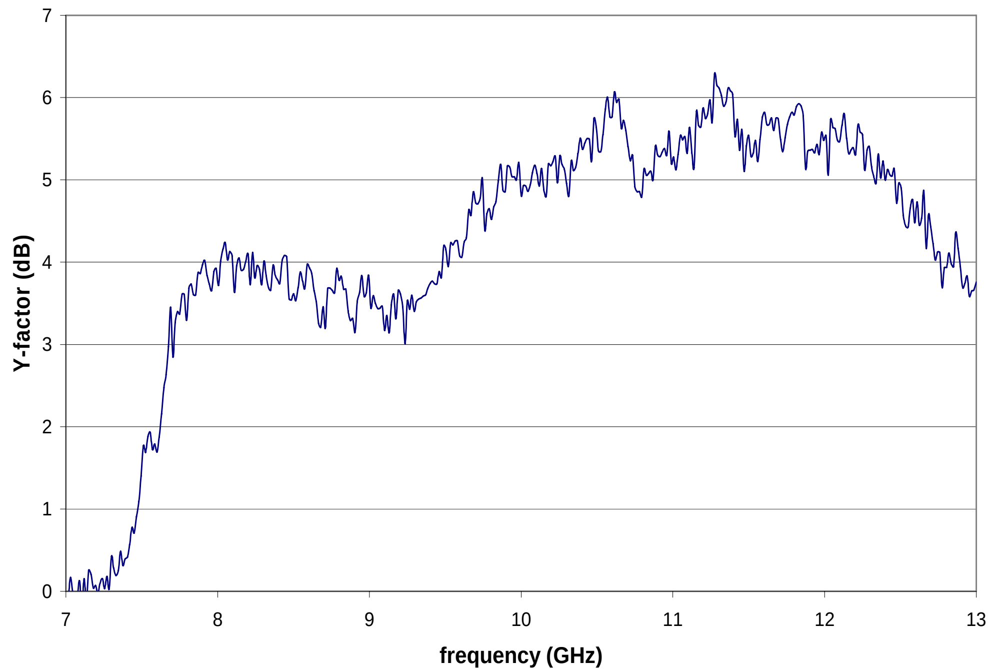

Figure 7: Instantaneous Y-factor at UX Converter output.

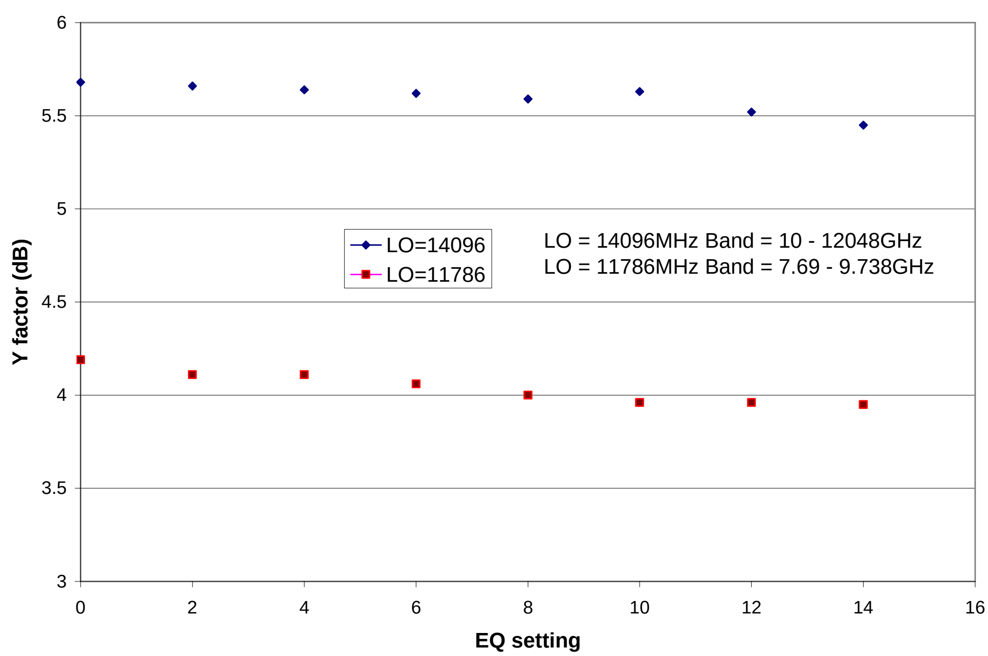

Figure 8: Wideband Y-factor measured at T304 output after proper LO frequency selection allowed viewing of flat regions of UX Converter output spectrum.

The UX Converter instantaneous Y-factor was calculated point-by-point from an Agilent 4407 Spectrum Analyzer. This analysis reveals that the Y-factor is not constant over the UX Converter output spectrum. Further analysis will be required to determine whether the frequency dependence originates in the receiver or the UX Converter.

The T304 output Y-factor was retested at two different LO frequencies: 14096 MHz, which resulted in band of 10 – 12.048 GHz, and 11.786 GHz, which resulted in a band of 7.69 - 9.738GHz. These two regions were chosen to provide flat response, in order to eliminate the effect of varying noise response upstream from the contribution of the T304/equalizer system. Figure 8 shows the resulting wideband Y-factors for these two measurements. The T304/equalizer combination preserves the input Y-factor without appreciable degradation of signal-to-noise ratio, as is to be expected.

6 Conclusions

The end-to-end test of the 2.048GHz – 4.096 GHz path of the EVLA IF system demonstrates that the high-frequency path of the T304 interfaces successfully with the prototype 3-bit digitizer. The passband slope can be measured, albeit visually, and the correction applied in the T304. The effects of these corrections can be observed in the digitized signal. The high-frequency path does not degrade system signal-to-noise ratio.

Further work will be required to develop and execute a method for (non-visual) determination of passband gain slope.

7 References

R. Hayward, M. Morgan and K. Saini, *EVLA Memo 80*, “A Gain Slope Correction Scheme for the EVLA Receiver System”

B. Carlson, R. Perley, *EVLA Memo 83*, “Quantization Loss for a Sloped Passband”

EVLA Project Book, M. McKinnon and R. Perley, Editors

8 Acknowledgements

The authors wish to thank the following individuals for their assistance: Donna Field, Robert Hayward, Matthew Morgan, Mike Revnell, and Robert Stupak. The preceding list was not intended to rank or otherwise valuate these contributions, and may not have been exhaustive.