Application Report

SLOA280A–February 2019–Revised August 2019

# Rad-hardened Fully Differential Amplifier (FDA) as Clock Buffer in Communication and Radar Payloads

*Christian Yots*

**ABSTRACT**

Communication and RADAR payloads for space applications require radiation-hardened transceivers to combat the harsh radiation environments of space. Within such systems, clock signals are critical, ensuring data converters are robustly processing the desired data. Buffering such clock signals is often needed, but must be implemented in a manner that preserves the integrity of the clock source. In addition, converting a single-ended clock source to a differential signal is often required to clock high-speed ADCs and DACs. The LMH5401-SP space grade fully differential amplifier (FDA) provides such clock buffering implementations. This application report presents measured phase noise and rms jitter performance of the LMH5401-SP over a wide frequency range showing how the device is ideal for using as a clock buffer in space-grade systems.

**Contents**



**List of Figures**

**List of Tables**



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## 1 Introduction

The LMH5401-SP is a space grade, wide bandwidth, fully differential amplifier (FDA) that offers versatility for its use cases. In addition to conditioning differential signals, the device can be configured to convert a single-ended signal to a differential signal similar to a balun or transformer. However, unlike its passive counter parts, the LMH5401-SP offers flexibility in the amount of signal gain it can provide by simply changing a few peripheral resistors. In addition, with approximately 4.5 GHz of useable bandwidth, the same device can be used to buffer, amplify, or condition a variety of signals with different frequencies and amplitudes. This makes such a device ideal for buffering clock signals of a system where distribution might require power gain to overcome transmission line losses, or, in other cases, might require 0 dB power gain to simply play the role of a passive balun in converting a single-ended clock signal to a differential clock signal. One such scenario is providing the differential sampling clock to high speed ADCs such as the ADC12D1620QML-SP or the ADC12DJ3200QML-SP. These ADCs provide 1.6 GSPS and 3.2 GSPS sample rates on two analog channels or 3.2 GSPS and 6.4 GSPS sample rates on a single analog channel, respectively, and require maximum sampling clocks of 1.6 GHz and 3.2 GHz, respectively. The LMH5401-SP FDA can convert a single-ended clock source and drive the differential clock inputs of these ADCs in addition to conditioning the signal of interest to drive the high speed ADCs, as shown in Figure 1. The effect of the LMH5401-SP on the phase noise and integrated rms jitter of the clock signal is critical so that the signal integrity of the clock is not compromised. This application report presents measured phase noise and integrated jitter performance of the LMH5401-SP and summarizes the additive jitter of the FDA over a wide frequency range.

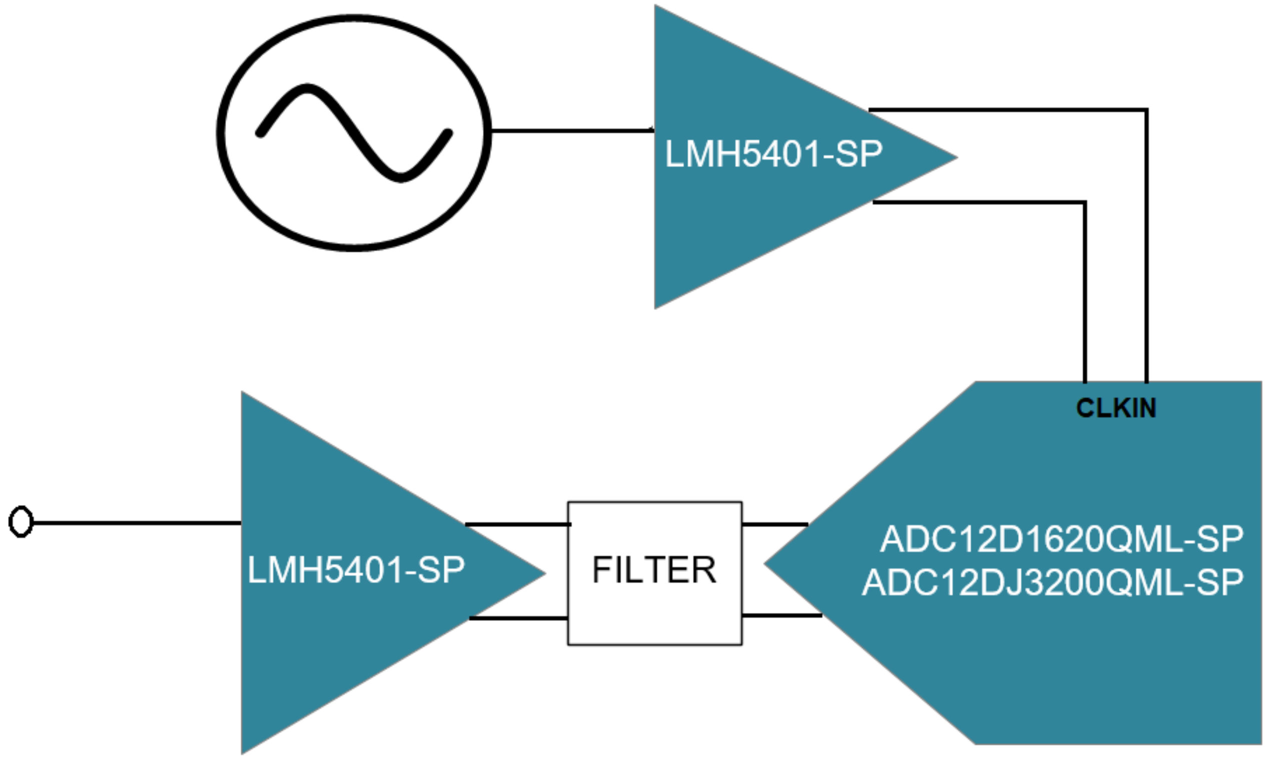


**Figure 1. LMH5401-SP as Clock Buffer**

## 2 Test Setup and Methodology

A standard LMH5401EVM-CVAL evaluation module, which is available for purchase from the LMH5401-SP product folder is used for testing. The EVM, shown in Figure 2, is configured for differential inputs and outputs. By adding a 50-Ω load to either of the inputs, the EVM can be driven single-endedly, thus, allowing the FDA to act as an active balun. In this active balun configuration, the EVM provides 17 dB (7 V/V) of voltage gain to the output of the amplifier, OUT_AMP, or, 8 dB of power gain to a matched 100-Ω differential load at the outputs. Figure 3 shows the default EVM configuration and provides these power and voltage gains.

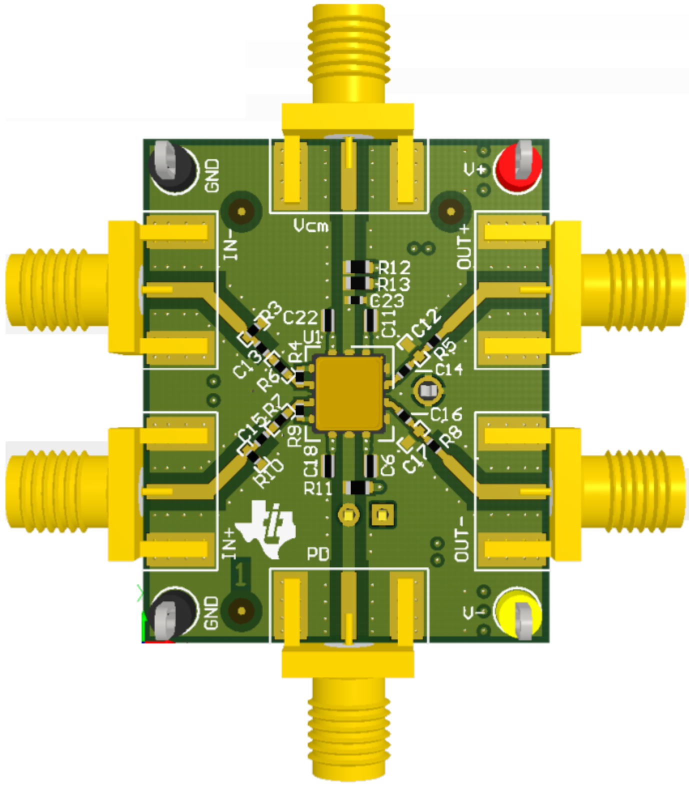


Figure 2. LMH5401EVM-CVAL Evalulation Module

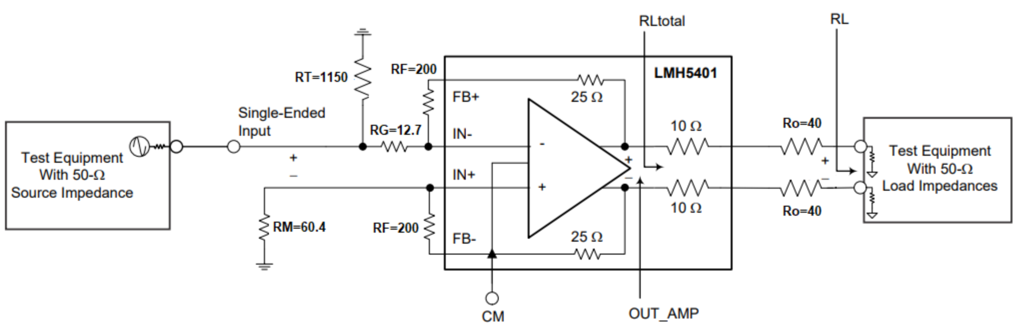


Figure 3. LMH5401-SP EVM Schematic

Figure 4 shows the frequency response of the EVM used for all measurements provided in this report. The scattering parameter Sds21 is the power gain from a single-ended 50-Ω source impedance at the input of FDA (port 1) to a 100-Ω differential load at the output of the FDA (port 2). The instrument used to measure this frequency response is the Rohde & Schwarz® 24 GHz ZVA vector network analyzer (VNA). The 3-dB bandwidth is approximately 4 GHz. Phase noise measurements from 50 MHz to 4.5-GHz are provided to cover the full usable bandwidth of the device.

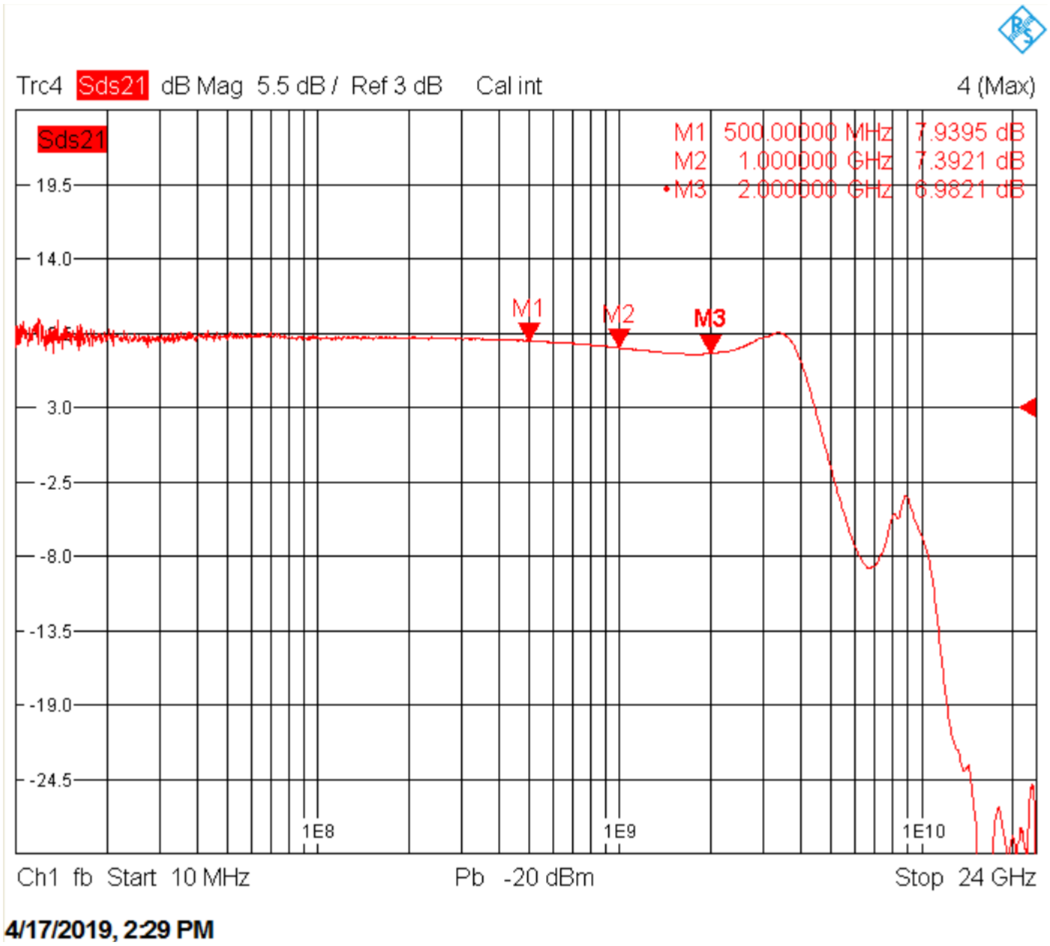


**Figure 4. LMH5401-SP Frequency Response, Sds21**

The instrument used to measure phase noise is the Agilent™ E5052A. This instrument provides a single-ended input which is split internally into two independent receiver paths. Cross-correlation techniques can be invoked to cancel uncorrelated noise between these two receiver paths, thus, lowering the sensitivity level for measuring the actual phase noise of the DUT. The use of this feature comes at the expense of test time. A correlation factor of four is used for all measurements as a higher number of correlations yields negligible improvements for the noise levels being measured.

Eliminating the phase noise of the signal source, in this case, the Rohde & Schwarz SMA100B, requires measuring the phase noise of the source and then removing this quantity from the total phase noise measured from the source plus the LMH5401-SP. Since the total RMS phase noise comprises the square root of the sum of the square (RSS) of each of the contributing sources, the additive jitter of the LMH5401-SP can be calculated knowing the RMS jitter of the signal source and the RMS jitter of the signal source plus the LMH5401-SP cascaded together. Equation 1 shows the RSS relationship and solving for J_(LMH5401-SP(RMS)) yields the additive jitter of the FDA.

$$J_{total(RMS)} = \sqrt{J_{SMA100B(RMS)}^2 + J_{LMH5401-SP(RMS)}^2} \tag{1}$$

However, before any phase noise measurements of the signal source are taken, the optimal power level of the signal source needs to be determined at each frequency of interest. This ensures that phase noise of the instrument is being characterized in the exact configuration which is used to drive the LMH5401-SP. The target output level of the LMH5401-SP is a 2 Vpp-diff signal at the amplifier output which corresponds to a 1 Vpp-diff signal on a matched 100-Ω load. The setup for determining these power levels is shown in Figure 5 and requires using a calibrated power meter, with 50-Ω termination resistance, on one output of the FDA and a 50-Ω termination on the other output. With this, the power level of the input signal to the FDA is varied until exactly one half the equivalent power of 1 Vpp on 100 Ω is observed.

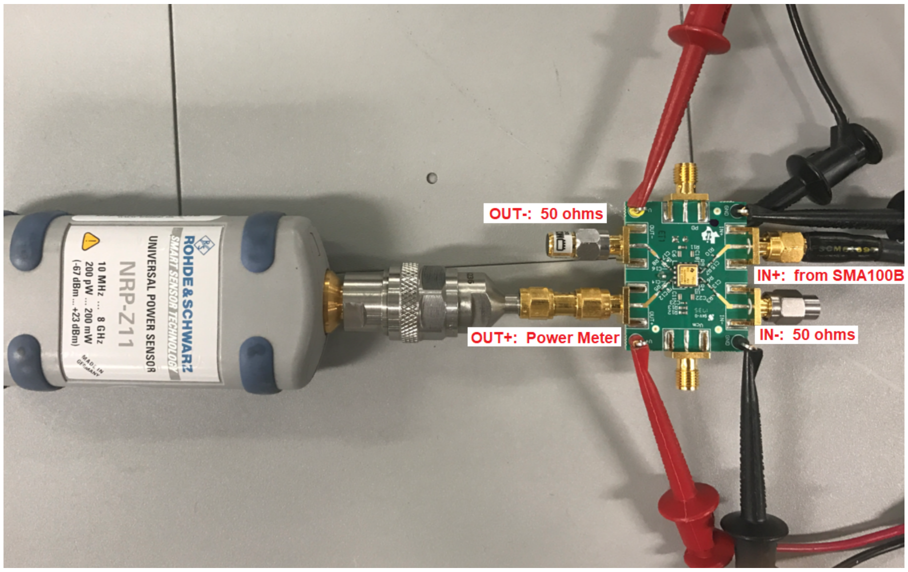


**Figure 5. Determining Signal Source Power Levels**

With the optimal input signal levels to the FDA known, phase noise measurements of the signal source instrument are taken. Figure 6 shows a picture of the test setup. Since the output of the LMH5401-SP is a differential signal and the input to the phase noise analyzer requires a single-ended signal, a broadband instrumentation balun (Picosecond 5310A) is used to convert the signal. The losses in this balun are inconsequential to the measurements since the power levels to achieve the desired signal swing at the output of the LMH5401-SP were determined without the use of the balun.


**Figure 6. SMA100B + LMH5401-SP Phase Noise Setup**

## 3 Test Results

This section describes the measurements at one frequency, 2 GHz, and summarizes the data. Screenshots of all measurements are provided in Appendix A.

Figure 7 shows screenshots from the E5052A instrument. The screenshots are provided in pairs with the left most graphic showing the measured phase noise of the signal source, SMA100B, and the right most showing the total phase noise of the SMA100B plus the LMH5401-SP. For each measurement, the phase noise is measured from 100 Hz to 40 MHz and the rms jitter is calculated by the instrument over an integration bandwidth from 12 kHz to 20 MHz. In addition, markers are placed at eight spot frequencies across the curve. Using the root sum of squares (RSS) equation previously presented, the additive jitter of the LMH5401-SP is calculated. Note that in theory, the phase noise of the signal generator plus the FDA should always be greater than or equal to the phase noise of the signal source itself. However, in reality, this is not always possible as is evident in comparing marker noise values between Tables 1 and 2 and between Tables 4 and 5. A lower (superior) marker phase noise measurement for the cascaded arrangement is attributed to measurement variability. This variability averages out on a large number of measurements as is evident by the integrated rms jitter measurements. The integrated rms jitter measurements of the signal source plus the LMH5401-SP are always higher (inferior) than that of the signal source alone.

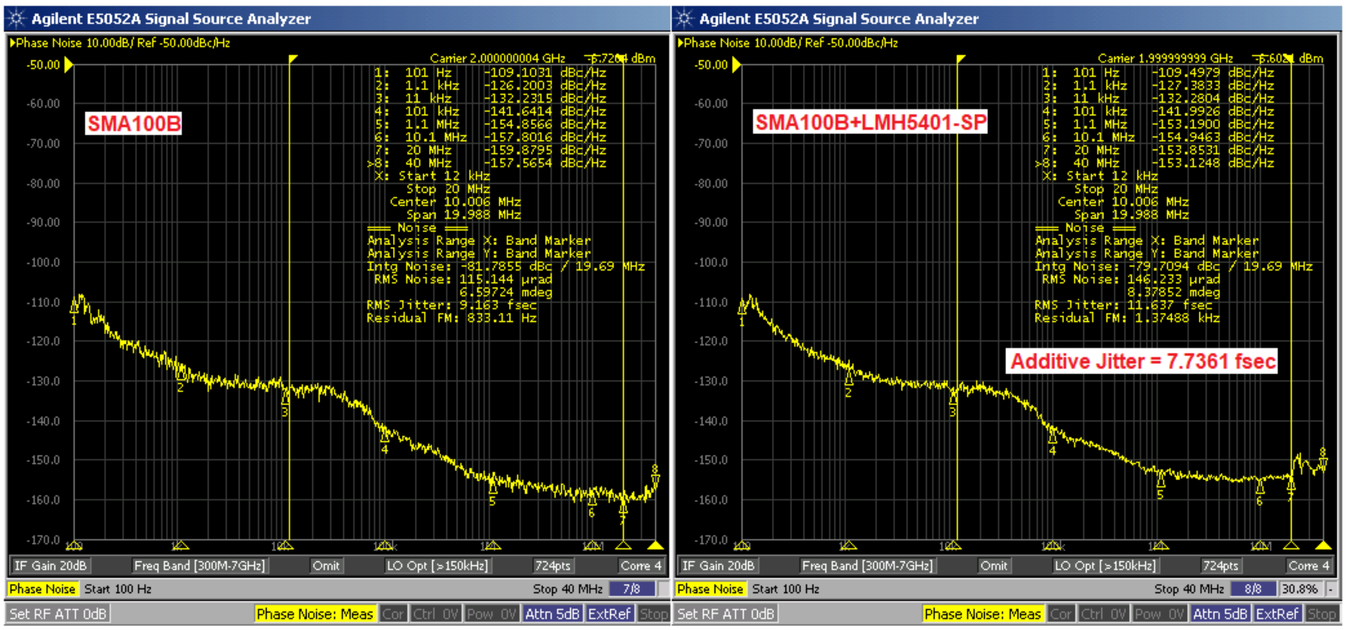


**Figure 7. Phase Noise 2 GHz, Spurs-Omit**

Figure 8 shows the exact same measurements with one exception: the spurs are not omitted from the measurements. As the plots show, the spurs are products of the signal source and not the LMH5401-SP as they appear unchanged between the signal source measurement and the cascaded measurement.

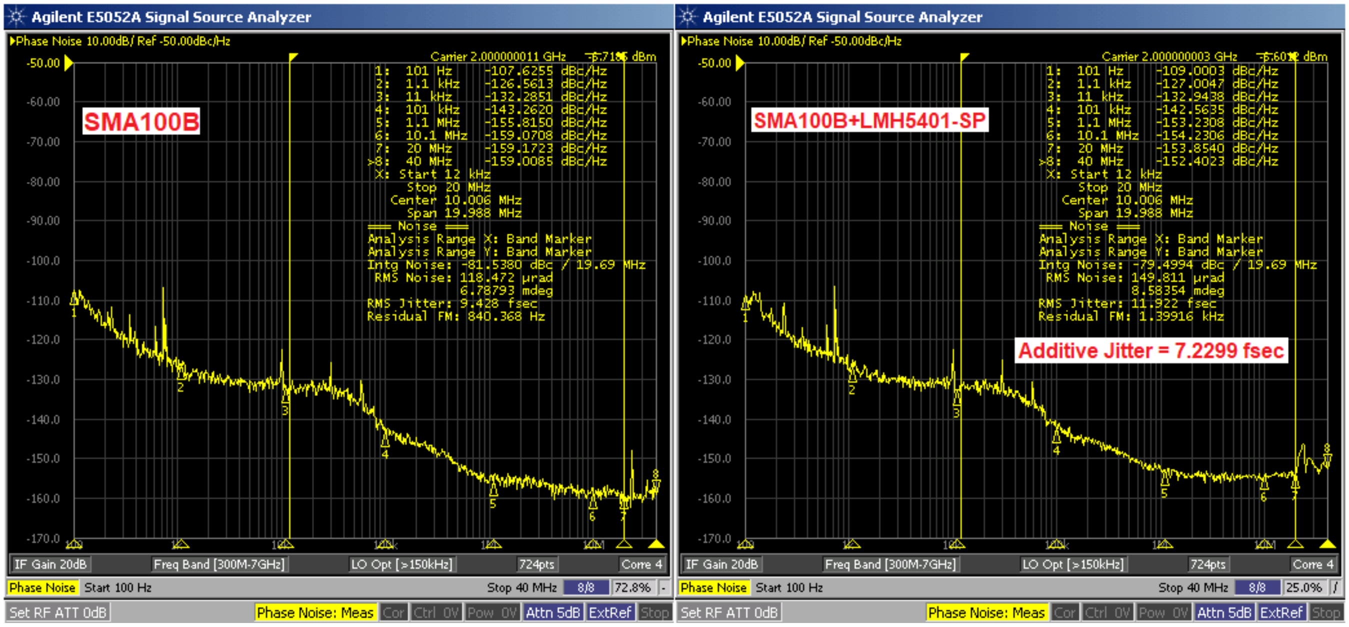


**Figure 8. Phase Noise 2 GHz, Spurs-Include**

Table 1 summarizes all measurements on the SMA100B with spurs omitted while Table 2 summarizes all measurements of the SMA100B + LMH5401-SP with spurs omitted as well.

**Table 1. SMA100B Phase Noise Summary, Spurs-Omit**

| FREQ. (MHz) | PN @ 101 Hz (dBc/Hz) | PN @ 1.1 kHz (dBc/Hz) | PN @ 11 kHz (dBc/Hz) | PN @ 101 kHz (dBc/Hz) | PN @ 1.1 MHz (dBc/Hz) | PN @ 10.1 MHz (dBc/Hz) | PN @ 20 MHz (dBc/Hz) | PN @ 40 MHz (dBc/Hz) | Int. NOISE (dBc/19.99 MHz) | RMS NOISE (urad) | RMS NOISE (mdeg) | RMS JITTER (fsec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | -125.49 | -138.50 | -149.25 | -155.04 | -156.61 | -160.21 | -160.88 | N/A | -85.96 | 71.18 | 4.08 | 227.57 |
| 250 | -124.10 | -138.41 | -146.93 | -154.45 | -156.05 | -160.17 | -160.07 | -159.49 | -85.84 | 72.22 | 4.13 | 45.98 |
| 500 | -120.03 | -135.91 | -143.15 | -151.55 | -155.97 | -158.73 | -158.62 | -158.46 | -84.73 | 82.04 | 4.71 | 26.11 |
| 1000 | -113.15 | -131.37 | -138.84 | -148.24 | -155.92 | -158.13 | -161.22 | -160.06 | -84.00 | 85.90 | 4.92 | 13.67 |
| 1500 | -112.51 | -128.88 | -132.43 | -143.37 | -155.28 | -158.13 | -159.63 | -158.06 | -81.52 | 118.66 | 6.80 | 12.59 |
| 2000 | -109.10 | -126.20 | -132.23 | -141.64 | -154.86 | -157.81 | -160.88 | -158.57 | -81.79 | 115.14 | 6.60 | 9.16 |
| 2500 | -107.41 | -124.04 | -126.93 | -137.10 | -152.09 | -157.23 | -157.97 | -157.57 | -77.48 | 189.03 | 10.83 | 12.03 |
| 3000 | -106.83 | -123.55 | -126.95 | -135.41 | -151.76 | -157.38 | -158.83 | -157.60 | -77.80 | 204.40 | 11.71 | 10.84 |
| 3500 | -103.21 | -121.41 | -128.41 | -138.55 | -150.31 | -155.98 | -157.59 | -155.91 | -77.85 | 181.09 | 10.38 | 8.24 |
| 4000 | -104.55 | -121.72 | -127.06 | -136.61 | -150.60 | -156.06 | -157.36 | -156.14 | -76.85 | 203.17 | 11.64 | 8.08 |
| 4500 | -102.96 | -120.45 | -127.05 | -134.07 | -149.60 | -153.17 | -156.57 | -154.23 | -75.45 | 238.74 | 13.68 | 8.44 |

**Table 2. SMA100B + LMH5401-SP Phase Noise Summary, Spurs-Omit**

| FREQ. (MHz) | PN @ 101 Hz (dBc/Hz) | PN @ 1.1 kHz (dBc/Hz) | PN @ 11 kHz (dBc/Hz) | PN @ 101 kHz (dBc/Hz) | PN @ 1.1 MHz (dBc/Hz) | PN @ 10.1 MHz (dBc/Hz) | PN @ 20 MHz (dBc/Hz) | PN @ 40 MHz (dBc/Hz) | INT. NOISE (dBc/19.99 MHz) | RMS NOISE (urad) | RMS NOISE (mdeg) | RMS JITTER (fsec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | -127.18 | -140.53 | -150.53 | -156.31 | -157.30 | -159.24 | -158.56 | N/A | -85.59 | 74.34 | 4.26 | 236.64 |
| 250 | -124.82 | -137.96 | -147.69 | -155.27 | -157.80 | -160.09 | -158.94 | -158.52 | -85.72 | 73.20 | 4.19 | 46.60 |
| 500 | -119.7 | -135.38 | -142.75 | -152.46 | -156.31 | -156.99 | -156.84 | -157.52 | -83.75 | 91.78 | 5.26 | 29.21 |
| 1000 | -113.45 | -131.95 | -137.86 | -148.80 | -156.72 | -158.41 | -159.96 | -156.44 | -83.86 | 90.63 | 5.19 | 14.43 |
| 1500 | -112.19 | -128.50 | -132.24 | -143.44 | -154.00 | -154.31 | -154.52 | -155.33 | -79.58 | 148.50 | 8.51 | 15.76 |
| 2000 | -109.91 | -127.00 | -131.64 | -142.56 | -153.25 | -154.83 | -153.70 | N/A | -79.45 | 150.69 | 8.63 | 11.99 |
| 2500 | -107.63 | -124.56 | -125.89 | -136.32 | -148.06 | -148.69 | -146.00 | N/A | -73.83 | 287.88 | 16.49 | 18.33 |
| 3000 | -104.61 | -123.31 | -127.45 | -136.64 | -144.65 | -144.11 | -141.31 | -138.01 | -70.01 | 446.76 | 25.60 | 23.70 |

**Table 2. SMA100B + LMH5401-SP Phase Noise Summary, Spurs-Omit (continued)**

| FREQ. (MHz) | PN @ 101 Hz (dBc/Hz) | PN @ 1.1 kHz (dBc/Hz) | PN @ 11 kHz (dBc/Hz) | PN @ 101 kHz (dBc/Hz) | PN @ 1.1 MHz (dBc/Hz) | PN @ 10.1 MHz (dBc/Hz) | PN @ 20 MHz (dBc/Hz) | PN @ 40 MHz (dBc/Hz) | INT. NOISE (dBc/19.99 MHz) | RMS NOISE (urad) | RMS NOISE (mdeg) | RMS JITTER (fsec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3500 | -106.16 | -121.75 | -128.33 | -138.13 | -146.48 | -147.36 | -145.41 | -143.76 | -73.17 | 310.53 | 17.79 | 14.12 |
| 4000 | -103.76 | -120.82 | -126.38 | -136.09 | -147.39 | -149.50 | -148.27 | -146.95 | -74.19 | 276.21 | 15.83 | 10.99 |
| 4500 | -101.28 | -120.62 | -126.16 | -134.71 | -145.18 | -148.37 | -150.03 | -148.94 | -72.61 | 331.29 | 18.98 | 11.72 |

Table 3 summarizes the additive jitter that is calculated at each frequency. Note that additive jitter shows a peaking around 3000 MHz corresponding to where frequency response also shows a peaking. This region corresponds to the loop gain cross-over frequency where the product of Aol times β equals 1 or, in other words, when Aol equals 1/ β. Even though the LMH5401-SP amplifier is compensated at the cross-over frequency, that is the phase margin is sufficient, there is still a slight effect on the jitter of the signal. However, as the impact to the jitter is very small, even in this cross-over region, the device can be considered for using as a clock buffer through this region, so long as the impact to the signal source is minimal.

**Table 3. LMH5401-SP Additive RMS Jitter vs Frequency Spurs-Omit**

| FREQ. (MHz) | LMH5401-SP ADDITIVE JITTER (OMITTING SPURS) (fsec) |
|---|---|
| 50 | 64.00 |
| 250 | 6.72 |
| 500 | 12.54 |
| 1000 | 5.26 |
| 1500 | 9.19 |
| 2000 | 7.23 |
| 2500 | 13.09 |
| 3000 | 21.07 |
| 3500 | 11.50 |
| 4000 | 7.56 |
| 4500 | 8.03 |

For completeness, Table 4 through Table 6 are provided for the measurements where spurs were included. As noted earlier, these spurs are attributed to the signal source and not the LMH5401-SP as is evident by the phase noise plots when measuring only the signal source (see Appendix A).

**Table 4. SMA100B Phase Noise Summary, Spurs-Include**

| FREQ. (MHz) | PN @ 101 Hz (dBc/Hz) | PN @ 1.1 kHz (dBc/Hz) | PN @ 11 kHz (dBc/Hz) | PN @ 101 kHz (dBc/Hz) | PN @ 1.1 MHz (dBc/Hz) | PN @ 10.1 MHz (dBc/Hz) | PN @ 20 MHz (dBc/Hz) | PN @ 40 MHz (dBc/Hz) | INT. NOISE (dBc/19.99 MHz) | RMS NOISE (urad) | RMS NOISE (mdeg) | RMS JITTER (fsec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | -125.63 | -138.25 | -149.17 | -155.52 | -156.95 | -159.42 | -159.75 | N/A | -85.76 | 72.88 | 4.18 | 232.00 |
| 250 | -123.61 | -137.11 | -147.73 | -153.87 | -155.58 | -160.04 | -160.17 | -160.14 | -85.70 | 73.34 | 4.20 | 46.69 |
| 500 | -120.68 | -135.21 | -142.73 | -152.37 | -155.72 | -158.06 | -159.12 | -158.01 | -84.65 | 82.77 | 4.74 | 26.35 |
| 1000 | -114.12 | -131.12 | -138.68 | -147.72 | -156.02 | -159.75 | -160.78 | -159.32 | -84.27 | 86.52 | 4.96 | 13.77 |
| 1500 | -112.40 | -129.66 | -132.26 | -141.69 | -154.70 | -158.82 | -158.26 | -160.04 | -81.37 | 120.75 | 6.92 | 12.81 |
| 2000 | -107.63 | -126.56 | -132.29 | -143.26 | -155.82 | -159.07 | -159.17 | -159.01 | -81.54 | 118.47 | 6.79 | 9.43 |
| 2500 | -106.99 | -124.48 | -126.16 | -136.30 | -152.23 | -155.56 | -156.94 | -156.25 | -77.25 | 194.10 | 11.12 | 12.36 |
| 3000 | -105.07 | -122.74 | -125.90 | -134.86 | -151.54 | -156.12 | -158.07 | -156.40 | -76.70 | 206.68 | 11.84 | 10.97 |
| 3500 | -105.29 | -122.57 | -127.44 | -137.52 | -151.57 | -155.40 | -156.76 | -156.97 | -77.69 | 184.58 | 10.58 | 8.39 |
| 4000 | -103.78 | -120.27 | -125.11 | -136.46 | -150.35 | -155.47 | -156.62 | -156.46 | -76.71 | 206.49 | 11.83 | 8.22 |
| 4500 | -103.38 | -120.99 | -124.91 | -134.94 | -149.37 | -154.01 | -154.90 | -154.22 | -75.25 | 244.38 | 14.00 | 8.64 |

**Table 5. SMA100B + LMH5401-SP Phase Noise Summary, Spurs-Include**

| FREQ. (MHz) | PN @ 101 Hz (dBc/Hz) | PN @ 1.1 kHz (dBc/Hz) | PN @ 11 kHz (dBc/Hz) | PN @ 101 kHz (dBc/Hz) | PN @ 1.1 MHz (dBc/Hz) | PN @ 10.1 MHz (dBc/Hz) | PN @ 20 MHz (dBc/Hz) | PN @ 40 MHz (dBc/Hz) | INT. NOISE (dBc/19.99 MHz) | RMS NOISE (urad) | RMS NOISE (mdeg) | RMS JITTER (fsec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 | -126.02 | -141.22 | -150.39 | -157.14 | -157.80 | -159.65 | -158.68 | -158.68 | -85.44 | 75.61 | 4.33 | 240.66 |
| 250 | -114.87 | -138.81 | -148.17 | -155.85 | -157.13 | -158.92 | -158.74 | -159.91 | -85.61 | 74.10 | 4.25 | 47.17 |
| 500 | -120.58 | -135.79 | -144.42 | -152.05 | -156.05 | -156.91 | -157.01 | -157.73 | -83.77 | 91.66 | 5.25 | 29.18 |
| 1000 | -114.92 | -131.01 | -139.22 | -148.81 | -156.26 | -158.49 | -157.42 | -157.40 | -83.68 | 92.61 | 5.31 | 14.74 |
| 1500 | -111.71 | -128.02 | -132.67 | -142.53 | -154.49 | -154.47 | -154.26 | -155.66 | -79.57 | 148.60 | 8.51 | 15.77 |
| 2000 | -110.03 | -126.44 | -132.38 | -142.74 | -153.08 | -154.65 | -154.38 | N/A | -79.53 | 149.31 | 8.55 | 11.88 |
| 2500 | -106.54 | -124.47 | -127.83 | -136.87 | -148.33 | -148.81 | -145.16 | N/A | -73.98 | 282.79 | 16.20 | 18.00 |
| 3000 | -104.34 | -122.36 | -126.38 | -136.23 | -144.76 | -144.14 | -141.26 | -137.99 | -69.99 | 447.63 | 25.65 | 23.75 |
| 3500 | -104.59 | -121.31 | -128.03 | -137.22 | -146.48 | -147.61 | -145.41 | -143.71 | -73.09 | 313.33 | 17.95 | 14.25 |
| 4000 | -102.87 | -121.38 | -126.13 | -135.77 | -147.77 | -149.39 | -148.14 | -146.98 | -74.05 | 280.66 | 16.08 | 11.17 |
| 4500 | -101.60 | -118.61 | -127.11 | -133.92 | -145.52 | -147.93 | -147.70 | -148.22 | -72.55 | 333.56 | 19.11 | 11.80 |

**Table 6. LMH5401-SP Additive RMS Jitter vs Frequency Spurs-Include**

| FREQ. (MHz) | LMH501-SP ADDITIVE JITTER (INCLUDING SPURS) (fsec) |
|---|---|
| 50 | 63.9969 |
| 250 | 6.7263 |
| 500 | 12.5371 |
| 1000 | 5.2560 |
| 1500 | 9.1897 |
| 2000 | 7.2299 |
| 2500 | 13.0925 |
| 3000 | 21.0650 |
| 3500 | 11.516 |
| 4000 | 7.5630 |
| 4500 | 8.0292 |

## 4 LMH5401-SP Buffering Clock of ADC12D1620QML-SP

The measured data presented within this report shows that the additive jitter of the LMH5401-SP is very low over a large frequency range. With such performance, the LMH5401-SP can be used to drive the differential clock input of high speed ADCs such as the ADC12DJ3200QML-SP or the ADC12D1620QML-SP. Figure 9 shows the results of a such a measurement with the ADC12D1620QML-SP. Using a modified version of the TSW12D1620EVM-CVAL evaluation module, a 1.6 GHz single-ended sinusoidal clock signal at 1.6 GHz is provided to the single-ended input of the LMH5401-SP by a R&S SMA100A instrument. The differential output of the LMH5401-SP drives the differential clock port of the ADC. An analog input signal is provided by another R&S SMA100A instrument at 247.77 MHz to another LMH5401-SP which converts this signal to a differential input signal to the ADC. In Dual-Edged-Sampling Mode (DES), the sample rate of the ADC is twice that of the clock provided, or, 3.2 GSPS in this case. The FFT of the digitized output of the ADC shows a full Nyquist SNR of 58.414 dBFS when the analog input signal is -0.5 dBFS. This is in line with the datasheet specification of 56.9 dBFS SNR, typically, for this mode.

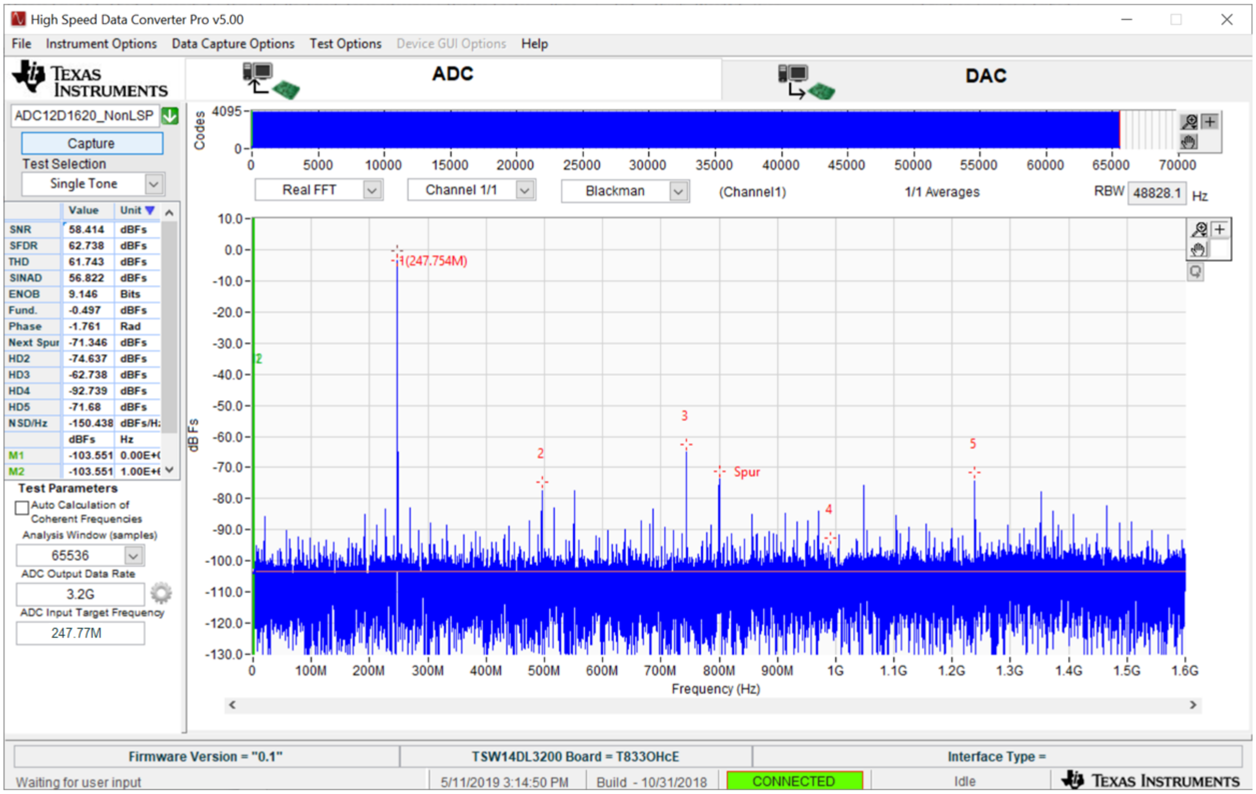


**Figure 9. ADC12D1620QML-SP 3.2 GSPS Spectrum with LMH5401-SP Buffering 1.6 GHz Clock**

## 5 Conclusion

A wideband fully differential amplifier such as the LMH5401-SP is an excellent candidate to use as a clock buffer in communications or radar payload end-equipment requiring radiation hardness for space environments. The versatility of the device allows you to customize gain for the application with only a few peripheral passive component changes. In addition, the device supports both differential-to-differential and single-ended-to-differential signaling, making it an ideal replacement to a passive balun but with higher reliability due to its monolithic implementation compared to the mechanical construction of the balun.

In any system requiring the conditioning or buffering of a clock signal, the goal is to do so without compromising the integrity of the clock signal source. Clock signal integrity is typically characterized by phase noise or rms phase jitter. As shown in the report, the LMH5401-SP FDA can buffer clock signals from DC to 4.5 GHz with minimal additive jitter, thus, maintaining the clock signal throughout the system.

## 6 References


- Texas Instruments, *LMH5401-SP Radiation Hardened 6.5-GHz Low-noise Low-power Gain-configurable Amp Data Sheet*
- Texas Instruments, *LMH5401EVM-CVAL Evaluation Module (EVM) User's Guide*

Screen shots of all measurements are provided in this appendix starting from 50MHz up to 4500MHz carrier frequency. The screenshots are provided in pairs with the left most graphic showing the measured phase noise of the signal source, SMA100B, and the right most showing the total phase noise of the SMA100B plus the LMH5401-SP. For each frequency, there are two pairs of screen shots, the first omitting spurs and the second including spurs. For each measurement, the phase noise is measured from 100Hz to 40MHz and the rms jitter is calculated by the instrument over an integration bandwidth from 12kHz to 20MHz. In addition, markers are placed at eight spot frequencies across the curve. Using the root sum of squares (RSS) equation previously presented, the additive jitter of the LMH5401-SP is calculated.

## A.1 Phase Noise Measurements

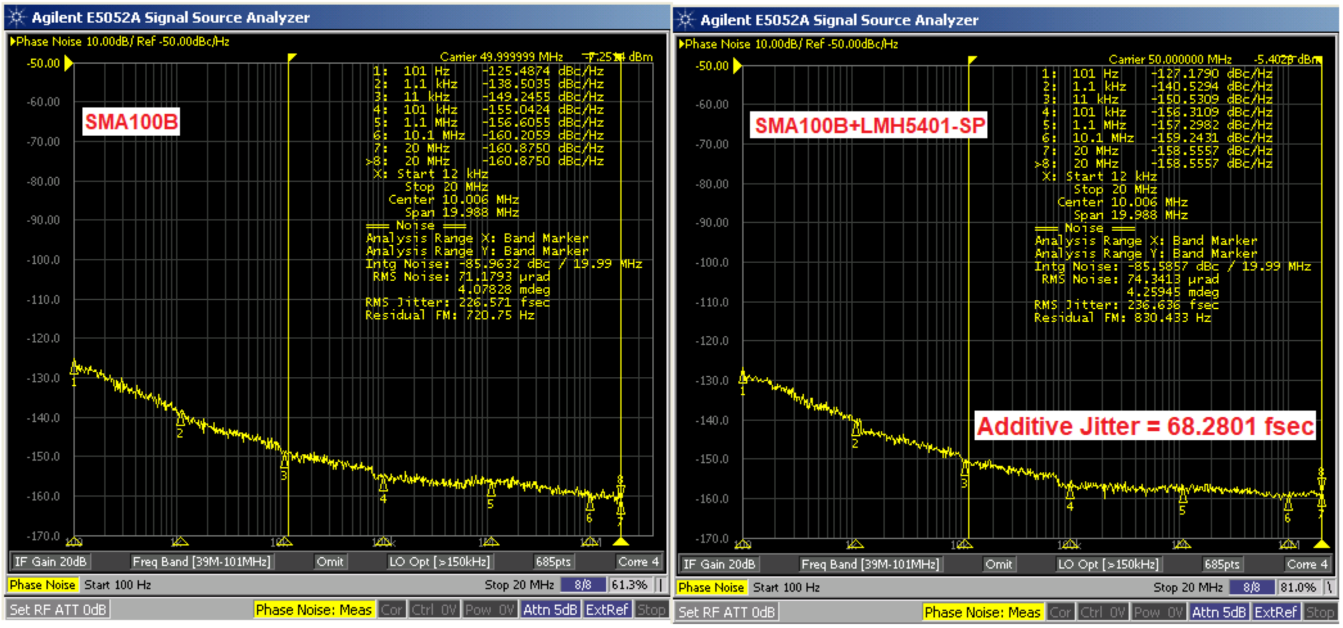


**Figure 10. f=50 MHz, Spurs-Omit**

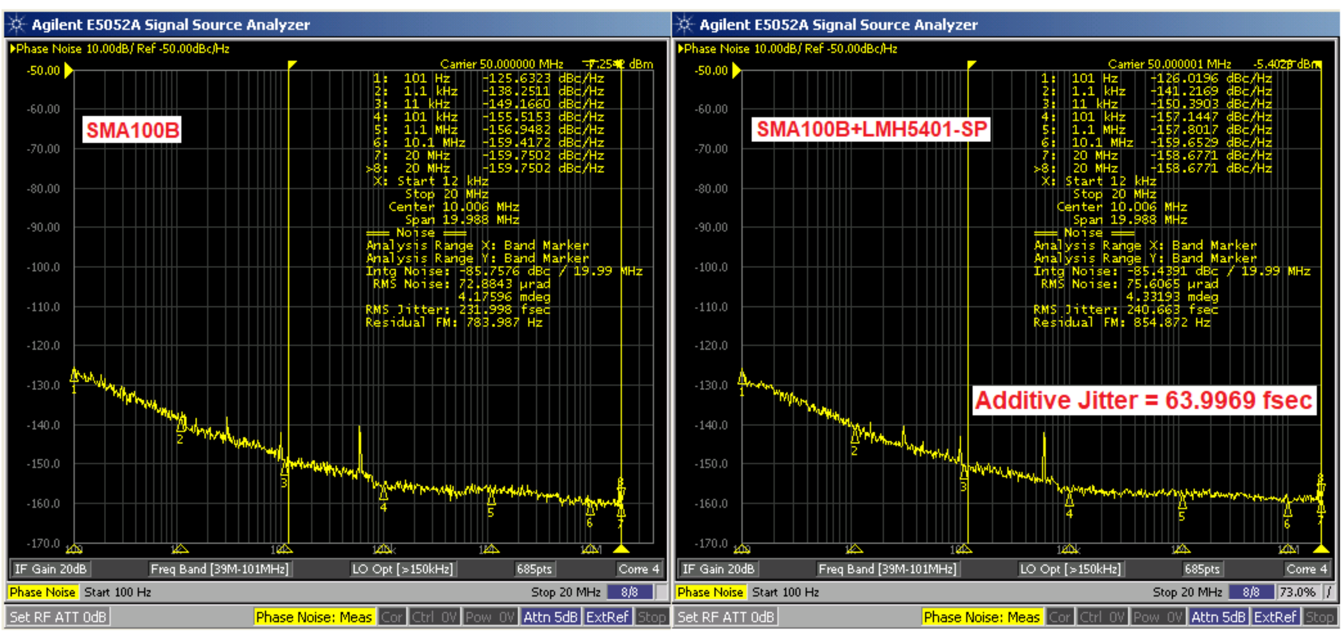


**Figure 11. f=50 MHz, Spurs-Include**

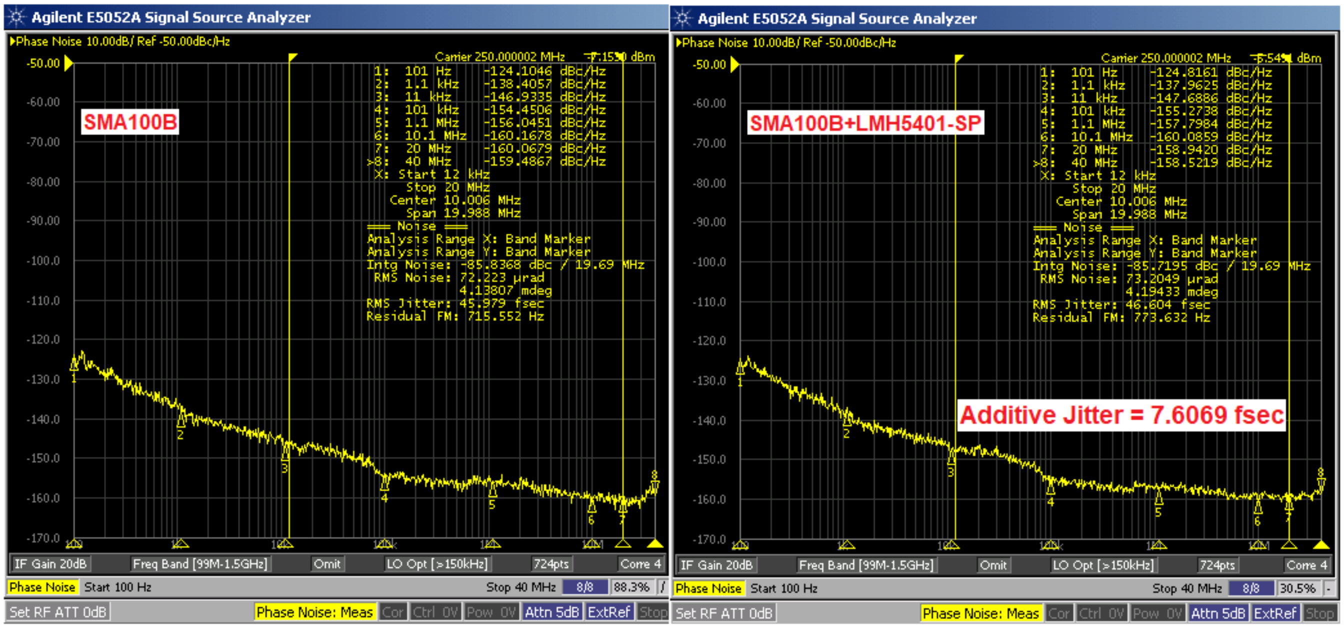


**Figure 12. f=250 MHz, Spurs-Omit**

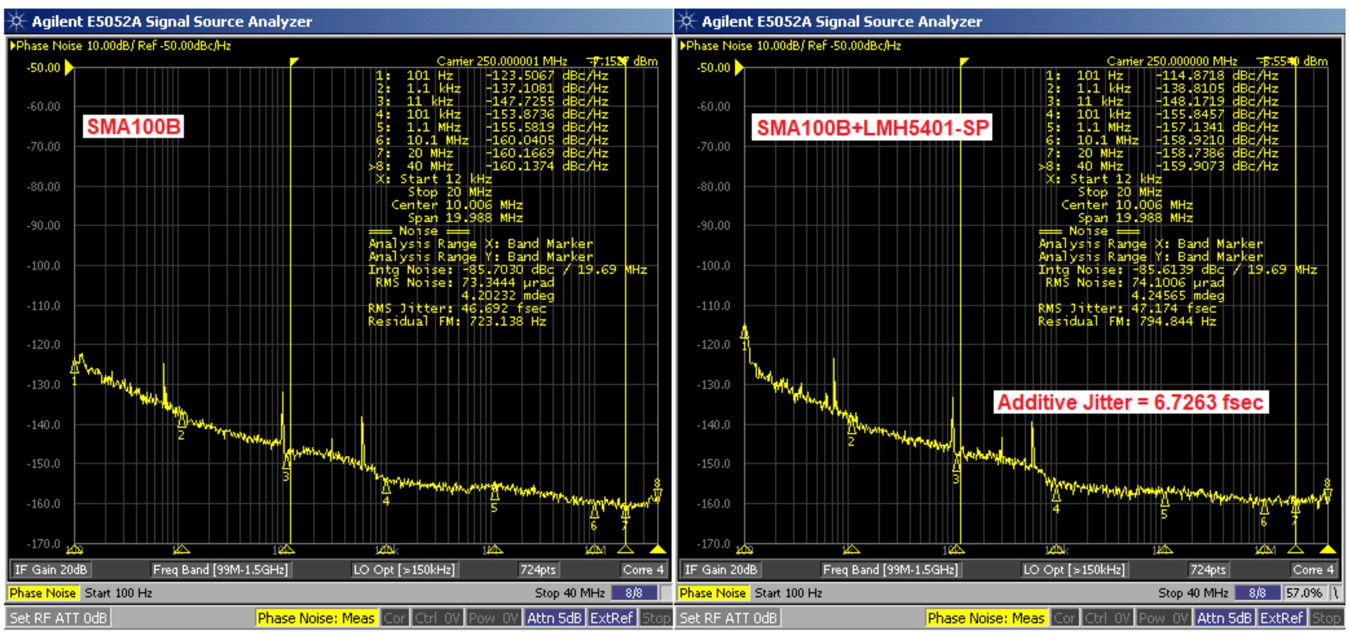


**Figure 13. f=250 MHz, Spurs-Include**

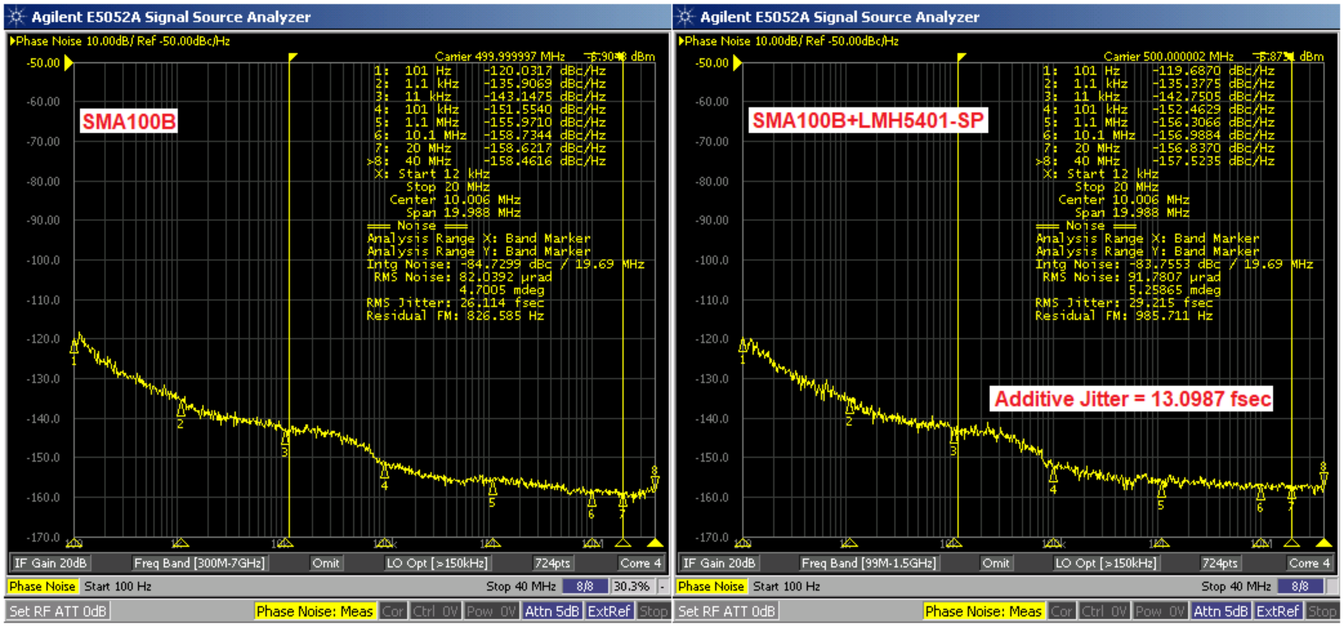


**Figure 14. f=500 MHz, Spurs-Omit**

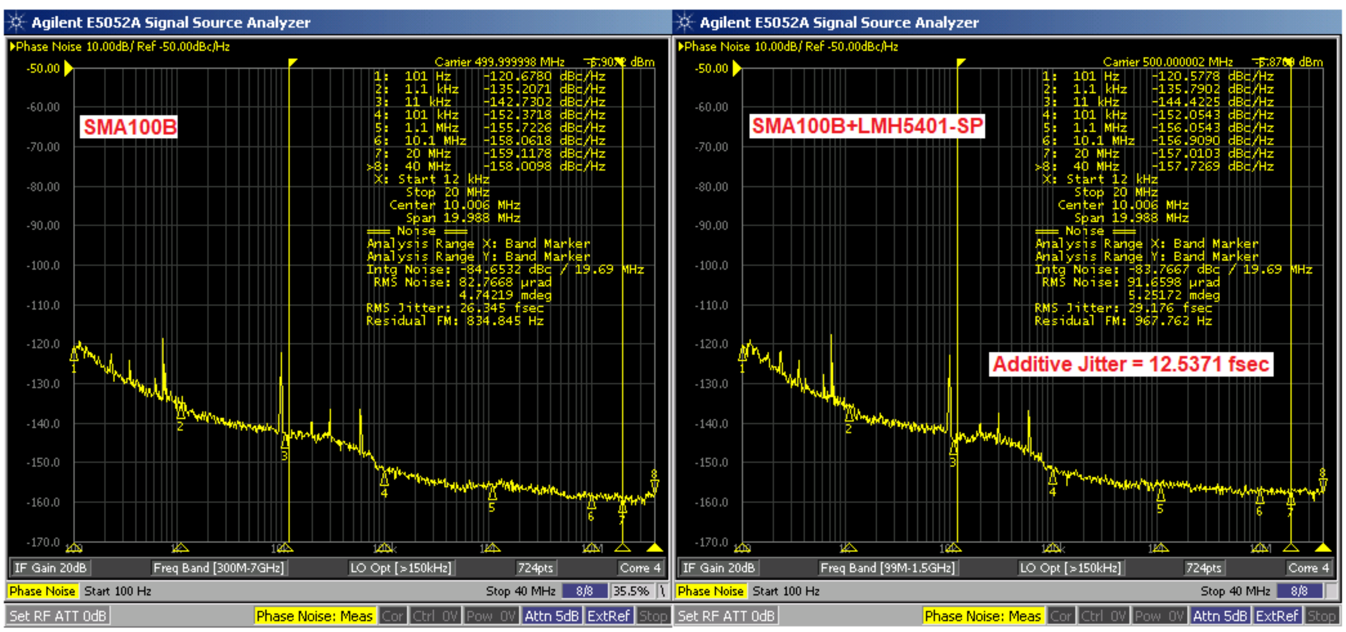


**Figure 15. f=500 MHz, Spurs-Include**

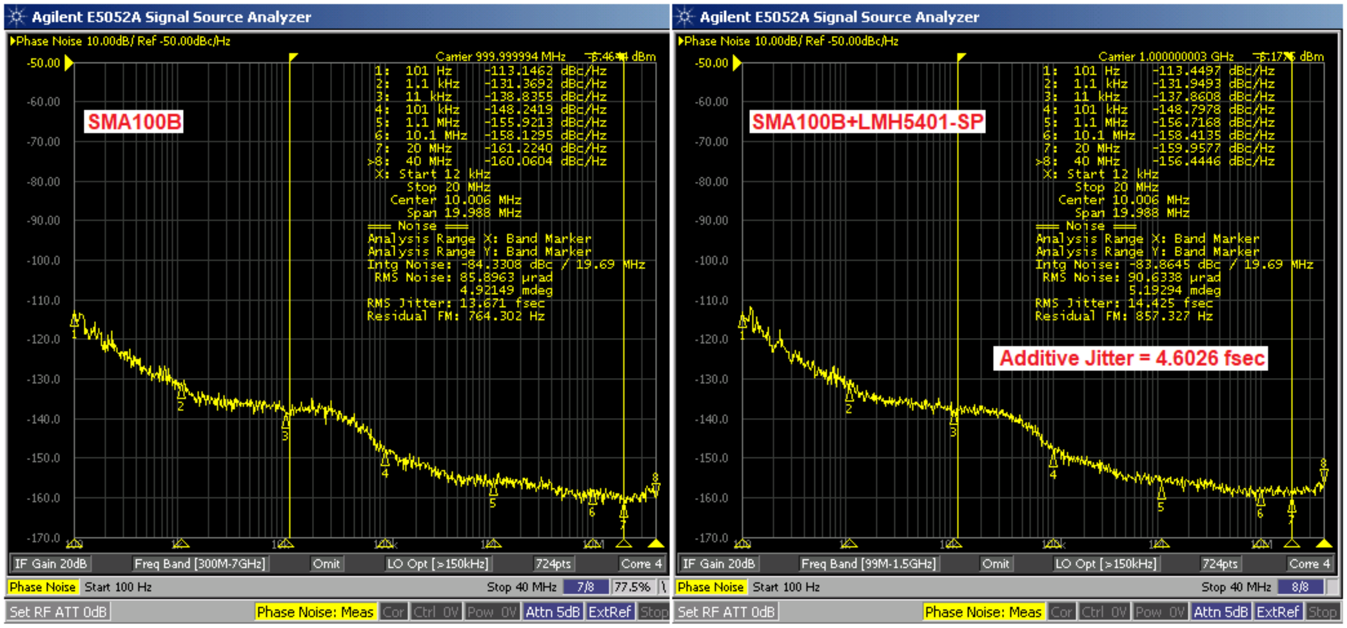


**Figure 16. f=1000 MHz, Spurs-Omit**

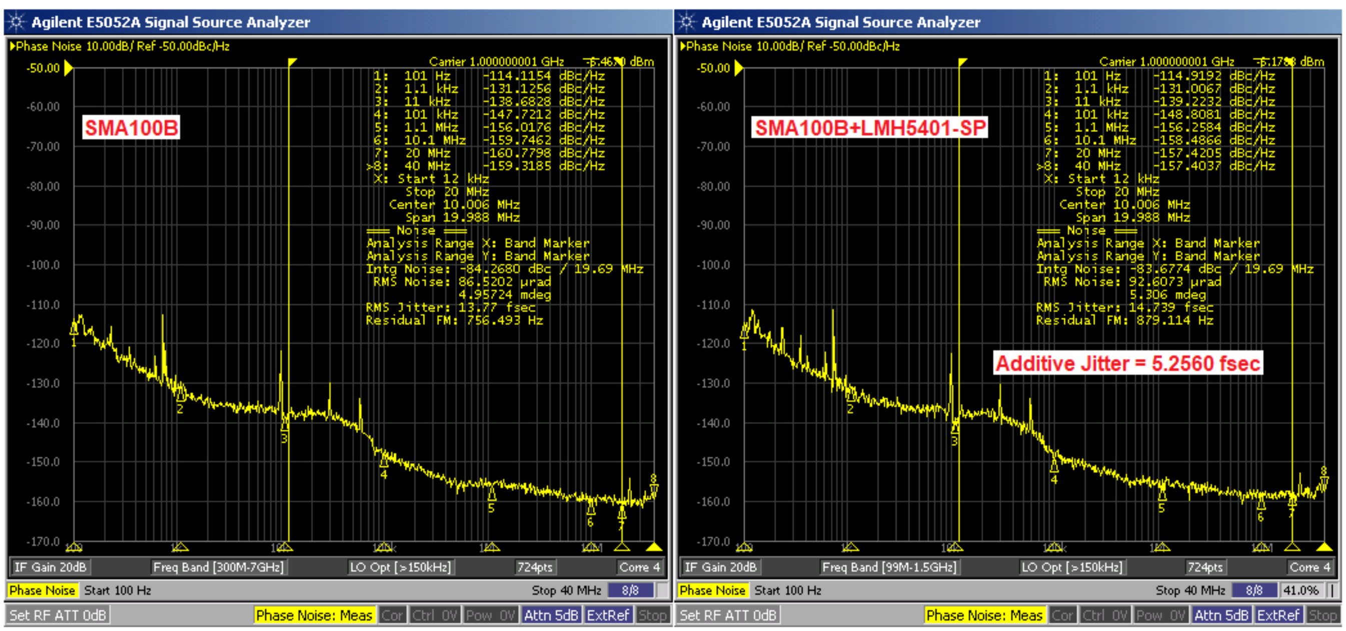


**Figure 17. f=1000 MHz, Spurs-Include**

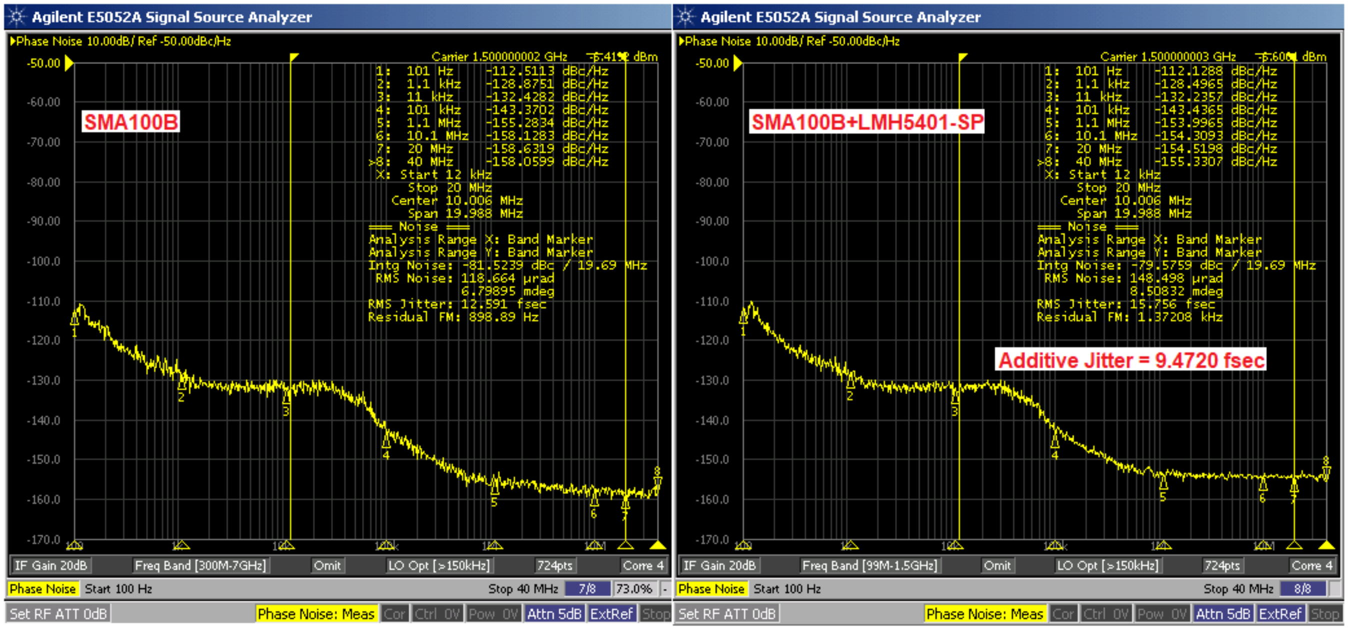


**Figure 18. f=1500 MHz, Spurs-Omit**

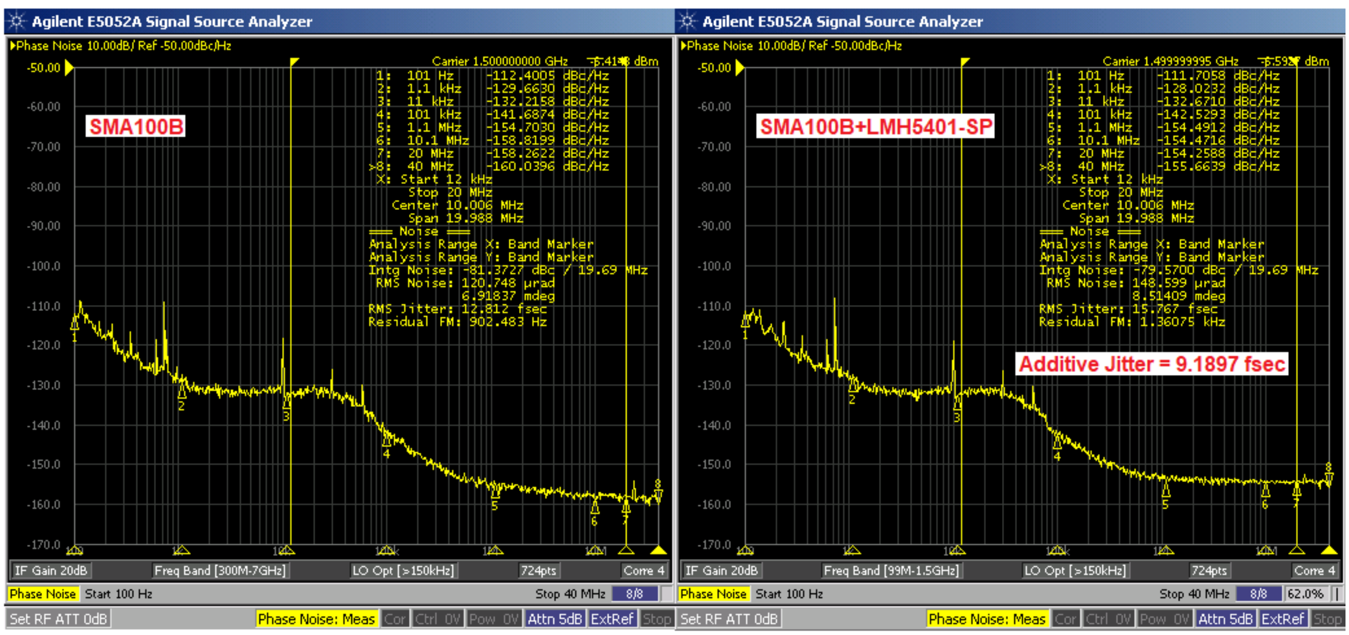


**Figure 19. f=1500 MHz, Spurs-Include**

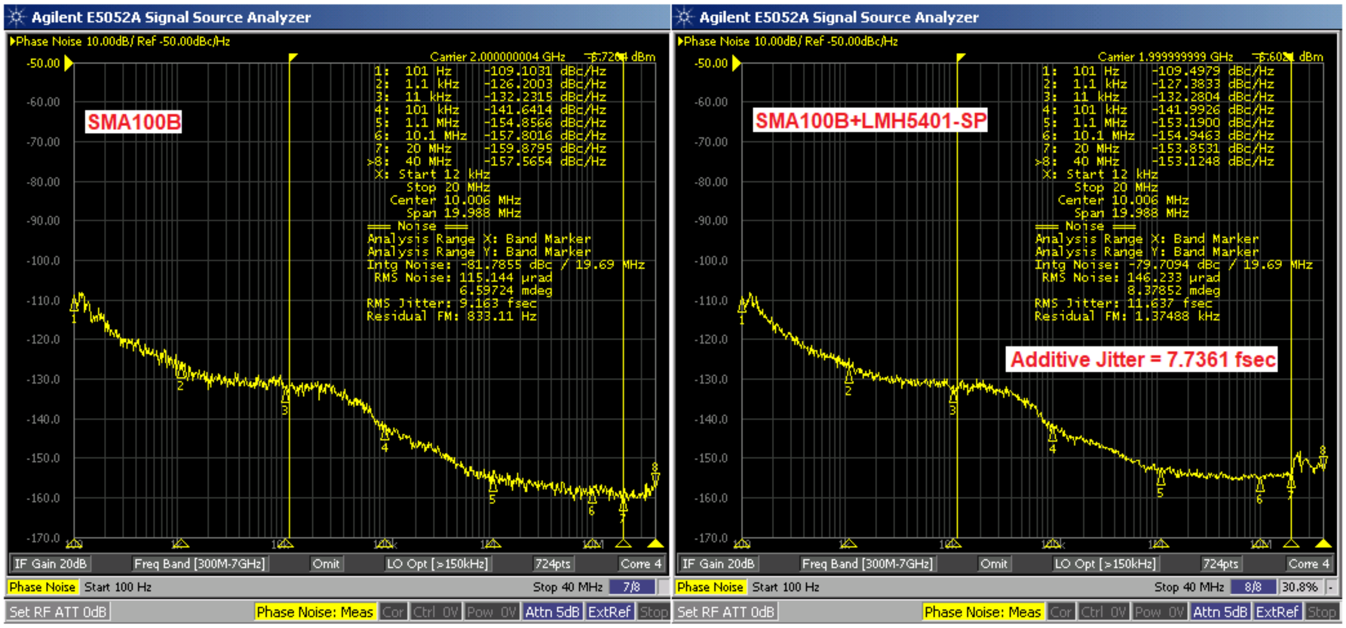


**Figure 20. f=2000 MHz, Spurs-Omit**

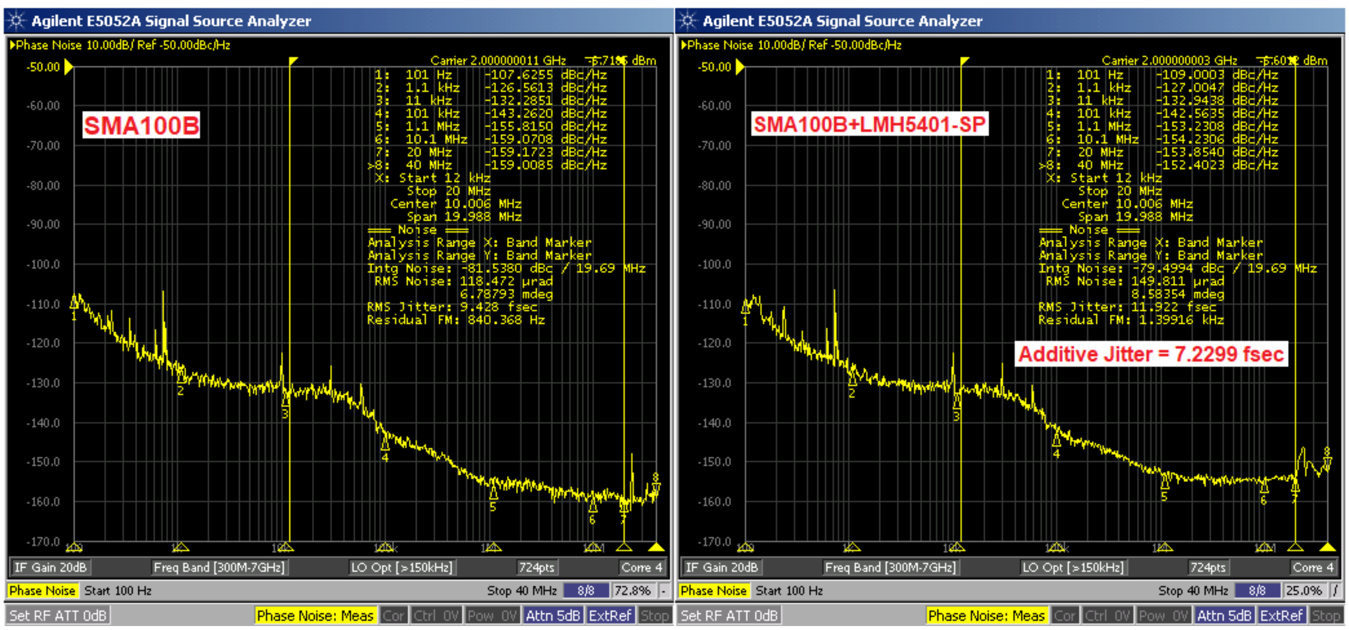


**Figure 21. f=2000 MHz, Spurs-Include**

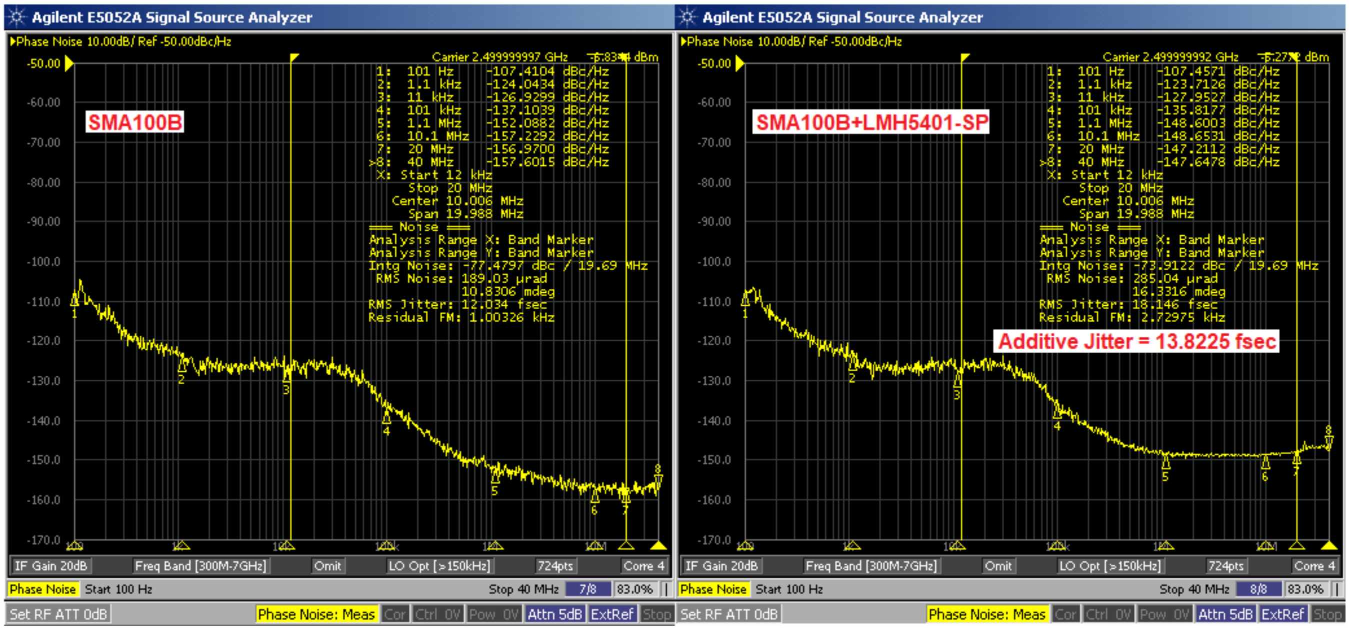


**Figure 22. f=2500 MHz, Spurs-Omit**

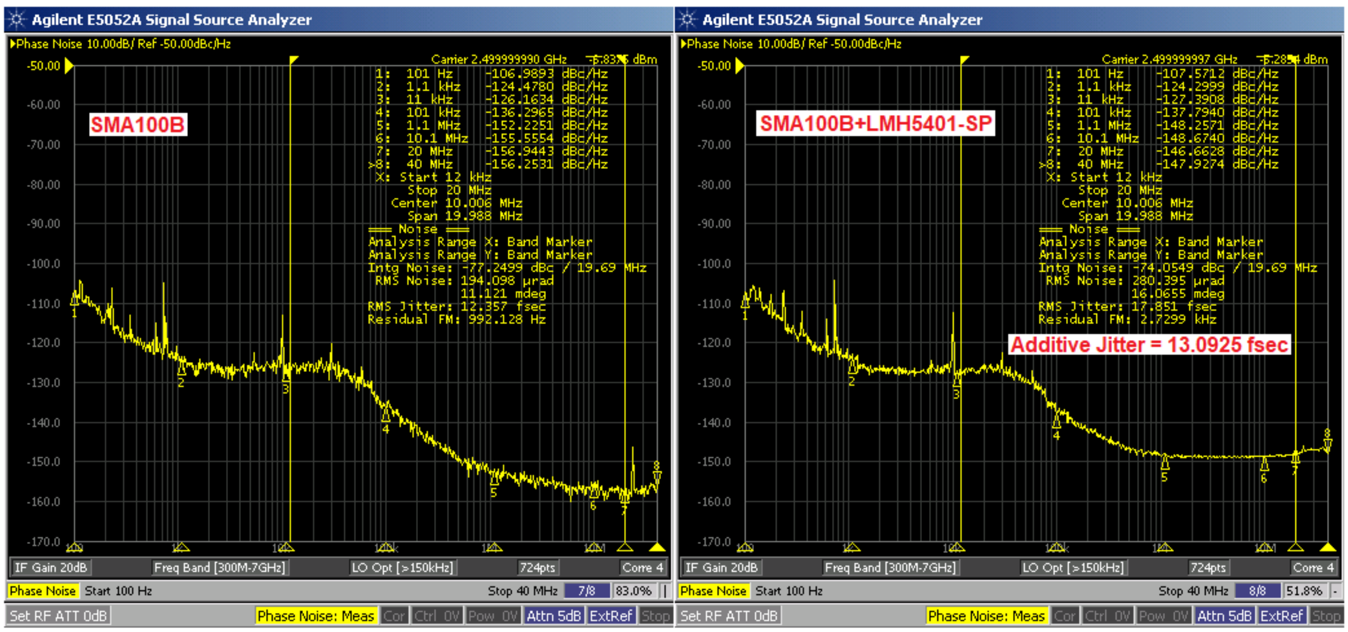


**Figure 23. f=2500 MHz, Spurs-Include**

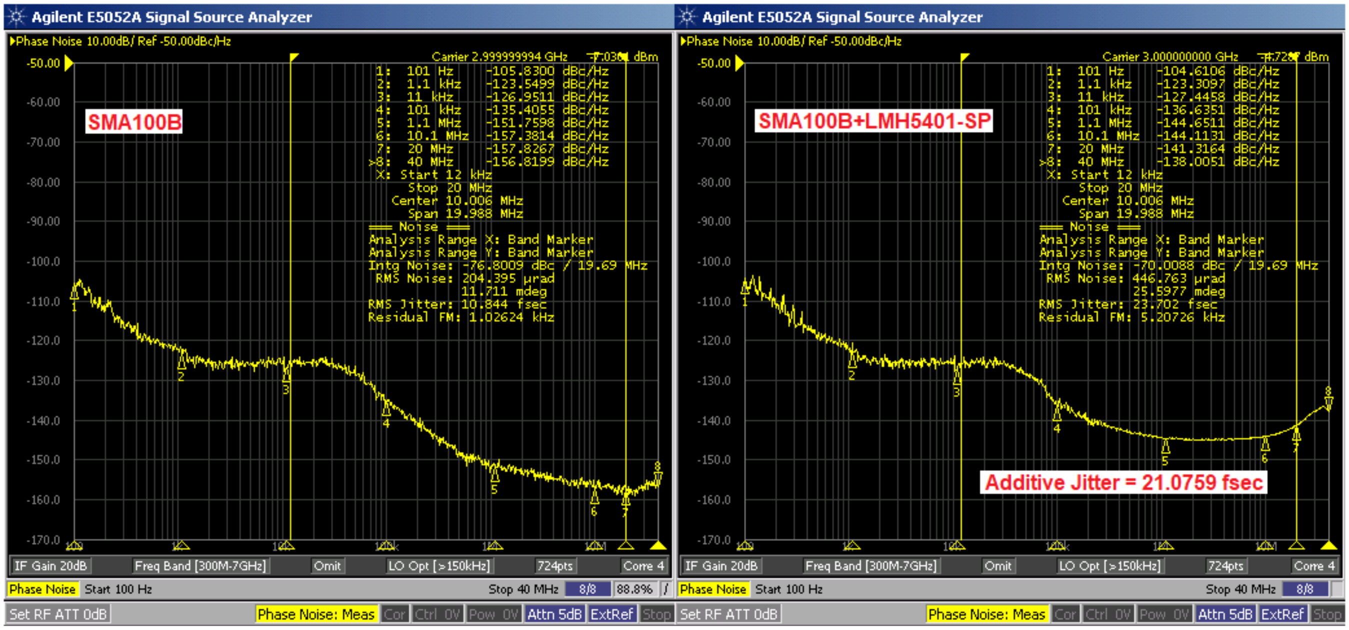


**Figure 24. f=3000 MHz, Spurs-Omit**

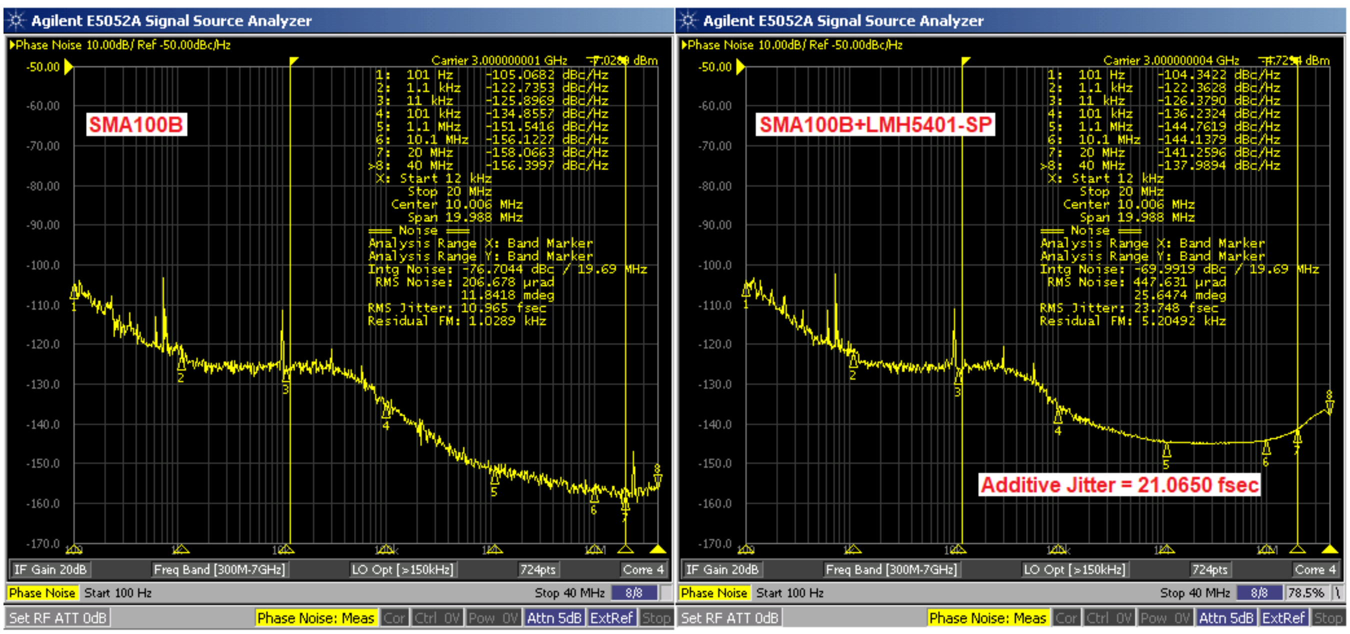


**Figure 25. f=3000 MHz, Spurs-Include**

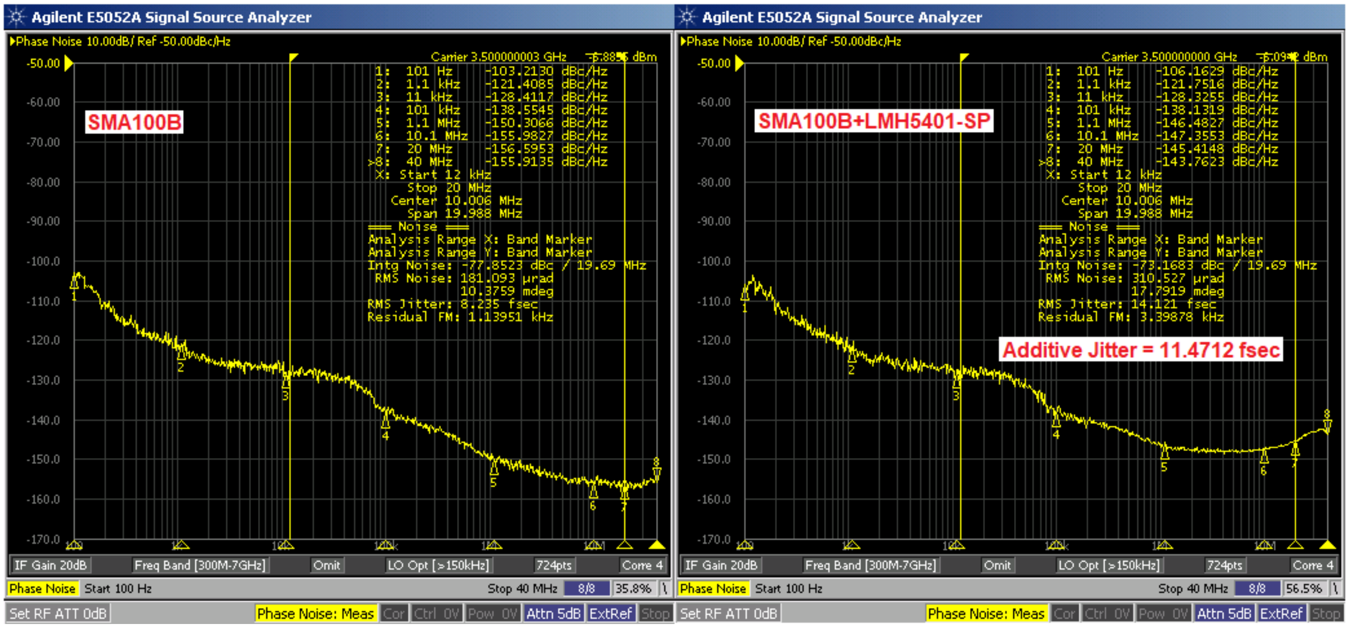


**Figure 26. f=3500 MHz, Spurs-Omit**

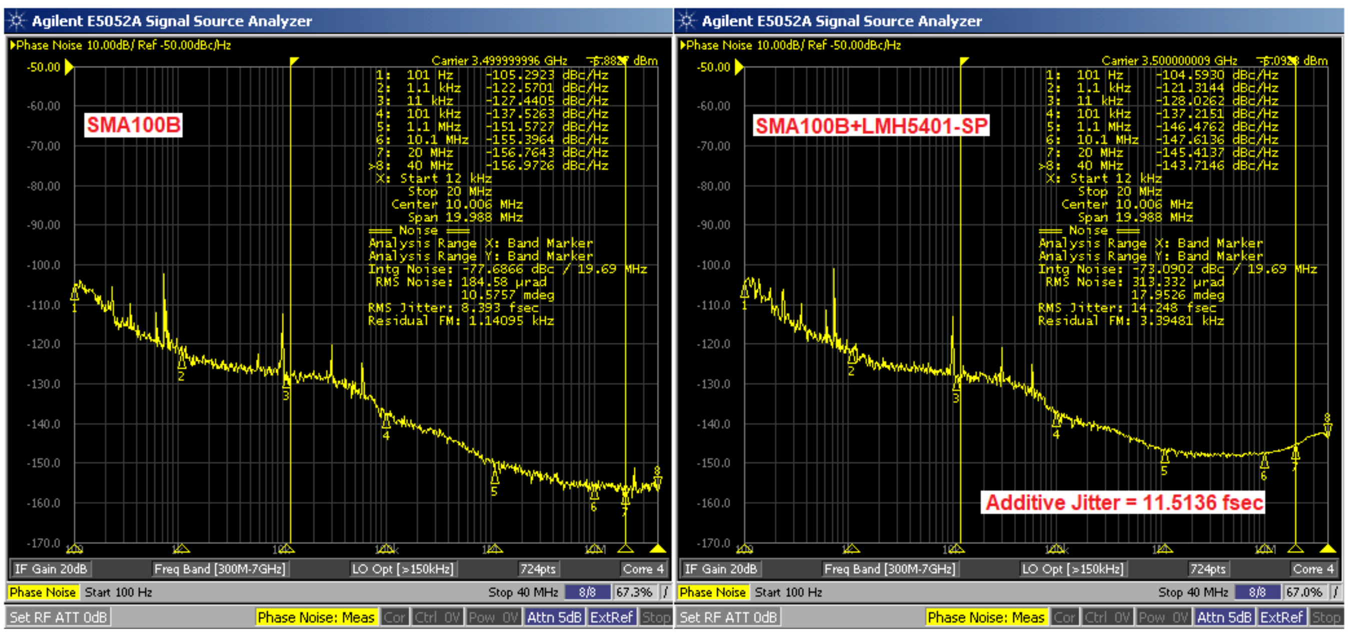


**Figure 27. f=3500 MHz, Spurs-Include**

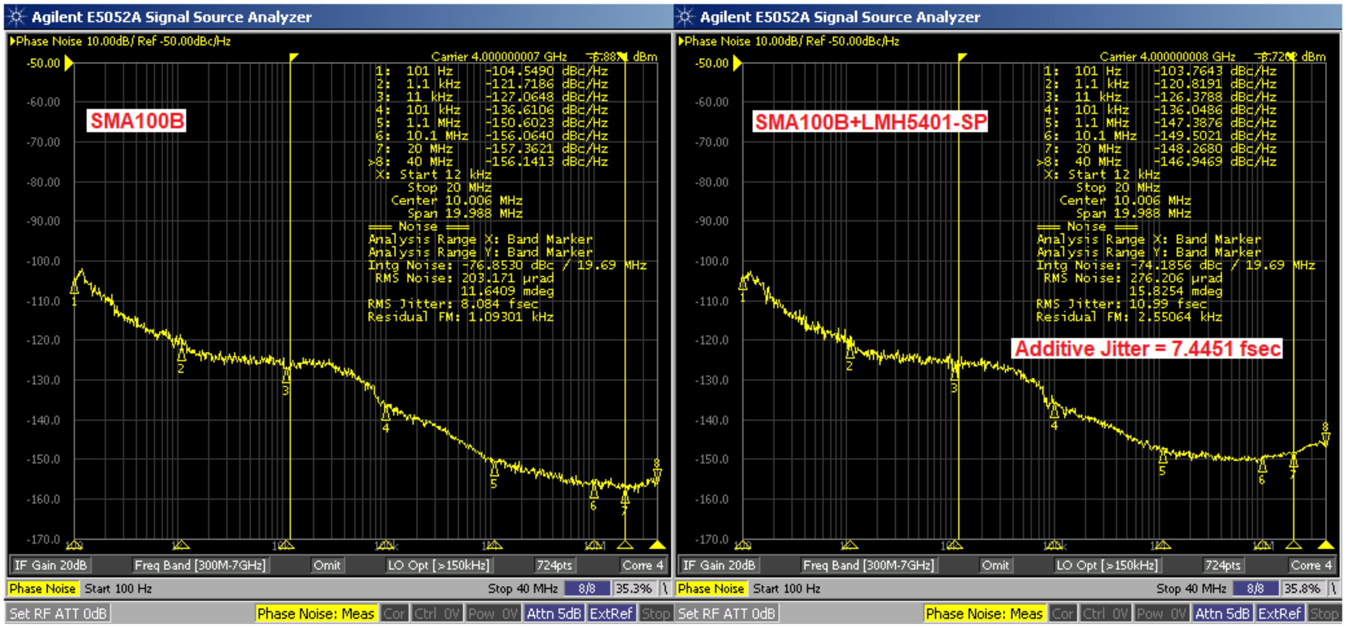


**Figure 28. f=4000 MHz, Spurs-Omit**

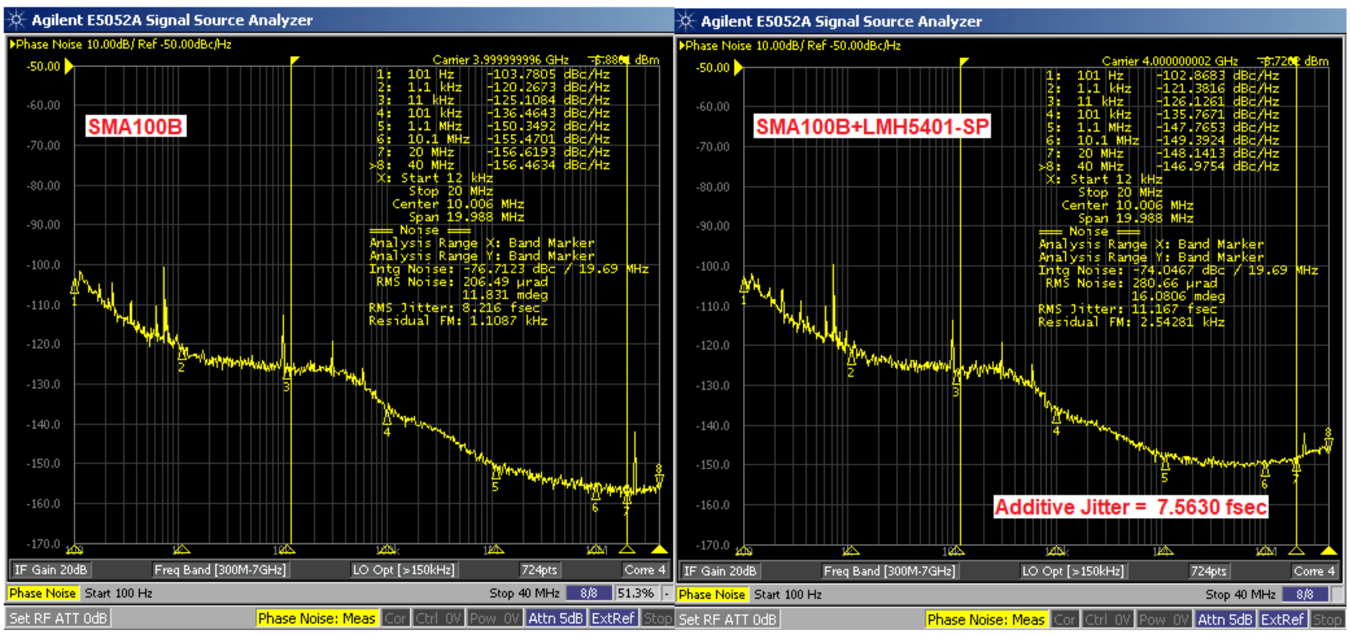


**Figure 29. f=4000 MHz, Spurs-Include**

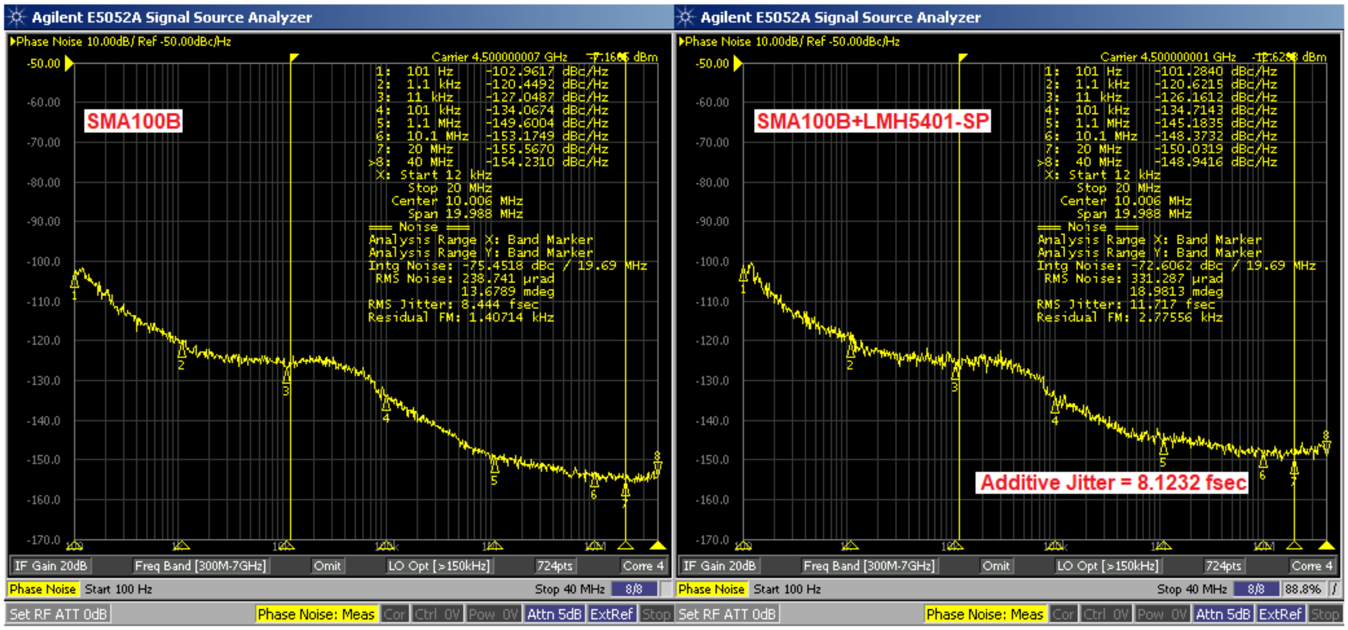


**Figure 30. f=4500 MHz, Spurs-Omit**

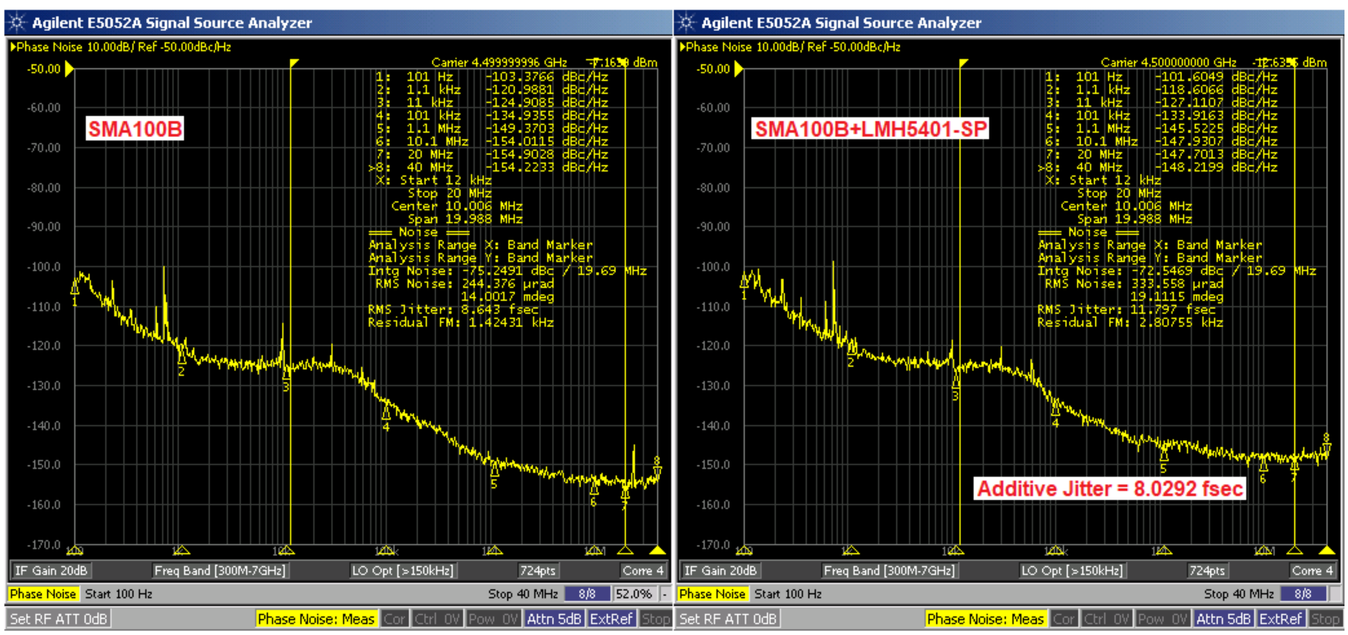


**Figure 31. f=4500 MHz, Spurs-Include**

## Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

| Changes from Original (February 2019) to A Revision | Page |
|---|---|
| • Changed the title. | 1 |

## IMPORTANT NOTICE AND DISCLAIMER