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# Report to Lincoln Labs on TWPAs

J. Dubois, G. Carosi, N. Woollett, E. Holland, M. Horsley, D. Qu, N. Materise, O. Drury, G. Chapline, S. Friedrich

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# Report to Lincoln Labs on TWPAs

09/26/17

Draft v2

Jonathan Dubois on behalf of LLNL Quantum Sensors Team*

Gianpaolo Carosi, Nathan Woollett, Eric Holland, Yaniv Rosen, Matt Horsley, Dongxia Qu, Stephan Friedrich, Nick Materise, Owen Drury, George Chapline

This past spring LLNL's Quantum Sensor's team received two TWPA amplifiers from Lincoln Labs along with a data-sheet explaining handling, operations and expected performance. Here we will outline some of the initial tests performed on this amplifiers as part of LLNL's Quantum Sensors Strategic Initiative (QSSI). Initial testing confirmed that both amplifiers worked and provided gain and SNR improvement similar to that called out in the data-sheets provided.

<u>Amplifiers Tested</u>

**Amplifier #1: W8-C1_#1 (Package #643)**

**Amplifier #2: W8-G5_#2 (Package #607)**

<u>Cryogenics of Testing Setup</u>

Both TWPAs were tested in a BlueFors XD Dilution refrigerator and were attached to the mixing chamber stage. The TWPAs did not have any magnetic shielding during these initial tests and they were located approximately 2-3 inches away from a set of Quinstar isolators (no mu-metal shielding). 20 dB, 10 dB and 3 dB XMA cryogenic attenuators (2782-6418-20-CRYO, 2782-6051-10-CRYO, and 2082-6418-03-CRYO) were used on the input lines for the signals and pump tone. K&L Microwave 1-12 GHz bandpass filters (6L250-12000/T26000-O/O) were placed on the mixing chamber portion of the input lines before the TWPA.

The initial tests were with the TWPA amplifier mounted to a cold finger attached to the mixing chamber with a Marki (Part #: C20-0116) directional coupler added to the opposite side of the cold finger in order to couple in the pump-tone with any signals.

The RF chain layout:

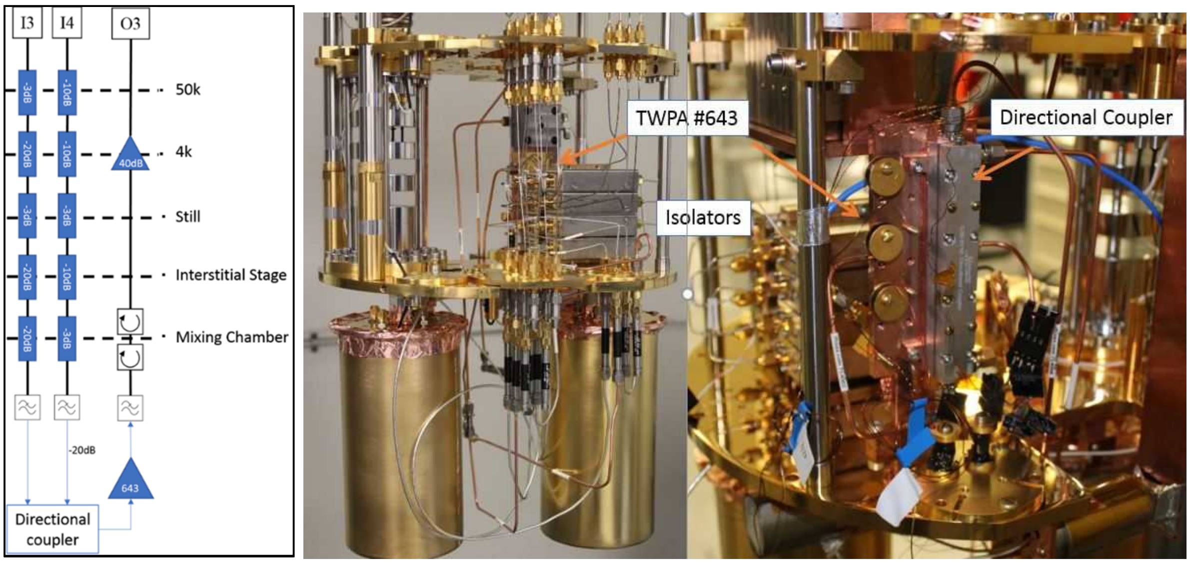



*Figure 1: Initial RF characterization layout with signal line I3, TWPA pump tone line I4, and output line O3. Mixing Chamber temperature was typically < 10 mK. Middle and Right figures show the location of the TWPA and the directional coupler on the cold-finger mounted to the top of the mixing chamber.*

Room-temperature Electronics

The VNA used was a Keysight E5063A and the initial pump source was a Keysight MXG N5381B signal generator. An Agilent MXA N9020A Signal Analyzer was used to look at the SNR improvement measurements.

Initial Testing

The initial tests were performed with a straight pass through of the TWPA mounted to the mixing chamber. Follow up tests included resonators in the lines directly before the TWPA.

Figure 1 shows the first tests on amplifier #607 which verified that it was operating as an amplifier. Figure 1 is a VNA sweep with input pump frequency at 6.135 GHz with approximately -66 dBm at the input to the TWPA (pump power at Keysight = 3.10 dBm with approximately 66 dB of attenuation + 3 dB room-temp cable).

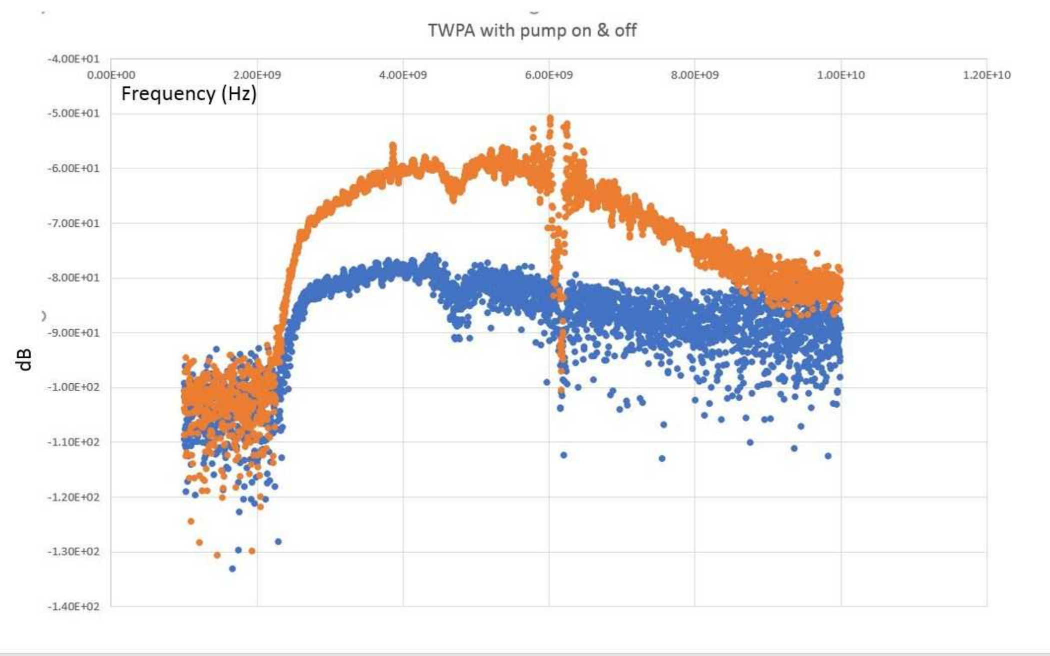



*Figure 2: Swept signal through TWPA #607 with pump off (Blue) and on (Orange). Initial gain of approximately 20 dB (before subtraction of insertion loss) was verified*

<u>Testing with TWPA #643</u>

Initial VNA sweep with high power (-5 dBm out of VNA or approximately -74 to -80 dBm at the input to the TWPA after accounting line loss and attenuation).

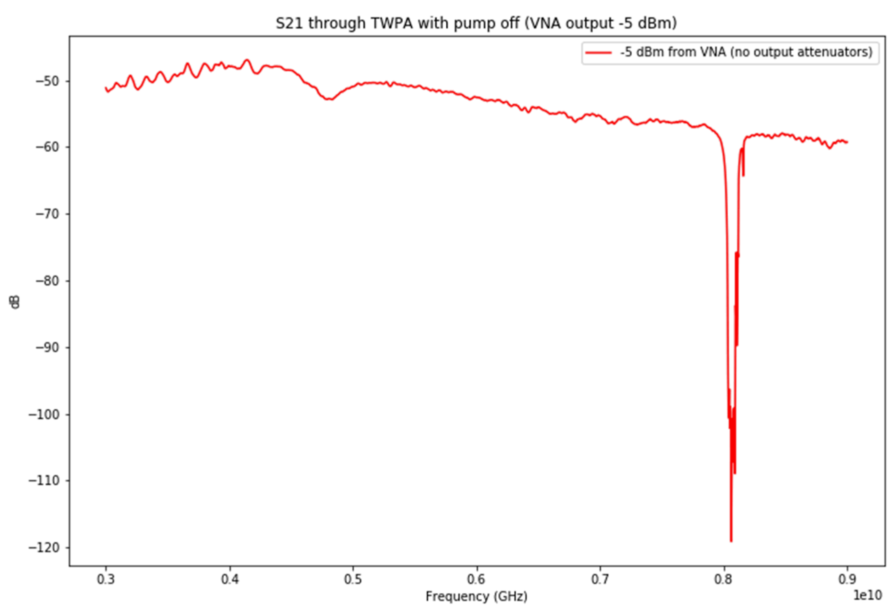



*Figure 3: High power VNA sweep from 3 - 9 GHz through TWPA #643*

We then added an additional 40 dB of room temperature attenuation to the input line in order to bring the input swept power below -106 dBm at the TWPA input (below the anticipated 1 dB compression point). Pump was set to the initial frequency provided by the data-sheet of 7.9591 GHz and swept through various pump powers. Highest gain achieved at 7.2 dBm output from Keysight MXG signal generator.

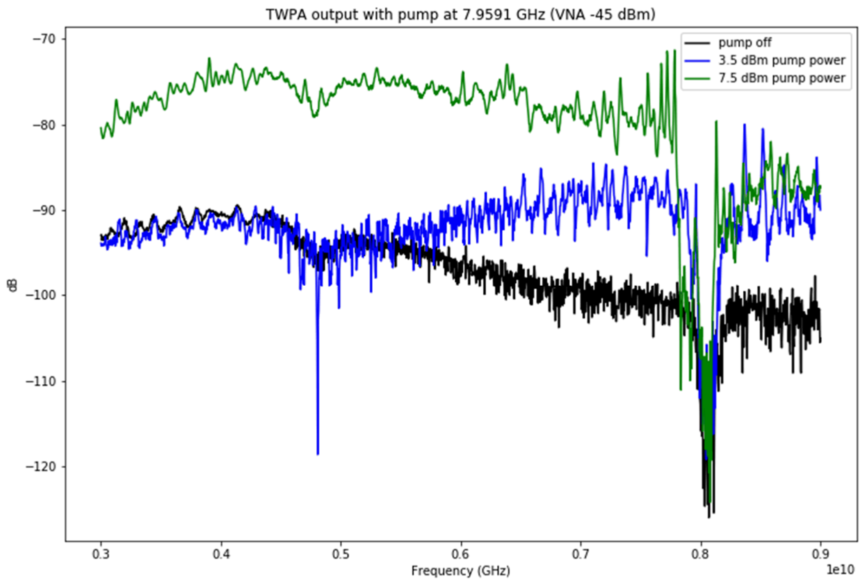



*Figure 4: Signal through the TWPA from VNA with different pump powers*

We then looked at a zoomed in region around 6 GHz to look at the overall gain (without accounting insertion loss of the TWPA with no pump tone).

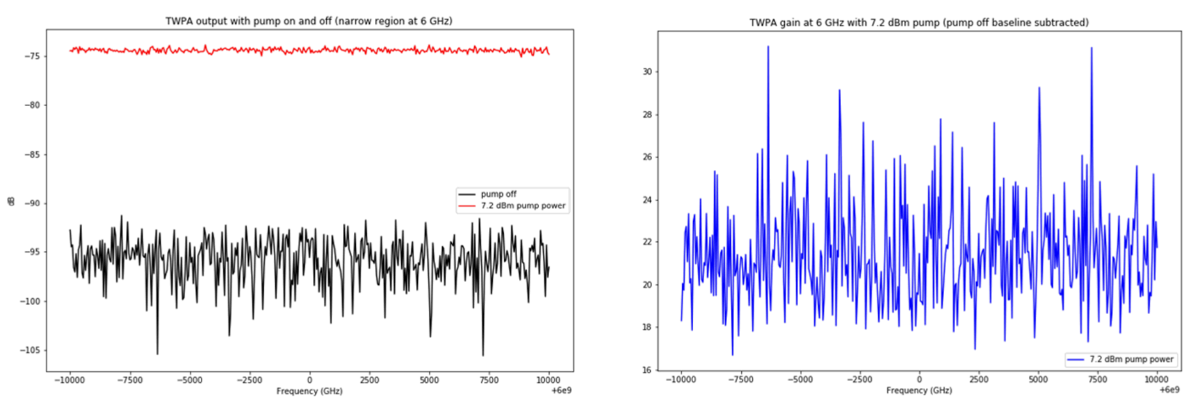
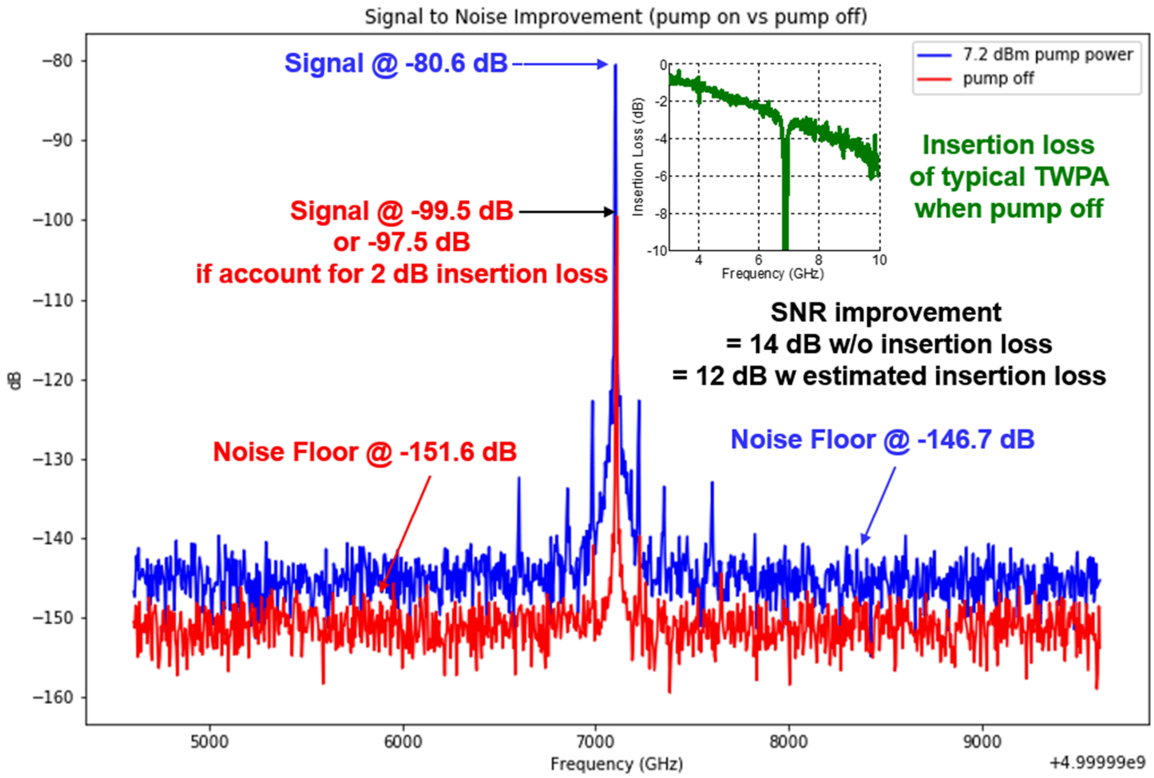



*Figure 5: Swept signal around 6 GHz with pump on vs off and the difference indicating gain*

We then used a Labbrick signal generator at 5 GHz to perform a Signal-to-Noise improvement check with the TWPA on vs off.




This figure showed an approximate 12 dB SNR improvement once accounting for the typical insertion loss of 2 dB at 5 GHz. The LNF amp has an expected noise temp of 3 K.

We then performed sweeps of the pump frequency with pump power set to a few dB below the optimal at 7.2 dBm (see figure 5). The pump power was also varied with the tone at 7.9591 GHz (see figure 6). Since it appeared that optimal gain was seen at lower power frequency the pump-power sweep was repeated for a pump frequency of 7.92 GHz.

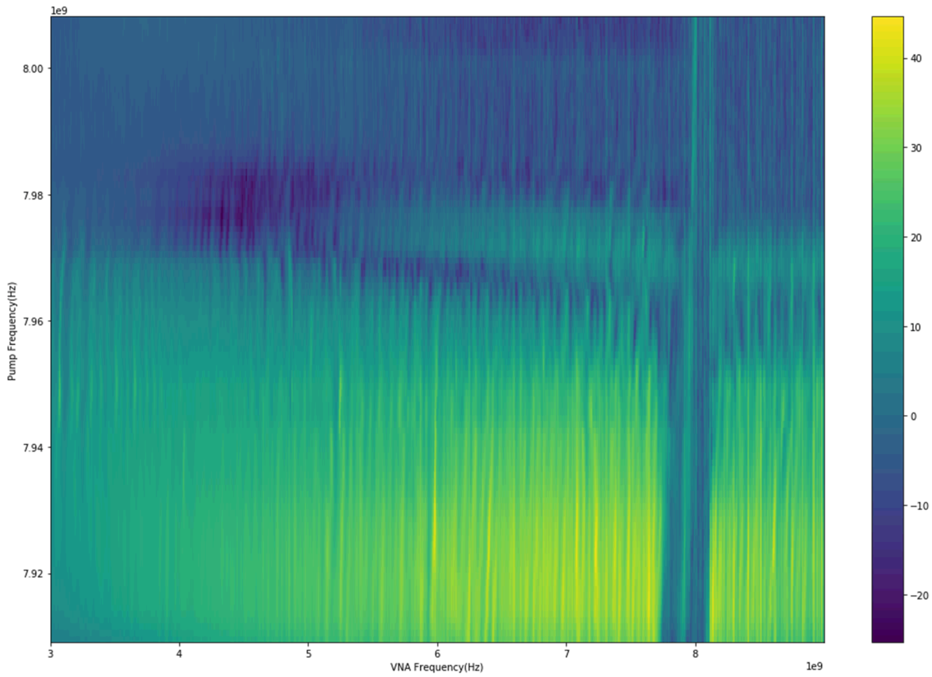



*Figure 6: Gain vs various pump tone frequencies. Frequency was varied between 7.91 and 8.01 GHz*

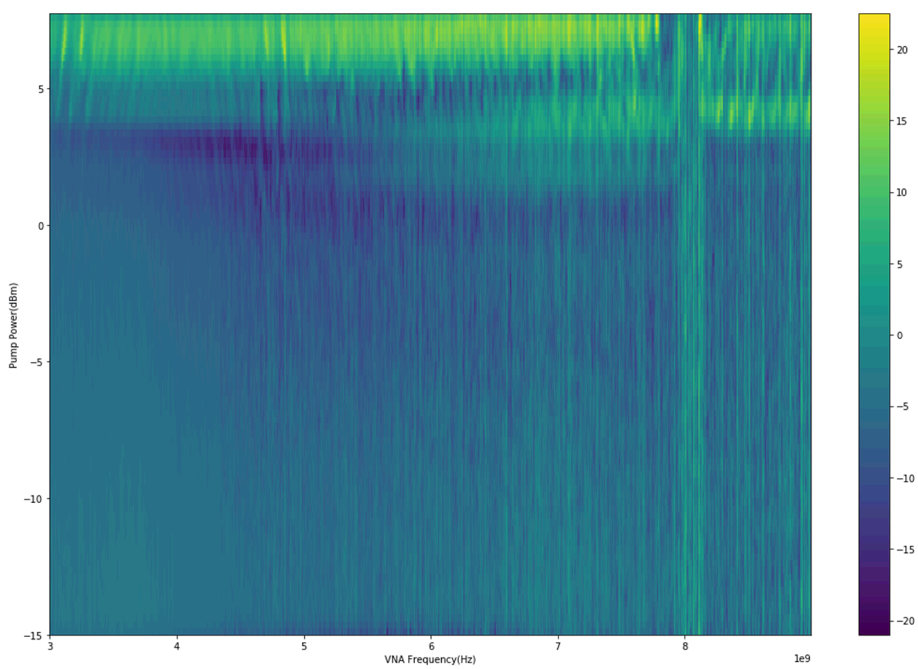



*Figure 7: Pump frequency at 7.9591 GHz power was swept from -15 dBm to 8 dBm with optimal gain around 7.2 dBm*

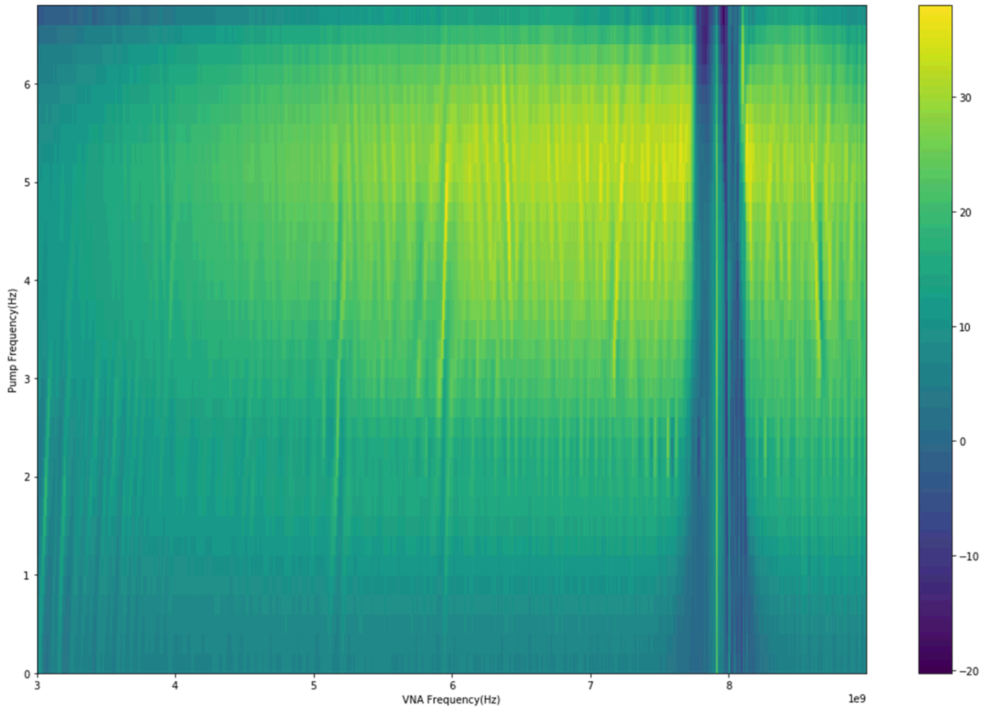



*Figure 8: Gain with pump frequency at 7.92 GHz and pump power varied between 0-7 dBm from source.*

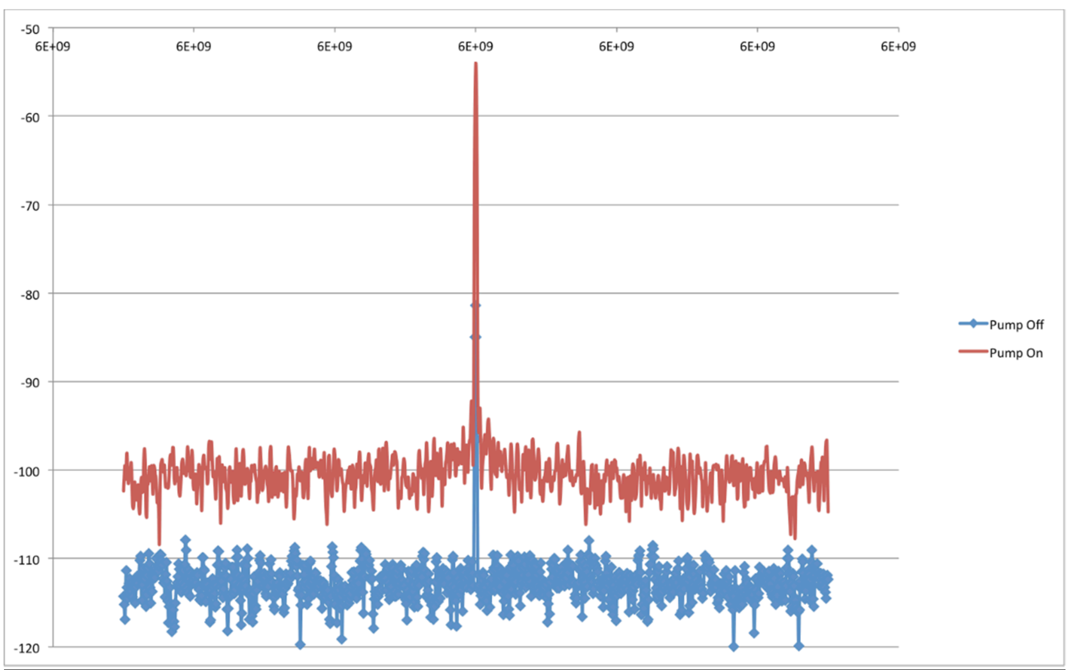



*Figure 9: SNR measurements with TWPA 643 pump on vs off. Get approximately 16 dB SNR improvement at 6 GHz. Saw 30 dB of gain (or 27 dB with the subtraction of the expected 3 dB of insertion loss at 6 GHz). TWPA pump at 7.92 GHz and 5.00 dBm.*

Comparison of different pump sources (Keysight versus Holtzworth)

We performed a direct comparison of TWPA # mounted on the output of a chain of resonators with a Keysight MXG and Holzworth HS9004A Signal Generator.

The outputs on both signal generators was set to a frequency of 7.92 GHz and output power at -7dBm. Gain was generally about 4 dB higher for the Holtzworth however this could be due to a slight variation on pump tone power from each of the signal generators. Future tests will calibrate each output with a room temperature spectrum analyzer ahead of the comparison.

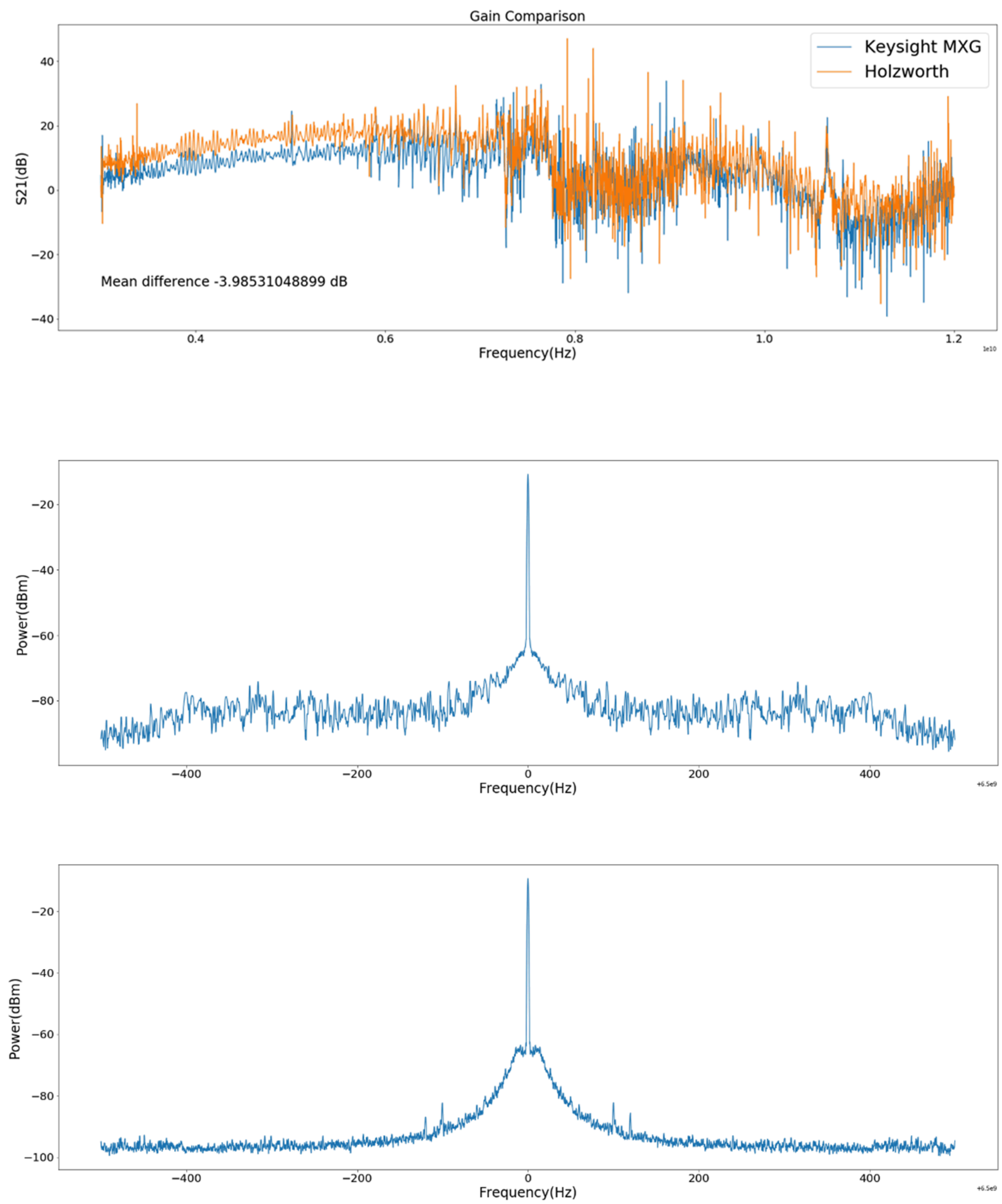



*Figure 10: Comparison of the pump-tones from the Keysight MXG (top) and the Holzworth HS9004A (bottom).*

**Initial Conclusions:**

The TWPAs provided by Lincoln Lab provide gain and signal to noise improvement similar to that listed in their data-sheets. The pump-tones optimal frequency and power are slightly different than listed but this is likely due to the operating conditions of our testing set up. This report will be updated as future tests are performed.