Two Stage WiFi 5GHz to 10GHz XBand Communication System

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Abstract

The up conversion of a 5GHz WiFi signal to 10.56GHz IF signal enables the transmission of the WiFi signal at XBand frequencies for high throughput digital communications over XBand. The XBand signal can be up converted from the 10.56GHz XBand signal to 60 GHz or 28 GHz bands. It is imperative that the WiFi channel be centered at a specific frequency, for example, 10.56GHz, for optimal performance and to meet ITU an FCC band allocation requirements. In addition, the WiFi channel centered at 10.56GHz must be interference (jammer) free so that the over the air signal is jammer free, a key requirement. The XBand Spectrum is also available for Amateur Extra Class from 10.0GHz to 10.5GHz so the capability to center the frequency is critical. This paper describes the challenges in up converting and down converting WiFi signals at 5GHz to X-Band and offers a unique solution that provides a jammer free spectrum and capability to dial in the center frequency. A complete system was designed, prototyped and built, verifying the design over the air. IEEE802.11ac Access Points were used at 5.21 GHz with a bandwidth of 160 MHz. This work paves the way for high throughput digital communication over XBand links links with bandwidths of 80MHz and 160MHz.

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Table of Contents

List of Figures

1 Introduction

The up conversion of a 5GHz WiFi signal to 10.56GHz IF signal enables the transmission of the WiFi signal at XBand frequencies [1] for high throughput digital communications over XBand. The XBand signal can be up converted from the 10.56GHz IF signal to, for example, the 60 GHz or 28 GHz bands. It is imperative that the WiFi channel be centered at a specific frequency, for example, 10.56GHz, for optimal performance and to meet ITU an FCC band allocation requirements. In addition, the WiFi channel centered at 10.56GHz must be interference (jammer) free so that the over the air signal is jammer free, a key requirement. The XBand Spectrum is also available for Amateur Extra Class from 10.0GHz to 10.5GHz[1] so the capability to center the frequency is critical. Work by Radio Amateurs in the XBand can be seen in [2]. The work in this paper can take it to a whole new level.

This paper describes the challenges in up converting and down converting WiFi signals at 5GHz to X-Band and offers a unique solution that provides a jammer free spectrum and capability to dial in the center frequency. A complete system was designed, prototyped and built verifying the design over the air. IEEE802.11ac Access Points were used at 5.21 GHz with a bandwidth of 160 MHz [3] using OFDM [4]. In the paper, the design of microstrip bandpass filter for 10 GHz and a band stop filter at 8.34GHz are presented.

2 Single Mixer Solutions

A simple single mixer solution that up converts the WiFi channel to 10.56GHz suffers from a number of problems. A high level block diagram of a single mixer up conversion and down conversion system is shown in Figure 1.

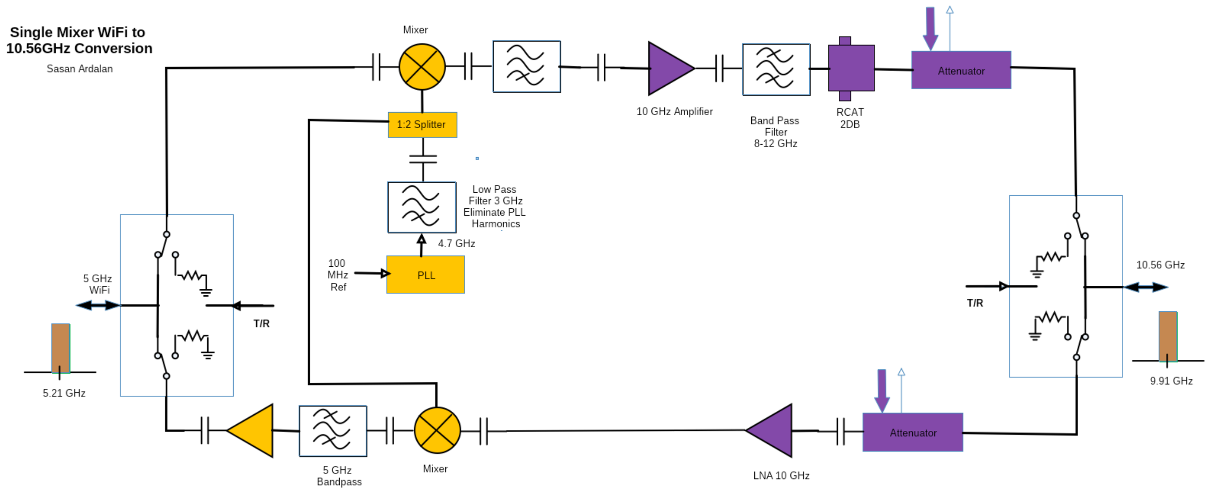

Figure 1 Single Mixer Solution

One key aspect is that we need separation between the PLL Local Oscillator (LO) and the WiFi channel so that the LO leakage can be separated from the WiFi channel when it is up converted. It is not possible to take a WiFi channel (5GHz) and dial it in (or center it) on 10.56GHz without introducing leakage that is very difficult to filter out. The LO leakage will appear at the up converted signal as an interferer (single carrier jammer) and due to its closeness to the desired channel it is very difficult to design a microstrip filter to suppress it.

Besides these problems, a worse problem is that the remote PLL will have a frequency error from the transmitting PLL. This will cause a beat frequency in the received demodulated WiFi signal. This manifests itself in a pulsating constellation and EVM (Video Demonstrations Available). Moving the channel around (again not centered on 10.56GHz) somewhat reduces the effect but puts limits on the channel selection. But due to frequency errors there is no way to solve this problem with the single mixer approach. More accurate 100 MHz reference sources (expensive) can also reduce the impact. We must note that the single mixer beat frequency problem is not to be confused with frequency offset correction in OFDM WiFi systems [5,6]. We will comment on this important fact later.

In Figure 2 we present a Capsim® [7] simulation of the beat frequency issue in single mixer approach. In Figure 3, we compare the time domain signals with and without frequency error.

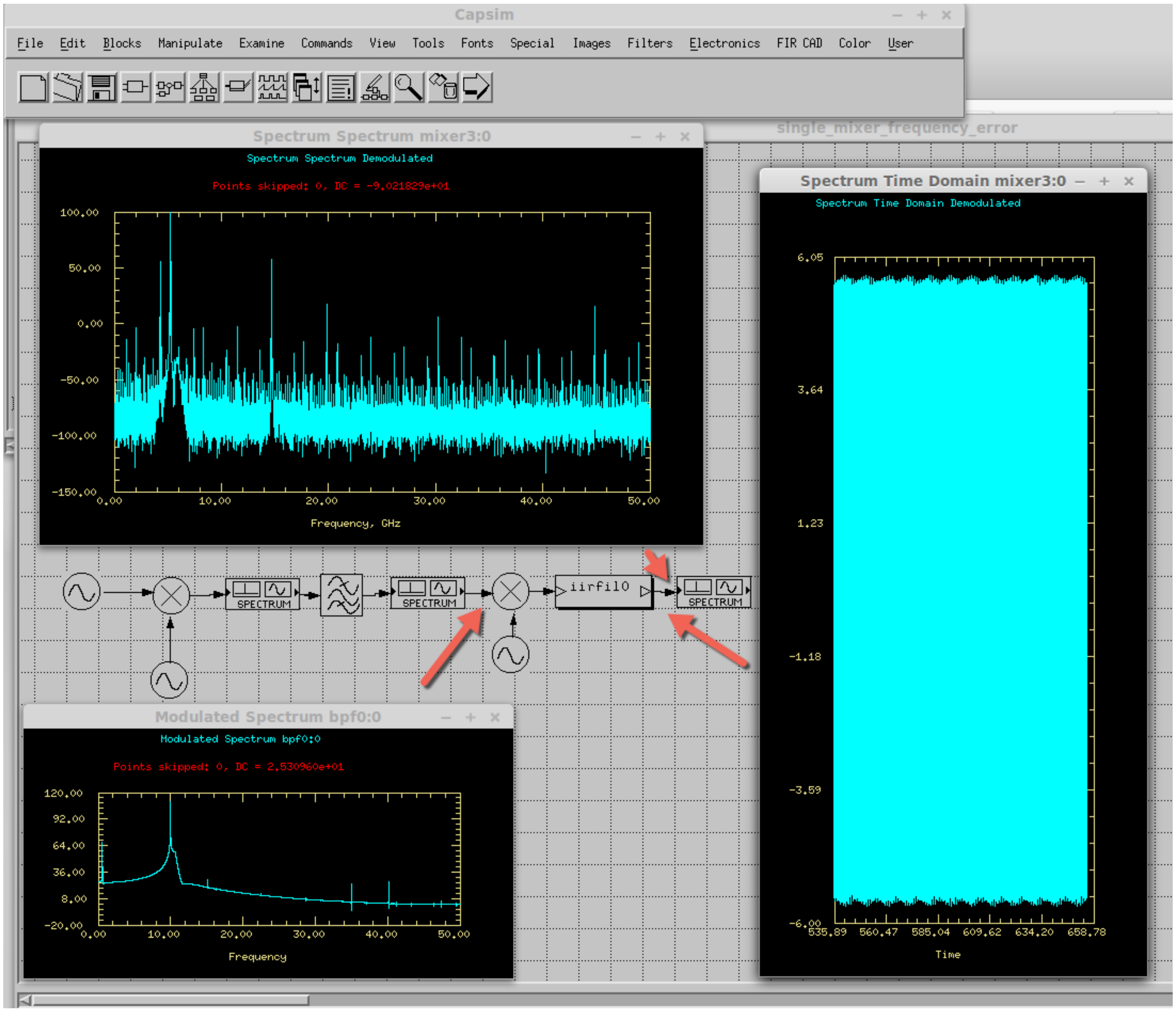

Figure 2 Capsim® Simulation Single Mixer With Frequency Error

In an OFDM system this will result in a pulsating Constellation and EVM.

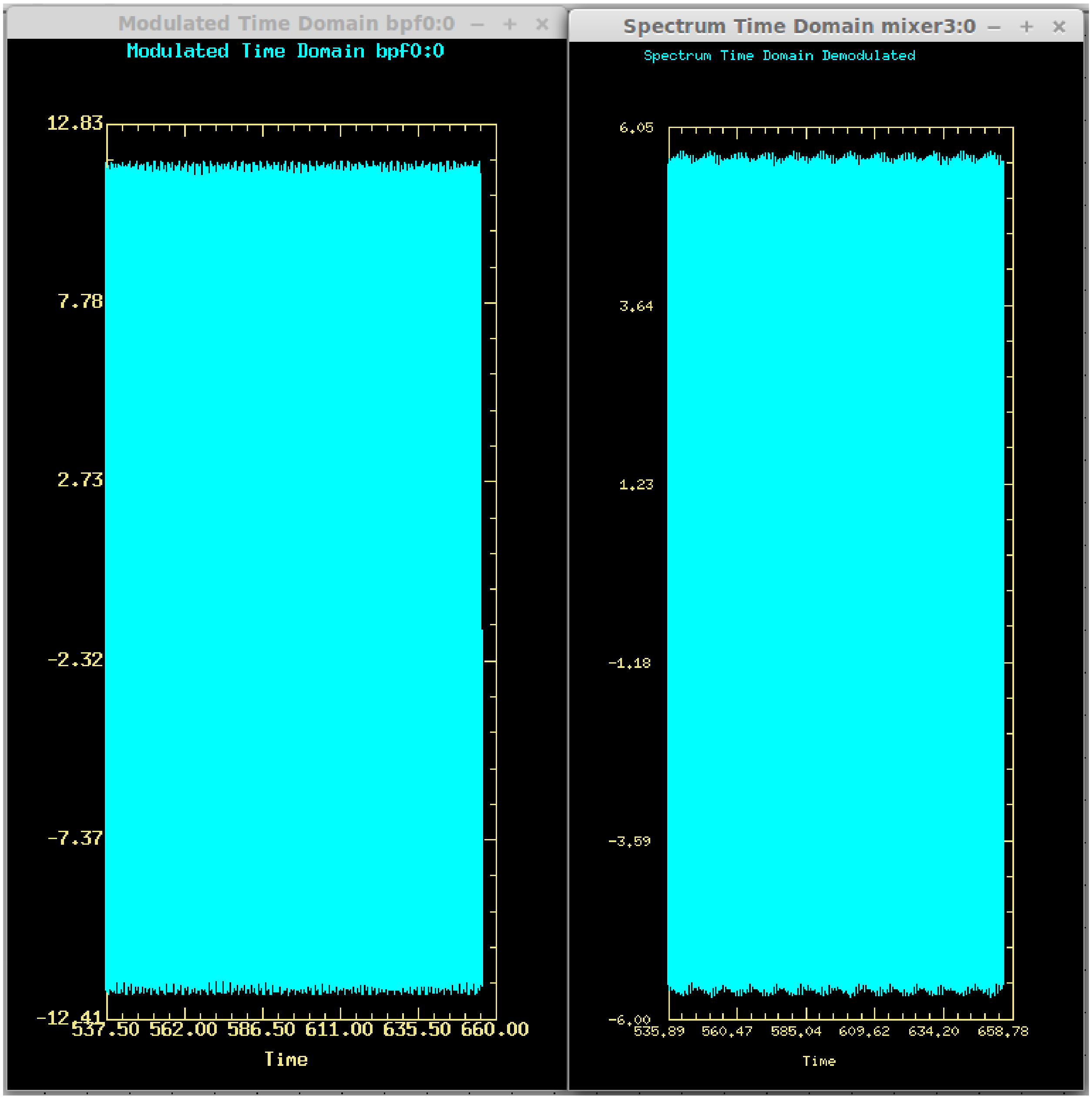

Figure 3 Demodulated Time Domain Single Mixer. Plot on left with no frequency error. Plot on right with frequency error Beat Frequency

A prototype of the single mixer solution shown in Figure 1 was built. Figure 4 shows the constellation and received parameters and time domain for 64 QAM. The EVM is around -28 dB. Note the variation in EVM due to beat frequency. The beat frequency issue will be more pronounced in BPSK (longer packets).

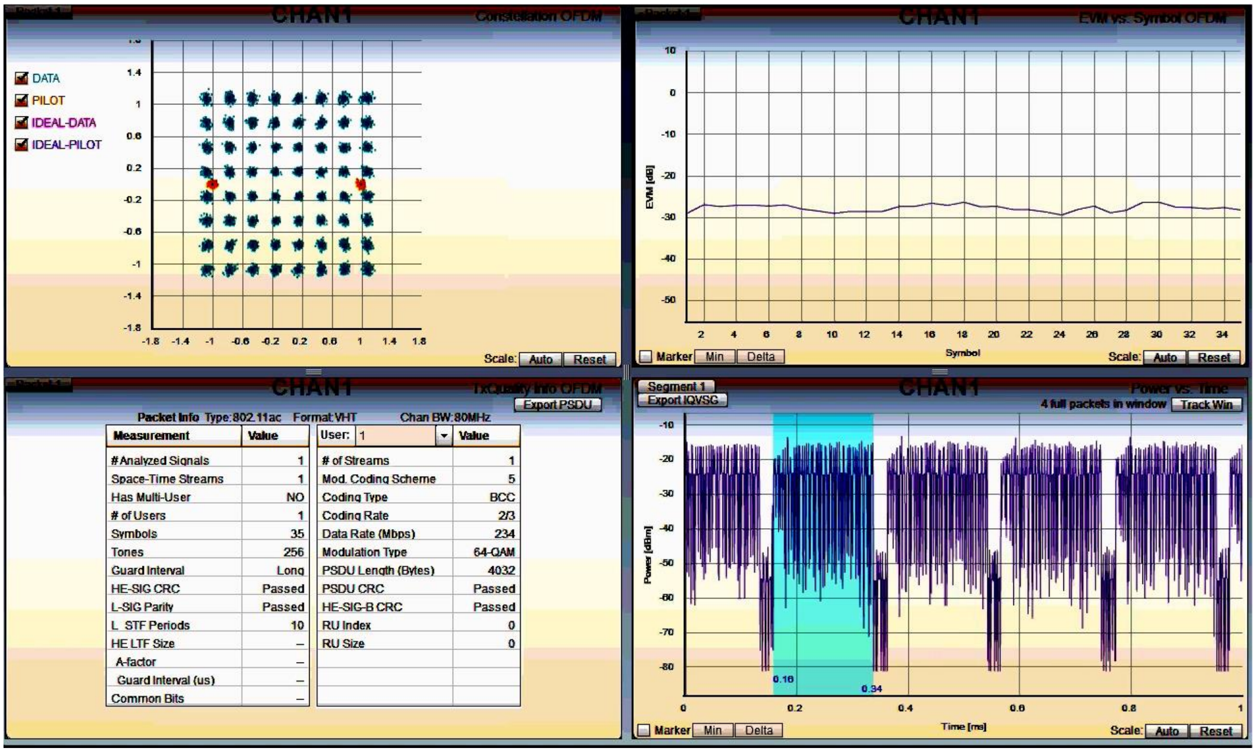

Figure 4 Single Mixer 5GHz WiFi (IEEE 802.11ac) to 10.56GHz IF Up Conversion and Down Conversion VSA Results

3 Two Stage Approach for Jammer Elimination and WiFi Spectrum Centering on 10.56GHz

3.1 Overview

The solution to the problem of centering any 5GHz channel on 10.56GHz XBand is to have a two stage approach. Figure 5 shows the concept. By adjusting the first PLL LO we mix the WiFi 5GHz signal down to 2 GHz. Then using the second PLL, we up convert to 10.56GHz. Since we have two knobs we can dial in the channel such that it is centered on 10.56GHz. In Figure 6 we illustrate centering a WiFi channel at 5.21 GHz (Channel 36 ,80 MHz IEEE 802.11ac).

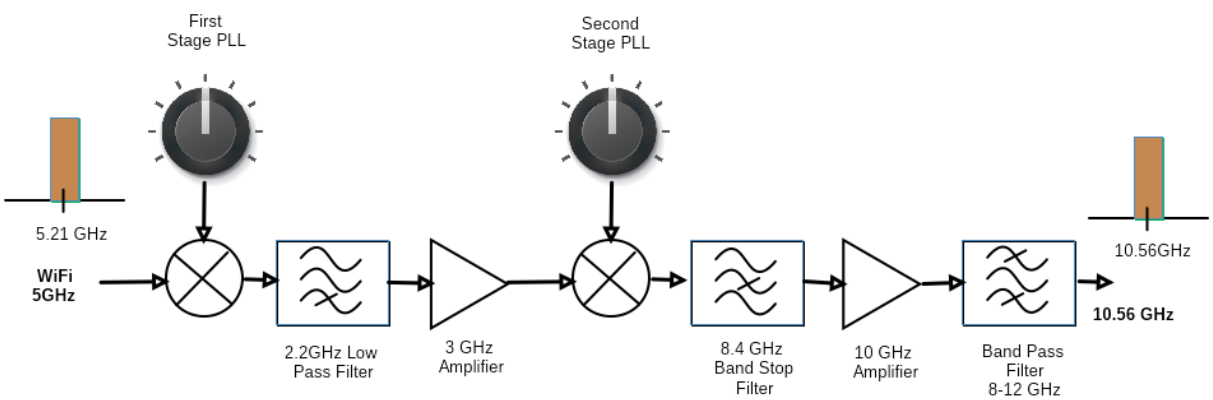

Figure 5 Two Stage Approach for Centering Channel on 10.56GHz and Jammer Elimination

The low pass filter in the first stage eliminates the 3 GHz leakage from the LO. The band stop filter (8.34 GHz) eliminates the LO leakage in the second stage. The fact that the LO leakage is at 8.34 GHz, results in the fact that it is separated enough that a microstrip band stop filter can be designed to eliminate it. The two stage solution puts enough separation from the desired and LO leakage so that they can be eliminated with realizable filters suitable for Printed Circuit Boards (surface mount filters at 2.2GHz and microstrip filters at 8.34 GHz).

3.2 Implementation and Performance

A full 1x1 SISO two stage solution for up conversion and down conversion is shown in the Figure 6.

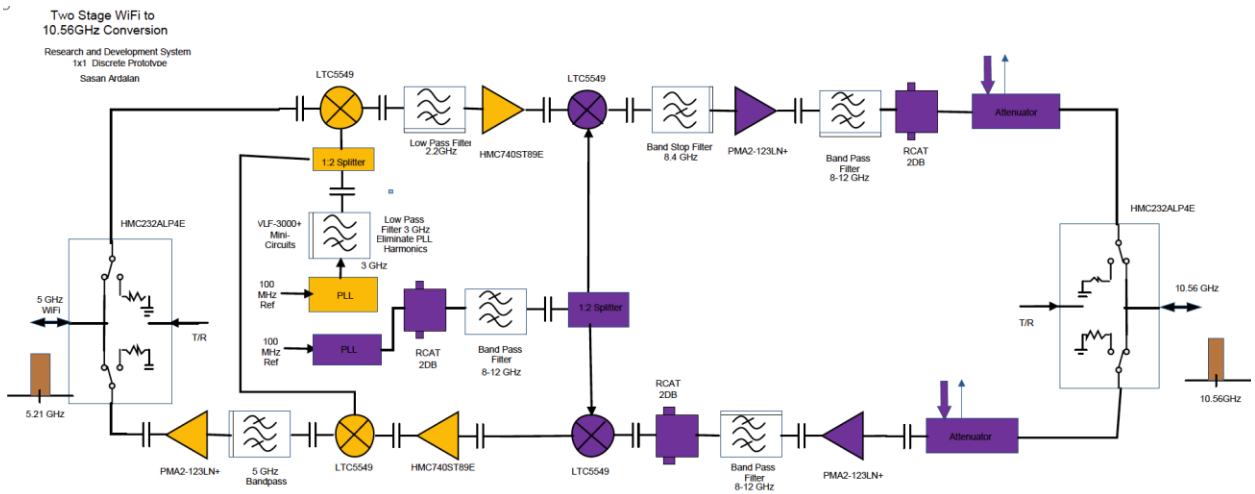

Figure 6 Two Stage Approach to 5 GHz WiFi to 10.56GHz IF Conversion

The system in Figure 6 was prototyped and built. The results of up conversion and down conversion (common PLLs) and feeding the signal (256 QAM) to a VSA is shown in Figure 7. Note also that we have a 10dB improvement in EVM overusing a single mixer solution.

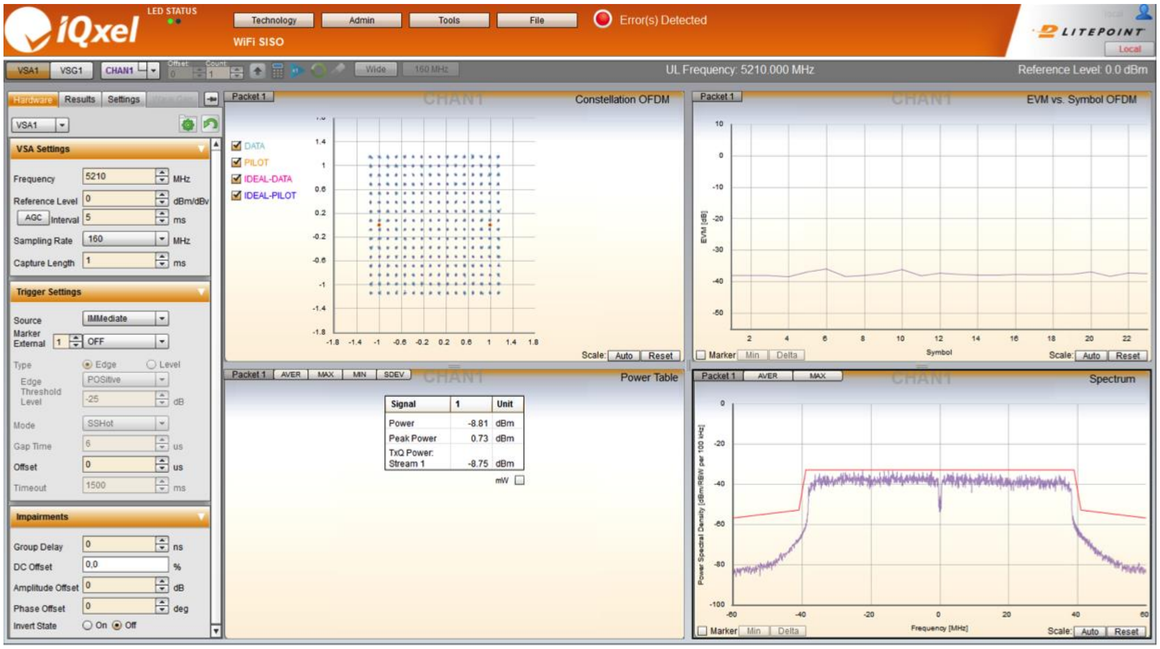

Figure 7 EVM and Constellation Two Stage Solution

Figure 8 shows the Constellation and EVM only.

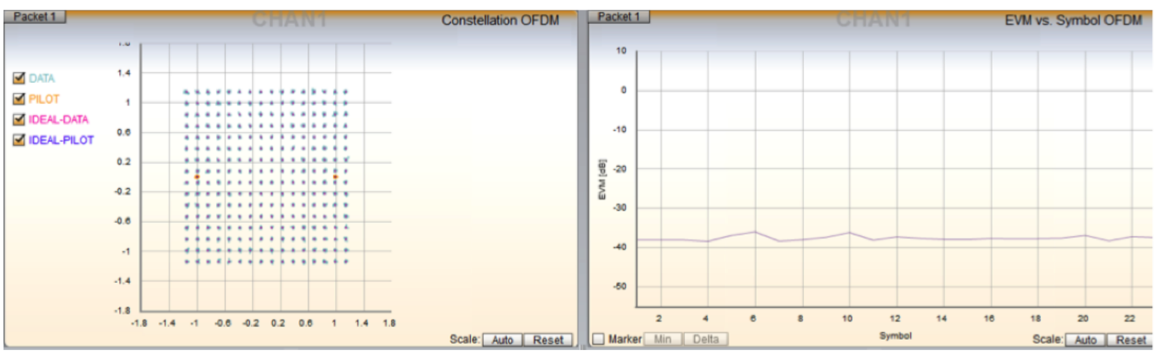

Figure 8 EVM Performance (-38 dB) Two Stage Solution Up Conversion to 10.56GHz and Down Conversion to 5 GHz.

The spectrum at the 10.56GHz IF is shown in Figure 9.

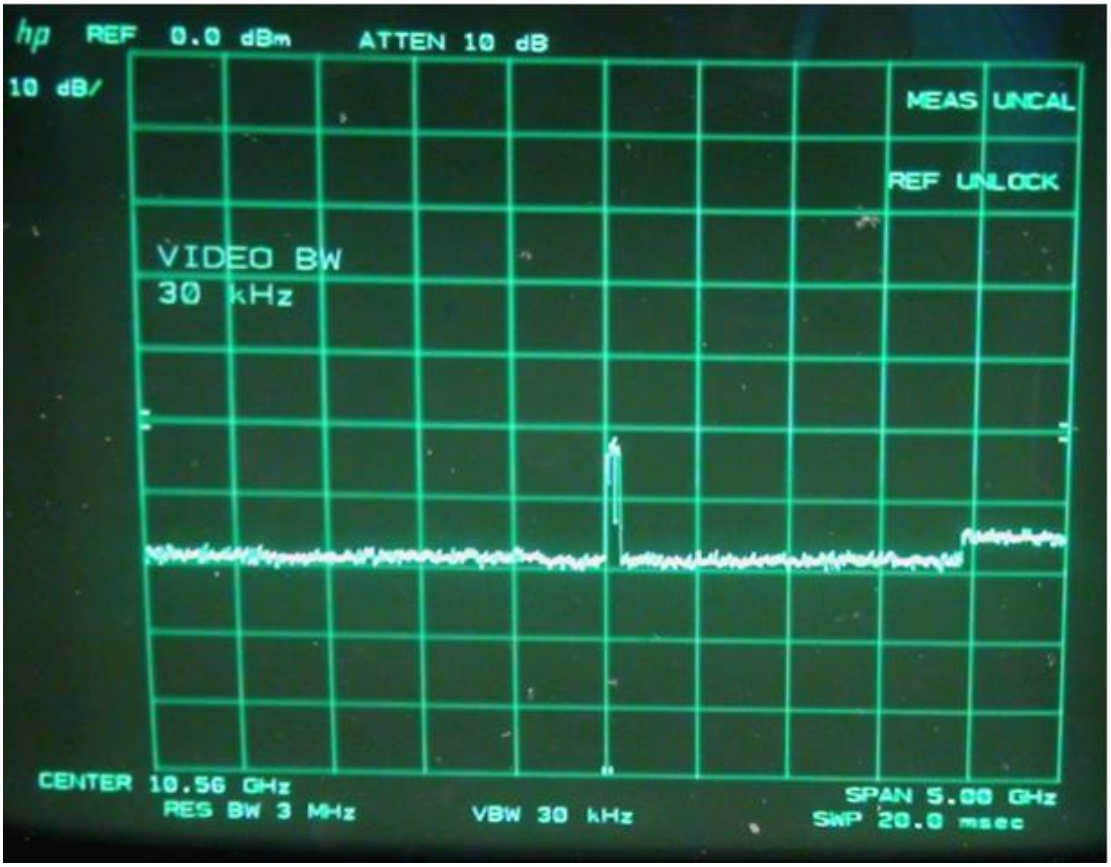

Figure 9 Two Stage Discrete Prototype 5.21 GHz WiFi Centered at 10.56GHz with no Single Carrier interferer (Jammers)

A key to achieving the performance in Figures 7 and 8 is the band stop filter, designed by the author, shown in Figure 10 which eliminates the 8.34GHz leakage (interferer single carrier jammer).

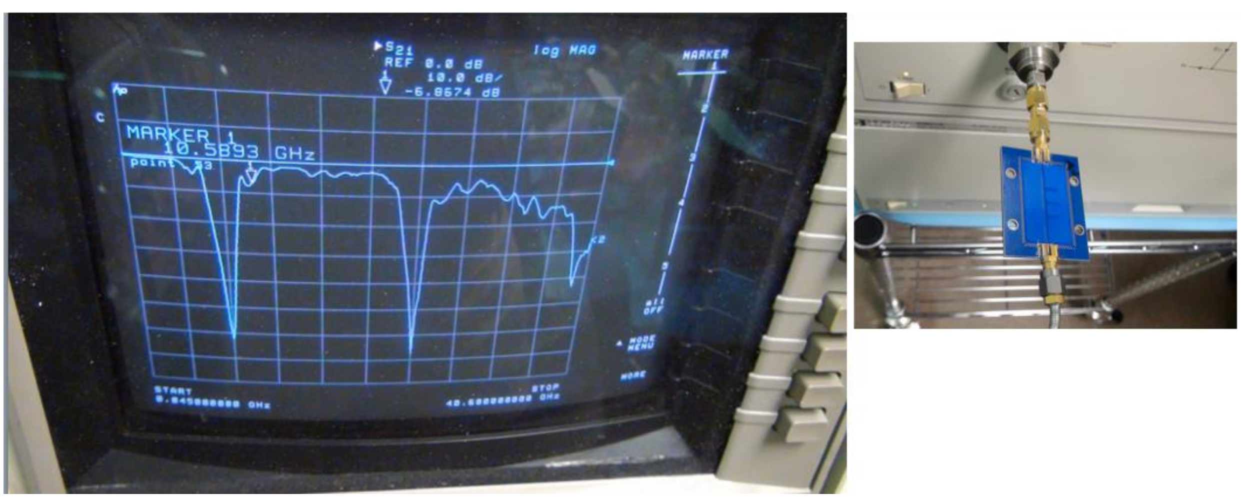

Figure 10 Performance of Microstrip Band Stop Filter (8.34 GHz).

The stop band microstrip filter as well as the 10GHz bandpass microstrip filters have been designed by the author using the open source Transmission Line Modeling Tool [6,7] also developed by the author. See the Appendix for the design of the 8.34GHz bandpass filter and 10 GHz bandpass filter.

3.3 Problem with the Two Stage Approach

With top performance, what can go wrong. The issue is that just like the single mixer approach, the two stage solution also suffers performance degradation due to frequency error between the PLLs at the second stage for transmit and receive systems with separate PLLs. The first stage PLL frequency errors (as long as they are within the capability for OFDM WiFi to correct[4]) do not cause an issue. Since the LO frequency is higher in the second stage, the frequency error is more pronounced in the two stage solution. See Figure 11 that shows the measured Constellation and EVM with frequency error between separate PLLs.

Therefore, we need a solution to the frequency error problem. The key point is that the two stage solution provides the two degrees of freedom (knobs) necessary to solve this problem. This will be shown in the next section.

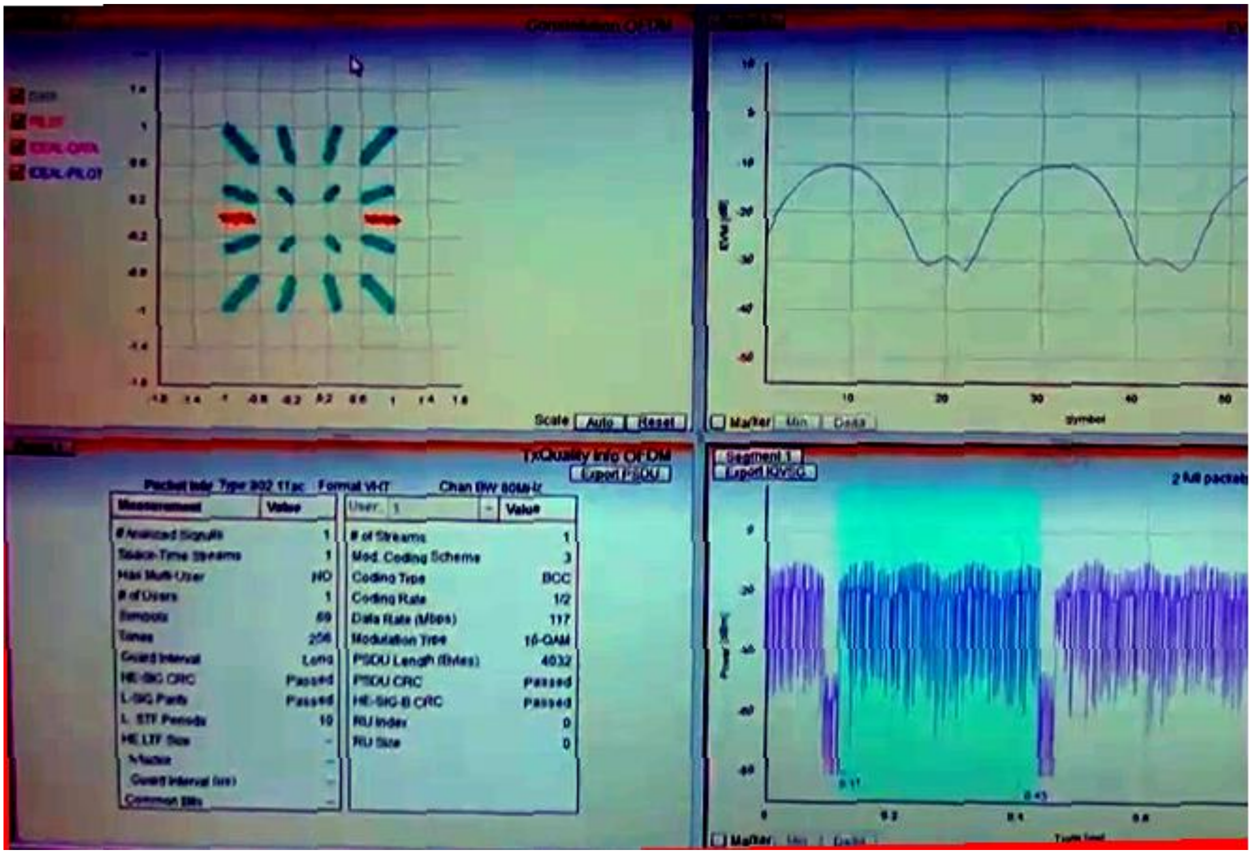

Figure 11 Two Stage with separate PLLs (Transmit and Receive) showing frequency error degradation due to second stage PLL frequency error.

4 Solution to the Frequency Error Problem with the Two Stage Approach

To solve the frequency error problem, we will turn the frequency beat problem on its head. That is, rather than increase the precision of the second stage PLLs to reduce the frequency error, we will increase the *frequency offset* to beyond two WiFi channels (240 MHz). What happens is that, when the frequency of the second stage transmit and receive are equal, two spectrums at the desired channel frequency (prior to stage one in demodulation) completely overlap and there is no beat frequency. Due to frequency error, the two spectrums are offset slightly and a beat frequency is created which causes the constellation to pulsate and EVM to degrade. Note that OFDM carrier offset correction [4] does not handle a beat frequency problem.

To take advantage of the ability of OFDM WiFi systems that correct for frequency offset, we purposely separate the transmit and receive second stage PLLs by at least two channels (e.g. 240 MHz). In this way, we no longer have a beat frequency problem as the two spectrums do not overlap but are separated by the frequency separation (240 MHz). We then use the second stage PLL to dial the separated channel back onto the desired channel. The signal now has a desired signal at the channel and another signal at another channel that is two or more channels apart. Any frequency offset in the desired channel is corrected by the OFDM frequency offset correction mechanism [4]. The second channel is filtered out by the receiving AP (since it is set to the desired channel) and suppressed. See [10] for filtering adjacent channels. We can also filter it out prior to the Access Point (AP) receive circuitry.

Figure 12 shows the detailed block diagram of the two stage solution to the frequency error problem. Note the frequency separation between the transmit second stage PLL and the receive second stage PLL. As well as the first stage PLL. Figure 13 shows the Discrete Prototype of Two Stage Mixer Solution 5.21GHz to 10.56GHz Conversion Transmit and Receive based on the system in Figure 12.

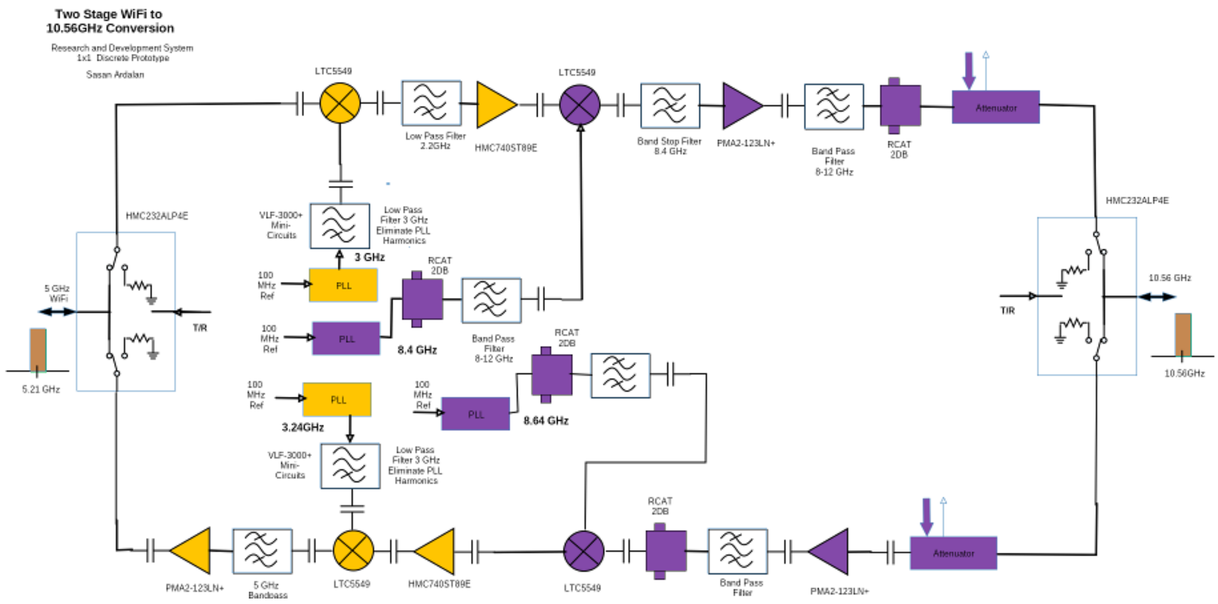

Figure 12 Two Stage Solution Mitigating the Frequency Error Problem Between Transmit Second Stage PLL and Receive Second Stage PLL.

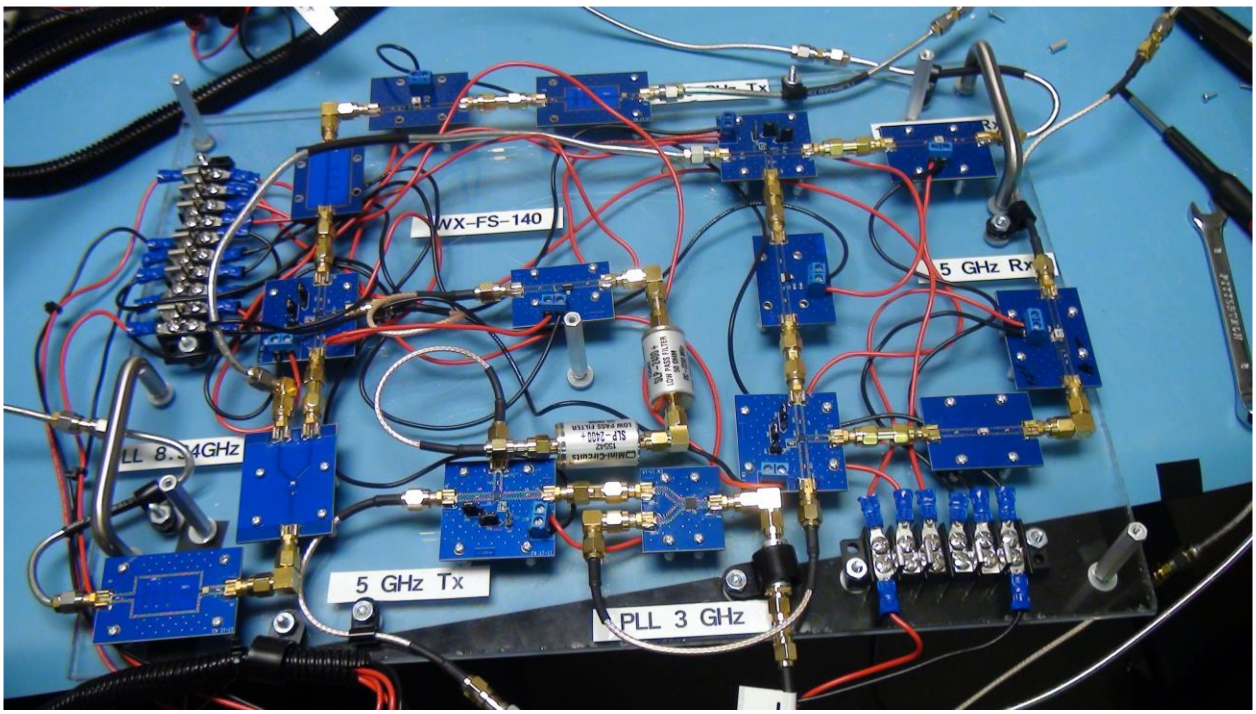

Figure 13 Discrete Prototype of Two Stage Mixer Solution 5.21GHz to 10.56GHz Conversion Transmit and Receive.

The Measured Signal Constellation and EVM with two *completely separate* transmitter and receiver discrete prototypes are shown in Figure 14. EVM is at -30 dB.

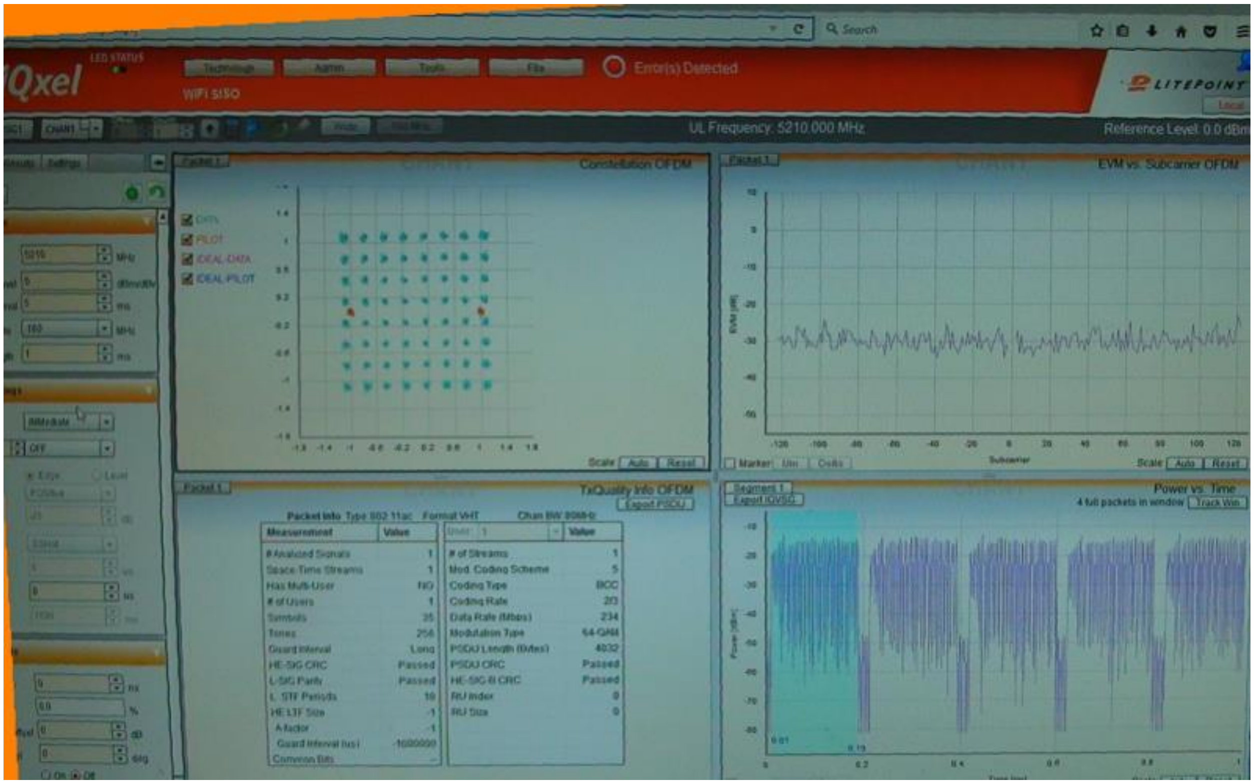

Figure 14 Constellation and EVM Two Completely Separate Transmitters and Receivers Two Stage Solution with Frequency Separation

The two discrete prototypes with separate PLLs are shown in Figure 15.

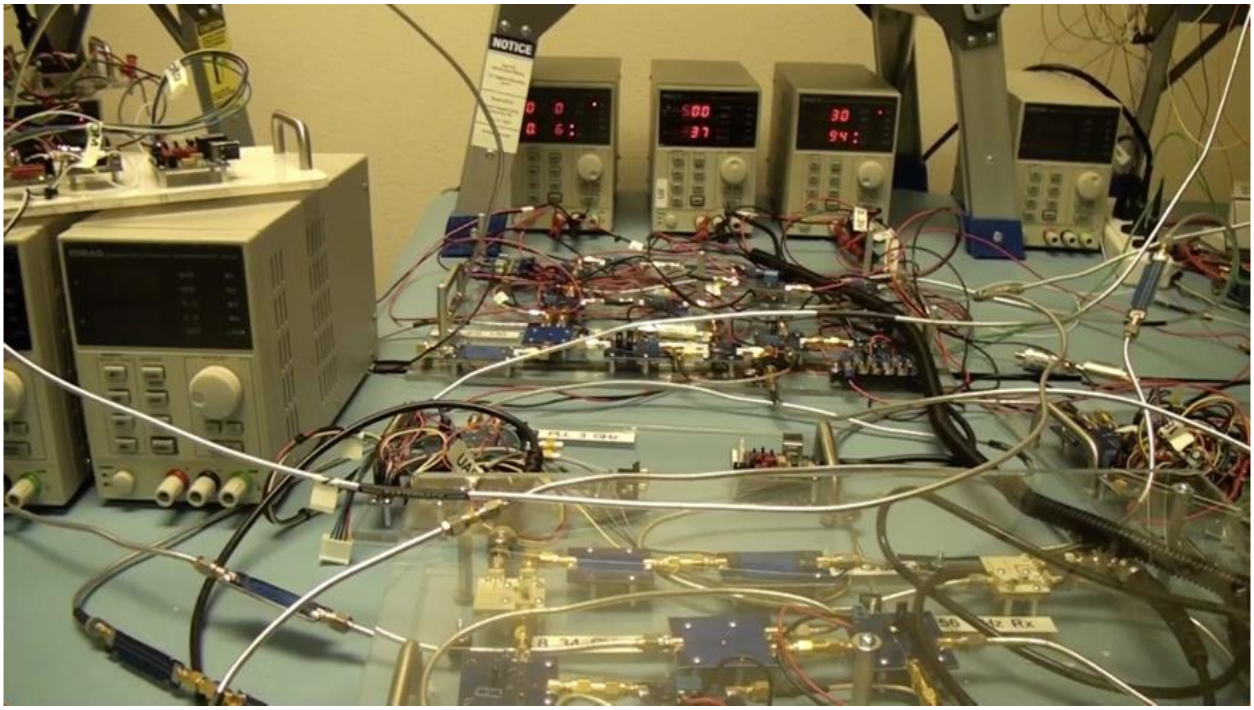

Figure 15 Two Stage Solution Completely Separate Transmit and Receive Discrete Prototypes with IF Through Cable and Attenuator With Frequency Error Issue Solved

Notice that there is no degradation in the constellation except for a loss in EVM (6-8 dB). However, further optimizations can improve the EVM. The key is that the two systems are completely separate (different PLL's Transmit and Receive) and can operate over long distances.

5 Conclusion

We have developed a two stage solution for the modulation and demodulation of 5 GHz WiFi signals to 10.56GHz XBand. The transmitter and receiver uses completely separate PLLs. This also opens the door for long distance transmission of 5 GHz WiFi over 28 GHz or 60 GHz links. We have eliminated frequency errors such that we take advantage of OFDM’s built in carrier offset correction.

The two stage approach allows channels to be dialed into and centered on 10.56 GHz XBand or other center frequency. The two stage solution allows for the complete elimination of interfering carriers (jammers) due to LO leakage in the mixers for a clean over the air spectrum.

6 Acknowledgement

The author would like to acknowledge Mr. Donal Elkins, Amateur Extra Class KF5NWY for the layout and tapeout of the microwave printed circuit board coupons especially the layout for the 10 GHz bandpass and 8.34 GHz stopband filters as well as other coupons including the PLL. Also, the author would like to acknowledge Mr. David Olsen a top Microwave Engineer in Reno, NV for support in prototyping and testing the system.

7 Appendix: Microwave Microstrip Filter Designs

7.1 Introduction

This section shows figures for the design of the microstrip 10GHz bandpass filter and the 8.34 GHz band stop filter. Both filters were designed using the Open Source Transmission Line Network Modeling Tool [6] (*TransNetCalc*). All the parameters are provided in order to build these filters.

7.2 Design of 10GHz Microstrip Bandpass Filter

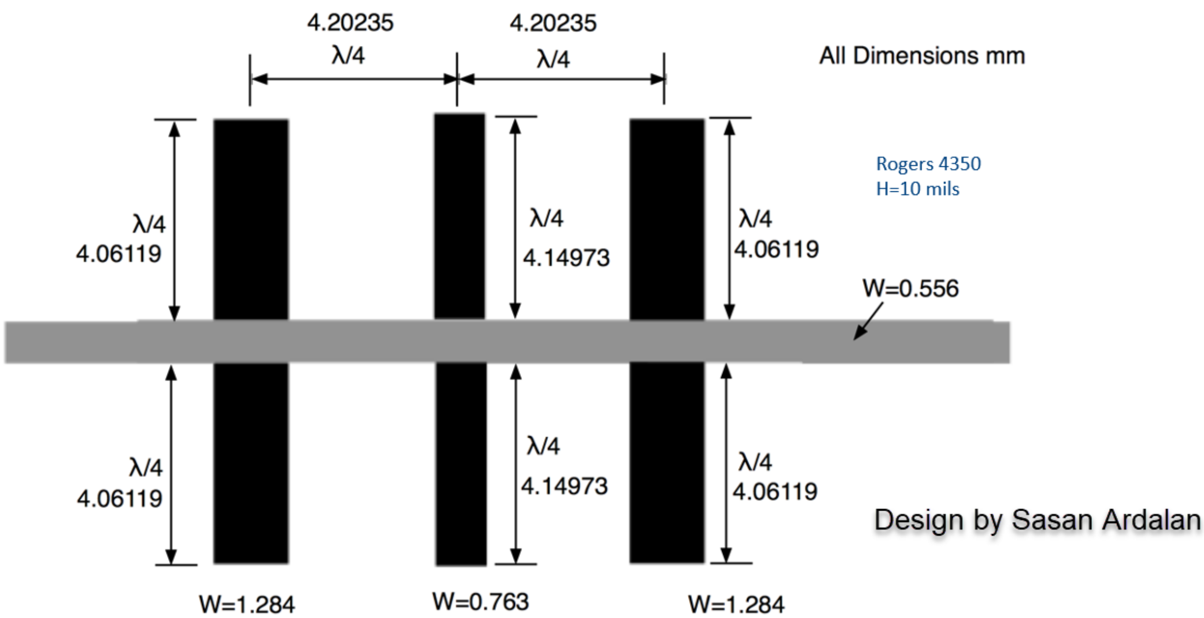

Figure 16 10 GHz Microstrip Bandpass Filter Layout (6 GHz Bandwidth)

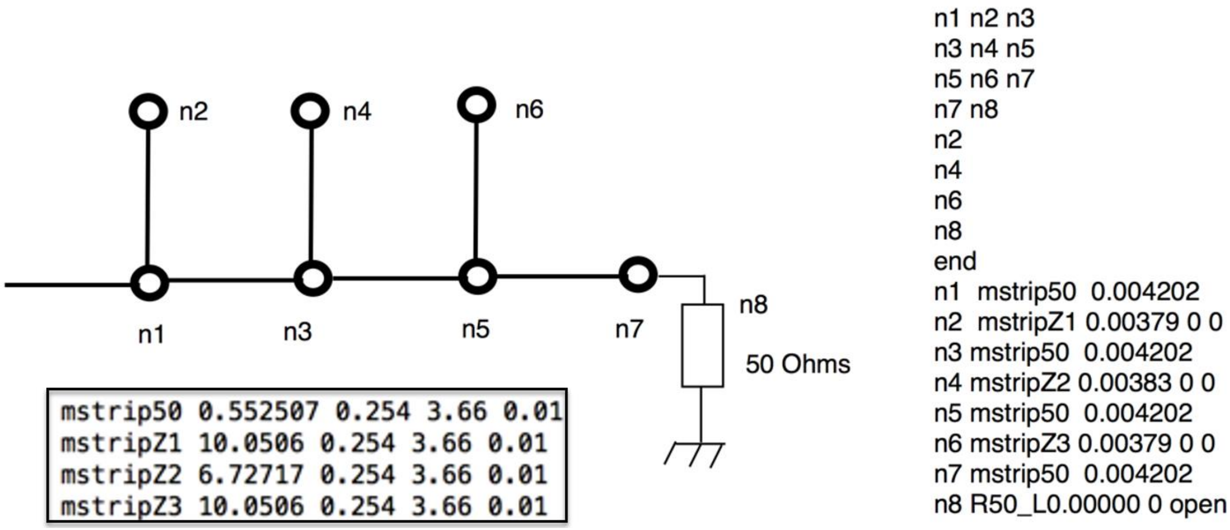

Figure 17 10 GHz Microstrip Bandpass Filter Model TransNetCalc Transmission Line Network Program [6]

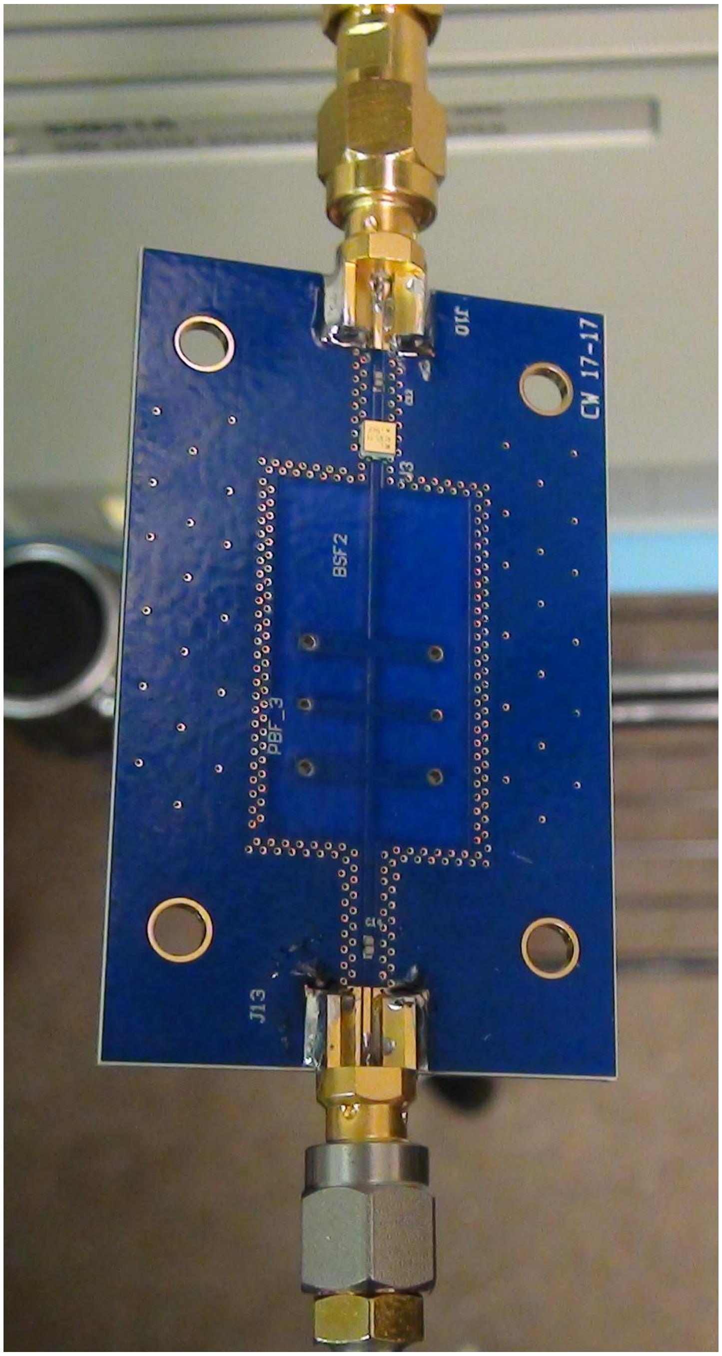

Figure 18 10 GHz Microstrip Bandpass Filter PCB Coupon. Note the Shorts at the Stubs

Figure 19 10 GHz Microstrip Bandpass Filter

Network Analyzer Response Sweep 40GHz

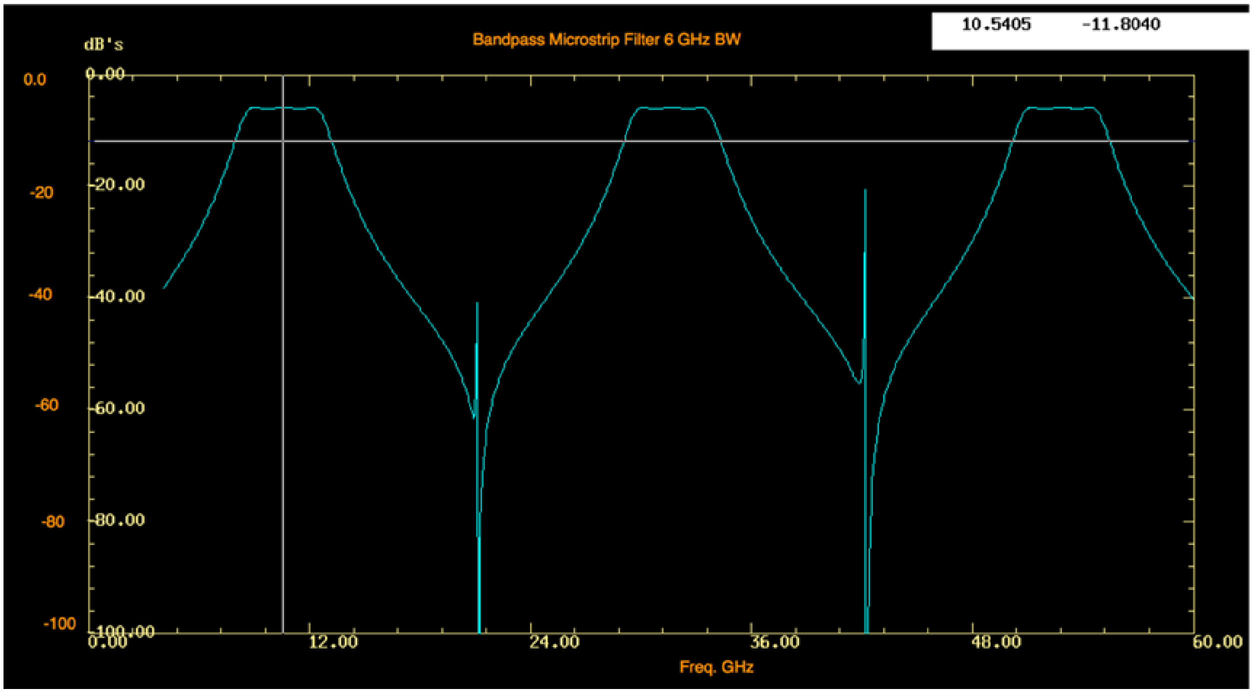

Figure 20 20 10 GHz Microstrip Bandpass Filter Calculated Response Using TransNetCalc[6].

7.3 Design of 8.34 GHz Microstrip Band Stop Filter

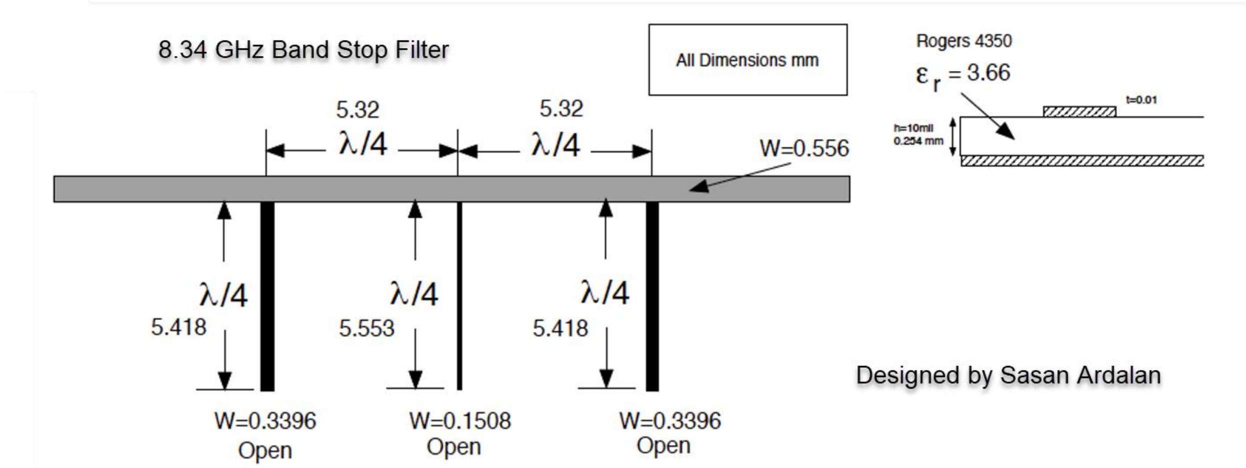

Figure 21 8.34GHz Microstrip Band Stop Filter Design

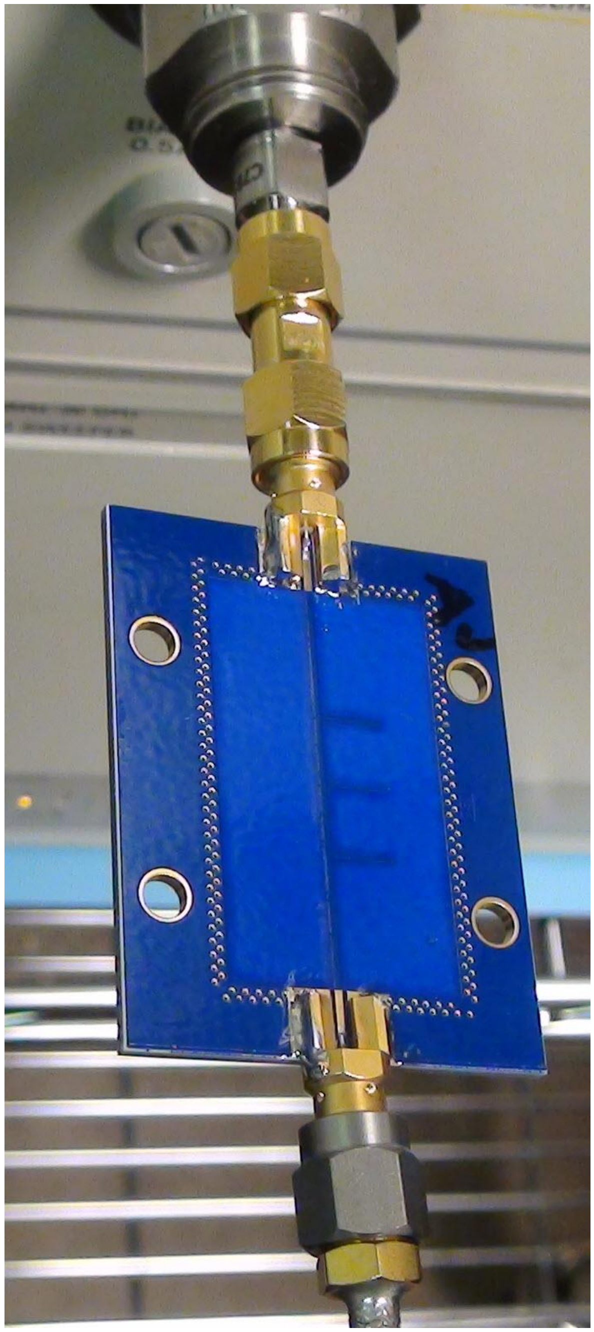

Figure 22 8.34GHz Microstrip Band Stop Filter Design PCB Coupon

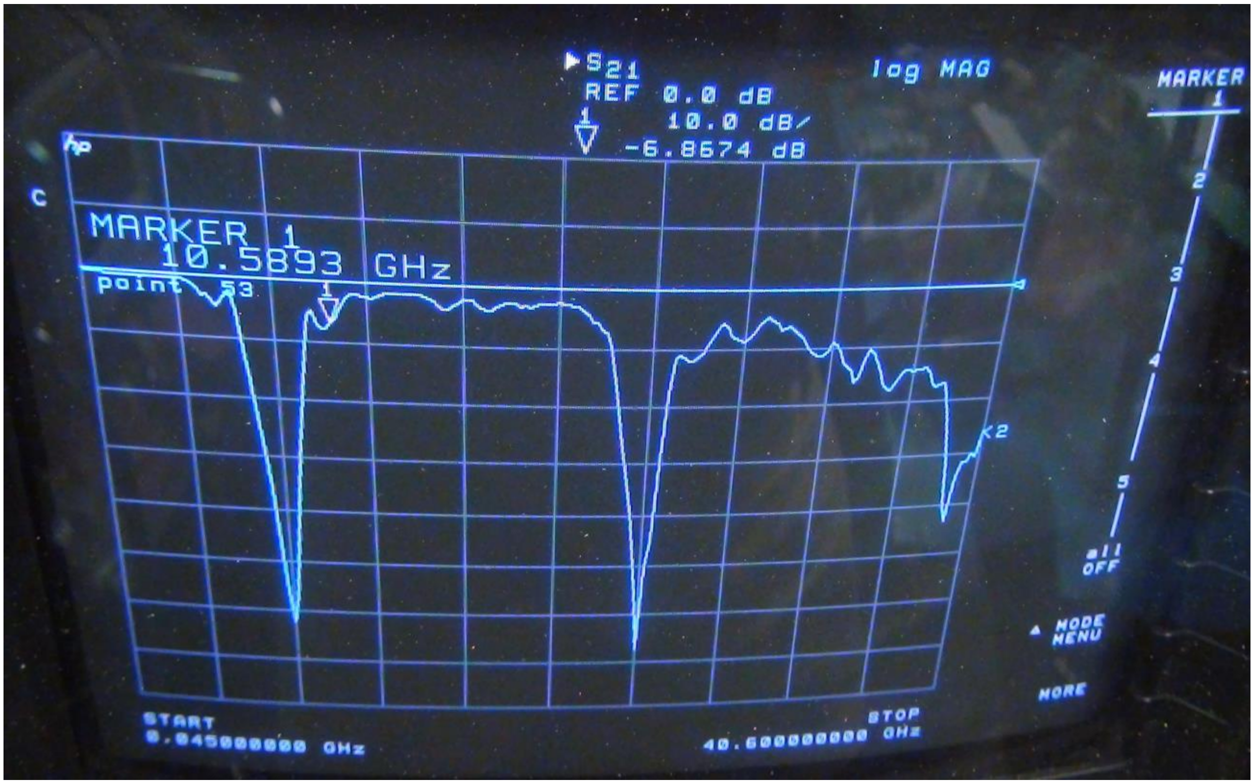

Figure 23 8.34GHz Microstrip Band Stop Filter Network Analyzer Sweep 40 GHz

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