Testing the Reliability and Flexibility of Digitizers adapting the RF/IF signals over IP applications using a testbed Platform.

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ABSTRACT

Many disadvantages from physical limitations in RF Telemetry can now be eliminated using RF over IP Networks. Digitizers mitigate the problem of signal degradation that RF has due to physical restrictions and provide reliability and flexibility to the signal. The digitizers are also able to preserve both frequency and timing characteristics, and then accurately reconstructing the original Telemetry signals to enable processing, recording or retransmission at another location. The digitizers along with the software-defined radios forms a flexible testbed platform which enables us to simulate both communication systems to qualify and quantify their behavior, while studying the interference between systems. In addition, quantization of noise is a critical parameter to determine the bit error rate in the testbed. Digitizers can be configured at a certain bandwidth and additional gain, in order to make this layer almost a transparent transmission.

INTRODUCTION

Telemetry signals have been one of the most important communications ways for many years. But there are many disadvantages that come with it, for example, telemetry signals degrades over long distances [1]. In addition, other effects like noise can compromise the telemetry signal. One of the big issues with telemetry is limitation to be able to transmit over long distances without losing the signal. Furthermore, Spectrum is already a high traffic density area compromising the telemetry signals [2]. One of the solutions is to use a flexible testbed with Software Defined Radios (SDR) that can replicate the signals in order to understand the problem and Digitizers can transmit over long distances without any telemetry issues. Telemetry signal will be digitize and can be transmitted and transported over a data transport Internet Protocol (IP) network. According to Thom "The motivation for moving to Telemetry over IP (TMoIP) was twofold: first, to find cost effective PCM data distribution and second, to provide reliable and robust PCM data distribution regardless of the destination. The global explosion of IP networking has provided a built in infrastructure with access to the most remote destinations [3]. IP networks are already worldwide even to remote places, on the other hand, RF also called TM signals have some disadvantages due to physical impediments.

In order to test reliability of the digitizers it is encouraged to first to have a run test from the flexible testbed to take into account any noise or other factors already present in the system. After this run testing will include the digitizers to now test the reliability of this alternative of transmission. In addition, the system is to be tested in the reliability to be a transparent media and observe the behavior of the signal after being converted and de-converted to transmit over IP network. The testbed platform can give us the flexibility to study at different frequencies, gain levels, modulation schemes and several other functions. The band of interest are the L-band (from 1-2GHz), S-band (from 2-4 GHz) and C-band (4-8 GHz) [3], this bands are focused in telemetry bands but there is also a coexistence of LTE source. Two frequencies will be choose to run the tests. Nevertheless, the modulation plays a big role for this experiments. Simple modulations will be the first to be tested. For example, Quadrature Phase Shift Keying (QPSK) modulation or Offset Quadrature Phase Shift Keying (OQPSK). In last, Orthogonal Frequency Divide Multiplexing (OFDM) a more aggressive modulation will be applied to the system to observe and describe the different behavior of the modulation in the system. In order to qualify and quantify the signal several parameters will need to be introduced. To quantify the signal Frame Error Rate (FER) will be used to observe how many frames of bits will produce an error. Likewise, to qualify the signal a constellation graph, power spectrum and eye diagram will be introduced. To conclude, different parameters will allows to do a thorough observation of the behavior of several signals over IP networks.

In addition, different set ups for the digitizers have to be applied in order to perform different functionalities. First the digitizers will be connected directly to each other. Second it will have a switch connection in between. Third, will be connected to the network but activated by the same computer. In last, digitizers will be in the same network but be pulled from different computers. Different set ups allow us also to quantify and qualify signal under regular IP Traffic. Moreover, a timing reference synchronization to have deterministic signal requires a GPS outside clock for both digitizers. But, there is also a programmed buffer built in the digitizers. For this experiments the programmed buffer is used, for future experiments the outside GPS clock can be used.

To summarize, there are many parameters to be taken care of, such as, modulation, set up of SDR and set up of digitizers. This parameters will determine how flexible could the system be with the different set ups. Also, the reliability of this system will be consider in how the signal is received and how clean is the signal.

BACKGROUND

The biggest advantage of transforming the Radio Frequency (RF) to Internet Packets (IP) is to perform log transmission with no physical disadvantages that real world produce. For example, a regular RF transmissions tend s to have different signal loss due to multipath fading or interference from other signals. In addition, there is already several traffic in the radio frequency spectrum. The range of the radio frequency spectrum is from 3 kHz up to 300 GHz [3]. This spectrum involves different types of company, such as, commercial, research, military and many more. Furthermore, there are different modulations of signals that can possibly affect other signals if transmitting to close to each other. For example, OFDM modulation is an aggressive modulation that can affect others increasing the noise level. The interested bands for testing reliability are the L-band, S-band and C-band. Figure 1 shows L-band frequency allocation. Figure 2 sows the S-band, another band of interest for the testbed experiments. In addition, Figure 3 shows C-band the last frequency band of interest.

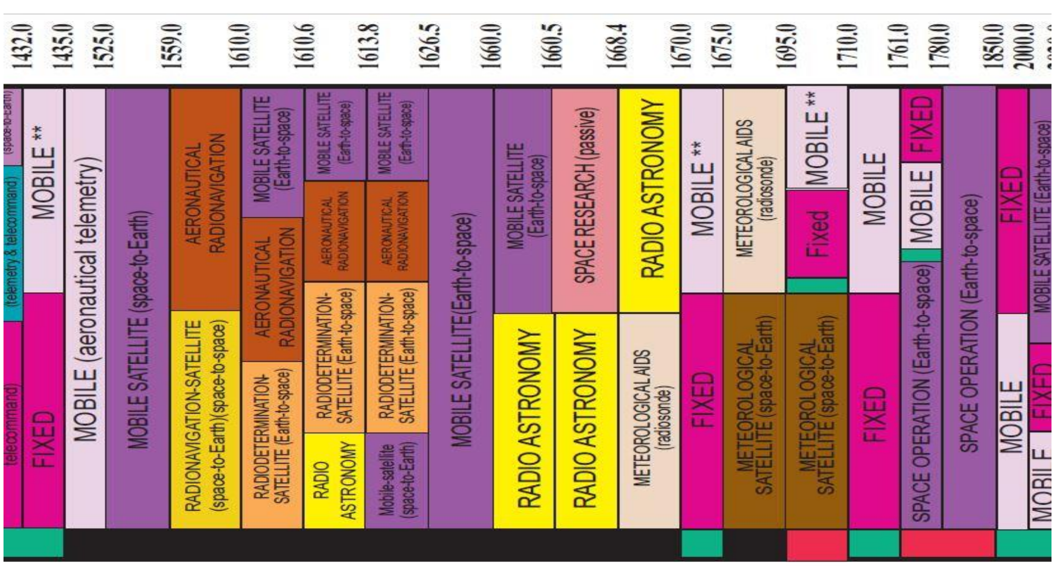

Figure 1 L-band frequency allocation [3].

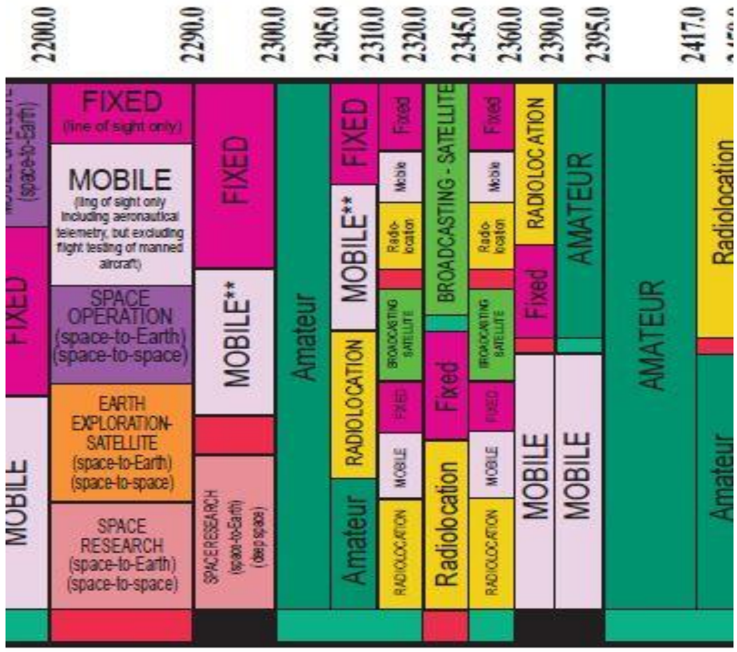

Figure 2 S-band frequency allocation [3].

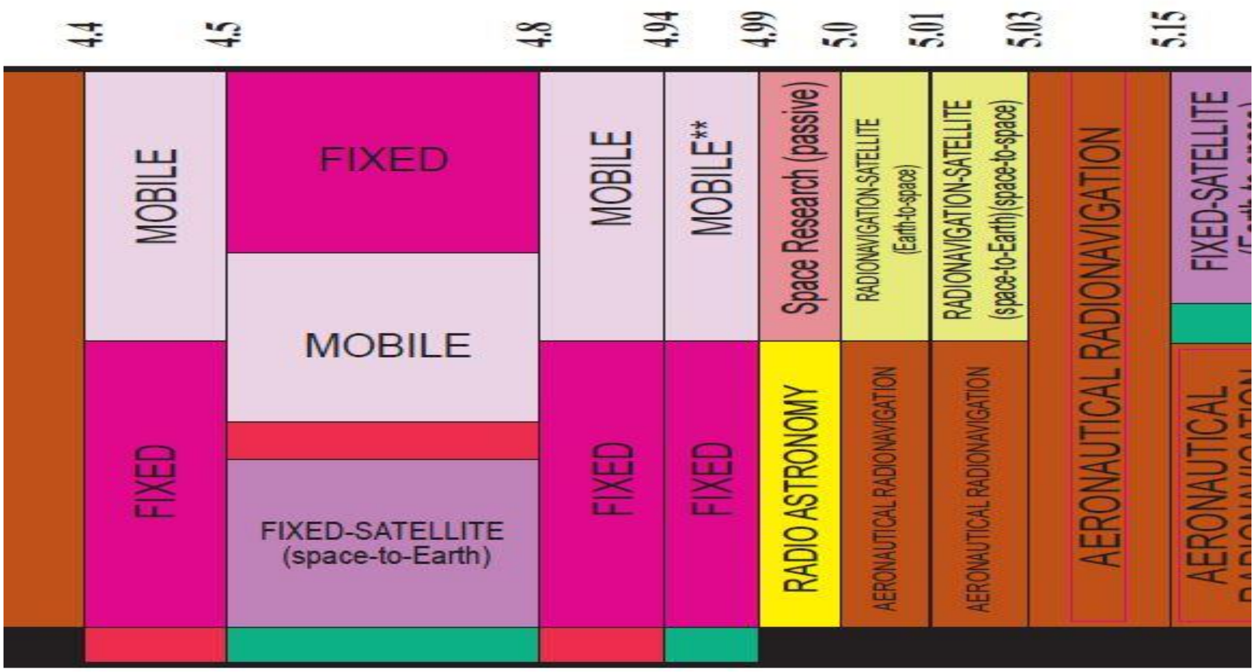

Figure 3 C-band frequency allocation [3].

The Federal Communications Commission (FCC) has the role to control and monitor the distribution of the radio frequency spectrum to prevent any type of problems between signals [1]. Users of the radio frequency spectrum must stayed on the frequency that was designated for its operation, in case of any trespass this could result in a several fine from FCC Enforcement

Bureau (FCCEB) [4]. Even, frequency band protection gaps are design, yet, there are still leakage from aggressive modulations, like OFDM. Variety of users in the radio frequency spectrum

One feasible solution for all the radio frequency spectrum users is to convert the RF over IP and de-convert the signal again to RF without losing any of its properties. Avoiding any fines from the FCCEB or other consequences.

METHODOLOGY

Methodology was follow by several parameters that can be adjusted. Numerical parameters are adjusted to select the best scenario of a signal transmission in the bands of interest. Also, visual parameters will indicate the quality of the signal. Methodology was implemented to have a scenario from SDR to SDR. Then, compare this scenario with Digitizers in the middle of the SDR's and qualify and quantify the errors in the signals. This, to explore the solution that RF over IP delivers by being a transparent connection between SDR's. Also, a spectrum analyzer is used to perceive the signal. Figure shows the design of the testbed that will used for several experiments. Figure 4 shows the set up for the testbed to perform the different tests. Also, a spectrum analyzer is added to the testbed in order to see the signal for measuring of power purposes.

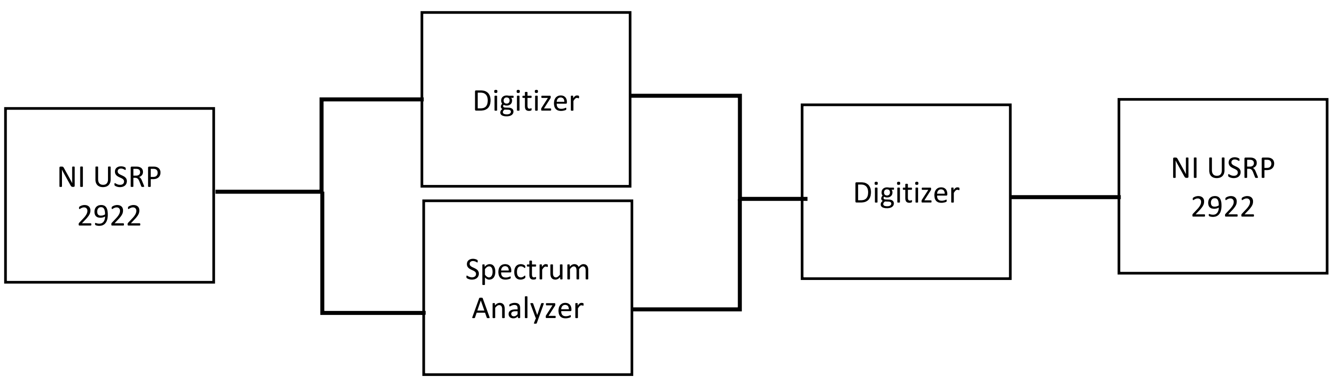

Figure 4 Testbed design for RF over IP.

Illustration 1 shows a complete set up of the testbed including the SDR's and digitizers without the spectrum analyzer. In addition, there is a back view of the testbed setup to show the connection to the digitizers. Top USRP is connected to the TX digitizer which is the top digitizer, furthermore, the bottom digitizer is the RX that will transform the signal to RF and delivered to the bottom USRP.

Illustration 1 Physical Testbed design with front (left) and back (right) views without spectrum analyzer

Nevertheless, testbed has visual and numerical parameters. This parameters will help to quantify and qualify the signal transmitted and received. In order to be able to observe the performance of the testbed it is essential to have this two types of parameters. Moreover, feasibility of RF over IP can be proved with this several parameters.

Numerical parameters

In order to quantify the signal there are several parameters that had to be considered. Testbed will have parameters in the USRP and the digitizer. There, are many parameters in both testbed platforms. Some parameters are repeated in order to achieve a synchronization between both testbed platforms.

Numerical Parameters for USRP's:

- Antenna Gain
  - G/t
- Bandwidth (*BW*) of the Transmitted Signal
- Center Frequency (f_c)
- Data Rate
- Frame Synchronization Error Rate (FSER)
  - Most likely required to be zero
- I/Q Rate
- Modulation Scheme
- Noise Floor
- RX Power
  - RX Sensitivity Level (detection threshold)
- SNR
- TX Power

Numerical Parameters for Digitizers:

- A/D Bits

- Center Frequency (f_c)
- Current/Min Gain
- Destination IP
- Digitizer Utilization
- Gain Mode
    - Automatic or Manual
- Manual Gain
- Max Packet size
- Min Delay
- Output Enabled
- Packet Protection
- Stream Bandwidth
- Stream Offset
- System Bandwidth (*BW*)

Visual parameters

In addition, visual parameters will support qualify the signal transmission. This parameters are essential to demonstrate performance of testbed. Numerical parameters are tied with visual parameters. Indeed parameters will explain and give more sense of signal transmission results. There are four key visual parameters that will give more detail of the signal quality. The visual parameters are:

- Constellation Diagram

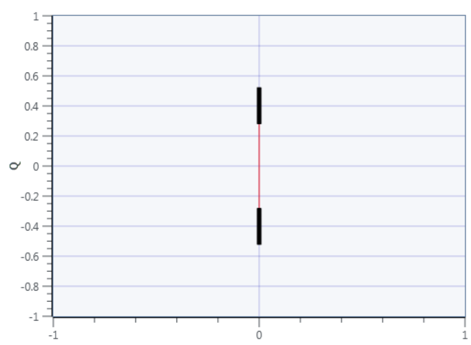

Figure 5 BPSK constellation diagram with a rotation of 90 degrees

- Eye Diagram

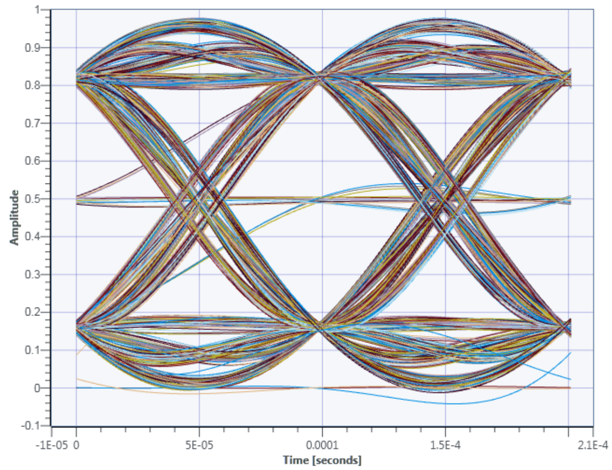

Figure 6 Eye Diagram representation for illustration purposes.

- Spectrum Graph (Display SNR)

Visual parameters can qualify the signal transmission. Also, we can classify the signal by taking visual contemplation in how signal is performing. In addition, visual parameters will identify Power of signal, SNR and many more. In last, several parameters are used in order to have a complete and thorough experiments for the testbed.

To conclude, testbed has many different parameters to have a more detailed analysis of the signal transmission. Moreover, signal should be classified by the experiment results helping define rules or procedures to follow for a better signal transmission.

Experiment description

Experiments will consist to send a signal directly from TX SDR to the RX SDR, which is the ideal case of signal transmission. Now, compare this signal transmission to a signal sent from TX SDR converted from RF to IP by a digitizer and de-convert IP to a RF signal and receive by the RX SDR. This signal transmission could add some noise to the signal, quantify and qualify this signal using the numerical and visual parameters to determine and classify the transmission.

Experiments will focus on specific bands, which are the bands of interest. Frequency bands of interest are L-band, S-band and C-band. Experiment will consist in comparing each case of the bands. For experimentation purposes S-band will be the frequency band to analyze. Table 1 shows the frequency bands of interest.

Table 1. L-band, S-band, C-band frequency bands of interest

Band		**Frequency Range (MHz)**	**Application**
L	**Lower**	**1435 – 1525**	**Mobile and Telemetry**
	Upper	**1710 – 1990**	**Telemetry: 1780 – 1850 MHz**
S	**Lower**	**2200 – 2290**	**Telemetry**
	Upper	**2360 – 2395**	**Telemetry**
C	**Lower**	**4400 – 4940**	**Telemetry**
	Mid	**5090 – 5150**	**Telemetry**

RESULTS

S-band

Most of the parameters are set in the system interface. After calculations, we got some quantitative and qualitative results. This results can lead to the design of rules and mitigation techniques. BPSK signal would be tested since it's a simple modulation. Figure 7 shows a signal transmission from TX SDR to RX SDR with a BPSK modulation. Constellation diagram is clear, Power spectrum shows a considerable difference from noise floor and eye diagram is open and clean.

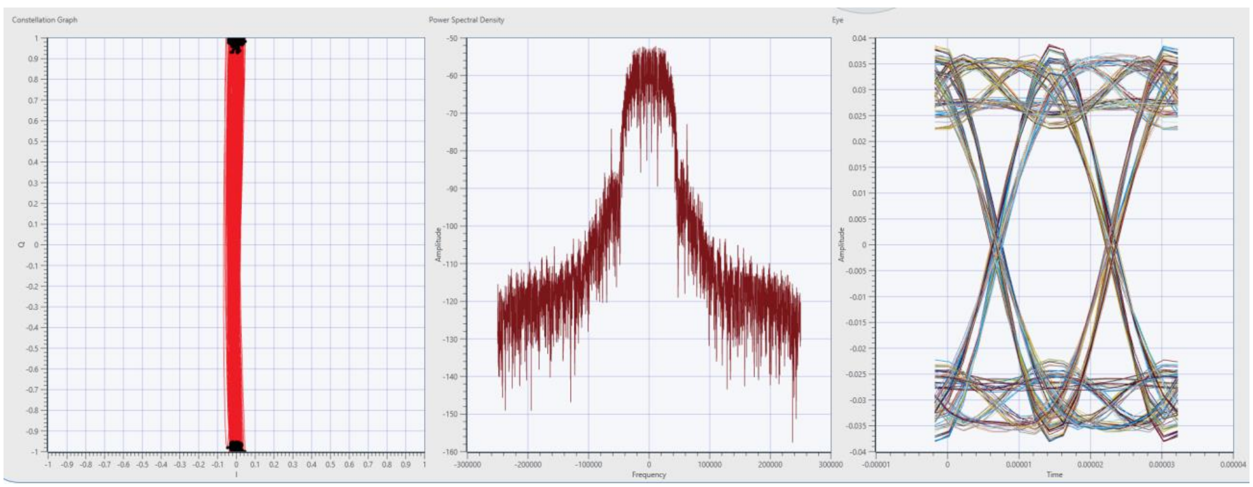

Figure 7 BPSK signal transmission parameters. Constellation Diagram. Power spectrum. Eye diagram.

In addition Figure 8 shows the FSER rate showing a clear signal with no errors. This will complete all parameters to be measured.

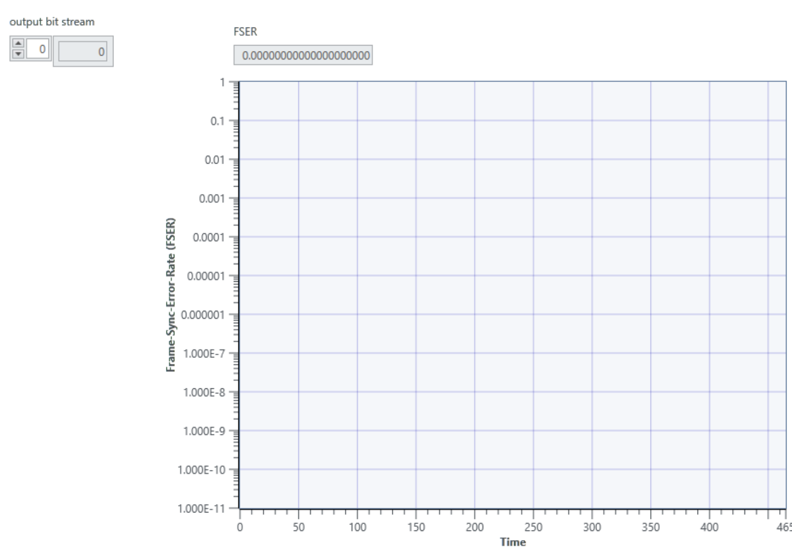

Figure 8 BPSK FSER diagram.

Now, an OQPSK signal will be transmitted, purpose is to appreciate behavior of the signal transmission. Figure 9 shows the ideal case of an OQPSK signal transmission sent from TX SDR to RX SDR. OQPSK is a more aggressive digital modulation. Constellation diagram is clean and has good accuracy. Also, Power spectrum is raised enough from bottom noise, meaning it has noble SNR. In addition, eye diagram looks clear showing a good transmission.

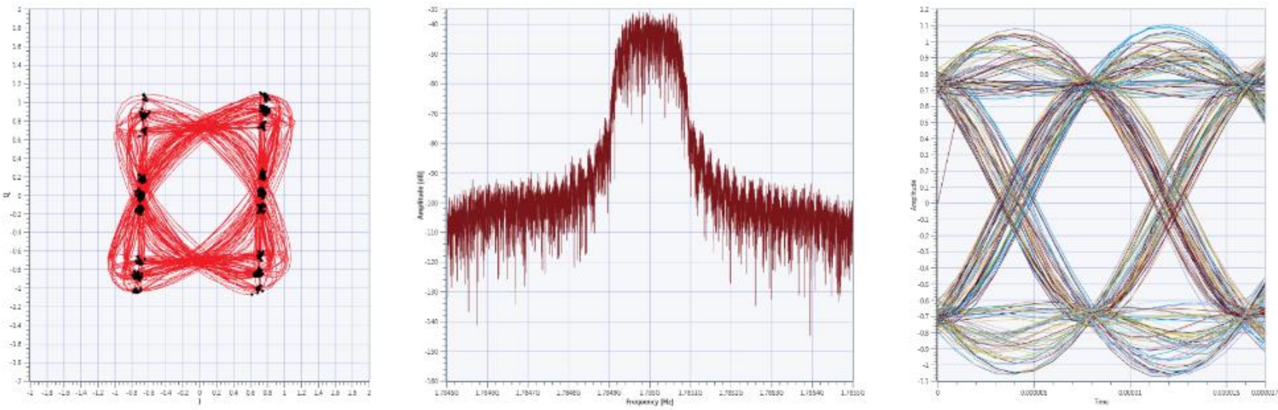

Figure 9 OQPSK signal transmission parameters. Constellation diagram. Power spectrum. Eye diagram.

Main parameters, are set in LabVIEW system interface. This experiment was only done in LabVIEW to provide an ideal transmission between SDR's. Figure 6 shows the FSER with a clean rate and operation is normal.
Furthermore, Figure 10 shows the FSER corresponding to the OQPSK transmission, also, showing clean with no errors.

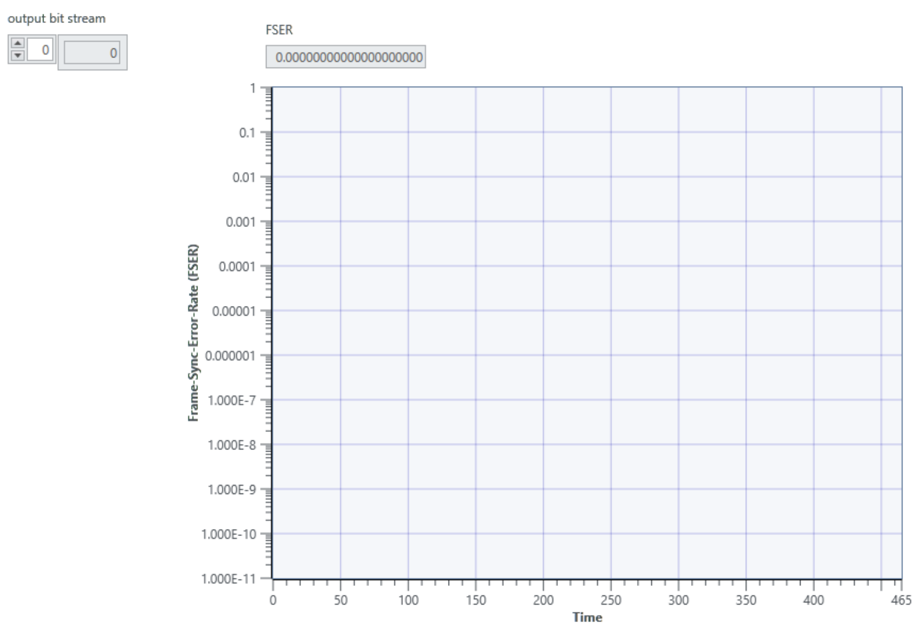

Figure 10 OQPSK FSER diagram

Now, testing will be followed by integrating the Digitizers in order to test signal transmission over an IP network. Transmission will now start as an RF signal then converted to IP network using OFDM modulation by the digitizers and de-convert signal to an RF, in order to be received by the SDR. Figure 11 shows a BPSK signal transmission. Constellation diagram which is jittery. Power spectrum shows a minimum difference from the noise floor. Eye diagram is completely closed.

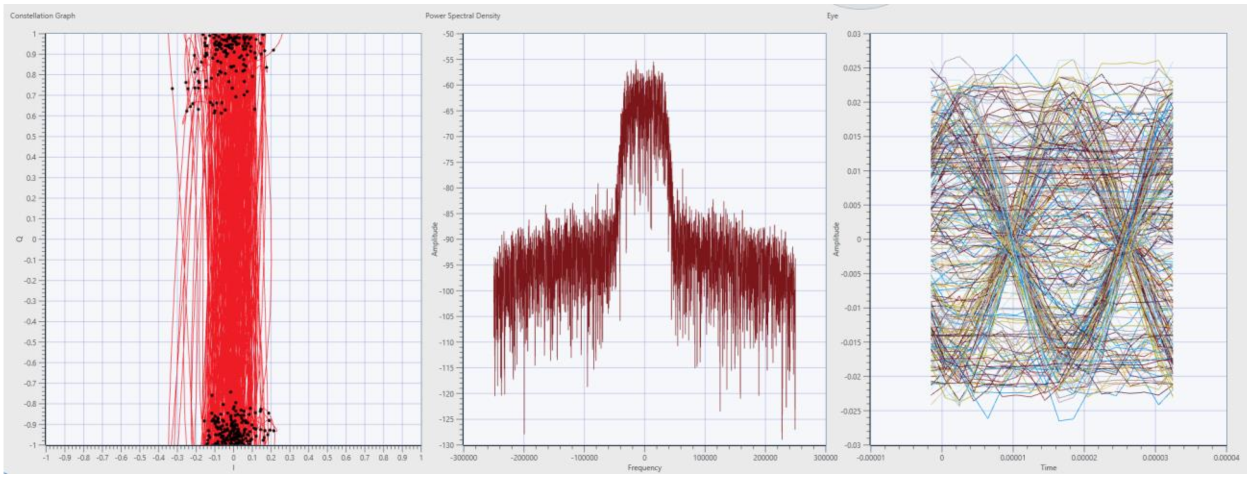

Figure 11 BPSK signal transmission over IP. Constellation Diagram. Power spectrum. Eye diagram.

In addition, Figure 12 shows FSER diagram with many errors over time. This is due to constellation diagram to be jittery and SNR to be too small.

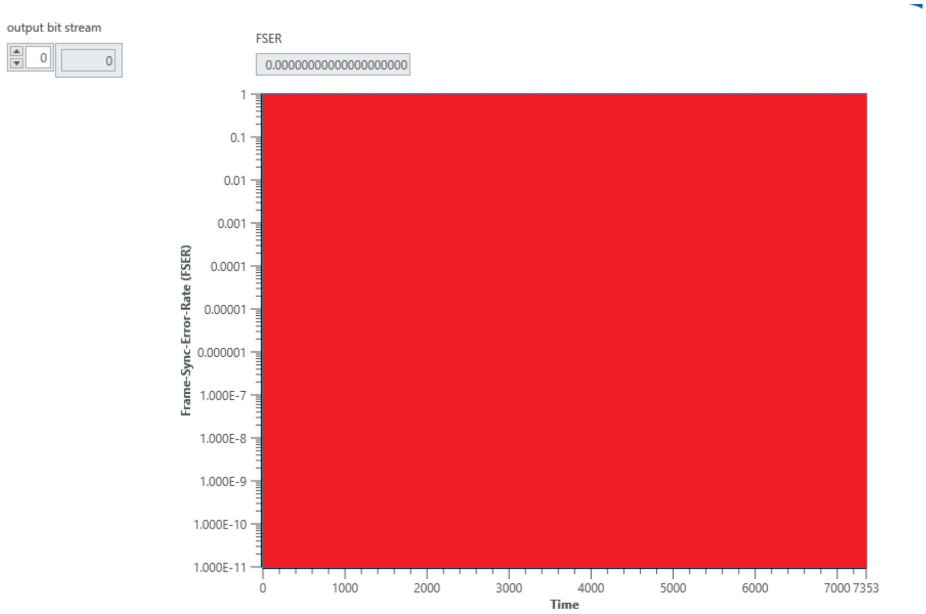

Figure 12 BPSK over IP FSER diagram.

Now, OQPSK over an IP network signal transmission. OQPSK modulation is a more aggressive modulation. Also, OQPSK signal will be converted in to OFDM modulation using a digitizer and de-convert by other digitizer in order to receive the signal by the SDR. Figure 13 shows an OQPSK signal transmission over IP network. Constellation is jittery but still accurate. Power spectrum has difference from noise floor. Eye diagram is not as clean as expected but it is open.

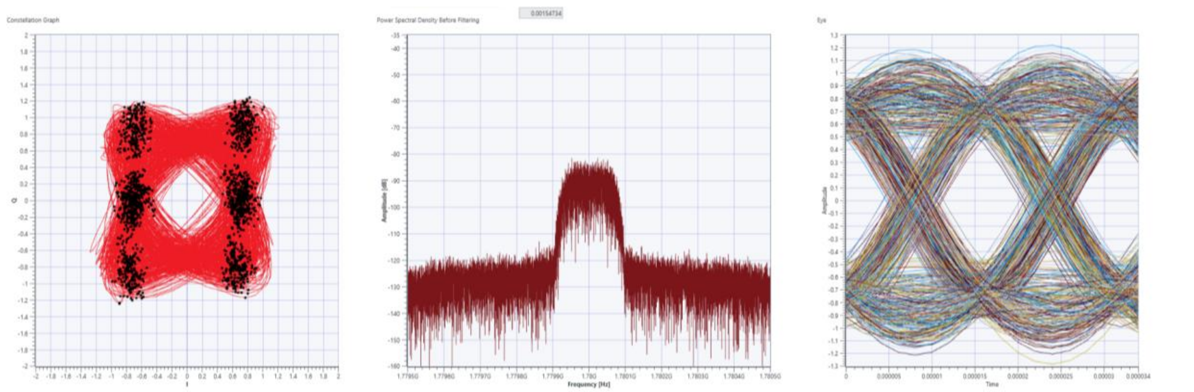

Figure 13 OQPSK signal transmission over IP. Constellation Diagram. Power spectrum. Eye Diagram.

In addition, Figure 14 shows FSER diagram, FSER diagram has a few errors but it is a reasonable signal transmission. Other techniques such as, Forward Error Correction could improve signal transmission.

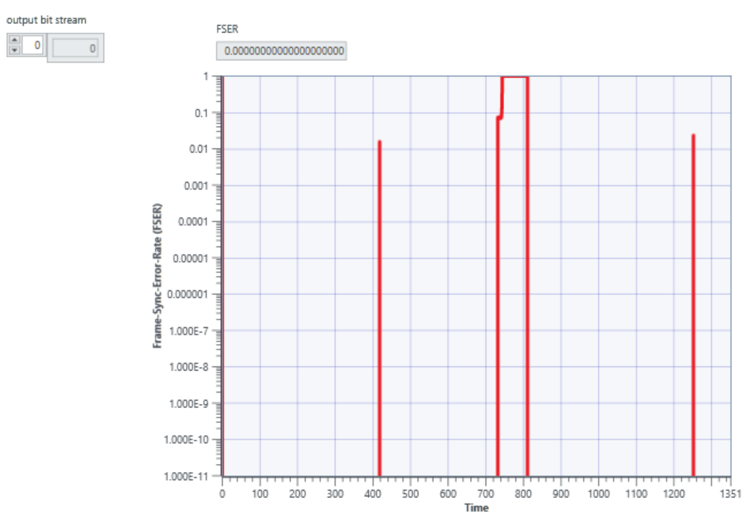

Figure 14 OQPSK over IP FSER diagram.

This concludes results for the testing in the S-band. Two different modulations were tested in order to have more feedback of this signal transmission. Remaining results are for future thesis work of the main author. This results will also include testing with a reference clock, several modulations and different setups.

CONCLUSION

RF disadvantages and high density traffic frequency due to overcrowding in the spectrum. Results were delivered and some rules in order to achieve decent signal transmission in order to mitigate Normal RF transmissions.

- High order modulation such as, OQPSK is required in order to transmit signals with some loss.
- RF over IP is still a viable option due to disadvantages over long transmissions of RF. For example, multipath fading or degradation over long distance.
- Forward Error coding could improve signal transmission.
- Linear predictive coding could be implemented in order to reduce the amount of bits transmitted over the IP network [2].
- Reference clock could reduce errors and receive a cleaner signal. Delivering a better constellation diagram, power spectrum and eye diagram.
- Other modulations, such as QAM could improve signal transmission.

To conclude, RF has many disadvantages, such as degradation and multipath fading. Main disadvantage is spectrum overcrowding. Even that FCC has rules designed for transmission, there are still some problems due to other modulations. Mitigations rules in research papers are already explored. For example “Interference Analysis and Mitigation of Telemetry (TM) and 4G Long-Term Evolution (LTE) Systems in Adjacent Spectrum Bands” [5] designed rules in order to mitigate several problems. In addition, a flexible system could be developed in order to detect RF signal loss and change to RF over IP if necessary to acieve a godd transmission. This system could also be implemented in 5G technologies or other platforms that will require no connection loss or high errors. To summarize, Testbed is a flexible paltform that can perform many experiments and will continue the research of reliability and mitigation of different frequencies using several parameters in irder to design a decent mitigation technique and high reliability.

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