A | Bandwidth measurement

Name: Group 651
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Purpose

The purpose of this measurement is to determine the bandwidth of the transmitted RF signals, for various bit rates, IQ rates and modulation types.

List of Equipment

Instrument	AAU-no.	Type
Spectrum analyzer	52766	Rohde & Schwarz FSIQ26
USRP	100784	N210
0.5 m SMA cable	-	-
Attenuators	-	1x20 dB and 2x10 dB
Ethernet cable	-	Must support gigabit ethernet
LabVIEW compatible with USRP N210	-	2015
A computer with gigabit ethernet	-	MSI GP60 2PE Leopard Pro
1x power supplies for USRP	-	6V DC

Procedure

The procedure is explained in the following:

General setup

1. Connect attenuators to the SMA cable.
2. Connect one end of the SMA cable to the RX1 terminal on the USRP, and the other end to the spectrum analyzer
3. Connect USRP to PC using Ethernet cable
4. Open the *SDR Transceiver* code in LabVIEW

5. Turn on USRP, and configure the USRP as described in the Transmitter part of Table 1.2.

Measuring the spectrum of different modulation types at high bitrate

6. Set IQ rate to 2 MS/s and bitrate to 500 kbps in the General tab
7. Write 100 in the *Repeat* field in the Transmitter tab
8. Set the center frequency of the spectrum analyzer to 2.425 GHz.
9. Set span to 2 MHz on the spectrum analyzer
10. Clear all traces, and configure a trace to display *max hold* on the spectrum analyzer
11. Click the *Transmit* button in the Transmitter tab
12. Observe transmitted spectrum on spectrum analyzer
13. Change marker type to *view*, and configure a new marker to *max hold*
14. Change modulation type to 8-PSK and click the *Transmit* button
15. Observe transmitted spectrum on spectrum analyzer

Measuring the spectrum of different modulation types at low bitrate

16. Set IQ rate to 200 kS/s and bitrate to 900 bps in the General tab
17. Set span to 400 kHz on the spectrum analyzer
18. Repeat step 10-15

Measuring the spectrum with constant IQ rate

19. Set span to 1 MHz on the spectrum analyzer
20. Set IQ rate to 2 MS/s and bitrate to 1 kbps in the General tab
21. Repeat step 10 to 13
22. Set bitrate to 400 kbps in the General tab
23. Repeat step 11 to 13
24. Set bitrate to 500 kbps in the General tab
25. Repeat step 11 to 13
26. Observe transmitted spectrum on spectrum analyzer

Measuring the spectrum with constant bitrate

27. Set span to 1 MHz on the spectrum analyzer
28. Set bitrate to 1 kbps and IQ rate to 1 MS/s in the General tab
29. Repeat step 10 to 13
30. Set IQ rate to 500 kS/s in the General tab
31. Repeat step 11 to 13
32. Set IQ rate to 400 kS/s in the General tab
33. Repeat step 11 to 13
34. Observe transmitted spectrum on spectrum analyzer

Measuring the spectrum with constant IQ rate/ bitrate ratio

35. Set IQ rate to 200 kS/s and bitrate to 5 kbps in the General tab
36. Repeat step 10 to 13
37. Set IQ rate to 400 kS/s and bitrate to 10 kbps in the General tab
38. Repeat step 11 to 13
39. Set IQ rate to 2 MS/s and bitrate to 50 kbps in the General tab
40. Repeat step 11 to 13
41. Observe transmitted spectrum on spectrum analyzer

Results

Screenshots of the power spectrums observed can be seen on Figure 2.11 to Figure 2.16.

The bandwidth is throughout these measurements defined as the width of the main lobe of the signal.

Measuring the spectrum of different modulation types at high bitrate
Looking at Figure 2.11, it can be seen how the bandwidth of the signal changes from approx. 400 kHz using 8-PSK, to 500 kHz when using OQPSK with a constant IQ rate and bitrate. This theory states that the maximum spectral efficiency of 8-PSK is 3 bps/Hz, while it for OQPSK is 2 bps/Hz, see **??**. With this in mind it is seen that the differences is not as significant as expected, but still in compliance with the theory.

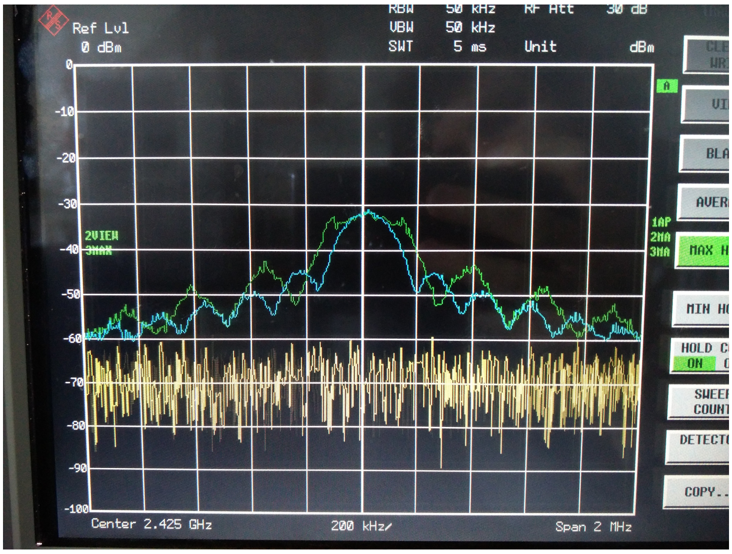

Figure 3.11: Power spectrum of OQPSK (green) and 8-PSK (blue) at a bitrate of 500 kbps and an IQ rate of 2 MS/s.

Measuring the spectrum of different modulation types at high bitrate
Looking at Figure 2.12, where a different bitrate and IQ rate has been used, the spectrums are not in compliance with the theory. This is because the main lobes width is the same for both OQPSK and 8-PSK, approx. 160 kHz, and neither has a bandwidth similar to that calculated from their spectral efficiencies, which should be 450 Hz for OQPSK and 300 Hz for 8-PSK, as calculated based on **??**.

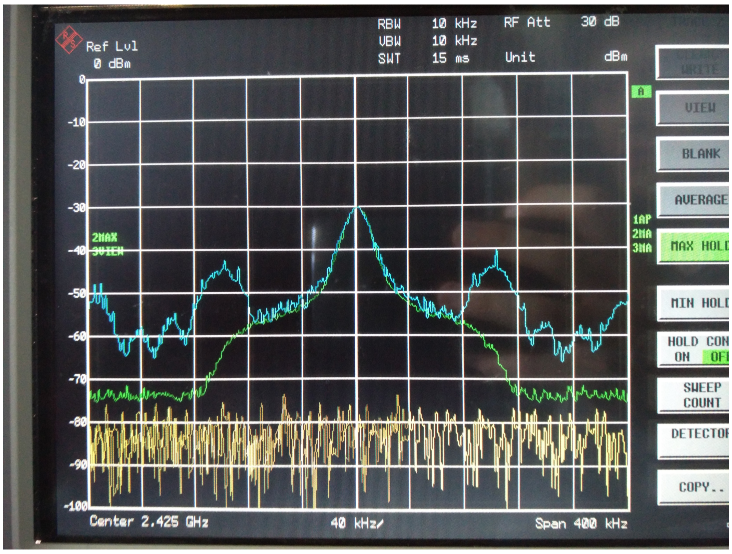

Figure 3.12: Power spectrum of OQPSK (green) and 8-PSK (blue) at a bitrate of 900 bps and an IQ rate of 200 kS/s.

In Figure 2.13, it can be seen how the spectrum actually is compromized of a narrower main lobe ($BW \approx 80$ kHz) and some "spurry" sidelobes, whose origin is not known. The narrower bandwidth signal is more in conformance with theory, but is not close to the theoretical bandwidth of 450 Hz, that should be obtained with a bitrate of 900 bps.

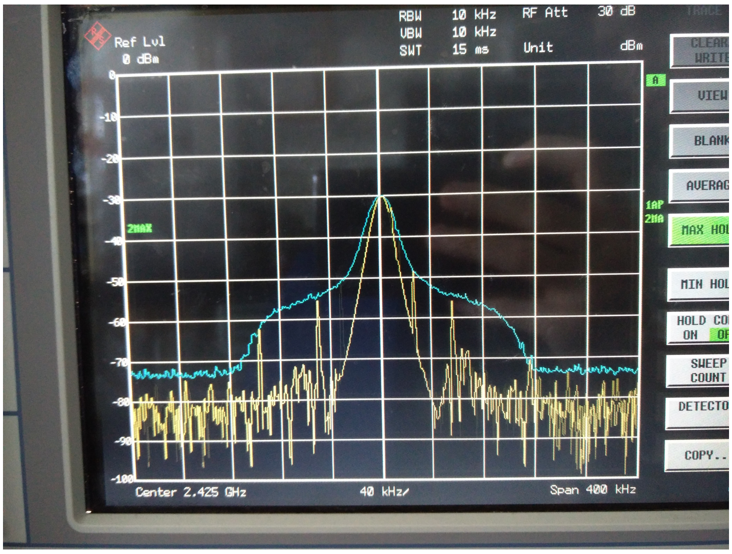

Figure 3.13: Power spectrum of OQPSK at a bitrate of 900 bps at an IQ rate of 200 kS/s. Blue is a max-hold and yellow is the current spectrum.

The other explanation for the observed spectrum is the Nyquist sampling theorem, stating that a signal must be sampled with at least twice the bandwidth of the signal, i.e.:

$$F_s > 2 \cdot \mathrm{BW} \tag{3.1}$$

Where:

F_s	is the sampling frequency	[Hz]
BW	is the bandwidth of the signal	[Hz]

In this case, the IQ rate of 200 kS/s is the sampling rate, implying a bandwidth of 100 kHz, which is close to the actual value. Applying this to the signals in Figure 2.11 does however not provide a good estimate of the bandwidth.

Measuring the spectrum with constant IQ rate

In Figure 2.14, the IQ rate is held constant, to see if the bitrate changes the bandwidth - this should be the case if the spectral efficiency is to be used for determining the bandwidth. As can be seen, this is the case, it is however noted that for low bitrates it is something else that is the determining factor of the bandwidth as the spectrum for the low bitrate both seems to have to wide a main lobe along with a "wrong" shape compared to the other bitrates.

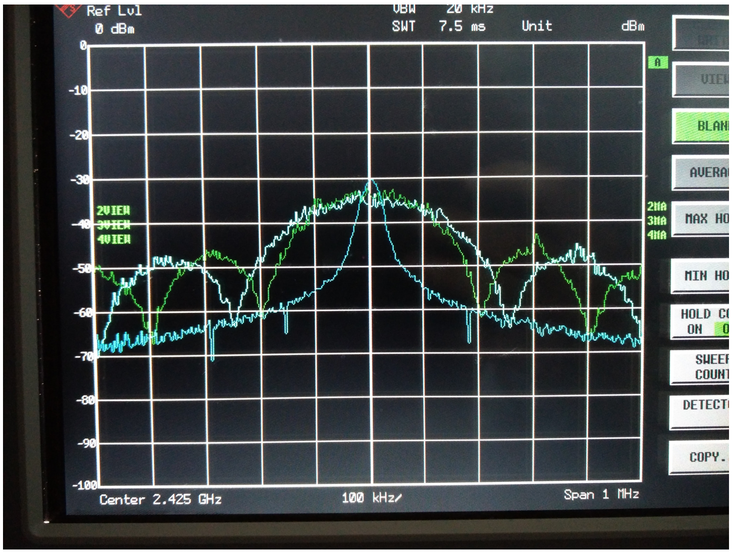

Figure 3.14: Power spectrum of OQPSK with a constant IQ rate of 2 MS/s with a bitrate of 1 kbps (blue), 400 kbps (green) and 500 kbps (light blue).

Measuring the spectrum with constant bitrate

In Figure 2.15, it was investigated if having a constant bit rate and changing the IQ rate would change the bandwidth of the signal. If the theory regarding spectral efficiency was applicable, this would not be the case. As can be seen, changing the IQ rate does however change the bandwidth. It is however noted, that in this case the bitrate is low, which from the previous test seemed to have some unknown external factor dominating the bandwidth.

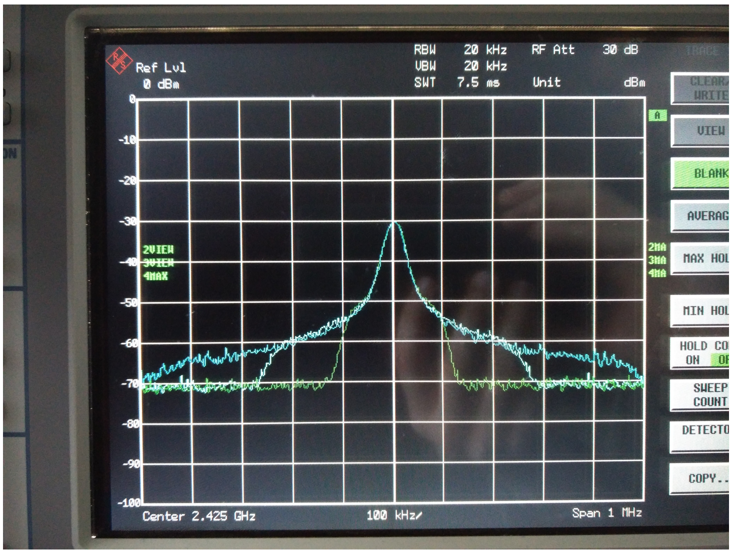

Figure 3.15: Power spectrum of OQPSK with a constant bit rate of 1 kbps with an IQ rate of 1 MS/s (blue), 500 kS/s (light blue) and 200 kS/s (green).

Measuring the spectrum with constant IQ rate/ bitrate ratio

Finally, it is investigated if it is the oversampling ratio that is a determining factor for the bandwidth, i.e. the ratio between the IQ rate and the bitrate. In Figure 2.16 the ratio between the IQ rate and the bitrate is held to 40, and then both values are changed with the same ratio. Here, it can be seen that the bandwidth is changing, and it can therefore be concluded that the absolute values seem more determining than the ratio, as the bandwidth seem to scale somewhat proportional to bitrate/IQ rate. It can here also be seen that when going to the high bitrate of 50 kbps, the shape of the spectrum regains the expected sidelobes.

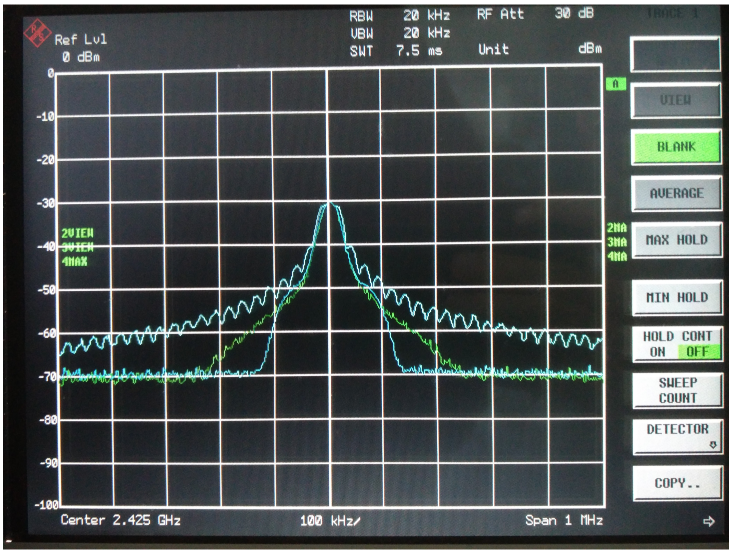

Figure 3.16: Power spectrum of OQPSK with a IQ rate:bitrate ratio of 1:40, for a bitrate of 5 kbps (blue), 10 kbps (green) and 50 kbps (light blue).

From this investigation, it can be concluded that primary factor that determines the bandwidth of the signal is the bitrate, but for low bitrates an unknown external factor has some implication for the bandwidth.
It is however noted that the bandwidth in general seems to be twice the expected value, based on the theory, since Figure 2.14 suggests a 1:1 ratio between bitrate and bandwidth for OQPSK.