VANIER COLLEGE – Computer Engineering Technology – Winter 2021

Telecommunications (247-410-VA)

Leonardo Fusser (1946995)

LABORATORY EXPERIMENT #6

Digital Modulation

NOTE:

To be completed in one lab session of 3 hrs.

To be submitted using the typical lab format, one week later – **at the start** of your respective lab session.

This exercise is to be done **individually** except where specified in the procedure.

OBJECTIVES:

After performing this experiment, the student will be able to:

1. Explain and contrast BPSK, QPSK, 8PSK and QAM modulation.
2. Understand the efficiency benefits and noise immunity trade-offs of high-order modulation
3. Calculate the Symbol rate and approximate bandwidth of a modulated signal
4. Edit a waveform and generate it on a waveform generator.
5. Use a waveform generator in BPSK mode

DISCUSSION OF THEORY

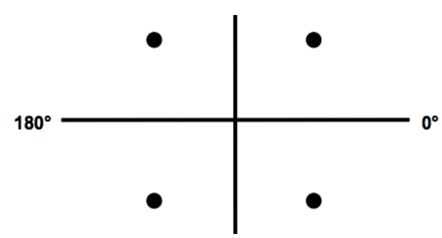
Digital modulation is the modulation of an analog carrier with a digital baseband signal. In digital, just like analog, it is possible to modulate the carrier's:

- Amplitude for Amplitude Shift Keying (ASK)
- Frequency for Frequency Shift Keying (FSK)
- Phase for Phase Shift Keying (PSK) - Common
- Both the Amplitude and Phase for Quadrature Amplitude Modulation (QAM) - Common

Binary modulation means that there are just 2 possible symbols (e.g. 2 phases for Binary PSK) that represent either a binary 0 or 1. It is possible and very common to use more than two symbols in the signaling vocabulary.

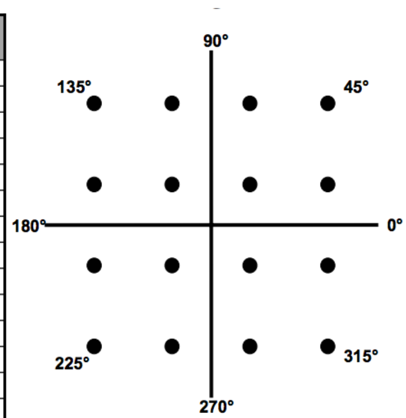
For example, Quadrature Phase Shift Keying (QPSK) uses 4 different phase symbols where each of the 4 phases represents 2 bits (00, 01, 11, 10), meaning that each time we send one phase symbol, we are actually transmitting two bits of information. That allows QPSK to send twice as many bits per second in a given bandwidth compared to BSPK. Likewise, 8PSK carries $\log_2(8)=3$ bits per symbol (3 times the bit rate as BPSK) and 16 QAM carries $\log_2(16)=4$ bits per symbol (4 times the bit rate as BPSK for same bandwidth).

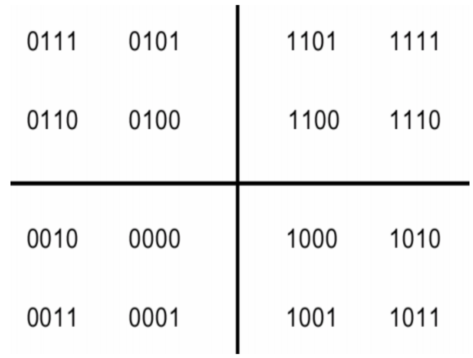
Symbol Transmitted	Carrier Phase	Carrier Amplitude
00	225°	1.0
01	135°	1.0
10	315°	1.0
11	45°	1.0



The above constellation shows how series of 2 bits are mapped to 4 different phase symbols in QPSK. The following constellation shows how 4 bits are mapped to each of the 16 possible symbols, each with different phase/amplitude combinations.

Symbol Transmitted	Carrier Phase	Carrier Amplitude
0000	225°	0.33
0001	255°	0.75
0010	195°	0.75
0011	225°	1.0
0100	135°	0.33
0101	105°	0.75
0110	165°	0.75
0111	135°	1.0
1000	315°	0.33
1001	285°	0.75
1010	345°	0.75
1011	315°	1.0
1100	45°	0.33
1101	75°	0.75
1110	15°	0.75
1111	45°	1.0





The trade-off of using high-order modulation like 16QAM, 64QAM or even 256QAM is that, while they are very efficient, they are increasingly susceptible to noise. 256QAM has symbols that are very hard to for the receiver to tell apart if the reception is noisy.

To reduce the probability of making bit errors, higher-order modulation usually uses a Forward Error Correction (FEC) code that transmits some redundant bits (along with the information) to let the receiver correct bit errors if they should occur. The code rate is a fraction that says how many of the transmitted bits are the actual information bits. For example, a FEC code that adds one redundant bit per 7 data bits would be a rate 7/8 code. That means that 8 total bits (including redundant FEC bits) need to be sent on the channel (and consume bandwidth) for every 7 data bits delivered to the user.

MATERIALS AND EQUIPMENT REQUIRED:

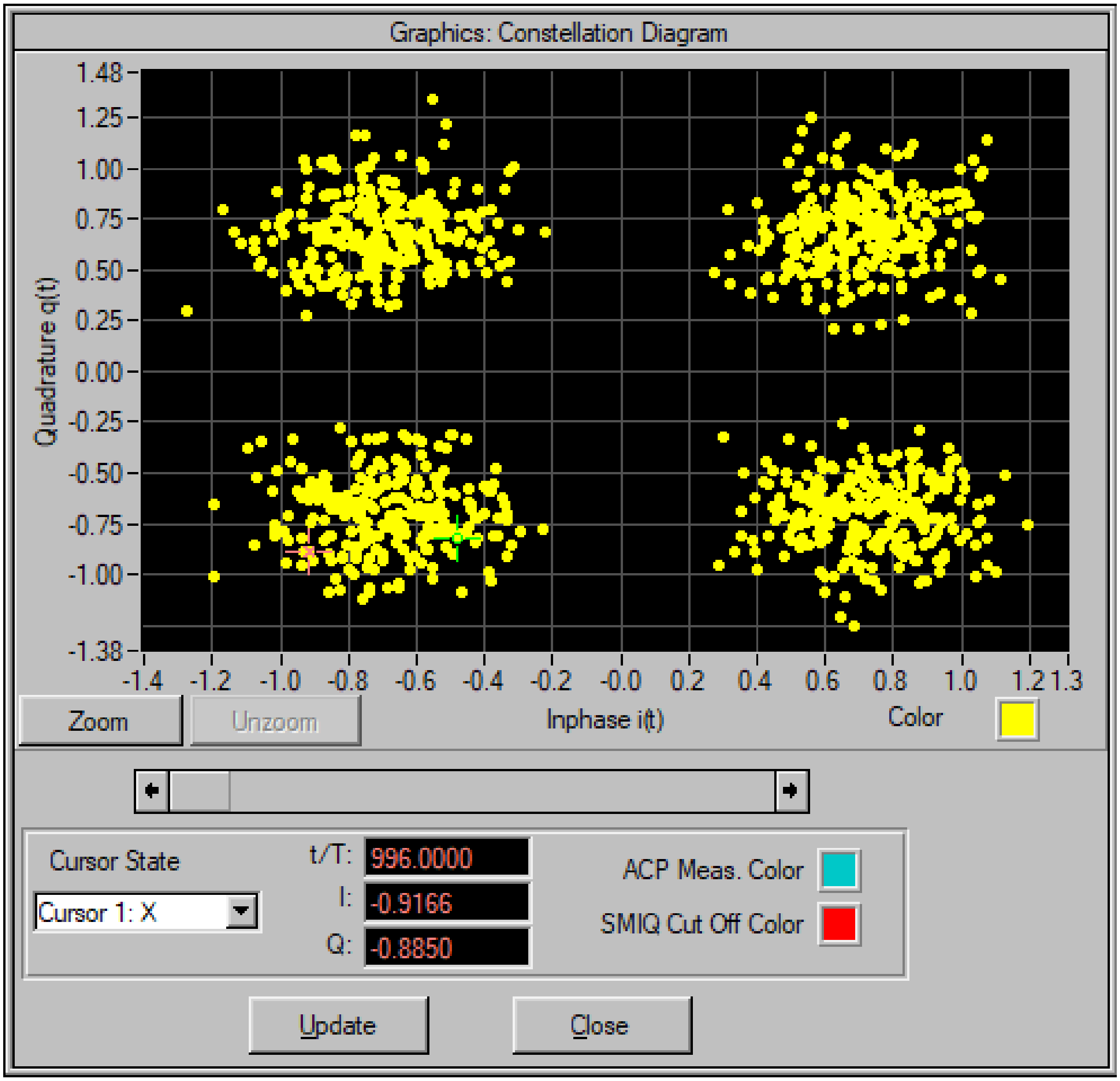
Spectrum or Signal Analyzer	Agilent 33522B Waveform Generator
Oscilloscope	Various Coaxial cables
BNC T-adaptor	WinIQSIM software

PROCEDURE

Part 1: PSK and QAM Constellations (WinIQSIM)

1. Launch the WinIQSIM software which will display the constellation for different digital modulation schemes and show what happens when there is noise on the signal.
2. Click on the Modulation Settings box in the Block Diagram and note that the modulation is set to **QPSK**. Set the Sequence Length to 1000 and click OK. This will simulate sending 1000 pseudo-random symbols. How many bits of information will be sent by these 1000 symbols?
3. In the Graphics menu (top menu bar), select Settings. Set the format to Constellation and click OK.
4. In the Graphics Menu, select Show Graphic to open the graphic window. Stretch it vertically until the black box is approximately square. You will see 4 dots, one near each corner. These dots represent the 4 different phase symbols representing 00, 01, 11 and 10 bit sequences. Because there is no noise, the received symbols land exactly where they should.
5. In the Block Diagram, click on the Noise box. Turn on the Noise switch and set the Eb/No (this is the signal to noise ratio) to 30 dB (i.e. the signal power is 1000 times stronger than the noise). Return to the Graphics window and click Update.

6. Gradually increase the noise by decreasing the Eb/No in steps of 2 dB (you have to click update on the graphic window each time) until the received symbols to start to blur with the adjacent symbol. When a received symbol crosses the dividing line with the adjacent symbol, there is a bit error. Record the minimum value of Eb/No required so that the symbols stay mostly clumped in their respective corners. Take a screenshot.

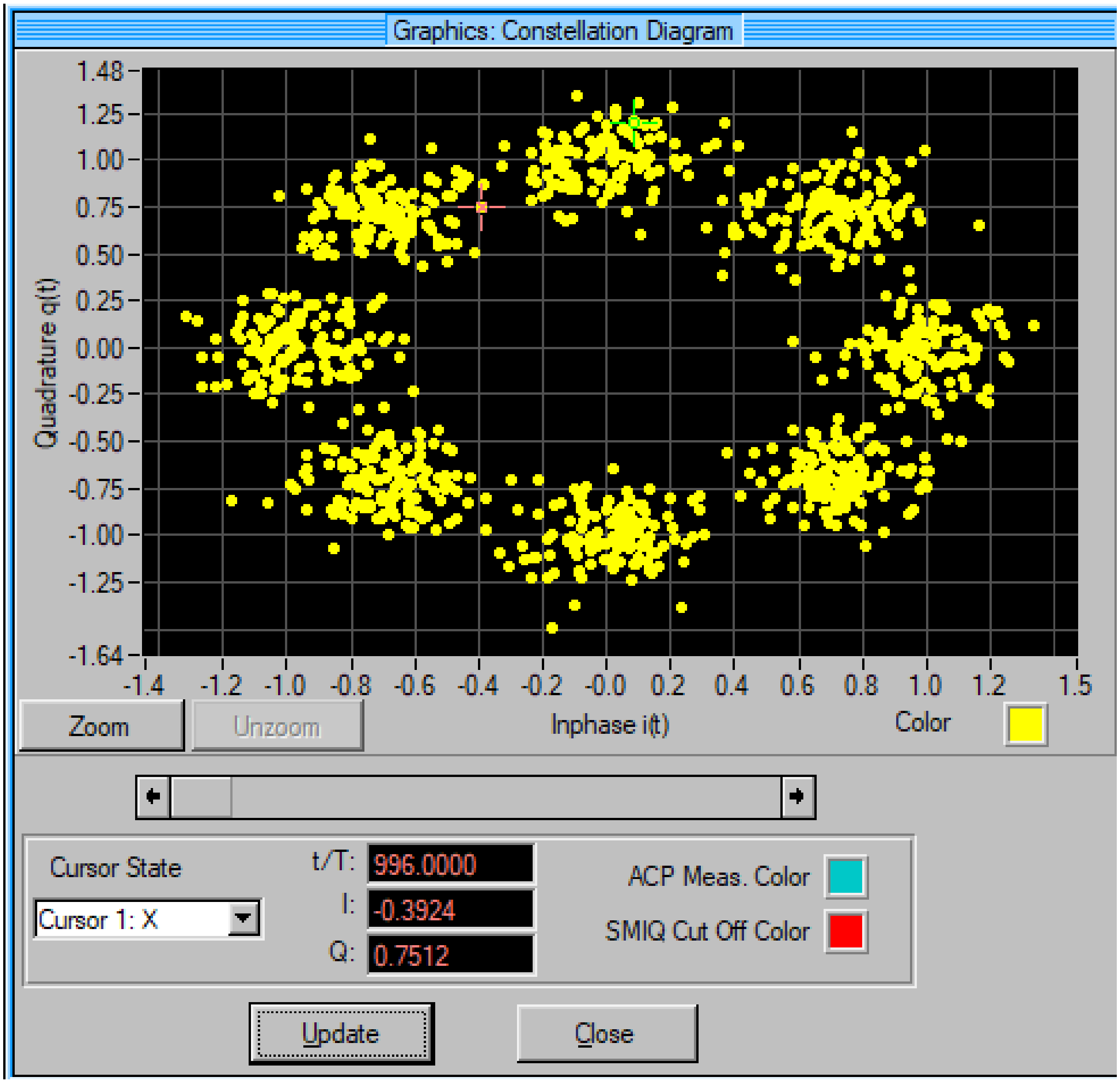


Result of QPSK signal shown above. Minimum Eb/No is 15dB so that the symbols don't interfere with one another.

7. Turn the Noise off and click on the Modulation Setting box in the block diagram. Set the Modulation Type to **8PSK** and click OK. Return to the Graphics window and click Update. Note that there are now 8 different phase symbols. If we transmit 1000 symbols, how many bits are sent?

   - If 1000 symbols are transmitted, then there will be 3000 bits sent per 1000 symbols (3 * 1000 = 3000).

8. Repeat steps 6-7 for 8PSK and record the minimum value of Eb/No for reliable reception of 8PSK.



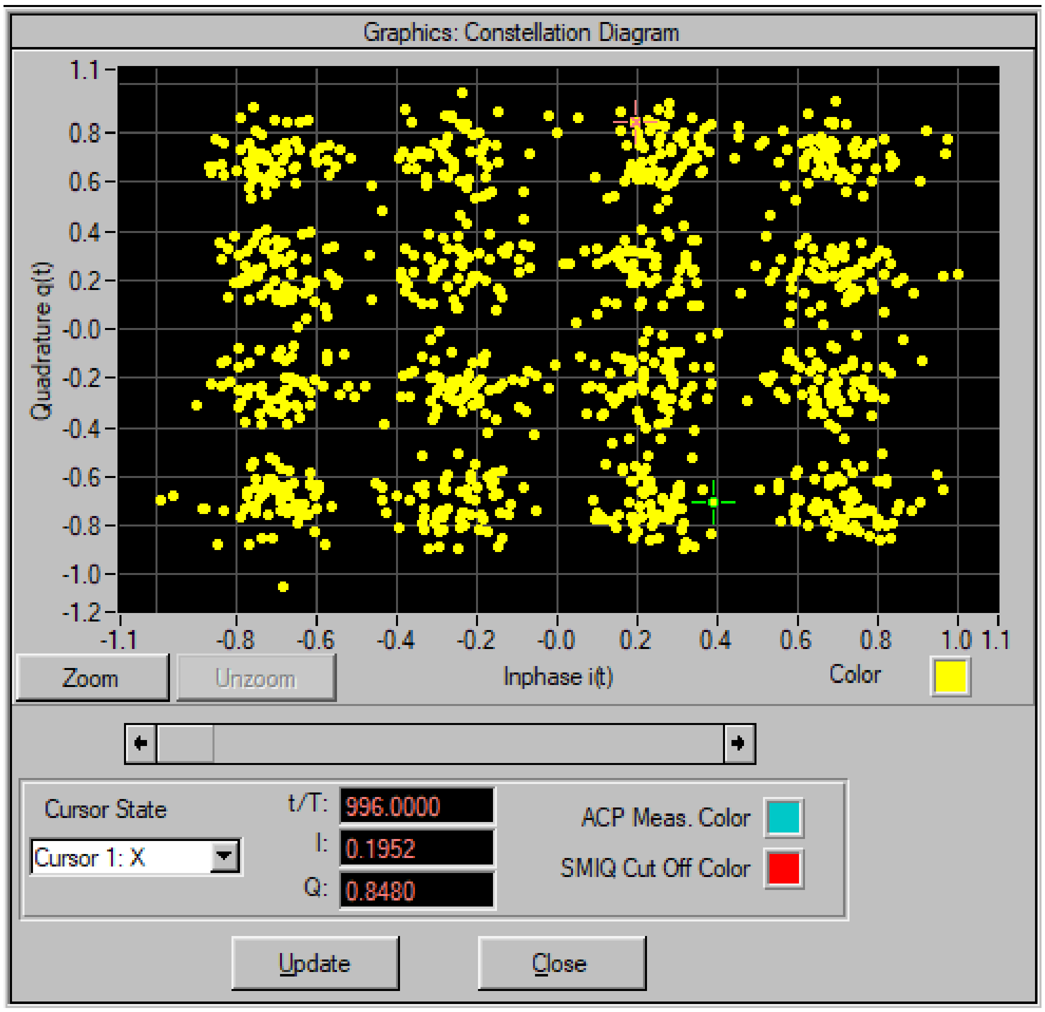
Result of 8PSK signal shown above. Minimum Eb/No is 15dB so that the symbols don't interfere with one another.

9. Repeat steps 8-9 for the following Modulation techniques:
    a. 16QAM (see screenshot below)
    b. 64QAM (see screenshot below)
    c. 256QAM (see screenshot below)

Record your results in the following table. The table show the number of bits sent per 1000 symbols and the minimum value of Eb/No (i.e. Signal to Noise ratio) required for each modulation scheme.

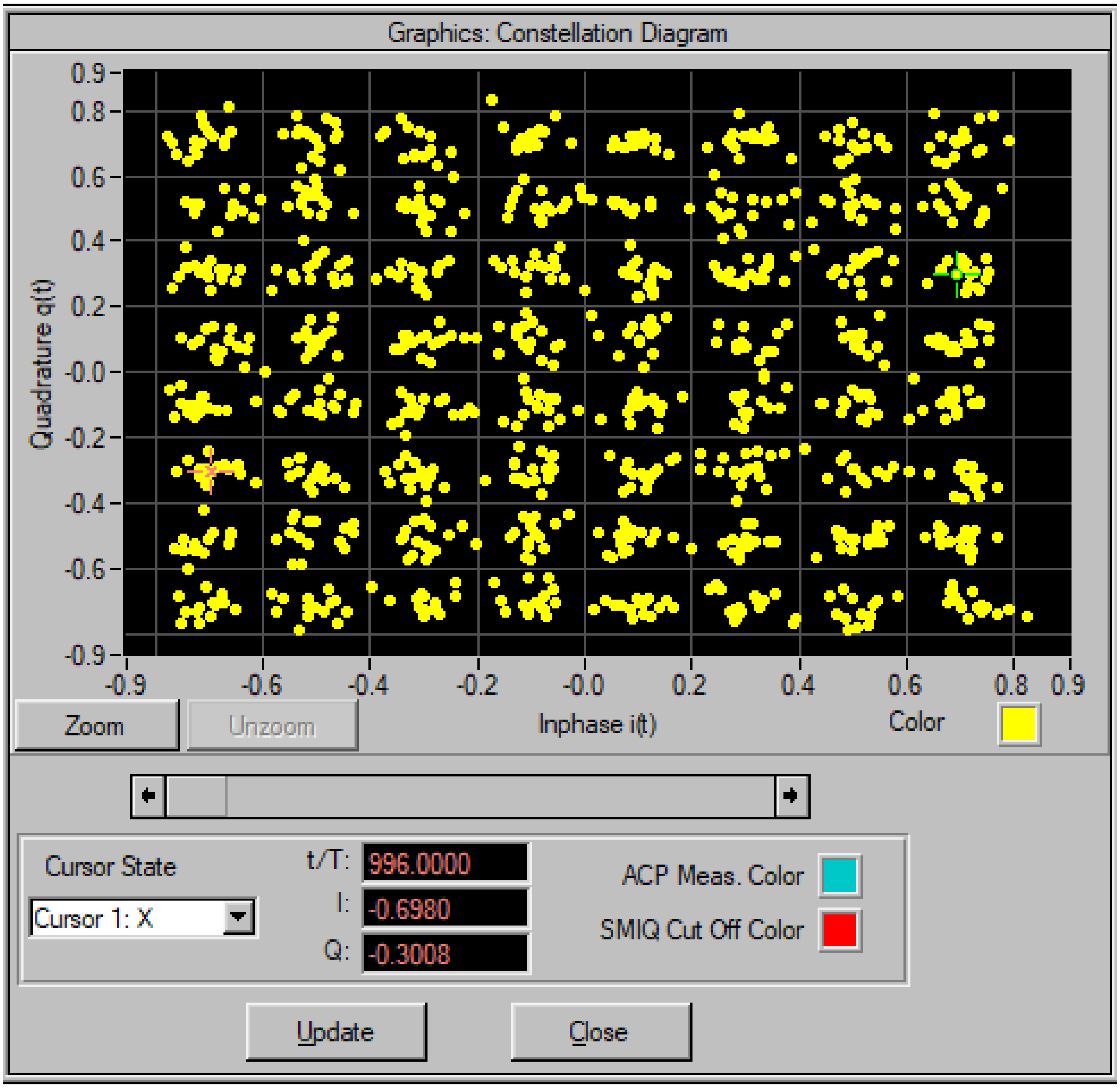
Modulation type:	**QPSK** (2 bits per symbol)	**8PSK** (3 bits per symbol)	**16QAM** (4 bits per symbol)	**64QAM** (6 bits per symbol)	**256QAM** (8 bits per symbol)
Number of bits sent per 1000 symbols.	2 * 1000 = 2000 bits sent per 1000 symbols.	3 * 1000 = 3000 bits sent per 1000 symbols.	4 * 1000 = 4000 bits sent per 1000 symbols.	6 * 1000 = 6000 bits sent per 1000 symbols.	8 * 1000 = 8000 bits sent per 1000 symbols.
Minimum Eb/No.	15dB	15dB	15dB	20dB	28dB

Screenshot for 9a



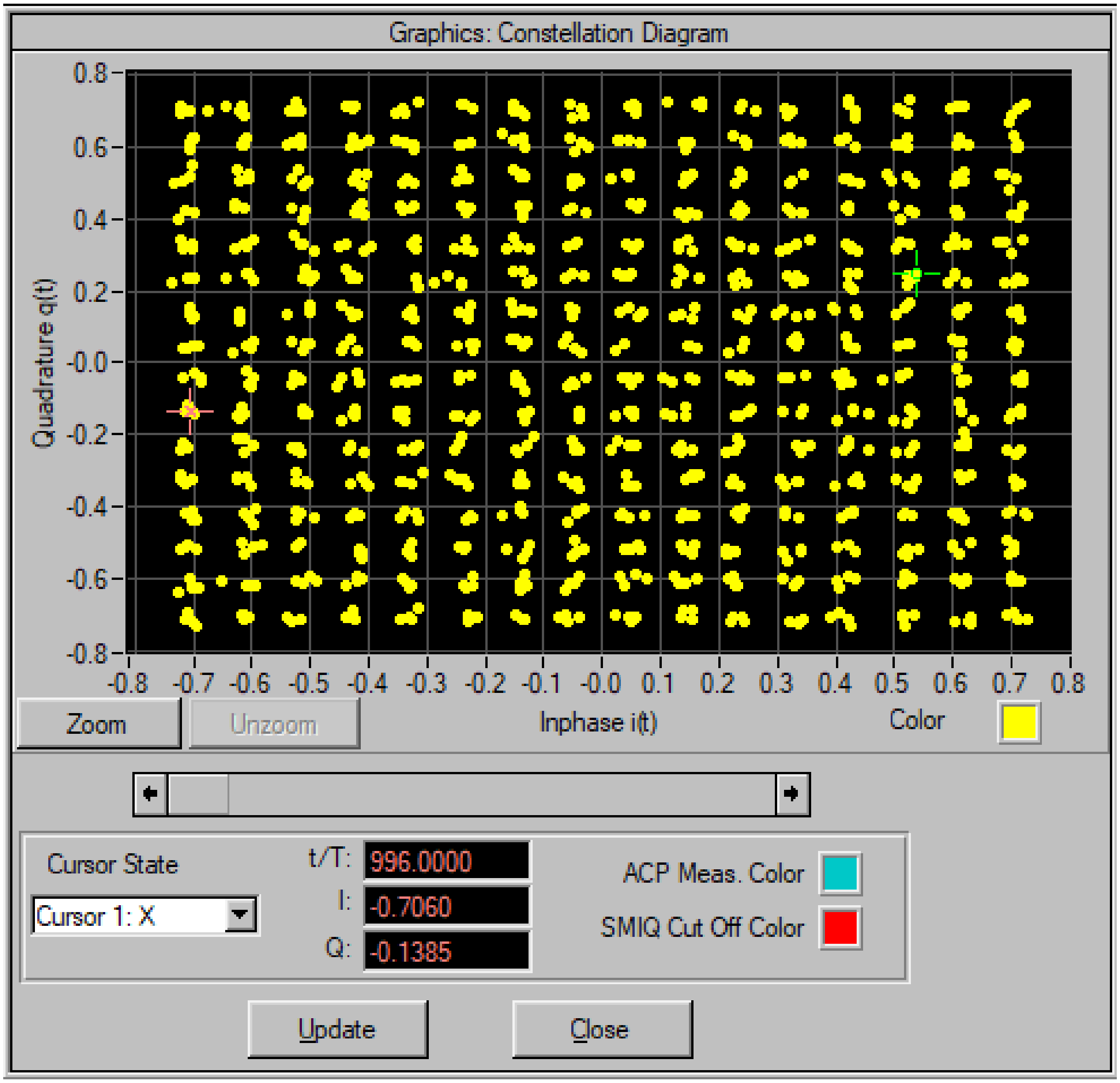
Result of 16QAM signal shown above. Minimum Eb/No is 15dB so that the symbols don't interfere with one another. Number of bits sent per 1000 symbols found in above table.

Screenshot for 9b



Result of 64QAM signal shown above. Minimum Eb/No is 20dB so that the symbols don't interfere with one another. Number of bits sent per 1000 symbols found in above table.

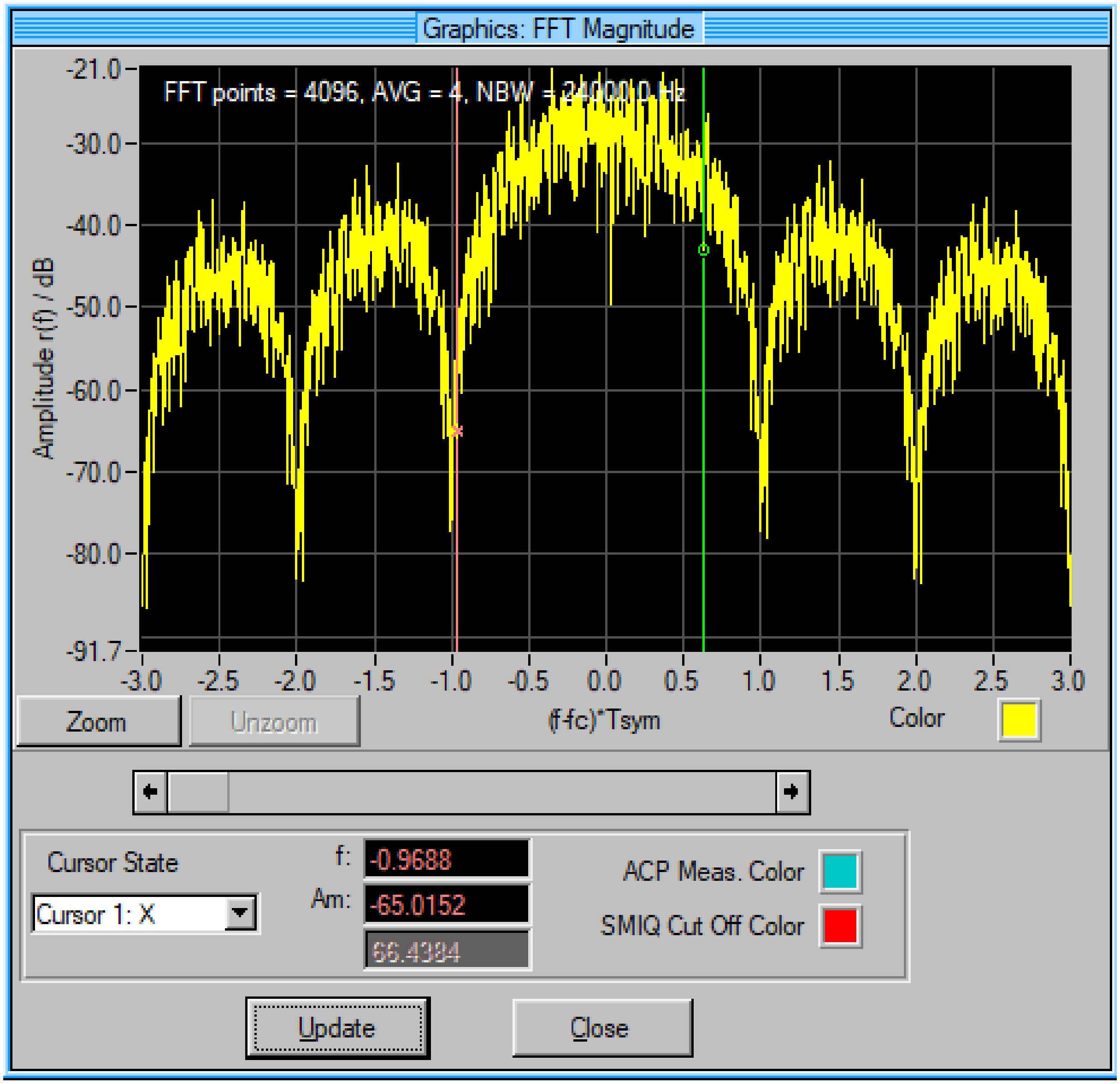
Screenshot for 9c



Result of 256QAM signal shown above. Minimum Eb/No is 28dB so that the symbols don't interfere with one another. Number of bits sent per 1000 symbols found in above table.

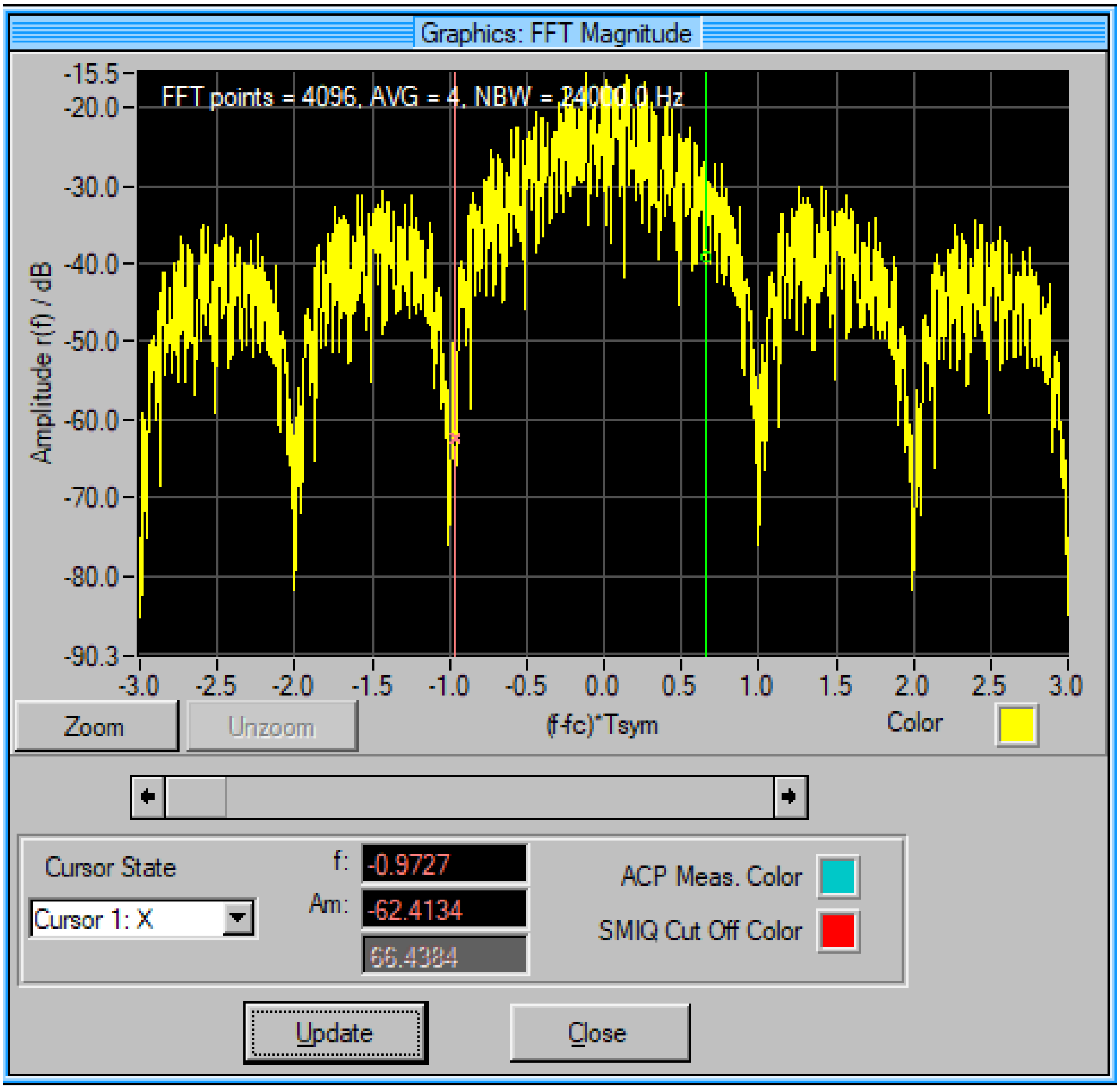
<u>Modulation Bandwidth</u>

10. Turn off the Noise and click OK to close the Interferer window. Get to Graphic Setting and set the Format to FFT MAG. Uncheck the FFT F Auto box and set the Min to -3 and the Max to 3. Click OK. This will display the frequency domain of the modulated signal (like you would see on a spectrum analyzer).



Frequency domain signal for 256QAM signal shown above.

11. Click on the Modulation Settings box and set the Modulation type to **QPSK**. Click Update on the graphics window to display the bandwidth of the modulated signal. Measure the bandwidth of the main lobe by counting the divisions between the two inside-most nulls. If we are transmitting 1000 symbols per second, how many bits/second are being sent in this bandwidth?

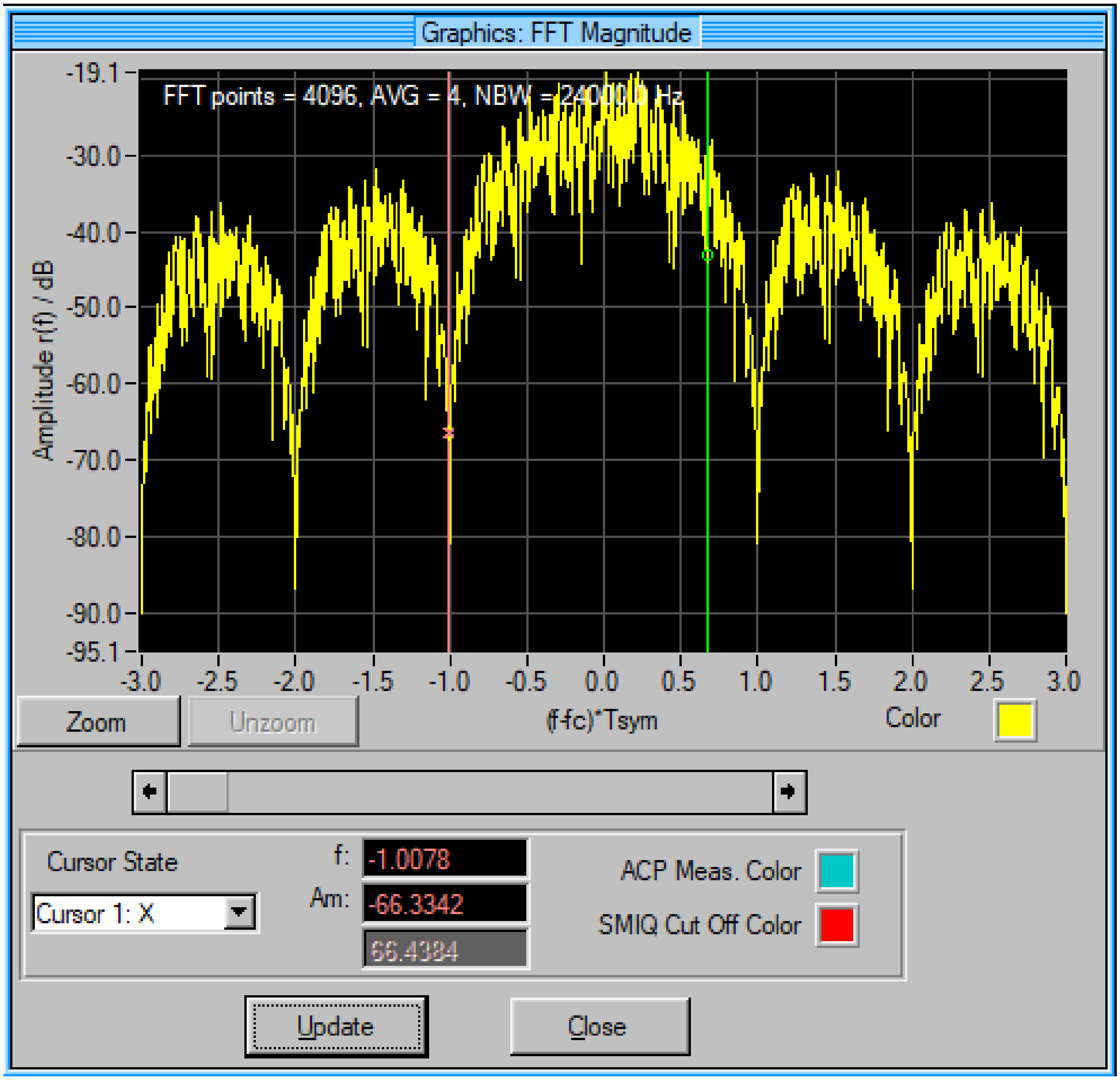


Frequency domain signal for QPSK signal shown above.

- If we are transmitting 1000 symbols per-second, therefore, there will be 2000 bits per-second will be sent in the bandwidth above for QPSK signal (2 * 1000 = 2000).

12. Repeat step 11 for the following Modulation techniques. Comment on if and how the bandwidth changes for different modulation types when the symbol rate is constant.
    a. 16QAM (see screenshot below)
    b. 256QAM (see screenshot below)

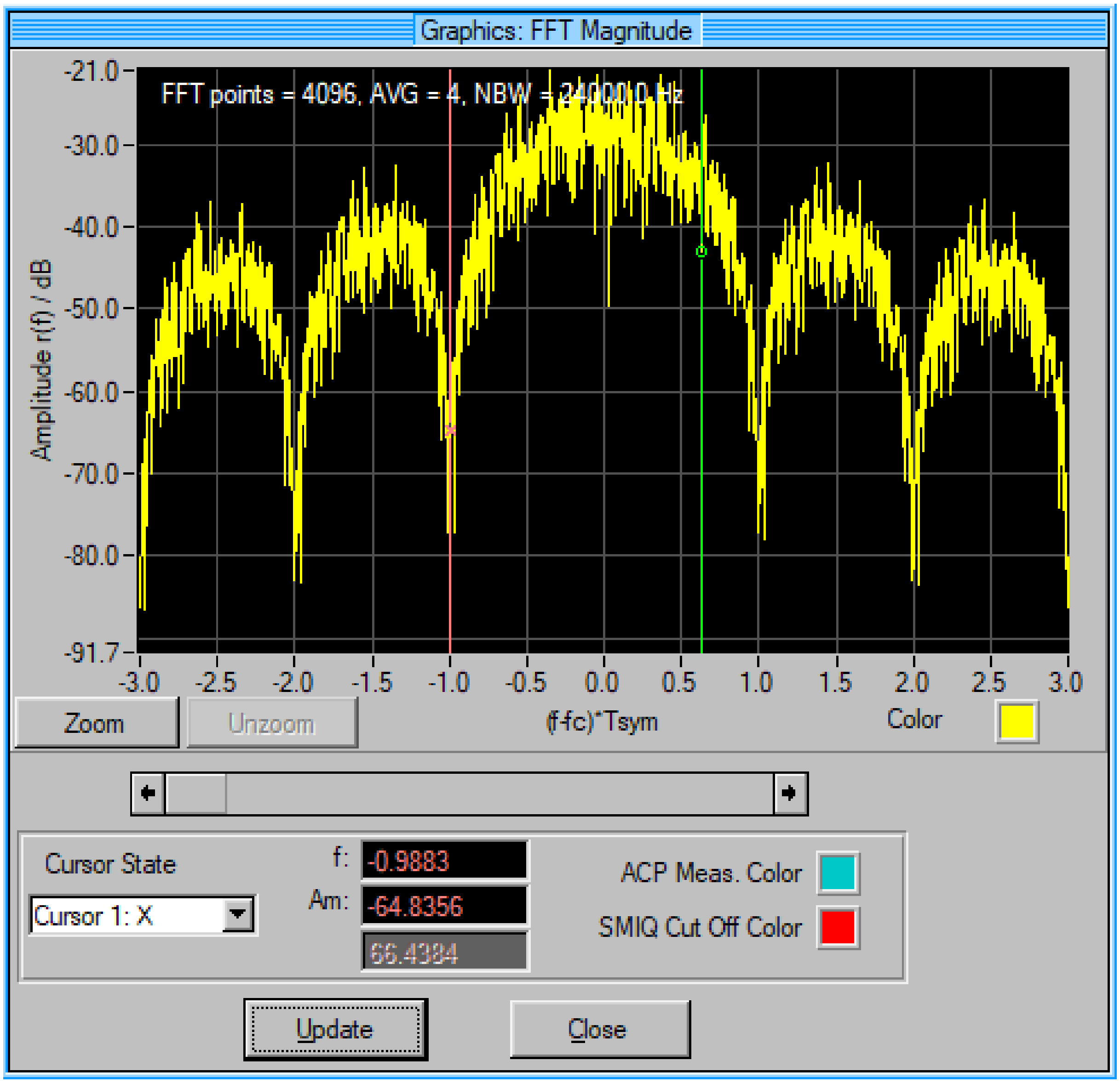
Screenshot for 12a



Frequency domain signal for 16QAM signal shown above.

- If we are transmitting 1000 symbols per-second, therefore, there will be 4000 bits per-second will be sent in the bandwidth above for 16QAM signal (4 * 1000 = 4000).

Screenshot for 12b



Frequency domain signal for 256QAM signal shown above.

- If we are transmitting 1000 symbols per-second, therefore, there will be 8000 bits per-second will be sent in the bandwidth above for 16QAM signal (8 * 1000 = 8000).