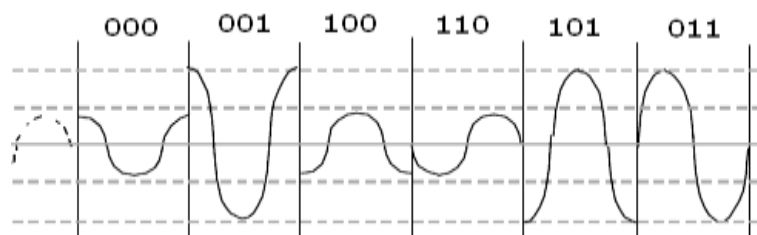
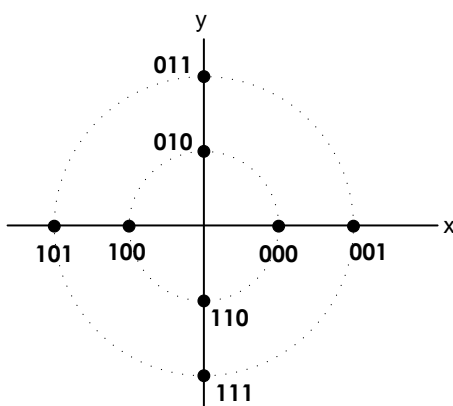


2.6.2 Hybrid Amplitude/Phase Modulation (QAM)

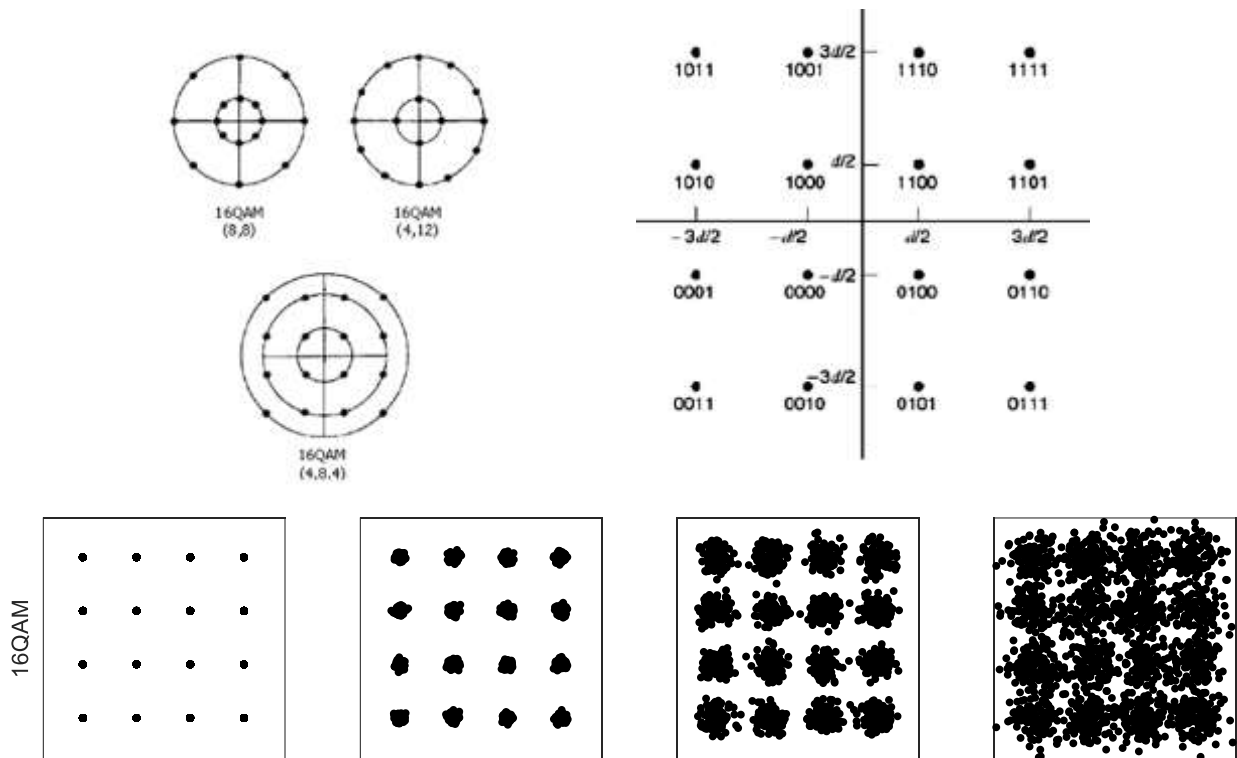
Also called Quadrature Amplitude Modulation. Here, it is possible to introduce amplitude as well as phase modulation to give an improved distribution of signal state in the phasor diagram.

The following illustrates the 8QAM:

Bit Combination	Phase Shift (Deg.)	Amplitude
000	0	Low
001	0	High
010	90	Low
011	90	High
100	180	Low
101	180	High
110	270	Low
111	270	High



The following figures illustrate the re-distribution of 16PSK to create 16QAM:

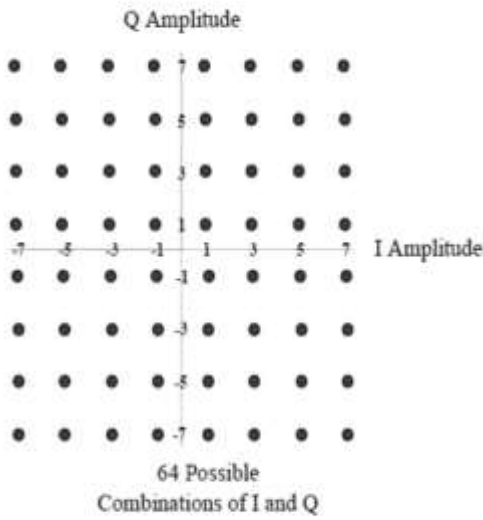


64 and 256 QAM Constellations

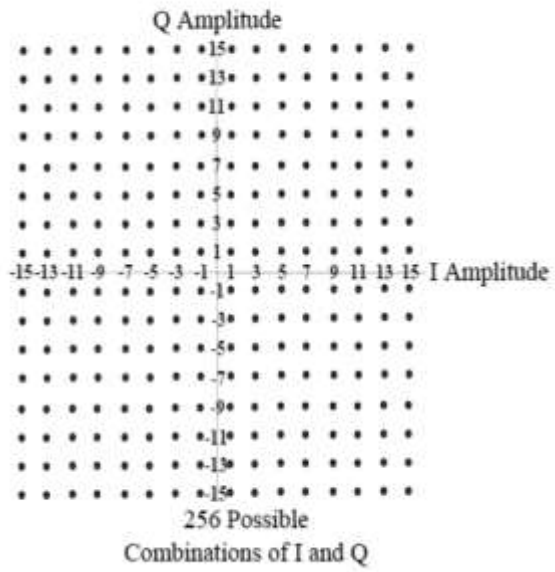
By adding more levels to the I and Q channels, higher data rates can be carried.

- The higher the number of levels, the more effect there will be from noise or interference.
- 64 QAM uses 8 levels in the I direction and 8 levels in the Q direction for a total of 8 squared or 64 symbols.
- 256 QAM uses 16 levels in the I direction and 16 levels in the Q direction for a total of 16 squared or 256 symbols.

64 QAM Constellation



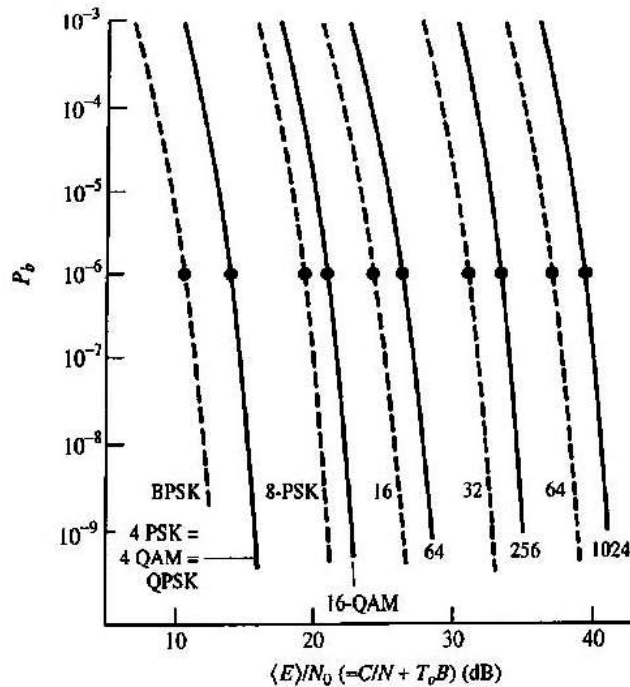
256 QAM Constellation



Probability of Error in MQSK*

$$P_E \approx 4 \left(1 - \frac{1}{\sqrt{M}} \right) \text{Erfc} \left(\sqrt{\frac{3E_{Avg}}{(M-1)\eta}} \right)$$

This figure shows clearly that the MQAM is much better than the MPSK for the same M .



What is the bandwidth of MQAM?

Part 3 APPENDIX

Q-FUNCTION AND ERROR FUNCTION COMPLEMENTARY

x	Erfc(x)	Erfc(x+0.01)	Erfc(x+0.02)	Erfc(x+0.03)	Erfc(x+0.04)	Erfc(x+0.05)	Erfc(x+0.06)	Erfc(x+0.07)	Erfc(x+0.08)	Erfc(x+0.09)
0	5.00E-1	4.96E-1	4.92E-1	4.88E-1	4.84E-1	4.80E-1	4.76E-1	4.72E-1	4.68E-1	4.64E-1
0.1	4.60E-1	4.56E-1	4.52E-1	4.48E-1	4.44E-1	4.40E-1	4.36E-1	4.33E-1	4.29E-1	4.25E-1
0.2	4.21E-1	4.17E-1	4.13E-1	4.09E-1	4.05E-1	4.01E-1	3.97E-1	3.94E-1	3.90E-1	3.86E-1
0.3	3.82E-1	3.78E-1	3.75E-1	3.71E-1	3.67E-1	3.63E-1	3.59E-1	3.56E-1	3.52E-1	3.48E-1
0.4	3.45E-1	3.41E-1	3.37E-1	3.34E-1	3.30E-1	3.26E-1	3.23E-1	3.19E-1	3.16E-1	3.12E-1
0.5	3.09E-1	3.05E-1	3.02E-1	2.98E-1	2.95E-1	2.91E-1	2.88E-1	2.84E-1	2.81E-1	2.78E-1
0.6	2.74E-1	2.71E-1	2.68E-1	2.64E-1	2.61E-1	2.58E-1	2.55E-1	2.51E-1	2.48E-1	2.45E-1
0.7	2.42E-1	2.39E-1	2.36E-1	2.33E-1	2.30E-1	2.27E-1	2.24E-1	2.21E-1	2.18E-1	2.15E-1
0.8	2.12E-1	2.09E-1	2.06E-1	2.03E-1	2.01E-1	1.98E-1	1.95E-1	1.92E-1	1.89E-1	1.87E-1
0.9	1.84E-1	1.81E-1	1.79E-1	1.76E-1	1.74E-1	1.71E-1	1.69E-1	1.66E-1	1.64E-1	1.61E-1
1	1.59E-1	1.56E-1	1.54E-1	1.52E-1	1.49E-1	1.47E-1	1.45E-1	1.42E-1	1.40E-1	1.38E-1
1.1	1.36E-1	1.34E-1	1.31E-1	1.29E-1	1.27E-1	1.25E-1	1.23E-1	1.21E-1	1.19E-1	1.17E-1
1.2	1.15E-1	1.13E-1	1.11E-1	1.09E-1	1.08E-1	1.06E-1	1.04E-1	1.02E-1	1.00E-1	9.85E-2
1.3	9.68E-2	9.51E-2	9.34E-2	9.18E-2	9.01E-2	8.85E-2	8.69E-2	8.53E-2	8.38E-2	8.23E-2
1.4	8.08E-2	7.93E-2	7.78E-2	7.64E-2	7.49E-2	7.35E-2	7.22E-2	7.08E-2	6.94E-2	6.81E-2
1.5	6.68E-2	6.55E-2	6.43E-2	6.30E-2	6.18E-2	6.06E-2	5.94E-2	5.82E-2	5.71E-2	5.59E-2
1.6	5.48E-2	5.37E-2	5.26E-2	5.16E-2	5.05E-2	4.95E-2	4.85E-2	4.75E-2	4.65E-2	4.55E-2
1.7	4.46E-2	4.36E-2	4.27E-2	4.18E-2	4.09E-2	4.01E-2	3.92E-2	3.84E-2	3.75E-2	3.67E-2
1.8	3.59E-2	3.52E-2	3.44E-2	3.36E-2	3.29E-2	3.22E-2	3.14E-2	3.07E-2	3.01E-2	2.94E-2
1.9	2.87E-2	2.81E-2	2.74E-2	2.68E-2	2.62E-2	2.56E-2	2.50E-2	2.44E-2	2.39E-2	2.33E-2
2	2.28E-2	2.22E-2	2.17E-2	2.12E-2	2.07E-2	2.02E-2	1.97E-2	1.92E-2	1.88E-2	1.83E-2
2.1	1.79E-2	1.74E-2	1.70E-2	1.66E-2	1.62E-2	1.58E-2	1.54E-2	1.50E-2	1.46E-2	1.43E-2
2.2	1.39E-2	1.36E-2	1.32E-2	1.29E-2	1.26E-2	1.22E-2	1.19E-2	1.16E-2	1.13E-2	1.10E-2
2.3	1.07E-2	1.04E-2	1.02E-2	9.90E-3	9.64E-3	9.39E-3	9.14E-3	8.89E-3	8.66E-3	8.42E-3
2.4	8.20E-3	7.98E-3	7.76E-3	7.55E-3	7.34E-3	7.14E-3	6.95E-3	6.76E-3	6.57E-3	6.39E-3
2.5	6.21E-3	6.04E-3	5.87E-3	5.70E-3	5.54E-3	5.39E-3	5.23E-3	5.09E-3	4.94E-3	4.80E-3
2.6	4.66E-3	4.53E-3	4.40E-3	4.27E-3	4.15E-3	4.03E-3	3.91E-3	3.79E-3	3.68E-3	3.57E-3
2.7	3.47E-3	3.36E-3	3.26E-3	3.17E-3	3.07E-3	2.98E-3	2.89E-3	2.80E-3	2.72E-3	2.64E-3
2.8	2.56E-3	2.48E-3	2.40E-3	2.33E-3	2.26E-3	2.19E-3	2.12E-3	2.05E-3	1.99E-3	1.93E-3
2.9	1.87E-3	1.81E-3	1.75E-3	1.70E-3	1.64E-3	1.59E-3	1.54E-3	1.49E-3	1.44E-3	1.40E-3

x	Effc(x)	Effc(x+0.01)	Effc(x+0.02)	Effc(x+0.03)	Effc(x+0.04)	Effc(x+0.05)	Effc(x+0.06)	Effc(x+0.07)	Effc(x+0.08)	Effc(x+0.09)
3	1.35E-3	1.31E-3	1.26E-3	1.22E-3	1.18E-3	1.14E-3	1.11E-3	1.07E-3	1.04E-3	1.00E-3
3.1	9.68E-4	9.35E-4	9.04E-4	8.74E-4	8.45E-4	8.16E-4	7.89E-4	7.62E-4	7.36E-4	7.11E-4
3.2	6.87E-4	6.64E-4	6.41E-4	6.19E-4	5.98E-4	5.77E-4	5.57E-4	5.38E-4	5.19E-4	5.01E-4
3.3	4.83E-4	4.67E-4	4.50E-4	4.34E-4	4.19E-4	4.04E-4	3.90E-4	3.76E-4	3.62E-4	3.50E-4
3.4	3.37E-4	3.25E-4	3.13E-4	3.02E-4	2.91E-4	2.80E-4	2.70E-4	2.60E-4	2.51E-4	2.42E-4
3.5	2.33E-4	2.24E-4	2.16E-4	2.08E-4	2.00E-4	1.93E-4	1.85E-4	1.79E-4	1.72E-4	1.65E-4
3.6	1.59E-4	1.53E-4	1.47E-4	1.42E-4	1.36E-4	1.31E-4	1.26E-4	1.21E-4	1.17E-4	1.12E-4
3.7	1.08E-4	1.04E-4	9.96E-5	9.57E-5	9.20E-5	8.84E-5	8.50E-5	8.16E-5	7.84E-5	7.53E-5
3.8	7.24E-5	6.95E-5	6.67E-5	6.41E-5	6.15E-5	5.91E-5	5.67E-5	5.44E-5	5.22E-5	5.01E-5
3.9	4.81E-5	4.62E-5	4.43E-5	4.25E-5	4.07E-5	3.91E-5	3.75E-5	3.59E-5	3.45E-5	3.30E-5
4	3.17E-5	3.04E-5	2.91E-5	2.79E-5	2.67E-5	2.56E-5	2.45E-5	2.35E-5	2.25E-5	2.16E-5
4.1	2.07E-5	1.98E-5	1.89E-5	1.81E-5	1.74E-5	1.66E-5	1.59E-5	1.52E-5	1.46E-5	1.40E-5
4.2	1.34E-5	1.28E-5	1.22E-5	1.17E-5	1.12E-5	1.07E-5	1.02E-5	9.77E-6	9.35E-6	8.93E-6
4.3	8.54E-6	8.16E-6	7.80E-6	7.46E-6	7.12E-6	6.81E-6	6.50E-6	6.21E-6	5.93E-6	5.67E-6
4.4	5.41E-6	5.17E-6	4.94E-6	4.71E-6	4.50E-6	4.29E-6	4.10E-6	3.91E-6	3.73E-6	3.56E-6
4.5	3.40E-6	3.24E-6	3.09E-6	2.95E-6	2.81E-6	2.68E-6	2.56E-6	2.44E-6	2.33E-6	2.22E-6
4.6	2.11E-6	2.01E-6	1.92E-6	1.83E-6	1.74E-6	1.66E-6	1.58E-6	1.51E-6	1.43E-6	1.37E-6
4.7	1.30E-6	1.24E-6	1.18E-6	1.12E-6	1.07E-6	1.02E-6	9.68E-7	9.21E-7	8.77E-7	8.34E-7
4.8	7.93E-7	7.55E-7	7.18E-7	6.83E-7	6.49E-7	6.17E-7	5.87E-7	5.58E-7	5.30E-7	5.04E-7
4.9	4.79E-7	4.55E-7	4.33E-7	4.11E-7	3.91E-7	3.71E-7	3.53E-7	3.35E-7	3.18E-7	3.02E-7
5	2.87E-7	2.72E-7	2.58E-7	2.45E-7	2.33E-7	2.21E-7	2.10E-7	1.99E-7	1.89E-7	1.79E-7
5.1	1.70E-7	1.61E-7	1.53E-7	1.45E-7	1.37E-7	1.30E-7	1.23E-7	1.17E-7	1.11E-7	1.05E-7
5.2	9.96E-8	9.44E-8	8.95E-8	8.48E-8	8.03E-8	7.61E-8	7.20E-8	6.82E-8	6.46E-8	6.12E-8
5.3	5.79E-8	5.48E-8	5.19E-8	4.91E-8	4.65E-8	4.40E-8	4.16E-8	3.94E-8	3.72E-8	3.52E-8
5.4	3.33E-8	3.15E-8	2.98E-8	2.82E-8	2.66E-8	2.52E-8	2.38E-8	2.25E-8	2.13E-8	2.01E-8
5.5	1.90E-8	1.79E-8	1.70E-8	1.60E-8	1.51E-8	1.43E-8	1.35E-8	1.27E-8	1.20E-8	1.14E-8
5.6	1.07E-8	1.01E-8	9.55E-9	9.01E-9	8.50E-9	8.02E-9	7.57E-9	7.14E-9	6.73E-9	6.35E-9
5.7	5.99E-9	5.65E-9	5.33E-9	5.02E-9	4.73E-9	4.46E-9	4.21E-9	3.96E-9	3.74E-9	3.52E-9
5.8	3.32E-9	3.12E-9	2.94E-9	2.77E-9	2.61E-9	2.46E-9	2.31E-9	2.18E-9	2.05E-9	1.93E-9
5.9	1.82E-9	1.71E-9	1.61E-9	1.51E-9	1.43E-9	1.34E-9	1.26E-9	1.19E-9	1.12E-9	1.05E-9