REVIEW OF LAST LECTURE

- * IDEAL CHANNEL – MAGNITUDE & PHASE RESPONSE (EQUALIZATION)
- * CHANNEL SHAPING – RAISED COSINE
- * AMPLIFICATION – LINEAR /NON-LINEAR
- * COHERENT DETECTION: MATCHED FILTER "CORRELATOR"
- * MODULATION SCHEMES:
  - PSK – PHASE SHIFT KEYING.
  - QUADRATURE (OR QUATERNARY) – PHASE SHIFT KEYING
  - FREQUENCY SHIFT KEYING.

TODAY'S LECTURE

- OQPSK (OFFSET QUADRATURE PHASE SHIFT KEYING)
- MSK (MINIMUM - SHIFT - KEYING)
- QAM (QUADRATURE - AMPLITUDE - MODULATION)

OQPSK – OFFSET QPSK

WE REPRESENTED THE QPSK SIGNAL BY

$$s(t) = \frac{1}{\sqrt{2}} a_I(t) \cos(\omega_c t + \pi/4) + \frac{1}{\sqrt{2}} a_Q(t) \sin(\omega_c t + \pi/4)$$

WHICH CAN BE REDUCED TO

$$s(t) = \cos[\omega_c t + \theta(t)].$$

THE $a_I(t)$ AND $a_Q(t)$ TERMS ARE THE ODD AND EVEN BITS OF THE INPUT MESSAGE STREAM.

* FOR OQPSK ALL WE DO IS CHANGE THE ALIGNMENT OF THE $a_I(t)$ AND $a_Q(t)$ BIT STREAMS.

* IN QPSK THE ODD AND EVEN BIT STREAMS ARE TRANSMITTED AT THE RATE OF $\frac{1}{2T}$ BAUD, AND ARE SYNCHRONOUSLY ALIGNED.

* FOR OQPSK WE SHIFT OR OFFSET THE RELATIVE ALIGNMENT OF $a_I(t)$ AND $a_Q(t)$. BY T.

* THE DIFFERENCE IN TIME ALIGNMENT IN THE BIT STREAMS DOES NOT CHANGE THE PSD WHICH HAS THE SAME $\text{sinc}(\omega_c T)$ SHAPE ASSOCIATED WITH THE RECTANGULAR PULSE USED FOR SIGNALLING.

* QPSK AND OQPSK BEHAVE DIFFERENTLY WHEN THEY UNDERGO HARDLIMITING SUCH AS WOULD BE ENCOUNTERED IN SATELLITE COMMS FOR EXAMPLE.

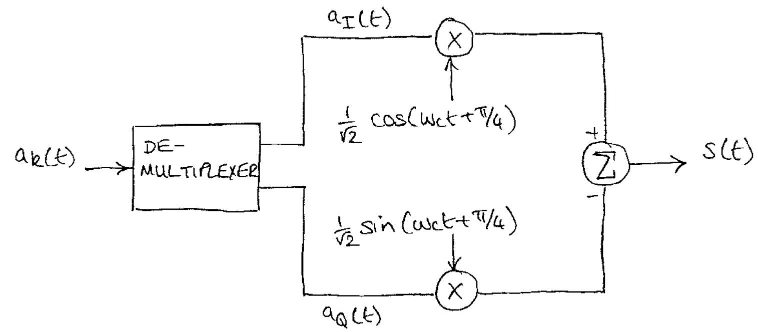
* THESE DIFFERENCES CAN BE SEEN BY LOOKING AT THE PHASE CHANGES IN THE CARRIER IN THE TWO MODULATION SCHEMES (SEE PAGE 4)

* IN OQPSK THE $a_I(t)$ AND $a_Q(t)$ COMPONENTS CANNOT CHANGE SIMULTANEOUSLY. ONE COMPONENT HAS TRANSITIONS IN THE MIDDLE OF THE OTHER SYMBOL.

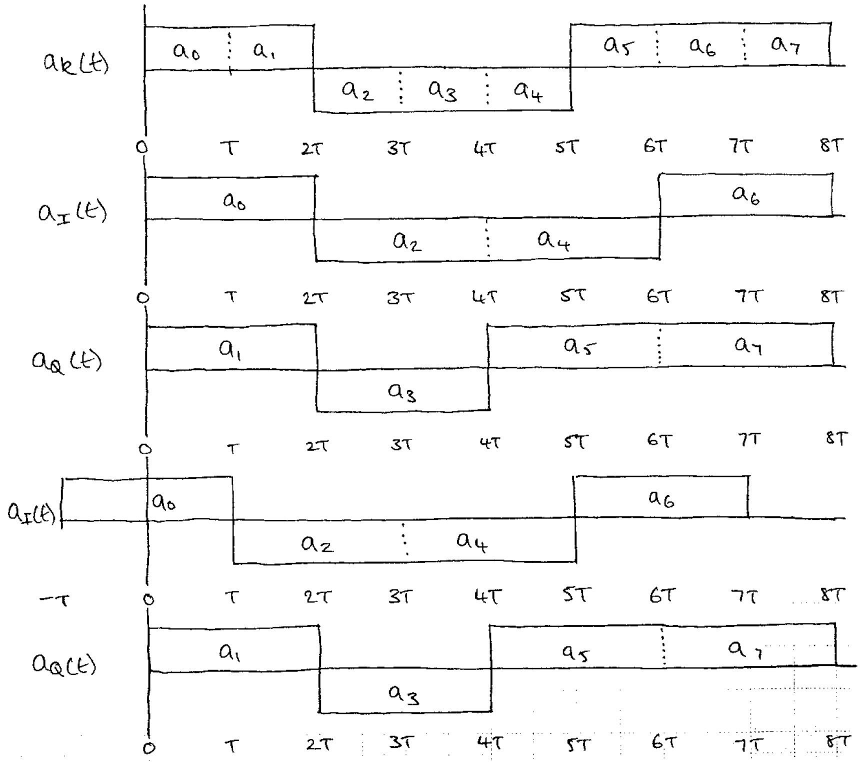
* THIS ELIMINATES THE POSSIBILITY OF 180° PHASE CHANGES. THE PHASE CHANGES ARE LIMITED TO 0° AND ±90° EVERY T SECONDS. SINCE PHASE SHIFTS OF 180° ARE AVOIDED, THE ENVELOPE DOES <u>NOT</u> GO TO ZERO WHEN BANDLIMITED, AS IS THE CASE FOR QPSK.

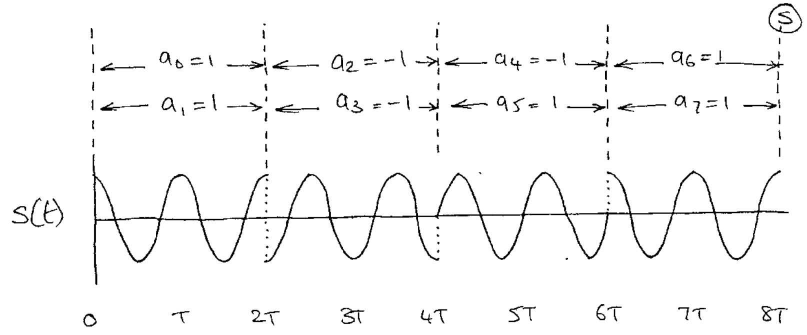
* THE IMPROVEMENT IN PERFORMANCE OF OQPSK (IN REDUCING OUT-OF-BAND RADIATION WHEN HARD-LIMITED) CAN BE ATTRIBUTED TO THE SMALLER PHASE CHANGES, COMPARED TO QPSK.

* MSK IS THE NEXT STEP FORWARD REMOVING PHASE TRANSITIONS ALTOGETHER (I.e CONTINUOUS PHASE, CONSTANT ENVELOPE)

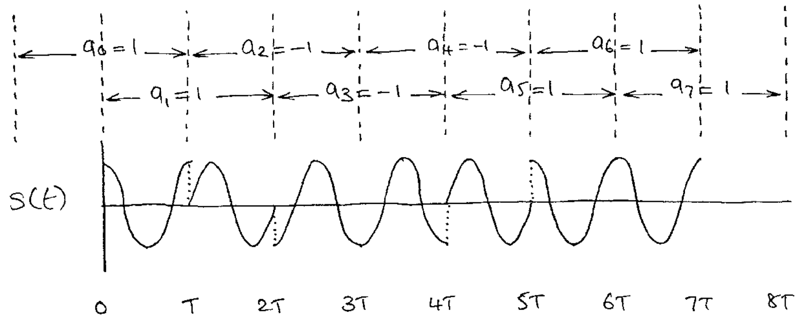


QPSK MODULATOR





QPSK PHASE TRANSITIONS



OQPSK PHASE TRANSITIONS

QPSK PHASE TRANSITIONS $0^\circ, \pm 90, 180^\circ$

OQPSK PHASE TRANSITIONS $0^\circ, \pm 90^\circ$

MINIMUM - SHIFT - KEYING (MSK)

MINIMUM SHIFT KEYING CAN BE THOUGHT OF AS A SPECIAL CASE OF OQPSK, WITH SINUSOIDAL PULSE SHAPING.

IF, INSTEAD OF RECTANGULAR PULSES WE USE SINUSOIDAL PULSES, THE SIGNAL CAN BE WRITTEN AS;

$$s(t) = \frac{1}{\sqrt{2}} a_I(t) \cos\left[\frac{\pi t}{2T}\right] \cos(\omega_c t + \pi/4)$$

$$+ \frac{1}{\sqrt{2}} a_Q(t) \sin\left[\frac{\pi t}{2T}\right] \sin(\omega_c t + \pi/4)$$

WITH A LITTLE TRIGONOMETRIC JIGGERY - POKERY WE CAN RE-WRITE $s(t)$ AS;

$$s(t) = \cos\left[\omega_c t + b_k(t)\frac{\pi t}{2T} + \phi_k\right]$$

WHERE:

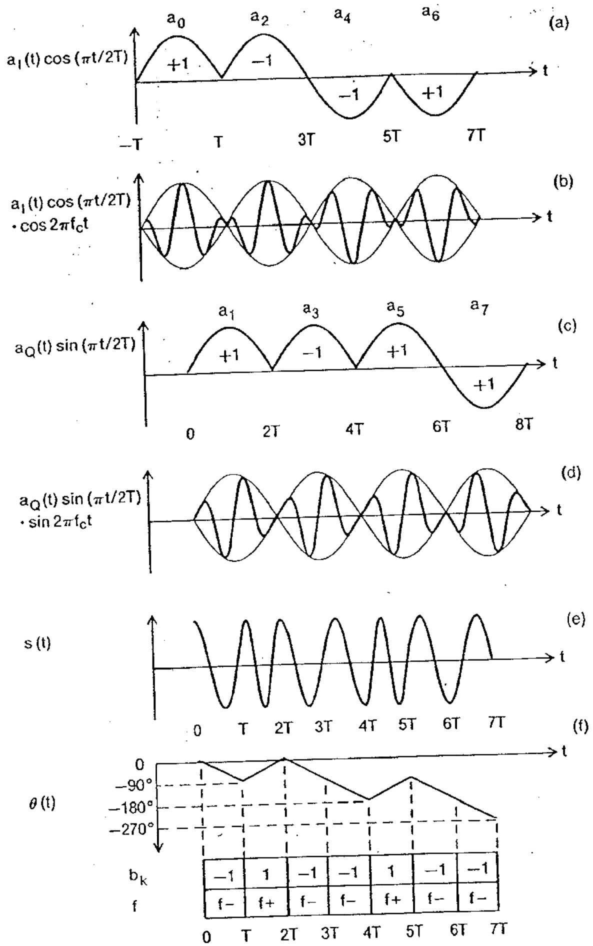
$b_k = +1$ WHEN a_I AND a_Q HAVE OPPOSITE SIGNS

$b_k = -1$ WHEN a_I AND a_Q HAVE SAME SIGN.

$\phi_k = 0$ WHEN $a_I = +1$
$\phi_k = \pi$ WHEN $a_I = -1$

b_k CAN BE EXPRESSED AS: $b_k = -a_I(t)\,a_Q(t)$

TAKEN FROM PASUPATHY, 1979
IEEE COMMS MAG. JULY, pp14 – 22



$f_+ = f_c + \frac{1}{4T}$ $f_- = f_c - \frac{1}{4T}$

SEE PAGE 8.

FROM THE FIGURES ON PAGES 5 AND 7, WE CAN DEDUCE THE FOLLOWING PROPERTIES OF MSK

* CONSTANT ENVELOPE – WE CAN USE NON-LINEAR P.A. STAGES.

* THERE IS PHASE CONTINUITY IN THE CARRIER AT THE BIT TRANSITIONS.

* THE MSK SIGNAL IS A FORM OF FSK SIGNAL, WHICH CAN BE EXPRESSED AS

$$s(t) = \cos[\omega_c t \pm \Delta\omega_c t + \phi_k]$$

WHERE:

$$\Delta\omega = \frac{\pi}{2T}$$

$$f_2 = f_c + \frac{1}{4T}, \quad f_2 = f_c - \frac{1}{4T} \quad f_2 - f_1 = \frac{1}{2T}.$$

THIS IS THE SAME MINIMUM FREQUENCY SPACING TO ENSURE THAT THE TWO SIGNALS ARE ORTHOGONAL.

MSK IS ALSO REFERRED TO AS FAST-FREQUENCY SHIFT KEYING FFSK

MSK CAN BE VIEWED AS:

* FAST FSK (ENSURING ORTHOGONALITY)
* OQPSK WITH SINUSOIDAL PULSE SHAPING.
* A CONTINUOUS PHASE SIGNAL WITH A FREQUENCY SEPARATION EQUAL TO HALF THE BIT RATE.

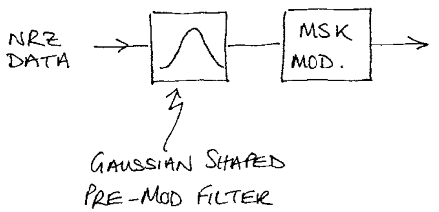
MSK IS A SPECIAL CASE OF CPFSK

CPFSK - CONTINUOUS - PHASE FSK.

CPFSK CAN BE GENERALIZED TO TRANSMIT M-ARY SIGNALS. DISCUSSION OF CPFSK IS BEYOND THE SCOPE OF THIS COURSE BUT CAN BE FOUND IN PROAKIS IF YOU'RE INTERESTED.

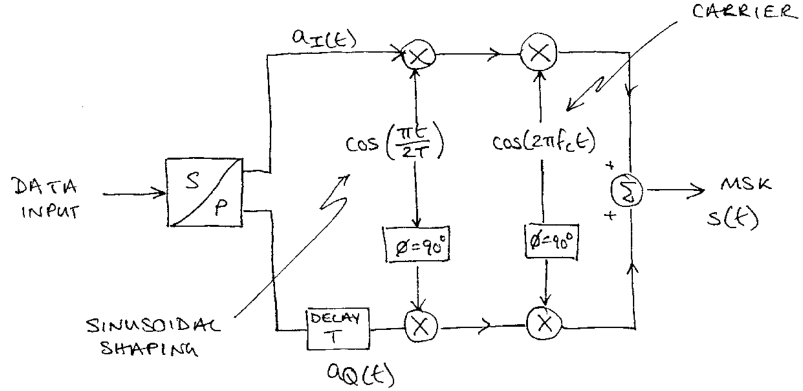
GAUSSIAN MINIMUM SHIFT KEYING

NOT IN THE SYLLABUS, BUT WIDELY USED IN CELLULAR PHONE SYSTEMS.

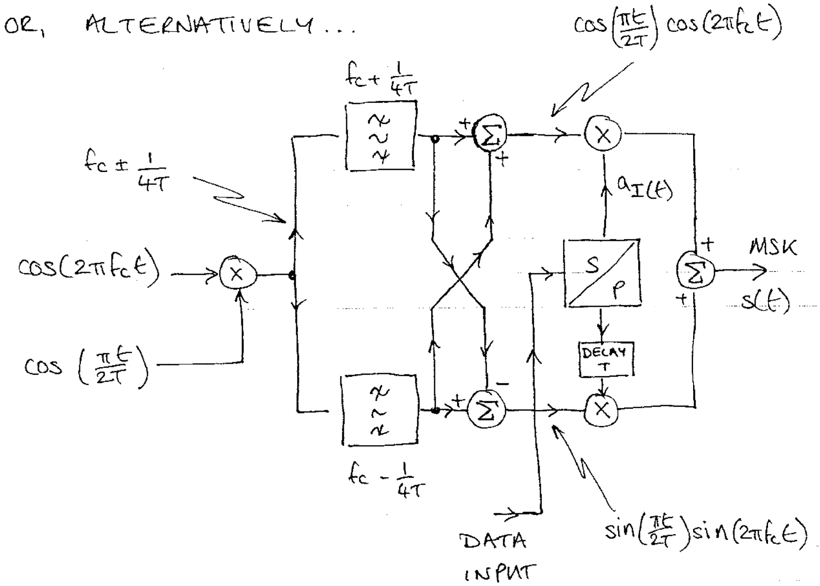


GAUSSIAN FILTER CAUSES ISI, BUT IMPROVES THE SPECTRAL EFFICIENCY (ERRORS CAN BE CORRECTED BY CODING)

GENERATION OF MSK

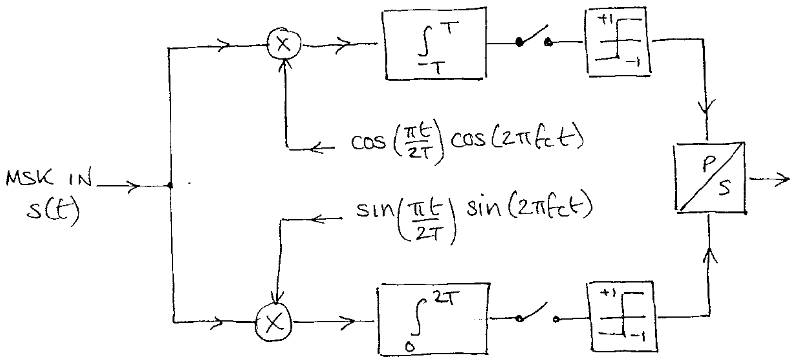


OR, ALTERNATIVELY...



DETECTION OF MSK

COHERENT, QUADRATURE DEMODULATION GIVES OPTIMUM PERFORMANCE FOR MSK DETECTION, AS IT DOES FOR QPSK



SPECTRAL EFFICIENCY

SEE PAGE 12, TAKEN FROM SKLAR

FOR 99% OF POWER BANDWIDTH REQUIRED IS;

$\simeq \frac{1.2}{T}$ FOR MSK

$\simeq \frac{8}{T}$ FOR QPSK AND OQPSK

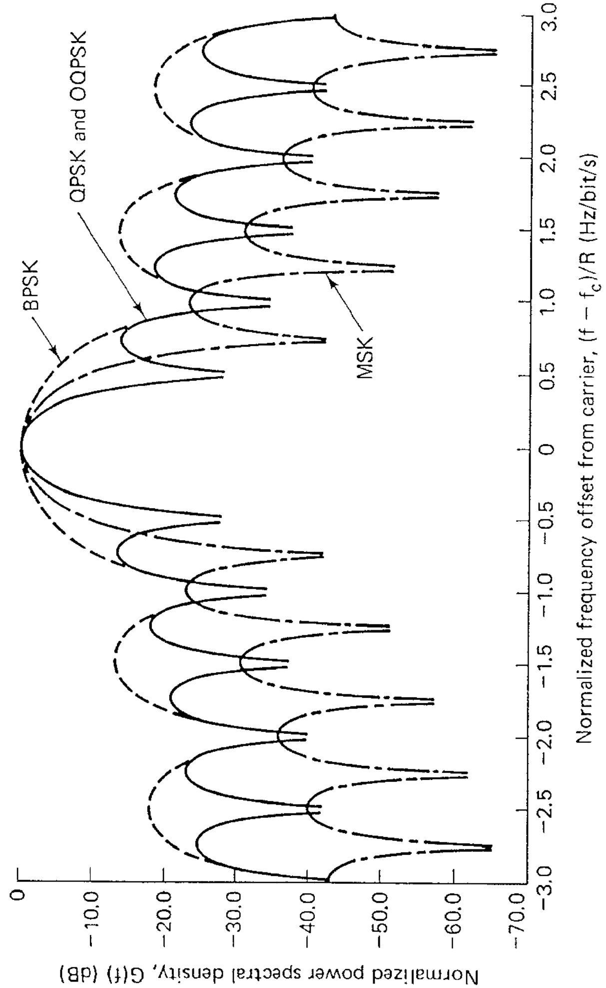


Figure 7.13 Normalized power spectral density for BPSK, QPSK, OQPSK, and MSK. (Reprinted with permission from F. Amoroso, "The Bandwidth of Digital Data Signals," *IEEE Commun. Mag.*, vol. 18, no. 6, Nov. 1980, Fig. 2A, p. 16. © 1980 IEEE.)

QUADRATURE AMPLITUDE MODULATION

THE QUADRATURE MODULATION TECHNIQUES WE HAVE DISCUSSED CAN BE READILY EXTENDED BY COMBINING AM WITH PSK TO GIVE

QAM - QUADRATURE AMPLITUDE MODULATION

OR

APSK - AMPLITUDE PHASE SHIFT KEYING

OF COURSE, WE NOW NO LONGER HAVE A CONSTANT AMPLITUDE SIGNAL. => LINEAR AMPLIFIERS

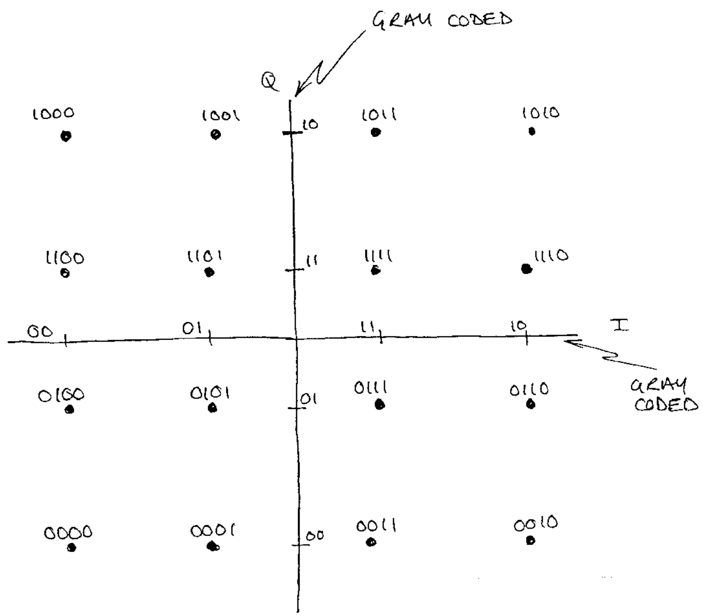
QAM OR ANY OTHER M-ARY SIGNALLING MODULATION SCHEME CAN BE COMBINED WITH CODING. THIS IS OFTEN DONE IN MODEMS WITH CONVOLUTIONAL CODES WHICH WE WILL LOOK AT NEXT LECTURE.

SUCH SCHEMES OF COMBINED MODULATION AND CODING ARE CALLED,

$\boxed{\text{TRELLIS CODED MODULATION}}$ SCHEMES.

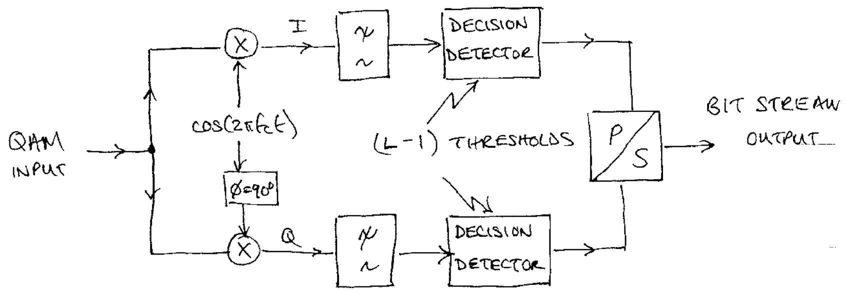
THESE CAN YIELD INCREDIBLE PERFORMANCE

QAM CONSTELLATION DIAGRAM (QAM-16)

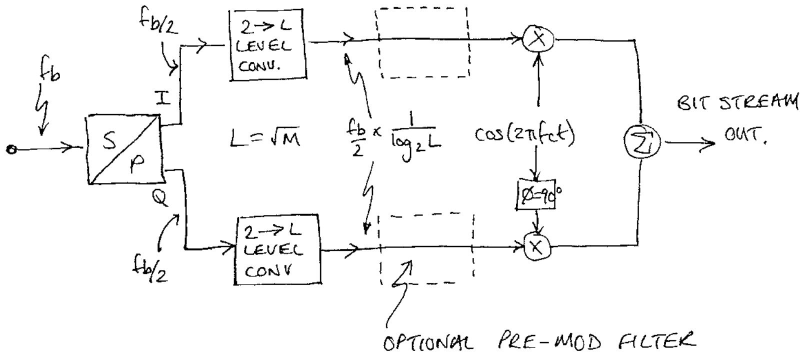


$M = 16 \quad L = \sqrt{M} = 4.$

DETECTION OF QAM



GENERATION OF QAM



16 LEVEL QAM EXAMPLE

* SUPPOSE OUR SOURCE BIT RATE IS $f_b = 10\,\text{Mbs}^{-1}$.
* EACH OF I AND Q ARE DE-MULTIPLEXED INTO TWO HALF-RATE STREAMS AT $\frac{f_b}{2} = 5\,\text{Mbs}^{-1}$.
* FOR M=16-LEVEL QAM, EACH OF THESE IS CONVERTED INTO $L = \sqrt{M} = \sqrt{16} = 4$ BASEBAND STREAMS, AT A RATE OF;

$$\frac{5\,\text{Mbs}^{-1}}{\log_2 \sqrt{M}} = \frac{5}{\log_2 4} = 2.5\,\text{M Symbols s}^{-1}$$

* AT 2.5M Symbols s^{-1}, THE REQUIRED BASEBAND BANDWIDTH IS;

$$BW_{BB} = \frac{f_s}{2}(1+\alpha)$$

* THE MODULATED BANDWIDTH IS THEREFORE (I AND Q STREAMS)

$$BW_{MOD} = 2 \times \frac{f_s}{2}(1+\alpha)$$

HENCE $BW_{MOD} \geq 2.5\,\text{MHz}$ (IF $\alpha = 0$)

* HENCE, THE SPECTRAL EFFICIENCY (OR BANDWIDTH EFFICIENCY) IS;

$$\eta_B = \frac{f_b}{BW_{MOD}} = \frac{10\,\text{Mbs}^{-1}}{2.5\,\text{MHz}}$$

$$= \underline{4 \text{ bits sec}^{-1}\,\text{Hz}^{-1}}$$

NOTE: THIS IS ONLY ACHIEVABLE IN IDEAL CONDITIONS. THE SIGNAL-TO-NOISE RATIO HAS A LARGE IMPACT ON PERFORMANCE

NOISE PERFORMANCE

PRACTICAL MEASUREMENTS ON TRANSMISSION SYSTEMS USUALLY MEASURE THE AVERAGE CARRIER TO AVERAGE NOISE POWER RATIO i.e.

$$\frac{C}{N} = \frac{\overline{E_s}}{N_0} \times \frac{f_s}{BW_N}$$

WHERE:

$\overline{E_s}$ = AVERAGE SYMBOL ENERGY
N_0 = SINGLE SIDED NOISE P.S.D.
BW_N = NOISE BW. AT RECEIVER.

FOR BINARY COMMS. $\left[f_B = f_s \underbrace{\log_2 M}_{\text{BITS PER SYMBOL}}\right]$ LEVELS

$$\frac{C}{N} = \frac{\overline{E_s}}{N_0} \times \frac{f_s}{BW_N} \equiv \frac{\overline{E_b}}{N_0} \times \frac{f_B}{BW_N}$$

FROM THE PREVIOUS EXAMPLE; THE CARRIER-TO-NOISE RATIO IS;

$$\frac{C}{N} = \frac{\bar{E_b}}{N_o} \times \frac{f_B}{BW}.$$

SUPPOSE $\frac{\bar{E_b}}{N_o} = 15\text{dB}$,

THEN, IN dB, OUR C/N IS;

$$C/N = 15 + 10\log_{10}\left[\frac{10}{2.5(1+\alpha)}\right]$$

SUPPOSE $\alpha = 0$ (IDEAL CHANNEL)

$$\frac{f_B}{BW} = 10\log_{10}\left[\frac{10}{2.5(1+0)}\right] \cong 6\text{ dB}$$

IF $\alpha = 1$ (RAISED COSINE)

$$\frac{f_B}{BW} = 10\log_{10}\left[\frac{10}{2.5(1+1)}\right] \cong 3\text{dB}$$

THAT IS: $C/N = 15+6 = 21\text{dB}$, FOR IDEAL CHANNEL
$C/N = 15+3 = 18\text{dB}$, FOR R.C CHANNEL

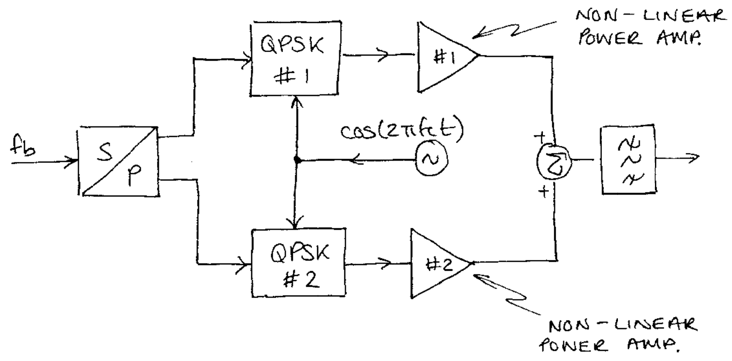
PRACTICAL HIGH-SPEED 16-LEVEL SYSTEMS HAVE BEEN IMPLEMENTED ACHEIVING $\eta_B = 3.7$ bits s^{-1} Hz^{-1}

BUT

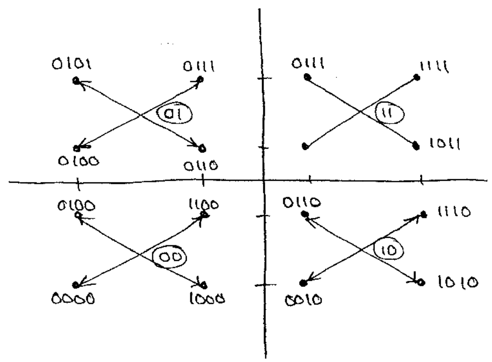
SUCH SYSTEMS REQUIRE EXTREMELY LINEAR AMPS. WITH MINIMUM AM-AM AND AM-PM CONVERSION

QAM GENERATION - AN ALTERNATIVE

16-QAM CAN BE GENERATED BY USING NON-LINEAR P. AMPS, AND TWO QPSK MODULATORS WITHOUT PRE-MOD FILTERS.



THE QPSK MODULATORS GENERATE A CONSTANT ENVELOPE SIGNAL THAT CAN BE AMPLIFIED BY A NON-LINEAR AMPLIFIER WITHOUT DISTORTION. IF THE GAIN OF AMP #1 IS TWICE THAT OF AMP #2, AFTER SUMMING, WE GET;



PROBABILITY OF ERROR PERFORMANCE

GIVEN A DATA RATE f_B AND A MEAN SIGNAL POWER, P.

PSK. $\quad P_E = Q\left[\sqrt{2SNR}\right]$ WHERE $SNR = \dfrac{P}{N_0 f_B} \equiv \dfrac{E_b}{N_0}$

QPSK TWO HALF RATE $(f_B/2)$ PSK CHANNELS IN QUADRATURE, - OCCUPY SAME BW AS A SINGLE PSK CHANNEL (MIN THEORETICAL $BW = f_B/2$) BUT SIGNAL POWER IN EACH CHANNEL IS $P/2$.

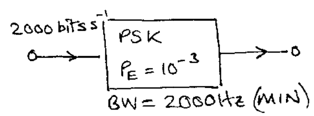
SO, FOR EACH CHANNEL OF THE QPSK SYSTEM;

$$SNR = \frac{(P/2)}{N_0(f_B/2)} = \frac{P}{N_0 f_B},$$

HENCE P_E IS THE SAME FOR QPSK AS IT IS FOR PSK (OF EQUIVALENT MEAN POWER & DATA RATE) - ASSUMING ALSO THAT QPSK IS GRAY CODED.

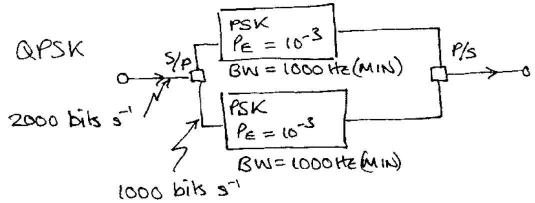
BUT QPSK USES HALF BW OF PSK

PSK :



2 ERRORS s^{-1}

QPSK



2 ERRORS s^{-1}