5. Bandpass (modulated) data communication systems.

In the previous chapter we studied how the signal were transmitted through wired medium.

In digital telephony, the voice signal range to 3400 Hz. The voice signal could thus be transmitted through a cable by amplifying the signal power (PAM).

But if the same signal had to traverse through air, the signal power won't be sufficient to get the message signal to the destination.

Wireless transmission thus requires antenna at transmitter and receiver.

The general length of antenna is given by $l = \lambda/4$, where,

$$\lambda = \frac{c}{f}$$

So, for voice signal,

$$\lambda = \frac{3\times10^8}{3\times10^3} \quad \& \quad \frac{\lambda}{4} = \frac{3\times10^8}{3\times10^3\times4} = 2.5\times10^4 m$$

$\therefore\ l = 2.5\times10^4 m.$

So, we can see that for the transmission of voiced signal without any modulation, we will need an antenna length equal to $2.5\times10^4 m$ which is not feasible.

Thus modulation of a carrier signal with bandpass frequency is required, such that the carrier frequency lies around 900 MHz (say), then the antenna length will be,

$$l = \frac{\lambda}{4} = \frac{3\times10^8}{4\times900\times10^6} = \frac{1}{12} = 0.083 m.$$

And thus, the antenna length is feasible.

So, the bandpass modulation now consists of a binary data or M-ary encoded version of modulating wave and a sinusoidal wave as the carrier.

5.1 Binary digital modulations.

i) Amplitude shift keying (ASK)

It is also known as ON-OFF keying (OOK). In ~~A~~ amplitude shift keying, a symbol '1' is represented by transmitting a high frequency carrier wave of fixed amplitude, frequency and phase, whereas a symbol '0' is represented by no carrier.

So, the amplitude of carrier signal is keyed according to the modulating digital signal.

i.e.

$$s(t) = A_c \cos 2\pi f_c t \quad \text{for } m(t) = 1$$
$$= 0 \quad \text{for } m(t) = 0.$$

Now, for $s(t) = A_c \cos 2\pi f_c t$

Power through $1\,\Omega$ resistor $= \left(\frac{A_c}{\sqrt{2}}\right)^2$

$$P = \frac{A_c^2}{2}$$

or $A_c = \sqrt{2P}$

Also, $P = \frac{\text{Energy}}{\text{Time}} = \frac{E_b}{T_b}$ where, E_b = bit energy

$$\therefore A_c = \sqrt{\frac{2E_b}{T_b}}$$

So,

$$s(t) = \sqrt{2P} \cos 2\pi f_c t = \sqrt{\frac{2E_b}{T_b}} \cos 2\pi f_c t \quad \Big\} \text{ for } m(t) = 1$$
$$= 0 \quad \Big\} \text{ for } m(t) = 0.$$

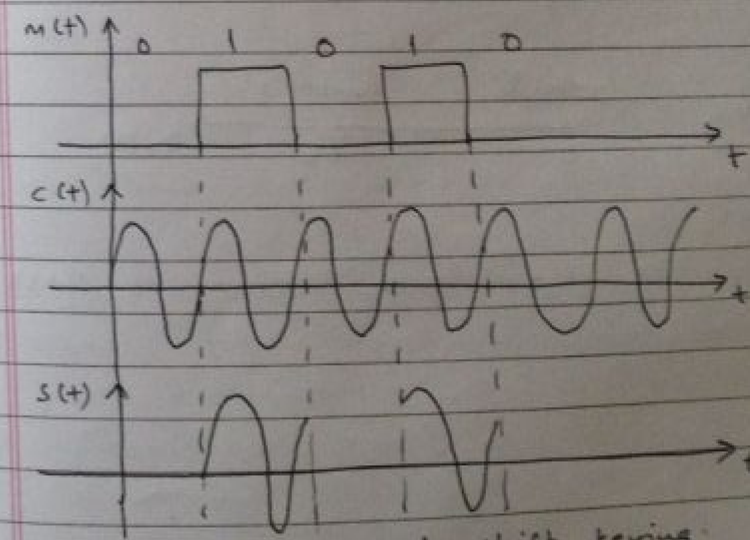


fig. Amplitude shift keying

Now, $s(t) = \sqrt{\frac{2E_b}{T_b}} \cos 2\pi f_c t \quad m(t) = 1$

$\quad\quad = 0 \quad\quad m(t) = 0$

$\therefore \; s(t) = \sqrt{E_b}\,\phi_1(t) \quad - \quad m(t) = 1$

$\quad\quad = 0 \cdot \phi_1(t) \quad\quad m(t) = 0$

where,

$\phi_1(t) = \sqrt{\frac{2}{T_b}} \cdot \cos 2\pi f_c t$ is carrier function.

Therefore, the signal space diagram can be shown as,

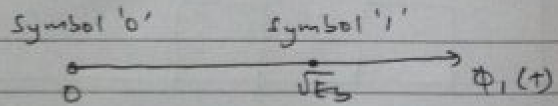


Fig. signal space diagram of BASK.

Generation of BASK signal.

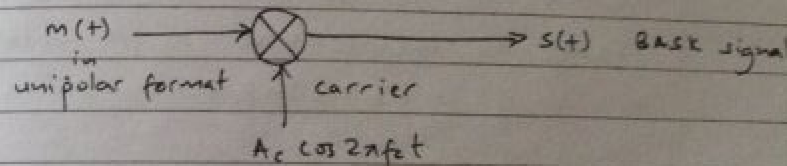


Fig. BASK generator

In the figure above, an incoming unipolar binary signal is modulated with a carrier sinusoid in a product modulator to get the output as binary amplitude shift keyed signal.

ii) Phase shift keying (PSK)

In phase shift keying, carrier signal with same frequency but having phase difference of 180° is used to represent symbols '1' and '0'.

Such that,

$$s_1(t) = A_c \cos 2\pi f_c t \qquad \text{for } m(t) = 1$$

$$s_2(t) = A_c \cos(2\pi f_c t + \pi) \qquad \text{for } m(t) = 0$$

$$= -A_c \cos 2\pi f_c t$$

Or in terms of power and energy,

$$\left.\begin{aligned} s_1(t) &= \sqrt{2P} \cos 2\pi f_c t \\ &= \sqrt{\frac{2E_b}{T_b}} \cos 2\pi f_c t \end{aligned}\right\} m(t) = 1$$

$$\left.\begin{aligned} s_2(t) &= -\sqrt{2P} \cos 2\pi f_c t \\ &= -\sqrt{\frac{2E_b}{T_b}} \cos 2\pi f_c t \end{aligned}\right\} m(t) = 0$$

Now, $s_1(t)$ and $s_2(t)$ signals are termed as antipodal signals as they differ only in relative phase ~~difference~~ shift of $180°$ (π).

Now, with $\phi_1(t)$ as carrier or basic function, i.e. $\phi_1(t) = \sqrt{2/T_b} \cdot \cos 2\pi f_c t$,

$$s_1(t) = \sqrt{E_b}\ \phi_1(t)$$

$$s_2(t) = -\sqrt{E_b}\ \phi_1(t)$$

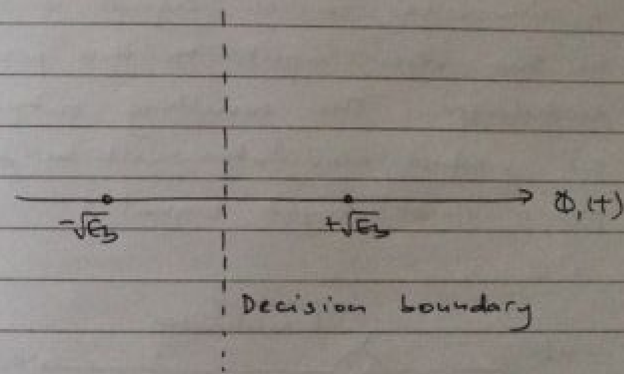


fig. signal space diagram of BPSK.

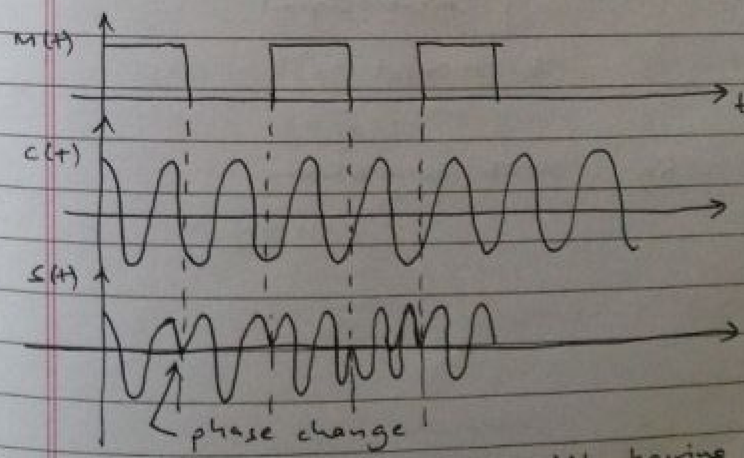


fig. Binary phase shift keying

(ii) Generation of B.PSK.

The generation of binary phase shift keyed signal can be achieved by applying a polar NRZ signal to one of the inputs of product ~~moduct~~ modulator. A sinusoidal carrier signal is then fed as the other input to the product modulator. The resulting output of the product modulator will be a binary phase shift keyed signal.

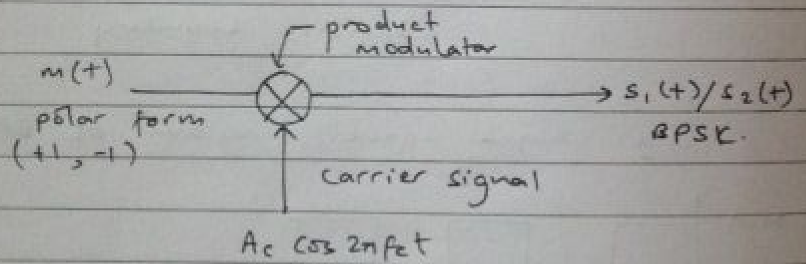


fig. BPSK generation.

iii) frequency shift keying (BFSK)

In frequency shift keying (FSK), binary '1' and '0' are represented by sinusoidal waves having different frequencies.

i.e.

$$s_1(t) = A_c \cos 2\pi f_1 (t) \qquad m(t) = 1$$

$$s_2(t) = A_c \cos 2\pi f_2 (t) \qquad m(t) = 0$$

In power & energy form,

$$\left.\begin{aligned} s_1(t) &= \sqrt{2P} \cos 2\pi f_1 t \\ &= \sqrt{\frac{2E_b}{T_b}} \cos 2\pi f_1 t \end{aligned}\right\} m(t) = 1$$

$$\left.\begin{aligned} s_2(t) &= \sqrt{2P} \cos 2\pi f_2 t \\ &= \sqrt{\frac{2E_b}{T_b}} \cos 2\pi f_2 t \end{aligned}\right\} m(t) = 0$$

or, in general,

$$s_i(t) = \sqrt{\frac{2E_b}{T_b}} \cos 2\pi f_i t \qquad 0 \le t \le T_b$$

$$= 0 \qquad \text{elsewhere}$$

where, $i = 1$ and 2.

Now, $f_i = \frac{n_c + i}{T_b}$; n_c = fixed integer

Now, the basic function,

$$\phi_i(t) = \sqrt{\frac{2}{T_b}} \cos 2\pi f_i t$$

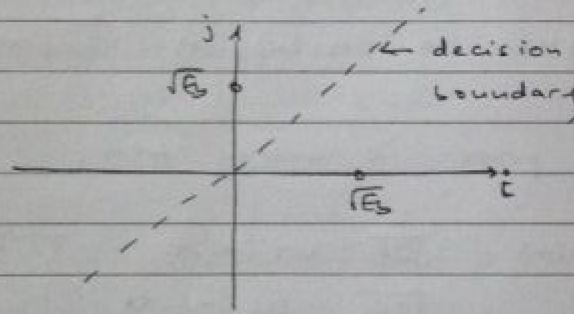


Fig. Signal space diagram for BFSK signal.

Generation of BFSK signal.

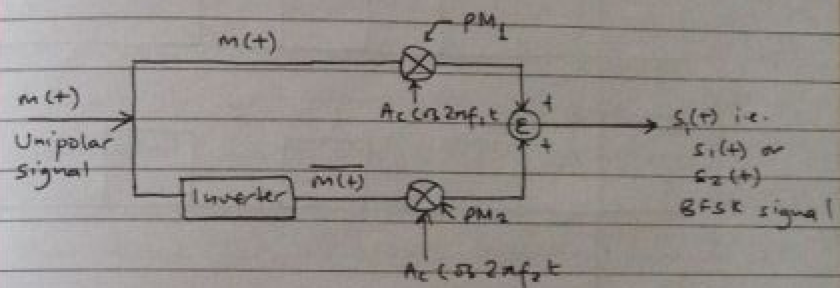


Fig. BFSK generator (transmitter)

In the above figure, the binary input is in unipolar format. Now, when '1' is fed in, then it is modulated with carrier signal, $A_c \cos 2\pi f_1 t$ at product modulator 'PM_1', ~~such that~~ taking the upper path. Taking lower path, the signal '1' is inverted such that a '0' is passed to product modulator 'PM_2', resulting is '0' output. Hence, the system output will be summation of upper path and lower path resulting in BFSK signal. Similarly when, input signal is '0', ~~upper~~ 'PM_1' output is '0' whereas PM_2 output is $A_c \cos 2\pi f_2 t$.

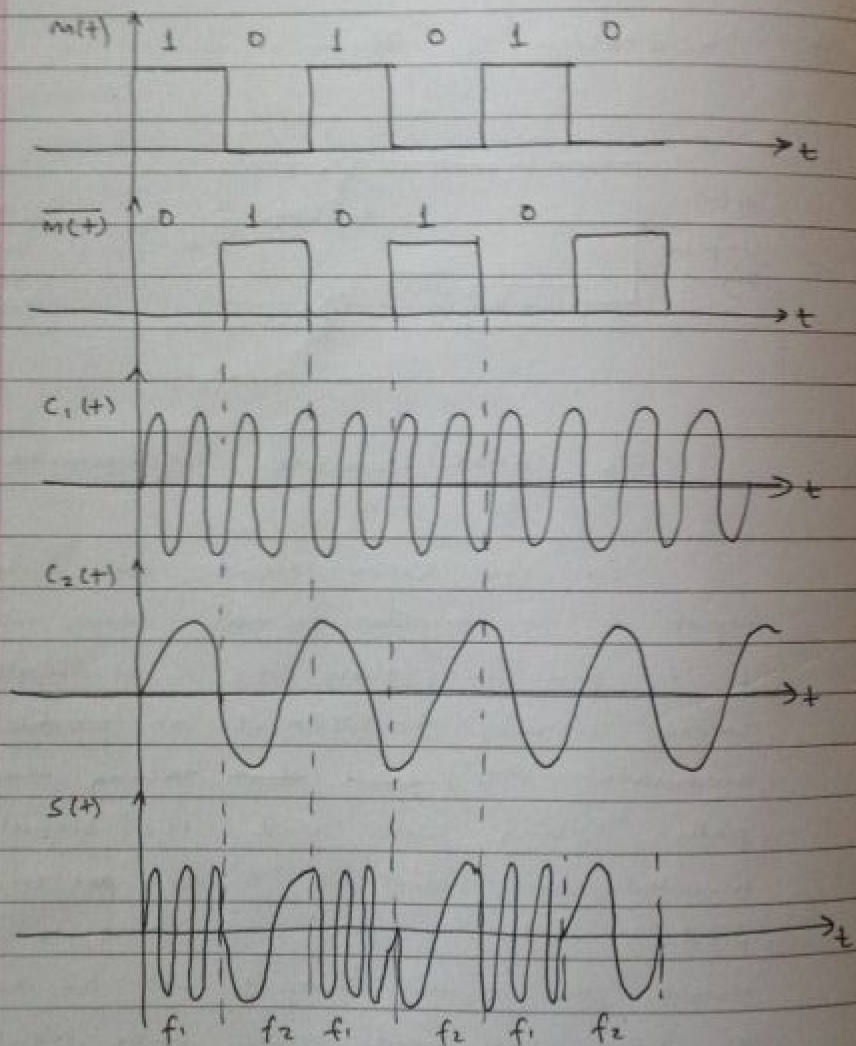


Fig. BFSK waveform

iv) Differential phase shift keying (DPSK)

A DPSK is a non-coherent form of BPSK. In a ~~DPA~~ DPSK, the phase of modulated signal is shifted relative to previous signal element. So a DPSK eliminates the need for coherent reference signal at the receiver by combining two basic operations at the transmitter.

i) differential encoding of i/p binary wave

ii) phase shift keying.

Hence the name, differential phase shift keying.

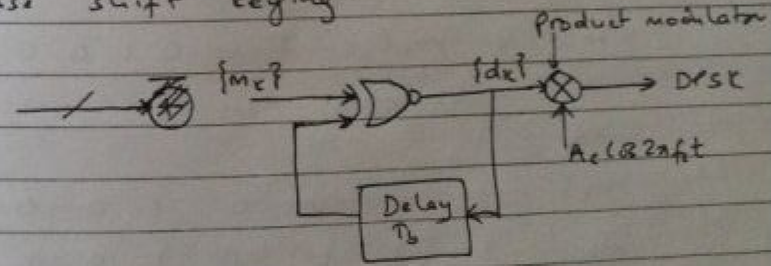


fig. DPSK encoder (Modulator)

from figure, for $\{m_k\}$ input binary sequence, $\{d_k\}$ differentially encoded sequence is generated by complementing the modulo-2 sum of m_k & d_{k-1}.

i.e. $d_k = \overline{m_k \oplus d_{k-1}}$

So, for $m_k = 0$,

if $d_{k-1} = 0$, $d_k = 1$

$d_{k-1} = 1$ $d_k = 0$

$\therefore d_{k-1} = \overline{d_k}$

for $m_k = 1$,

$d_k = d_{k-1}$

So, if $\{m_k\} = 1\ 0\ 0\ 1\ 0\ 0\ 1\ 1$

assuming $d_{k-1} = 1$

i.e.

$\{m_k\}$		1	0	0	1	0	0	1	1
d_k	1	1	0	1	1	0	1	1	1

~~Shifted~~
phase

Now, this $\{d_k\}$ is passed through a product modulator to obtain a DPSK signal. A carrier sinusoid is applied to the product modulator as other input.

Now, at the product modulator, the input carrier sinusoid is either

$+A_c \cos 2\pi f_c t = A_c \cos(2\pi f_c t + 0)$ for 1

or $-A_c \cos 2\pi f_c t = A_c \cos(2\pi f_c t + \pi)$ for 0

So the transmitted phase can be shown as,

m_k		1	0	0	1	0	0	1	1
d_k	1	1	0	1	1	0	1	1	1
Phase	0	π	0	0	π	0	0	0	

Therefore,

$$s(t) = \pm A_c \cos(2\pi f_c t)$$

$$= \pm \sqrt{2P} \cos 2\pi f_c t$$

$$= \pm \sqrt{\frac{2E_b}{T_b}} \cos 2\pi f_c t$$

v) Quadrature phase shift keying (QPSK)

A QPSK is a variation of BPSK, in which it sends two bits of digital information at a time.

As in BPSK, the information is contained in the phase with QPSK providing four message signals as output.

So, for QPSK we take four phases as, $\pi/4$, $3\pi/4$, $5\pi/4$ & $7\pi/4$, such that,

$$s_i(t) = A_c \cos\left[2\pi f_c t + (2i-1)\pi/4\right]$$

where, $i = 1, 2, 3$ & 4.

f_c = carrier frequency.

or,

$$s_i(t) = A_c\left[\cos(2\pi f_c t)\cos(2i-1)\pi/4 - \sin(2\pi f_c t)\sin(2i-1)\pi/4\right]$$

$$= \pm \cancel{A_c}\, \frac{A_c}{\sqrt{2}} \cos 2\pi f_c t$$

$$= \pm \frac{1}{\sqrt{2}} \cdot A_c \left[\cos 2\pi f_c t + \sin 2\pi f_c t\right]$$

$$= \pm \sqrt{P}\, \cancel{A_c} \left[\cos 2\pi f_c t + \sin 2\pi f_c t\right]$$

Generation of QPSK signal.

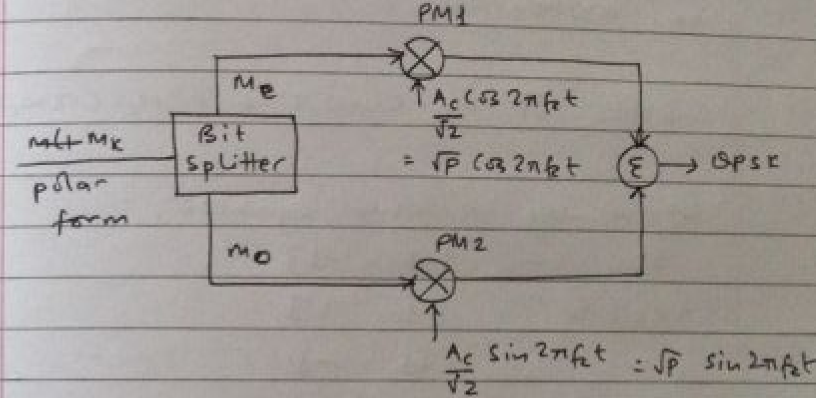


Figure: QPSK modulator.

In the figure above, a bit splitter is used to separate the odd and even bits from the incoming message signal m_k.

The ~~odd~~ even bits (M_e) are modulated with a carrier $\frac{A_c}{\sqrt{2}} \cos 2\pi f_c t$ and the ~~even~~ odd bits (M_o) are modulated with carrier $\frac{A_c}{\sqrt{2}} \sin 2\pi f_c t$.

Finally, the output of both product modulators are added to generate the QPSK signal.

So, the output of the QPSK modulatar can be written as

$$s(t) = \sqrt{P} \cdot m_o \cdot \sin 2\pi f_c t + \sqrt{P} \cdot m_e \cdot \cos 2\pi f_c t$$

Such that if input binary bits are

01 , then $m_o = 0 = -1$

$m_e = 1 = +1$

So, ~~then~~ ~~as~~ then we have,

$$s(t) = -\sqrt{P} \sin 2\pi f_c t + \sqrt{P} \cos 2\pi f_c t$$

Similarly,

for

10 , $m_o = 1 = +1$

$m_e = 0 = -1$

so, $s(t) = \sqrt{P} \sin 2\pi f_c t - \sqrt{P} \cos 2\pi f_c t$

Similarly for bits 00, $m_o = -1$, $m_e = -1$,

$$s(t) = -\sqrt{P} \sin 2 f_c t - \sqrt{P} \cos 2\pi f_c t$$

and

for bits 11 , $m_o = m_e = +1$ and

$$s(t) = \sqrt{P} \sin 2\pi f_c t + \sqrt{P} \cos 2\pi f_c t$$

OR,

$$s(t) = \begin{cases} A_c \cos\left(2\pi f_c t + \frac{3\pi}{4}\right) & \{00\} \ \{-1\ -1\} \\ A_c \cos\left(2\pi f_c t + \frac{\pi}{4}\right) & \{10\} \ \{+1\ -1\} \\ A_c \cos\left(2\pi f_c t + \frac{5\pi}{4}\right) & \{01\} \ \{-1\ +1\} \\ A_c \cos\left(2\pi f_c t + \frac{7\pi}{4}\right) & \{11\} \ \{+1\ +1\} \end{cases}$$

So, a QPSK is an example of M-ary phase shift keying where, $M = 4$. Thus it can also be termed as 4 phase PSK system.

Now, there is another way of generating M-ary signal by combining different methods of modulation. In this way we derive a hybrid form.

vi) QAM (Quadrature amplitude Modulation)

QAM is a hybrid modulation process, where the carrier experiences both amplitude and phase modulation.

The general form of QAM is defined as:

$$s_i(t) = \sqrt{\tfrac{2}{T}}\, A_c \cdot a_i \cos 2\pi f_c t + A_c \cdot b_i \sin 2\pi f_c t$$

where,

a_i & b_i = pair of independent integers.

We can see that $s_i(t)$ consists of inphase and quadrature ~~compents~~ carriers in $\cos 2\pi f_c t$ & $\sin 2\pi f_c t$ respectively. They are then modulated by a_i & b_i respectively in terms of amplitude and hence the name quadrature amplitude modulation.

Generation of QAM:

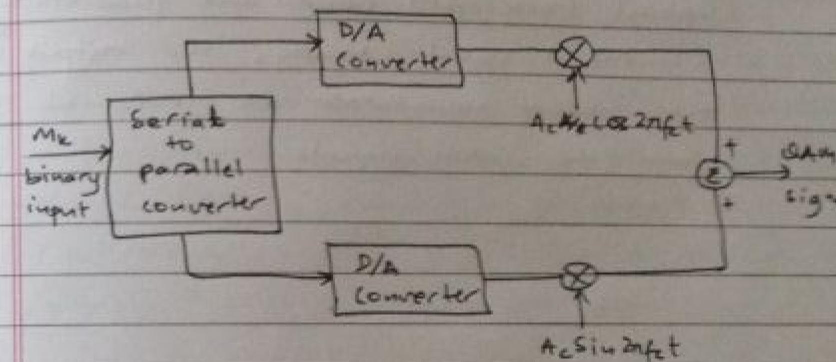


fig. QAM transmitter

In the figure above, a serial to parallel converter (or a bit splitter) accepts a binary sequence 'M_k' at a bit rate $R_b = 1/T_b$ and splits them into group of bits. so for 4-QAM, the input sequence is splitted into group of two bits and for 8-QAM, group of 3 bits are formed.

Now, the D/A converter produces an 'L' level outputs which are then fed to the inphase and quadrature channel inputs.

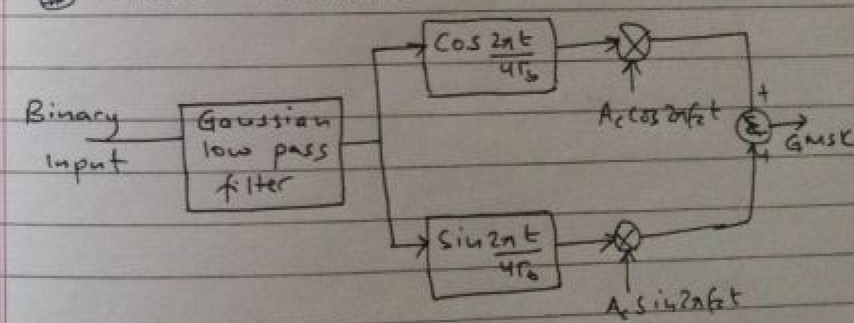
Here, $L = M = 2^n$, n = number of bits in the group separated.

These L-levels signals modulate the inphase ($\cos 2\pi f_c t$) signal and quadrature ($\sin 2\pi f_c t$) signal. Finally, the output of two product modulators are combined to form the QAM signals.

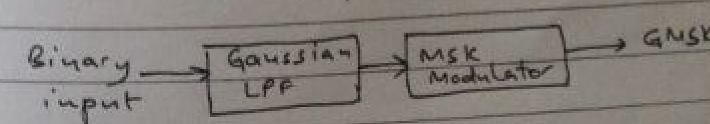
vii) Gaussian minimum shift keying (GMSK)

A GMSK is an advanced version of MSK. An MSK (minimum shift keying) is a continuous phase frequency shift keying procedure where the modulating signal is a smooth signal (follows a sinusoid) rather than a rectangular signal.

GMSK Transmitter



OR,



GMSK is most widely used with 2G GSM mobile communication.

Demodulation of binary digital modulated signals.

To perform demodulation at the receiver, a coherent or non-coherent detection can be implemented.

Coherent detection:

It is a synchronous detection where the local carrier generated at the receiver is phase locked with the carrier at the transmitter. Thus it indicates that the exact replica of possible signals arriving at the receiver is available at the receiver beforehand.

This increases the complexity of the system, but with less error.

Non-coherent detection:

In such demodulation technique, the detection process does not need receiver carrier to be phase locked with the transmitter carrier. That is, no prior knowledge of arriving signals is required.

This reduces complexity but increases the chances of error.

Coherent demodulation of BASK.

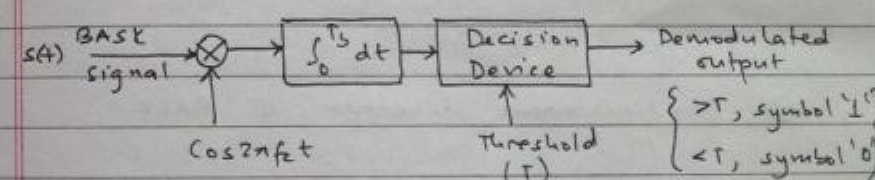


figure : BASK receiver.

In ~~the~~ the figure above, A BASK signal is applied to one of the inputs of a product modulator. A locally generated ~~sine~~ sinusoidal carrier is fed to the other input of product modulator. The output of product modulator is then applied to an integrator which operates on the output of product modulator for successive bit intervals. This integrator essentially performs as a low-pass filter.

Now at the decision device, the output of the integrator is compared with a threshold value. If the integrator output is greater than threshold then a symbol '1' is decided otherwise '0' is decided.

Non-coherent detection of BASK.

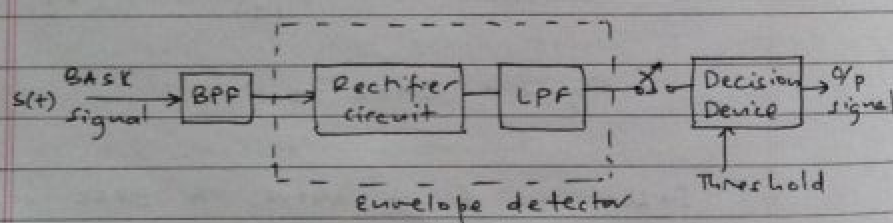
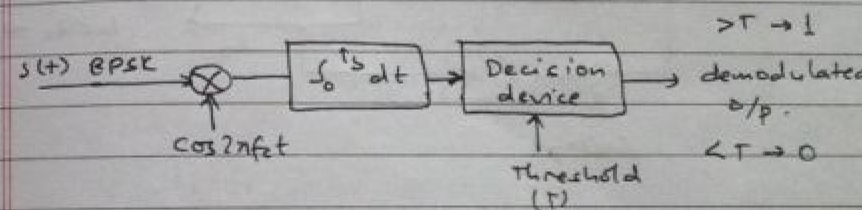


Fig. Non-coherent BASK receiver.

For non-coherent detection of BASK, we can use an envelope detector. The combination of rectifier and LPF generates an envelope voltage which is compared to a threshold to determine '0' or '1' as the output.

Coherent detection of BPSK.



We have,

$$s(t) = \pm A_c \cos 2\pi f_c t$$

$\therefore$

$$s(t) \cdot \cos 2\pi f_c t = \pm A_c \cos^2 2\pi f_c t$$

$$= \pm A_c \left[\frac{1 + \cos 4\pi f_c t}{2}\right]$$

$$= \pm \frac{A_c}{2} \pm \frac{A_c}{2} \cos 4\pi f_c t$$

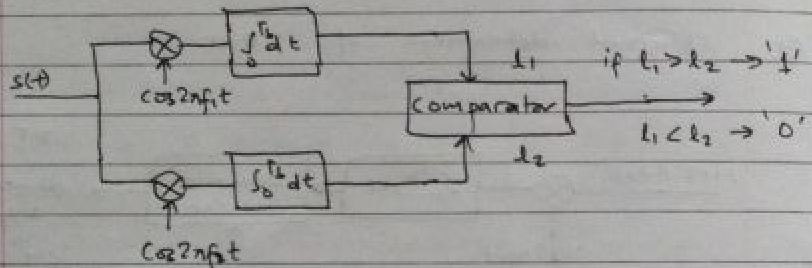
On integration we get

$$\int_0^{T_b} \left[\pm \frac{A_c}{2} \pm \frac{A_c}{2} \overbrace{\cos 4\pi f_c t}^{0}\right] dt$$

$$= \pm \frac{A_c}{2} \cdot T_b$$

$\therefore$ When compared with threshold we can decide if the o/p bit is '0' or '1'.

Coherent detection of FSK.



Here, $s(t) = A_c \cos 2\pi f_1 t$ for $x(t) = 1 = +1$

$A_c \cos 2\pi f_2 t$ for $x(t) = 0 : -1$.

As for coherent detection of FSK, the incoming FSK signal is fed to two product modulators with locally generated carriers $\cos 2\pi f_1 t$ & $\cos 2\pi f_2 t$ respectively.

Taking the upper path the integrator output may be,

$$\int \cos 2\pi f_1 t \cdot A_c \cos 2\pi f_1 t \, dt$$

$$= \int A_c \cos^2 2\pi f_1 t \, dt$$

$$l_1 = \frac{A_c T_b}{2}$$

or $\int \cos 2\pi f_2 t \cdot A_c \cos 2\pi f_1 t \, dt$

$$l_1 = \int_0^{T_b} A_c \cos 2\pi f_1 t \cdot \cos 2\pi f_2 t \, dt$$

Similarly for lower path,

$$l_2 : \frac{A_c T_b}{2}$$

or

$$l_2 = \int_0^{T_b} A_c \cos 2\pi f_1 t \cdot \cos 2\pi f_2 t \, dt.$$

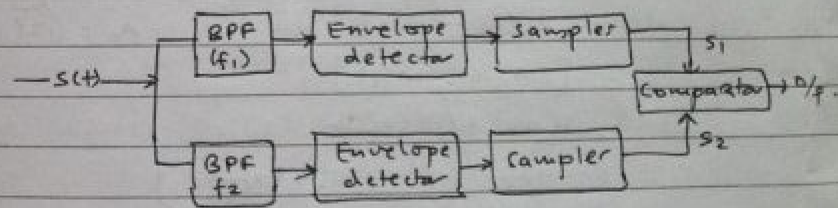
Now, at the comparator,

if $l_1 - l_2 > 1$ then ~~sym~~ symbol '1' is o/p

and

if $l_1 - l_2 \leq 1$ then symbol '0' is o/p.

Non-coherent detection of BFSK.



The two bandpass filters centered around f_1 and f_2 separates the incoming FSK signal accordingly. The resulting envelope for each path is then compared such that if the envelope voltage S_1 is greater than envelope voltage S_2, then symbol '1' is detected else symbol '0'.

i.e. if $s_2 > s_1$, '1'

$s_2 < s_1$ '0'.