ESE 2024
Main Examination

UPSC ENGINEERING SERVICES EXAMINATION

Topicwise

Conventional Practice Questions

Electronics & Telecommunication Engineering

PAPER-II

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ESE Main Examination • Conventional Practice Questions :
Electronics & Telecommunication Engineering PAPER-II

First Edition: 2023

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1 Analog & Digital Communication Systems

1. Analog Modulation

Level-1

1.1 An FM signal with a frequency deviation of 10 kHz at a modulation frequency of 5 kHz is applied to two frequency multipliers connected in cascade. The first multiplier doubles the frequency and the second multiplier triples the frequency. Determine the frequency deviation and the modulation index of the FM signal obtained at the second multiplier output. What is the frequency separation of the adjacent side frequency of this FM signal? (8 Marks)

Solution:

Overall frequency multiplication ratio,

$$n = 2 \times 3 = 6$$

Instantaneous frequency at input of first frequency multiplier is

$$f_{i1}(t) = f_c + \Delta f \cos(2\pi f_m t)$$

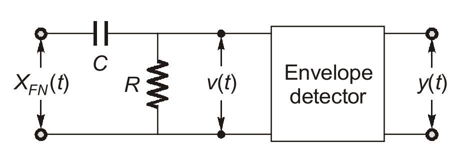
So, frequency deviation is

$$n\Delta f = 6 \times 10 = 60 \text{ kHz}$$

and modulation index is $\dfrac{n\Delta f}{f_m} = \dfrac{60}{5} = 12$

The frequency separation will be unchanged and same as $f_m = 5$ kHz

1.2 An FM signal $X_{FM}(t) = A\cos\left(\omega_c t + K_f \int_{-\infty}^{t} m(\lambda)d\lambda\right)$ is applied to the system shown in figure, consisting of a high pass RC filter and an envelope detector. Assume that $\omega RC << 1$ in the frequency band occupied by $X_{FM}(t)$. Determine the output signal $y(t)$. Assuming $K_f|m(t)| < \omega_c$ for all t.



(10 Marks)

Solution:

Frequency response of high pass filter is

$$H(\omega) = \frac{R}{R + \frac{1}{j\omega C}} = \frac{j\omega RC}{1 + j\omega RC}$$

If $WRC << 1$

$$H(\omega) \approx j\omega RC$$

Finding output of RC filter in time domain

$$V(t) \approx RC\frac{d}{dt}[X_{FM}(t)]$$

because multiplication by $j\omega$ in frequency domain result differentiation in time domain.

So $$V(t) = -ARC[\omega_c + K_f m(t)]\sin\left[\omega_c t + K_f \int_{-\infty}^{t} m(\lambda)d\lambda\right]$$

So the envelope detector output is

$$y(t) = ARc[\omega_c + K_f m(t)]$$

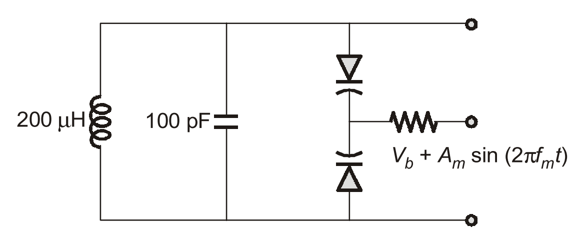
So output is proportional to $m(t)$ except one additional DC term $ARC\omega_c$.

1.3 In figure shown the frequency determining network of a voltage - controlled oscillator. Frequency modulation is produced by applying the modulating signal $A_m \sin 2\pi f_m t$ plus a bias V_b to a pair of varactor diodes connected across the parallel combination of a 200 μH inductor and 100 pF capacitor. The capacitor of each varactor diode is related to the voltage V (in volts) applied across its electrodes by $C = 100\ V^{-1/2}$ pF.

The unmodulated frequency of oscillations is 1 MHz. The VCO output is applied to a frequency multiplier to produce an FM signal with a carrier frequency of 64 MHz and a modulation index of 5. Determine:

(a) The magnitude of the bias voltage V_b and

(b) The amplitude A_m of the modulating wave, given f_m = 10 kHz.



(12 Marks)

Solution:

(a) Let L denotes inductive component and C denotes capacitive component of each varactor diode due to bias voltage V_b alone then

$$C_0 = 100\ V^{-1/2}\ \text{pF}$$

and frequency of oscillations is

$$f_0 = \frac{1}{2\pi\sqrt{L\left(C + \frac{C_0}{2}\right)}}$$

So, $$10^6 = \frac{1}{2\pi\sqrt{200\times10^{-6}\left(100\times10^{-12} + 50V_b^{-1/2}\times10^{-12}\right)}}$$

So, $$V_b = 3.52 \text{ volts}$$

(b) Frequency multiplication ratio is 64, so modulation index at frequency multiplier input is

$$\beta = \frac{5}{64} = 0.078$$

This indicates that it is NBFM. Which means that amplitude A_m is small compared to V_b.

So instantaneous frequency can be written as

$$fi(t) = \frac{1}{2\pi}\left[2\pi\times10^{-6}(100\times10^{-12}) + 50\times10^{-12}(3.52A_m \sin 2\pi f_m t)^{-1/2}\right]^{-1/2}$$

$$= \frac{10^7}{2\sqrt{2}\pi}\left(1+0.266\left(1+\frac{A_m}{3.52}\sin 2\pi f_m t\right)^{-1/2}\right)^{-1/2}$$

$$= \frac{10^7}{2\sqrt{2}\pi}\left(1+0.266\left(1+\frac{A_m}{7.04}\sin 2\pi f_m t\right)^{-1/2}\right)^{-1/2}$$

$$= 10^6[1-0.03A_m \sin 2\pi f_m t]^{-1/2}$$

$$= 10^6[1 + 0.015\, A_m \sin 2\,\pi f_m t]$$

$\therefore$ $\beta = 0.078$

So, $\Delta f = \beta \cdot f_m$

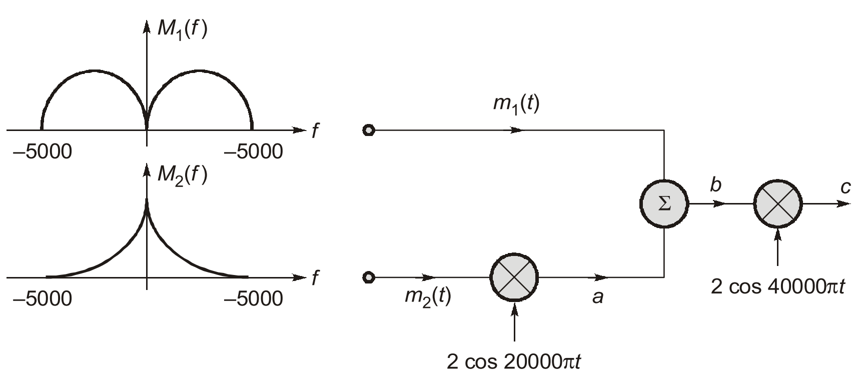
$= 0.078 \times 10^4$ Hz

So, $A_m = 52 \times 10^{-3}$ Volts

1.4 Two signals $m_1(t)$ and $m_2(t)$ both band limited to 5000 Hz, are to be transmitted simultaneously over a channel by the multiplexing scheme shown in figure. The signal at point (b) is the multiplexed signal, which now modulates a carrier of frequency 20000 Hz. The modulated signal at point C is transmitted over a channel.

(a) What are the spectrums of the signals obtained at a, b, c points.

(b) How much channel BW is required to transmit the signal.



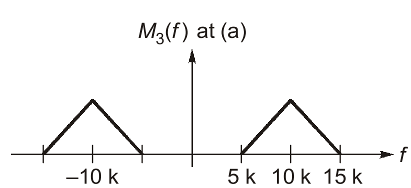
(10 Marks)

Solution:

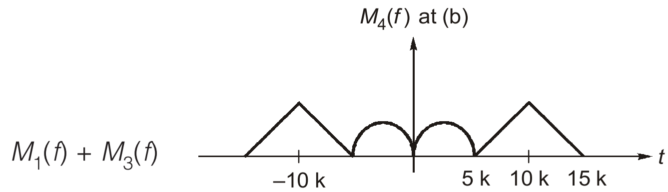
(a) at 'a'

signal is $m_2(t)$. 2 cos 20000 πt

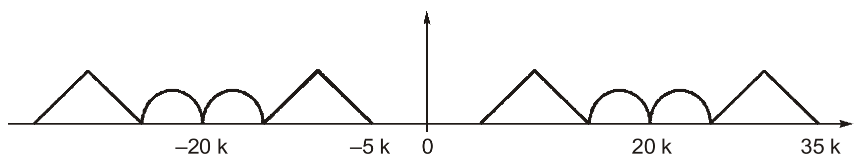
by converting this signal in frequency domain and drawing the spectrum at 'a'



at 'b'



at 'c'



(b) From spectrum at point 'c' the channel bandwidth is (35k – 5k) = 30000 Hz

(From 5000 Hz to 35000 Hz)

1.5 An amplitude modulated signal is given by,

$$s(t) = [20 + 2\cos(3000\pi t) + 10\cos(6000\pi t)]\cos(2\pi f_c t) \text{ V}$$

Where $f_c = 10^5$ Hz

(i) Determine and sketch the spectrum of $s(t)$.

(ii) Determine the power in each frequency component of $s(t)$.

(iii) Determine the power in the sidebands, the total power, and the ratio of the sidebands power to the total power.

(12 Marks)

Solution:

(i)
$$s(t) = [20 + 2\cos(3000\pi t) + 10\cos(6000\pi t)]\cos(2\pi f_c t)$$

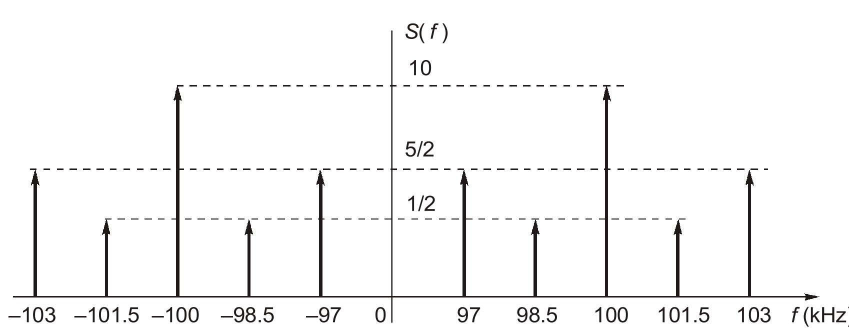
Let, $\omega_1 = 3000\pi$ rad/sec and $\omega_2 = 6000\pi$ rad/sec

So,
$$\begin{aligned} s(t) &= 20\cos(\omega_c t) + 2\cos(\omega_c t)\cos(\omega_1 t) + 10\cos(\omega_c t)\cos(\omega_2 t) \\ &= 20\cos(\omega_c t) + \cos(\omega_c + \omega_1)t + \cos(\omega_c - \omega_1)t + 5\cos(\omega_c + \omega_2)t + 5\cos(\omega_c - \omega_2)t \end{aligned}$$

By taking the Fourier transform of $s(t)$, we get,

$$\begin{aligned} S(f) &= 10\delta(f + f_c) + 10\delta(f - f_c) + \frac{1}{2}\delta(f + f_c + f_1) + \frac{1}{2}\delta(f - f_c - f_1) + \frac{1}{2}\delta(f + f_c - f_1) \\ &\quad + \frac{1}{2}\delta(f - f_c + f_1) + \frac{5}{2}\delta(f + f_c + f_2) + \frac{5}{2}\delta(f - f_c - f_2) + \frac{5}{2}\delta(f + f_c - f_2) + \frac{5}{2}\delta(f - f_c + f_2) \\ &= 10\delta(f + 100\text{k}) + 10\delta(f - 100\text{k}) + \frac{1}{2}\delta(f + 101.5\text{k}) + \frac{1}{2}\delta(f - 101.5\text{k}) + \frac{1}{2}\delta(f + 98.5\text{k}) \\ &\quad + \frac{1}{2}\delta(f - 98.5\text{k}) + \frac{5}{2}\delta(f + 103\text{k}) + \frac{5}{2}\delta(f - 103\text{k}) + \frac{5}{2}\delta(f + 97\text{k}) + \frac{5}{2}\delta(f - 97\text{k}) \end{aligned}$$

The spectrum of $s(t)$ can be plotted as follows:



(ii) The power contained by different frequency components of $s(t)$ are,

$$P_{100k} = (10)^2 + (10)^2 = 200 \text{ W}$$

$$P_{98.5k} = \left(\frac{1}{2}\right)^2 + \left(\frac{1}{2}\right)^2 = \frac{1}{2} \text{ W}$$

$$P_{97k} = \left(\frac{5}{2}\right)^2 + \left(\frac{5}{2}\right)^2 = \frac{25}{2} \text{ W}$$

$$P_{101.5k} = \left(\frac{1}{2}\right)^2 + \left(\frac{1}{2}\right)^2 = \frac{1}{2} \text{ W}$$

$$P_{103k} = \left(\frac{5}{2}\right)^2 + \left(\frac{5}{2}\right)^2 = \frac{25}{2} \text{ W}$$

(iii) Power in sidebands,

$$P_{SB} = P_{97k} + P_{98.5k} + P_{101.5k} + P_{103k}$$

$$= \frac{1}{2} + \frac{25}{2} + \frac{1}{2} + \frac{25}{2} \text{ W} = 26 \text{ W}$$

Total power, $P_{total} = P_{100k} + P_{SB} = 200 + 26 = 226$ W

So, $\dfrac{P_{SB}}{P_{total}} = \dfrac{26}{226} = 0.115$

Level-2

1.6 The single tone modulating signal $m(t) = A_m \cos 2\pi f_m t$ is used to generate the VSB signal $s(t) = \frac{1}{2}aA_m A_c \cos[2\pi(F_c + F_m)t] + \frac{1}{2}A_m A_c (1-a)\cos[2\pi(f_c - f_m)t]$ where a is a constant, less than unity, representing the attenuation of the upper side frequency.

(a) Find the quadrature component of the VSB signal $s(t)$.

(b) The VSB signal, plus the carrier $A_c \cos(2\pi f_c)$, is passed through an envelope detector. Determine the distortion produced by the quadrature component.

(c) What is the value of constant a for which this distortion reaches its worst possible condition.

(15 Marks)

Solution:

(a)
$$s(t) = \frac{1}{2}aA_m A_c \cos 2\pi f_c t \cos 2\pi f_m t - \frac{1}{2}aA_m A_c \sin 2\pi f_c t \sin 2\pi f_m t$$
$$+\frac{1}{2}(1-a)A_c A_m \cos 2\pi f_c t \cos 2\pi f_m t + \frac{1}{2}(1-a)A_m A_c \sin 2\pi f_c t \sin 2\pi f_m t$$
$$= \frac{1}{2}A_m A_c \cos 2\pi f_c t \cos 2\pi f_m t + \frac{1}{2}A_m A_c (1-2a)\sin 2\pi f_c t \sin 2\pi f_m t$$

So, the quadrature component is

$$= \frac{1}{2}A_m A_c (1-2a)\sin 2\pi f_m t$$

(b) After adding the carrier,

$$s(t) = A_c\left[1 + \frac{1}{2}A_m \cos 2\pi f_m t\right]\cos 2\pi f_c t + \frac{1}{2}A_c A_m (1-2a)\sin 2\pi f_m t \sin 2\pi f_c t$$

the envelope can be written as

$$e(t) = A_c\sqrt{\left(1+\frac{1}{2}A_m\cos 2\pi f_m t\right)^2 + \left(\frac{1}{2}A_m(1-2a)\sin 2\pi f_m t\right)^2}$$

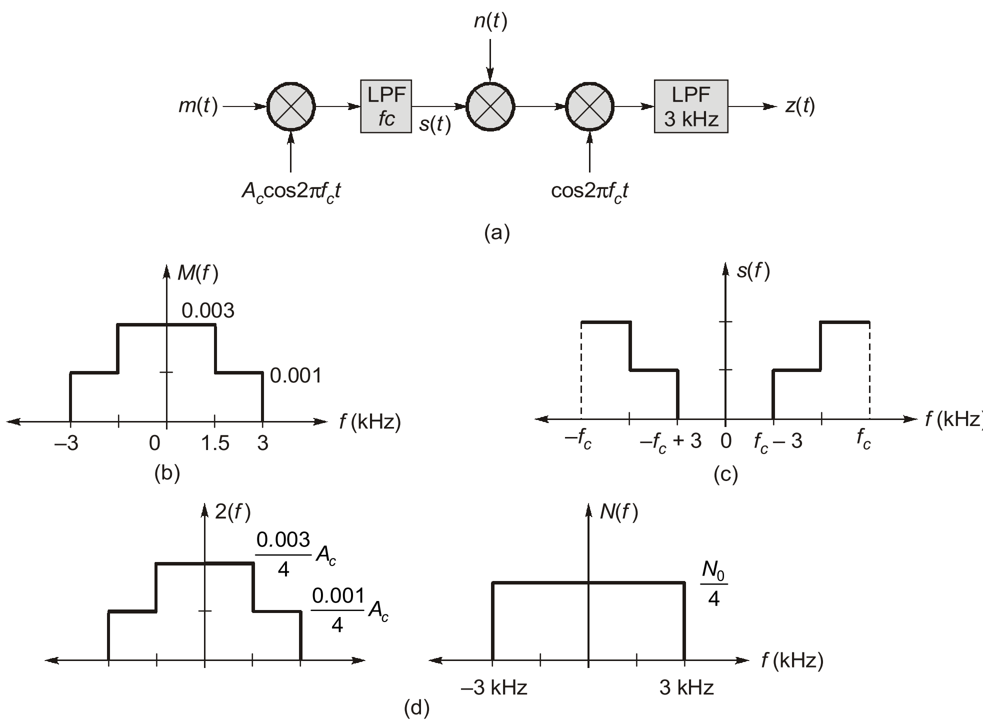
$$= A_c\left(1+\frac{1}{2}A_m\cos 2\pi f_m t\right)\sqrt{1+\left(\frac{\frac{1}{2}A_m(1-2a)\sin 2\pi f_m t}{1+\frac{1}{2}A_m\cos 2\pi f_m t}\right)^2}$$

$$= A_c\left(1+\frac{1}{2}A_m\cos 2\pi f_m t\right)d(t)$$

Here $d(t)$ is distortion.

(c) $d(t)$ is greater when $a = 0$.

1.7 Consider the SSB system shown below which transmits the lower sideband modulated signal $s(t)$.



assume that the message signal $m(t)$ has PSD $|M(f)|^2$ and its Fourier transform

$$M(f) = \begin{cases} 0.003 & |f| \le 1.5\text{ kHz} \\ 0.001 & 1.5\text{ kHz} \le f \le 3\text{ kHz} \\ 0 & |f| > 3\text{ kHz} \end{cases}$$

(a) Find A_c such that the power in $s(t)$ is equal to 100 mW.

(b) What would be the corresponding power in the demodulator output $Z(t)$ in the absence of noises.

(c) It $n(t)$ is a white Gaussian process with $S_n(f) = \frac{N_0}{2}$, what is the noise power in the demodulator output s for $N_0 = 0.0001$ mW/Hz?

(d) Find the SNR for this system at the demodulator output? (20 Marks)

Solution:

(a)
$$\text{Power in } s(t) = \int_{-\infty}^{0} |s(t)|^2\, dt = \int_{-\infty}^{\infty} \left|s(F)^2\right| dt$$

$$= 2\left[1500\left(\frac{0.01A_c}{2}\right)^2 + 1500\left(\frac{0.003A_c}{2}\right)^2\right] = 100 \text{ mW}$$

$$= \frac{1}{2}\left[1500A_c^2 \times 10^{-6} + 1500A_c^2 \times 9 \times 10^{-6}\right] = 100 \times 10^{-3}$$

$$\Rightarrow \qquad A_c = 3.65$$

(b)
$$\text{Power of } z(t) = 2\left[1500\left(\frac{0.003A_c}{4}\right)^2 + 1500\left(\frac{0.001A_c}{4}\right)^2\right] = 25 \text{ mW}$$

(c) $n(t)$ is *AwGN*, $S_n(f) = \dfrac{N_0}{2}$

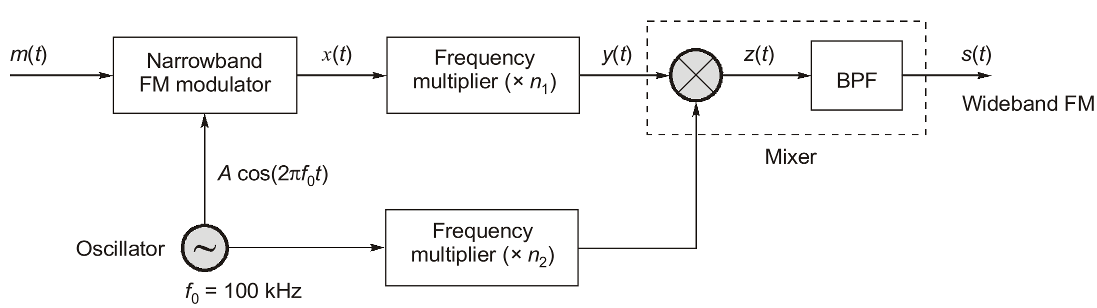
$n(t)\cos 2\pi f_c t$ will have PSD of $\dfrac{1}{4}S_n(f - f_c) + \dfrac{1}{4}S_n(f + f_c)$

$$= \frac{1}{4}\left(\frac{N_0}{2}\right) + \frac{1}{4}\left(\frac{N_0}{2}\right) = \frac{N_0}{4}$$

$$\text{Power} = \frac{6000}{4}(0.0001 \times 10^{-3}) = 0.15 \text{ mW}$$

(d)
$$\text{SNR at output} = \frac{25 \text{ mW}}{0.15 \text{ mW}} = 166.67 \approx 22.2 \text{ dB}$$

1.8 Consider the Armstrong FM modulator shown in the figure below:



The narrowband FM signal has a maximum angular deviation of 0.10 radians in order to keep distortion under control. The message signal $m(t)$ has a bandwidth of 15 kHz, the oscillator frequency is 100 kHz and the mixer circuit is used for the up-conversion.

(i) If the wideband FM signal $s(t)$ has a carrier frequency of f_c = 104 MHz and a maximum frequency deviation of Δf_{max} = 75 kHz, then determine the multiplication factors of frequency multipliers.

(ii) If the acceptable tolerance band of the carrier frequency of the wideband FM signal $s(t)$ is ±2 Hz, then determine the maximum allowable drift of the 100 kHz oscillator.

(12 + 8 Marks)

Solution:

(i) The output of the narrowband FM modulator can be given by,

$$x(t) = A\cos[2\pi f_0 t + \phi(t)] \; ; \; |\phi(t)|_{max} = 0.10 \text{ radians}$$

The signal at the output of upper frequency multiplier can be given by,

$$y(t) = A\cos[2\pi n_1 f_0 t + n_1\phi(t)]$$

After mixing $y(t)$ with the output signal of the lower frequency multiplier, we get,

$$z(t) = A^2\cos[2\pi n_1 f_0 t + n_1\phi(t)]\,\cos[2\pi n_2 f_0 t]$$

$$= \frac{A^2}{2}\cos[2\pi(n_1+n_2)f_0 t + n_1\phi(t)] + \frac{A^2}{2}\cos[2\pi(n_1-n_2)f_0 t + n_1\phi(t)]$$

It given that the mixer is designed for up-conversion. So, the signal $s(t)$ can be given by,

$$s(t) = \frac{A^2}{2}\cos[2\pi(n_1+n_2)f_0 t + n_1\phi(t)] \qquad \text{...(i)}$$

It is given that, f_c = 104 MHz and Δf_{max} = 75 kHz for $s(t)$.

So, the modulation index of the wideband signal $s(t)$ will be,

$$\beta = \frac{\Delta f_{max}}{f_{m(max)}} = n_1|\phi(t)|_{max}$$

$$n_1(0.10) = \frac{75\text{ kHz}}{15\text{ kHz}} = 5$$

$$n_1 = \frac{5}{0.10} = 50$$

$$f_c = (n_1 + n_2)f_0 = 104 \text{ MHz}$$

$$(n_1 + n_2)\times 100 = 104\times 1000 \qquad \because f_0 = 100 \text{ kHz}$$

$$n_2 = 1040 - n_1 = 1040 - 50 = 990$$

So, the desired multiplication factors of the frequency multipliers are n_1 = 50 and n_2 = 990.

(ii) It is given that the allowed drift in f_c is 2 Hz.

So, $\Delta f_c = \pm 2$ Hz

$$\Delta[(n_1+n_2)f_0] = \pm 2 \text{ Hz}$$

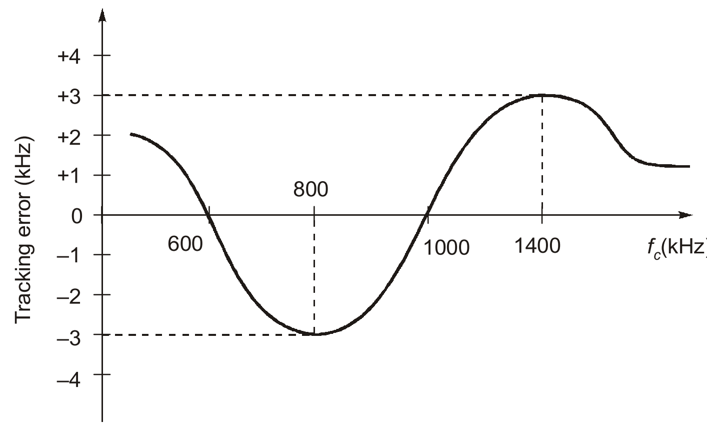
$$(n_1+n_2)\Delta f_0 = \pm 2 \text{ Hz}$$

$$\Delta f_0 = \pm\frac{2}{990+50}\text{ Hz} = \pm\frac{2}{1040}\text{ Hz}$$

$$= \pm 0.001923 \text{ Hz} = \pm 1.923 \text{ mHz}$$

So, the maximum allowable drift of 100 kHz oscillator is 1.923 mHz.

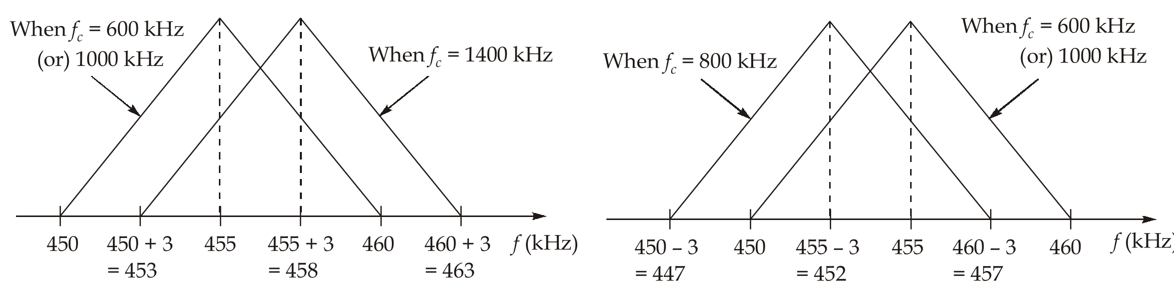
1.9 The tracking error at different frequencies of a AM superheterodyne receiver is shown in the figure below. The intermediate frequency of the receiver is 455 kHz. If the maximum frequency of the modulating signal is 5 kHz, then determine the minimum bandwidth required by the IF amplifier of the receiver.



(15 Marks)

Solution:

- Given that the maximum frequency of the modulating signal is $f_{m(\max)}$ = 5 kHz. So, the bandwidth of AM modulated signal is 10 kHz.
- For ideal tracking (i.e. zero tracking error for any input carrier frequency), the minimum bandwidth required by the IF amplifier is 10 kHz. In this case, the IF amplifier has a flat band from 450 kHz to 460 kHz.
- But it is given that the tracking is not ideal. From the given tracking error curve it is clear that only for the carrier frequency of 600 kHz and 1000 kHz the tracking error is zero. So, only for these frequencies the spectrum will lie in the range (450 to 460) kHz at the input of the IF amplifier.
- From the given tracking error curve, it is clear that, maximum deviation occur from ideality at f_c = 800 kHz, 1400 kHz. The spectrum produced at the input of IF amplifier for these carrier frequencies will be in the range as shown in the following figure.



- So, the minimum bandwidth required by the IF amplifier can be given by,

$$BW_{IF(\min)} = f_{\max} - f_{\min}$$

$$f_{\max} = f_{IF} + |\text{Max. positive tracking error}| + f_{m(\max)}$$

$$= 455 + 3 + 5 = 463 \text{ kHz}$$

$$f_{\min} = f_{IF} - |\text{Max. negative tracking error}| - f_{m(\max)}$$

$$= 455 - 3 - 5 = 447 \text{ kHz}$$

So, $$BW_{IF(\min)} = 463 - 447 = 16 \text{ kHz}$$

1.10 (i) Explain briefly the advantages and disadvantages of angle modulation in comparison with amplitude modulation.

(ii) What are the capture effect and threshold effect in an FM system? List two different methods used for FM threshold improvement.

(10 + 10 Marks)

Solution:

(i) Advantages of Angle Modulation:

Noise immunity: Probably the most significant advantage of angle modulation transmission (FM and PM) over amplitude modulation transmission is noise immunity. Most noise (including man-made noise) results in unwanted amplitude variations in the modulated wave (i.e., AM noise). FM and PM receivers include limiters that remove most of the AM noise from the received signal before the final demodulation process occurs - a process that cannot be used with AM receivers because the information is also contained in amplitude variations, and removing the noise would also remove the information.

Noise performance and signal-to-noise ratio improvement: With the use of limiters, FM and PM demodulators can actually reduce the noise level and improve the signal-to-noise ratio during the demodulation process. This is called FM thresholding. With AM, once the noise has contaminated the signal, it cannot be removed.

Capture effect: With FM and PM, a phenomenon known as the capture effect allows a receiver to differentiate between two signals received with the same frequency. Providing one signal at least twice as high in amplitude as the other, the receiver will capture the stronger signal and eliminate the weaker signal. With amplitude modulation, if two or more signals are received with the same frequency, both will be demodulated and produce audio signals. One may be larger in amplitude than the other, but both can be heard.

Power utilization and efficiency: With AM transmission (especially DSBFC), most of the transmitted power is contained in the carrier while the information is contained in the much lower-power sidebands. With angle modulation, the total power remains constant regardless if modulation is present. With AM, the carrier power remains constant with modulation, and the side-band power simply adds to the carrier power. With angle modulation, power is taken from the carrier with modulation and redistributed in the sidebands; thus, we might say, angle modulation puts most of its power in the information.

Disadvantages of Angle Modulation:

Bandwidth: High-quality angle modulation produces many side frequencies, thus necessitating a much wider bandwidth than is necessary for AM transmission. Narrowband FM utilizes a low modulation index and, consequently, produces only one set of sidebands. Those side-bands, however, contain an even more disproportionate percentage of the total power than a comparable AM system. For high-quality transmission, FM and PM require much more bandwidth than AM. Each station in the commercial AM radio band is assigned 10 kHz of bandwidth, whereas in the commercial FM broadcast band, 200 kHz is assigned each station.

Circuit complexity and cost: PM and FM modulators, demodulators, transmitters and receivers are more complex to design and build than their AM counterparts. At one time, more complex meant more expensive. Today, however, with the advent of inexpensive, large-scale integration ICs, the cost of manufacturing FM and PM circuits is comparable to their AM counterparts.

(ii) Capture effect:

The inherent ability of FM to diminish the effects of interfering signals is called the *capture effect*. Unlike in AM receivers, FM receivers have the ability to differentiate between two signals received at the same frequency. Therefore, if two stations are received simultaneously at the same or nearly the same frequency, the receiver locks onto the stronger station while suppressing the weaker station. The *capture ratio* of an FM receiver is the minimum dB difference in signal strength between two received signals necessary for the capture effect to suppress the weaker signal. Capture ratios of 1 dB are typical for high quality FM receivers.

Threshold effect:

It is observed experimentally that when the signal to noise ratio $(S/N)_r$ at the FM receiver input becomes even slightly less than unity, an impulse or spike of noise generated. This noise impulse appears at the output of the FM receiver in the form of a "click" sound. When the $(S/N)_r$ is slightly less than unity, the frequency of spike generation is small, and each spike produces individual clicking sound at the receiver output. But, when the $(S/N)_r$ is moderately less than unity, the spikes are generated rapidly and the clicks merge into a *sputtering sound*. This phenomena is known as threshold effect in FM. The minimum $(S/N)_r$ for which the sputtering effect cannot cause distortion in the FM receiver is called as *threshold* of the FM receiver.

- The threshold effect is more serious in FM compared to AM. The process of lowering the threshold level is known as threshold improvement or threshold reduction.
- The popularly using methods for threshold improvement in FM are,
  (a) Using pre-emphasis and de-emphasis circuits.
  (b) Frequency modulation with feedback (FMFB), i.e. using PLL for FM demodulation.

2. Digital Communication Schemes

Level-1

2.1 Consider a low-pass signal with a bandwidth of 3 kHz, a linear delta modulation system with step Δ = 0.1 V, is used to process this signal at a sampling rate ten times the nyquist rate.

(a) Evaluate the maximum amplitude of a test sinusoidal of a frequency 1 kHz, which can be processed by the system without slope-overload distortion.

(b) For the specifications given in part (a) evaluate the output signal to noise ratio under.

(i) pre-filterred

(ii) post-filtered conditions (10 Marks)

Solution:

(a) For linear delta modulation, the maximum amplitude of a sinusoidal signal without slope-overload distortion is

$$A = \frac{\Delta f_s}{2\pi f_m} = \frac{0.1\times 60\times 10^3}{2\pi\times 1\times 10^3} = 0.95 \text{ V}$$

(b) Under pre-filtered condition, we assume that granular quantization noise is uniformly distributed between $-\Delta$ to Δ. Hence variance of N_Q is

$$\sigma_2^2 = \int_{-\Delta}^{\Delta} \frac{1}{2\Delta}(q)^2\,dq = \frac{1}{6\Delta}(q^3)_{-\Delta}^{\Delta} = \Delta^{2/3}$$

So $$(\text{SNR})_{\text{pre-filtered}} = \frac{A^2/2}{\Delta^2/3} = \frac{3A^2}{2\Delta^2}$$

$$(\text{SNR})_{\text{pre-filtered}} = \frac{3\times(0.95)^2}{2(0.1)^2} = 135$$

$$(\text{SNR})_{\text{dB}} = 21.3 \text{ dB}$$

$(\text{SNR})_{\text{post-filtered}}$

$$(S/N)_{\text{post-filtered}} = \frac{3}{16\pi^2} \times \frac{f_s^3}{f_m^2 W} = \frac{3}{16\pi^2}\left(\frac{(60)^3}{1\times 3}\right) = 1367$$

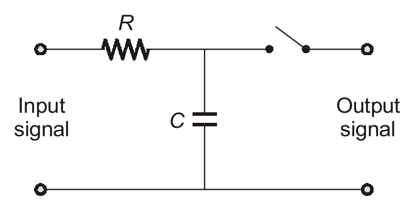
$$\left(\frac{S}{N}\right)_{\text{dB}} = 31.3 \text{ dB}$$

The flittering gain in SNR due to use of reconstruction fitter at the demodulator o/p is (31.3 – 21.3) = 10 dB

2.2 An RC-low pass filter is given in the figure, the frequency response of this filter is

$$H(f) = \frac{1}{1 + j\left(\frac{f}{f_0}\right)} \;;\; \text{Where } f_0 = \frac{1}{2\pi RC}.$$

The input signal $g(t)$ is a rectangular pulse of amplitude A and duration T. The requirement is to optimize the selection of the 3-dB cutoff frequency f_0 of the filter so that the peak pulse SNR at the filter output is maximized. Hence show that the optimum value of f_0 is $0.2/T$, for which the loss in SNR compared to the ideal matched filter is about 1 dB.



(10 Marks)

Solution:

The output of the LP.RC filter produced by a rectangular pulse of amplitude A and duration T is

$$S_0(t) = A\left[1 - e^{-2\pi f_0 T}\right]$$

output pulse power.

$$P_{\text{out}} = A^2\left[1 - e^{-2\pi f_0 T}\right]^2$$

Here f_0 is the 3-dB cutoff frequency of RC filter the average output noise power is

$$N_{\text{out}} = \frac{N_0}{2}\int_{-\infty}^{\infty} \frac{1}{1 + \left(\frac{f}{f_0}\right)^2} dt = \frac{N_0 \pi f_0}{2}$$

$$(\text{SNR})_{\text{out}} = \frac{2A^2}{N_0 \pi f_0}\left[1 - e^{(-2\pi f_0 T)}\right]$$

differentiating $(\text{SNR})_0$ with respect to F_0T and setting the result equal to 0,

$(\text{SNR})_{0,\,\max}$ value is attained at $f_0 = \dfrac{0.2}{T}$

So, $$(\text{SNR})_{0,\,\max} = \frac{2A^2 T}{0.2\pi N_0}\left[1 - e^{-0.4\pi}\right]^2 = \frac{1.62A^2 T}{N_0}$$

For perfect matched filter $(\text{SNR})_{0,\,\text{mathched}}$

$$= \frac{2E}{N_0} = \frac{2A^2 T}{N_0}$$

Hence, we find that transmitted energy must be increased to the ratio $\dfrac{2}{1.162}$ that is by 0.92 dB.