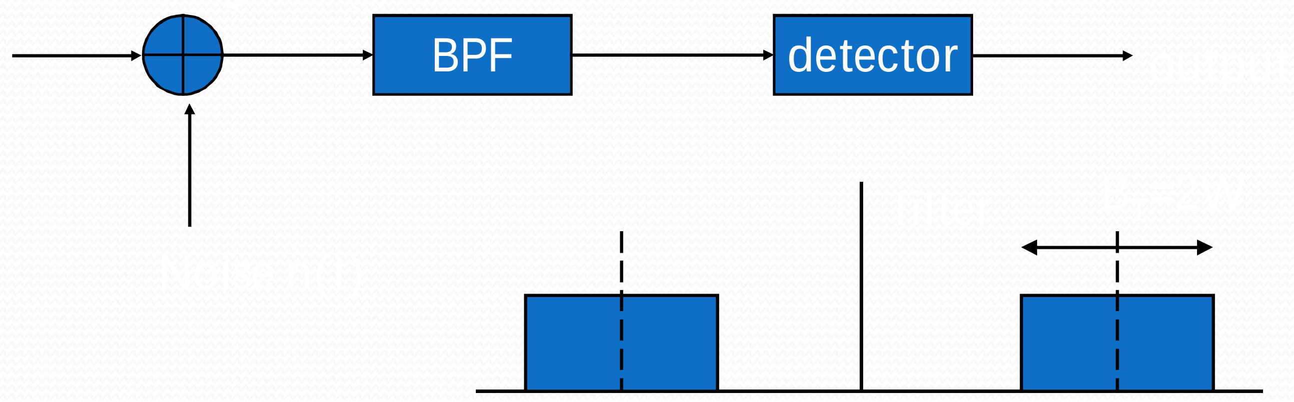
NOISE IN ANALOG MODULATION

AMPLITUDE MODULATION

Receiver Model

- The objective here is to establish a relationship between input and and output SNR of an AM receiver



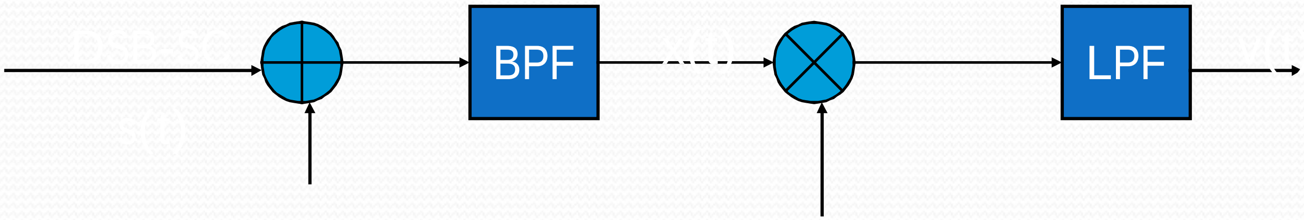
Establishing a reference SNR

- Define "channel" SNR measured at receiver input

$(SNR)_c$=avg. power of modulated signal/
avg. noise power in the message bandwidth

Noise in DSB-SC Receiver

- Tuner plus coherent detection



$$s(t) = A_c m(t) \cos\left(2\pi f_c t\right)$$

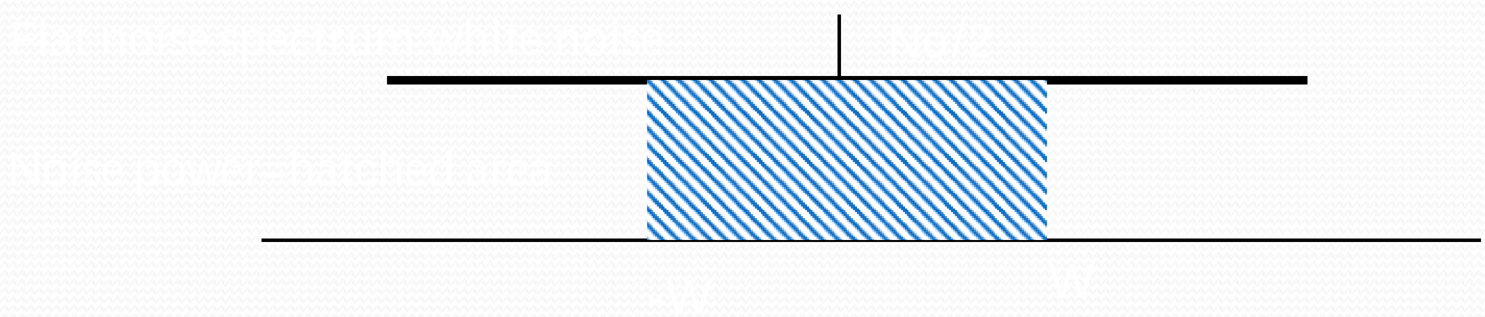
$$< s^2(t) >= avg.power = A_c^{\ 2} < m^2(t) > /2 = A_c^2 P / 2$$

$$P = \text{avg. message power}$$

Receiver input SNR

- Also defined as channel SNR:

$$(SNR)_c = \frac{A_c^2 P/2}{\underbrace{WN_o}_{\text{noise power in the message bandwidth}}} = \frac{A_c^2 P}{2WN_o}$$



Output SNR

- Carrying signal and noise through the rest of the receiver, it can be shown that output SNR comes out to be equal to the input. Hence

$$\frac{(SNR)_o}{(SNR)_c} = 1$$

- Therefore, any reduct … put SNR is linearly reflected in the output

$(SNR)_o$ for DSB-AM

- Following a similar approach,

$$\frac{(SNR)_o}{(SNR)_c} = \frac{k^2 P}{1 + k^2 P} < 1$$

k : AM modulation index

P : avg. message power

- Best case is achieved for 100% modulation index which, for tone modulation, is only 1/3

DSB-AM and DSB-SC noise performance

- An AM system using envelope detection needs 3 times as much power to achieve the same output SNR as a suppressed carrier AM with coherent detection
- This is a result similar to power efficiency of the two schemes

Threshold effect-AM

- In DSB-AM (not DSB-SC) there is a phenomenon called *threshold effect*
- This means that there is a massive drop in output SNR if input SNR drops below a threshold
- For DSB-AM with envelope detection, this threshold is about 6.6 dB

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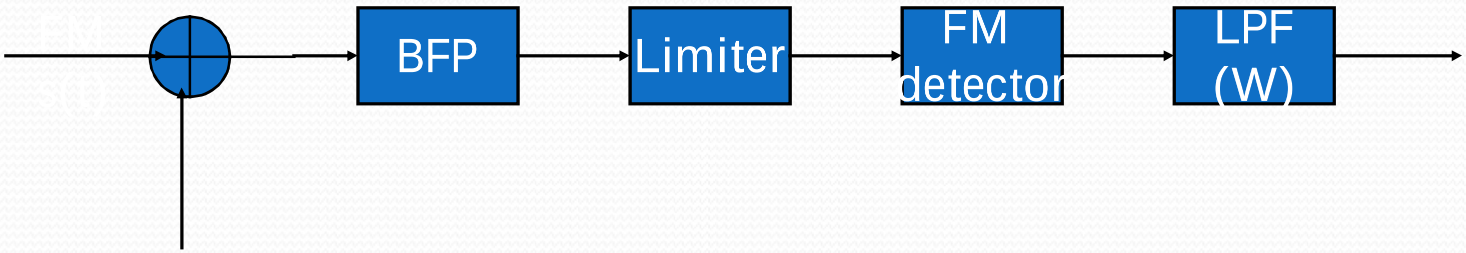
FREQUENCY MODULATION

Receiver model



- Noisy FM signal at BPF's output is

$$x(t) = s(t) + n(t) =$$

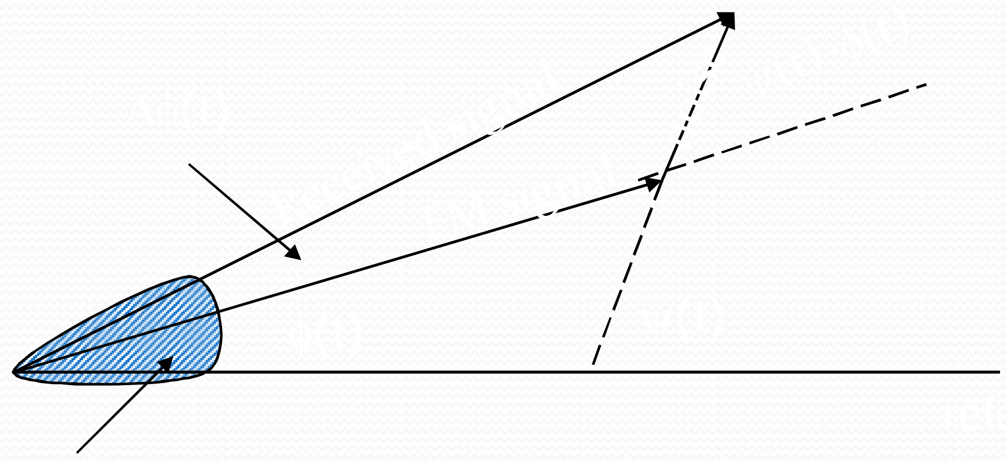
$$A_c \cos\left(2\pi f_c t + \phi(t)\right) + \underbrace{r(t)\cos\left(2\pi f_c t + \psi(t)\right)}_{noise}$$

$$where$$

$$\phi(t) = \int m(t)dt$$

Phasor model

- We can see the effect of noise graphically



Small noise

- For small noise, it can be approximated that the noise inflicted phase error is

$$\Delta\phi=[r/Ac]\mathrm{Sin}(\psi-\phi)$$

- So the angle available to the FM detector is $\phi+\Delta\phi$
- FM Detector computes the derivative of this angle. It will then follow that...

FM SNR for tone modulation

- Skipping further detail, we can show that for tone modulation, we have the following ratio

$$\frac{(SNR)_o}{(SNR)_c} = \frac{3}{2}\beta^2$$

- SNR rises as power of 2 of bandwidth; e.g. doubling deviation ratio quadruples the SNR

⇒ Bandwidth-SNR exchange

Comparison with AM

- In DSB-SC the ratio was 1 regardless.
- For commercial FM, β=5. Therefore,

$$(SNR)_o/(SNR)_c=(1.5)x25=37.5$$

- Compare this with just 1 for AM

Capture effect in FM

- An FM receiver locks on to the stronger of two received signals of the same frequency and suppresses the weaker one
- Capture ratio is the necessary difference(in dB) between the two signals for capture effect to go into action
- Typical number for capture ratio is 1 dB

Normalized transmission bandwidth

- With all these bandwidths numbers, it is good to have a normalized quantity.
- Define

$$\text{normalized bandwidth} = B_n = B_T / W$$

Where W is the baseband bandwidth

Examples of B_n

- For AM:

$$B_n = B_T / W = 2W / W = 2$$

- For FM

$$B_n = B_T / W \sim 2\beta \text{ to } 3\beta$$

- For $\beta = 5$ in commercial FM, this is a very large expenditure in bandwidth which is rewarded in increased SNR

Noise/bandwidth summary

- AM-envelope detection

$$(SNR)_o = \frac{\mu^2}{2+\mu^2}(SNR)_c$$

$$B_n = 2$$

Noise/bandwidth summary

- DSB-SC/coherent detection

$$(SNR)_o=(SNR)_c$$

$$B_n=2$$

- SSB

$$(SNR)_o=(SNR)_c$$

$$B_n=1$$

Noise/bandwidth summary

- FM-tone modulation and $\beta=5$

$$(SNR)_o = 1.5\,\beta^2 (SNR)_c = 37.5\,(SNR)_c$$

$$B_n \sim 16 \text{ for } \beta=5$$

Preemphasis and demphasis

- High pitched sounds are generally of lower amplitude than bass. In FM lower amplitudes means lower frequency deviation hence lower SNR.
- Preemphasis is a technique where high frequency components are amplified before modulation
- Deemphasis network returns the baseband to its original form

Pre/demphasis response

- Flat up to ~500Hz, rises from 500-15000 Hz