Summary of Frequency Division Multiplexing (FDM) and Orthogonal Frequency Division Multiplexing (OFDM)

FDM enables sharing of spectrum
Guard bands are placed between the channels to prevent adjacent channel interference.
FDM can support independent transmitters and receivers, i.e., the broadcast case.
Composite baseband signals can be constructed using FDM then modulated to RF.
Bandwidth of FDM signals.
FDMA
Combined TDMA and FDMA
OFDM

- No explicit sidebands
  - $\frac{1}{T_s} = \Delta f$ (subcarriers are orthogonal)
- N=Number of subcarriers
- $B_{RF} = (N+1)\Delta f$ (Not a function of the QAM modulation on each subcarrier)
- $r_b = N * \Delta f * \gamma$ (γ=#bits/symbol, assumes same QAM on all subcarrier)
- Transmitter/receiver structure use IDFT/DFT

OFDM combined with TDMA

- T_f=frame time = Number of slots $*$ (Number of OFDM symbols/time slot) $* T_s$
- $r_b = \frac{\text{Number of bits in a } T_f}{T_f}$

Summary of DSB-LC

$B_{RF} = 2\, B_{bb}$.

Not power efficient, power efficiency = $\frac{\mu^2}{1+\mu^2}$ with maximum = 33%.

Poor low frequency response.
Very simple receiver, envelope detector. No carrier recovery required.
ASK is a form of DSB-LC, an envelope detector followed by an integrate and dump can be used as an ASK receiver.

Summary of SSB

$B_{RF} = B_{bb}$
Transmitter- Sideband Filtering, requires sharp frequency cut-off on the BPF
Transmitter-Phasing, requires wideband constant amplitude phase shifting filter.
Needs a coherent receiver, carrier synchronization is required.
SSB-LC is feasible, wastes power in transmitting the carrier, enables the use of an envelope detector with poor LF response.

Introduced a signal space diagram for analog modulated signals.

Summary of VSB

$B_{bb} < B_{RF} < 2\,B_{bb}$

Requires a transmit BPF with specific characteristics, $H_v(f + f_c) + H_v(f - f_c) = \text{constant}$

VSB without a large carrier requires carrier synchronization.

VSB-LC can be received with an envelope detector.

Moduation	B_{RF}	Transmitter Complexity	Receiver Complexity	Power Efficency
DSB – SC	$2\,B_{bb}$	Simple	Complex Requires Carrier Recovery	Adequate
DSB – LC	$2\,B_{bb}$	Simple	Simple Envelope Detector	Poor
SSB	B_{bb}	Complex	Complex Requires Carrier Recovery	Adequate
VSB – SC	$B_{bb} < B_{RF} < 2\,B_{bb}$	Complex	Complex Requires Carrier Recovery	Adequate
VSB – LC	$B_{bb} < B_{RF} < 2\,B_{bb}$	Complex	Simple Envelope Detector	Poor

Summary of FM and PM

Instantaneous phase $\theta_i(t)$ and frequency $f_i(t) = \frac{1}{2\pi}\frac{\theta_i(t)}{dt}$ (Hz)

In FM $f_i(t) \propto x_{bb}(t)$.

In PM $\theta_i(t) \propto x_{bb}(t)$

The spectrum of $X_{FM}(f)$ is not a translation of $X_{bb}(f)$.

FM (PM) is a non-linear modulation

Considered the special case of $x_{bb}(t) = A_m \cos(2\pi f_m t)$

For $x_{bb}(t) = A_m \cos(2\pi f_c t)$ defined the frequency deviation Δf and the FM modulation index $\beta = \frac{\Delta f}{f_m}$

For $x_{bb}(t) = A_m \cos(2\pi f_c t)$ the FM signal is

$$x_{FM}(t) = A_c \cos(2\pi f_c t + \beta \sin(2\pi f_m t)) = A_c \sum_{n=-\infty}^{\infty} J_n(\beta) \cos(2\pi(f_c + n f_m)t)$$

The characteristics (spectrum) of $X_{FM}(f)$ are driven by the properties of the Bessel function $J_n(\beta)$

Spectrum of FM signals with tone modulation.

The approximate RF bandwidth for FM is $B_{RF} = 2\,B_{bb}(1+\beta)$

The average power in $x_{FM}(t) = P_{FM} = \frac{A_c^2}{2}$, same as the power in an unmodulated carrier.

FM transmitters;

- Indirect FM
- VCO

FM demodulators;

- Differentiator/envelope detector
- Balanced discriminator
- PLL

Digital FM techniques;

- FSK
- M-ary FSK
- DPSK
- For coherent FSK systems orthogonal carriers can be used with $\Delta f = \frac{1}{T_s}$
- For non-coherent FSK systems $\Delta f \geq \frac{2}{T_s}$ and a noncoherent (envelope) receiver can be used.
- The approximate RF bandwidth for $BFSK = 2\Delta f + (1+\alpha)\, r_s$

<u>Summary of Superheterodyne Receiver</u>

Down converts RF signal to a fixed IF frequency.
RF section provides sensitivity; Bandwidth of RF section = B_{RF}
IF section provides selectivity; Bandwidth of IF section = B_{RF}
As desired carrier frequency changes the local oscillator frequency changes

$$f_{IF} = f_{LO} - f_c$$

Image frequency

<u>Summary of Communications Channels, Noise and Link Budgets</u>

Path loss, function of the carrier frequency and the environment.
Antenna gain, function of the carrier frequency and the antenna size, i.e., the size of the antenna relative to the wavelength.
Signal-to-noise ratio (S/N), S/N is the $\frac{\text{Power in } x_o(t)}{\text{Power in } n_o(t)}$.
Flat noise, $S_n(f) = \frac{N_o}{2}\ \forall f$. Noise Power = N_0B
Thermal noise, kTB noise; Noise Power = kTB
External noise input to the receiver is modeled as an T_a= antenna temperature.
Specification of component noise using equivalent temperature of the device, T_e.
Noise Power = $N_0 B = kTB = k(T_a + T_e)B$, $N_0 = k(T_a + T_e)$
Specification of component noise using noise figure of the device, F.
Relationship between equivalent temperature and noise figure $T_e = T_0(F-1)$. $T_0=290$
Noise figure of resistive attenuator, $F = 1 + (L-1)\frac{T_P}{T_o}$ if $T_P = T_o$ then F=L.

For multistage systems $T_e = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + \frac{T_4}{G_1 G_2 G_3}$ ....

For multistage systems F = $F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3}$ .....

Link budgets are used to evaluate system tradeoffs.

$$(S/N)_{\text{pre}} = \frac{P_T G_T G_R}{L_M L_p k(T_a + T_0(F-1)) B_e}$$

If $T_a = T_o$ then

$(S/N)_{\text{pre}}$ (dB)= P_T (dB$_W$) + G_T(dB) + G_R(dB) - L_M(dB)- L_p (dB) - 10 Log(k T_0 B_e) - F(dB)= P_T (dB$_W$) + G_T(dB) + G_R(dB) - L_M(dB)- L_p (dB) - 10 Log(k T_0) + 10 Log(B_e) - F(dB)