Communication Systems

Curated undergraduate study track (not accredited, no external exam). Original explanations and practice only, following the reviewed course handout.

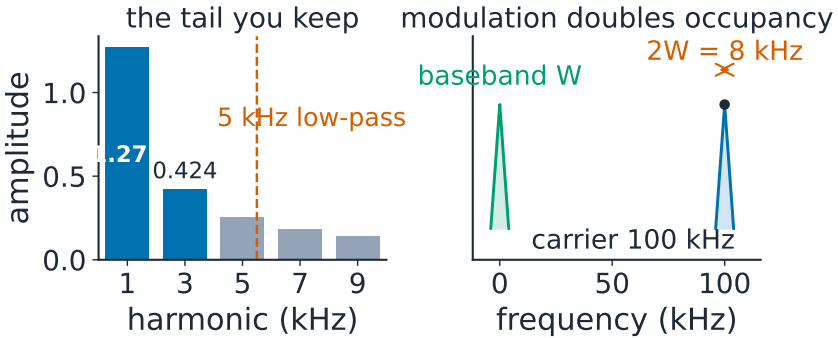
Sending signals across real channels

- Analogue first (spectra, AM, FM), then the digital chain (noise, PCM, modulation), then the limits (**entropy**, capacity, coding).
- Every dB claim recomputed as a ratio; every power budget closed; every bandwidth tested against its channel.

Spectra and bandwidth: the tail you keep

1. **Harmonics** Amplitudes 1.273, 0.424, 0.255 - a 5 kHz low-pass on a 1 kHz square keeps the 1st and 3rd, and the wave rounds over.
2. **Power** The odd-harmonic power series sums to $\pi^2/8$, so the fundamental holds $8/\pi^2 = 0.811$ of everything - energy concentrates low.
3. **Channel** A 4 kHz message on a 100 kHz carrier fills 96-104 kHz; single-sideband sends only the top half and halves the spectrum.

The tail you keep

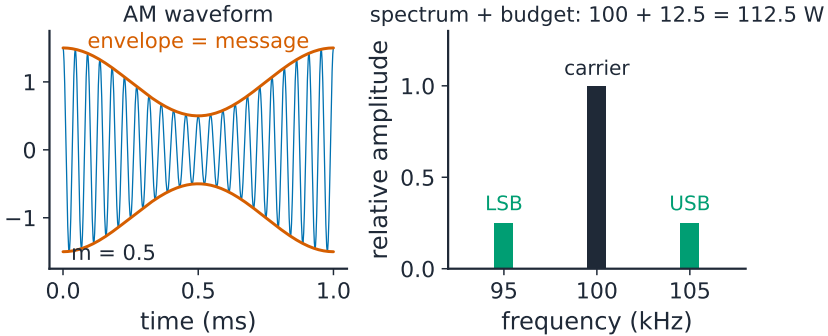


A 1 kHz square through a 5 kHz low-pass keeps harmonics 1 and 3 (about 90 percent of the power); modulation doubles occupancy to 2W.

Amplitude modulation: the power budget

1. **Budget** Carrier 100 W, m = 0.5: sidebands 12.5 W, total 112.5 W, 11.1% efficient; at m = 1 it is 50/150 W = 33.3% - two-thirds of the transmitter heats the antenna.
2. **Detector** Carrier 100 kHz, message 5 kHz: τ between 1.6 and 31.8 µs; 10 µs fits. At m = 0.9 the upper bound tightens to sqrt(1 - m^2)/(m · ω_m) = 15.4 µs.
3. **Fix** DSB-SC puts ALL the transmitter power into sidebands (the m = 0.7 station of sheet 11.2: 2450 W becomes 12 450 W, 5.1×) - the receiver pays with a coherent carrier.

The envelope and the budget

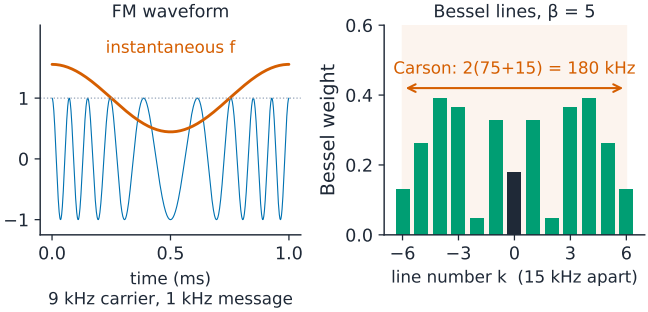


At m = 0.5 the sidebands carry 12.5 W of 112.5 W - 11 percent; the carrier takes the rest. 100 W + 12.5 W closes on carrier $\times$ $(1 + m^2/2)$.

Angle modulation: Carson draws the line

1. **Broadcast** Δf = 75 kHz, f$_m$ = 15 kHz: $\beta = 5$, B = 180 kHz inside the 200 kHz channel - the guard band is designed in.
2. **Range** Δf = 50 kHz: at f$_m$ = 15 kHz B = 130 kHz; at 300 Hz B = 101 kHz - the highest message frequency sets the worst case.
3. **Trade** Wideband FM converts bandwidth to SNR at $3\beta^2/2$ (15.7 dB at $\beta = 5$) - and loses it all below threshold, where clicks and capture rule.

The frequency bends, Carson fences

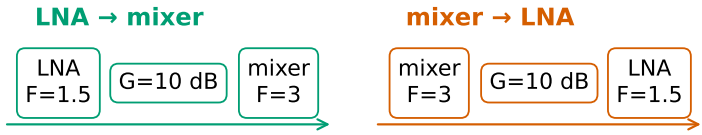


$\beta = 5$: lines spaced 15 kHz with Bessel weights under the Carson 180 kHz fence - the 200 kHz spacing leaves a guard.

Noise and SNR: the front end decides

1. **Cascade** LNA F = 1.5, G = 10 dB before mixer F = 3: F = 1.70 (2.3 dB); reversed, 3.05 (4.84 dB) - the order is worth 2.5 dB.
2. **Floor** -174 + 53 = -121 dBm in a 200 kHz channel; add NF 2.3 and demand 10 dB SNR: the minimum signal is -108.7 dBm.
3. **Cliff** BPSK bit energy at 5 dB: 6×10^{-3}; 9 dB: 3.3×10^{-5}; 12 dB: 9×10^{-9} - each dB near the wall buys an order of magnitude.

Same blocks, swapped order



$F = 1.5 + (3-1)/10$
$= 1.70$ (2.30 dB)

$F = 3 + (1.5-1)/10$
$= 3.05$ (4.84 dB)

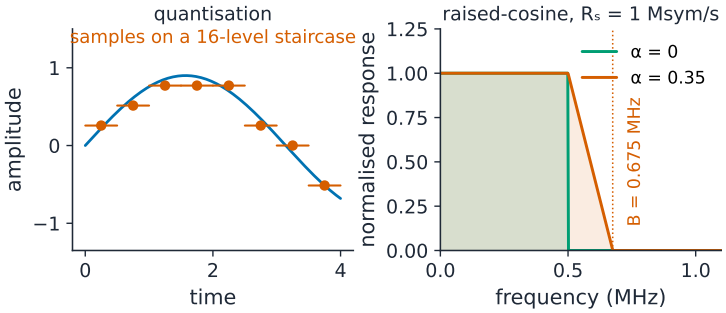
thermal floor: -174 dBm/Hz + $10 \cdot \log_{10} B$ (-121.4 dBm in 180 kHz)

LNA first: $F = 1.70$ (2.30 dB). Mixer first: 4.84 dB - front-end gain IS the protection, above the -121.4 dBm floor.

PCM and baseband: bits from waves

1. **Voice** 8 kHz sampling $\times$ 8 bits $=$ 64 kbps at 49.9 dB - the trunk standard; 12-bit masters buy 74.0 dB.
2. **Design** 60 dB target needs n $=$ 10 (61.96 dB): 44.1 kHz $\times$ 10 $=$ 441 kbps, 3.31 MB per minute.
3. **Fit** 1 Msym/s in a 0.75 MHz channel: $\alpha = 0.5$ lands exactly at 0.75 MHz; Manchester coding would need twice that and does not fit - NRZ plus a scrambler it is.

From voltage to shaped pulses

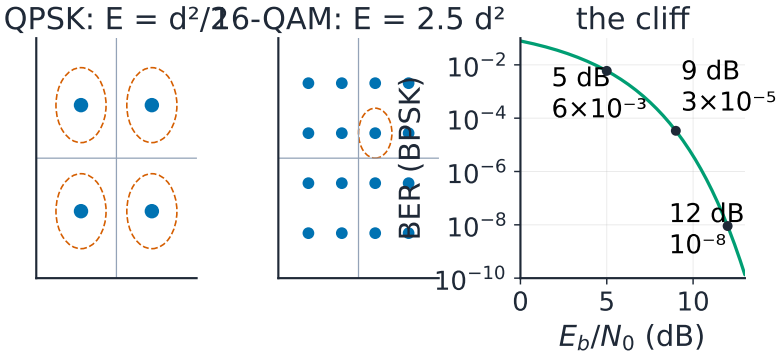


Samples on a 16-level staircase (SQNR 6.02n + 1.76 dB) and the **raised-cosine** 0.675 MHz at $\alpha = 0.35$.

Digital modulation: the constellation plane

1. **Energy** d $= 2$: QPSK averages E $= 2$, 16-QAM averages 10 - a factor $5 = 7.0$ dB for twice the bits per symbol.
2. **Rates** 2 Mbps with $\alpha = 0.35$: QPSK needs 0.675 MHz (2.96 b/s/Hz); 16-QAM needs 0.3375 MHz (5.93 b/s/Hz) - both under Shannon's 6.66 at 20 dB.
3. **Bits** QPSK at the same symbol energy halves the bit energy: 5 dB drops to 2 dB and BER goes 6×10^{-3} to 3.7×10^{-2} - bits, not symbols, consume energy.

Points, distance and the cliff

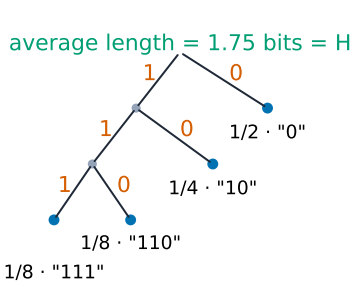


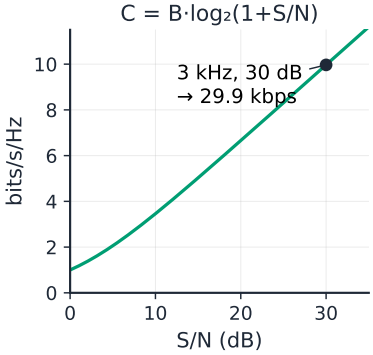
Equal d: QPSK $d^2/2$, 16-QAM $2.5d^2$ (7 dB for $2\times$ bits); BER falls two decades per 4 dB - a cliff, not a slope.

Information and coding: the limits

1. **Source** Quartile source (1/2, 1/4, 1/8, 1/8): H = 1.75 bits and Huffman lengths 1,2,3,3 average exactly 1.75 - dyadic probabilities meet the bound.
2. **Channel** 3 kHz at 30 dB: C = 29.9 kbps - the dial-up ceiling, approached (V.90) and never beaten.
3. **Code** Encode 1011 to 0 1 1 0 0 1 1; flip bit 5 and the syndrome reads $101_2 = 5$ - the code points at its own error. Doubles miscorrect silently unless extended (8,4) catches them.

The bound met, the ceiling drawn





Huffman lengths 1,2,3,3 average exactly H = 1.75 bits; capacity 3 kHz at 30 dB is 29.9 kbps - approached never beaten.

Check yourself

- AM: carrier 100 W, m = 1 - **sideband** power and efficiency? (50 W, 33.3%.)
- FM: Δf 75 kHz, f_m 15 kHz - Carson bandwidth? (180 kHz.)
- PCM: 8 bits - SQNR? (49.9 dB.)
- Coding: quartile source **entropy**? (1.75 bits.)