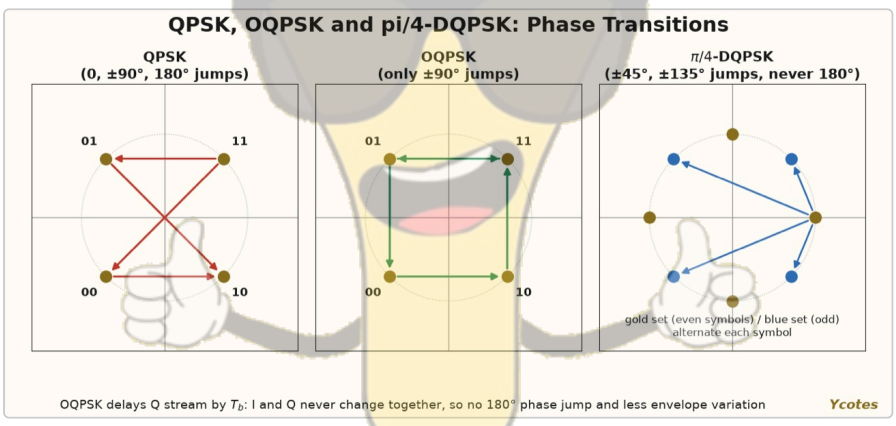
UNIT–3 : Digital Signalling for Fading Channels (PYQ Solution)

PART–A Answers (≈70 Words Each)

Q1. Describe the principle of offset-QPSK (OQPSK). (2019, Feb 2024, 2025)

In QPSK the in-phase (I) and quadrature (Q) bits change together, so the carrier phase can jump by 180 degrees, which causes envelope dips after filtering.

In OQPSK the Q stream is delayed by half a symbol (one bit period T_b). I and Q never change at the same instant, so the phase changes by at most 90 degrees. This reduces envelope fluctuation and spectral regrowth in nonlinear amplifiers, while BER and bandwidth equal QPSK.



Q2. Explain the cyclic prefix. (Feb 2024)

The cyclic prefix (CP) is a copy of the last N_{cp} samples of an OFDM symbol placed in front of it. It acts as a guard interval.

If its duration is at least the maximum delay spread, there is no inter-symbol interference between OFDM symbols, and linear convolution with the channel becomes circular, so each subcarrier is equalised with a single complex gain after the FFT. The cost is a bandwidth and power overhead $N_{cp}/(N + N_{cp})$.

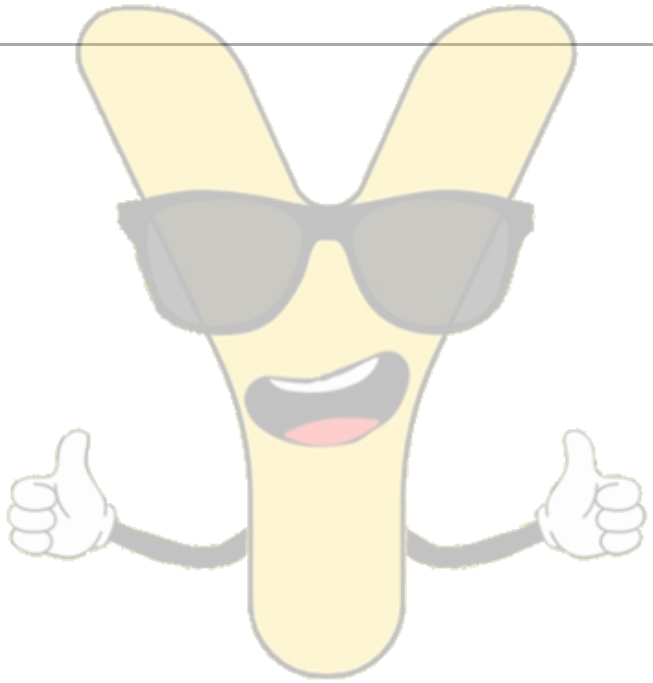
Q3. Define PAPR in OFDM systems. (2025)

PAPR (peak to average power ratio) of an OFDM signal is

$$\mathrm{PAPR} = \frac{\max |x(t)|^2}{E[|x(t)|^2]}$$

Since the output is the sum of N independent subcarriers, they occasionally add in phase to give large peaks; the worst case is N ($10 \log N$ dB, e.g. 18 dB for 64 carriers).

High PAPR forces power amplifier back-off, reduces efficiency and causes nonlinear distortion. It is reduced by clipping, SLM, PTS or tone reservation.



PART–B Answers (≈250 Words Each)

Q1. Write a short note on digital modulation in a frequency selective mobile channel. (2019)

In a **frequency selective channel** the RMS delay spread exceeds the symbol period ($\sigma_\tau > T_s$, or $B_s > B_c$). Delayed copies of previous symbols interfere with the current one, causing **inter-symbol interference (ISI)** and an **irreducible bit error floor** that does not improve with higher SNR. Mobility also adds Doppler spread.

Effects on modulation:

- Linear modulations (QPSK, QAM) suffer ISI directly
- Constant-envelope schemes (MSK, GMSK) still suffer ISI; GSM therefore uses an equaliser
- Error rate $P_e \approx$ proportional to $(\sigma_\tau / T_s)^2$ for large spread

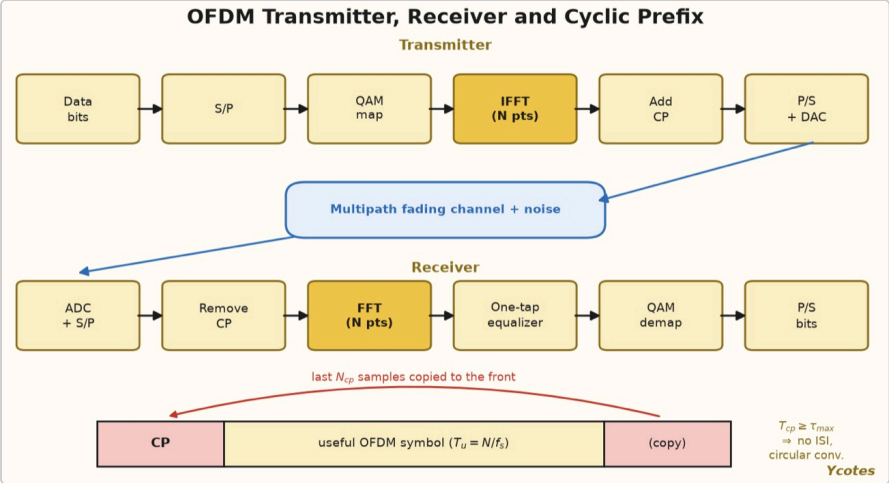
Solutions:

1. **Adaptive equaliser** (linear, DFE, MLSE) with a training sequence
2. **Spread spectrum with RAKE** reception, which turns multipath into diversity
3. **Multicarrier modulation (OFDM):** converts the wideband channel into many narrow flat-fading subchannels, with a cyclic prefix to remove ISI
4. Lower symbol rate over several carriers, and channel coding with interleaving

Choice of modulation: use pi/4-DQPSK or GMSK for power-efficient mobile terminals, and OFDM with QAM for high data rates.

Q2. What are cyclic prefix and PAPR? (2019)

Cyclic prefix: the last N_{cp} samples of every OFDM symbol are copied in front of it. If $T_{cp} \geq$ maximum excess delay, the echoes of the previous symbol fall only inside the prefix, which is discarded at the receiver. Hence there is no ISI, and the channel acts as a circular convolution, allowing one-tap frequency-domain equalisation. Overhead $= N_{cp}/(N + N_{cp})$. Example: $N = 64$, $N_{cp} = 16$ at 20 MHz gives 0.8 us tolerance and 20% overhead.



PAPR: the peak to average power ratio

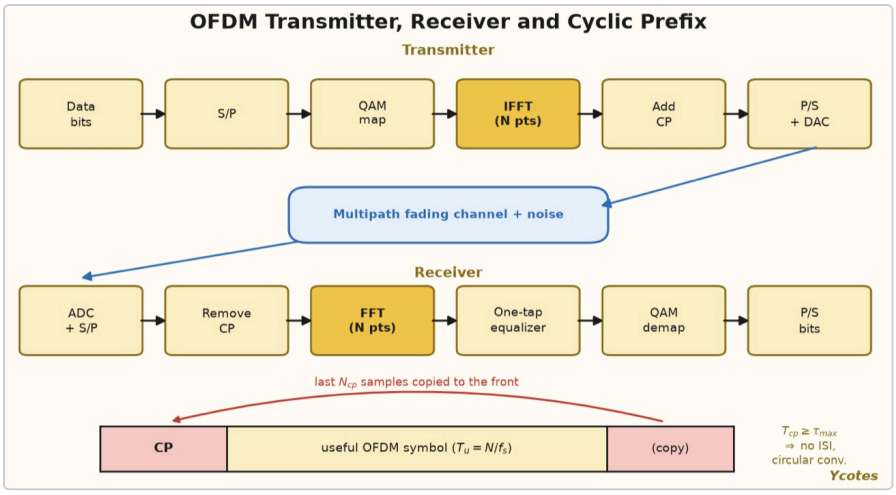
$$\text{PAPR} = \frac{\max |x(t)|^2}{E[|x(t)|^2]}$$

For N subcarriers it can reach N, i.e. $10 \log_{10} N = 18.06$ dB for $N = 64$, though large peaks are rare (Gaussian-like amplitude). A high PAPR requires a linear amplifier with large back-off, which lowers power efficiency and causes out-of-band emission.

Reduction methods: clipping and filtering, selective mapping, partial transmit sequences, tone reservation and coding.

Q3. Explain the principle of OFDM. Discuss how cyclic prefix and windowing improve performance in fading channels. (2025)

Principle of OFDM: a high-rate stream of rate R is split into N parallel streams of rate R/N, each modulating one of N subcarriers spaced by $\Delta f = 1/T_u$. This spacing makes subcarriers **orthogonal** so they overlap in the spectrum without interference. The modulation is done by an **IFFT** at the transmitter and the **FFT** at the receiver. Each subcarrier bandwidth is below the coherence bandwidth, so every subcarrier sees flat fading and needs only a one-tap equaliser.



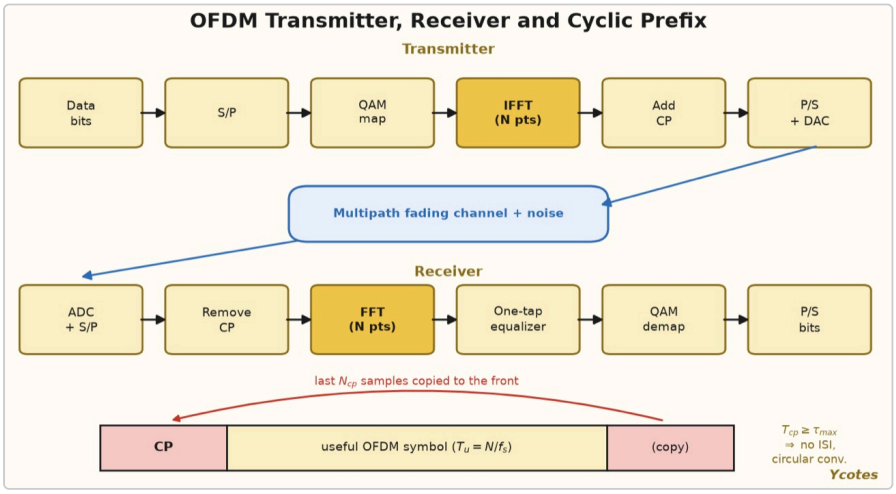
Cyclic prefix: copying the symbol tail to the front makes the guard interval carry a periodic extension. If $T_{cp} \geq \tau_{max}$: (1) no ISI, (2) no inter-carrier interference (orthogonality preserved), (3) circular convolution, so $Y_k = H_k X_k + N_k$.

Windowing: an OFDM symbol with rectangular edges has a sinc spectrum with high side lobes. Applying a smooth window (raised cosine) with a roll-off over the edges, overlapping adjacent symbols inside the prefix, reduces **out-of-band emission** and adjacent channel interference without losing orthogonality at the FFT window. It also reduces the effect of abrupt transients.

Overall: the CP combats multipath fading (ISI), windowing improves spectral containment, and coding across subcarriers handles the deep faded tones.

Q4. Explain OFDM and its working. (Feb 2024)

OFDM is a multicarrier technique that divides the available bandwidth into many closely spaced orthogonal subcarriers, each carrying a low-rate stream, used in Wi-Fi, LTE and 5G.



Transmitter:

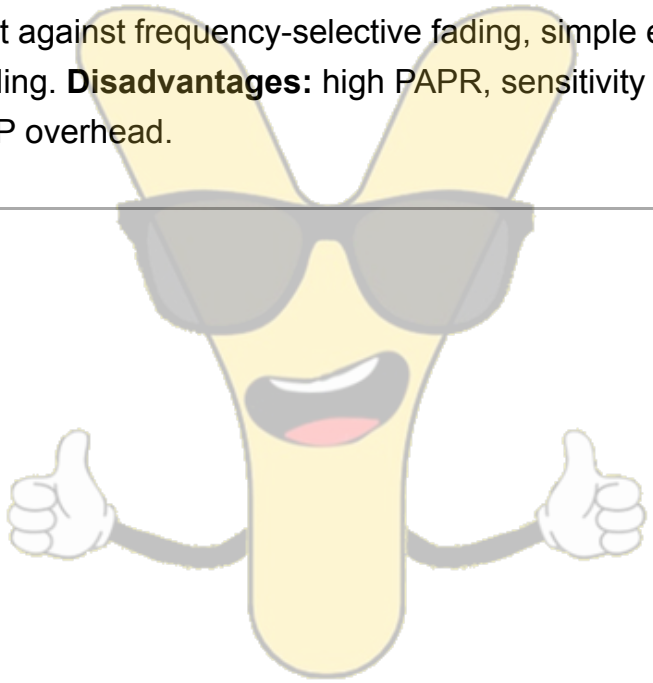
1. Incoming bits are converted to parallel by the S/P block
2. Each group is mapped to QAM/PSK symbols
3. An **IFFT** of N points creates the time-domain OFDM symbol: $x[n] = \sum_k X_k e^{j2\pi kn/N}$
4. The cyclic prefix is added, followed by P/S, DAC and RF up-conversion

Channel: multipath fading and noise, $y = h * x + n$.

Receiver: after down-conversion and ADC, the CP is removed, an **FFT** returns $Y_k = H_k X_k + N_k$, a one-tap equaliser $\hat{X}_k = Y_k / H_k$ is applied per subcarrier, and demapping gives the bits.

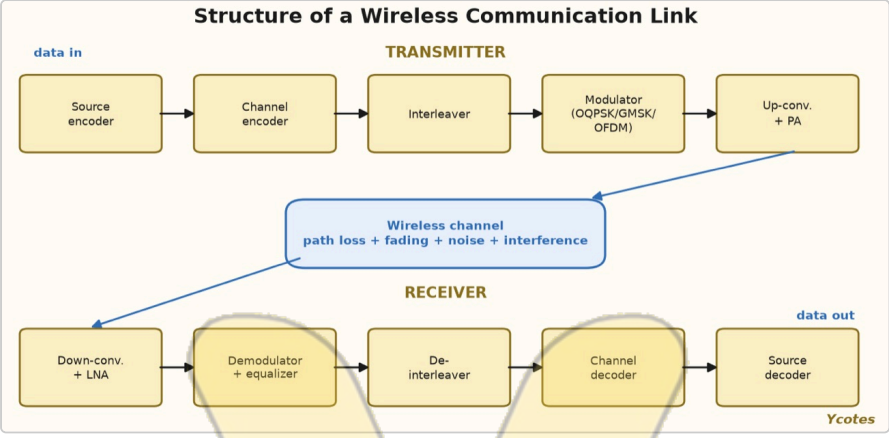
Key parameters: $\Delta f = 1/T_u$, $T_{cp} \geq \tau_{max}$, N subcarriers.

Advantages: robust against frequency-selective fading, simple equalisation, efficient FFT, flexible bit loading. **Disadvantages:** high PAPR, sensitivity to frequency offset and Doppler, and CP overhead.



PART–C Answers (≈500 Words Each)

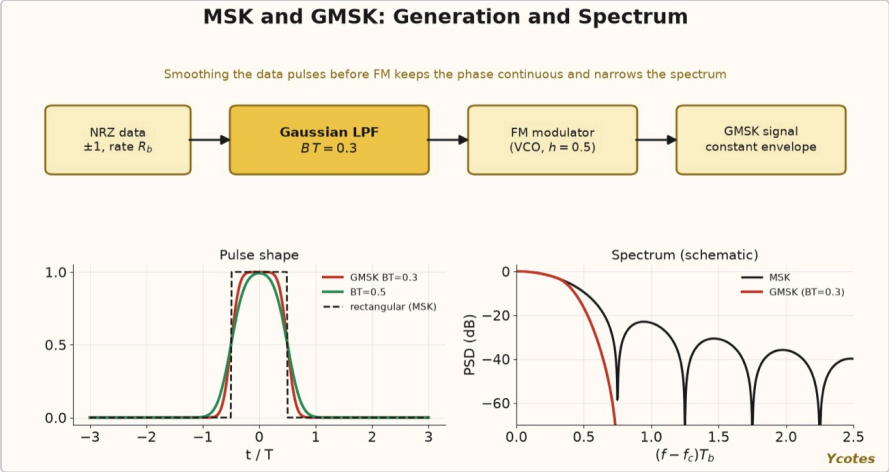
Q1. Describe the structure of a wireless communication link with a suitable diagram. Explain Gaussian minimum shift keying and OFDM principle. (2019)



Structure of the link:

- **Source encoder:** removes redundancy (speech or video compression).
- **Channel encoder:** adds redundancy for error detection and correction (convolutional, turbo, LDPC).
- **Interleaver:** spreads burst errors due to fades so the decoder sees scattered errors.
- **Modulator:** maps bits to a carrier waveform (GMSK, QPSK, OFDM), then **up-converter** and **power amplifier**.
- **Channel:** path loss, shadowing, multipath fading, Doppler, noise and interference.
- **Receiver:** LNA and down-converter, **demodulator** with equaliser, RAKE or diversity combiner, de-interleaver, channel decoder and source decoder.

GMSK: MSK is a continuous-phase FSK with modulation index $h = 0.5$. In GMSK the NRZ data is first filtered by a **Gaussian low-pass filter** with transfer function $H(f) = e^{-(\ln 2/2)(f/B)^2}$ before the FM modulator.

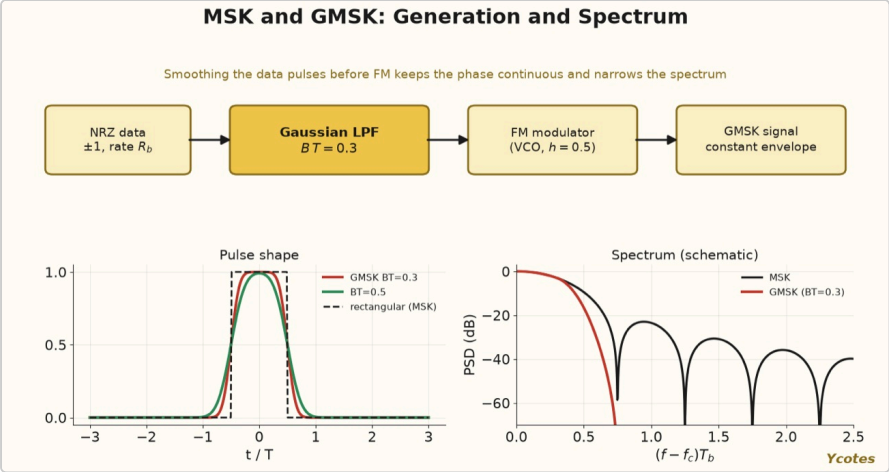


- The product BT (filter 3 dB bandwidth times bit time) controls the spectrum; GSM uses $BT = 0.3$.
- Smoother frequency pulses give very low side lobes (good adjacent channel performance).
- The envelope is constant, so efficient nonlinear class-C amplifiers can be used.
- The price is a controlled ISI and a loss of about 1 dB in BER compared with MSK; detection can be coherent or differential.

OFDM principle: one wideband stream is split into N orthogonal narrowband subcarriers with spacing $\Delta f = 1/T_u$, generated by an IFFT and demodulated with an FFT. Each subcarrier sees flat fading and is equalised by one tap. A cyclic prefix longer than the delay spread removes ISI and ICI. Advantages: robustness to multipath, spectral efficiency; disadvantage: high PAPR.

Q2. Describe Gaussian Minimum shift Keying. Differentiate between QPSK and MSK. (Feb 2024)

Gaussian minimum shift keying (GMSK) is a constant-envelope, continuous-phase digital FM scheme derived from MSK by passing the data through a Gaussian pre-modulation filter. The Gaussian filter has impulse response $h(t) \propto e^{-t^2/(2\sigma^2)}$, and BT is its normalised bandwidth.



Generation: NRZ data ± 1, Gaussian filter, FM modulator (VCO) with deviation giving $h = 0.5$, producing

$$s(t) = A\cos\left[2\pi f_c t + \phi(t)\right], \quad \phi(t) = \pi h \int_{-\infty}^{t} g(\tau)\, d\tau$$

Properties: the smaller BT, the narrower the spectrum but the more ISI. GSM uses $BT = 0.3$, which keeps out-of-band power below -60 dB. Detection: coherent or differential, usually with an equaliser.

MSK: CPFSK with $h = 0.5$, the two frequencies differ by $1/(2T_b)$, phase changes by $\pm\pi/2$ per bit, so phase is continuous and the envelope constant.

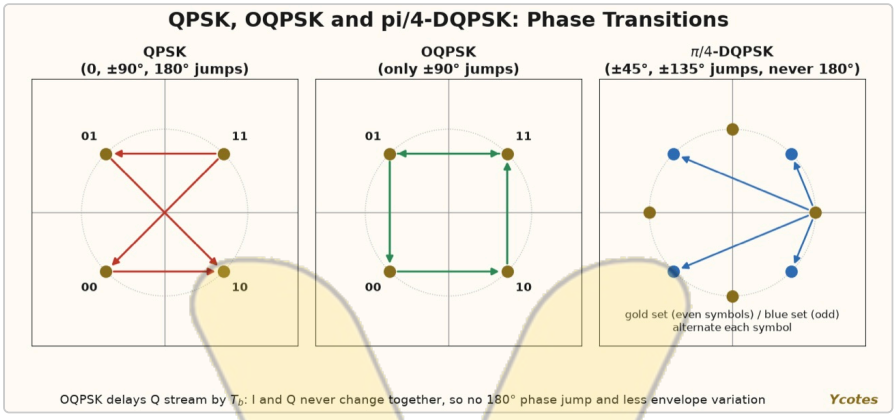
QPSK	MSK
Phase jumps of 0, 90, 180 degrees	Continuous phase, no jumps
Envelope fluctuates after filtering	Constant envelope
Narrow main lobe (rate $1/2T_b$) but high side lobes	Wider main lobe (about 1.5 times), lower side lobes
Needs linear amplifier	Works with nonlinear amplifier
Same BER, $Q(\sqrt{2E_b/N_0})$	Same BER with coherent detection
Linear modulation	Nonlinear modulation (can be seen as OQPSK with sinusoidal pulse)

Conclusion: MSK is a good compromise for power-efficient mobile systems, and GMSK improves it further for spectral efficiency.

Q3. Write a short note on DQPSK (pi/4-DQPSK). (2025)

DQPSK is differential QPSK: the information is carried in the **phase difference** between successive symbols, not the absolute phase. So the receiver can use differential detection without carrier phase recovery, which is robust in fading.

pi/4-DQPSK: the constellation is shifted by 45 degrees alternately each symbol, using two QPSK constellations (0, 90, 180, 270 and 45, 135, 225, 315 degrees).



Phase changes: the dibit $00, 01, 11, 10$ corresponds to $+\pi/4, +3\pi/4, -3\pi/4, -\pi/4$. Since the possible changes are only $\pm 45^\circ$ and $\pm 135^\circ$, there is **never a 180 degree jump**, so the envelope never goes through zero and is less variable than QPSK (but more than OQPSK).

Features:

- Symbol rate half the bit rate, same bandwidth as QPSK
- Works with non-coherent (differential or FM discriminator) detection, so simple receivers
- Not constant envelope, but tolerates nonlinear amplifiers better than QPSK
- BER about 3 dB worse than coherent QPSK when differential detection is used

Applications: North American IS-136 (digital AMPS), Japanese PDC and TETRA.
