OFDM

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OFDM

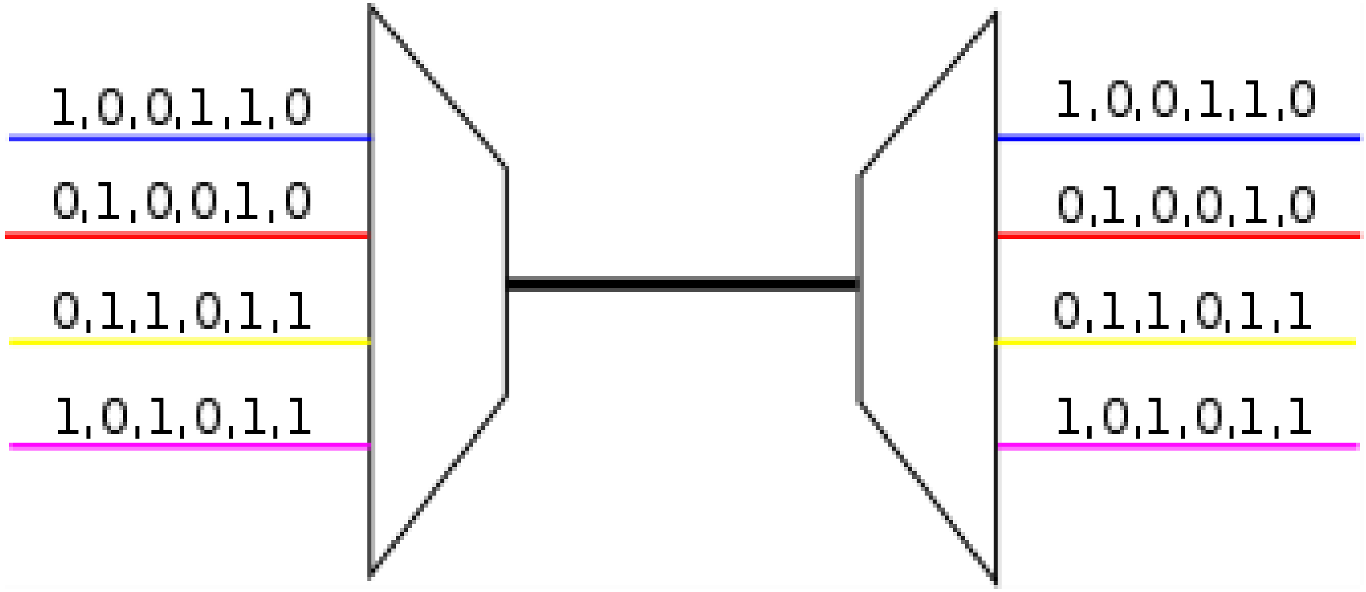
Orthogonal Frequency-division Multiplexing

OFDM

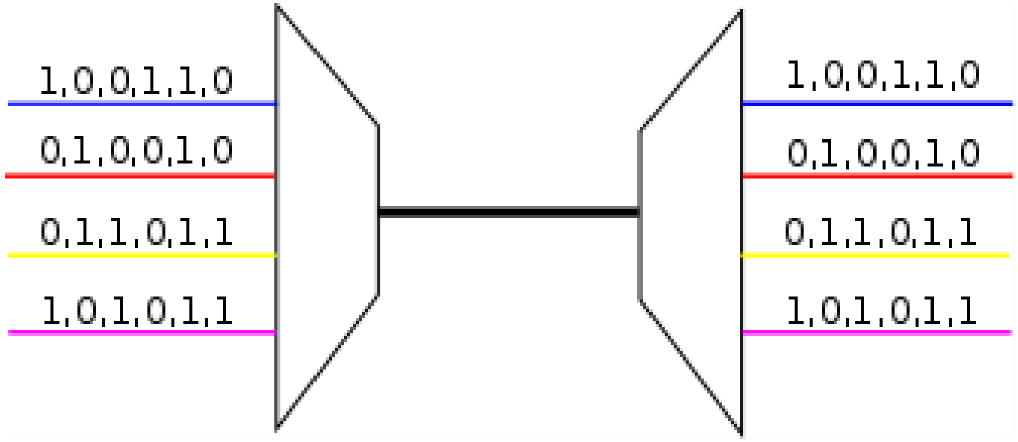
- Orthogonal?
- Frequency-division multiplexing?

OFDM: Transmit independent streams

Let’s observe the following problem: transmit and receive independent streams of data through a channel



OFDM: Transmit independent streams



- Orthogonality: Allows the receiver to separate the original subchannels and recover the bits without error (ideally)
- FDM: The subchannels occupy different frequencies, which allows multiplexing

How is it done?

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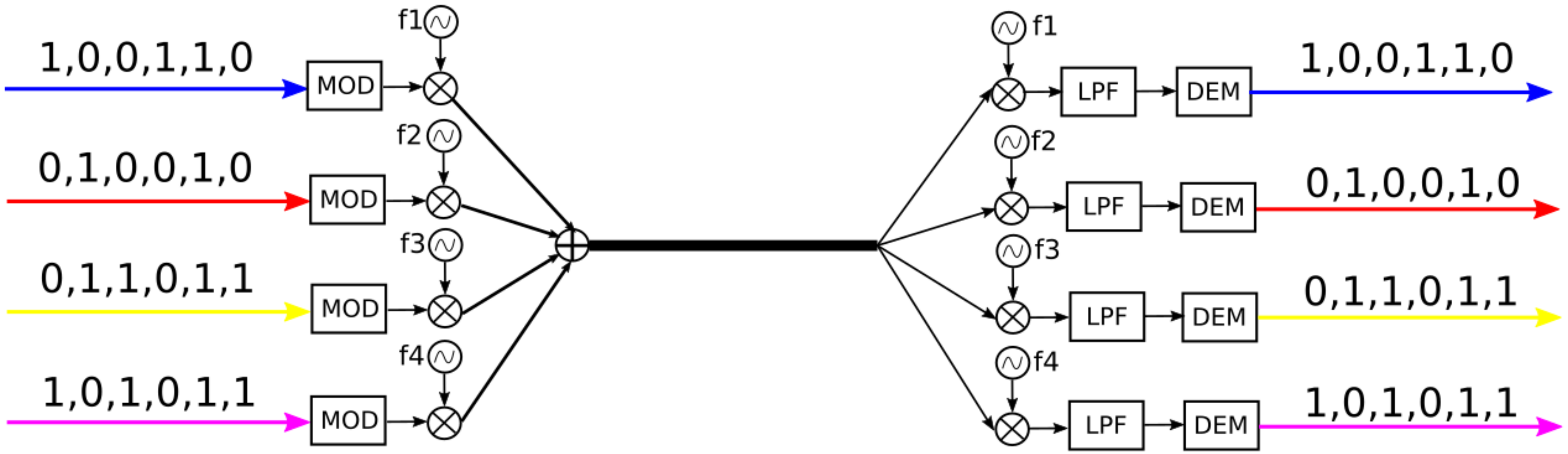
FDM system block diagram



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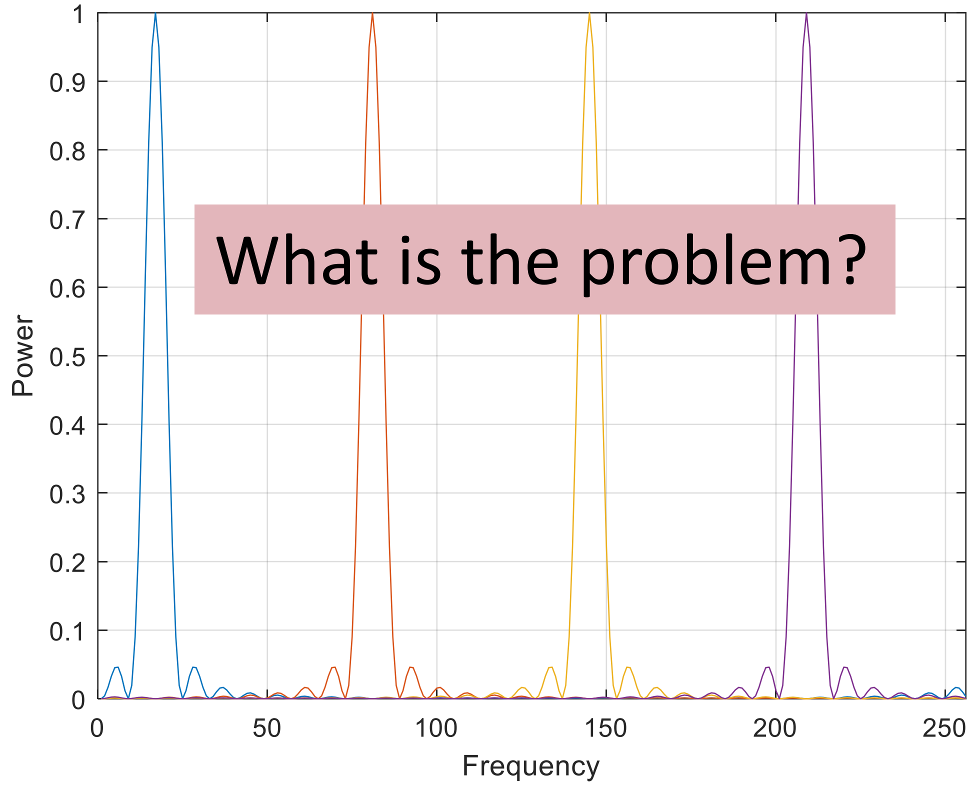
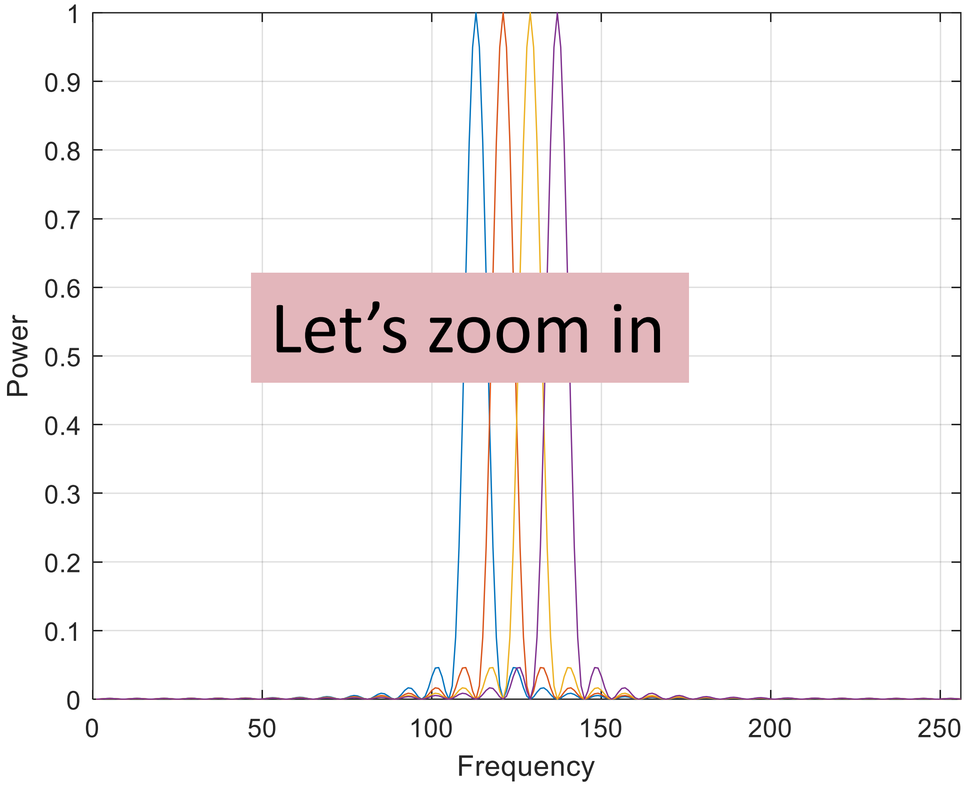
OFDM: Approach 1

Approach 1: Separate frequencies to minimize interference.



OFDM: Approach 2

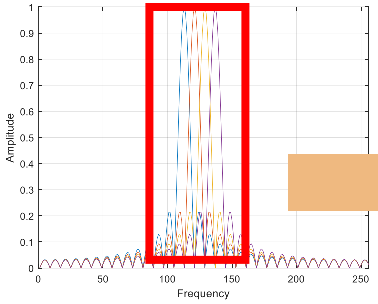
Approach 2: For a given frequency separation, the subcarriers do not interfere -> orthogonality.

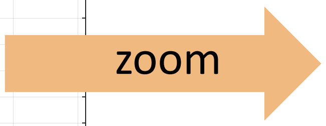


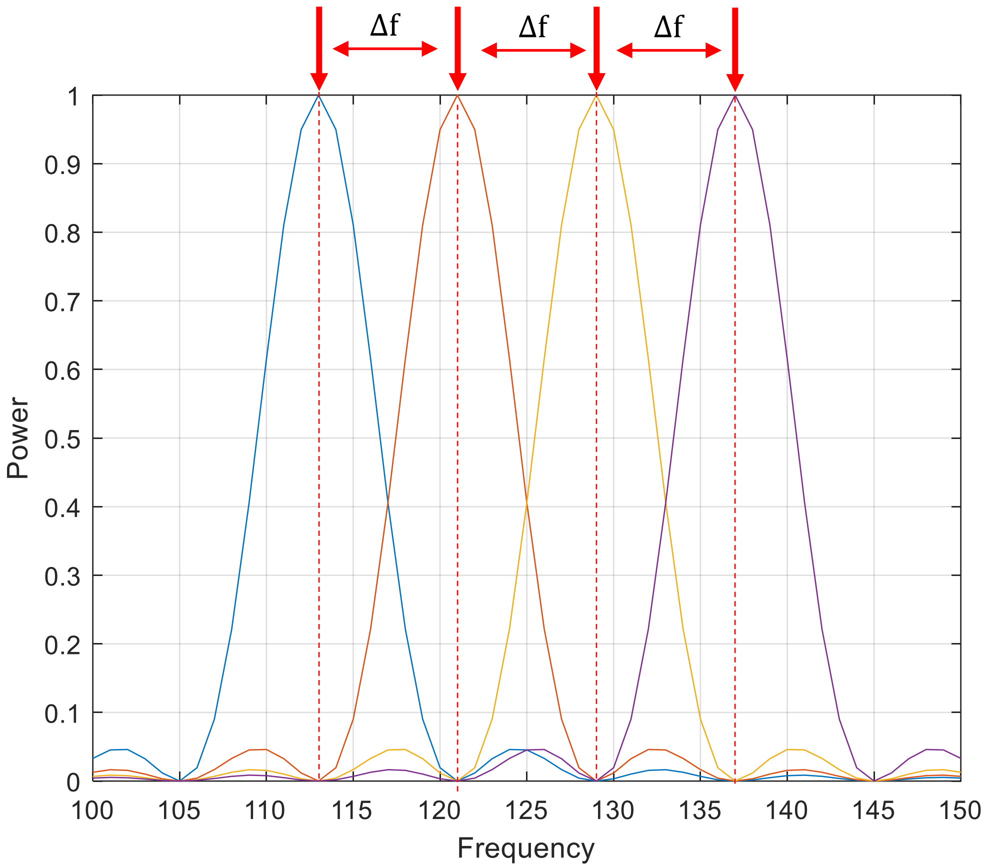
Let’s zoom in

OFDM: Approach 2

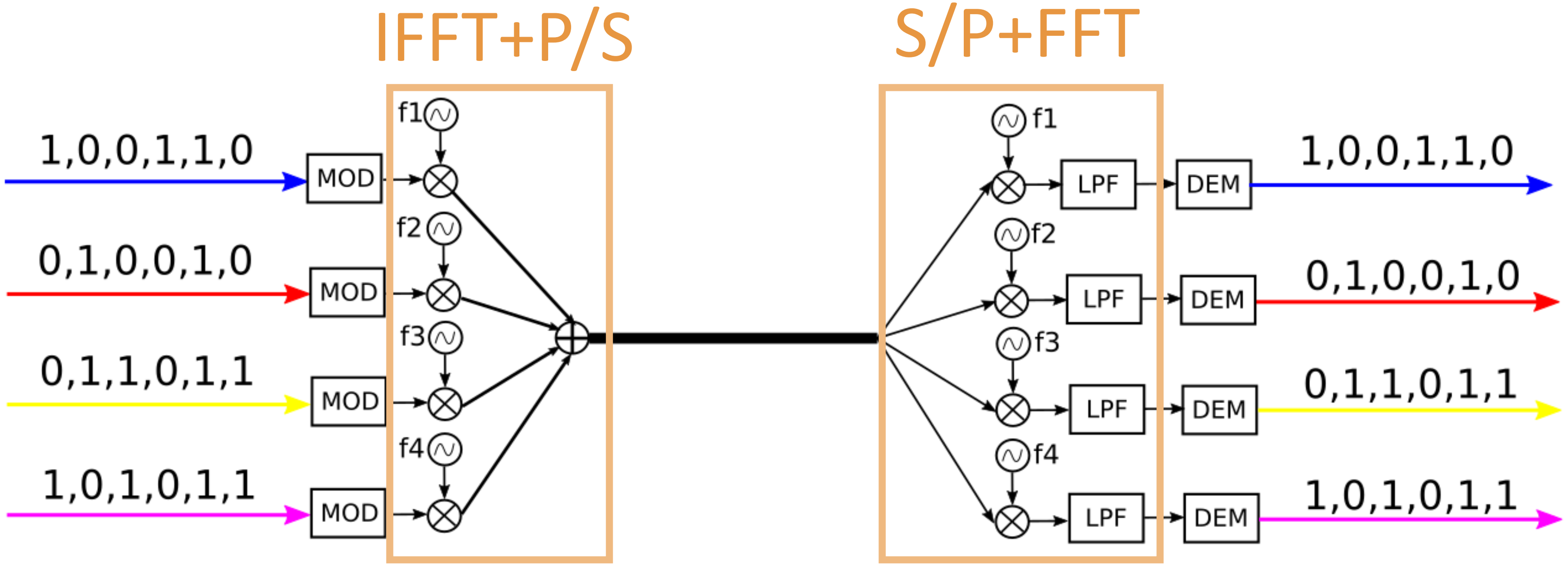
If we sample at the peak position then no interference!







OFDM: Block diagram



How can it be efficiently done?

P/S: Parallel-to-serial
S/P: Serial-to-parallel

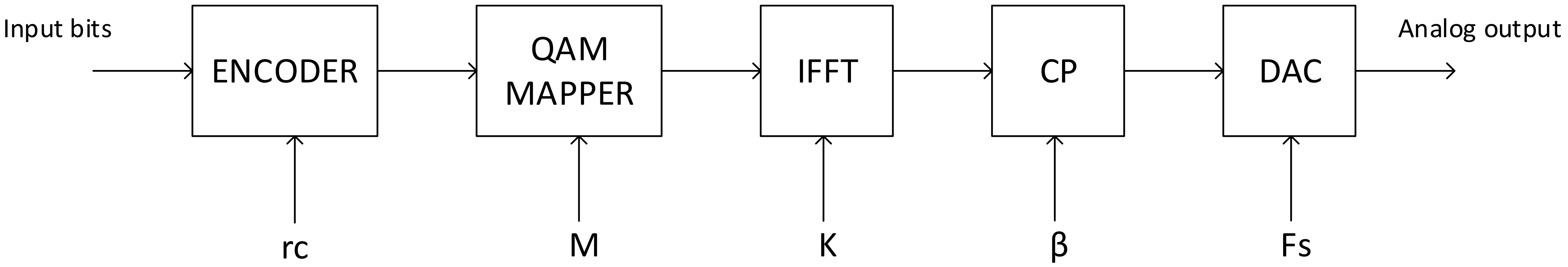
OFDM: Considerations

- One complex symbol from each data stream forms the input of IFFT (frequency samples).
- Samples obtained after FFT (time samples), serialized and transmitted through the channel.
- Same amount of frequency and time samples.

What if I need to transmit more symbols?

Compute IFFTs successively

OFDM Transmitter



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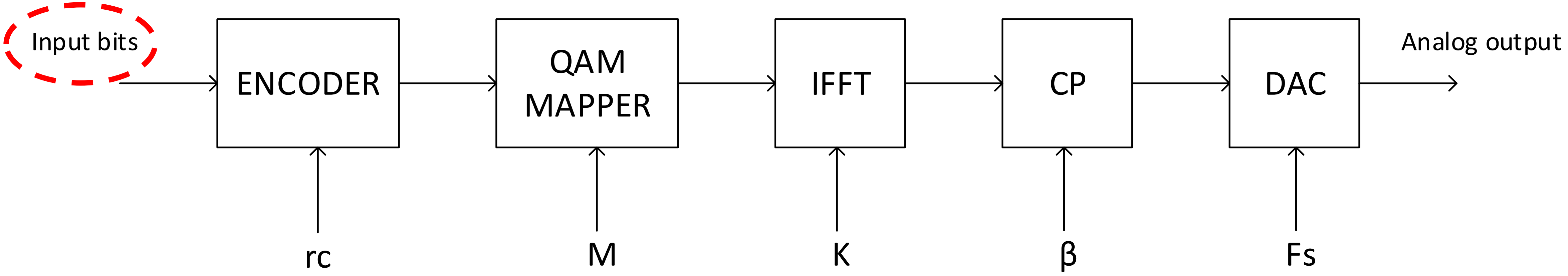
OFDM Transmitter



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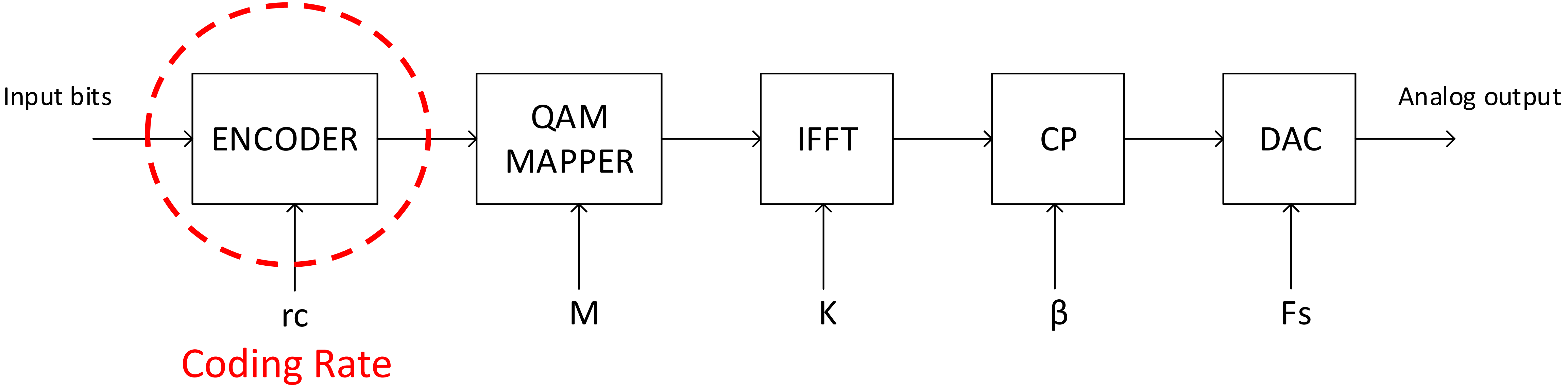
OFDM Transmitter



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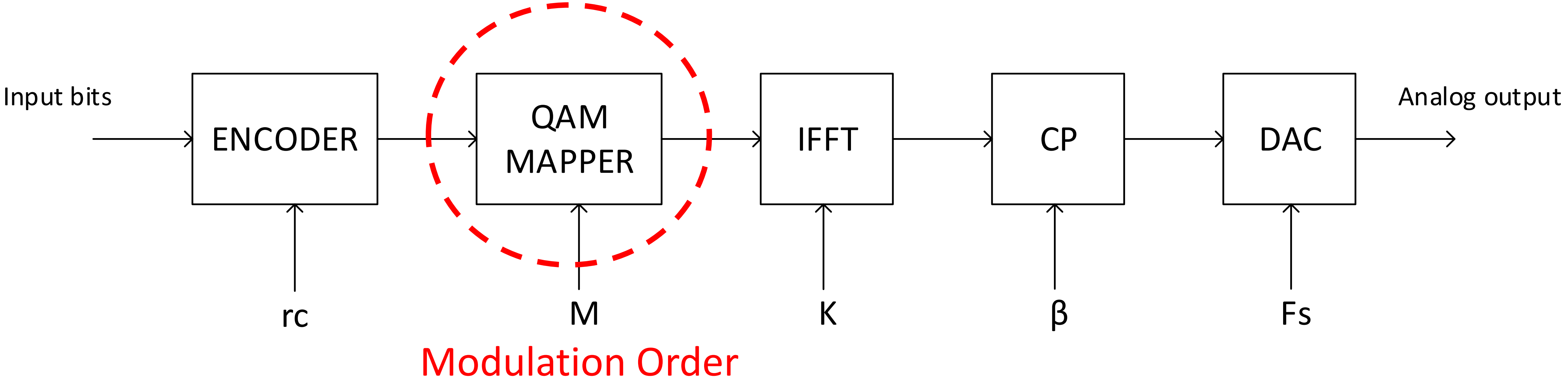
OFDM Transmitter



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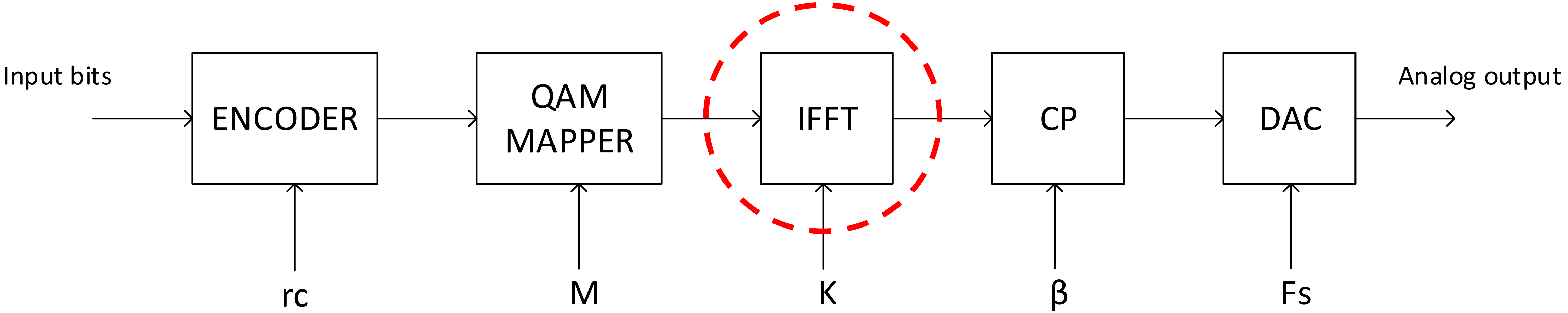
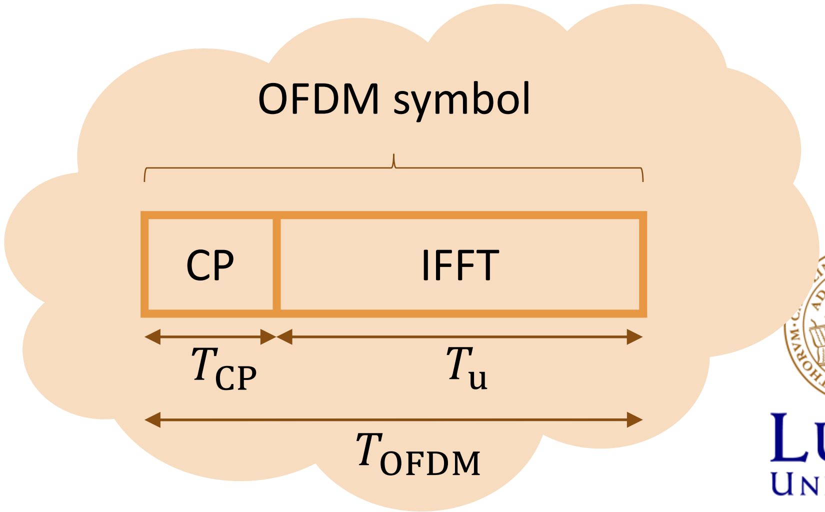
OFDM Transmitter



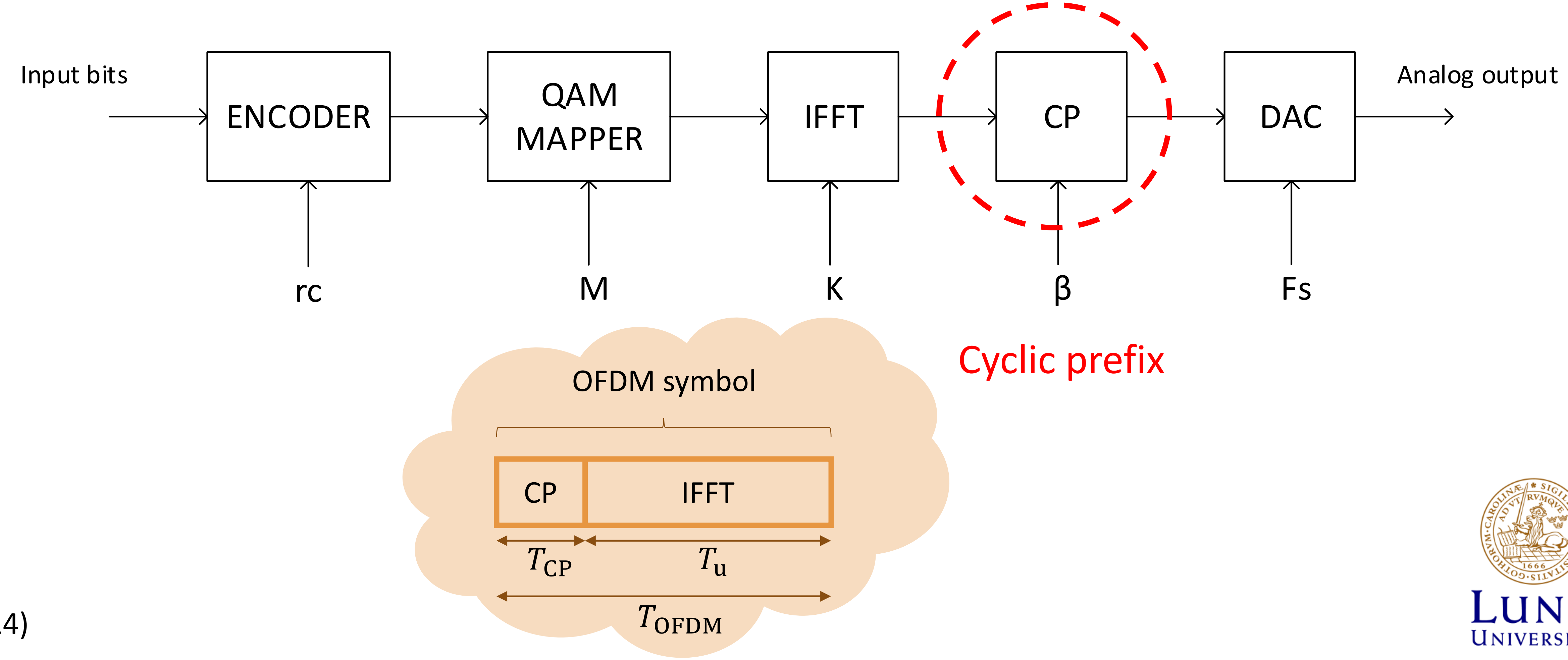
Number of subcarriers

$BW = K\Delta_f$

$T_u = \frac{1}{\Delta_f}$



OFDM Transmitter



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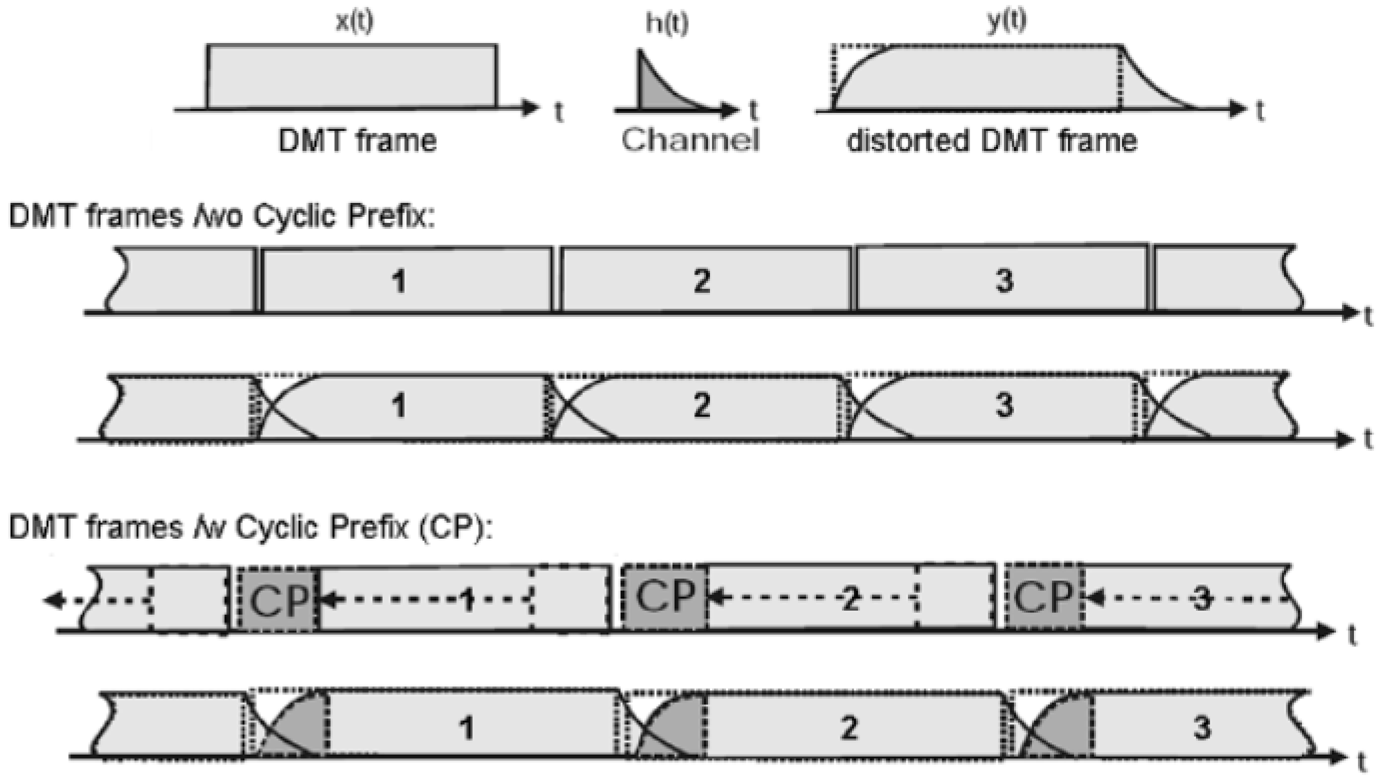
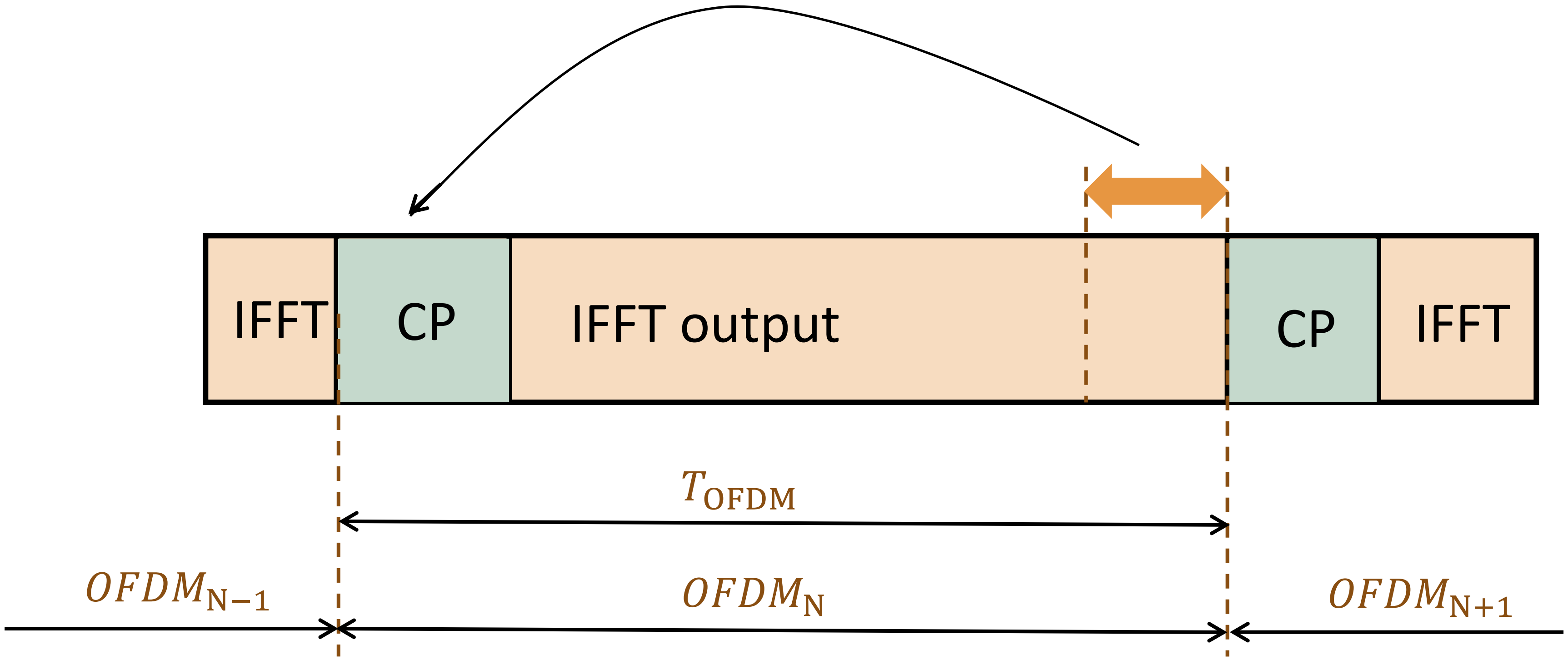
Cyclic Prefix



Combating multipath dispersion using cyclic prefix (CP).

Lee, S. & Breyer, F. & Randel, S. & Boom, Henrie & Koonen, A.. (2020). Orthogonal frequency division multiplexing over multimode optical fibers.

Cyclic Prefix



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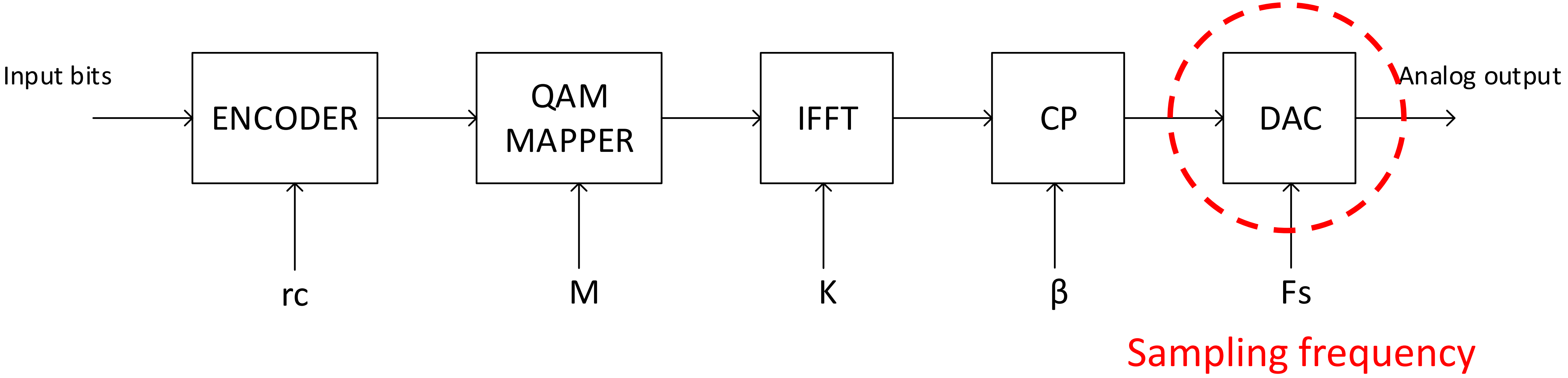
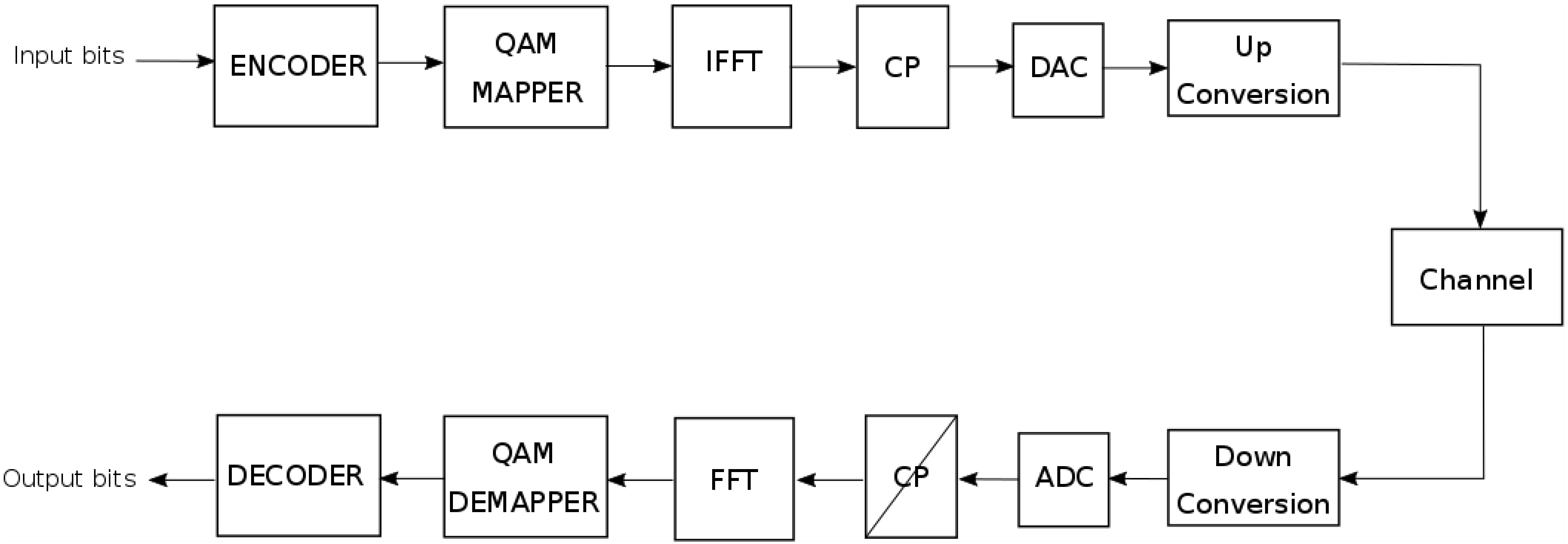
OFDM Transmitter



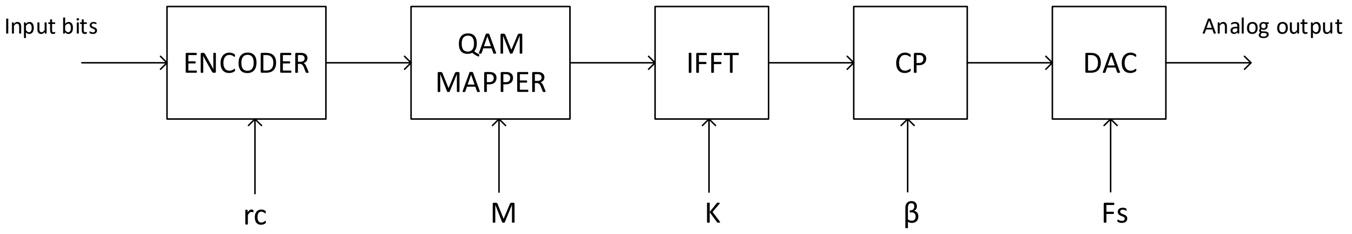
$$T_{OFDM} = N_{OFDM}\, T_S = \frac{N_{OFDM}}{F_S}$$

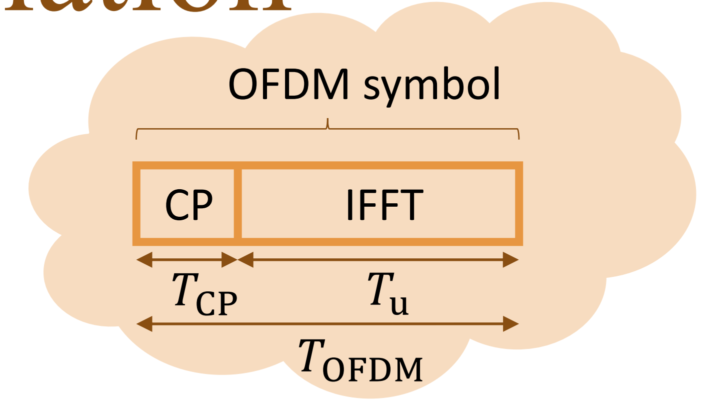
OFDM System



Note: FFT and IFFT include S/P and P/S.

OFDM: Throughput calculation





Throughput: Information bits per second

1) Encoded bits in an OFDM symbol:

$$Enc.bits_{\mathrm{OFDM}} = K\log_2(M)$$

[if all subcarriers have same order, what if not?]

K: active subcarriers

2) Information bits in an OFDM symbol:

$$Bits_{\mathrm{OFDM}} = r_{\mathrm{c}}K\log_2(M)$$

3) Throughput:

$$R_{\mathrm{OFDM}} = \frac{r_{\mathrm{c}}K\log_2(M)}{T_{\mathrm{OFDM}}}$$

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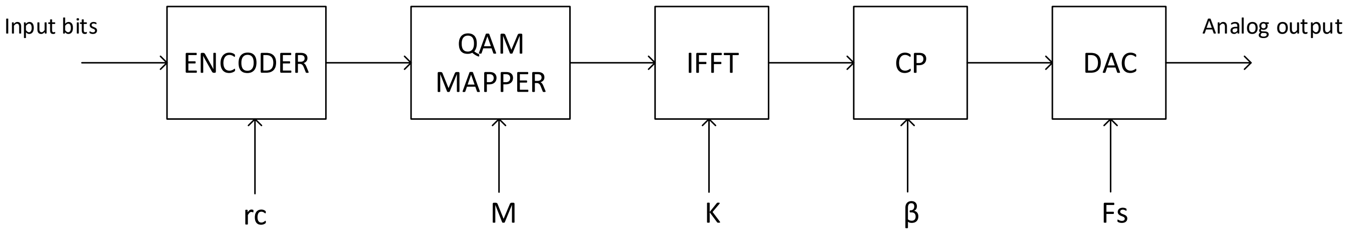
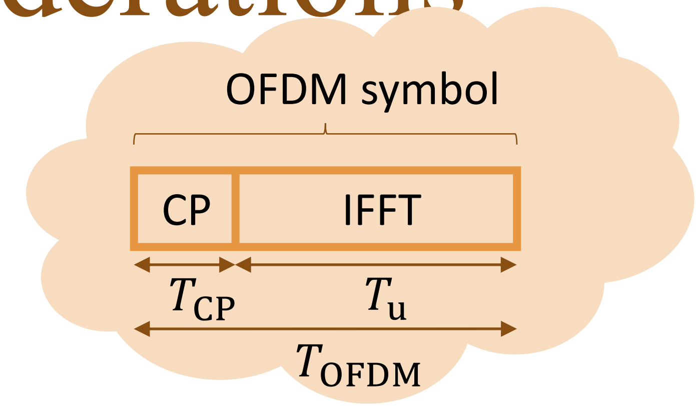
OFDM: Throughput considerations





$$R = \frac{r_c K \log_2(M)}{T_{\text{OFDM}}}$$

$$T_{\text{u}} = 1/\Delta_{\text{f}}$$

- What is the effect of encoding in the throughput?
  Less redundancy increases the throughput. Drawback?
- What is the effect of K?
  Enabling more subcarriers increases throughput.
- What is the effect of M?
  Increasing modulation order increases throughput. Drawback?
- What is the effect of T_{CP}?
  Decreasing T_{CP} increases throughput. Drawback?
- What is the effect of Δ_{f}?
  Increasing Δ_{f}, decreases T_{u}, which increases throughput. Drawback?
- What is the effect of F_s?
  Changing F_s changes T_{u} and therefore Δ_{f}. Potential issue?

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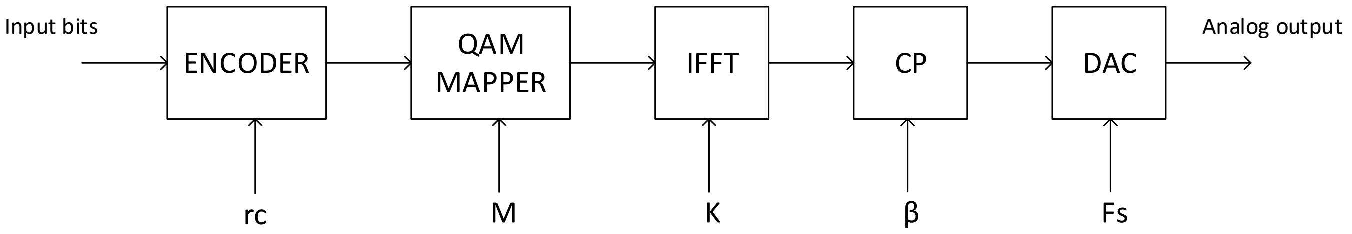
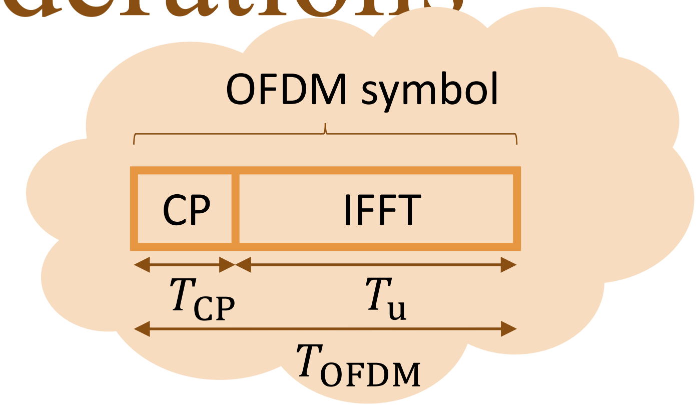
OFDM: Throughput considerations





How are throughput and BW related?

If T_{OFDM} and Δ_{f} are constant, both are proportional to K.

- What if K is constant and Δ_{f} changes?

  BW_{OFDM} changes proportionally, but not R_{OFDM} (why?)

$$T_{\mathrm{OFDM}} = T_{\mathrm{CP}} + T_{\mathrm{u}} = T_{\mathrm{CP}} + \frac{1}{\Delta_{\mathrm{f}}}$$

- What if T_{CP}=0?

  Both are linearly proportional.

$$R = \frac{r_{\mathrm{c}} K \log_2(M)}{T_{\mathrm{OFDM}}}$$

$$BW_{\mathrm{OFDM}} = K\Delta_{\mathrm{f}}$$

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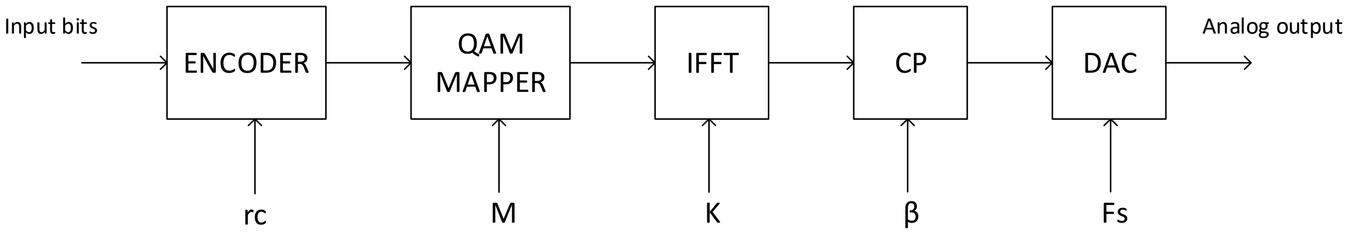
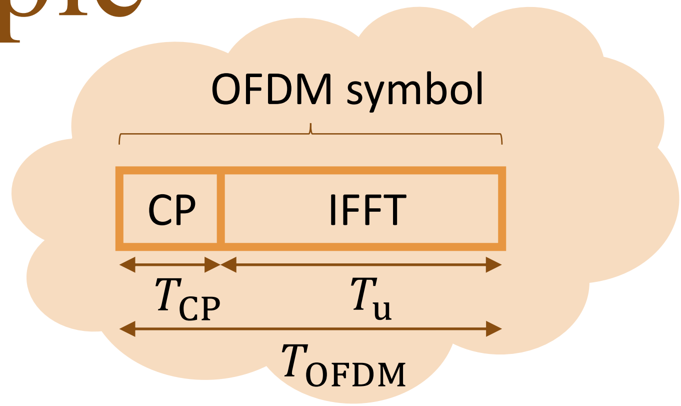
OFDM: Throughput example





LTE example:

- r_c = 1/3
- K = 1200
- M = 16
- Δ_f = 15KHz
- T_{CP} = 5us

R and BW?

$$R = \frac{r_c K \log_2(M)}{T_{OFDM}}$$

$$BW_{OFDM} = K\Delta_f$$