EEN 1043/EE452 Wireless and Mobile Communication

Multiplexing

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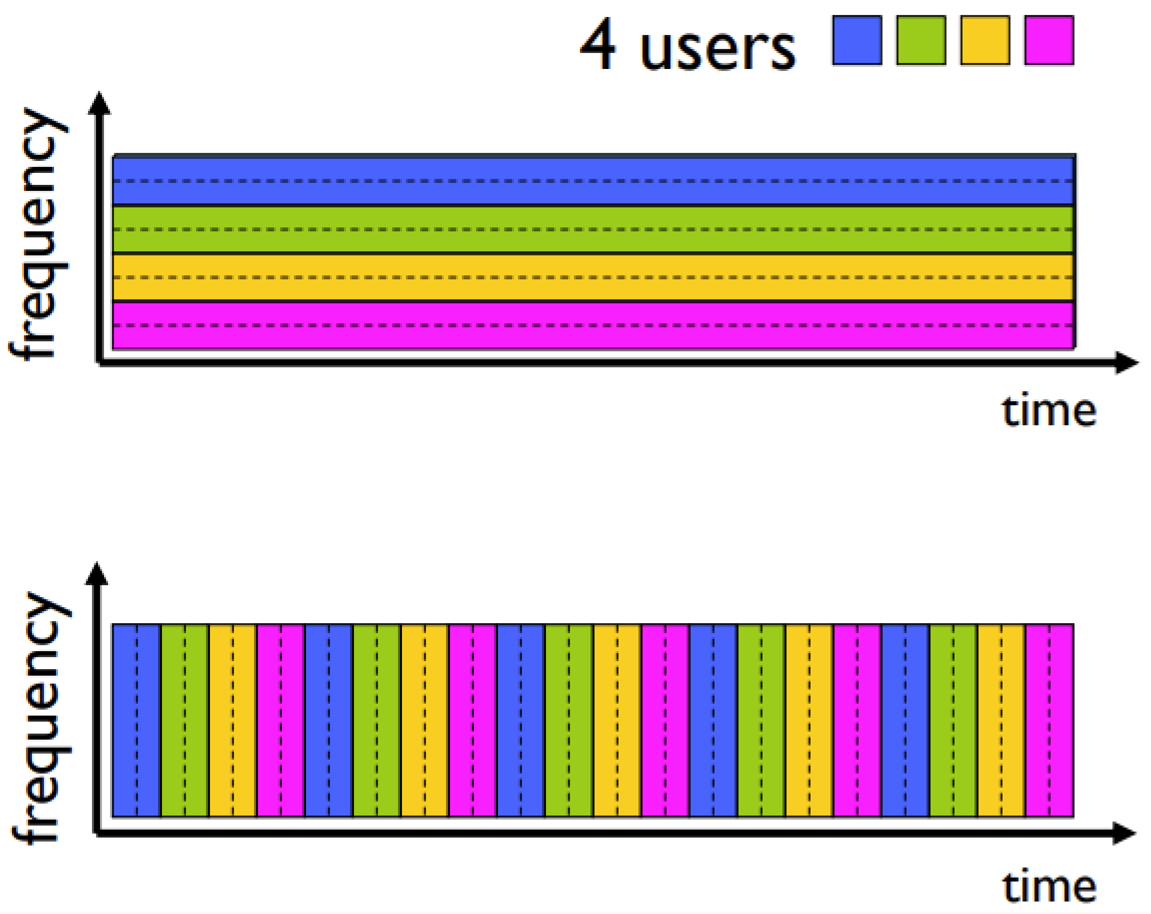
Multiplexing

- Capacity of the transmission medium usually exceeds the capacity required for a single signal
- Single signal can never occupy the whole medium
- Thus, sharing is necessary
- Since the spectrum is huge multiplexing is a must for wireless 3

Multiplexing enables multiple signals to share the same transmission medium

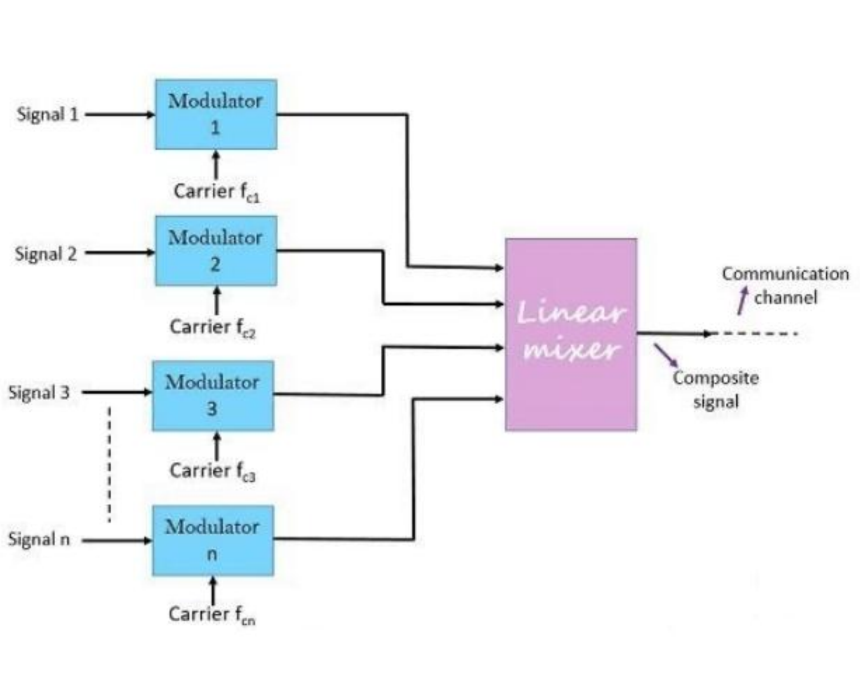
Multiplexing

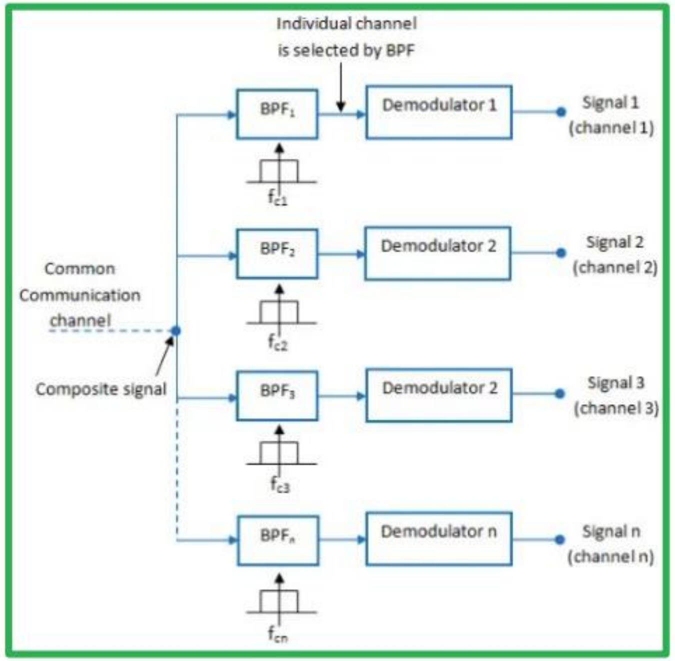
- Frequency Division Multiplexing (FDM)
  - optical, electromagnetic frequencies divided into (narrow) frequency bands
  - each call allocated its own band, can transmit at max rate of that narrow band
- Time Division Multiplexing (TDM)
  - time divided into slots
  - each call allocated periodic slot(s), can transmit at maximum rate of (wider) frequency band (only) during its time slot(s)



FDM

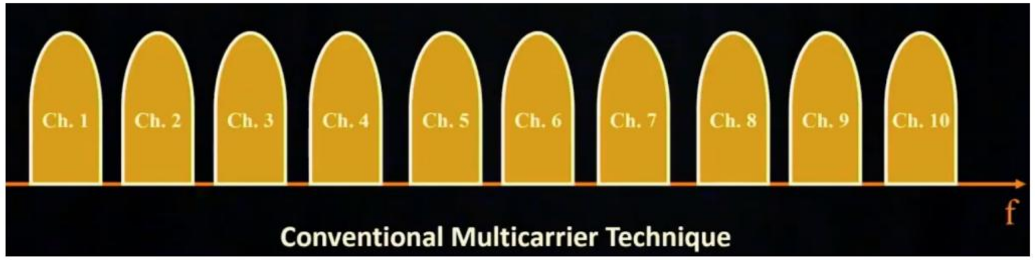
Sender gathers each signal from a different user, modulates each with a different frequency, add them all up, and transmit





Receiver uses band pass filters (BFP) to filter out non relevant frequency band and modulate each to separate out each signal

In FDM it is important to have guard band in between so that it's easier to separate each channel



OFDM

- Orthogonal Frequency Division Multiplexing (OFDM) employs both modulation and multiplexing
- Modulation: mapping information (bits) to changes in the carrier phase, frequency, and/or amplitude
- Frequency Multiplexing: method of sharing a frequency bandwidth among independent data channels

OFDM

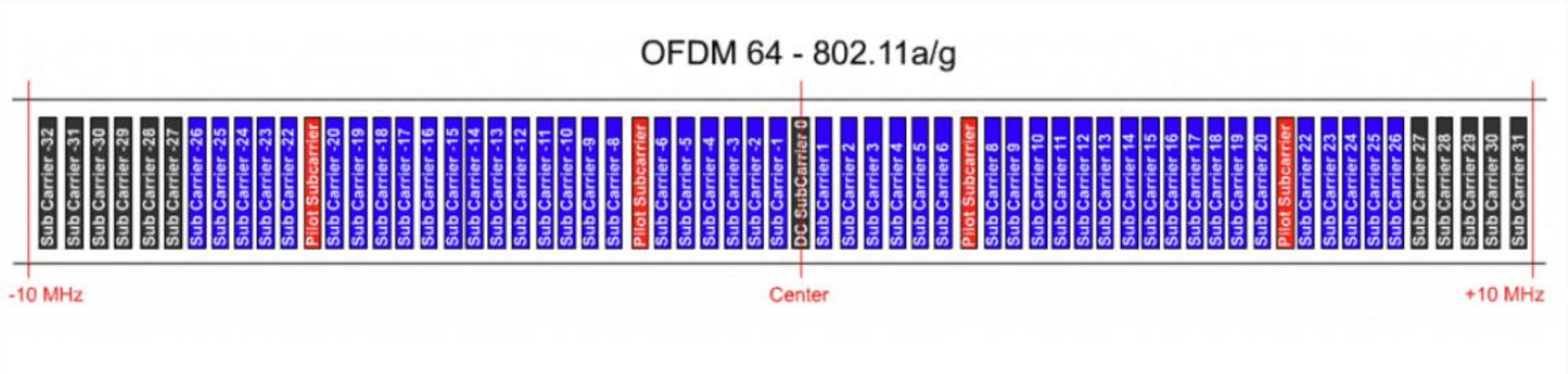
- OFDM serves single user not multiple users sharing
- OFDM “splits” one main signal into independent sub-signals to do multiplexing
- Sub-signals are orthogonal to each other

OFDM

- Used by a wide variety of systems
  - Cellular systems (3GLTE, WiMAX)
  - Wireless local area networks (LANs)
  - digital audio radio
  - underwater communications
  - optical light modulation
- Why so great?
  - Greater spectral efficiency
  - Fights against inter-symbol interference
  - Resilient to multi-path distortion

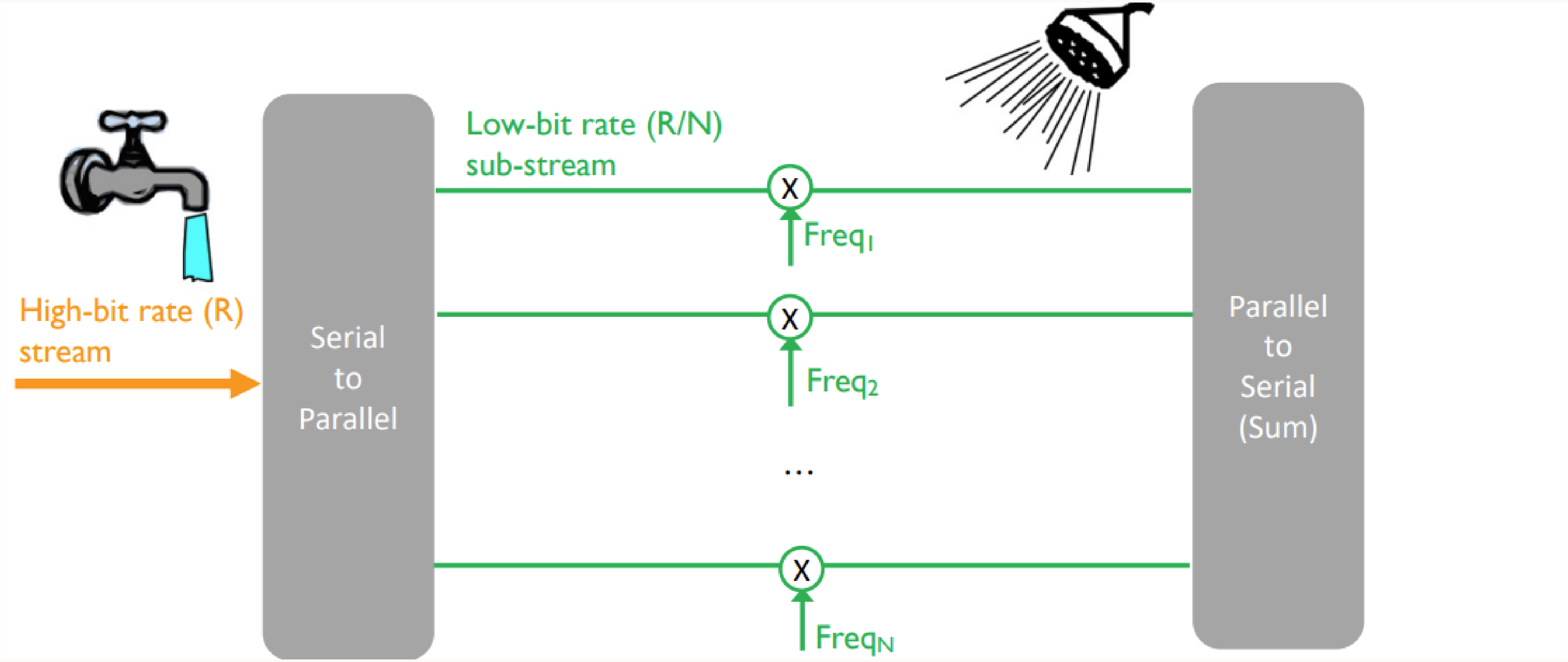
Subcarriers

- OFDM divides a frequency band into sub-band called subcarriers



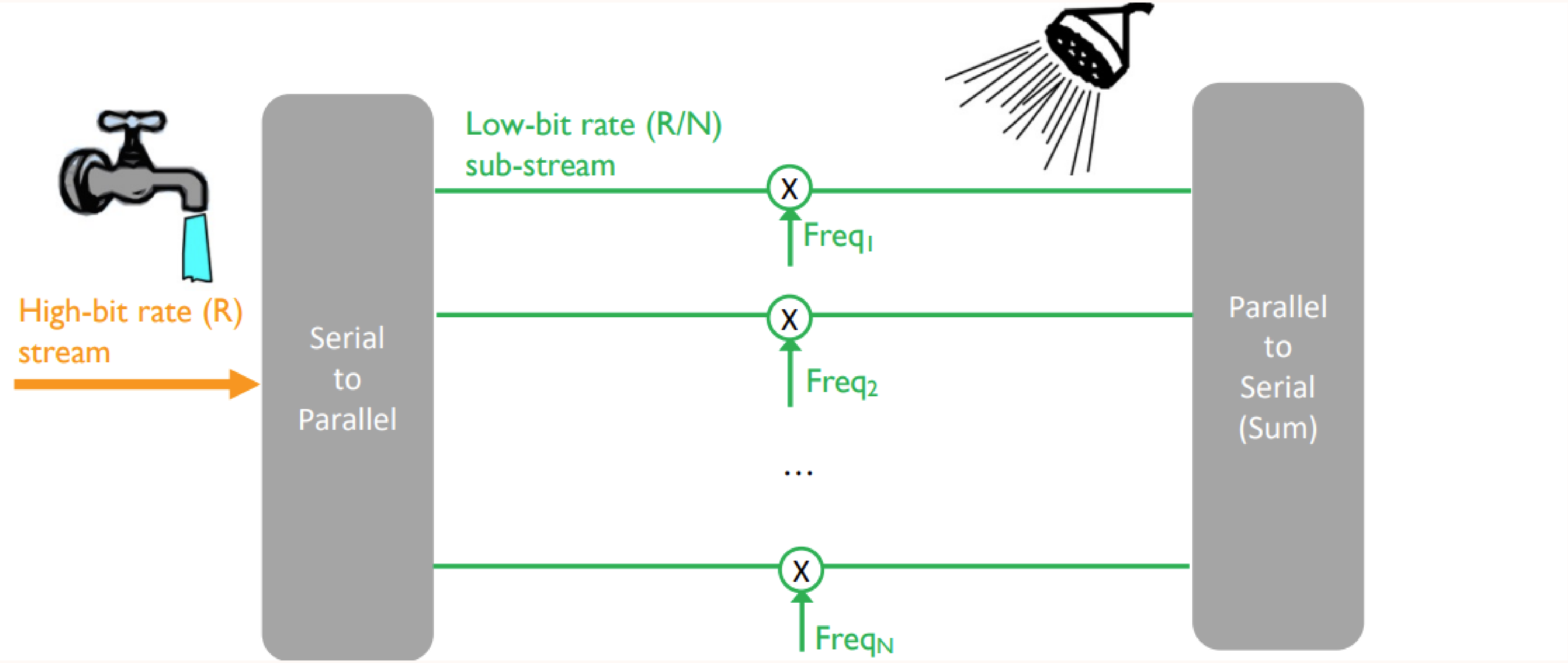
https://www.cs.utexas.edu/~mhan/courses/cs356r/sp23/lecture_notes/CS356R-03-11-PHY-OFDM.pdf

OFDM



- OFDM also splits user data stream into several sub-streams where each sub-streams sent in parallel on each subcarrier
- Each sub-stream of data is independent

OFDM



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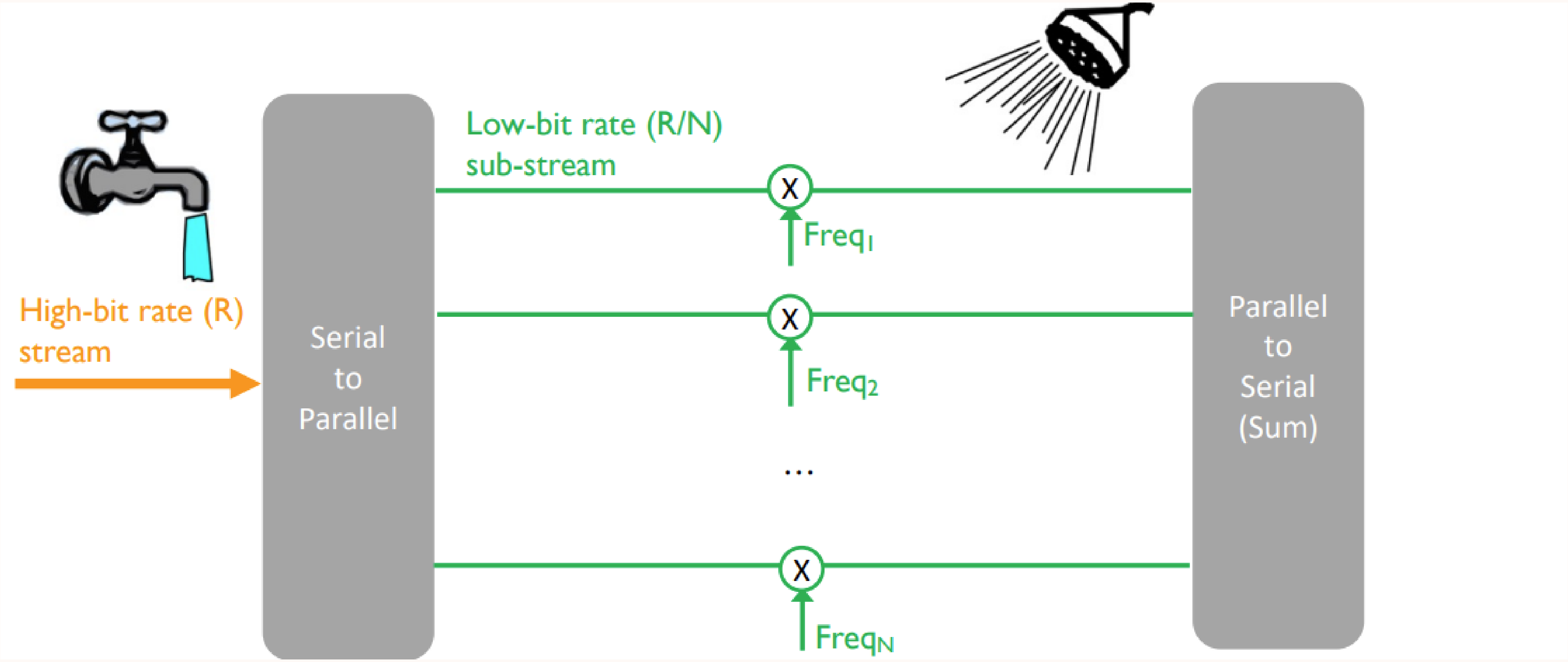
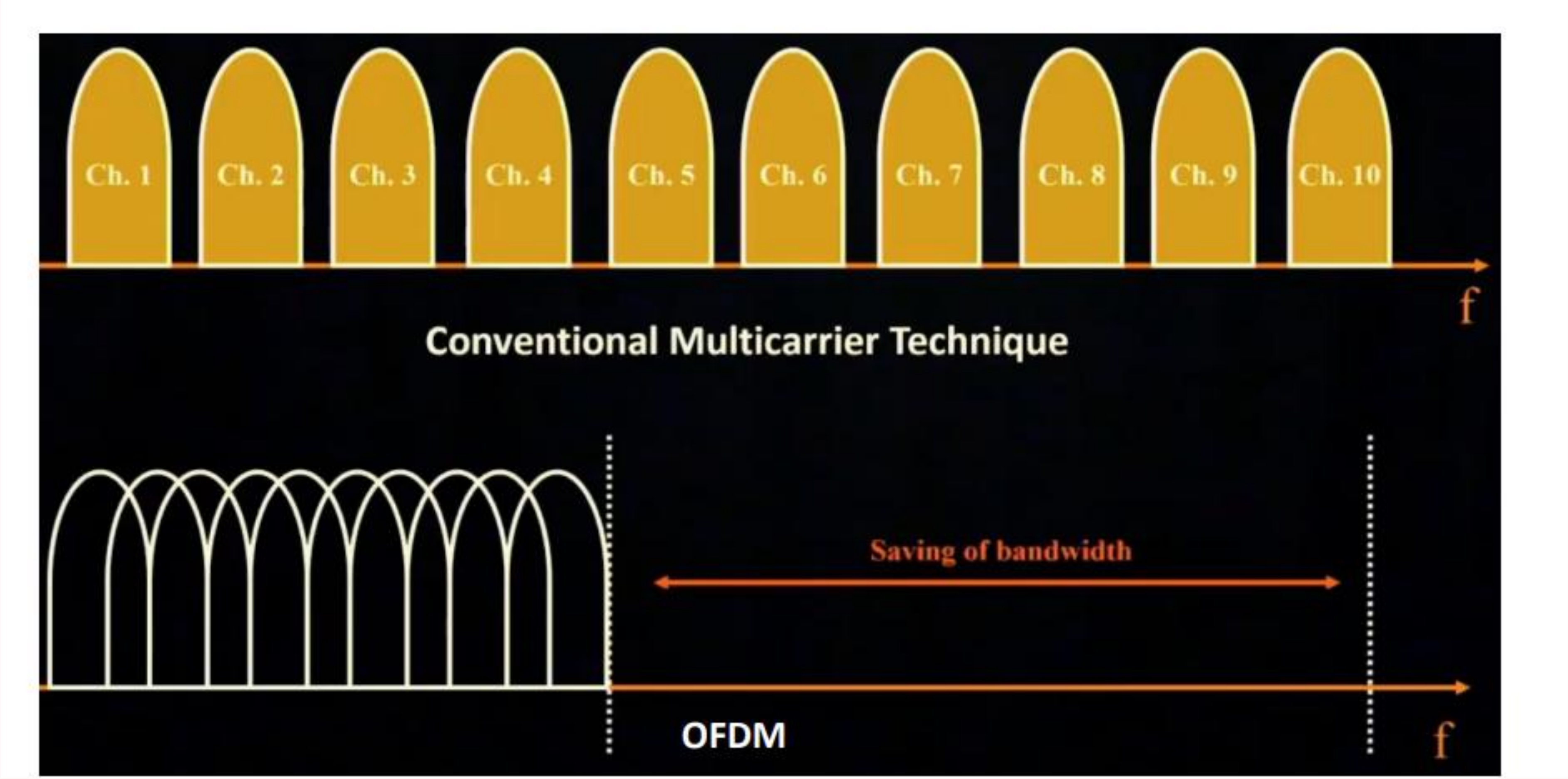
- Having lower bit rate in each carrier makes it less susceptible to frequency selective fading

OFDM



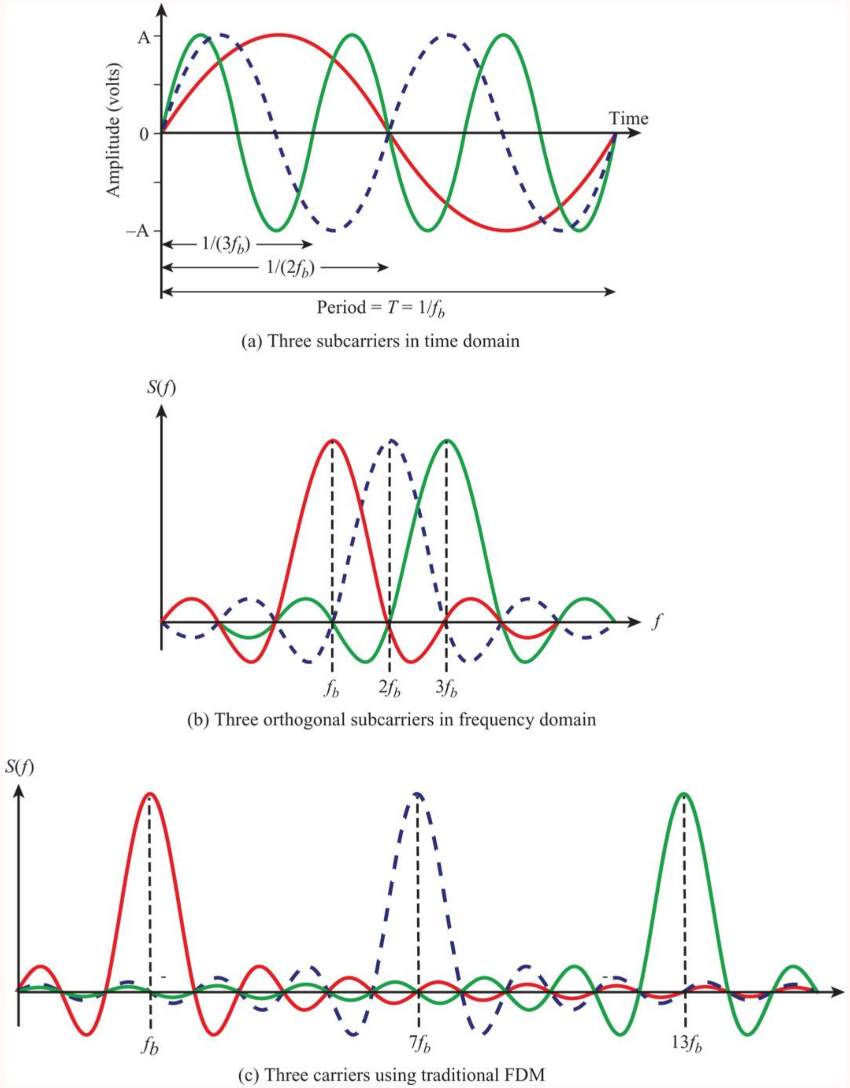
- OFDM also splits user data stream into several sub-streams where each sub-streams sent in parallel on each subcarrier
- For modulating each sub-stream BPSK, QPSK, 16QAM, 256 QAM can be used

FDM Vs OFDM Frequency Usage



OFDM Spectrum

- In OFDM we place each subcarrier as tightly spaced as possible resulting in much higher spectrum efficiency
- Spectral peaks of each subcarrier occurs at the zero crossings of all the other pulses!



ODFM Spectrum

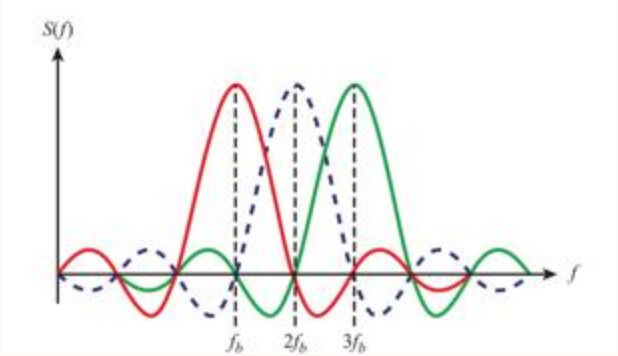
- Why each carrier is a sinc wave?
- Given a pulse (bit duration)

$$\boldsymbol{x(t)} = \begin{cases} \mathbf{1} & |\boldsymbol{t}| < \boldsymbol{T/2} \\ \mathbf{0} & \boldsymbol{else} \end{cases}$$

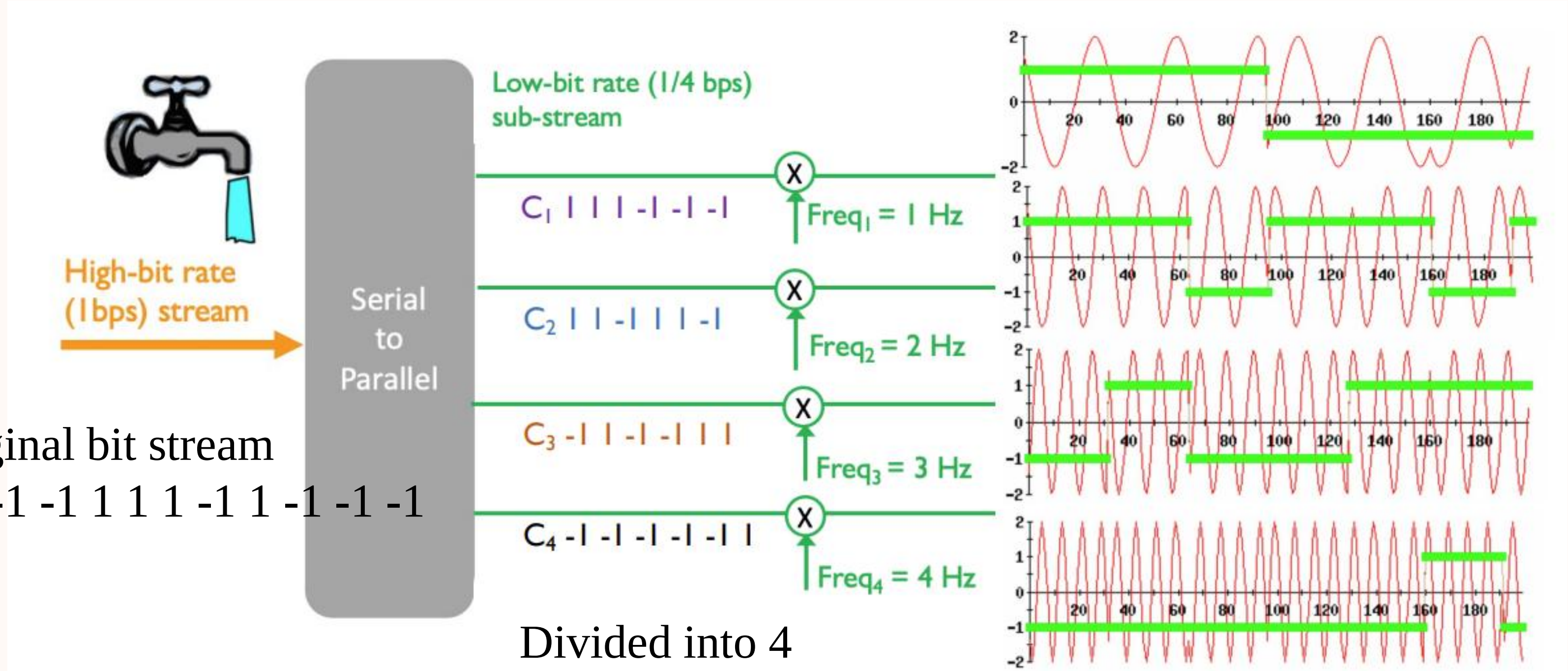
- The Fourier transform is

$$\boldsymbol{X(\omega)} = \int_{-T/2}^{T/2} \boldsymbol{e^{j\omega t}\, dt} = \boldsymbol{T}\frac{\boldsymbol{sin(\omega T/2)}}{\boldsymbol{(\omega T/2)}}$$

- Each subcarriers must be orthogonal to one another
- e^{iwt} are orthogonal to one another where w = k π/L
- f_b is the fundamental frequency and $2f_b$and $3f_b$ are its harmonics



OFDM



Original bit stream

1 1 -1 -1 1 1 1 -1 1 -1 -1 -1

Divided into 4 substreams

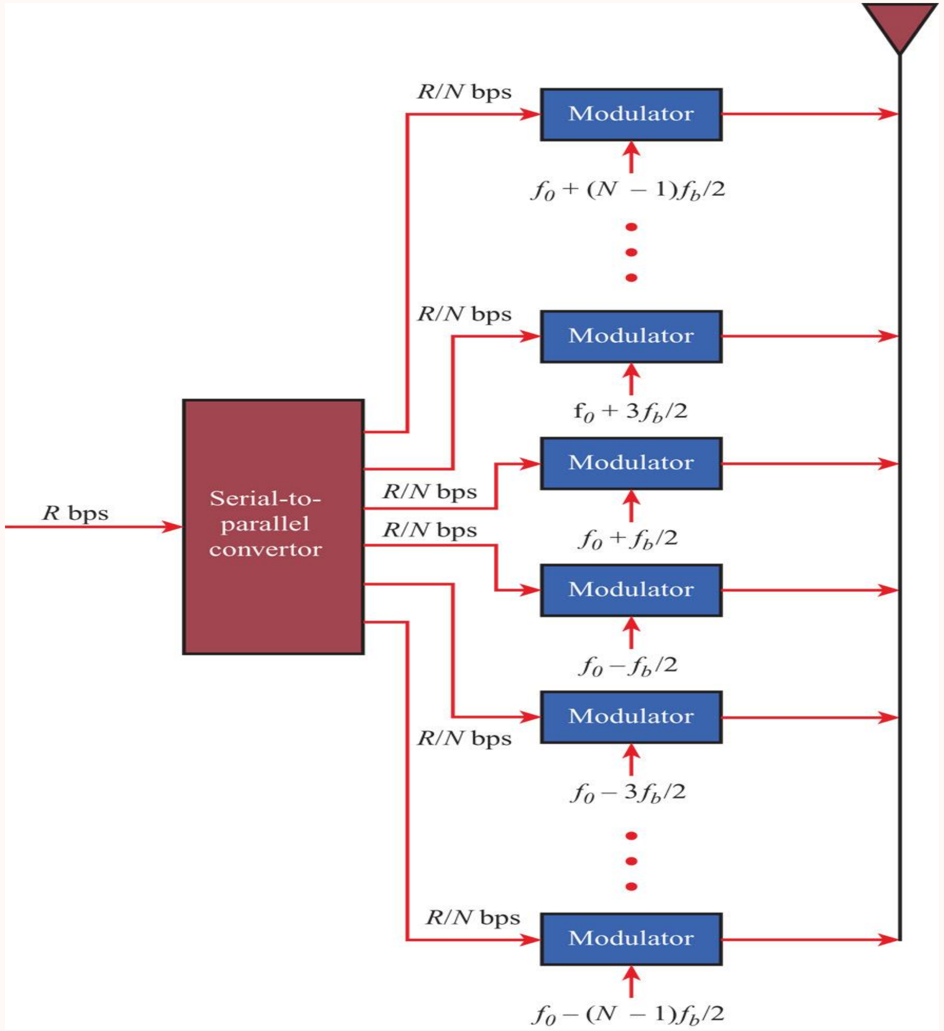
Let each bit to be modulated by subcarrier C_k be X_k, where $X_k \in$ {1, -1} Let T be the symbol time

$$x(t) = \sum_{k=1}^{4} X_k e^{\frac{jkt}{T}}$$

$$x(t) = \sum_{k=1}^{L} X_k e^{\frac{jkt}{T}} \text{ (Generalize)}$$

This is Inverse Discrete Fourier Transform

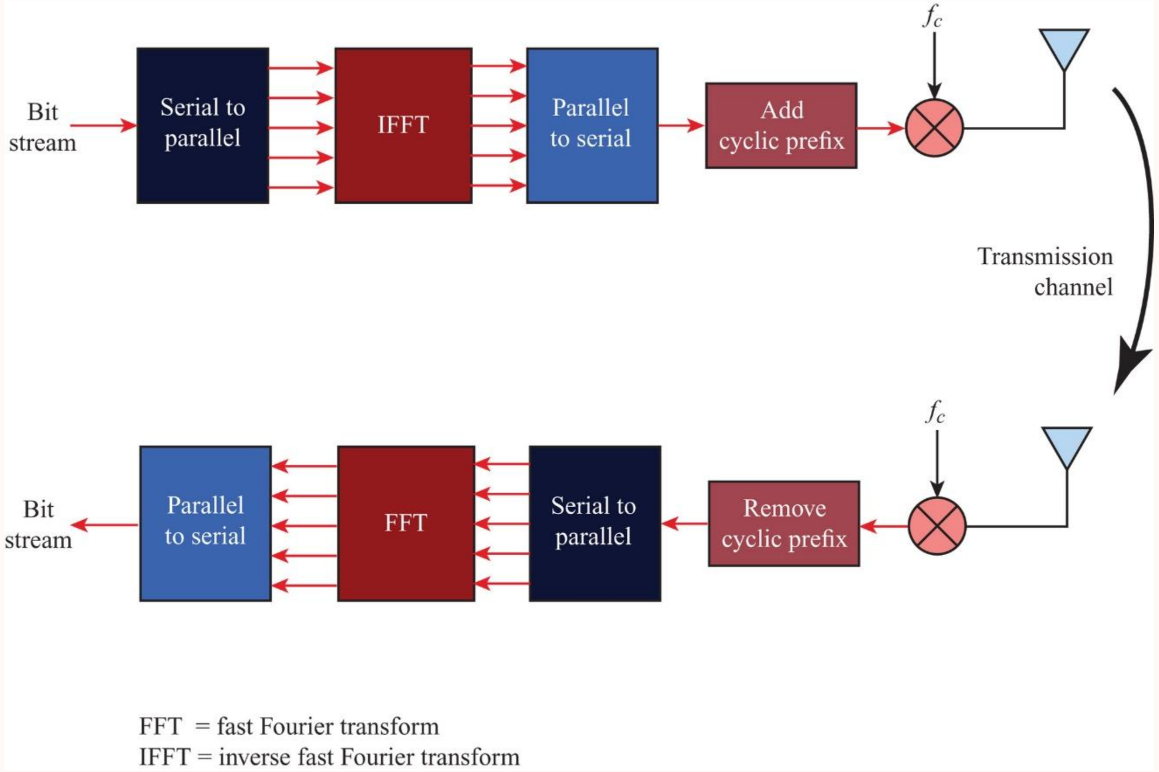
OFDM



R bps
Serial-to-parallel convertor
R/N bps
R/N bps
R/N bps
R/N bps
R/N bps
R/N bps
Modulator
Modulator
Modulator
Modulator
Modulator
Modulator
$f_0 + (N-1)f_b/2$
$f_0 + 3f_b/2$
$f_0 + f_b/2$
$f_0 - f_b/2$
$f_0 - 3f_b/2$
$f_0 - (N-1)f_b/2$

OFDM Implementation

- Note that it would be impractical to implement OFDM as originally presented.
  - Modulated onto N subcarriers.
- Implementation of OFDM is aided by the use of the Fast Fourier Transform (FFT).
- Observe that our OFDM symbol consists of a finite number of tones, and hence can be represented using a finite number of fourier coefficients.
  - Hence, we can use a discrete fourier transform representation
  - This is good because we can generated the signal using Inverse Fast Fourier Transforms (IFFT) which are easily implemented in hardware.

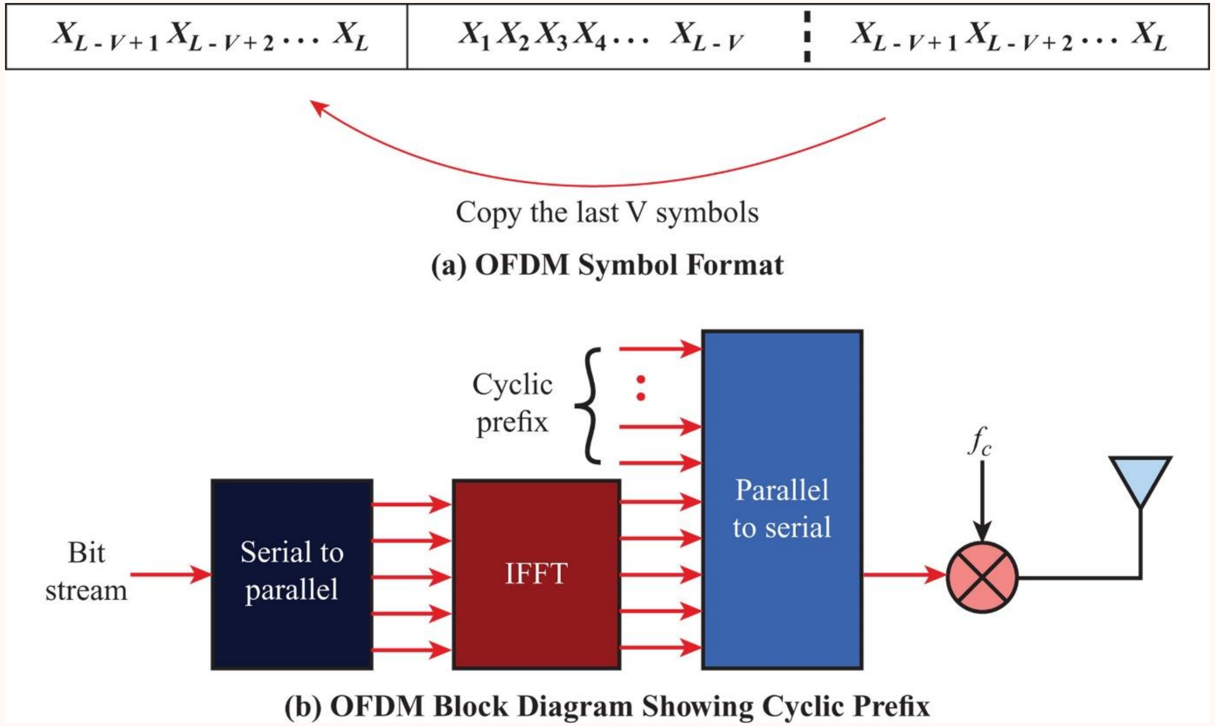


OFDM

- One factor complicating this picture is

  multipath delay.
  - Potentially, there is intersymbol interference –

    the overlap in the reception of the current and previous symbol.
  - To avoid this, a guard interval is added to the bit transmission
    - the guard interval signal is a cyclic prefix, or copy of the OFDM symbol.



(a) OFDM Symbol Format

(b) OFDM Block Diagram Showing Cyclic Prefix

OFDM

- Example 1
  - Given a 1000 tone system and a data stream with rate 1 Mbps (bit duration 1μsec)
    - We convert to 100 data streams rate 1 Kbps (bit duration 1msec)
    - Suppose we add a guard time of 1/8 symbol duration, or 125μsec
    - Interference can be avoided if the multipath time spreading is less than the guard time
      - Difference of 37.5 km between path lengths.

OFDM

- Example 2: LTE
  - 15kHz subcarriers, OFDM symbol of 1024 subcarriers
  - Cyclic prefix
    - Nominal 7%: .07x1024=72 guard symbols
    - Extended 25%: 0.25x1024=256 guard symbols
  - 600 subcarriers used for data transfer
  - Assume 10MHz transmission bandwidth and QAM modulation (4 bits per symbol)

$$\boldsymbol{R_{nominal} = 10MHz \frac{600\ data\ subcarriers}{1024 + 72\ total\ symbols}(4) = 21.9Mbps}$$

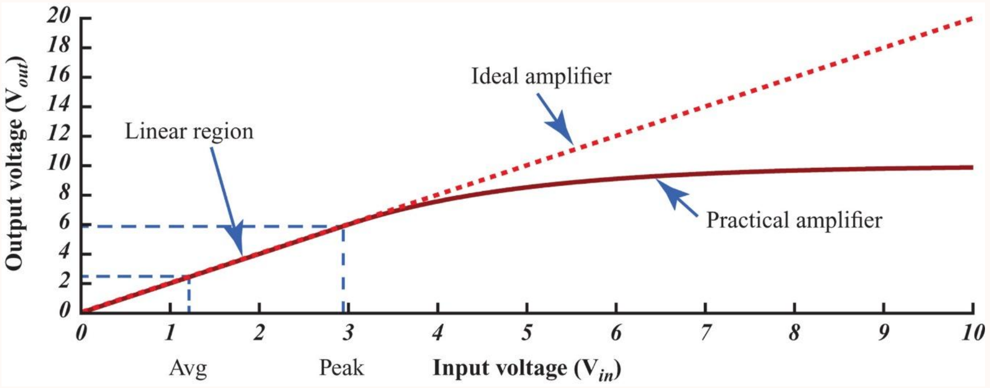
$$\boldsymbol{R_{extended} = 10MHz \frac{600\ data\ subcarriers}{1024 + 256\ total\ symbols}(4) = 18.8Mbps}$$

OFDM

- OFDM also suffers from doppler effects.
- It is required that the subcarrier spacing be much greater than the doppler spread.
  - $\Delta \boldsymbol{f} \gg \boldsymbol{f}_{\boldsymbol{Doppler}}$
- Example 3: LTE
  - Maximum speed 350km/hr
  - Maximum carrier frequency 3.5GHz.
  - Maximum doppler shift 1.1kHz
  - This is 7% of the subcarrier spacing of 15kHz.

OFDM

- One final complication for OFDM is the large Peak-to-Average Power Ratio for OFDM signals.
  - Arises out of the combination of many narrowband signals.
  - Voltage amplifiers not linear, hence may distort signal.
  - Compensate by
    - Better amplifier (expensive)
    - Input back off (more susceptible to noise)
    - Special coding (complexity)



OFDMA

- OFDM essentially divided the spectrum into sub-channels.
  - So far, we have considered the use of all of the subchannels by a single user.
  - There is no reason that different subchannels cannot be assigned to different users.
- OFDMA stands for Orthogonal Frequency Division Multiple Access.
  - Technique to allow multiple users to share the spectrum.
  - Uses a combination of FDMA and TDMA.
  - Bit rate implications.
  - Allows subcarriers to be shared according to which subcarrier has the strongest signal.

OFDMA

- Users are allocated *groups* of subcarriers (referred to as a *subchannel*).
  - A single subcarrier does not have enough capacity, and there are too many to schedule individually.
- Subchannels can be allocated in three ways:
  - Adjacent subcarriers: contiguous block of frequencies.
    - SINR roughly equal across block.
    - System must try to choose best block.
      - Requires system to have good knowledge of channel characteristics.
    - Used by WiMAX and LTE.
  - Regularly spaced subcarriers: distributed periodically through spectrum.
    - Good frequency diversity, so system doesn’t need to worry as much about channel characteristics.
    - Used by LTE
  - Randomly Spaced Subcarriers:
    - Also good frequency diversity.
    - Used by WiMAX

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OFDMA Example

LTE

- On the downlink, LTE uses OFDM combined with either
  - QPSK
  - 16 QAM
  - 64 QAM
- So, the number of bits per signalling element varies according to channel conditions.
  - A signalling element is contained in a resource block
    - Δf = 15kHz band
    - 0.5 msec (1/ Δf + cyclic prefix)

OFDMA Example
LTE

- OFDM symbols grouped into resource blocks
  - 180kHz in frequency domain, 0.5msec in time domain.
  - Users allocated a number of resource blocks in the time-frequency grid.
  - How many resources granted based on QoS negotiation with network.
    - Considerations include:
      - Efficiency: improve SINR
      - Fairness (or proportional fairness)
        - All users should get some resources
      - Application requirements
      - Priority

OFDMA Example

LTE

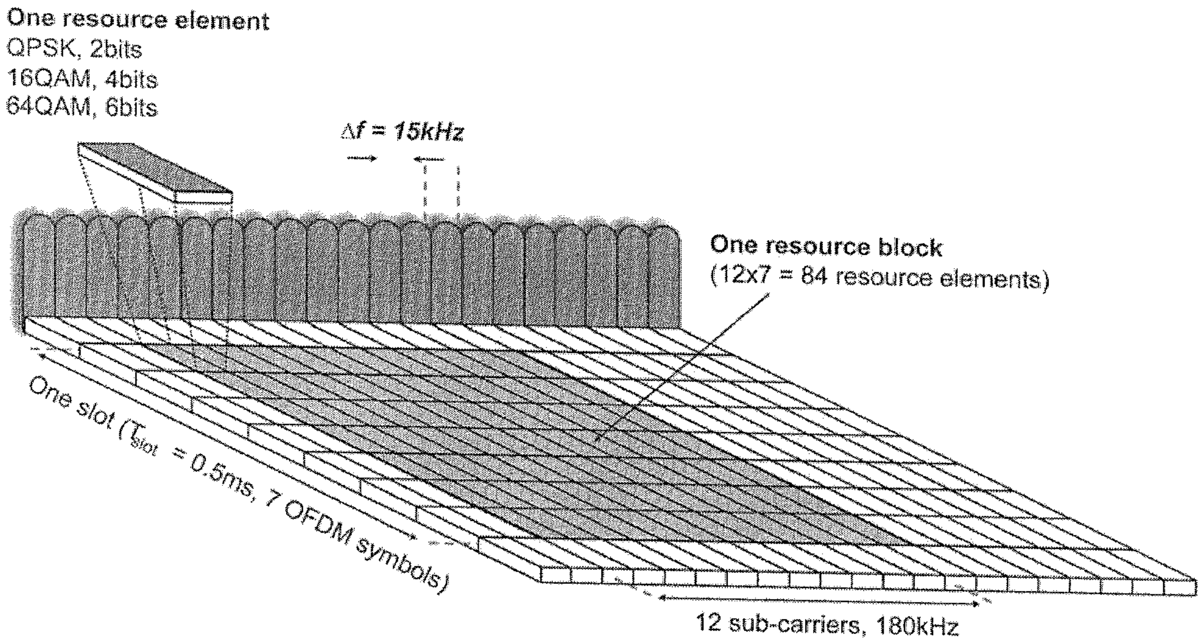


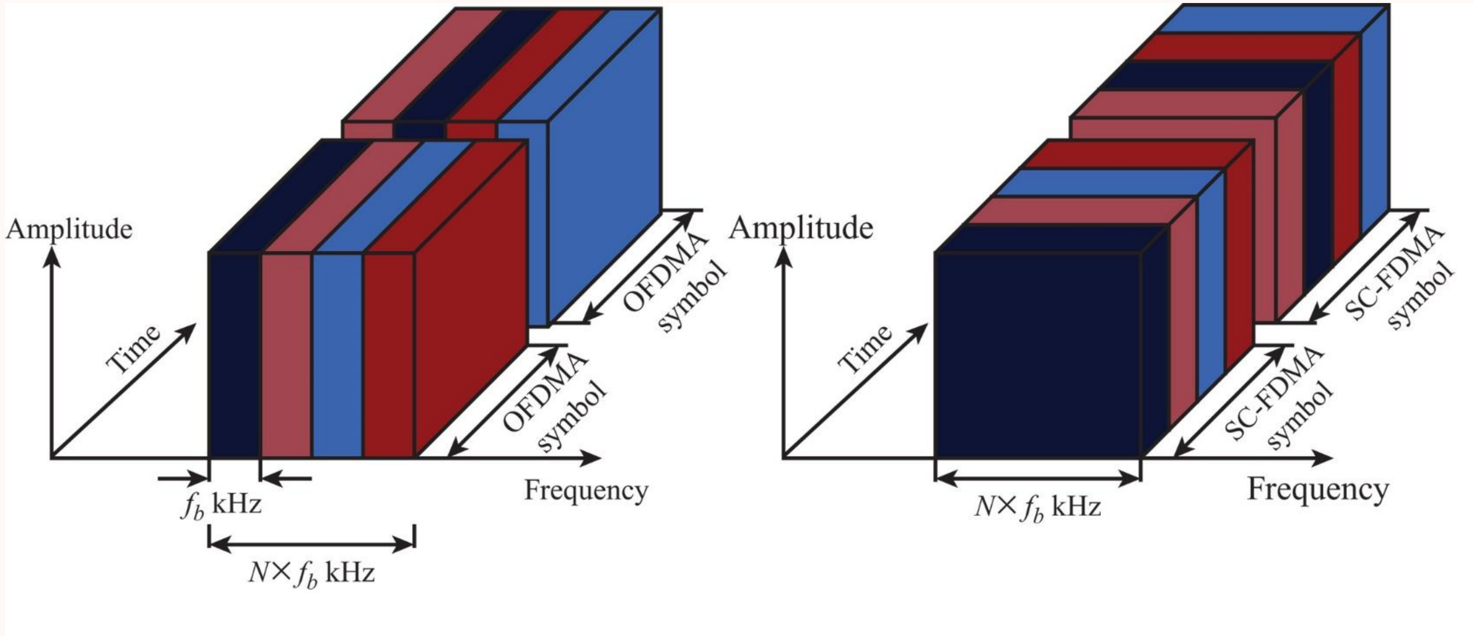
Figure 4: The LTE downlink physical resource based on OFDM

OFDMA Example
LTE

- On the uplink, LTE uses Single Carrier Frequency Division Multiple Access (SC-FDMA)
  - Precoded version of OFDM
  - Resources grouped to optimise power control.

SC-FDMA

- SC-FDMA despite what the name implies, does not use FDMA.
  - Multiple access is achieved via TDMA.
    - Symbols transmitted at a higher rate, but over greater frequency bandwidth.
    - Source data stream replicated N times, copies sent on all subcarriers.



(a) OFDMA: Data symbols occupy f_b kHz for one OFDMA symbol period

(b) SC-FDMA: Data symbols occupy $N\times f_b$ kHz for 1/N SC-FDMA symbol period

OFDM vs. CDMA

- Advantages of OFDM
  - It is robust when combatting narrow-band co-channel interference. As only some of the channels will be affected, not all data is lost and error coding can combat this.
    - This advantage lessens as less channels assigned.
  - Intersymbol interference, ISI is less of a problem with OFDM than CDMA because low data rates are carried by each carrier.
  - Provides higher levels of spectral efficiency than CDMA.

OFDMA vs. CDMA

OFDMA	CDMA
• OFDM can combat multipath interference with greater robustness and less complexity. Equalisation can be undertaken on a carrier by carrier basis. • OFDMA can achieve higher spectral efficiency with MIMO than CDMA using a RAKE receiver. • Cell breathing does not occur as additional users connect to the base station. • Can be used to provide a single frequency network. • It is relatively easy to aggregate spectrum. • It can be scaled according to the requirements relatively easily	• Not as complicated to implement as OFDM based systems • As CDMA has a wide bandwidth, it is difficult to equalise the overall spectrum - significant levels of processing would be needed for this as it consists of a continuous signal and not discrete carriers. • Not as easy to aggregate spectrum as for OFDM