Digital Signal Processing

ICT 41205 Digital Control Systems

Nimal Skandhakumar

Faculty of Technology
University of Sri Jayewardenepura

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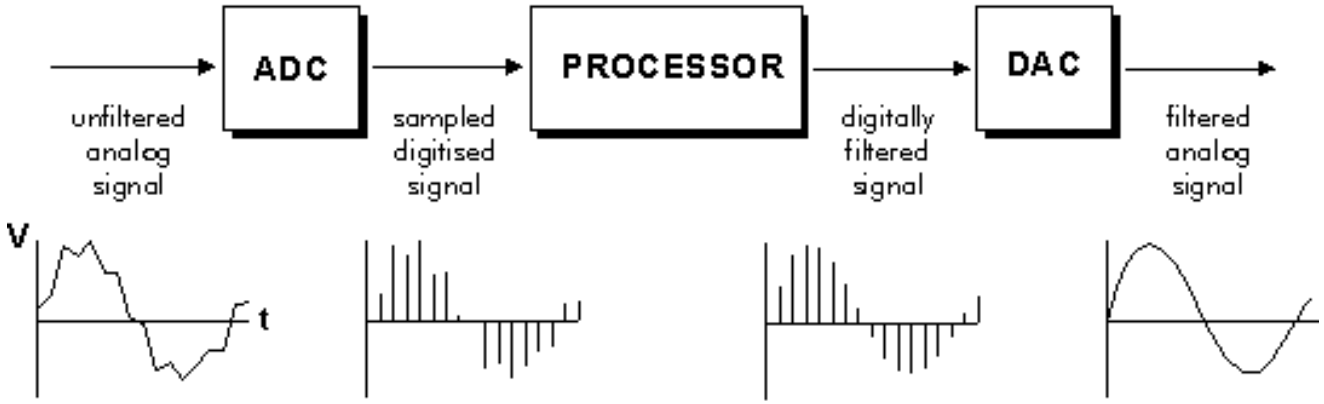
What is Digital Signal Processing (DSP)?

- Analog-to-digital conversions
- Perform processing on these numbers with a digital processor
- Digital-to-analog conversion

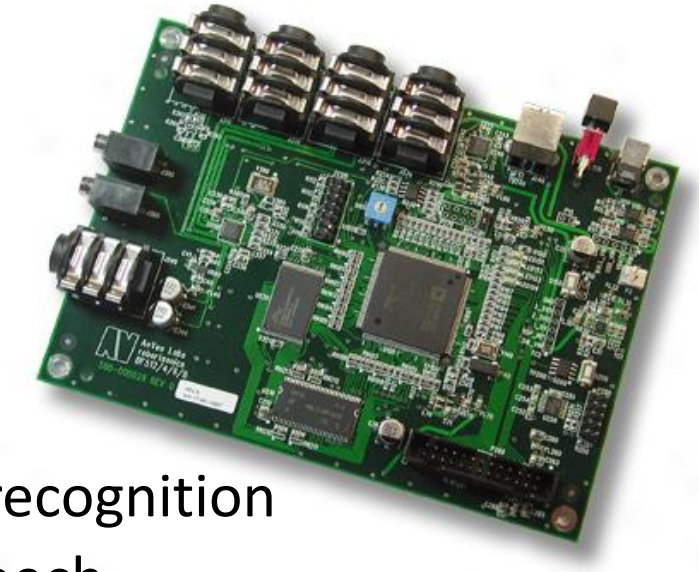


- Represent signals by a sequence of numbers
  - Analog input – Analog output
    - Digital recording of music
  - Analog input – Digital output
    - Touch tone phone dialling
  - Digital input – Analog output
    - Text to speech

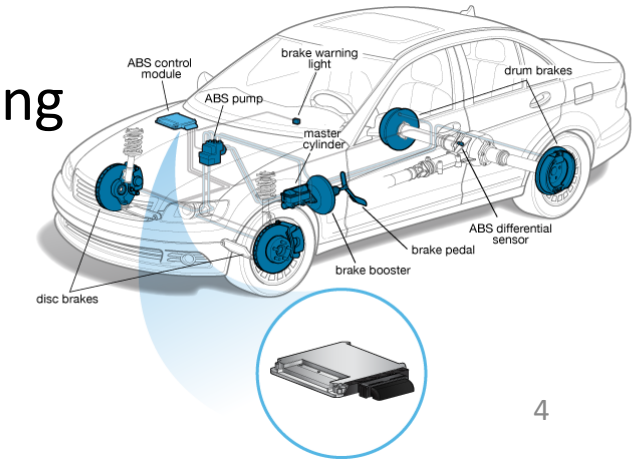
Why do we need a DSP?

- DSP processor is designed for high speed data-manipulation
  - Audio, comms, image manipulation, data acquisition and control
- Cannot use a general-purpose microprocessor
  - Operations done in few clock cycles (e.g. Y=mX+C)
- Most DSPs have a single operation
  - Does Y=mX+C in one operation
- DSP will perform in a single cycle implementing all shift and add operations in parallel
  - Makes chip much more complex
  - If the DSP is not fast enough then an analogue circuit or a specialised DSP chip is required

DSP – Applications



- Sound applications
  - Compression, enhancement, special effects, synthesis, recognition
  - Cell Phones, MP3 Players, Movies, Dictation, Text-to-speech
- Communication
  - Modulation, coding, detection, equalization, echo cancellation
  - Cell Phones, dial-up modem, DSL modem, Satellite Receiver
- Automotive
  - ABS, GPS, Active Noise Cancellation, Cruise Control, Parking



DSP – Applications

- Medical
  - Magnetic Resonance, Tomography, Electrocardiogram
- Military
  - Radar, Sonar, Space photographs, remote sensing
- Image and Video Applications
  - DVD, JPEG, Movie special effects, video conferencing
- Mechanical
  - Motor control, process control, oil and mineral prospecting

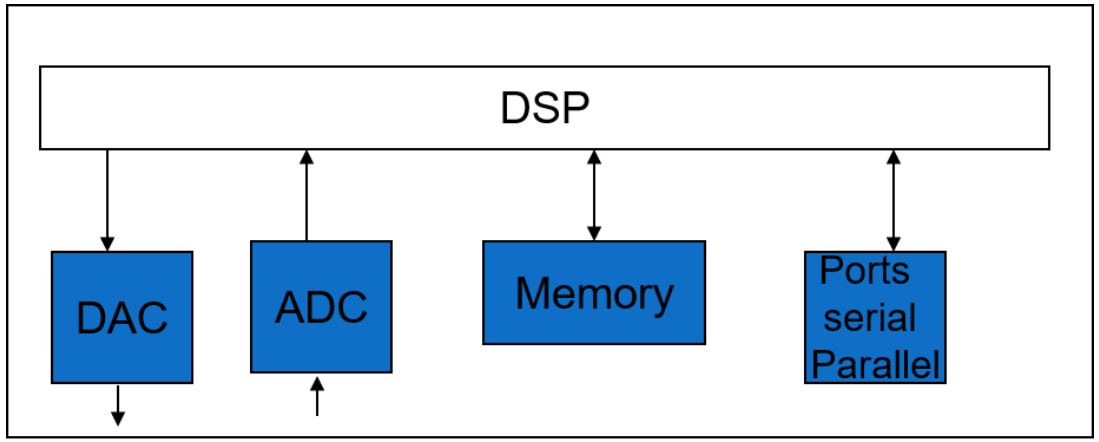
DSP – Advantages

- High Accuracy
  - Digital circuits are less sensitive to tolerances of components.
- Cheaper
  - Digital circuits can be reproduced easily in large quantities at lower cost.
- Flexibility
  - DSP System can be easily reconfigured only by changing the program.
- Ease of storage
  - Digital signals are easily stored without loss of quality of signal reproduction.
- High sophistication
  - Sophisticated signal processing algorithms can be implemented easily.

DSP – Disadvantages

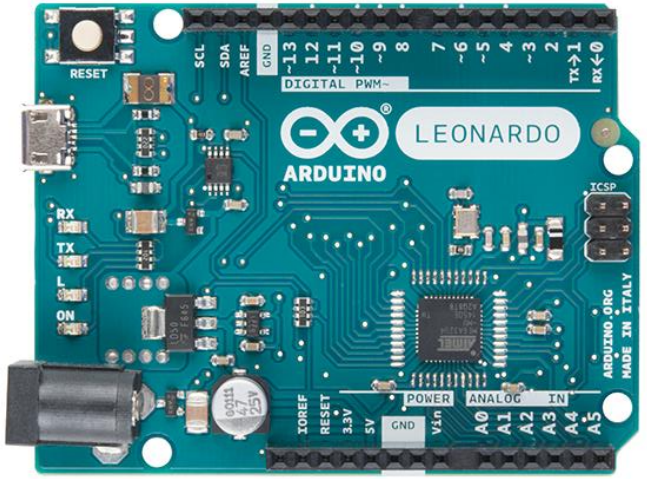
- Bandwidth
  - The digital communications require a greater bandwidth than analogue to transmit the same information.
- Limiting speed of processors
  - When analogue signal is changing very fast, it is difficult to convert digital form (beyond 100KHz range).
- Loss of information
  - Information loss during sampling and quantization round-off errors.
- Non-reversible
  - When the signal is weak, within a few tenths of millivolts, we cannot amplify the signal after it is digitised.

DSP – Architecture



- DAC and ADC
- Ports
  - To communicate with other devices through a serial or a parallel port
- Memory
  - Holds the data and instructions to be used
- Central ALU
  - Performs the major functions – very fast
- Aux ALU
  - Maybe present and performs similar operations in parallel

DSP – Hardware



- DSPs can be purchased in three forms:

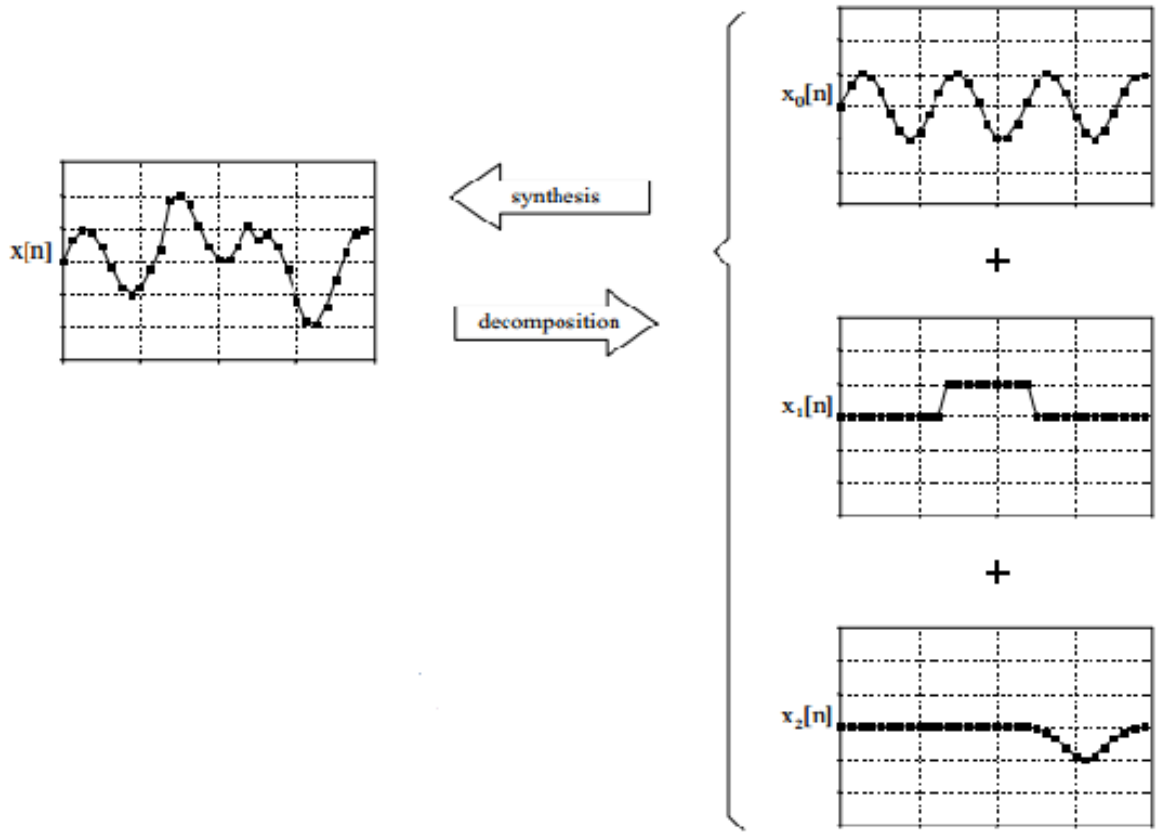
1. as a core
   - In DSP, the term "core" refers to the section of the processor where the key tasks are carried out, including the data registers, multiplier, ALU, address generator, and program sequencer.
2. as a processor
   - A complete processor requires combining the core with memory and interfaces to the outside world.
3. as a board level product
   - These have such features as extra memory, A/D and D/A converters, EPROM sockets, multiple processors on the same board, and so on.

DSP – Techniques

- Most DSP techniques are based on a divide-and-conquer strategy called superposition.
- The signal being processed is broken into simple components, each component is processed individually, and the results reunited.
- This approach has the tremendous power of breaking a single complicated problem into many easy ones.
- Superposition can only be used with linear systems, a term meaning that certain mathematical rules apply.
- Fortunately, most of the applications encountered in science and engineering fall into this category.

DSP – Techniques

- There are 2 important concepts in linear systems DSP.
- Synthesis
  - Combining multiple signals through scaling and addition.
- Decomposition
  - Take one signal and break it into multiple signals.
- E.g.
  - The figure shows three signals: $x_0[n]$, $x_1[n]$ and $x_2[n]$ are added to form a fourth signal, $x[n]$.



DSP – Programming

- High level language programmes easier to write/Assembler faster execution
- Can combine both in a DSP programme
- Time critical sections in assembler
- Other sections in HLL

DSP – Tools

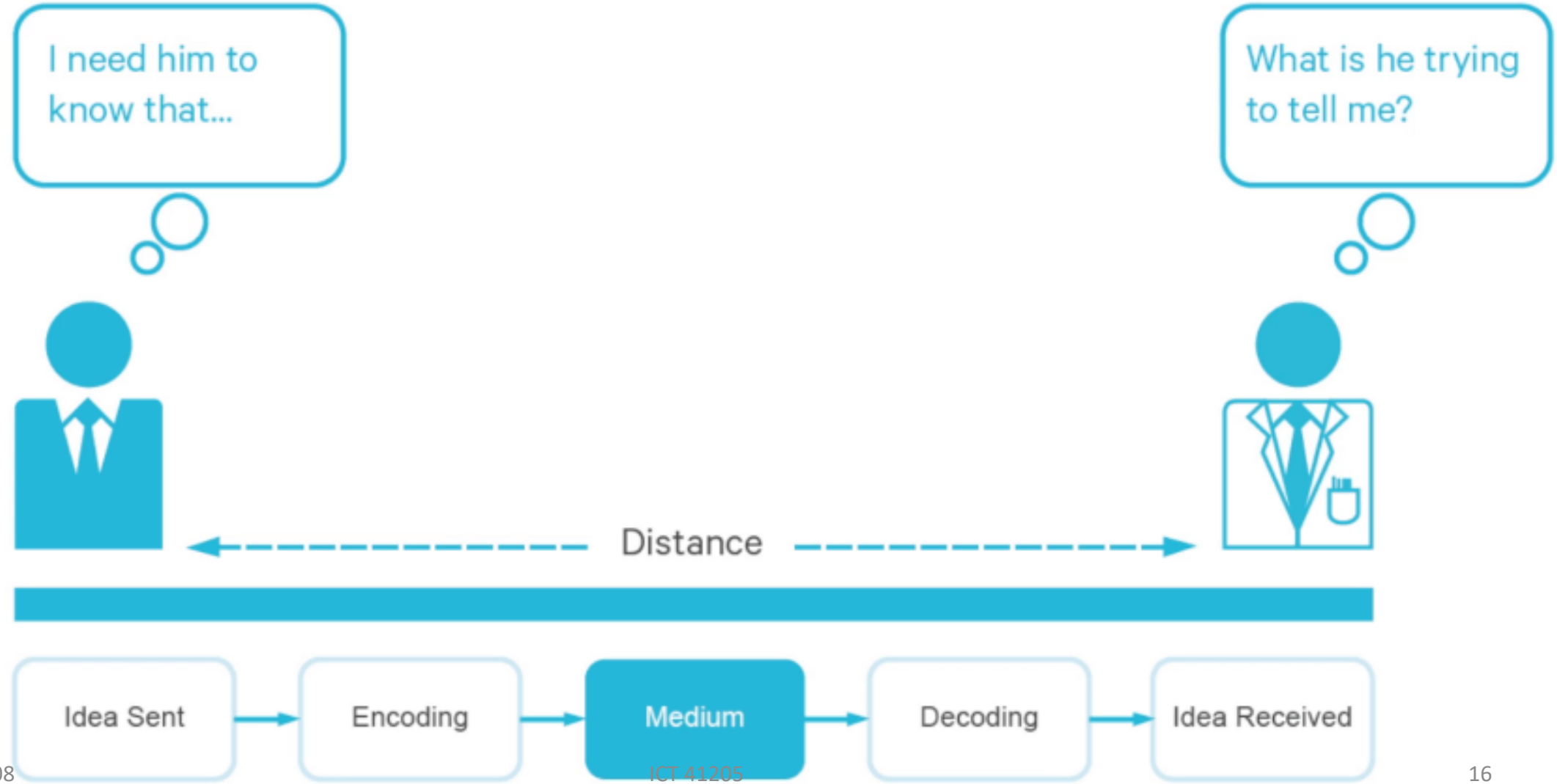
- Simulators
  - Software implementation of the chip
  - Used to try out programme design before a more costly implementation
- Emulators
  - Allows direct control and debug the results of instructions on a DSP
  - Emulator runs on PC but exerts control over DSP
  - Possible to see all the internal changes in the device at each step
  - Can execute instructions one step at time and check outputs such as voltage levels to monitor affects etc.

DSP – Tools

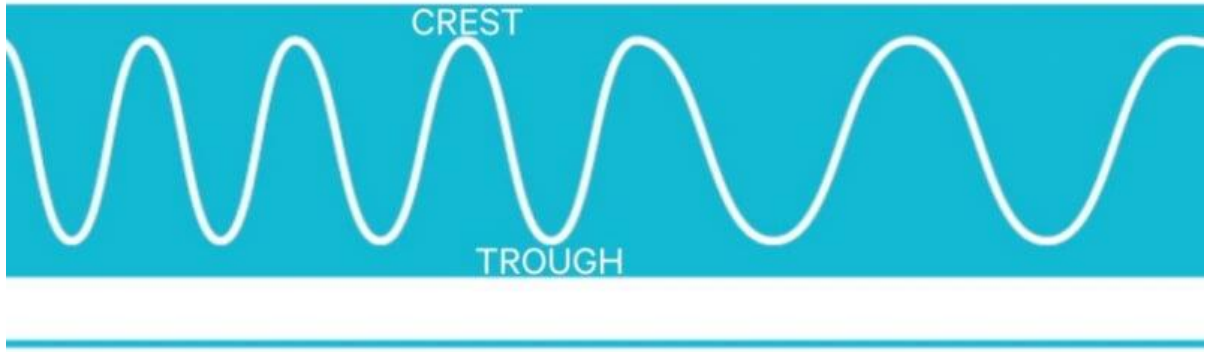
- Debugger
  - Has a user interface on PC to modify and control the execution on the chip
  - Contents of DSP processor memory is loaded into debugger interface
  - Loaded from either emulator or serial comms link to DSP
  - Used to display programme execution info in a useful format for the programmer
  - Advantage over emulators - allows user to operate in real time and designer to see performance of chip in operation

Fundamentals of Radio Communications

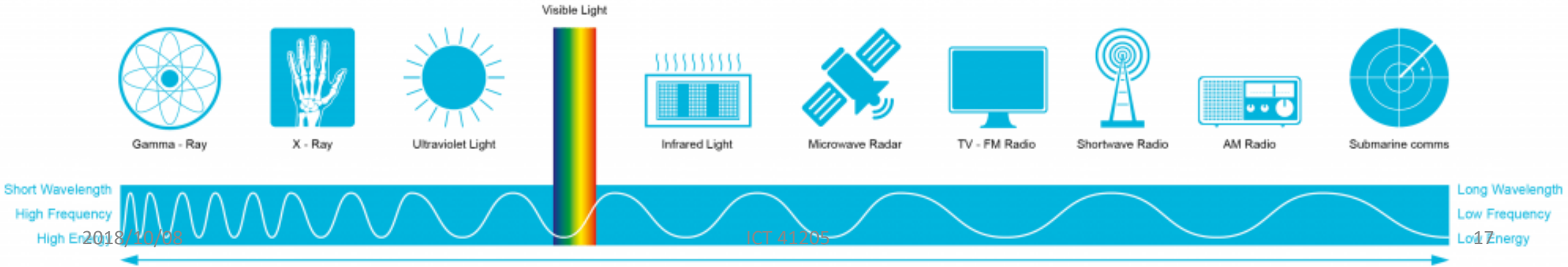
What is Communication?



What is a radio wave?

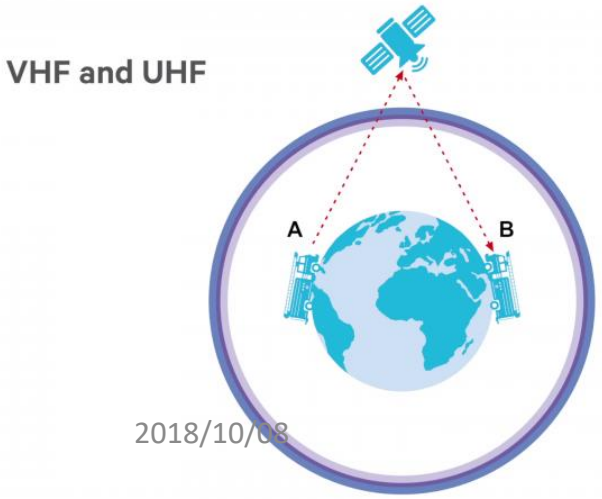


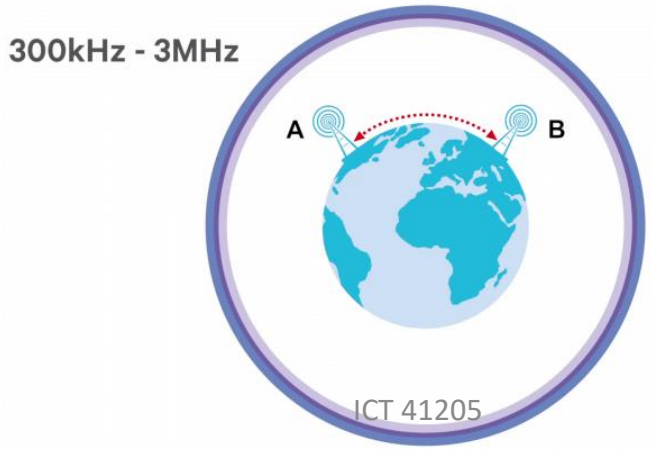
- Energy is pumped into the atmosphere to compress molecules together.
- The high point of the energy which squashes the molecules closer together is called the crest of the wave.
- The low point of the energy, when the molecules are far apart, is called the trough of the wave.
- The number of waves passing by in a single second that would be the frequency.
- The distance between the same positions on two waves is the wavelength.

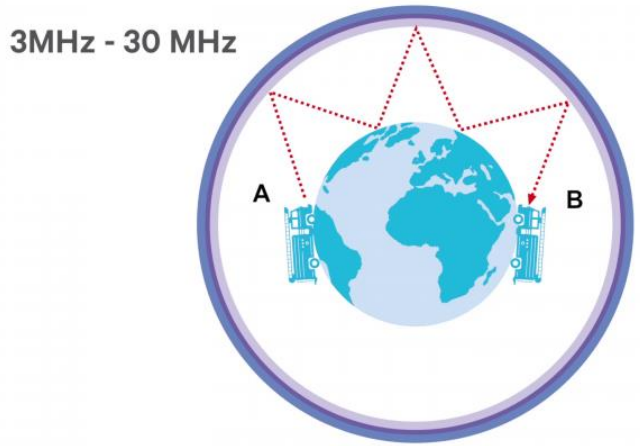


Propagation

- Radio waves propagate differently depending on their wave length
  - Line of sight
    - VHF/UHF bands travels in a straight line
  - Curve around the horizon or the curvature of the Earth
    - Lower short wave
  - Bounces off a top layer of the atmosphere
    - Higher short wave

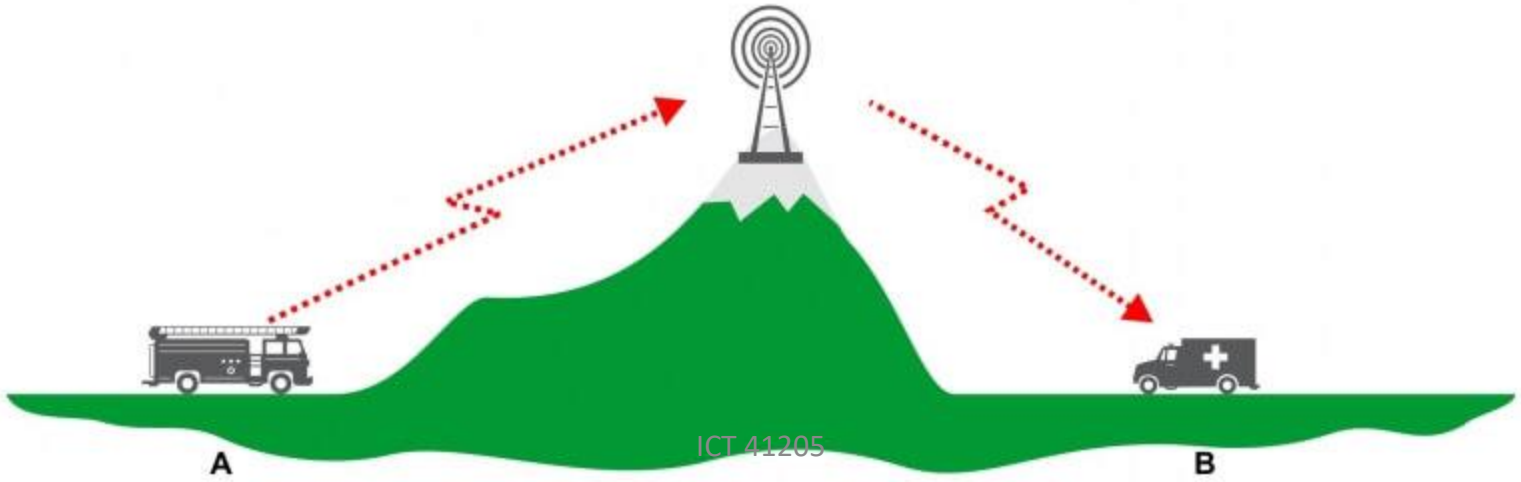






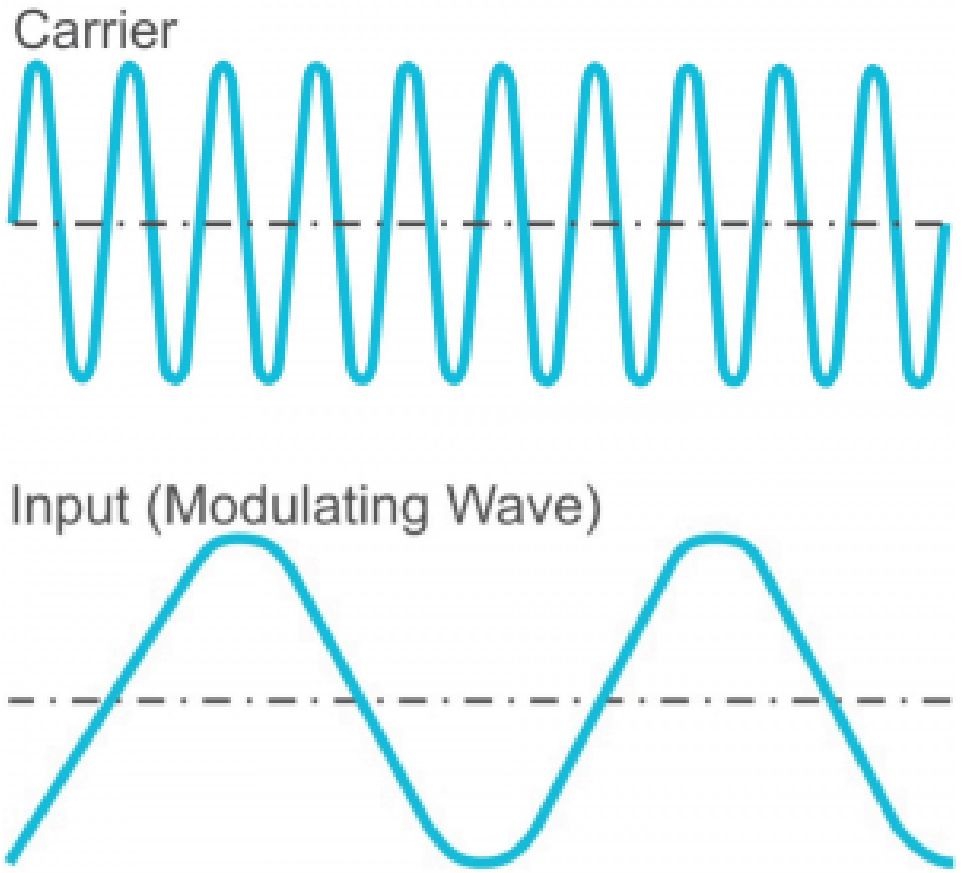
Repeaters

- The repeater needs to receive the frequency that the caller transmitted with.
- Then the repeater re-transmits that same message down to the user on the other side of the mountain.
- It works similarly to the satellite discussed with VHF radio propagation.



Modulation

- A carrier wave is a pure wave of constant frequency, like a sine wave.
- To include speech information or data information, another wave needs to be imposed, called an input signal, on top of the carrier wave.
- This process of imposing an input signal onto a carrier wave is called modulation.



Modulation

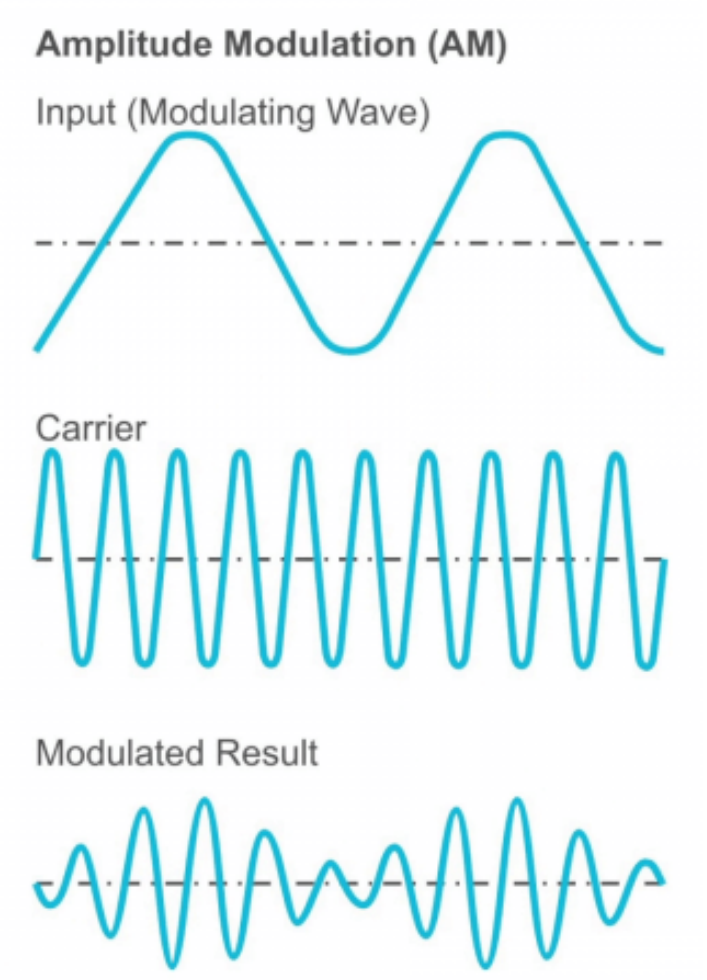
- Why have carrier waves in modulation at all? Why not simply use the input signal directly?
- The input signals could be carried (without a carrier wave) by very low frequency electromagnetic waves.
- The problem, however, is that this will need quite a bit of amplification in order to transmit those very low frequencies.
- The input signals themselves do not have much power and need a fairly large antenna in order to transmit the information.

Modulation

- Modulation changes the shape of a carrier wave to somehow encode the speech or data information that we were interested in carrying.
- There are different strategies for modulating the carrier wave based on the basic properties of any wave:
  1. Amplitude – the height of the wave
  2. Frequency – a number of waves passing through in a given second
  3. Phase – where the phase is at any given moment.

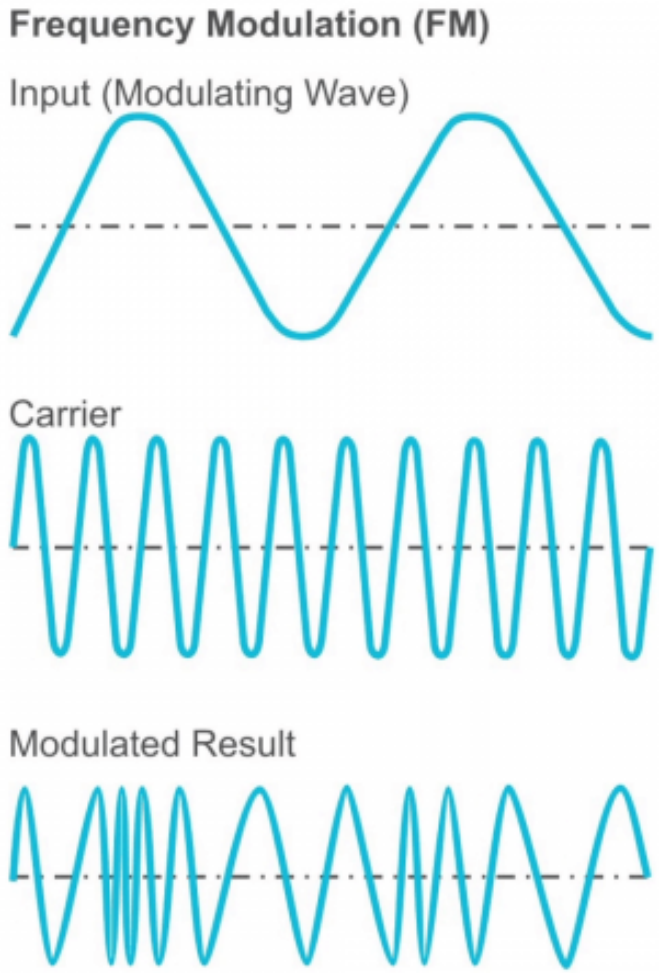
Amplitude Modulation (AM)

- Tweak the height of the carrier.
- If an input signal's height varies with the loudness of a user's voice and then adds this to the carrier.
- The carrier's amplitude will change corresponding to the input signal that's been fed into it.



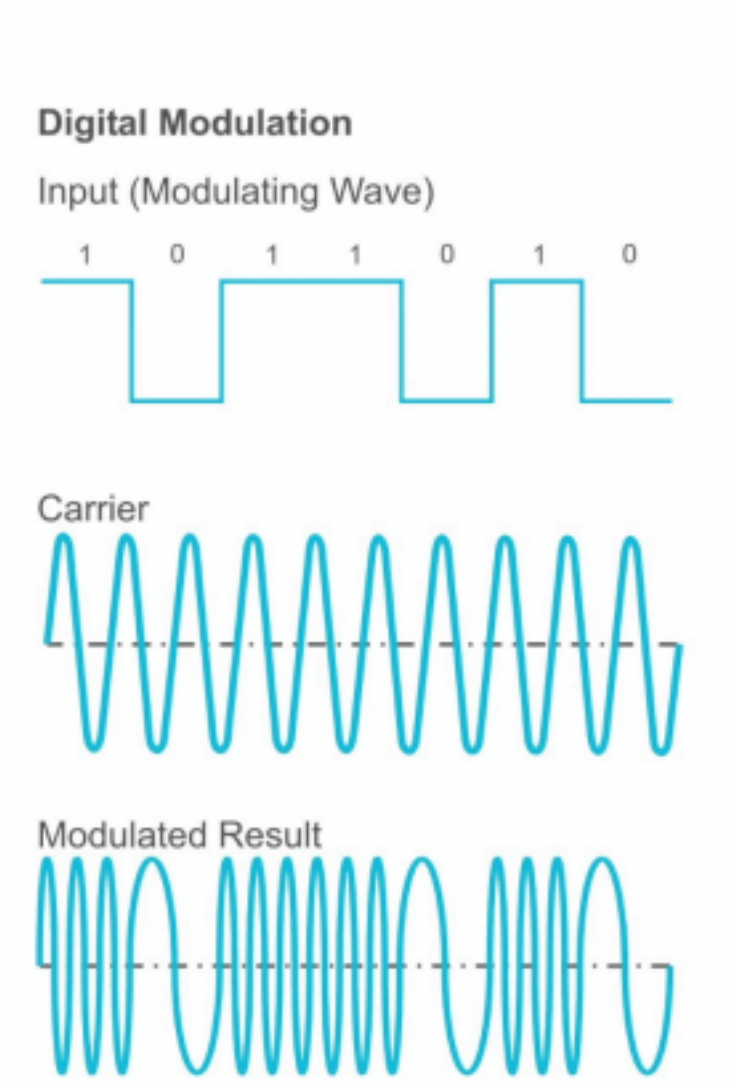
Frequency Modulation (FM)

- Frequency of an input signal can also be changed.
- If this input signal is added to the pure carrier wave, it will thereby change the frequency of the carrier wave.
- In that way, users can use changes of frequency to carry speech information.

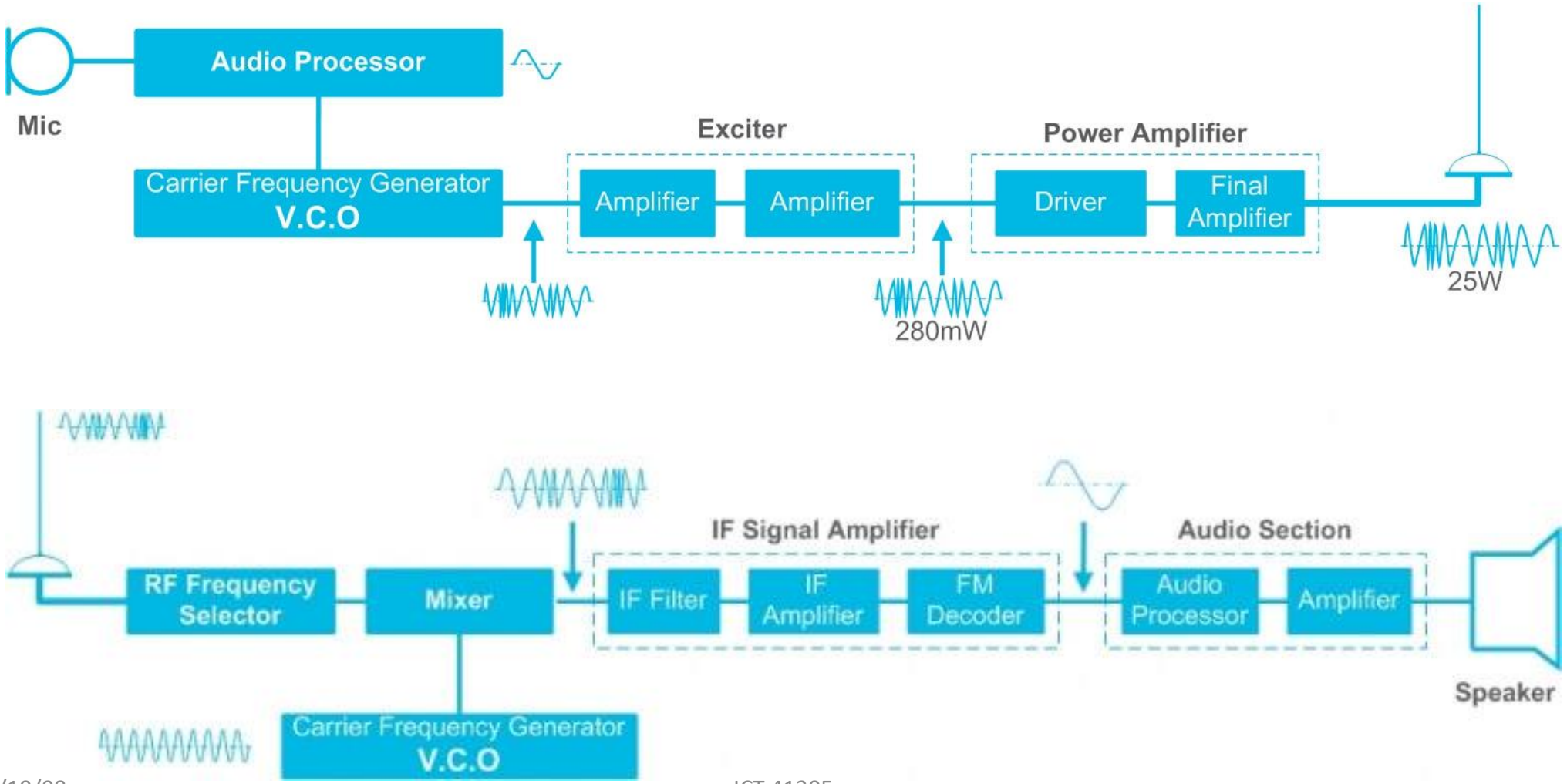


Digital Modulation

- Modulation schemes can be analog or digital.
- In digital modulation scheme, voice is sampled at some rate and then compressed and turned into a bit stream.
- This in turn is created into a particular kind of wave which is then superimposed on the carrier.



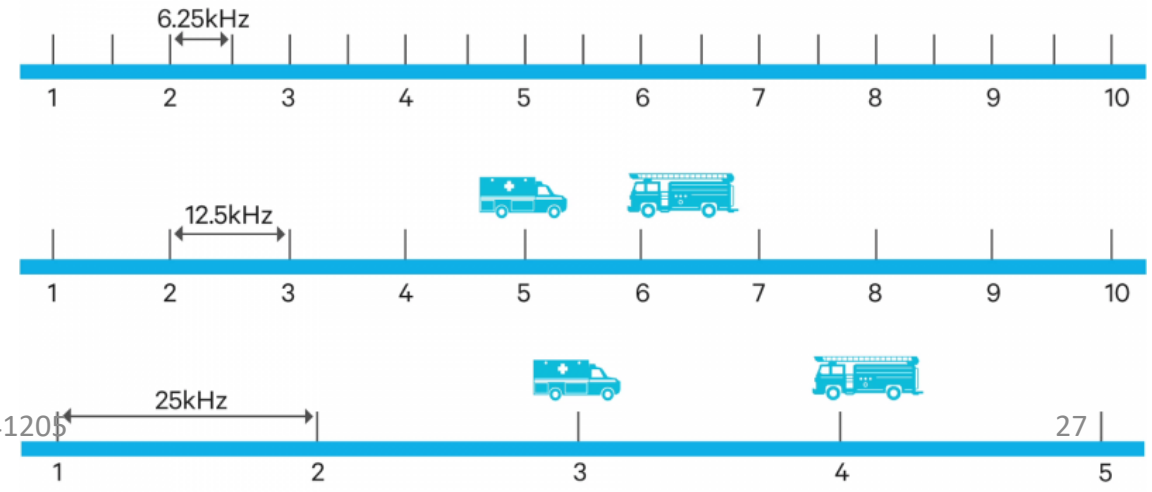
How does an FM Transceiver work?



Channel Spacing

- Radio spectrum is very limited.
- Every user of radio spectrum needs a “pipeline” or block of pipelines in order to communicate over.
- These pipelines are called channels and they are differentiated by their frequency.

- **Wideband** channels occupy 25 kilohertz of radio spectrum
- **Narrowband** channel is half that size and occupies 12.5 kilohertz
- **Ultra narrowband** is half the size again at 6.25 kilohertz



Multiple Access

- An RF channel occupies a certain amount of radio spectrum.
- How to efficiently use of this small?
- There are two different techniques:
  - Frequency division multiple access (FDMA)
    - There is only one conversation and one user at a time per radio channel. More radio channels require more frequencies.
  - Time division multiple access (TDMA)
    - It allows two users to occupy the same channel at what appears to them to be the same time.
    - This process is so fast that each user thinks they have exclusive use of the frequency channel.