EEEN3006J

Wireless Systems

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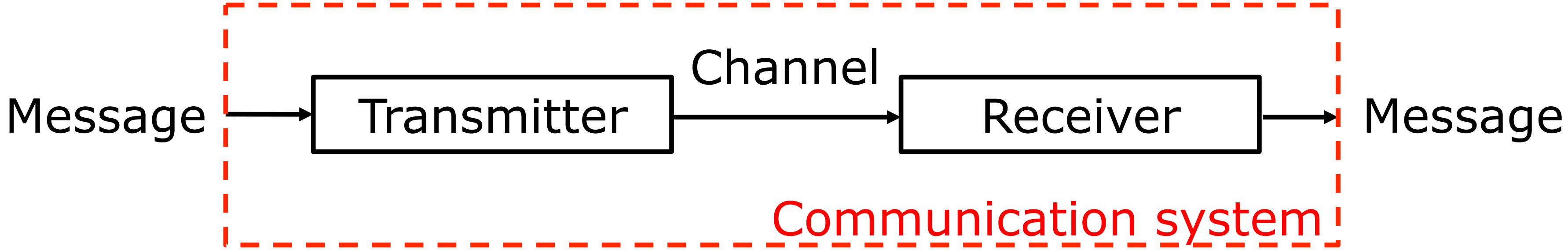
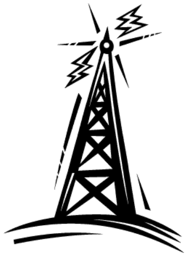
- A communication system is some device for faithfully transmitting a message from one location to another.



- The channel is often a wire, or an optical fibre.
- In wireless systems, the channel is a radio link.

- Wireless systems have become extremely common in the 21st century.
- Examples include Wifi and mobile phones*.
- Older examples include broadcast television and radio, and ship and aircraft radio communications.



* You may hear me use the terms mobile phone and cell phone interchangeably. Mobile is more common in British English, and cell phone in American English.

Syllabus

- Components of Wireless Systems
- Wireless System Design
- Electromagnetics
- Antennas

Syllabus

- Components of Wireless Systems
  - Oscillators and frequency generation
  - Filters
  - Mixers
  - Amplifiers
- Wireless System Design
- Electromagnetics
- Antennas

Syllabus

- Components of Wireless Systems
- Wireless System Design
  - Noise
  - Transmitters, receivers and transceivers
  - Regulation and specifications
- Electromagnetics
- Antennas

Syllabus

- Components of Wireless Systems
- Wireless System Design
- Electromagnetics
  - Vector calculus
  - Maxwell’s equations
  - The wave equation
- Antennas

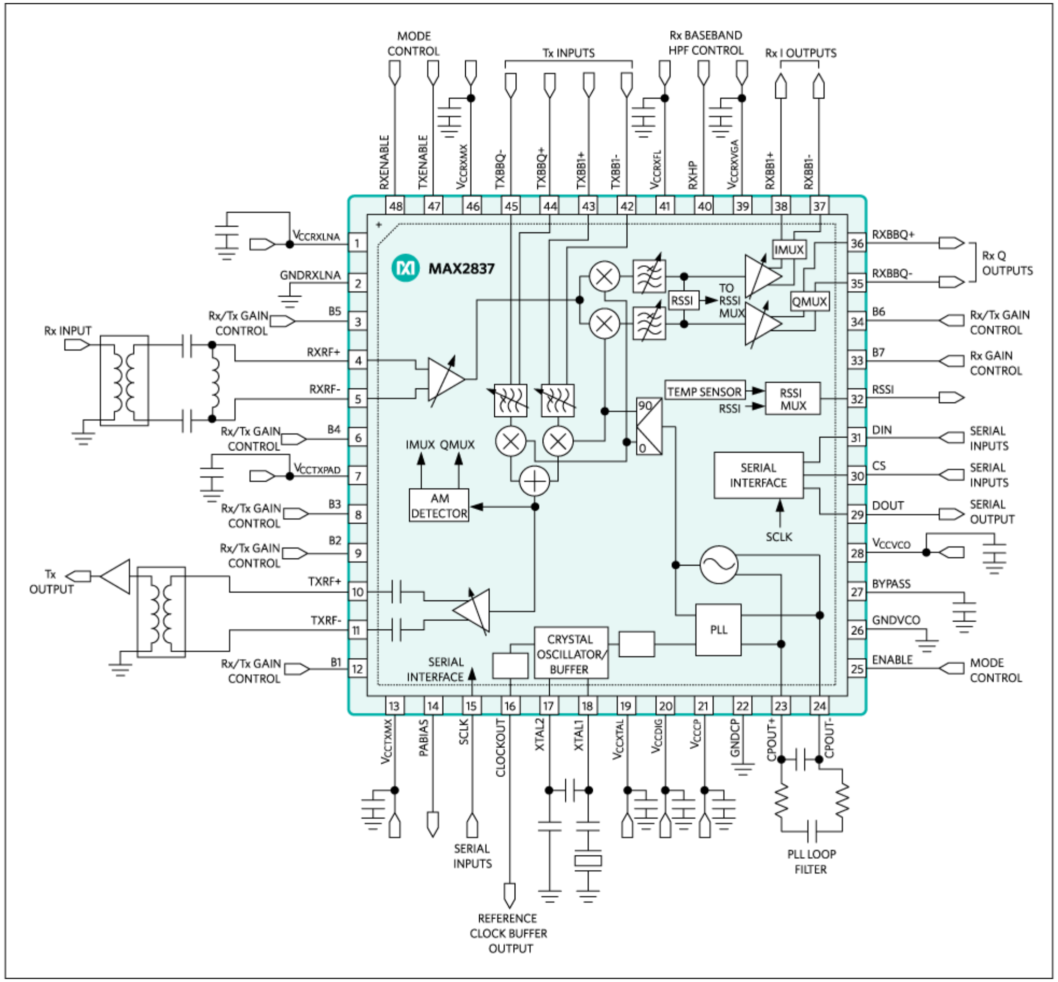
Syllabus

- Components of Wireless Systems
- Wireless System Design
- Electromagnetics
- Antennas
  - The Hertzian dipole – basic antennas.
  - Radiation patterns
  - Radio wave propagation

MAX2837 2.3GHz to 2.7GHz Wireless Broadband RF Transceiver

By the end of the course, you should be able to explain what this device does.

In fact, this circuit has come up in previous papers.



What is the role of the transmitter?

- Turns the message (analogue signal or stream of bits) into an electrical signal suitable for transmission.
- Mostly, I will leave a discussion of modulation to your Communication Theory module.

What is the role of the receiver

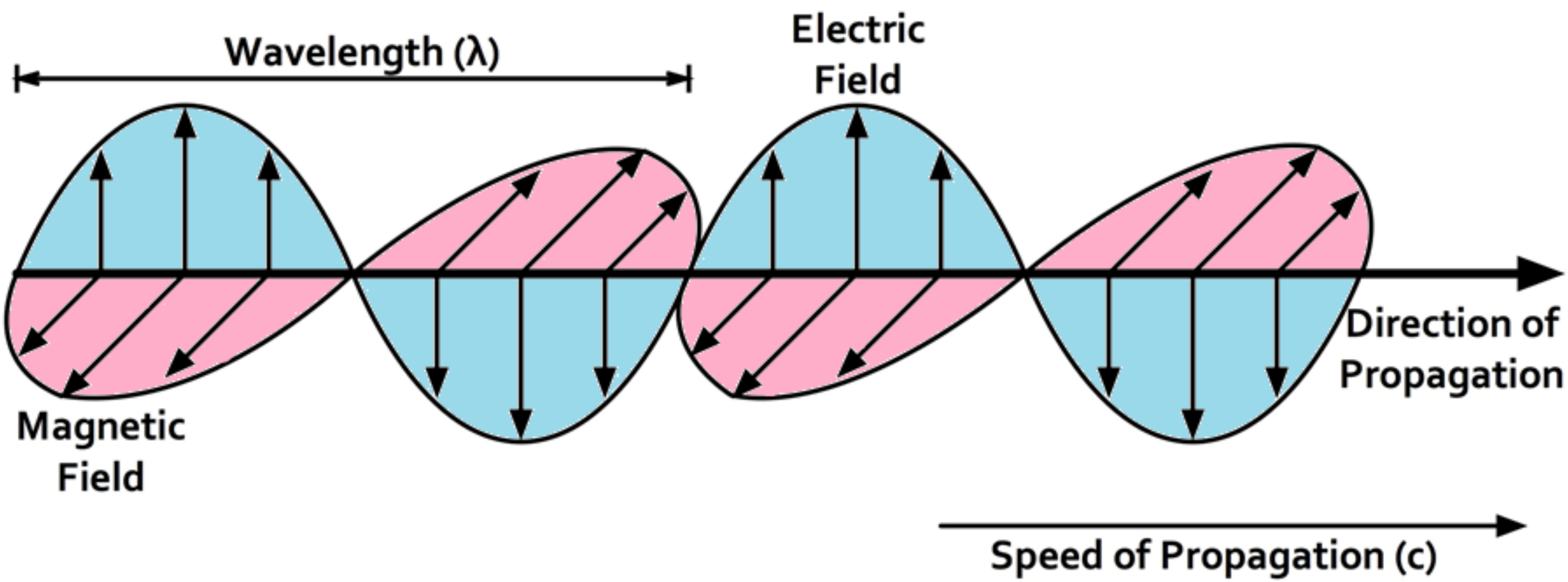
- The receiver has to interpret the signal that its antenna picks up.
- This signal is often very weak.
- Transmission will have damaged the signal, and added noise. The receiver tries to undo this.
- There may be other signals received at the same time – these must be rejected.

The wireless channel - radio

- In your physics courses, you learned about the concept of electric charge.
- Electrically charged objects exert a force on each other, which we call an electromagnetic force.
- Imagine taking a unit charge (1 Coulomb), and move it to different locations (x,y,z). If we recorded the force acting on this charge at each point, we would have measured the electric field, $E\,(x,y,z)$.

- This field propagates through space as a wave, like ripples from a stone skipping on water.
  - As a wave, it obeys the wave equation, which for the electric field is $\nabla^2 E = \mu_0 \varepsilon_0 \partial^2 E / \partial t^2$.
  - We will prove this later in the course.
  - We refer to the electric and magnetic fields together as an electromagnetic (EM) wave.
- In wireless communications, we put a time-varying pattern on an electromagnetic field.
  - Pattern contains message we want to send.

Frequency of an EM wave

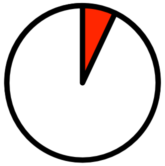


$f = c/\lambda$

f = frequency
λ = wavelength
c = speed of light ≈ $3\text{x}10^8$ m/s

In-class Exercise

Time:
2 minutes



- Take out a pen and paper.
- Work individually.
- Given: There is a rule of thumb that says antennas usually longer than $\lambda/4$.
- Given: Voice data has a bandwidth of ~4kHz.
  - i.e. if we transmit 8000 samples of the signal each second, we can understand it (Nyquist theorem).
- Given: $f = 8000$ Hz, $c = 3\text{x}10^8$ m/s
- Antenna length > x
- Find λ, and hence find x.

Solution

- From physics, we know $c = f \lambda$
- Here, $\lambda = 300000000 / 8000 = 37500$ m
- Hence, the antenna must be at least 9375 m = 9.375 km
- This will not fit in your phone!
- So, how do we transmit voice data from a phone?

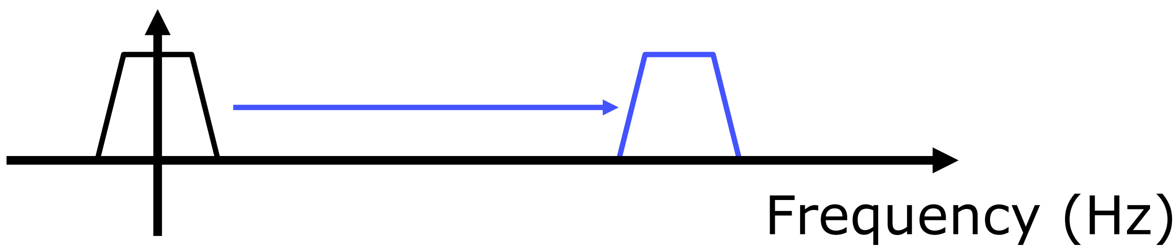
Broadcast frequencies

- Big antennas exist.
- Mostly for military use – communicating with submarines.
- Why are they useful for this purpose?
- However, most antennas are shorter.
  - They use higher frequencies.

US Navy VLF transmitter at Lualualei, Hawaii.
This is the tallest mast radiator in the world at ~460 m.
It was built in 1962.

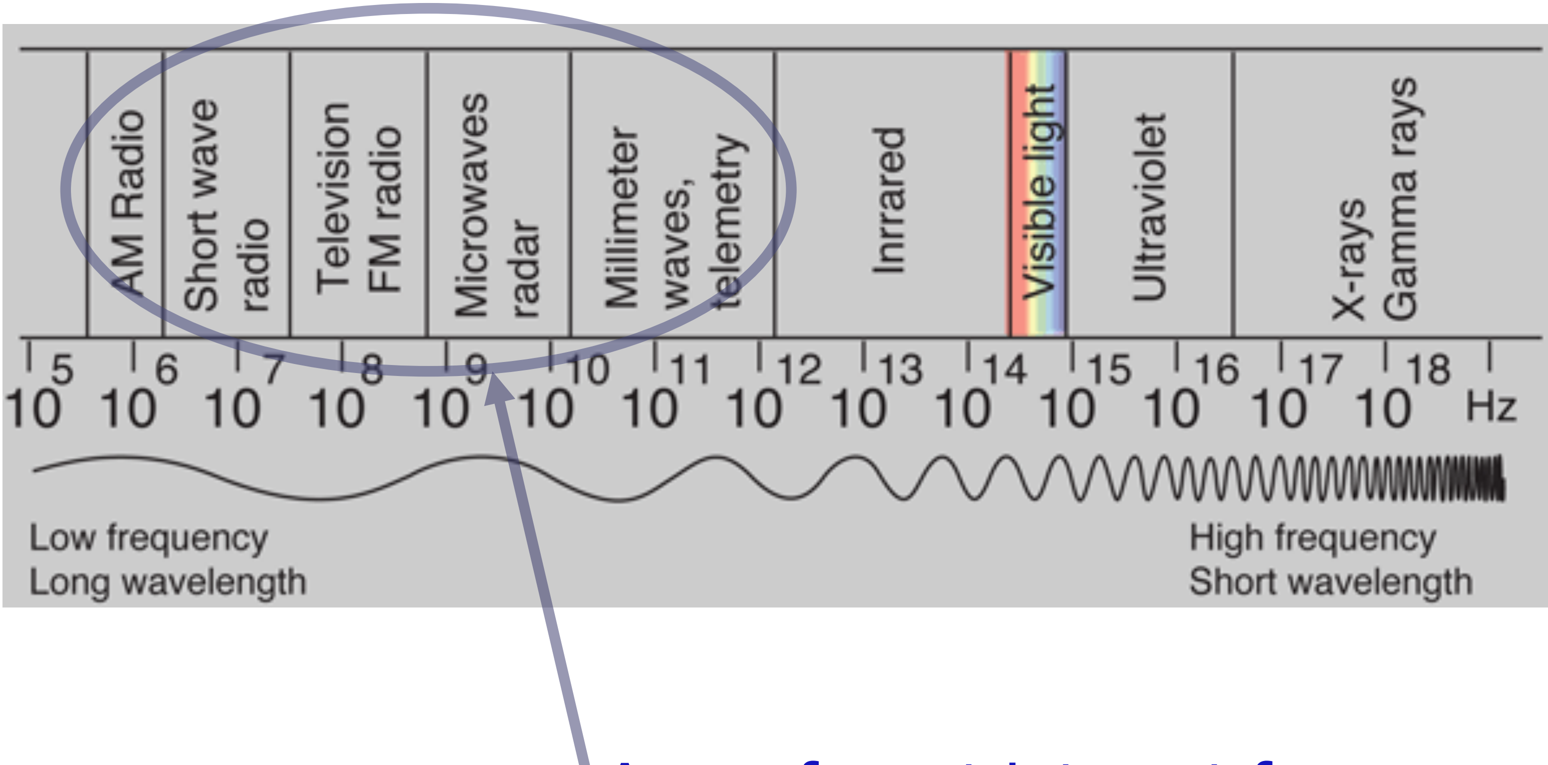
Broadcast frequencies

- We make a change our signal so it occurs at frequencies which are practical.



- This is called upconversion.
- We can perform upconversion using modulation, or directly with a mixer.
  – You will learn about modulation from Dr Deepu John in Communication Theory.

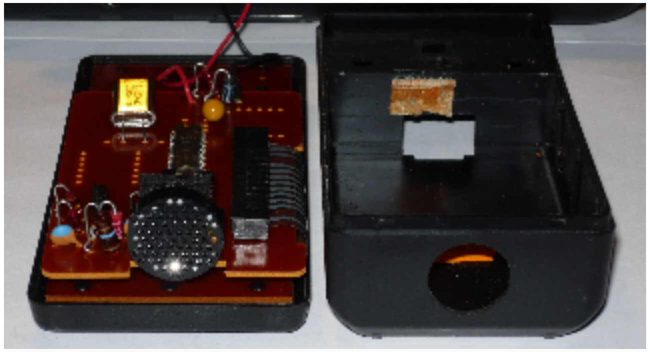
Frequencies of interest



Area of most interest for this module

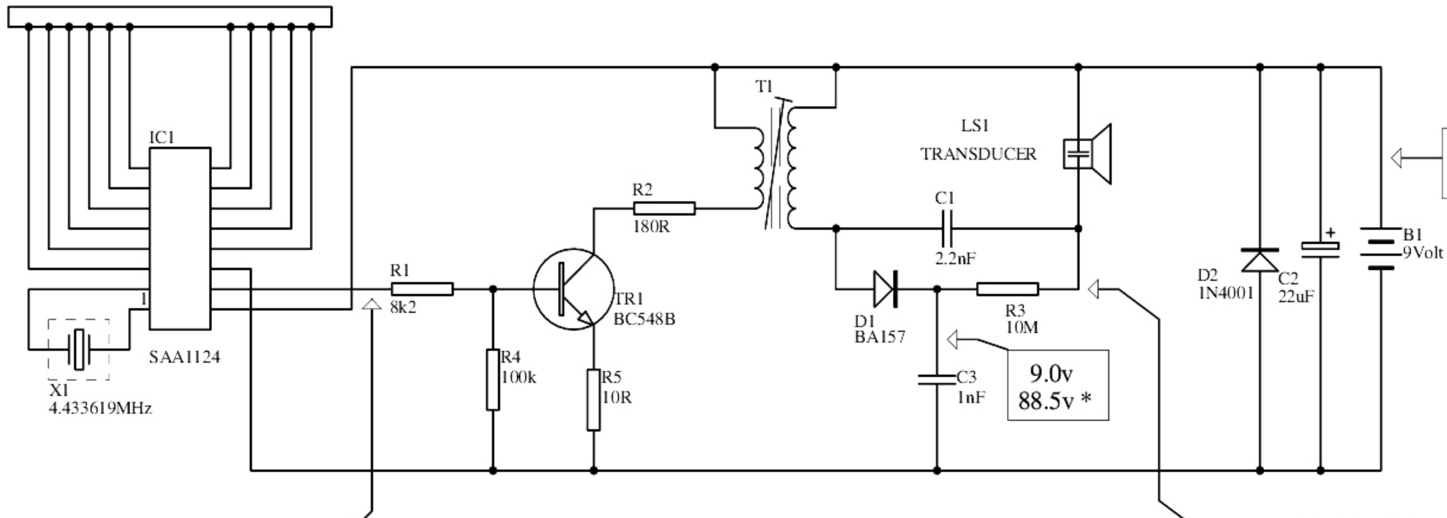
Which frequency should we use?

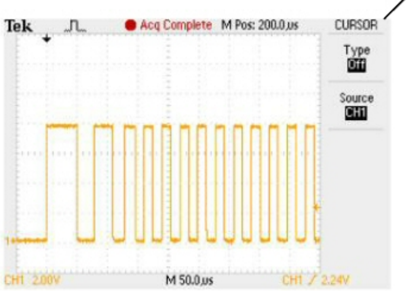
- Some early systems used high frequency sound (ultrasound).
- For example, on the right is a TV remote for a Sony G11 television, manufactured in the late 1970s.



Which frequency should we use?

G11 Ultrasonic remote schematic



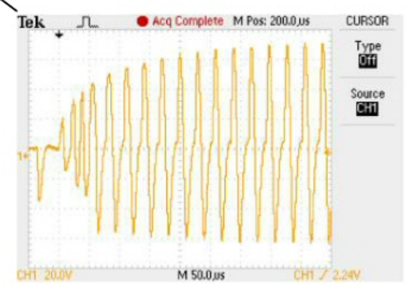


alues Measured with Keithley 2000 series D M

* indicates button pressed

BUTTON TO FREQUENCY TABLE

BRI +	34.65kHz	STANDBY	33.96kHz
BRI -	35.34kHz	RESET	35.00kHz
COL +	36.04kHz	MUTE	34.30kHz
COL -	36.73kHz		
OL +	37.42kHz		
OL -	38.11kHz		
BBC1	44.00kHz	BBC1	42.96kHz
IT	43.66kHz	IT	42.62kHz
BBC2	43.31kHz	CR	42.27kHz



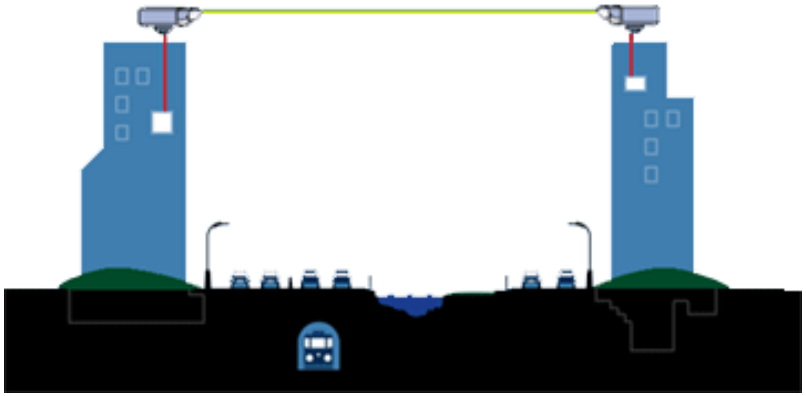
- Can you identify the parts of this circuit?

Which frequency should we use?

- Ultimately, ultrasound is of limited use.
- Ultrasound cannot achieve high data rates.
  - Typically, the bandwidth of a signal is roughly proportional to the centre frequency.
    - Higher frequencies allow higher bandwidth.
  - 4G phone: 5-40 MHz channel and 0.8-2.6 GHz centre frequency.
  - From the last slide, transmission was centred on ~40 kHz. A 5 MHz channel wouldn’t fit!
- Other problems include interference and pets reacting to the sound!

Which frequency should we use?

Free space optics



- TV remotes now use infra-red (IR) light.
- Optical links can achieve high data rates.
- They are also fairly insensitive to interference from other transmitters.
- However, they are easily blocked by obstructions (e.g. buildings) and weather (e.g. rain or fog).
  - We say they require line of sight.
  - Diffraction & absorption depend on frequency.

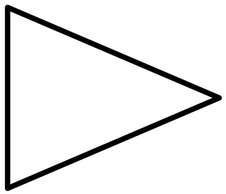
Radio frequencies

Tianjin TV and radio tower

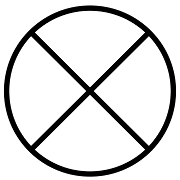
- Most modern radio communications rely on radio frequency or microwave signals.
  - 100 MHz - 30 GHz, most commonly 800 MHz to a few GHz. Some examples:
    - Wifi 2.4 GHz.
    - Mobile phone 1.8 GHz.
    - Digital television 46-230 MHz (Ireland)
    - Digital television 48.5-215 MHz (China).
  - These frequencies can penetrate obstacles like buildings and fog, and can achieve high data rates.
- Note: the bands depend on country – the radio spectrum is regulated by national laws.

Symbols we will use

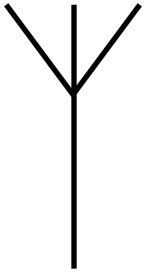
- Amplifier



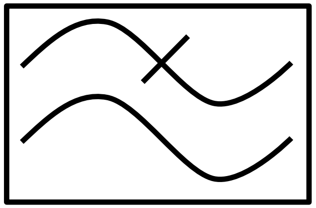
- Mixer



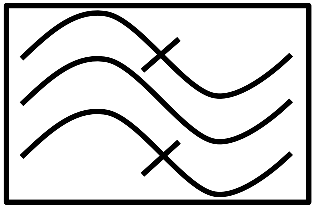
- Antenna



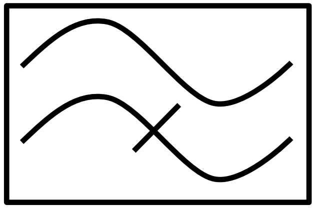
- Low pass filter



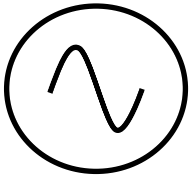
- Band pass filter



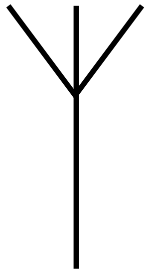
- High pass filter



- Oscillator

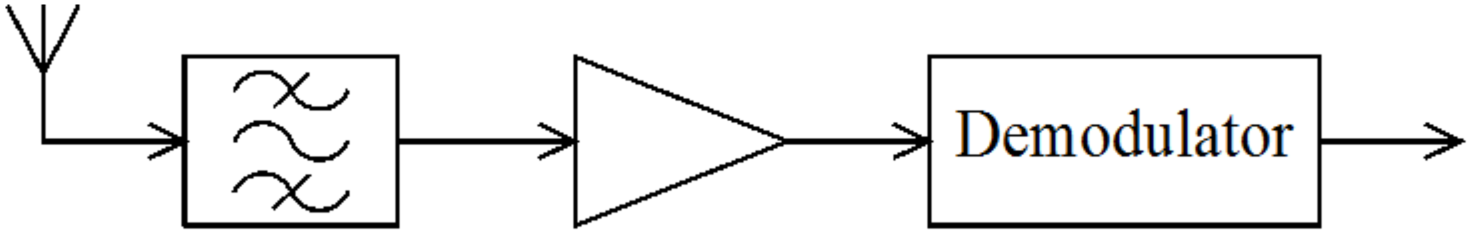


Antenna



- An antenna is an interface between a radio signal and an electrical circuit.
- Later in the course, we will discuss how they work in more detail.

Simple Receiver Structure

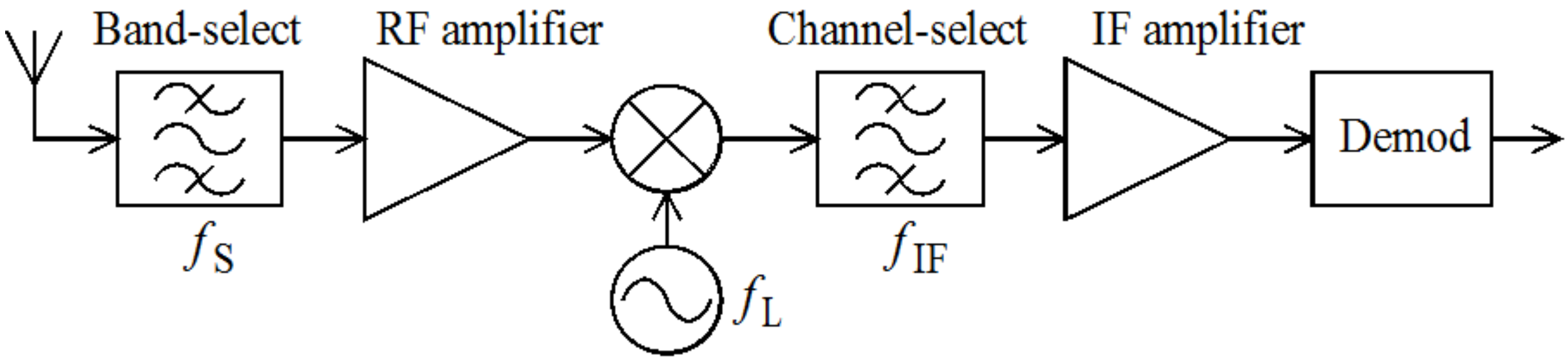


- This example works at fixed frequency, so it can only receive on one channel.
- The received signal is often very small, so we need to amplify it so the demodulator will work properly.
- We need filter to make sure we only have the wanted signal.
- The filter goes first, to protect the amplifier.

- Why do we need to protect the amplifier?
- One of the major themes of this course is that it’s difficult to build circuits at radio frequencies.
- In this case, the amplifier may be approximately linear only for certain frequencies.
- If we allow a signal at the wrong frequencies to enter the amplifier, it may interfere with the signal we care about.

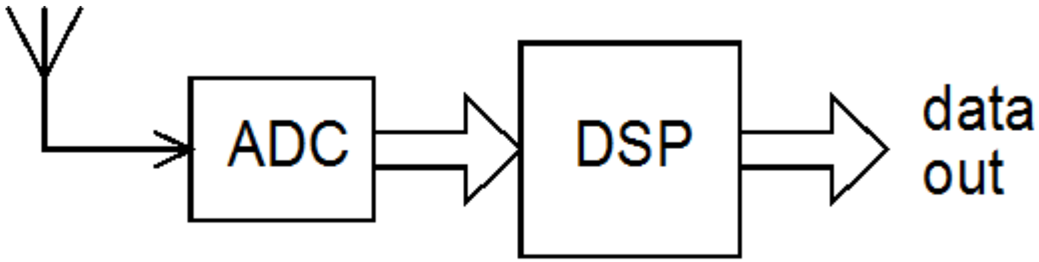
- Another problem is that the filter has to work at radio frequencies.
- We can make such a filter, but it is difficult to make a very good one, especially if it is adjustable.
- This means that the wrong signals may leak into the amplifier after all, especially if one of the unwanted signals is relatively powerful.
  - This often happens at RF, e.g. a base station must be able to listen to a far away phone even if a nearby phone is also transmitting.

Superheterodyne Receiver



- This is a superheterodyne receiver.
  - Invented in 1918 by Major Edwin Armstrong.
- The mixer and oscillator perform frequency shifting
  - move the wanted signal to the *intermediate frequency* (IF).
  - only early part of receiver has to work at radio frequencies.

Software defined radio



- Software defined radio means connecting the antenna directly to a computer via an analogue-to-digital converter (ADC), which samples and quantizes it.
- The computer performs all of the remaining operations required of a receiver in software.

Software-defined radio

- In theory, most of the parts of a transmitter (and receiver) can be done on a computer.
  - Filtering, amplification, frequency conversion, demodulation.
- This would be useful because it would be very flexible.
  - Can just change settings file instead of circuit.
- In practice, much of the transmitter (and receiver) remain analogue because we need high sampling rates and dynamic range, among other problems.

- In the coming lectures, we will see how these components work.
  - Mixers
  - Oscillators
  - Amplifiers
  - Filters (and noise).
- Then we will return to the bigger picture.

Course outline

Teaching	
Lectures	Thursdays: 15.25 TB4 1-15 Mondays: 13:30 TB4 2~2~14
Tutorials	Instead of selected lectures: will announce in class.
Labs	Wednesdays 8 am Information Bd. Weeks: 4, 6, 12, 14 5, 7, 9, 13

Assessment	
Mid-term (Week 8)	10%
Labs and in class Quizes	20%
Final Exam	70%

Questions are welcome after class, or you can make an appointment to see me by email.

Labs

- 4 Labs
  - Software simulations of Hardware implementations (LTspice)
  - Software processing (Matlab)
  - Pen and Paper Design!

Labs

- Lab 1
  - Frequency Generation
- Lab 2
  - Frequency Shifting
- Lab 3
  - Building a filter
  - Determining filter character tradeoff
- Lab 4
  - Electromag – Leplace’s equation

Labs

- Lab Reporting
  - Cover Sheet (name, student number, title)
  - Well structured
  - Effective headings
  - Neat and clear images
  - Captions on images
  - Results and findings clearly marked