## Topic 4.4.2 – Advanced Radio Receivers

## Learning Objectives:

At the end of this topic you will be able to;

- ☑ explain that an RF amplifier can be used to improve sensitivity;
- ☑ explain that a superheterodyne receiver offers improved selectivity and sensitivity;
- ☑ draw a block diagram of a superheterodyne receiver, consisting of antenna, tuned RF amplifier, mixer, local oscillator, IF Filter, IF amplifier, detector/demodulator, audio amplifier and loudspeaker;
- ☑ appreciate that the IF filter is a preset band pass filter;
- ☑ describe the function of each of these subsystems.

## Advanced AM Radio Receivers

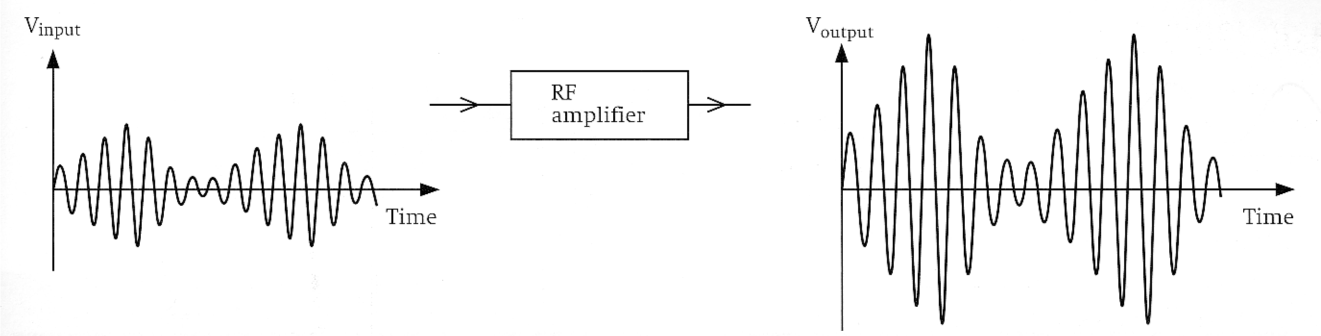
In the previous section, 4.4.1 we looked at the basic functions of an AM radio receiver. During the course of these discussions we discovered two weaknesses of the simple radio receiver.

The first was the lack of sensitivity, or the inability to pick up anything other than very strong radio signals. This usually limits the radio reception of the simple radio described in the last topic to just two or three very local radio stations.

The problem is that radio waves lose energy as they propagate out from the transmitting aerial and the very small signal voltage from the tuned circuit might not be sufficiently large to allow the detector and RF filter to work (in which case the radio will not work either). For these very small signals to be successfully received they must be amplified. This means that we need to build a Radio Frequency Amplifier to boost all of the incoming signals so that there is a chance of being able to pick them out using a tuning circuit.

### The RF amplifier

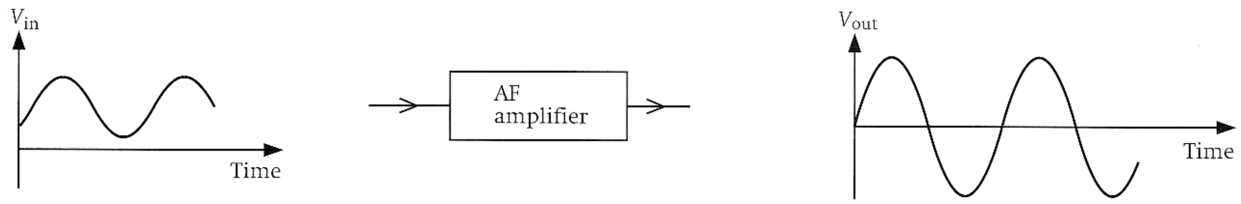
An RF amplifier is designed to enlarge signals that have frequencies much higher than audio frequencies. (RF may be generally taken to mean any frequency greater than 20 kHz.) The RF amplifier is placed after the tuned circuit and before the detector.



Now the RF signal will be much larger and it will be possible to select more stations than without the RF Amplifier. The radio has better sensitivity but has the same selectivity as the Simple Radio Receiver, because cross talk from adjacent radio stations is also amplified with the selected channel. The addition of an Audio Frequency Amplifier after the RF Filter will allow the output to be passed through to a loudspeaker, instead of headphones.

**The AF amplifier**

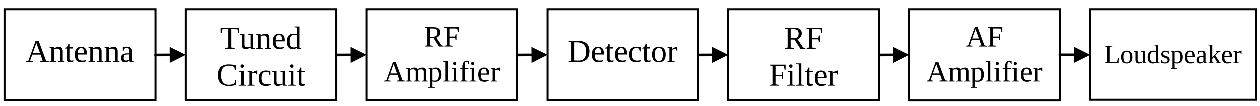
The output from the demodulator is a small audio-frequency voltage. This output voltage would be too feeble to drive a loudspeaker. The audio frequency amplifier boosts the output signal in order to drive the loudspeaker. An AF amplifier helps to reduce cross talk slightly because it has a very high input impedance, which reduces the loading effect on the tuned circuit. This is shown below.




An AF amplifier is designed to enlarge signals at frequencies in the audio frequency range (20 to 20 kHz).

The addition of the RF and AF amplifiers means that a power supply is needed to operate these amplifiers. The power supply connections are not shown on the block diagrams. Even with this RF and AF amplification the improved radio receiver is not very effective.

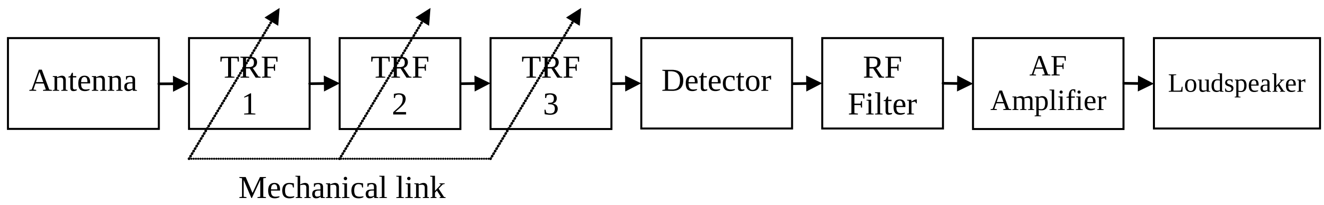
The improved Radio Receiver block diagram is as shown below.



This improved radio receiver still has several limitations.

- The required station is only being selected by one tuned circuit and this is not very good at separating stations which are transmitting on frequencies which are close to each other.
- A single tuned circuit is not very good at selecting a weak station if there is a strong station nearby.

To over come this poor selectivity in the early days of radio many receiver designs were produced which tried to overcome this problem.
Engineers experimented with adding more and more tuning circuits and RF amplifiers to improve the ability of a radio to receive even very weak radio signals. These efforts resulted in the development of the tuned radio frequency (TRF) radio. The block diagram for this system is shown on the following page.

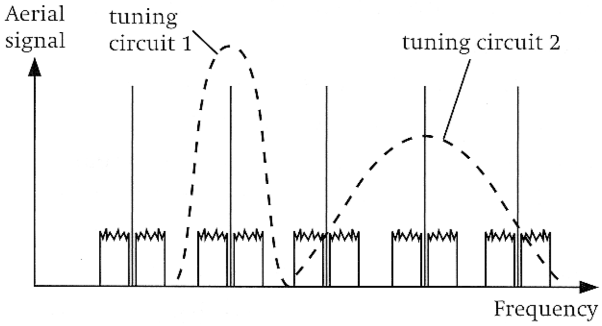



In the TRF radio receiver above there are three tuned RF amplifier circuits which amplify and select a particular carrier frequency. For any output to be heard from the loudspeaker all **three** tuned amplifier circuits must select exactly the same frequency, and hence the reason for the mechanical link between each of the three TRF stages. All three variable capacitors are mounted on the same shaft so that when one is altered the other two change to the same position at the same time.

The need to manufacture three identical tuning circuits and amplifiers and to set up each individual radio set made these radio sets very expensive, especially as building RF amplifiers that could track across the wide range of frequencies used to broadcast radio was very difficult.

The TRF radio succeeded in improving the ability of the radio to select and tune in even weak radio signals but it only made a very small improvement to the second problem encountered with the simple radio set, i.e. the ability to reject nearby stations.

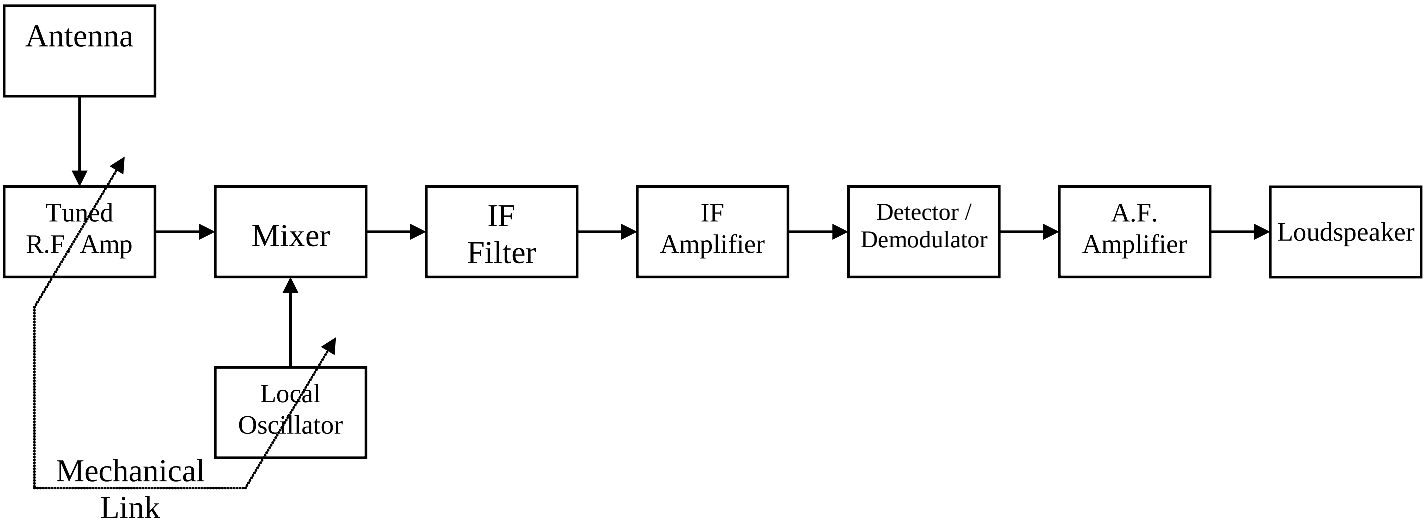
In topic 4.1.1 we looked at the following diagram which illustrates this problem.




In order to be very selective we need the response of tuning circuit 1, where only a single carrier and its sidebands are covered by the response curve which excludes all other signals. Tuning circuit 2 on the other hand is highly undesirable because it is not selective, even though it is centred on a single carrier frequency, it spreads and includes the sidebands of two additional radio stations. This will result in a very unsatisfactory output because there will be interference from the other stations on the main radio signal.

Unfortunately trying to make tuned circuits that can cover the entire range of radio frequencies and have very tight characteristics as shown by tuning circuit 1 is very difficult, and therefore the TRF radio receiver became obsolete relatively quickly.

The next stage of radio development was the creation of the Superheterodyne Receiver or Superhet. This receiver overcame both the issues of the lack of sensitivity and selectivity. The block diagram of the superheterodyne receiver is as follows:




Some parts of the block diagram you will recognise from either the simple radio receiver or the TRF receiver, but we will look at each block in turn.

**Antenna**

As with all radio stations, the antenna will pick up the electromagnetic radio waves from the atmosphere and convert these into very small electrical currents.

**Tuned R.F. Amplifier.**

This block amplifies the very small currents created in the antenna, to improve the sensitivity of the radio receiver, in the same way that it was used in the TRF radio.

**Local Oscillator.**

A new addition to the superhet radio. This is a sine wave generator which is mechanically linked to the tuning capacitor. This ensures that it always produces a frequency at a fixed amount above the resonant frequency of the tuned amplifier. This is typically in the range 450 kHz to 480 kHz.

**Mixer.**

Again a new addition to the superhet radio, but is the critical addition, as it combines the received modulated radio frequency carrier ($f_c$) from the R.F.Amplifier, and the Local Oscillator ($f_o$). The output of the mixer produces at its output four different frequency signals containing the following frequencies, $f_c$, $f_o$-$f_c$, $f_o$+$f_c$, $f_o$. Three of these frequencies $f_c$, $f_o$-$f_c$, $f_o$+$f_c$ are amplitude modulated signals each containing all the information about the original audio signal. The only one that does **not** contain the original signal is $f_o$, the local oscillator frequency which is a pure sine wave. The most important of these is $f_o$-$f_c$ because irrespective of the carrier frequency that is tuned in, this frequency will always be the same, since the output of the local oscillator tracks the carrier frequency tuned in. This modulated frequency is called the **intermediate frequency (I.F.)** and contains the audio signal from the original radio station no matter what station is tuned in.

e.g.

a. If the carrier frequency $f_c$ = 1.4MHz and local oscillator frequency $f_o$ = 1.85MHz then the frequencies produced at the output of the mixer will be

$f_c$ = **1.4 MHz.**
$f_o$-$f_c$ = 1.85 MHz – 1.4 MHz = 0.450 MHz = **450 kHz.**
$f_o$+$f_c$ = 1.85 MHz + 1.4 MHz = **2.25 MHz.**
$f_o$ = **1.85 MHz**

b. If the carrier frequency changes to $f_c$ = 1.1MHz determine the new frequencies produced at the output of the mixer.

We know that local oscillator frequency tracks the carrier frequency.
From part a we see that $f_o$ is 450kHz *above* $f_c$
so $f_o$ = 1.1MHz + 450kHz = 1.55MHz

*and the new frequencies are*

$f_c$ = **1.1 MHz**.
$f_o - f_c$ = 1.55 MHz – 1.1 MHz = 0.450 MHz = **450 kHz**.
$f_o + f_c$ = 1.55 MHz + 1.1 MHz = **2.65 MHz**.
$f_o$ = **1.55 MHz**

Even though $f_c$ and $f_o$ have changed in these two examples $f_o - f_c$ gives an output of 450 kHz.

**IF Filter**

The I.F. Filter is a fixed range band pass filter with very high selectivity, specifically designed to pass only the intermediate frequency. It is this which gives the superheterodyne receiver it's big advantage because no matter what radio station is tuned in, it will be transferred by the mixer to the intermediate frequency and this highly specialised band pass filter will be able to select this single frequency from the four produced by the mixer every time with perfect rejection of the others.

**IF Amplifier.**

This stage provides extra amplification for the signal after the IF filter, and again is carefully designed to provide maximum gain at the IF frequency. The combined effect of the IF filter and IF amplifier give the superheterodyne receiver its excellent selectivity. Commercial radio receivers may have several pairs of IF filters and amplifiers all tuned to an identical IF Frequency. This is often referred to as the IF Strip.

**Detector / demodulator.**

As in the simple radio receiver, the detector/demodulator block contains the diode and RF filter to produce the non-zero signal, and remove the remaining RF carrier.

**AF Amplifier.**

The recovered audio signal is now amplified so that it can provide a meaning full signal to the loudspeaker.

**Loudspeaker.**

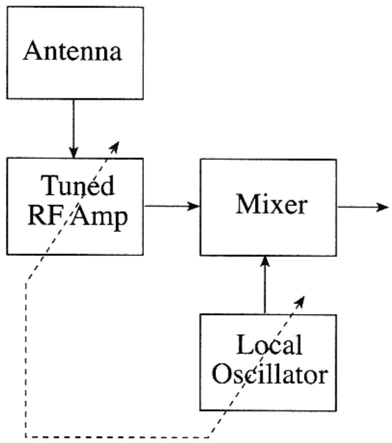
Converts the amplified audio signal into sound.

Examination questions on this topic will be limited to

i. recognition and completion of the block diagram of the superheterodyne receiver.
ii. explanation of how the superheterodyne receiver achieves improved sensitivity and selectivity.
iii. determination of the resonant frequency of the tuned circuit.
iv. design of the IF Filter as a specific example of a band pass filter in the same way as covered in topic 4.2.3 – Resonant Filters.

**Student Exercise 1.**

1. The superheterodyne radio receiver offers improved selectivity and sensitivity compared to the simple radio receiver. The front end of the superheterodyne receiver is shown below:




(a) The tuned RF amplifier has been tuned to a frequency of 1.3 MHz. The local oscillator output is measured at 1.77 MHz. What four frequency signals will be present at the output of the mixer.

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[2]

(b) Which of these frequencies is the intermediate frequency?

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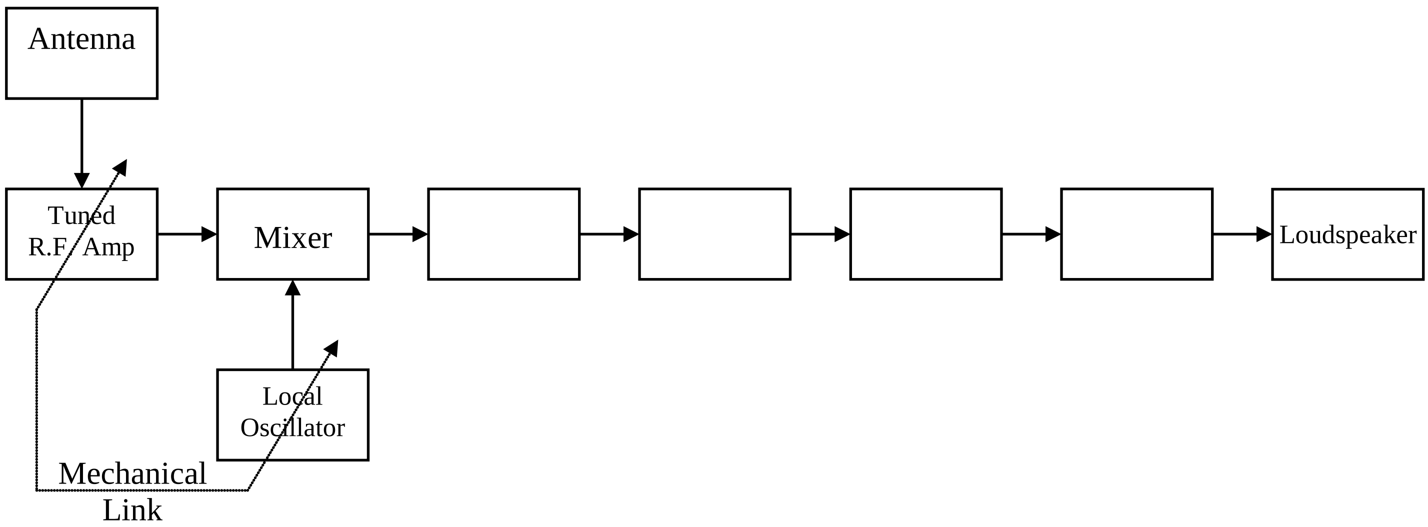
[1]

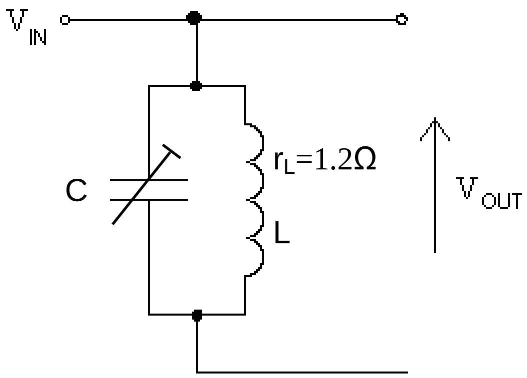
(c) Complete the following block diagram of the full superheterodyne receiver.




[4]

2. The I.F. filter of a superheterodyne receiver is shown below:

The inductor has a resistance $r_L$ of 1.2 Ω. The resonant frequency of the filter must be 465 kHz, with a bandwidth of 8 kHz.




*(a)* Calculate the Q-factor of the circuit.

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*(b)* Use your answer to (a) to determine the value of the inductor L required.

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*(c)* Use your answer to (b) in order to calculate the setting of the preset capacitor required to complete the filter so that resonance occurs at 465 kHz.

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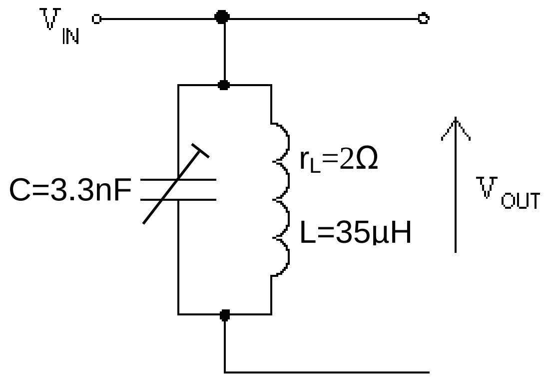
3. The following circuit shows the IF filter of a superheterodyne receiver.




(a) Calculate the resonant frequency of the filter.

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(b) Use your answer to (a) to calculate the Q-factor of the circuit.

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(c) Using your answer to (b) calculate the bandwidth of the filter.

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# Topic 4.4.2 – Advanced Radio Receivers

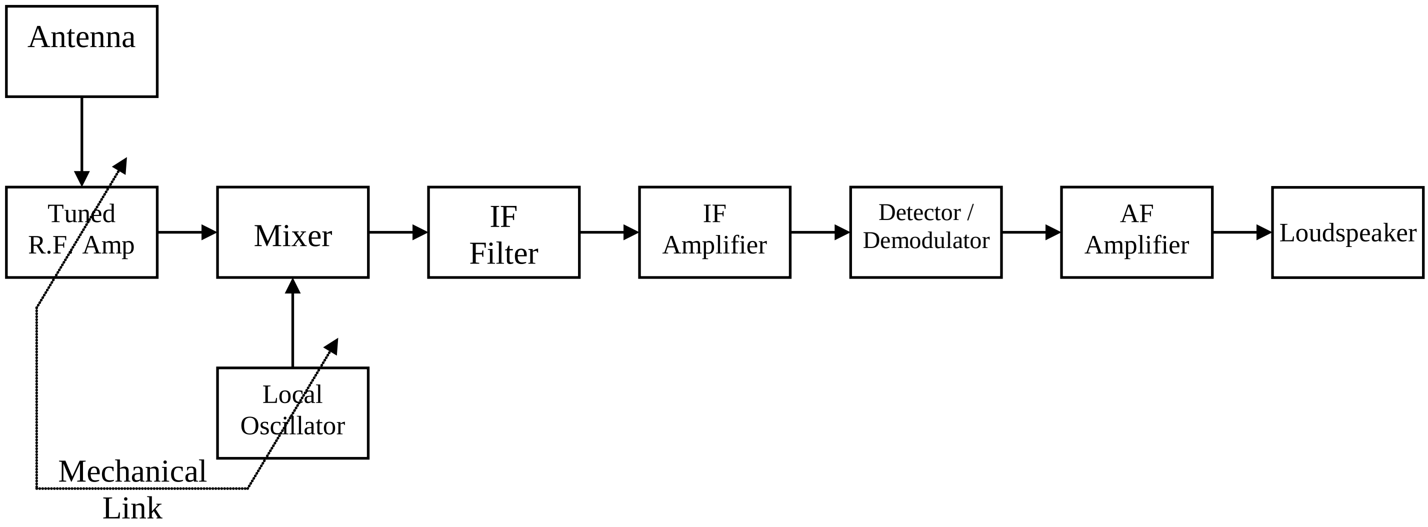
## Solutions to Student Exercise

### Exercise 1.

1. (a) 1.3 MHz, 1.77 MHz, 3.07 MHz, & 0.470 MHz (or 470 kHz)

   (b) 0.470 MHz (or 470 kHz)

   (c)




2. (a) $Q = \frac{f_o}{B} = \frac{465}{8} = 58.125$

   (b)

$$Q = \frac{2\pi f_o L}{r_L}$$

$$L = \frac{Q \times r_L}{2\pi f_o} = \frac{58.125 \times 1.2}{2 \times \pi \times 465 \times 10^3} = 23.87\ \mu\text{H} \approx 24\ \mu\text{H}$$

   (c)

$$C = \frac{1}{4\pi^2 f_o^2 L} = \frac{1}{4 \times \pi^2 \times (465 \times 10^3)^2 \times 24 \times 10^{-6}} = 4.88 \times 10^{-9} = 4.88\ \text{nF}$$

3. (a)

$$f_o = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{35\times10^{-6}\times3.3\times10^{-9}}} = 468305\ \text{Hz} \approx 468\ \text{kHz}$$

(b)

$$Q = \frac{2\pi f_o L}{r_L} = \frac{2\pi\times468\times10^{3}\times35\times10^{-6}}{2} = 51.45$$

(c)

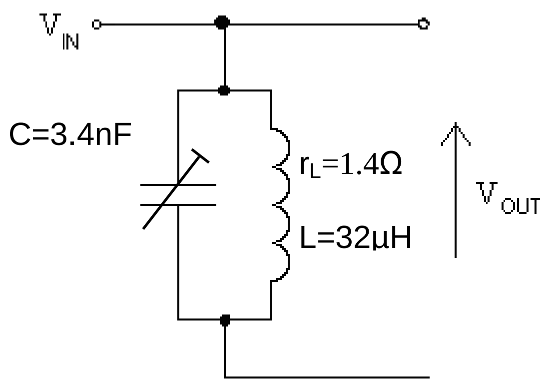
$$Q = \frac{f_o}{B}$$

$$\text{Bandwidth} = \frac{f_o}{Q} = \frac{468000}{51.45} = 9096\ \text{Hz} \approx 9\ \text{kHz}$$

**Now for some examination style questions.**

# Examination Style Questions

1. The following circuit shows the IF filter of a superheterodyne receiver.




(a) Calculate the resonant frequency of the filter.

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(b) Use your answer to (a) to calculate the Q-factor of the circuit.

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(c) Using your answer to (b) calculate the bandwidth of the filter.

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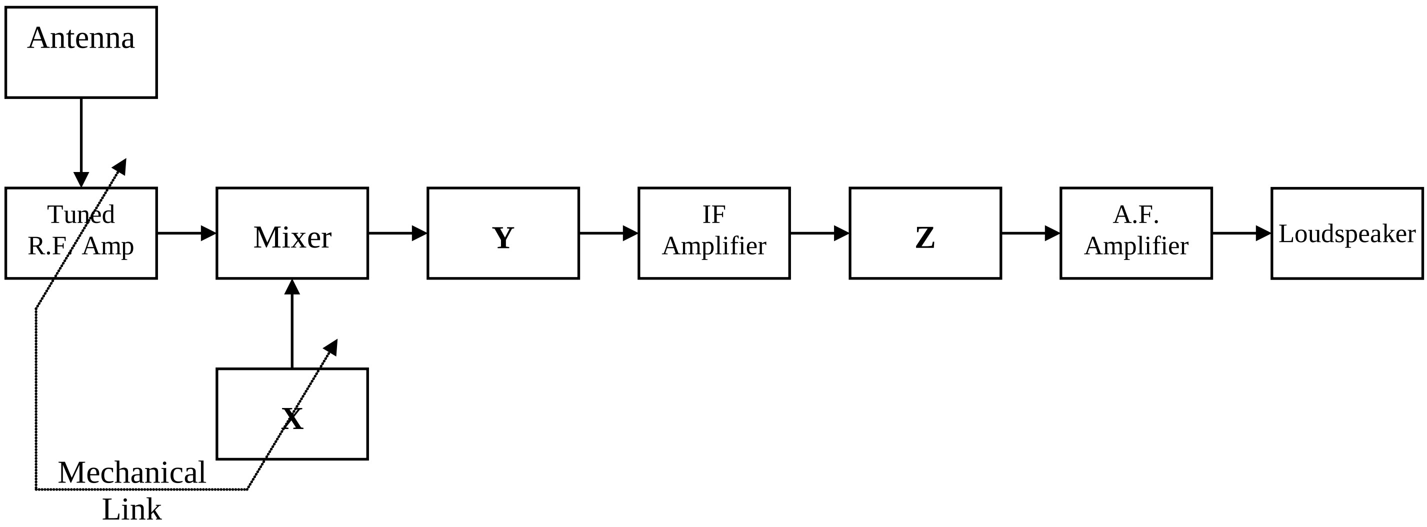
2. Here is the block diagram for a superheterodyne radio receiver.




(a) Identify the blocks labelled X, Y and Z.

X = ........................................................

Y = ........................................................

Z = ........................................................

[2]

(b) Which block increases the sensitivity of this receiver over a *simple radio receiver*?

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[1]

(c) Which block separates the audio signal from the radio frequency carrier?

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[1]

(d) This receiver is designed to use an IF (Intermediate Frequency) of 480 kHz.
The radio is tuned to a radio signal which has a carrier frequency of 1.2 MHz.

(i) What will be the frequency at the output of the local oscillator?

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[1]

(ii) Write down the frequencies of four components present in the output of the mixer.

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(iii) Which of these frequencies will be amplitude modulated?

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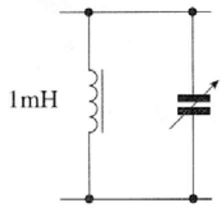
[2]

(e) The diagram shows the tuned circuit for this receiver.




Which of the following tuning capacitors allows the radio to tune to carrier frequencies between 0.8MHz and 2.8MHz.

| Variable Capacitor | Capacitance range |
|---|---|
| A | 2-22 pF |
| B | 3-45 pF |
| C | 5-100 pF |
| D | 15-160 pF |

All calculations must be shown.

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3. The superhet radio receiver has better sensitivity and selectivity than the simple radio receiver.

(a) What is meant by *sensitivity* in this context?

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[1]

(b) Which sub-system in the superhet receiver accounts for the improved *sensitivity*?

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[1]

(c) What is meant by *selectivity* in this context?

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(d) Explain how the superhet receiver achieves improved *selectivity*.

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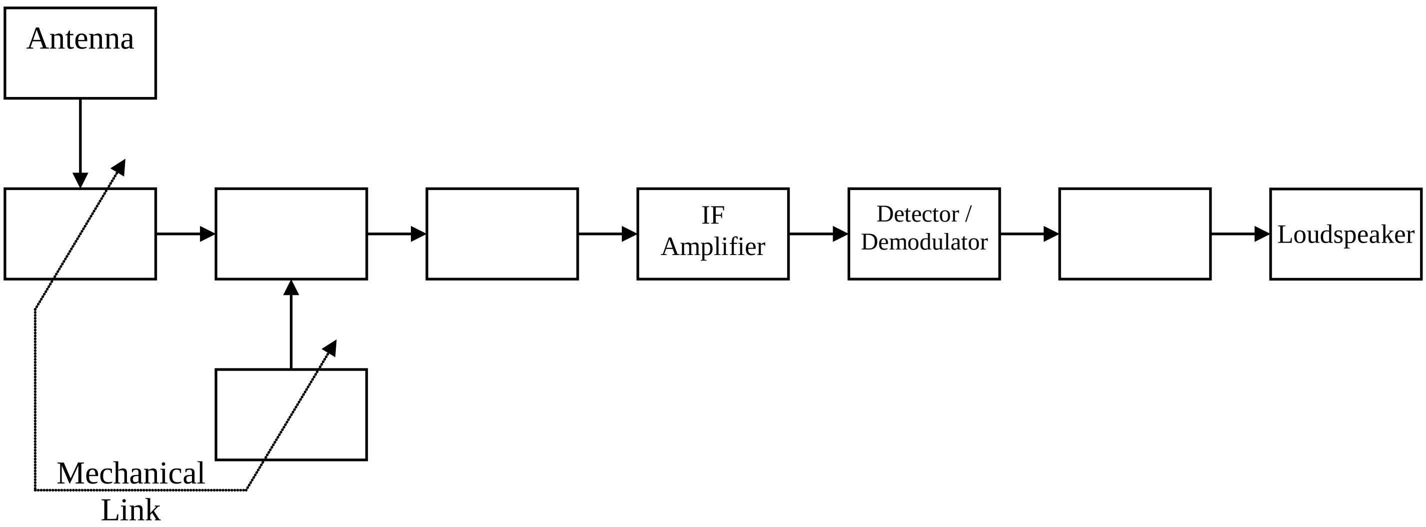
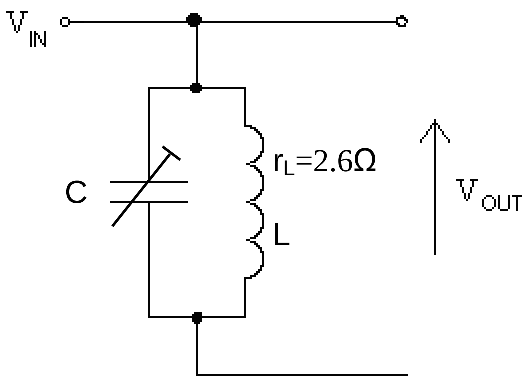
(e) Complete the block diagram of the superheterodyne receiver below.




[5]

4. The I.F. filter of a superheterodyne receiver is shown below:

The inductor has a resistance $r_L$ of 2.6Ω. The resonant frequency of the filter must be 455kHz, with a bandwidth of 8kHz.




*(a)* Calculate the Q-factor of the circuit.

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*(b)* Use your answer to (a) to determine the value of the inductor L required.

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*(c)* Use your answer to (b) in order to calculate the setting of the preset capacitor required to complete the filter so that resonance occurs at 465 kHz.

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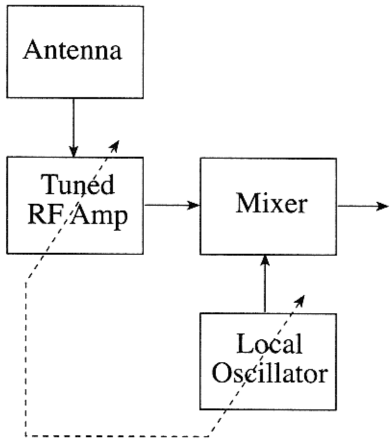
5. The superheterodyne radio receiver offers improved selectivity and sensitivity compared to the simple radio receiver. The front end of the superheterodyne receiver is shown below:




(a) The tuned RF amplifier has been tuned to a frequency of 1 MHz. The local oscillator output is measured at 1.45 MHz. What four frequency signals will be present at the output of the mixer.

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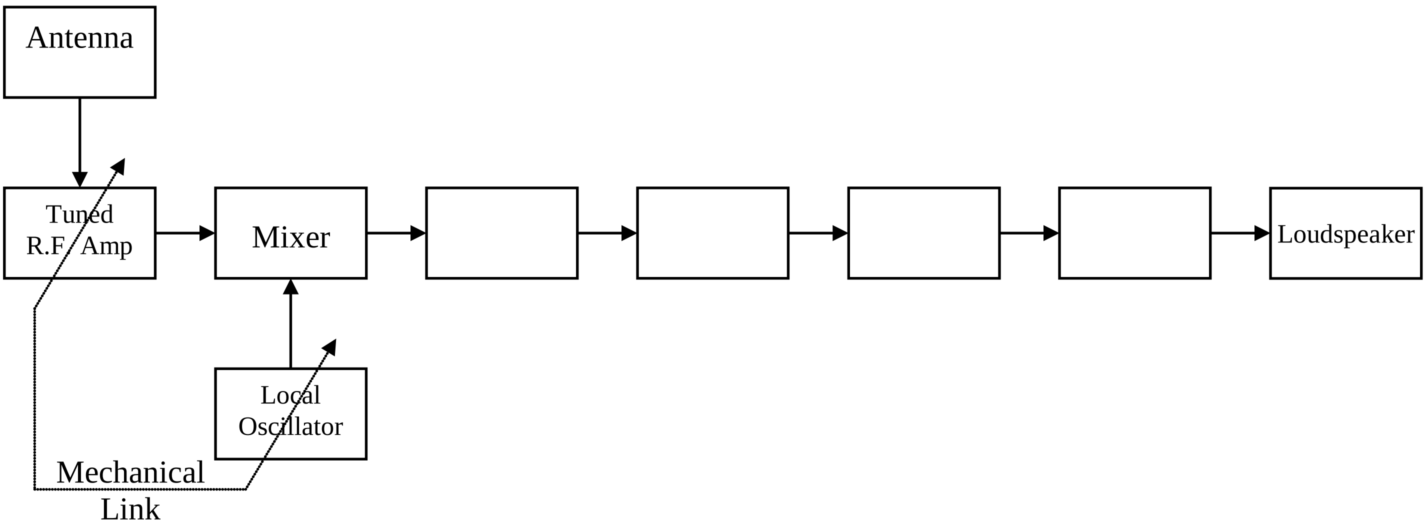
[2]

(b) Which of these frequencies is **not** amplitude modulated? .......................................

[1]

(c) Complete the following block diagram of the full superheterodyne receiver.




[4]

## Topic 4.4.2 – Advanced Radio Receivers

### Self Evaluation Review

| Learning Objectives | My personal review of these objectives: | | |
|---|---|---|---|
| | ☺ | 😐 | ☹ |
| explain that an RF amplifier can be used to improve sensitivity; | | | |
| explain that a superheterodyne receiver offers improved selectivity and sensitivity; | | | |
| draw a block diagram of a superheterodyne receiver, consisting of antenna, tuned RF amplifier, mixer, local oscillator, IF Filter, IF amplifier, detector/demodulator, audio amplifier and loudspeaker; | | | |
| appreciate that the IF filter is a preset band pass filter; | | | |
| describe the function of each of these subsystems. | | | |

Targets: 1. ..................................................................................................................

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2. ..................................................................................................................

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