University of Bahrain

Department of Electrical and Electronics Engineering

EENG372

Communication Systems I

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Topic 2: Receivers

Receiver

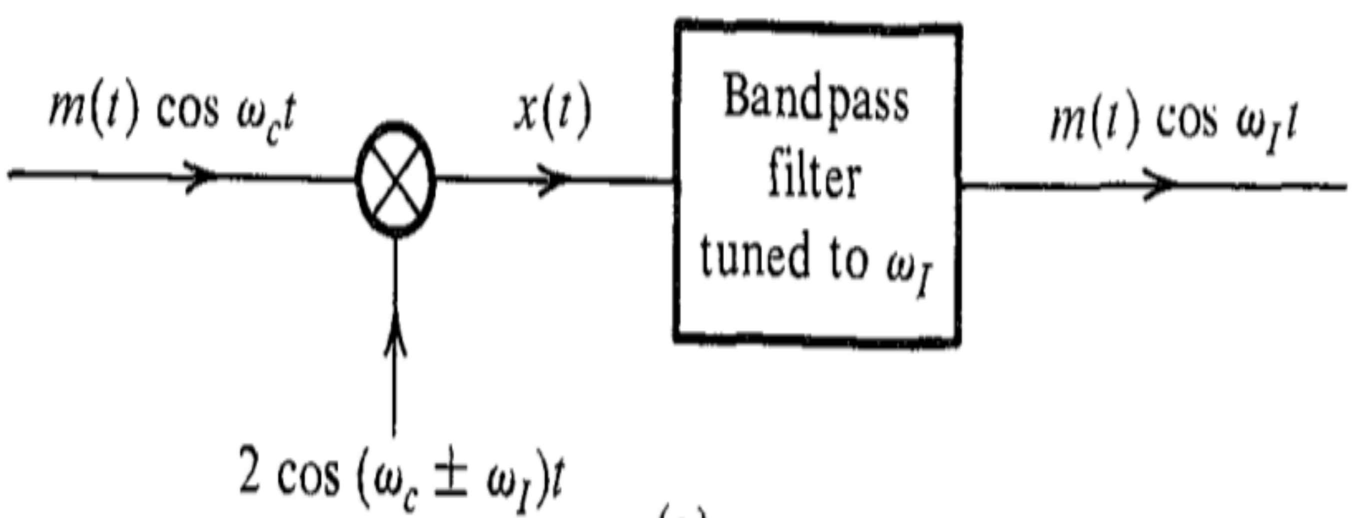
Q: What is a Receiver?

It is the circuit that receives (selects), amplifies and detects the communication signal.

Q: What are the requirements of a Receiver?

1. Selectivity: the ability of the receiver to select a desire communication signal and reject other frequencies.
2. Sensitivity: the ability of the receiver to pick up weak signals. (in the presence of Noise)

Frequency Mixer or Converter (Ex 4-2)



(a)

We shall analyze a frequency mixer, or frequency converter, used to change the carrier frequency of a modulated signal $m(t)\cos\omega_c t$ from ω_c to some other frequency ω_I.

This can be done by multiplying $m(t)\cos\omega_c t$ by $2\cos\ \omega_{\text{mix}}t$, where $\omega_{\text{mix}} = \omega_c + \omega_I$ or $\omega_c - \omega_I$, and then bandpass-filtering the product, as shown in Fig. 4.7a.

The product $x(t)$ is

$$x(t) = 2m(t)\cos\ \omega_c t \cos\ \omega_{\text{mix}} t$$

$$= m(t)[\cos\ (\omega_c - \omega_{\text{mix}})t + \cos\ (\omega_c + \omega_{\text{mix}})t]$$

If we select $\omega_{\text{mix}} = \omega_c - \omega_I$,

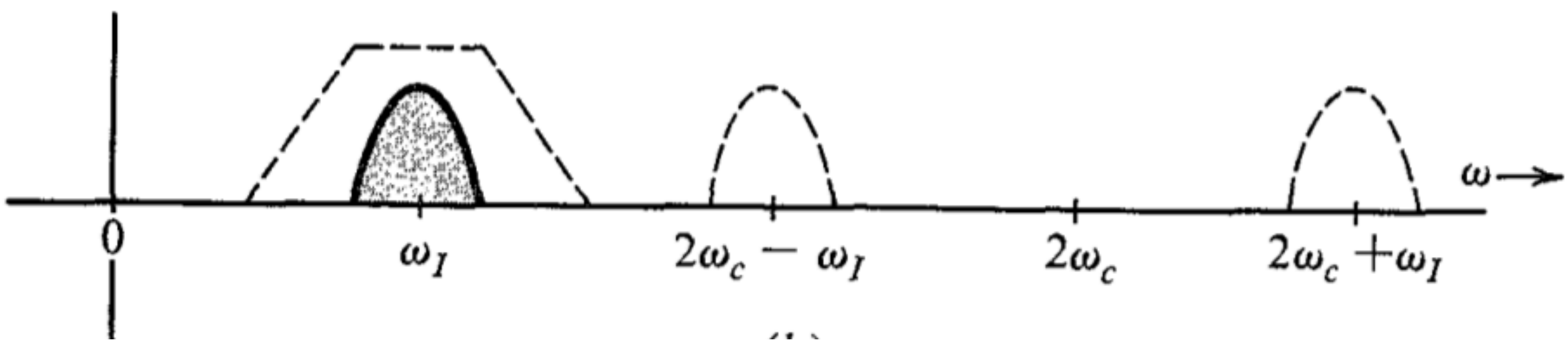
$$x(t) = m(t)[\cos\ \omega_I t + \cos\ (2\omega_c - \omega_I)t]$$

If we select $\omega_{\text{mix}} = \omega_c + \omega_I$,

$$x(t) = m(t)[\cos\ \omega_I t + \cos\ (2\omega_c + \omega_I)t]$$

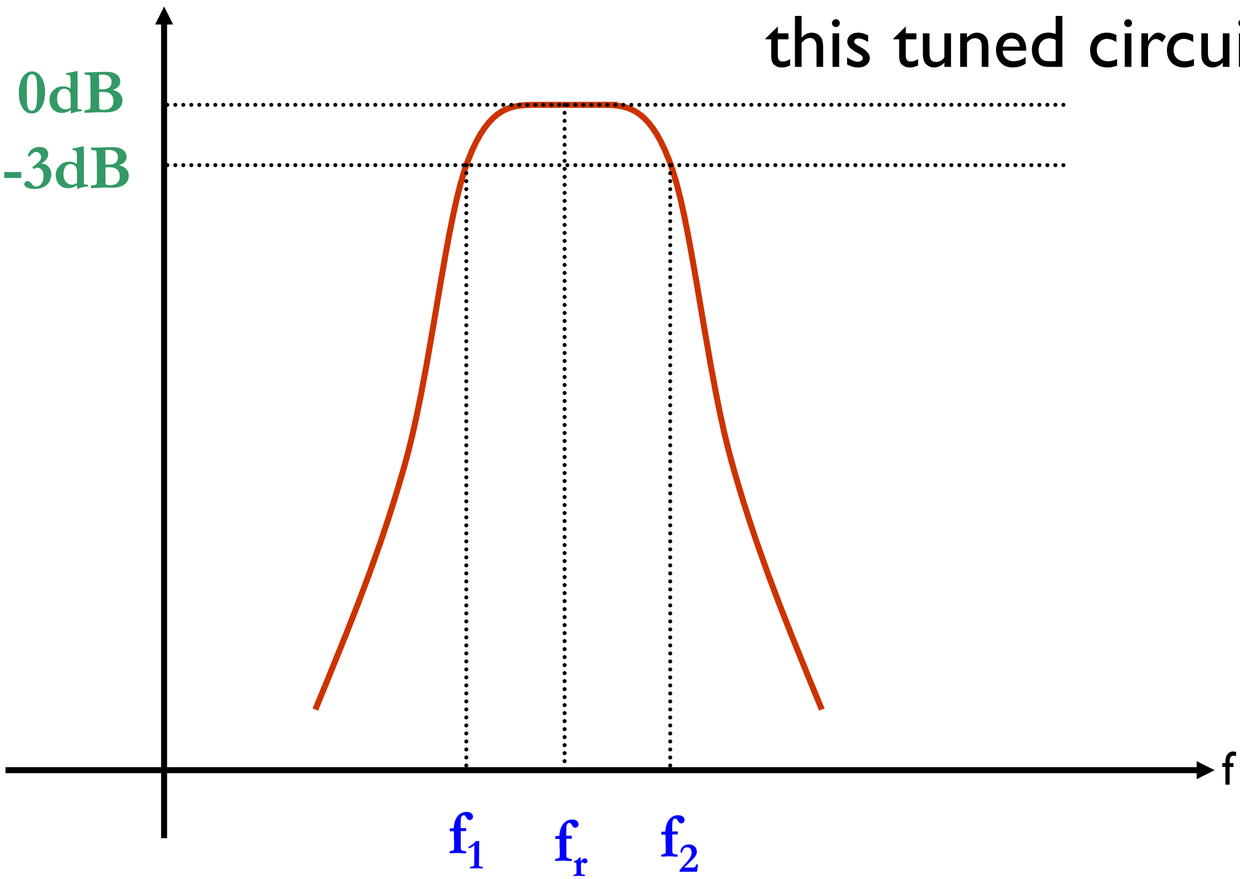
In either case, a bandpass filter at the output, tuned to ω_I, will pass the term $m(t)\cos\ \omega_I t$ and suppress the other term, yielding the output $m(t)\cos\ \omega_I t$.* Thus, the carrier frequency has been translated to ω_I from ω_c.

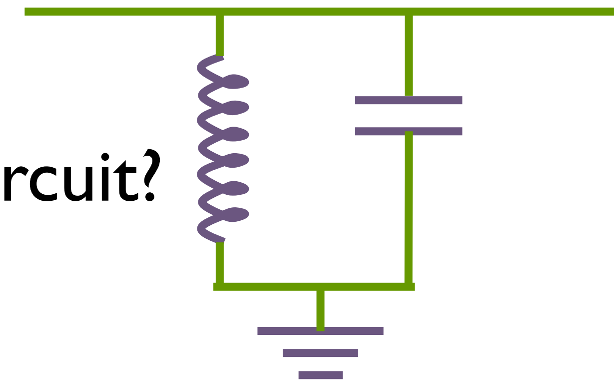
The operation of frequency mixing, or frequency conversion (also known as hetero-dyning), is identical to the operation of modulation with a modulating carrier frequency (the mixer oscillator frequency ω_{mix}) that differs from the incoming carrier frequency by ω_I. Any one of the modulators discussed earlier can be used for frequency mixing. When we select the local carrier frequency $\omega_{mix} = \omega_c + \omega_I$, the operation is called **up-conversion**, and when we select $\omega_{mix} = \omega_c - \omega_I$, the operation is **down-conversion**.



Tunable Band Pass filter

Q: What is the response of this tuned circuit?





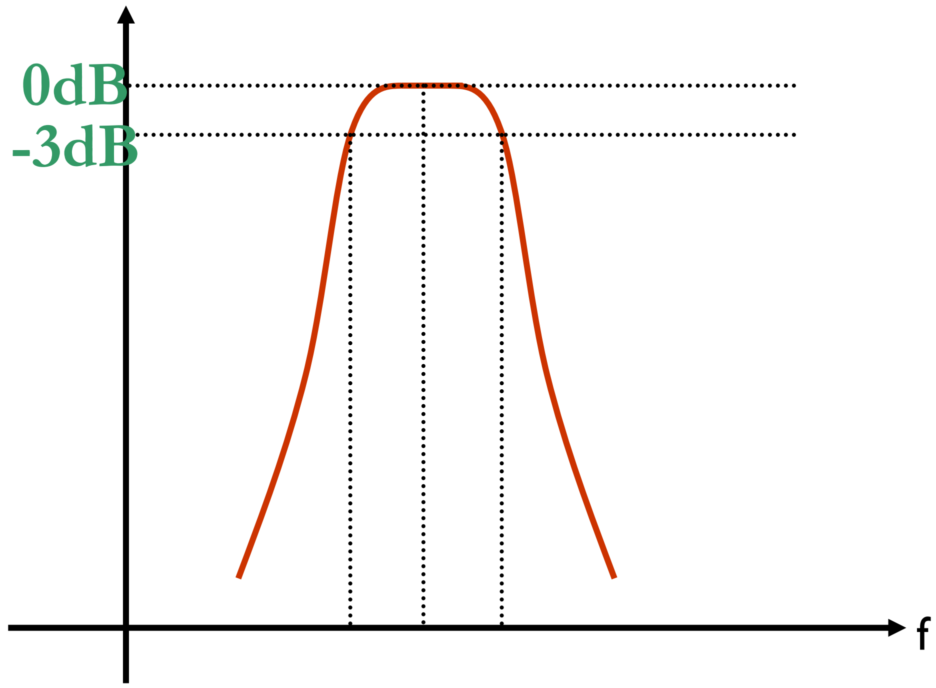
$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$Q = \frac{X_L}{R} = \frac{2\pi f_r L}{R}$$

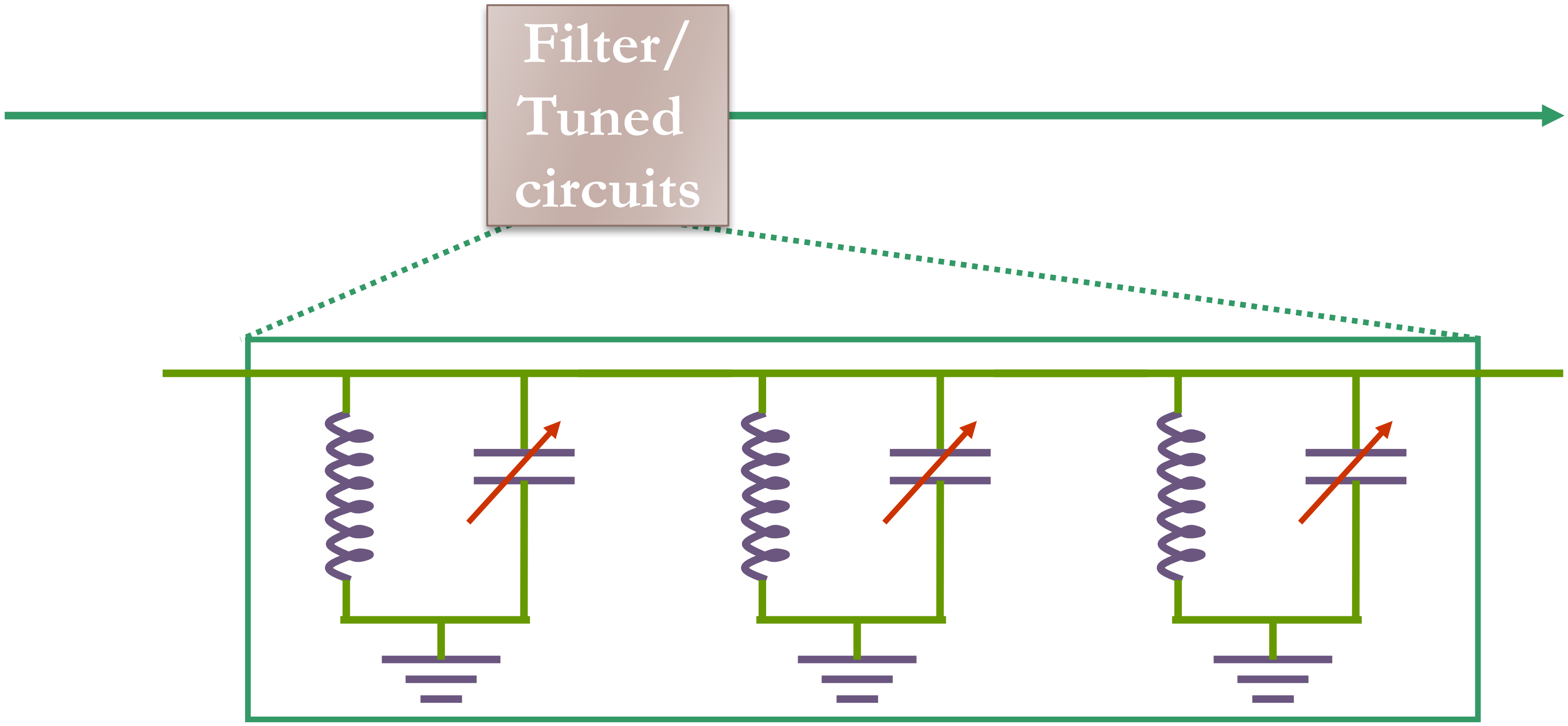
$$BW = \frac{f_r}{Q}$$

Tunable Band Pass filter

Example: Find the resonance frequency, Quality Factor and BW of the following tuning circuit where L=10μH, R_L = 20Ω and C=101.4pF?

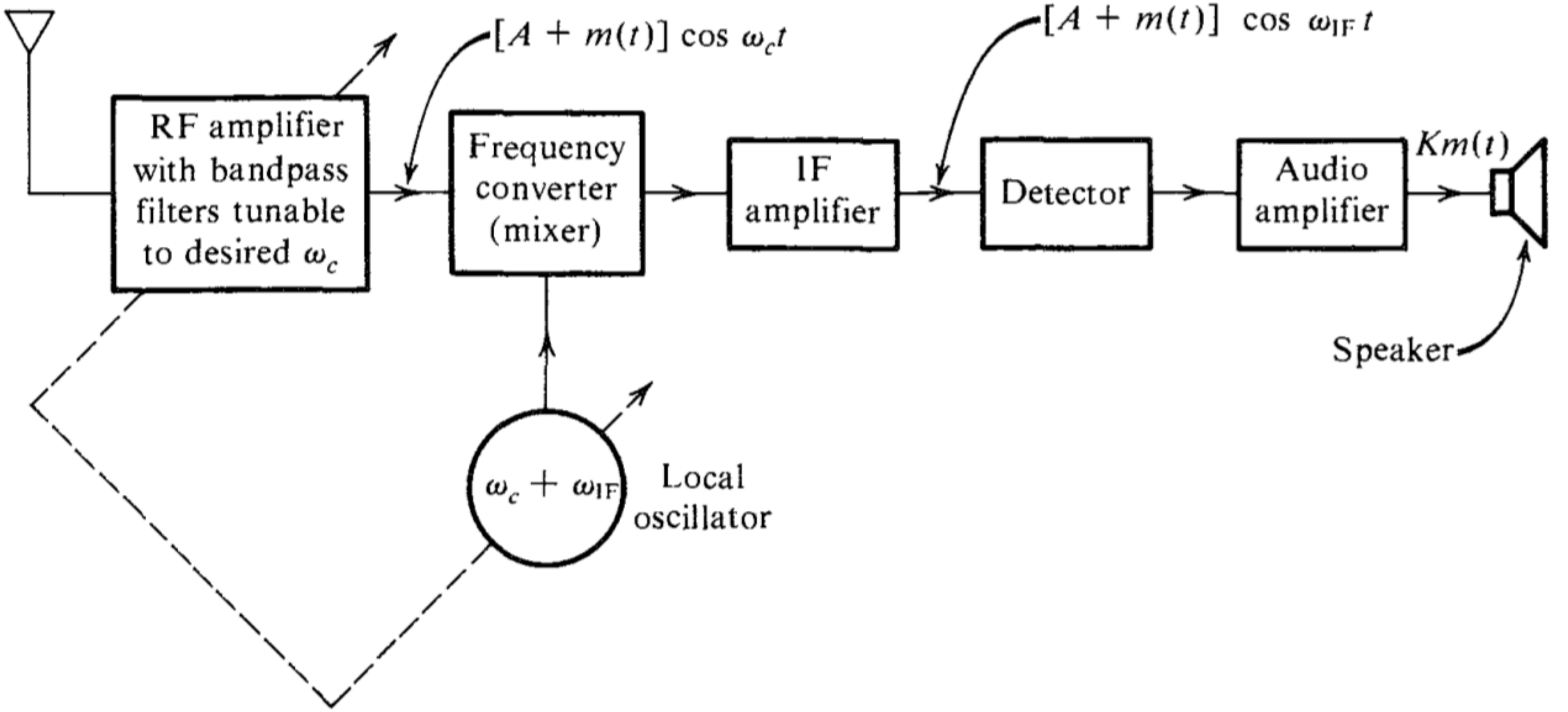


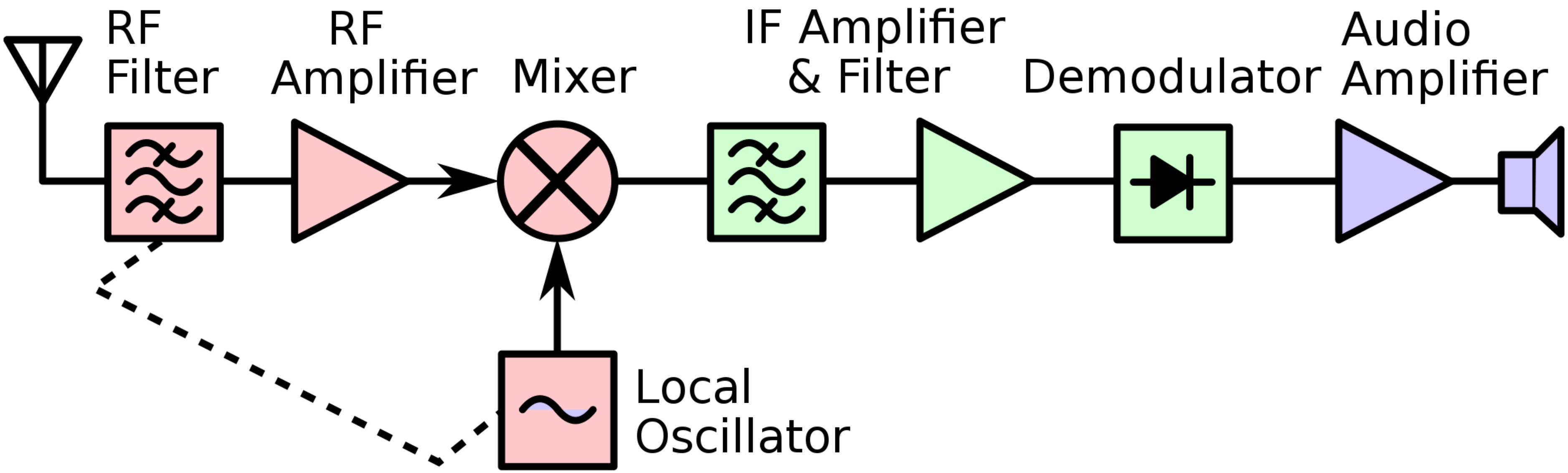
Filter / Tuned Circuits (more selectivity)



To get better selectivity several tank circuits are used

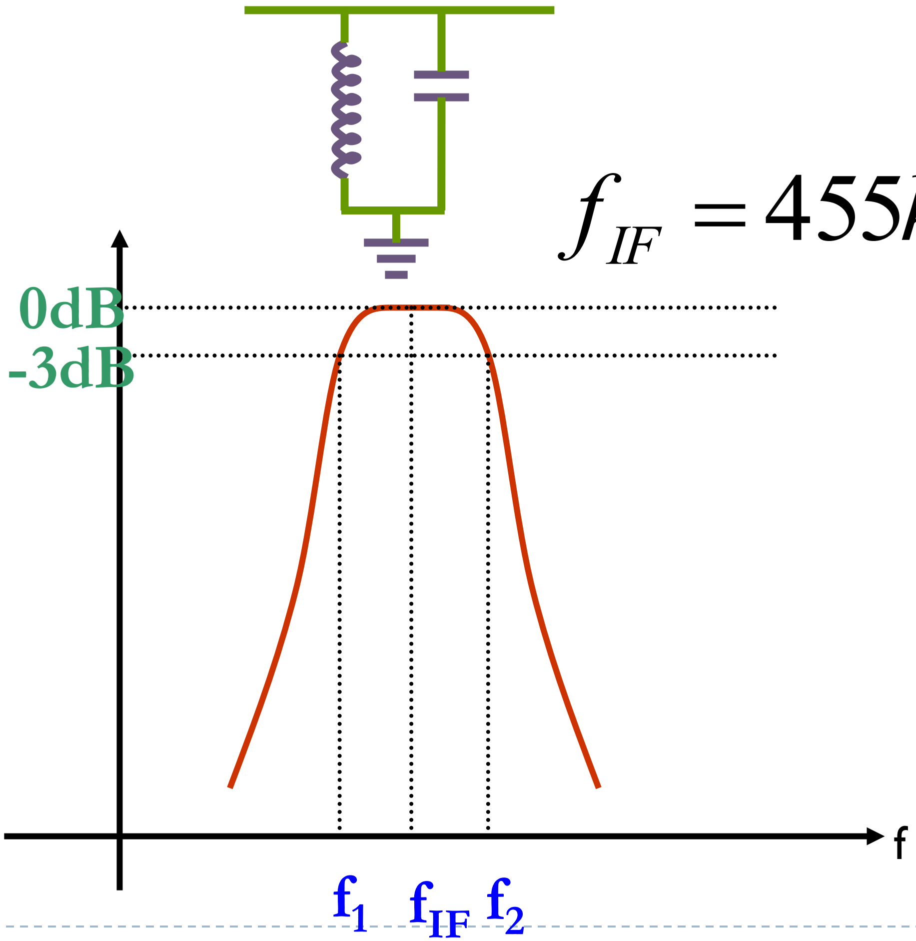
Superheterodyne Analog AM/FM Receiver




RF
Filter
RF
Amplifier
Mixer
IF Amplifier
& Filter
Demodulator
Audio
Amplifier
Local
Oscillator

Superheterodyne Receiver

Q: Design the tank circuit for BW = 10kHz ?



$$f_{IF} = 455kHz$$

The IF amplifier than selects the

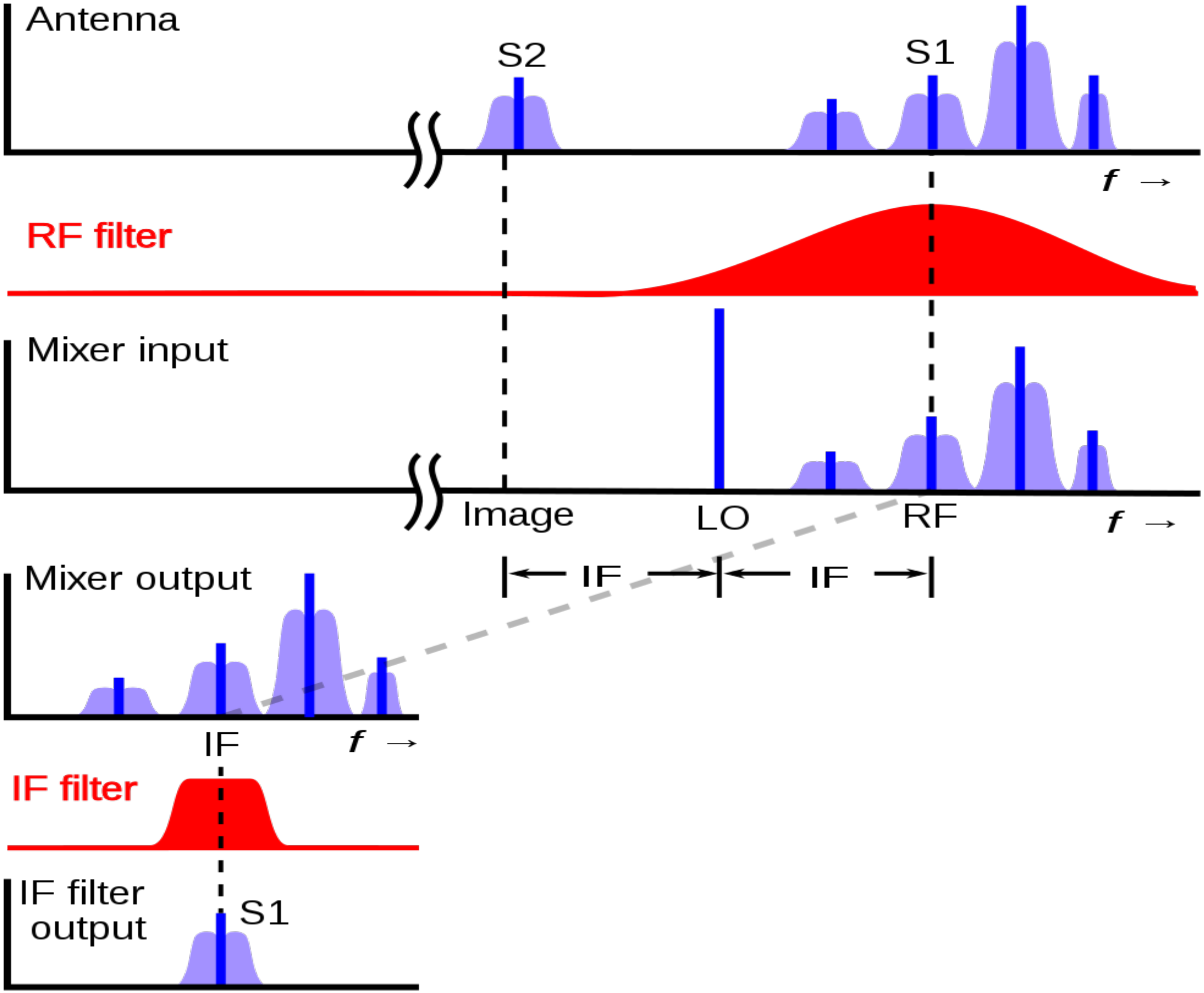
Using a tuning circuit with the following response

$$f_{diff} = f_{LO} - f_{RF}$$

$$f_r = f_{diff} = f_{IF} = \frac{1}{2\pi\sqrt{LC}}$$

$$Q = \frac{X_L}{R} = \frac{2\pi f_r L}{R}$$

$$BW = \frac{f_r}{Q}$$


Antenna
S2
S1
f →
RF filter
Mixer input
Image
LO
RF
f →
IF
IF
Mixer output
IF
f →
IF filter
IF filter output
S1

Superheterodyne Receiver (why RF Filter ?)

Q: Why do we need the RF Amplifier /Filter ?

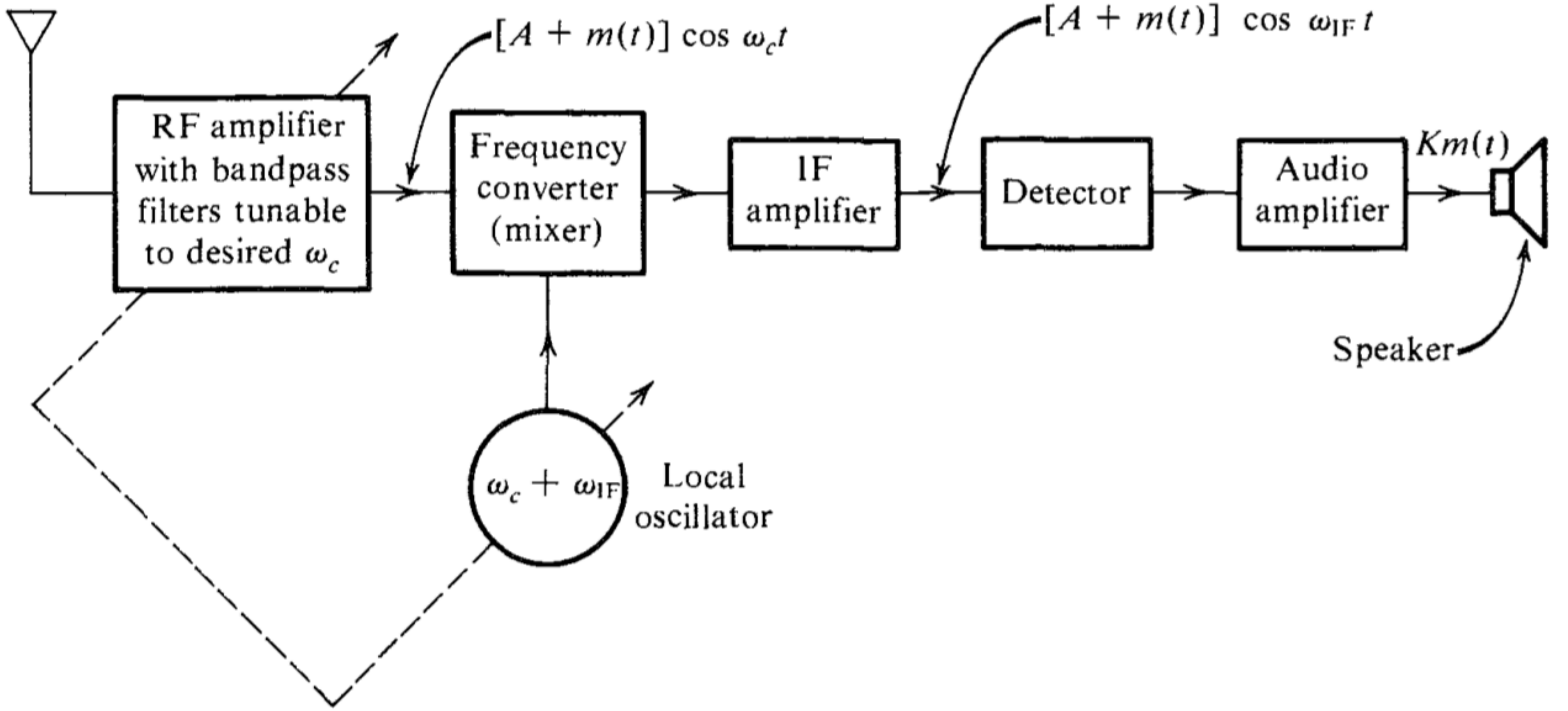
$$f_{LO} = f_{RF\ desired} + 455kHz = 1000 + 455 = 1455kHz$$

Image frequency

f_{RF}	$1000kHz$	$1910kHz$
f_{diff}	$f_{diff} = 455kHz$	$f_{diff} = 455kHz$
f_{Sum}	$f_{Sum} = 1910kHz$	$f_{Sum} = 3365kHz$

So the RF filter removes image frequencies

Superheterodyne Analog AM/FM Receiver



The RF section is basically a tunable filter and an amplifier that picks up the desired station by tuning the filter to the right frequency band. The next section, the frequency mixer (converter), translates the carrier from ω_c to a fixed IF frequency of 455 kHz (see Example 4.2 for frequency conversion). For this purpose, it uses a local oscillator whose frequency f_{LO} is exactly 455 kHz above the incoming carrier frequency f_c; that is, $f_{LO} = f_c + f_{IF}$ ($f_{IF} =$ 455 kHz). Note that this is up-conversion. The tuning of the local oscillator and the RF tunable filter is done by one knob. Tuning capacitors in both circuits are ganged together and are designed so that the tuning frequency of the local oscillator is always 455 kHz above the tuning frequency of the RF filter. This means every station that is tuned in is translated to a fixed carrier frequency of 455 kHz by the frequency converter.

The reason for translating all stations to a fixed carrier frequency of 455 kHz is to obtain adequate selectivity. It is difficult to design sharp bandpass filters of bandwidth 10 kHz (the modulated audio spectrum) if the center frequency f_c is very high. This is particularly true if this filter is tunable. Hence, the RF filter cannot provide adequate selectivity against adjacent channels. But when this signal is translated to an IF frequency by a converter, it is further amplified by an IF amplifier (usually a three-stage amplifier), which does have good selectivity. This is because the IF frequency is reasonably low, and, second, its center frequency is fixed

and factory-tuned. Hence, the IF section can effectively suppress adjacent-channel interference because of its high selectivity. It also amplifies thc signal for envelope detection.

In reality, practically all of the selectivity is realized in the IF section; the RF section plays a negligible role. The main function of the RF section is image frequency suppression. As observed in Example 4.2, the mixer, or converter, output consists of components of the difference between the incoming (f_c) and the local-oscillator (f_{LO}) frequencies (that is, $f_{IF} = |f_{LO} - f_c|$). Now, if the incoming carrier frequency f_c = 1000 kHz, then $f_{LO} = f_c + f_{RF} = 1000 + 455 = 1455$ kHz. But another carrier, with $f_c' = 1455 + 455 = 1910$ kHz, will also be picked up because the difference $f_c' - f_{LO}$ is also 455 kHz. The station at 1910 kHz is said to be the **image** of the station of 1000 kHz. Stations that are $2f_{IF} = 910$ kHz apart are called **image stations** and would both appear simultaneously at the IF output if it were not for the RF filter at receiver input. The RF filter may provide poor selectivity against adjacent stations separated by 10 kHz, but it can provide reasonable selectivity against a station separated by 910 kHz. Thus, when we wish to tune in a station at 1000 kHz, the RF filter, tuned to 1000 kHz, provides adequate suppression of the image station at 1910 kHz.

The receiver (Fig. 4.28) converts the incoming carrier frequency to the IF frequency by using a local oscillator of frequency f_{LO} higher than the incoming carrier frequency (up-conversion) and, hence, is called a superheterodyne receiver. The principle of superheterodyning, first introduce by E. H. Armstrong, is used in AM and FM as well as in television receivers. The reason for up-conversion rather than down-conversion is that the former leads to a smaller tuning range (smaller ratio of the maximum to minimum tuning frequency) for the local oscillator than does the latter. The broadcast-band frequencies range from 550 to 1600 kHz. The up-conversion f_{LO} ranges from 1005 to 2055 kHz (ratio of 2.045) , whereas the down-conversion range of f_{LO} would be 95 to 1145 kHz (ratio of 12.05). It is much easier to design an oscillator that is tunable over a smaller frequency ratio.

The importance of the superheterodyne principle cannot be overstressed in radio and television broadcasting. In the early days (before 1919), the entire selectivity against adjacent stations was realized in the RF filter. Because this filter has poor selectivity, it was necessary to use several stages (several resonant circuits) in cascade for adequate selectivity. In the earlier receivers each filter was tuned individually. It was very time-consuming and cumbersome to tune in a station by bringing all resonant circuits into synchronism. This was improved upon as variable capacitors were ganged together by mounting them on the same shaft rotated by one knob. But variable capacitors are bulky, and there is a limit to the number that can be ganged together. This limited the selectivity available from receivers. Consequently, adjacent carrier frequencies had to be separated widely, resulting in fewer frequency bands. It was the superheterodyne receiver that made it possible to accommodate many more radio stations.