FREQUENCY CONVERTERS

Lecture 6

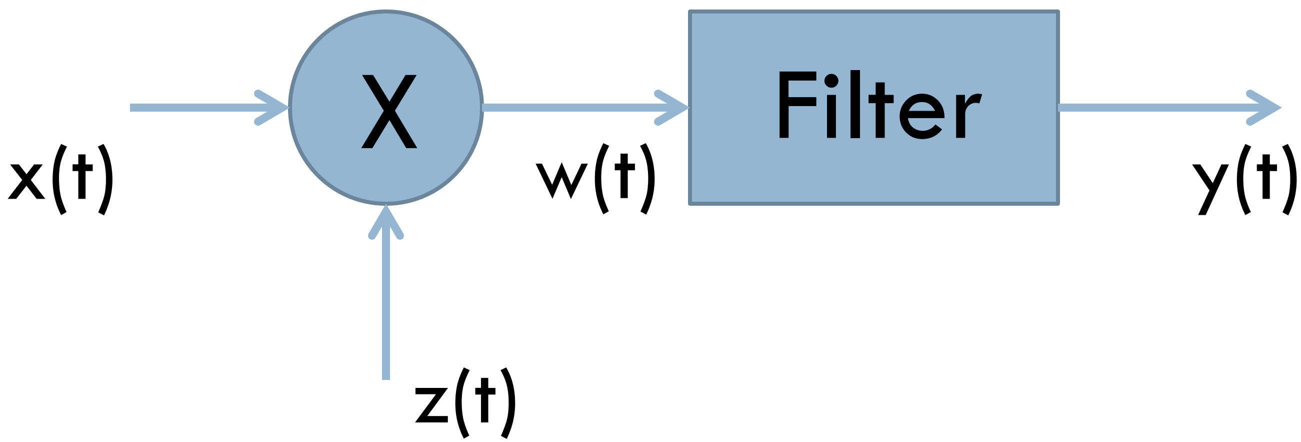
Frequency converters

- Frequency converter is used to change the center frequency of a modulated signal
- Modulated signal

  $x(t) = A(t)\cos[\omega_c t + \theta(t)]$

  $y(t) = k_c A(t)\cos[\omega_d t + \theta(t)]$
- If ω_d is higher than ω_c it is called an up converter
- If ω_d is lower than ω_c it is called a down converter
- Achieved by multiplier followed by filter

Block diagram of a Frequency converter

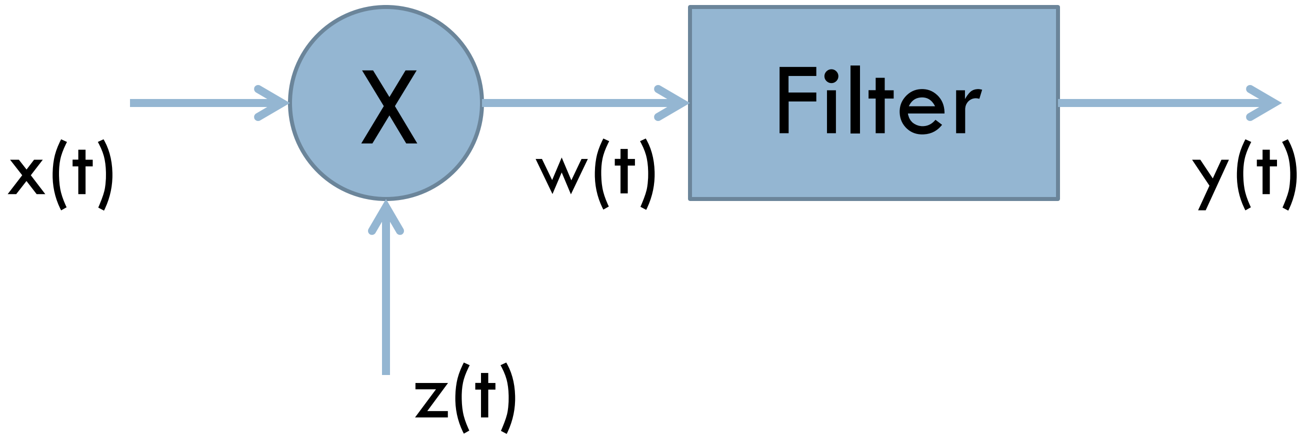


$$w(t) = k_m \, x(t) \, z(t)$$

$$x(t) = A(t) \cos[\omega_c t + \theta(t)]$$

$$z(t) = A_0 \cos \omega_0 t$$

Block diagram of a converter



$$w(t) = k_m A(t)\cos[\omega_c t + \theta(t)].\ A_0 \cos \omega_0 t$$

$$w(t) = \frac{k_m A(t) A_0}{2}\cos\left[(\omega_0 + \omega_c)t + \theta(t)\right] + \frac{k_m A(t) A_0}{2}\cos\left[(\omega_0 - \omega_c)t - \theta(t)\right]$$

$$y(t) = \frac{k_m k_f A(t) A_0}{2}\cos\left[(\omega_0 - \omega_c)t + \theta(t)\right]$$

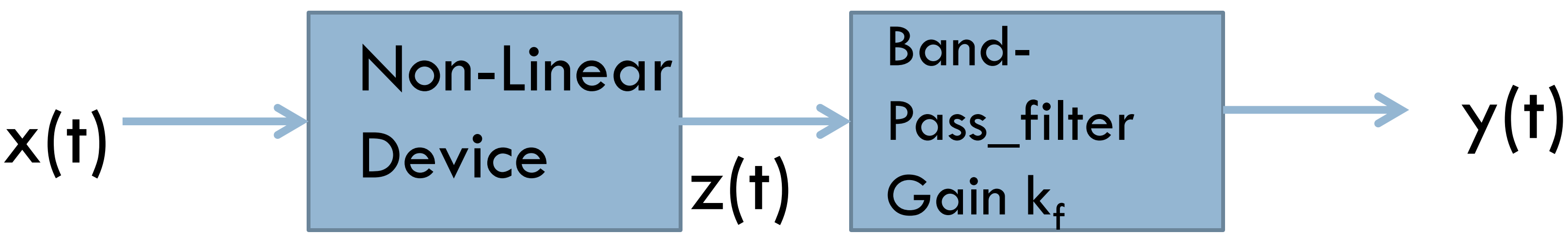
Frequency converter

- If the filter selects $\omega_c+\omega_0$ the circuit is an up converter
- If the filter selects $\omega_0-\omega_c$ then the circuit is called a down converter
- Frequency conversion does not affect the modulation (Waveshape of neither $A(t)$ or $\theta(t)$ is changed)

Frequency multiplier

- This circuit multiplies the carrier frequency of the input by a factor of n
- If input frequency is fc then output carrier is nfc
- Achieved by a non-linear device followed by a band-pass filter

Frequency multiplier



$$z(t) = a\,x(t) + b\,x^2(t) + c\,x^3(t) + - - -$$

$$x(t) = A(t)\cos[\omega_c t + \theta(t)]$$

Frequency Doubler

$$z(t) = a\,x(t) + b\,x^2(t)$$

$$x(t) = A(t)\cos\left[\omega_c t + \theta(t)\right]$$

$$z(t) = aA(t)\cos\left[\omega_c t + \theta(t)\right] + bA^2(t)\cos^2\left[\omega_c t + \theta(t)\right]$$

$$z(t) = aA(t)\cos\left[\omega_c t + \theta(t)\right] + \frac{bA^2(t)}{2}\left\{1 + \cos\left[2\omega_c t + 2\theta(t)\right]\right\}$$

$$y(t) = k_f \frac{b}{2} A^2(t)\left\{\cos\left[2\omega_c t + 2\theta(t)\right]\right\}$$

Frequency doubler

- Note that the carrier frequency is doubled
- Amplitude is distorted
- Phase is not distorted but doubled

  Frequency is also doubled.
- Can be used for changing the carrier of frequency or phase modulated signal but not for amplitude modulated signal

Frequency multiplication by "n"

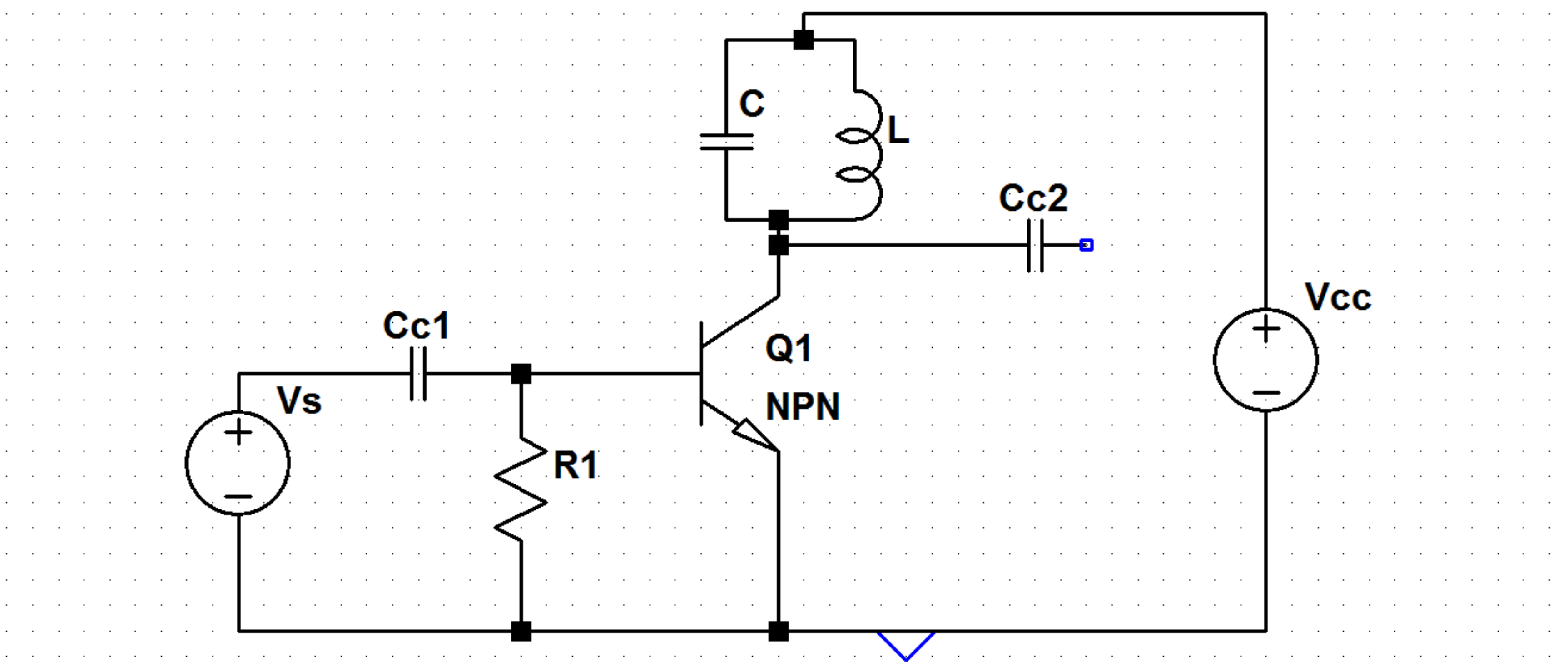
$$z(t) = a\,x(t) + b\,x^2(t) + c\,x^3(t) + - - - kx^n(t)$$

$$x(t) = A(t)\cos\left[\omega_c t + \theta(t)\right]$$

$$z(t) = k_n A^n(t)\cos\{[n\omega_c t + n\theta(t)]\} + other\ terms$$

$$y(t) = k_n k_f A^n(t)\cos\{[n\omega_c t + n\theta(t)]\}$$

Frequency multiplier circuit



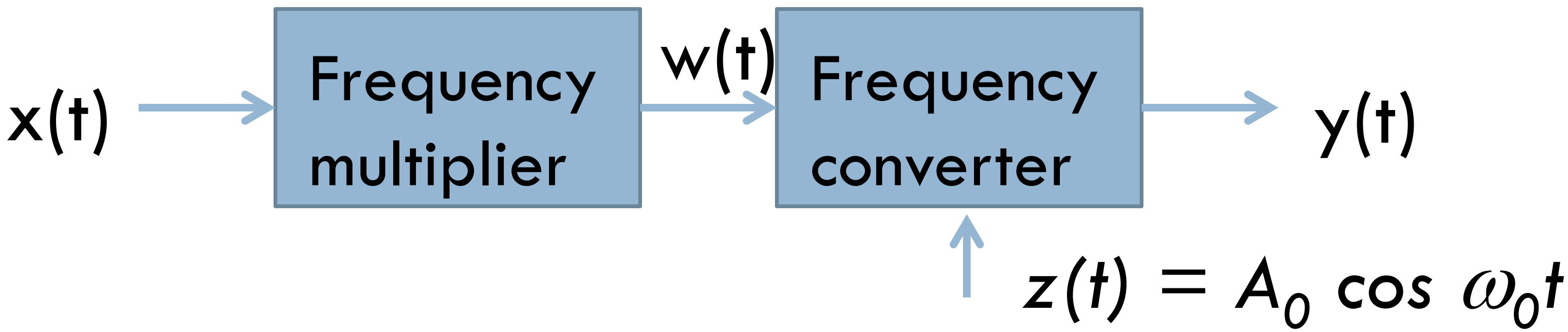
Cascade of frequency multiplier and frequency converter

$$x(t) = A(t)\cos\left[\omega_c t + \theta(t)\right]$$

The requirement is

$$y(t) = kB(t)\cos\left[n_1\omega_c t + n_2\theta(t)\right]$$

The block diagram



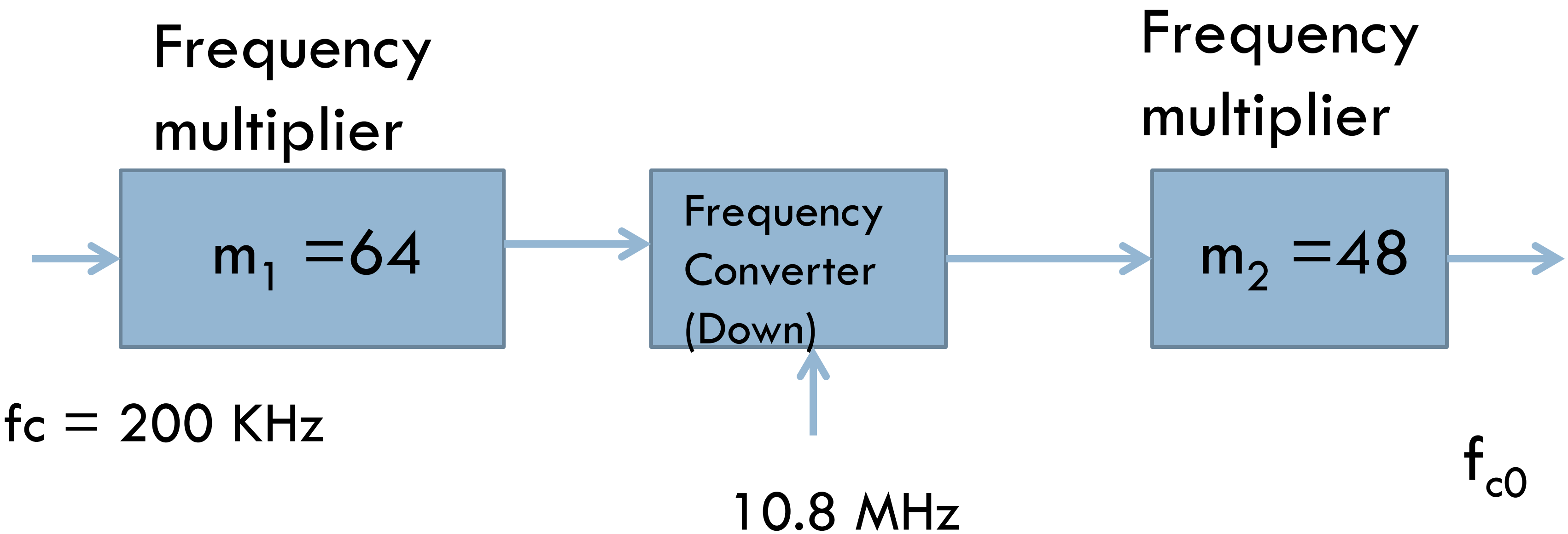
$$x(t) = A(t)\cos\left[\omega_c t + \theta(t)\right]$$

$$w(t) = k_m B(t)\cos\{n_2\omega_c t + n_2\theta(t)\}$$

$$y(t) = kB(t)\cos\{n_1\omega_c t + n_2\theta(t)\}$$

$$\omega_0 - n_2\omega_c = n_1\omega_c$$

Problem



Find out f_{c0} and n_1 and n_2

Solution

$$The\ output\ of\ the\ first\ multiplier\ has\ freuency$$

$$f_{c1} = 0.2 \times 64 = 12.8\ MHz$$

$$The\ frequency\ at\ the\ output\ of\ frequency\ converter$$

$$12.8 - 10.8 = 2\ MHz$$

$$The\ frequency\ at\ the\ output\ of\ second\ multiplier$$

$$2 \times 48 = 96\,MHz$$

$$n_1 = \frac{96}{0.2} = 480$$

$$n_2 = 64 \times 48 = 3072$$

Problem

- 200 Khz to be converted to 96 Mhz
- Only frequency triplers are to be used
- n2 is not specified

Solution

- Three blocks in cascade

(1) 4 Frequency triplers

n1 = 81

The output frequency is 81x0.2 = 16.2 Mhz

(2) UP converter with reference fo = 15.8 Mhz

The output frequency is 32 Mhz

(3) 1 tripler

The output frequency is 32x3 = 96 Mhz

Use of frequency converters in radio transmitters and Receivers

- Transmitter

  200 Khz crystal oscillator

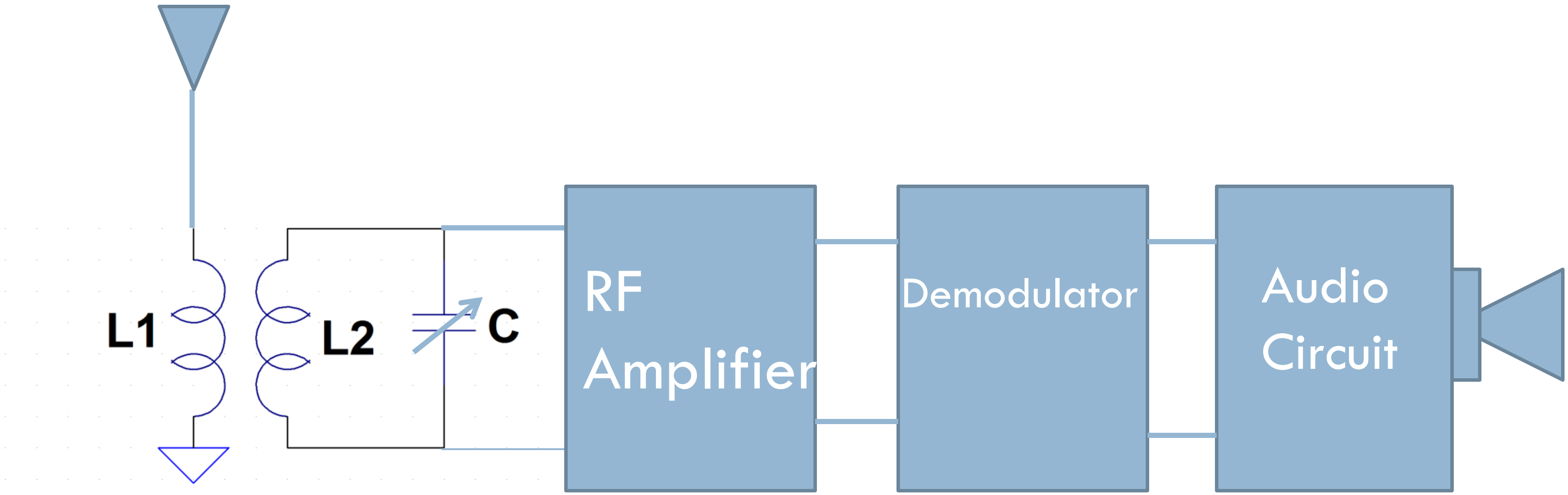
  The output frequency required 100 MHz

  Frequency converters used

- Receiver

  To understand this we first study RF receiver

Tuned RF receiver



Disadvantages of TRF receivers

- High Q requirement in RF amplifier tank circuit

  fc = 100 MHz : BW = 200 Khz

  Q = 100/0.2 = 500 : Rather large

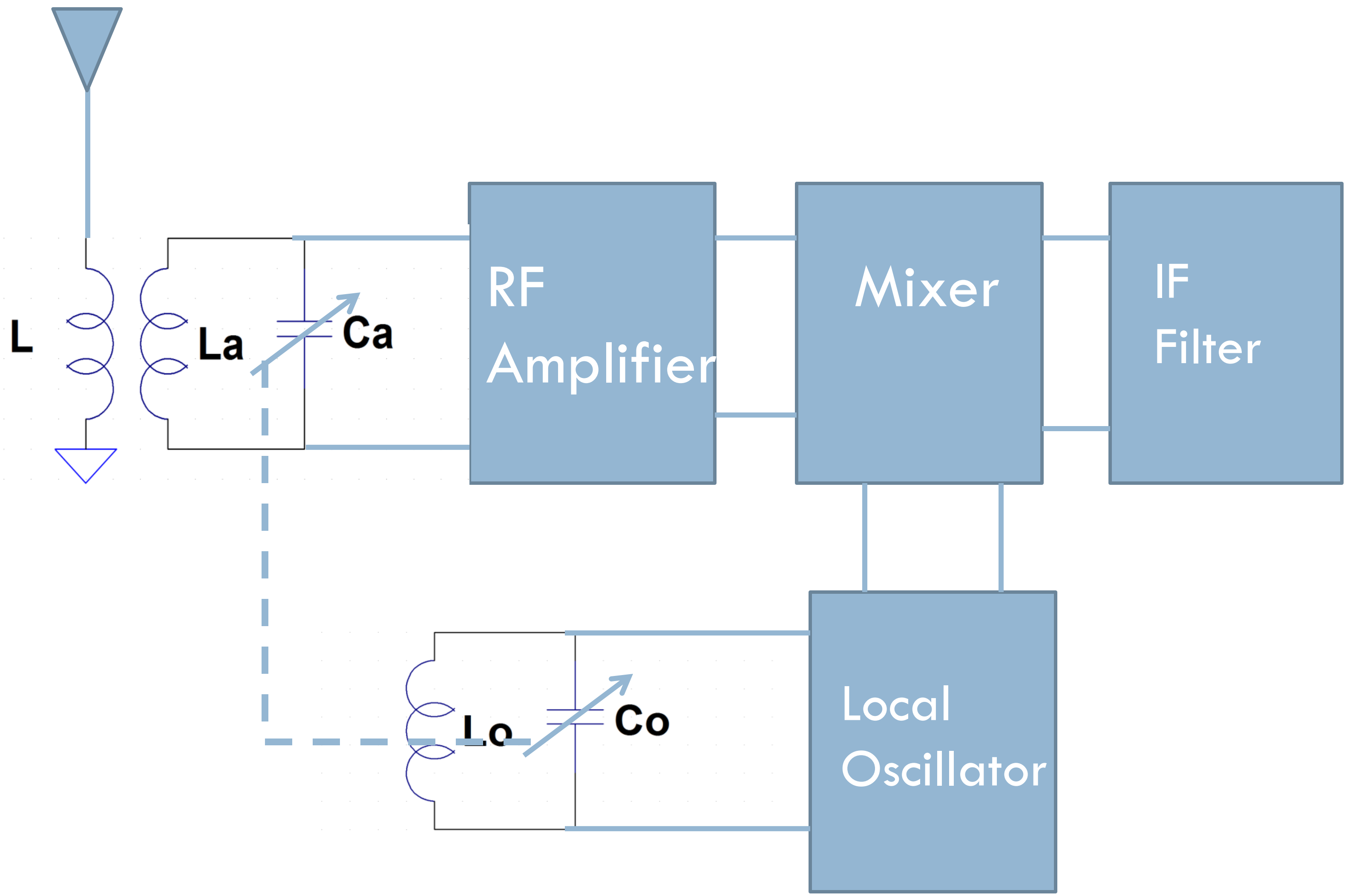
- To get large gain many stages are cascaded so many tank circuits have to be simultaneously tuned.

  Multisection gangs were used

- To avoid oscillations neutralization might have to be used

  Different neutralizing circuits for different frequencies

Frequency converter in Radio Receiver



Frequency relationships

- fa : Resonant frequency of the antenna tank circuit
  Set to the carrier frequency of the desired station
- fo: Resonant frequency of the oscillator tank circuit
- fif : Intermediate frequency = fo-fa
  Remains constant regardless of the station being tuned
  455.5 Khz in AM : 10 Khz BW
  10.7 Mhz in FM : 200 Khz BW

Advantages

- Q requirement goes down

  For AM : 455.5/10 = 45.55

  For FM : 10.7/0.2 = 53.5

- Most gain is designed at IF amplifier

  Only two section gang required

  Neutralization is easily achieved

Choice of intermediate frequency

- It should be outside the band of interest
- For AM radio the band is from 500 kHz to 30 MHz

  Including Medium Wave and Short wave
- Above 30 MHz the Q requirement is too high
- So it is kept below 500 Khz
- Should be as large as possible to keep image interference low

Choice of local oscillator frequency

- f_0 can be chosen to be higher than fc or lower than fc
- Chosen higher than fc
- Why ?
- Consider Medium wave band

  500 KHz to 1500 kHz
- If chosen higher

  $f_{0min} = 500+455.5 = 955.5$ kHz

  $f_{0max} = 1500+455.5=1955.5$ kHz
- Ratio of f_{0max} to f_{0min} is approx. 2

Smaller local oscillator frequency

- $f_{0min} = 500\text{-}455.5 = 44.5$ kHz
- $f_{0max} = 1500\text{-}455.5 = 1044.5$ kHz
- So the ratio of f_{0max} to f_{0min} is greater than 20.

Tracking error

- Ideally we want fo-fa = fif at all settings of fa
- Mechanical gang with identical gang sections

  True only at one frequency (Center frequency) of the band
- At other settings there is tracking error
- Desired station is received away from fa
- Specially shaped gang with non identical sections required
- With digital control and electronic tuning

  Tracking error can

  be eliminated

$$fo - fa = fif \pm \Delta f$$

Δf *is called tracking error*

$$fif = (fo - fa) \mp \Delta f$$

$$fo - (fa \pm \Delta f)$$

Question

(a) In a radio receiver using identical gang sections find antenna tank coil inductance at gang setting of $C = 175$ pF and $fa = 1000$ kHz . Next calculate oscillator coil inductance assuming there is no tracking error.

(b) Using above coils if the gang capacitor is set to 150 pF find the tracking error

Answers

- La = 144.7445 μH
- Lo= 68.32471 μH
- At C= 150 pF

  fa = 1.080124 MHz

  fo = 1.57212 MHz

  fo-fa = 0.491996 MHz

  Tracking error = 0.491996-0.45555 = 0.036496 MHz

Image frequency in a radio receiver

- The antenna tank circuit has low Q

  Hence it allows many signals to go to the input of converter

  But only those signals which generate fif will go to the output

  fo-fc = fif : fo=fc+fif

  Now consider a frequency fi= fc+2fif

  So output frequency is fi-fo=fc+2fif-fc-fif= fif
- So fi causes interference and is called image frequency

Reducing the effect of image

- Tuned circuit ahead of mixer
- Larger the IF frequency easier it is to reject the image frequency

Problem

- A varactor tuned antenna tank circuit has a resonant frequency of 1400 Khz
- L = 145 microhenries
- The varactor characteristic is linear and two points on this are given below

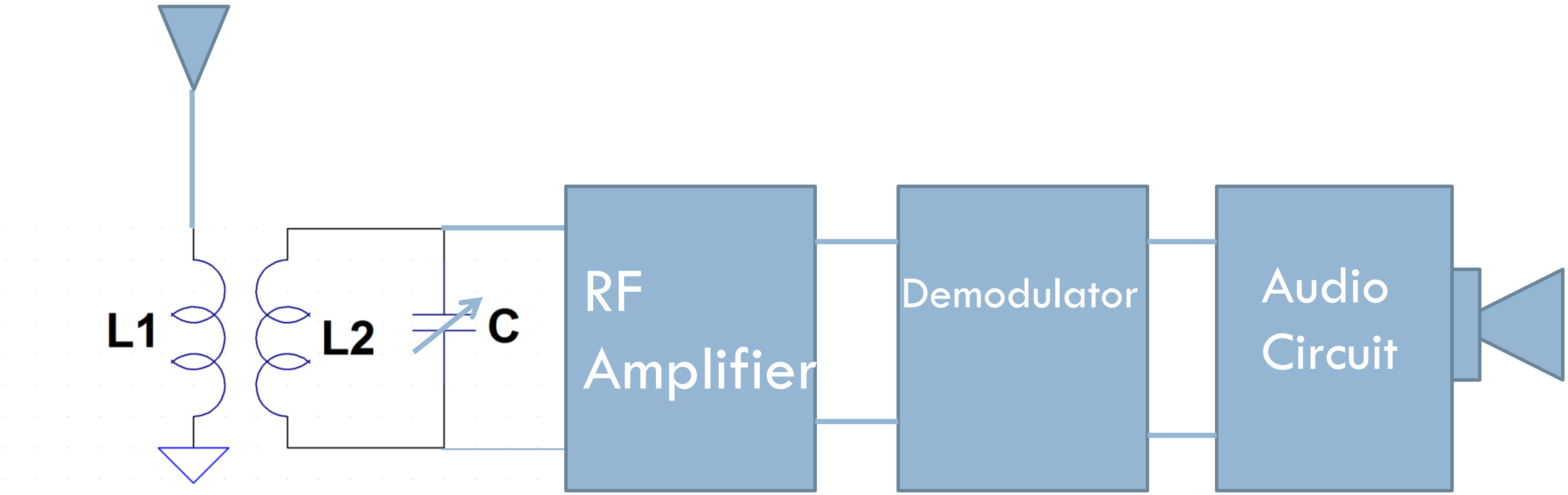
V (Volts)	C(pF)
3.5	192
6	61

- Find C and V

Answers

- C = 89 pF
- V = 5.48 volts

Automatic gain control(AGC)



Stages in a Software defined radio

- Front End
  - Low noise amplifier
  - Down converter
  - A/D converter
- Processor
- D/A converter

LNA

- Output of Receiving antenna goes to the input of a low noise amplifier
- In a multistage cascade the first stage noise is dominant so it has to be carefully designed

For example consider 4 stages of amplification

The noise added by the first transistor is amplified by 3 stages

Noise added by the second stage is amplified only by 2 stages

Low noise stage

- Low noise transistor is chosen
- Operated at comparatively small bias currents