Thumb Rule: Main problem of TRF Rx is Insufficient adjacent frequency rejection (Poor adjacent signal rejection)... This is mainly due to large BW and low Q of the selectivity curve.

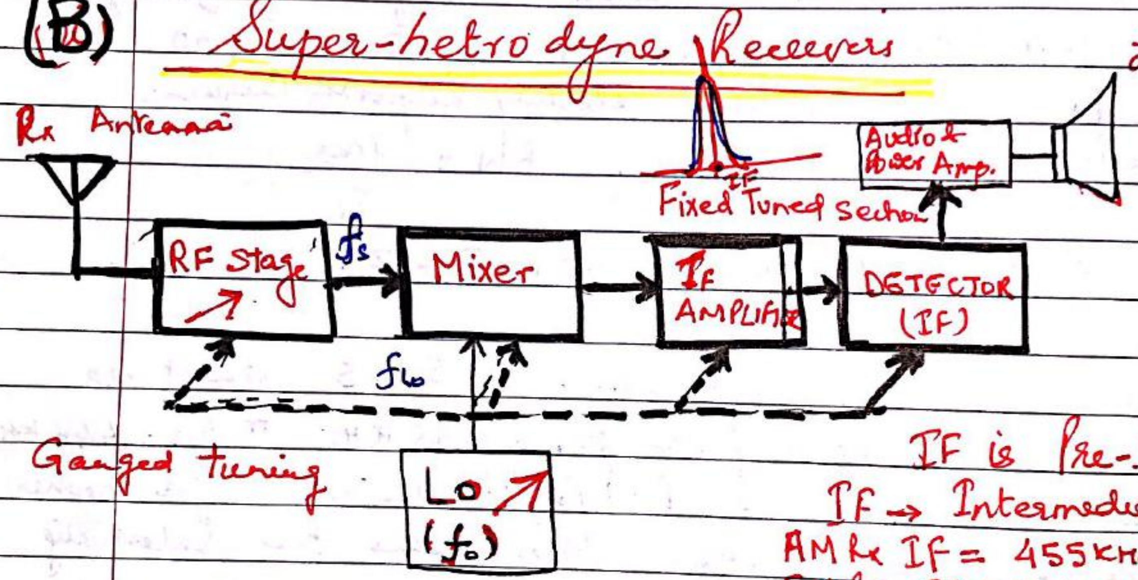
Another serious problem of TRF-Rx is that Q curve shape varies over the tuning range.

Q.8 What is the Ganged tuned arrangmt in the Rxs?

~~Super hetrodyne R~~

LECTURE # 21 (STARTS HERE)

(B) Super-hetrodyne Receivers



IF is Pre-defined
IF → Intermediate Frequency
AM Rx IF = 455 kHz
FM Rx IF = 10.7 MHz
TV Rx IF = 45 MHz.

Figure 14 Block Diagram of a Superhetrodyne Rx.

The above figure no 14 shows a Basic Super-hetrodyne Rx block diagram. This is the basic practical Version. Other Varients are also available. Superhetrodyne is used in radio and TV Rxs. This technique allows the Rxs to be tuned to a particular IF (intermediate frequency) even though the front end is Variably tuned. This Implies that front end of Super-hetrodyne is variably tuned to any of the desired modulated carriers just like the TRF Rx. However the intermediate stage is fixed tuned to a particular IF only. To explain this statement further let us assume the incoming carrier frequency range is $f_{c} = 535$ KHZ to 1640 KHZ. This means that lowest modulated carrier expected at antenna is 535 KHZ and the highest modulated carrier at Rx antenna is 1640 HZ. So the front end can be variable tuned from 535 KHZ to 1640 HZ. Now according to Super-hetrodyne technique the middle stage of Rx will always be fixed tuned to a particular IF no matter where the front end is tuned to. For any front-end tuning position range 535 KHZ - 1640 KHZ, the middle stage is always fixed tuned to IF.

Purpose of using IF (intermediate Frequency):

In typical Amplitude Modulation (AM Radio) in US the receivers use IF = 455 KHZ.

IF for FM Rx_s, it is usually = 10.7 MHZ

IF for Television is = 45 MHZ.

In any of the above cases, the IF stage is so designed so that the Amplifiers are highly selective to the IF. Subsequent stages following the IF amplifier are also designed to perform best around this IF. From this we realize that just as in TRF Rx here also in super-hetrodyne Rxs the front End show BW variation, Q variation and response curve variation, & Selectivity variation over the tuning range. But this demerit is overcome by the middle IF stage which is designed to offer best selectivity & response curve.

Three principale parts of a Super-hetrodyne

The three principle parts of a Superhetrodyne are

(i) Local Oscillator (f_{LO}).
(ii) Mixer
(iii) IF amplifier

Before we can explain further, we write the brief introduction of each of these three parts.

Local Oscillator :- This produces a signal (f_{LO}) close to the signal to be detected. It is preferred that if $f_{S\text{-}min}$ denotes the minimum tuning position (eg 535 kHz) then $f_{LO} < f_{S_{min}}$.

Mixer : This performs mixing operation b/w two inputs - (i) The modulated carrier (f_s) and (ii) the local oscillator (f_{LO}). With these inputs fed to this non-linear device will produce outputs like $f_s, f_{LO}, |f_{LO}-f_s|, f_{LO}+f_s$. $|f_{LO}-f_s|$ implies that if $f_{LO}>f_s$ then the difference is given as $f_{LO}-f_s$ but if $f_{LO}<f_s$ then the difference is f_s-f_{LO}. Out of all these output components, the difference is the pre-defined IF. ie $\boxed{|f_{LO}-f_s| = IF}$

IF Amplifier The subsequent stage is the IF amplifier which is designed so that its

$$f_{res} = IF = |f_{LO} - f_s|$$

The Q curve of the IF amp has high selective, narrow bandwidth curve so that this resonance curve will cancel and attenuate all the components f_s, f_{LO}, $f_{LO}+f_s$ but will pass without attenuation its $f_{res} = IF = |f_{LO} - f_s|$

Hetrodyne Action of Local Oscillator, Mixer & IF Amplifier

Super-hetrodyne action used in Radio and TV Rx is a technique that allows the Rxs to be always fixed tuned to a particular pre-defined IF irrespective of the front end tuning position.

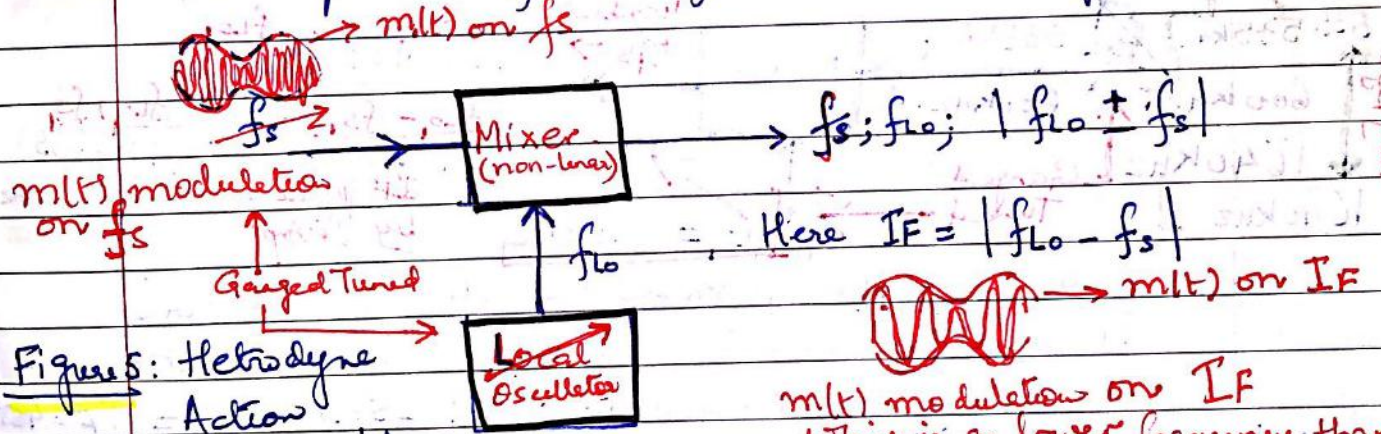


Figure 5: Hetrodyne Action essential blocks.

Already it has been explained in previous chapters that the mixer is a non-linear device. It is basically an amplitude modulator which will be a result of mixing action between inputs f_s & f_{LO}. Due to the Amplitude Modulation action of a Mixer the output will be mainly 3 components → $|f_{LO} - f_s|$, f_{LO}, $(f_{LO}+f_s)$ as is expected in case of an amplitude modulator. However f_s also trickles down through the mixer and appears at output. Same modulation as on f_s now appears on IF too.

DOWN CONVERSION & UPCONVERSION

Examples of Super-Hetrodyne action..

Case (a) If $f_{LO} > f_s$ then $IF = f_{LO} - f_s$, where predefined $I_F = 455$ KHZ,

Down Conversion

$IF = |f_{LO} - f_s|$

or $\boxed{f_{LO} = I_F + f_s}$

This means the the local Oscillator is designed to oscillate at such a frequency so that difference b/w f_{LO} & f_s always produces IF

IMP: In Case of Down Conversion, $f_{LO} > f_s$; $I_F = f_{LO} - f_s$; $f_s > I_F$

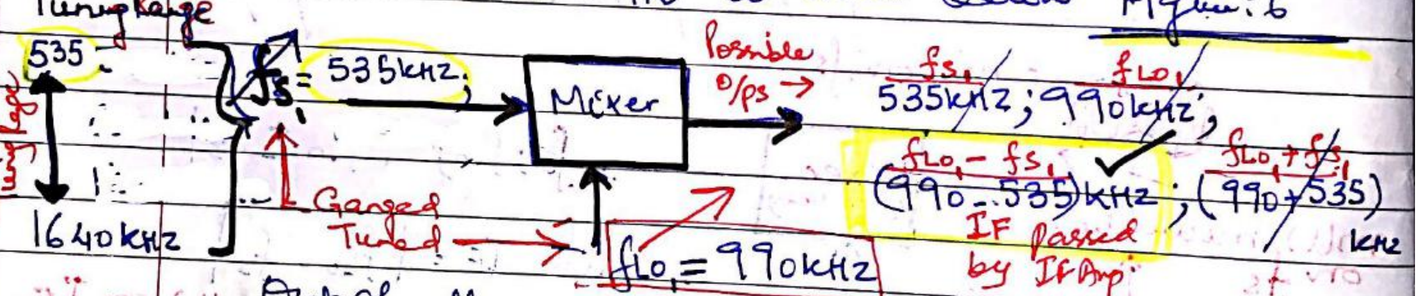
Example (i): Let $f_{s_1} = 535$ KHZ & $I_F = 455$ KHZ.

Then $f_{LO_1} = I_F + f_{s_1}$

$= (455 + 535)$ KHZ.

$\therefore \boxed{f_{LO_1} = 990 \text{ KHZ}}$

Figure no 6: This is shown in illustration below Figure: 6



Out of all the possible outputs the following IF amplifier cancels all the components but it's freq matches with $(990 - 535)$ KHZ $= I_F = 455$

Same Modulation on f_{s_1} will now be present on $(f_{s_1} - f_{LO_1}) = 455$ KHZ.

Example (ii) Now let us tune to next station say at $f_{s_2} = 600$ KHZ.

f_{s_2} at 600 KHZ is $\boxed{65 \text{ KHZ}}$ above first station position of f_{s_1} at 535 KHZ. A very important point to note

IMP → down in case of superhetrodyne action is that the Local oscillator output also shifts up by 65 KHZ. The set up is called Ganged Tuning

Due to this Ganged tuning of Front end tuner and the Local oscillator, now $f_{LO_2} = 990$ KHZ + 65 KHZ

∴ New LO oscillations for second tuning position is

DOMS Page No. Date / /

given as $f_{lo_2} = f_{lo_1} + 65\,KHZ = 1055\,KHZ$

IMP → i.e. f... This again implies that a mixing action takes place between $fs_2 = 600\,KHZ$ and $f_{lo_2} = 1055\,KHZ$ to produce following possible outputs at the mixer O/P:—

Mixer O/p in second Tuning position $= fs_2,\ flo_2,\ |flo_2 - fs_2|,\ flo_2 + fs_2$

$= 600\,KHZ;\ 1055\,KHZ,\ 455\,KHZ,\ 1655\,KHZ.$

→ IF Passed by IF Amp.

Hence out of all these components at O/p of mixer the subsequent IF Amp with same freq = IF = 455 KHZ cancells all other Components but allows to pass only 455 KHZ. Here also the modulation (information) on $fs_2 = 600\,KHZ$ will also be present on f... $(f_{LO_2} - fs_2) = 455\,KHZ.$

Example (iii) Likewise let us tune to the highest position on the tuning range. Here fs_3 at 1640 KHZ which is 1040 KHZ above previous tuning position fs_2 at 600 KHZ. Due to Ganged Tuning the Capacitor in LO also changes to produce $f_{LO_3} = f_{lo_2} + 1040\,KHZ$

Now LO oscillated at $f_{LO_3} = 1055\,KHZ + 1040\,KHZ = 2095\,KHZ$

This again implies that a mixing action takes place between $f_{S_3} = 1640\,KHZ$ and $f_{lo_3} = 2095\,KHZ$ to produce following possible output at mixer O/p'

Mixer O/p in third tuning position =

$fs_3;\ flo_3,\ |flo_3 - fs_3|,\ flo_3 + fs_3.$

$= 1640\,KHZ;\ 2095\,KHZ;\ 455\,KHZ;\ 3735\,KHZ$

→ IF passed thro IF Amp.

Wherever the modulation information is on fs_3 will also be present on $(flo_3 - fS_3) = 455\,KHZ.$

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CONTD: IMPORTANT POINTS OF SUPER HETRODYNE Rx.

Imp.→ Earlier modulation (m(t)) before mixing operation, was carried by f_s. After mixing operation the modulation m(t) will be carried by all those components in which f_s appears. These are f_s itself, $f_{LO}-f_s$, and $f_{LO}+f_s$.

Imp. Down Conversion Defn. When $f_s > I_F$; $f_{LO} > f_s$ & $I_F = f_{LO} - f_s$

Since modulation m(t) was carried by f_s prior to mixing operation and after mixing operation modulation m(t) is carried on the selected predefined IF where $f_s > I_F$ then this is called Down Conversion

e.g as in example (i) $f_{s_1} = 535\,kHz > 455\,kHz$; $f_{LO_1} = 990\,kHz$

example (ii) $f_{s_2} = 600\,kHz > 455\,kHz$; $f_{LO_2} = 1055$

example (iii) $f_{s_3} = 1640\,kHz > 455\,kHz$; $f_{LO_3} = 2095$

In other words modulation is now carried on a lower frequency, Hence this is called down conversion

Imp:- Now we can say output is an IF modulated signal.

Imp The Superhetrodyne Rx. offers a ganged arrangement of capacitors where all the capacitors are ganged tuned. Any change in one capacitor results in a corresponding change in the other capacitors. It is due to this Ganged arrangement that as f_s changes, so does f_{LO} to maintain O/p mixer always as IF as one of the components.

→ Another possibility of Down Conversion (so that $f_s > I_F$) is when $f_{LO} < f_s$; so that $I_F = f_s - f_{LO}$.

Case (b) If $f_{LO} < f_s$ then $I_F = f_s - f_{LO}$ where predefined $I_F = 455$ kHz.

Down Conversion $I_F = |f_{LO} - f_s|$, ∴ $f_s > f_{LO}$, Here also $f_s > I_F$.

However here $\boxed{I_F = f_s - f_{LO}}$

Example IV :- Let $f_{s_1} = 535$ kHz & $I_F = 455$ kHz.

then in this case of down conversion

Since $f_{s_1} > f_{LO_1}$ ∴ $I_F = f_{s_1} - f_{LO_1}$

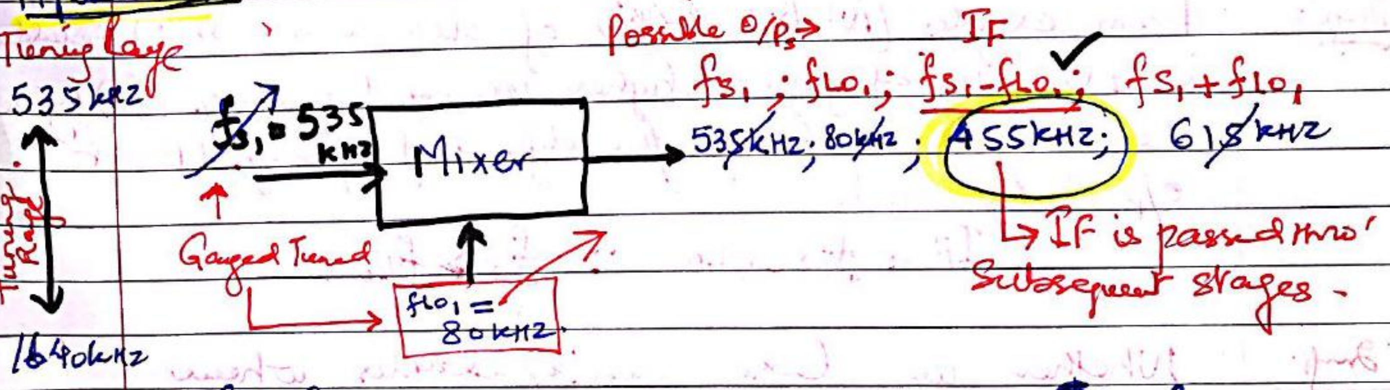
This implies $455\text{ kHz} = 535\text{ kHz} - f_{LO_1}$.

∴ Required $f_{LO_1} = 535\text{ kHz} - 455\text{ kHz} = 80\text{ kHz}$

Here also f_{s_1} gets downconverted to IF where $f_{s_1} > I_F$, however here we are now using LO (f_{LO_1}) frequency smaller than f_{s_1}.

This is shown in illustration no Figure 7 below:

Figure no: 7



Example V Let $f_{s_2} = 700$ kHz, & $I_F = 455$ kHz; Then $I_F = f_{s_2} - f_{LO_2}$

∴ $f_{LO_2} = f_{s_2} - I_F \Rightarrow f_{LO_2} = 700\text{ kHz} - 455\text{ kHz}$

∴ $f_{LO_2} = 245$ kHz.

Example VI: Let $f_{s_3} = 1640$ kHz & $I_F = 455$ kHz, Then $I_F = f_{s_3} - f_{LO_3}$

∴ $f_{LO_3} = f_{s_3} - I_F \Rightarrow f_{LO_3} = 1640\text{ kHz} - 455\text{ kHz}$.

∴ $f_{LO_3} = 1,185$ kHz

Imp:- In the following Down conversion cases as explained in examples (IV), (V) & (VI), we summarize the study as a Down conversion defn where $f_s > IF$; $f_{LO} < f_s$; & $IF = f_s - f_{LO}$

Here also before mixing the m(t) baseband modulation is carried on a higher frequency fs and after mixing the same modulation is now translated on a lower IF frequency. Where
In example (iv) $f_{s1} = 535\text{ KHZ} > 455\text{ KHZ}$; $f_{LO_1} = 80\text{ KHZ}$
example (V) $f_{s2} = 700\text{ KHZ} > 455\text{ KHZ}$; $f_{LO_2} = 245\text{ KHZ}$
example (VI) $f_{s3} = 1640\text{ KHZ} > 455\text{ KHZ}$; $f_{LO_3} = 1185\text{ KHZ}$

Case (a)

Imp:- From examples (i), (ii) & (iii) of down conversion, m(t) modulation is shifted from a higher frequency (fs) to a lower pre-defined frequency IF at o/p of Rx where
$IF = f_{LO} - f_s$ ∵ $f_{LO} > f_s$.

Case (b)

Imp:- From examples (iv), (v) & (vi) of down conversion, m(t) modulation is also shifted from a higher incoming frequency (fs) before the mixer to a lower pre-defined frequency IF at o/p of Rx where
$IF = f_s - f_{LO}$ ∵ $f_s > f_{LO}$.

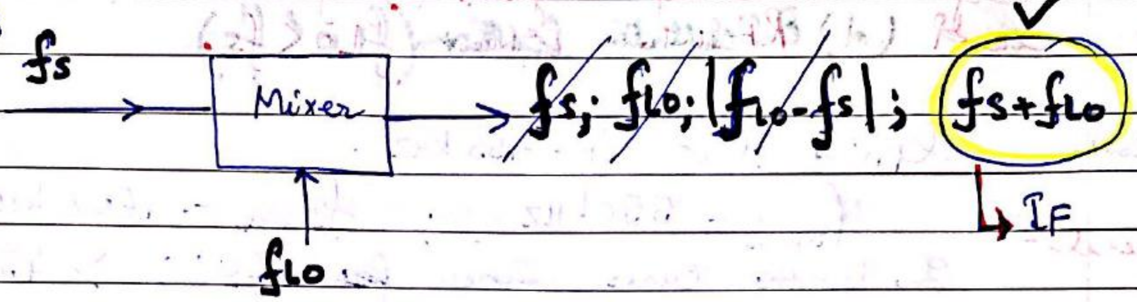
Imp. Whether we take Case (a) examples where $IF = f_{LO} - f_s$ or Case (b) examples where $IF = f_s - f_{LO}$; in either cases every incremental change in the tuning position of fs results in an equal incremental changes in fLO values also. This is possible only because the capacitive (C) element in front end tuner and capacitive (C) element in LO are ganged together. This is called Ganged tuning!

Down Conversion + UP Conversion (Contd).

Case (c) UpConversion.

If $IF = f_S + f_{LO}$, this implies that $f_S = IF - f_{LO}$ and $f_S < IF$. Here modulation m(t) is carried on a lower frequency (f_s) before mixing operation and after mixing operation it is carried on a higher frequency IF. This would be referred to as UpConversion. See figure no. 8.

Figure no: 8



Imp:- Q.9 In Superheterodyne Rx. out of the many possible o/ps of the mixer (ie f_s, f_{LO}; $|f_{LO}-f_s|$, f_s+f_{LO}) down Conversion setup is preferred to upconversion. Thus it would be preferred to have an arrangement where always $f_s > IF$ so that $IF = |f_{LO} - f_s|$. Upconversion arrangement where $IF = f_{LO} + f_s$ is not preferred. (Why?)

Imp:- Q.10 Further In downConversion $f_{LO} > f_s$ is preferred so that $IF = f_{LO} - f_s$ ✓ (Why?)

Imp:- Q.11 For the upconversion arrangement the tuning range of 535 KHz – 1640 kHz would not be applicable (Why?) if IF = 455 KHz.

Q.12 A Rx is designed to tune to incoming signal carrier frequencies over range $fs_{min} = 550\,kHz$ to $fs_{max} = 1600\,kHz$. Assume the predefined IF = 445 kHz.

(i) Find the frequency tuning range (R_f) and the Capacitive tuning range (R_c) for the (a) RF section and (b) Oscillator section when ($f_{LO} > f_s$)

(ii) Find the frequency tuning range (R_f) and the Capacitive tuning range (R_c) for the (c) RF section and (d) Oscillator section ($f_{LO} < f_s$)

Solution:- Given that IF = 455 kHz.

General:- $fs_{min} = 550\,kHz$; $fs_{max} = 1600\,kHz$.

In both cases since $fs_{min} > 455\,kHz$ and $fs_{max} > 455\,kHz$ ($f_s > IF$) therefore this is superhetrodyne action employing down conversion.

Defn R_f: By Definition Frequency tuning range (R_f) is given by

$$R_f = \frac{fs_{max}}{fs_{min}}$$

and correspondingly

Defn R_c: R_c Capacitive tuning range is obtained from R_f by using equation substitution of $f = \frac{1}{2\pi\sqrt{LC}}$. Hence

$$fs_{max} = \frac{1}{2\pi\sqrt{LC_{min}}} \quad \& \quad fs_{min} = \frac{1}{2\pi\sqrt{LC_{max}}} \Rightarrow R_c = \frac{C_{max}}{C_{min}} = R_f^2$$

i (a) For $f_{LO} > f_s$ ∴ $IF = f_{LO} - f_s$.

RF section is before mixer.

Here $R_f = \frac{fs_{max}}{fs_{min}} = \frac{1600\,kHz}{550\,kHz} = 2.909$

$R_c = R_f^2 = 8.4622 = C_{max}/C_{min}$ ∴ $C_{max} = 8.46\,C_{min}$

This implies that to tune from fs_{min} of 550 kHz to fs_{max} of 1600 kHz, Capacitor has to be varied as $C_{max} = 8.46$ times C_{min}.

i(b) For the Oscillator Section in case of $f_{LO} > f_s$ &

$IF = f_{LO} - f_s \quad \therefore f_{LO} = IF + f_s$

$\therefore f_{LO_{min}} = IF + f_{s_{min}} = 455 + 550 = 1005\ KHZ$

$f_{LO_{max}} = IF + f_{s_{max}} = 455 + 1600 = 2055\ KHZ$.

Frequency tuning range at Oscillator

$$R_{f_0} = \frac{f_{LO_{max}}}{f_{LO_{min}}} = \frac{2055\ KHZ}{1005\ KHZ} = 2.045\ KHZ$$

This means the Oscillator has to change its oscillation from $f_{LO_{min}} = 1005\ KHZ$ to $f_{LO_{max}} = 2055\ KHz$. To achieve this it has to employ a Variable capacitor with the capacitive tuning range of Oscillator as

$$R_{C_0} = (R_{f_{LO}})^2$$

$$\therefore R_{C_0} = (2.045)^2 = 4.182 = \frac{C_{O_{max}}}{C_{O_{min}}}$$

Therefore required is a Variable capacitor at Oscillator where $\boxed{C_{O_{max}} = 4.182\ C_{O_{min}}}$.

Q.12

ii(a) Here. $f_{LO} < f_s$; $IF = f_s - f_{LO} \therefore f_{LO} = f_s - IF$

Rf Section:- Show that here also $R_f = \frac{f_{s_{max}}}{f_{s_{min}}} = 2.909$

Q.12 Show that corresponding $R_C = (R_f)^2 = \frac{C_{max}}{C_{min}} = 8.46$ (Just as in i(a)).

(ii b) Q:12 Show that in the Oscillator Section $R_{f_0} = 12.052$ when $f_{LO} < f_s$.

Q:12 Show that in the Oscillator Section $R_{C_0} = 144$. when $f_{LO} < f_s$!

Important Comment:- With reference to the previous solved example

$f_{LO} > f_s$ we conclude that if $f_{LO} > f_s$, ~~then tuning range of Oscillator will require Capacitive Element such that $C_{max} = 8.46 C_{min}$~~.

For RF section requires a variable capacitor so that
$C_{max} = 8.46 C_{min}$

For Oscillator section requires a variable capacitor so that
$C_{O max} = 4.182 C_{O min}$ ✓

This is a practical tuning range of a capacitor

$f_{LO} < f_s$ Here for RF section, we require a variable capacitor of same capacitive tuning range such that
$C_{max} = 8.46 C_{min}$

For Oscillator section it requires a variable capacitor so that $C_{O max} = 144 C_{O min}$

This is not a practical tuning range of a capacitor.

I.P.:- Finally we conclude that in case of down conversion

Q.10 where $IF = |f_{LO} - f_s|$, it is preferred to have $f_{LO} > f_s$ and not $f_s > f_{LO}$. (Why?)