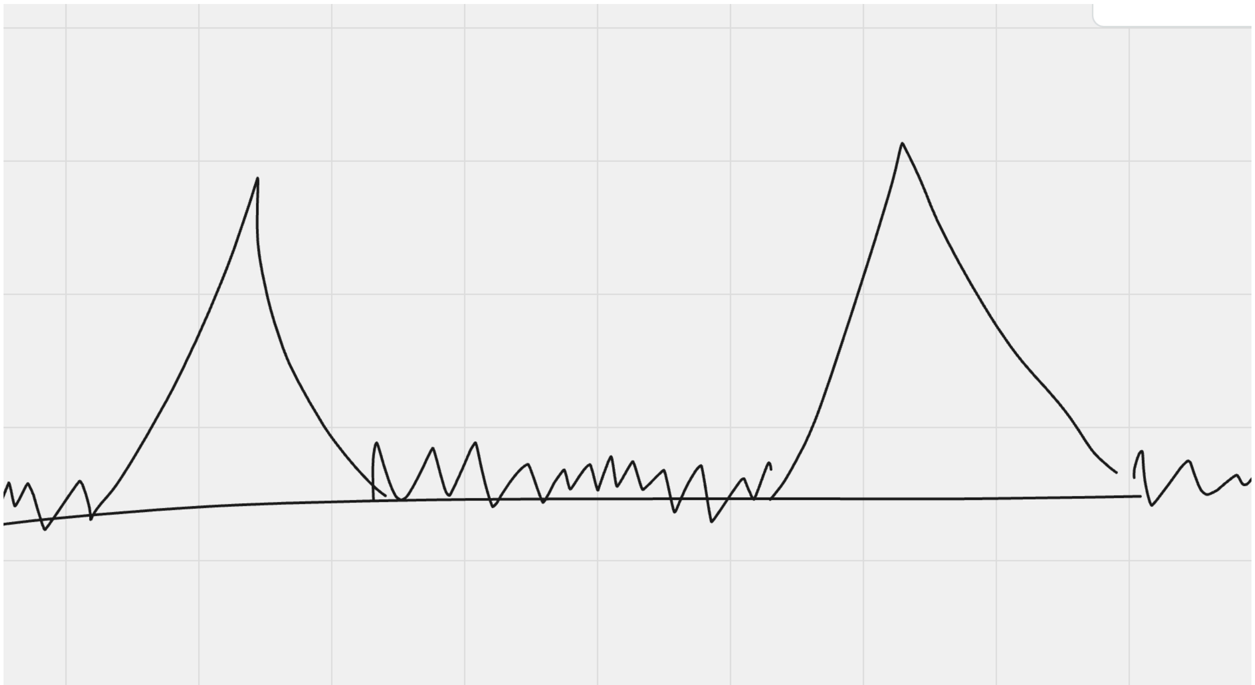
Rf oscillators

What it is

- In most general sense, they provide sinusoidal outputs which minimize undesired harmonics and noise sideband



- Noise sideband/ undesired harmonis - around main harmonics that occur periodically
- When designing oscillators, we design to achieve instability, this can be shown conceptually as:

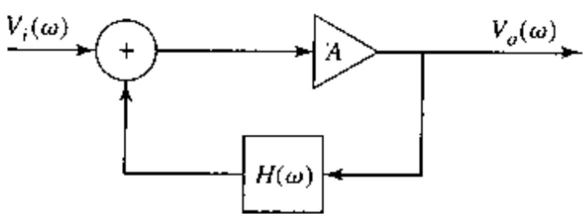


FIGURE 13.1 Block diagram of a sinusoidal oscillator using an amplifier with a frequency-dependent feedback path.

the circuit. The output voltage can be expressed as

$$V_o(\omega) = AV_i(\omega) + H(\omega)AV_o(\omega), \tag{13.1}$$

which can be solved to yield the output voltage in terms of the input voltage as

$$V_o(\omega) = \frac{A}{1 - AH(\omega)} V_i(\omega). \tag{13.2}$$

- From equation (13.2), we see that when the denominator is 0, we still have a defined non-zero output when the input voltage is zero. HOW??????? This is because when the denominator is 0, we have the condition 1-AH(w) = 0 -> 1 = AH(w), this means that we have self-sustained oscillation, basically when noise is interpreted in the signal output the feedback will allow it to oscillate indefinitely (because AH(w) = 1)

Key Insight: Perfect Tuning for Oscillation

The condition $AH(\omega) = 1$ means the system is perfectly tuned to balance:

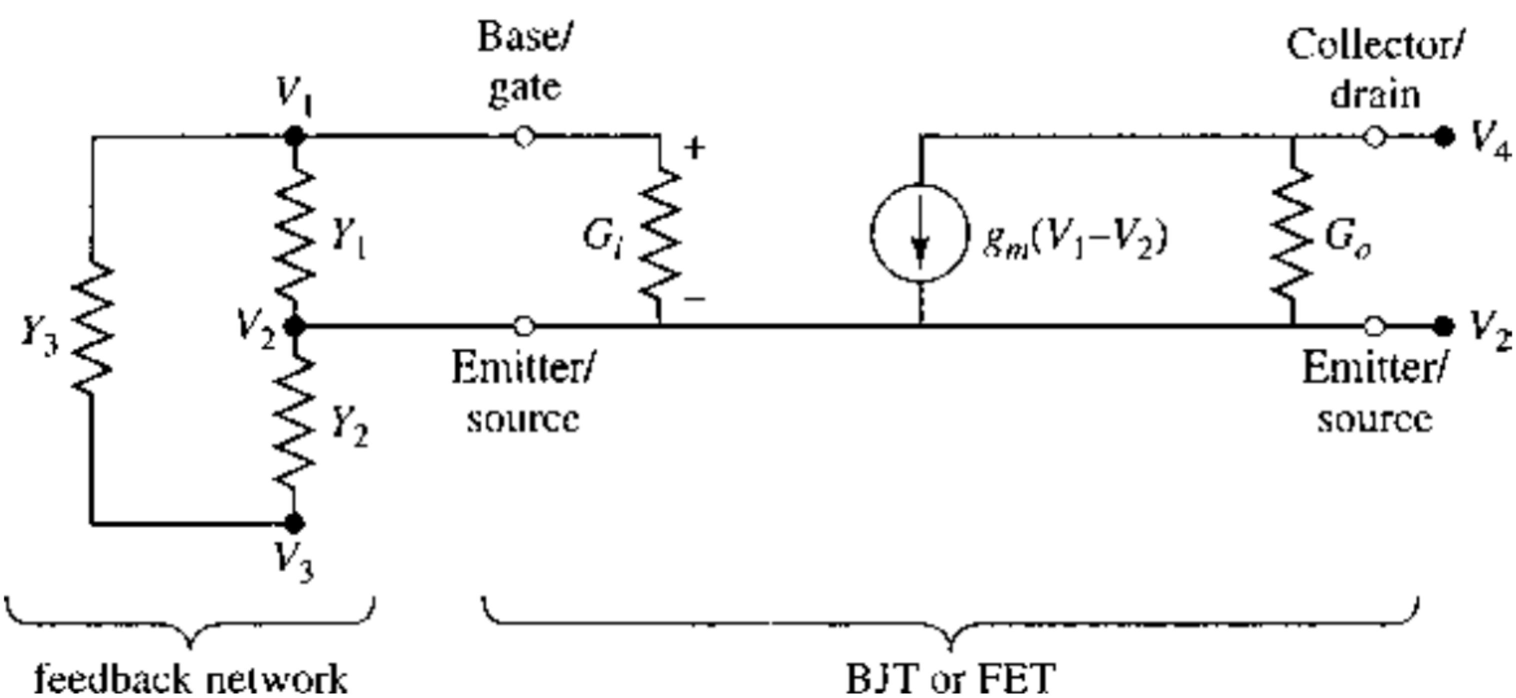
- Energy amplification (A): Ensures the oscillation does not decay.
- Feedback shaping ($H(\omega)$): Selects the frequency of oscillation.

If $|AH(\omega)| > 1$, the oscillation grows until nonlinear effects limit the amplitude.
If $|AH(\omega)| < 1$, the oscillation decays and dies out.

When $|AH(\omega)| = 1$, the system neither grows nor decays—resulting in a stable, steady oscillation.

Aspect	RF Circuits	Microwave Circuits
Frequency Range	Typically **3 kHz to 300 MHz** (up to GHz in some cases)	**300 MHz to 300 GHz**
Wavelength	Longer wavelengths (1 m to 100 km)	Shorter wavelengths (1 mm to 1 m)
Components	Uses lumped elements (resistors, capacitors, inductors)	Uses distributed elements (waveguides, microstrip, stripline)
Transmission Lines	Coaxial cables, PCB traces	Microstrip, stripline, waveguides
Design Tools	SPICE, ADS, HFSS for high-frequency	Advanced tools like ADS, CST, HFSS
Applications	AM/FM radio, Wi-Fi (2.4 GHz), Bluetooth, TV transmission	Radar, satellite communication, 5G, military applications
Challenges	Less affected by parasitics and layout issues	More sensitive to layout, skin effect, and signal integrity issues

Circuits



- In this FET, we have real input and output admittances Gi and Go and transistor transconductance
- The feedback network (formed in a T configuration) used inductors and capacitors to provide a frequency-selective transfer function with high Q
- To complete the feedback path, connect V3 and V4
- Using KCL, we can represent the voltage across the 4 nodes as:

$$\begin{bmatrix} (Y_1+Y_3+G_i) & -(Y_1+G_i) & -Y_3 & 0 \\ -(Y_1+G_i+g_m) & (Y_1+Y_2+G_i+G_o+g_m) & -Y_2 & -G_o \\ -Y_3 & -Y_2 & (Y_2+Y_3) & 0 \\ g_m & -(G_o+g_m) & 0 & G_o \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} = 0 \tag{13.3}$$

Now consider the following example:

Oscillators Using a Common Emitter BJT

As a specific example, consider an oscillator using a bipolar junction transistor in a common emitter configuration. In this case we have $V_2 = 0$, with feedback provided from the collector, so that $V_3 = V_4$. In addition, the output admittance of the transistor is negligible, so we set $G_o = 0$. These conditions serve to reduce the matrix of (13.3) to the following:

$$\begin{bmatrix} (Y_1+Y_3+G_i) & -Y_3 \\ (g_m-Y_3) & (Y_2+Y_3) \end{bmatrix} \begin{bmatrix} V_1 \\ V \end{bmatrix} = 0, \tag{13.4}$$

where $V = V_3 = V_4$.

- This matrix represents the KCL equations of a unilateral transistor that provides oscillations
- Now we solve for the matrix values to find transistor values (derivation found in textbook)

Applications

Now consider the following question:

Design a 50 MHz Colpitts oscillator using a bipolar junction transistor in a com- mon emitter configuration with β = *gm*/*Gi* = 30, and a transistor input resistance of *Ri* = 1/*Gi* = 1200 . Use an inductor with *L*3 = 0.10 μH and an unloaded *Q* of 100. What is the minimum *Q* of the inductor for which oscillation will be sustained?

What is happening at 50MHz??? At 50 MHz our transistor, which has a closed loop transfer function as eqn (13.2) satisfies AH(w) = 1, meaning that even with no input voltage, we can have continued noise oscillation since the feedback transfer function completely replicated the output to its input. We can then use these oscillators in DC to AC converters/ in modulators/demodulators/ etc…

Microwave Oscillation

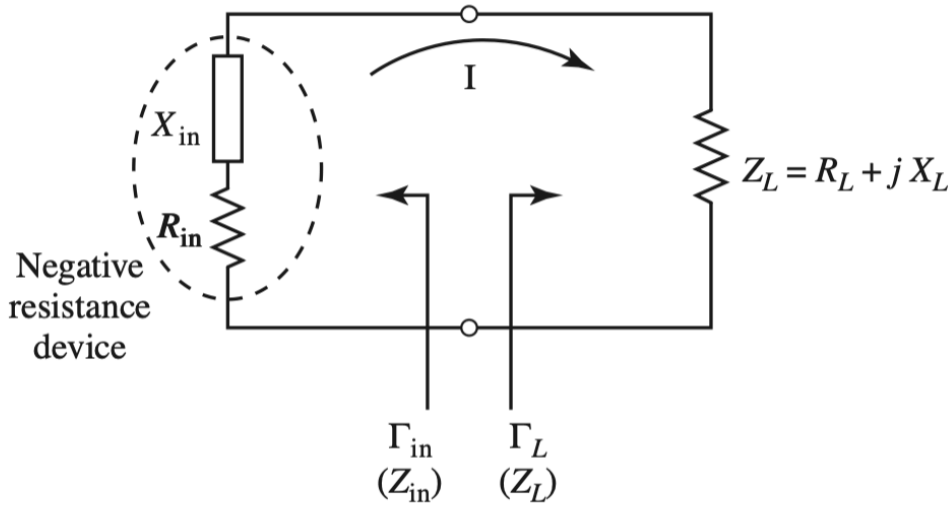


FIGURE 13.6 Circuit for a one-port negative resistance oscillator.

By KCL, we have:

$$(Z_L + Z_{in})I = 0. \tag{13.24}$$

for oscillation to occur, we need non-zero current, thus:

$$R_L + R_{in} = 0, \tag{13.25a}$$

$$X_L + X_{in} = 0. \tag{13.25b}$$

Since our load is passive, Rl is positive, there Rin is negative (therefore a negative resistor implies an energy source).

- Now in the case, that we want steady-state oscillation (oscillation is constant amplitude) we
- We know 13.25b controls the resonant freq. 13.25b is used to represent (we tune Xin) the resonant condition where capacitive reactance cancels inductive reactance at the desired oscillating frequency. This is when f_o is defined
    - Resonance is important because it allows the circuit to transfer energy back and forth between capacitor and inductor, sustaining oscillation for less loss
    - At resonance:
        - The inductive and capacitive energy storage are in phase opposition, meaning the energy stored in one component is released to the other without loss. This balance creates a feedback loop that sustains oscillations.
- FOR OSCILLATION TO BEGIN: it depends on the non-linear behavior of Zin. However, for initial oscillation, we need initial instability, so Rin(I,jw) + RL < 0. Then at any noise from the circuit, an oscillation will build up at this w because Rin(I,jw) + RL < 0. NOW, as our current slowly increases from our initial condition (started as 0), our Rin decreases (why?? Because Rin is a non-linear/active device which eventually saturates at some given current, at some limited current our gain slightly decreases making it “less negative”. Additionally a more physical reason: For the active device to sustain oscillations, it must provide energy to offset the losses in the circuit. However, there’s a physical limit to how much energy the active device can supply. therefore , at higher

currents, the device starts to move away from its ideal operating region, reducing its ability to provide negative

- Mathematically, R_{in} is linked to the gain as:

$$R_{\text{in}} \propto -\frac{1}{g_m}$$

This means higher gain g_m leads to a more negative R_{in}.

resistance.)

  - explanation for lower gain mean less negative Rin

- Now at this point we have,

to build up at the frequency ω. As I increases, $R_{\text{in}}(I, j\omega)$ must become less negative until the current I_0 is reached such that $R_{\text{in}}(I_0, j\omega_0) + R_L = 0$, and $X_{\text{in}}(I_0, j\omega_0) + X_L(j\omega_0) = 0$. At this point the oscillator can run in a stable state. The final frequency, ω_0, generally differs from the startup frequency because X_{in} is current dependent, so that $X_{\text{in}}(I, j\omega) \neq X_{\text{in}}(I_0, j\omega_0)$.

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- The below screenshot states conditions for steady oscillation

Thus we see that the conditions of (13.25) are not enough to guarantee a stable state of oscillation. In particular, stability requires that any perturbation in current or frequency will be damped out, allowing the oscillator to return to its original state. This condition can be quantified by considering the effect of a small change, δI, in the current, and a small change, δs, in the complex frequency $s = \alpha + j\omega$. If we let $Z_T(I, s) = Z_{\text{in}}(I, s) + Z_L(s)$, then we can write a Taylor series for $Z_T(I, s)$ about the stable operating point I_0, ω_0 as

$$Z_T(I, s) = Z_T(I_0, s_0) + \left.\frac{\partial Z_T}{\partial s}\right|_{s_0, I_0} \delta s + \left.\frac{\partial Z_T}{\partial I}\right|_{s_0, I_0} \delta I = 0, \tag{13.27}$$

since $Z_T(I, s)$ must still equal zero if oscillation is occurring. In (13.27), $s_0 = j\omega_0$ is the complex frequency at the original operating point. Now use the fact that $Z_T(I_0, s_0) = 0$, and that $\partial Z_T/\partial s = -j(\partial Z_T/\partial \omega)$, to solve (13.27) for $\delta s = \delta\alpha + j\delta\omega$:

$$\delta s = \delta\alpha + j\delta\omega = \left.\frac{-\partial Z_T/\partial I}{\partial Z_T/\partial s}\right|_{s_0, I_0} \delta I = \frac{-j(\partial Z_T/\partial I)(\partial Z_T^*/\partial \omega)}{|\partial Z_T/\partial \omega|^2} \delta I. \tag{13.28}$$

If the transient caused by δI and $\delta\omega$ is to decay, we must have $\delta\alpha < 0$ when $\delta I > 0$. Equation (13.28) then implies that

$$\text{Im}\left\{\frac{\partial Z_T}{\partial I}\frac{\partial Z_T^*}{\partial \omega}\right\} < 0,$$

or

$$\frac{\partial R_T}{\partial I}\frac{\partial X_T}{\partial \omega} - \frac{\partial X_T}{\partial I}\frac{\partial R_T}{\partial \omega} > 0. \tag{13.29}$$

This relation is sometimes known as *Kurokawa's condition*. For a passive load, $\partial R_L/\partial I = \partial X_L/\partial I = \partial R_L/\partial \omega = 0$, so (13.29) reduces to

$$\frac{\partial R_{\text{in}}}{\partial I}\frac{\partial}{\partial \omega}(X_L + X_{\text{in}}) - \frac{\partial X_{\text{in}}}{\partial I}\frac{\partial R_{\text{in}}}{\partial \omega} > 0. \tag{13.30}$$

As discussed above, we usually have that $\partial R_{\text{in}}/\partial I > 0$, so (13.30) can be satisfied if $\partial(X_L + X_{\text{in}})/\partial \omega \gg 0$. This implies that a high-Q circuit will result in maximum oscillator stability. Cavity and dielectric resonators are often used for this purpose.

- Additionally a high Q is better, why??? The Q-factor determines the sharpness of the resonance curve. A high QQQ value corresponds to a narrow bandwidth around the resonant frequency. This narrow bandwidth ensures that the oscillator operates at a precise and stable frequency, minimizing the likelihood of generating oscillations at undesired frequencies (spurious oscillations). A high Q-factor indicates that the resonant circuit has low energy losses (e.g., due to resistive or dielectric losses). Oscillators require the active device (transistor, negative resistance, etc.) to compensate for these losses. A lower Q results in higher losses, requiring the active device to supply more energy, which can lead to instability or inefficient operation.

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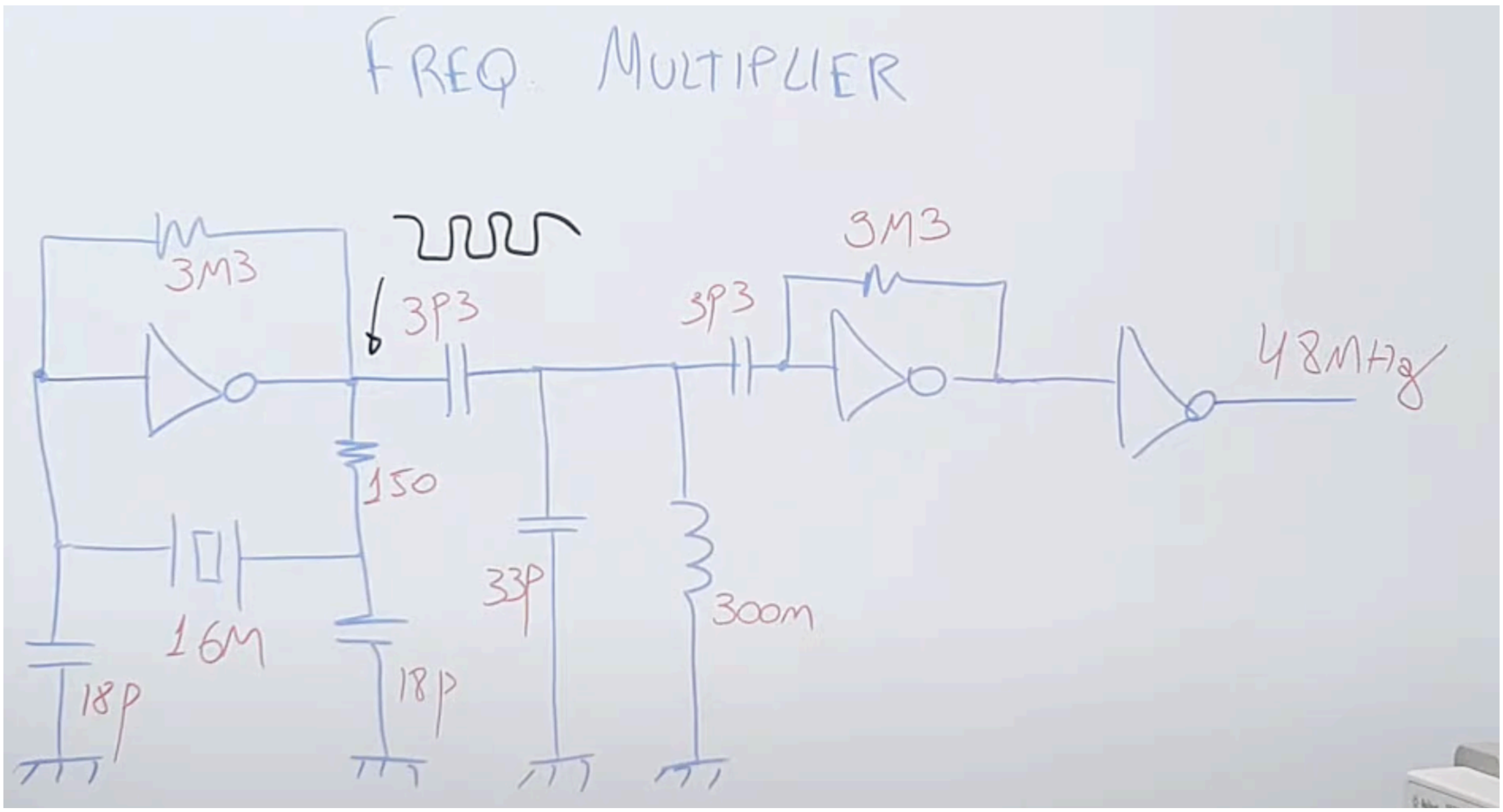
Applications

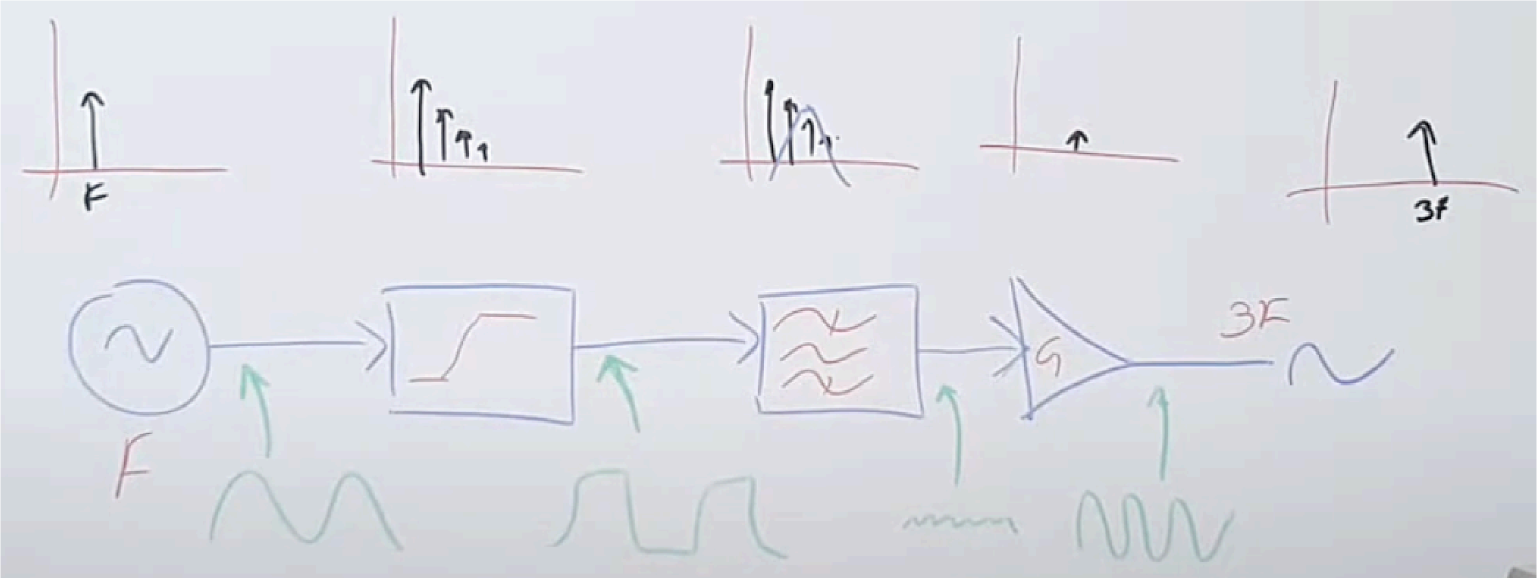
Freq multipliers

- We can use a VCO to generate some fundamental freq, then use some non-linear device to create multiples of this fundamental freq, then we use a bpf to filter out the desired multiplied freq
- We use a nonlinearity to generate harmonics of some fundamental freq
    - VCO: lets says we use a colpitts oscillator (capacitor divider), we know the frequency oscillation is determined by: f0=1/(2π*sqrt(L · C1)). Now to make it voltage controlled, a varactor diode (voltage-dependent capacitor) is used in the LC circuit. The capacitance of the varactor changes with the applied control voltage, thereby varying the frequency.



Oscillator bpf amplifier

(note in the photo above we use a crystal oscillator instead of a VCO)

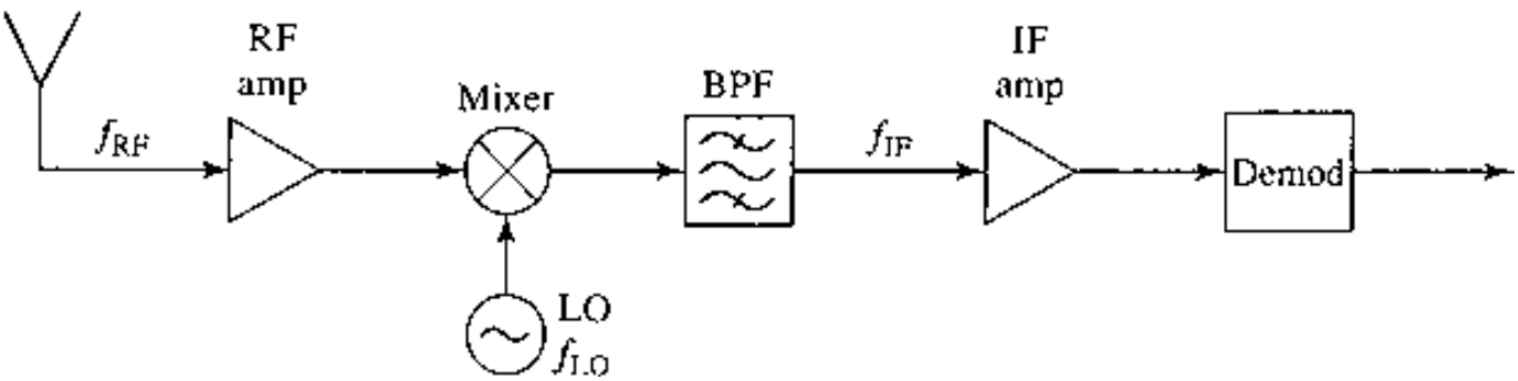


- https://www.youtube.com/watch?v=A9g3nspGRc8

Crytal controlled oscialltor

- A crystal oscillator is an electronic oscillator circuit that uses a piezoelectric crystal as a frequency-selective element. The oscillator frequency is often used to keep track of time, as in quartz wristwatches, to provide a stable clock signal for digital integrated circuits, and to stabilize frequencies for radio transmitters and receivers

Single-conversion superheterodyne receiver.



- Its primary purpose is to generate a stable and precise signal, called the local oscillator (LO) signal, which is used to mix with the incoming radio frequency (RF) signal to produce an intermediate frequency (IF). The incoming RF signal is fed into a mixer, along with the signal from the local oscillator (LO). The mixer combines the RF signal and the LO signal to produce sum and difference frequencies:

$$f_{\text{mix}} = |f_{\text{RF}} - f_{\text{LO}}| \quad \text{(Intermediate Frequency, IF)}$$

and

$$f_{\text{mix}} = f_{\text{RF}} + f_{\text{LO}} \quad \text{(high-frequency component, filtered out).}$$