EE 402 (Microwave Communication System Design)

P1

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Radiation:

Radiation is to find the electric and magnetic fields (power) at a distance R away from the given source.

Source: AC Current.

To find $\underbrace{\bar{E}}_{\text{Electric field}}$ and $\underbrace{\bar{H}}_{\text{Magnetic field}}$:

Sources $\rho, \bar{J}$ $\xrightarrow[\text{Integration path 1.}]{R}$ $\bar{E}, \bar{H}$

ρ = charge density $\left(\frac{C}{m^3}\right)$

$\bar{J}$ = Current density vector $\left(\frac{A}{m^2}\right)$

$\underset{\text{Current}}{I} = \int_s \bar{J} \cdot \bar{ds}$

$\bar{E}$ = Electric field $\left(\frac{V}{m}\right)$

$\bar{H}$ = Magnetic field intensity $\left(\frac{A}{m}\right)$

Sources $\xrightarrow{\text{Integration path 2}}$ Auxiliary Potentials $V, \bar{A}$ $\xrightarrow{\text{Differentiation path.}}$ $\bar{E}, \bar{H}$

V = Voltage (V)

$\bar{A}$ = Magnetic potential vector (A)

Integration path 2 is easier than Integration path 1

$\boxed{\text{Integration path 2:}}$

$$\left.\begin{aligned} &\boxed{\bar{A} = \frac{\mu}{4\pi}\int_v \bar{J}\,\frac{e^{-jkR}}{R}\,dv'} \quad \text{for volumetric sources.} \\ &\text{or} \\ &\boxed{\bar{A} = \frac{\mu}{4\pi}\int_s \bar{J}_s \cdot \frac{e^{-jkR}}{R}\,ds'} \quad \text{for planar sources.} \\ &\text{or} \\ &\boxed{\bar{A} = \frac{\mu}{4\pi}\int_c \bar{I} \cdot \frac{e^{-jkR}}{R}\,dl'} \quad \text{for linear sources} \end{aligned}\right\} (1)$$

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$\mu = \mu_0 = 4\pi \times 10^{-7} \left(\frac{H}{m}\right)$

Also, prime coordinates indicate source.

Differentiation Path:

$\boxed{\bar{E} = -j\omega A}$ (far field $\Rightarrow R \gg \lambda$) for spherical coord.

Ex.

Find the radiation problem for a "dipole antenna" whose current is given as:

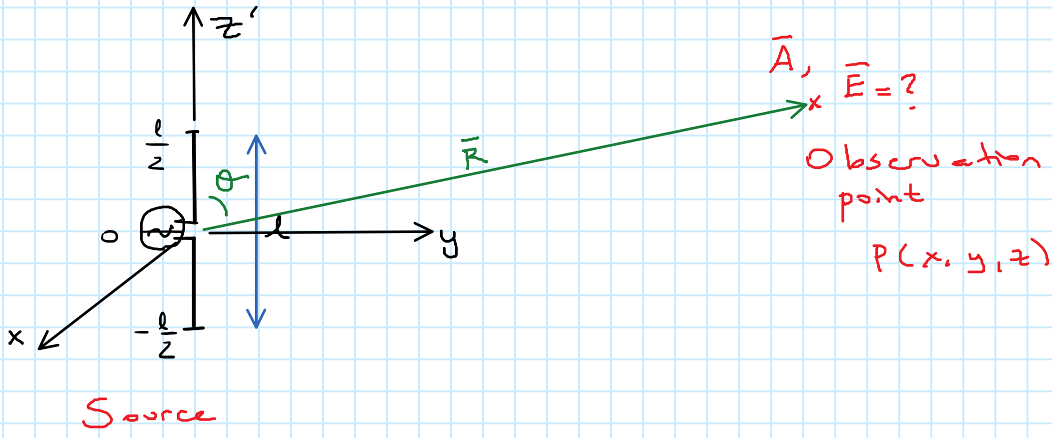
$$\bar{I}(z') = \begin{cases} \hat{a}_z I_o \sin\left[k\left(\frac{l}{2} - z'\right)\right], & 0 \leq z' \leq \frac{l}{2} \\ \hat{a}_z I_o \sin\left[k\left(\frac{l}{2} + z'\right)\right], & -\frac{l}{2} \leq z' \leq 0 \end{cases}$$

where k = wavenumber = $\frac{2\pi}{\lambda}$, λ = wavelength (m.), $\lambda = \frac{c}{f}$, $c = 3\times10^8\, m/s$

and l = dipole length.

Solution:

Using $\bar{A} = \frac{\mu}{4\pi} \int_C \bar{I} \cdot \frac{e^{-jkR}}{R} dl'$, we will find $\bar{A}$, and then find $\bar{E}$ from $\bar{E} = -j\omega \bar{A}$



$$\bar{A} = \frac{\mu}{4\pi} \int_C \bar{I} \cdot \frac{e^{-jkR}}{R} dl', \quad dl' = dz', \quad R = \|\bar{R}\|, \quad k = \frac{2\pi}{\lambda}$$

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or

$$\bar{A} = \frac{\mu_o}{4\pi}\int_{-\frac{l}{2}}^{0} \hat{a}_z I_o \sin\left[k\left(\frac{l}{2}+z'\right)\right] \frac{e^{-jk\overbrace{R}^{R - z'\cos\theta}}}{\underbrace{R}_{\to R}} dz' +$$

$$\frac{\mu_o}{4\pi}\int_{0}^{\frac{l}{2}} \hat{a}_z I_o \sin\left[k\left(\frac{l}{2}-z'\right)\right] \frac{e^{-jkR}}{R} dz'$$

$\vdots$

In order to evaluate the integral

$R = R$ (denominator term)

$R = R - z'\cos\theta$ (exponential term)

} Far field approximations.

We find $\bar{A}$, and from $\bar{E} = -j\omega\bar{A}$ for E_θ as:

$$\boxed{E_\theta = j\eta\frac{I_o e^{-jkR}}{2\pi R}\cdot f(\theta)} \quad , \quad k = \frac{2\pi}{\lambda} \text{ (wavenumber)}$$

where

$$f(\theta) = \boxed{\text{Pattern function} = \frac{\cos\left(\frac{kl}{2}\cos\theta\right) - \cos\left(\frac{kl}{2}\right)}{\sin\theta}}.$$

and

$$\boxed{H_\phi = \frac{E_\theta}{\eta}} \quad \boxed{, \quad \bar{W}_{avg} = \frac{1}{2}\operatorname{Re}\left[\bar{E}\times\bar{H}^*\right] = \frac{1}{2}\operatorname{Re}\left[\bar{E}_\theta \times \bar{H}_\phi^*\right] = \hat{a}_R \frac{1}{2\eta}|E_\theta|^2 = \eta\frac{I_o^2}{8\pi^2}\underbrace{\left[\frac{\cos\left(\frac{kl}{2}\cos\theta\right) - \cos\left(\frac{kl}{2}\right)}{\sin\theta}\right]^2}_{\text{Power density function } \left(\frac{W}{m^2}\right)}}$$

Ex:

For $l = 1m$, $f = 1kHz$, $I_o = 1A$, $R = 5m$., $\theta = 90^\circ = \frac{\pi}{2}$ rad

Find the Electric field, magnetic field and $\bar{P} = ?$ $\left(\frac{W}{m^2}\right)$ at the observation point $P(R,\theta) = P(5,\frac{\pi}{2})$

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Ans.

$$\lambda = \frac{3\times10^8}{1\times10^3} = 3\times10^5$$

$$\bar{E}(5,\tfrac{\pi}{2}) = \underbrace{j\eta}_{377\Omega} \frac{I_0 e^{-jkR}}{2\pi R} f(\theta) = j(377)\frac{1\cdot e^{-j\frac{2\pi}{3\times10^5}\cdot 5}}{2\pi\cdot(5)} \cdot f(\theta)$$

$$= e^{j\frac{\pi}{2}}(377)\frac{1\cdot e^{-j\frac{2\cancel{\pi}}{3\times10^5}\cdot 5}}{2\pi\cdot(5)}\cdot f(\theta) \qquad \frac{10}{10^5} = 10^{-4}$$

$$= e^{j(\frac{\pi}{2} - \cancel{10^{-4}})}(377)\cdot\frac{1}{10\pi}\cdot f(\theta)$$

$$\approx e^{j\frac{\pi}{2}}\cdot(118.43)\cdot f(\theta)$$

where

$$f(\theta) = \frac{\cos\left(\frac{kl}{2}\cos\theta\right) - \cos\left(\frac{kl}{2}\right)}{\sin\theta}, \quad kl = \frac{2\cancel{\pi}}{\cancel{3}\times10^5}\cdot 1 = 2\times10^{-5}$$

$\theta \to \frac{\pi}{2}$

$$= \frac{\cos\left(\frac{10^{-4}}{2}\cdot\cos\frac{\pi}{2}\right) - \cos\left(\frac{2\times10^{-5}}{2}\right)}{\sin\frac{\pi}{2}}$$

$$= 1 - 0.999 \approx 0$$

If f was 100 MHz as an example, $\Rightarrow kl = \frac{2\pi}{3}\cdot 1 = 2$

Hence, $\bar{E}$, $\bar{H}$ and $\bar{P}$ are greater. $\lambda = 3m \quad l = 1m$

$l = \frac{\lambda}{3}$

For $f = 100MHz$,

$$f(\theta) = 1 - 0.54 = 0.46$$

$$|\bar{E}| = 118\cdot(0.46) = 54.1 \ \frac{V}{m}$$

$$|\bar{H}| = \frac{|E|}{\eta} = \frac{54.1}{377} = 0.144 \ \frac{A}{m}$$

$$\bar{P} = \frac{|E|^2}{\eta} = \frac{(54.1)^2}{377} = 7.86 \ \frac{W}{m^2}$$

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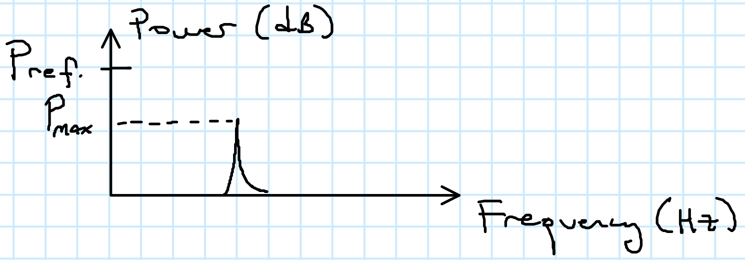
Spectrum Analysis:

Spectrum = Frequency. Thus, spectrum analysis refers to the frequency analysis. We aim to plot the E.M. waves in power vs. frequency graph.

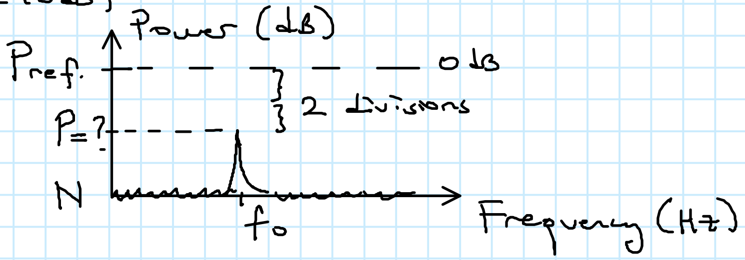


P_{ref} = Reference power. It is usually set to 0 dB = 1W.

Because,
$$P_{dB} = 10\log_{10} \frac{P_{ref}}{1W} = 0 \Rightarrow P_{ref} = 10^{0} = 1W$$

To determine the signal power, we count down the divisions from the P_{ref}.

Ex: Evaluate the power of the signal at $f = f_0$.



Ans:

$$P_{difference} = (dB/div) \times (div) = 10\,dB \cdot 2 = 20\,dB$$

$$\Rightarrow P = 0\,dB - 20\,dB = -20\,dB = 10^{-2} = 0.01\,W = 10\,mW.$$

N = Noise power (usually −60 dB or −70 dB at room temperature 300 K°

Anything above 0 K generates noise. Noise is a random E.M. radiation at every frequency (white noise)

Noise is destructive to telecommunication.

The measure of telecommunication quality is "signal to noise ratio". (SNR)

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$$SNR = \frac{\text{Signal power}}{\text{Noise power}} = \frac{S}{N} \rightarrow 10\log_{10}\frac{S}{N}$$

$$= \underbrace{10\log_{10} S}_{S_{dB}} - \underbrace{10\log_{10} N}_{N_{dB}}$$

Usually SNR is given in decibels.

$$\Rightarrow SNR_{dB} = S_{dB} - N_{dB}$$

In general,

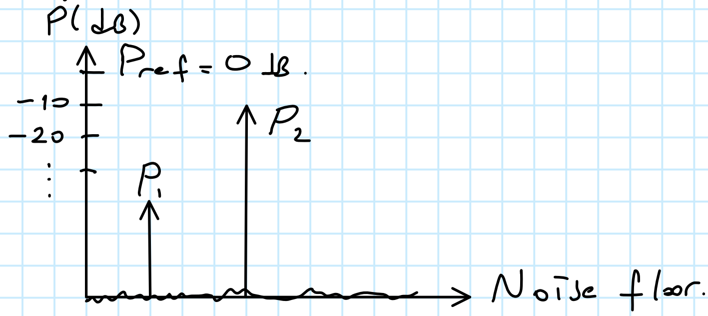
$SNR < 15\,dB$ (poor reception)

$20\,dB < SNR < 40\,dB$ (good reception)

$SNR > 40\,dB$ (excellent reception)

<u>Ex:</u>

The spectrum analyzer has the following received signal levels:



Find SNR for P_1 and P_2? Evaluate the type of reception.

$SNR_{P_1} = P_1(dB) - N(dB) = -40\,dB - (-70\,dB) = 30\,dB$. Good reception.

$SNR_{P_2} = P_2(dB) - N(dB) = -10 - (-70) = 60\,dB$. Excellent reception.

—o—

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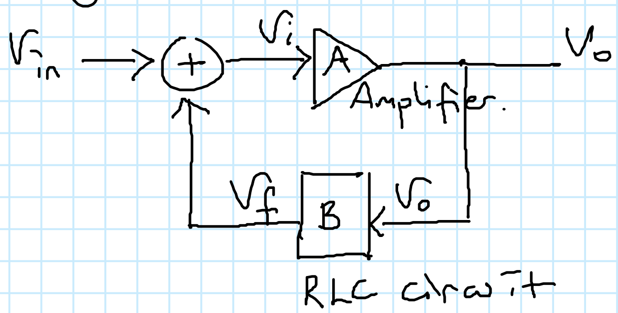
- The function generators in our labs can reach to at most 20MHz.
- Thus, we need high frequencies for radiation.

- High Frequency (RF) Oscillator Design -

Theory is based on positive feedback:



The analysis:

$$V_i = V_{in} + V_f \quad (+\text{ feedback})$$

Also,

$$V_o = A V_i$$

and

$$V_f = B V_o$$

We want to find the closed loop gain

$$\frac{V_o}{V_{in}} = ?$$

$$\Rightarrow V_i = V_{in} + V_f$$

$$\frac{V_o}{A} = V_{in} + B V_o \Rightarrow V_{in} = V_o\left(\frac{1}{A} - B\right)$$

or

$$\frac{V_o}{V_{in}} = \frac{1}{\frac{1}{A} - B} = \frac{A}{1 - AB} \quad \text{(Closed loop gain)}$$

- When $|AB| = 1$, the gain becomes ∞.
- So, initially, we make $|AB| < 1$ to grow the signal inside the loop.
- The initial spike comes from noise.

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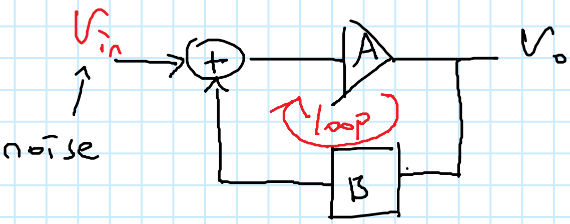
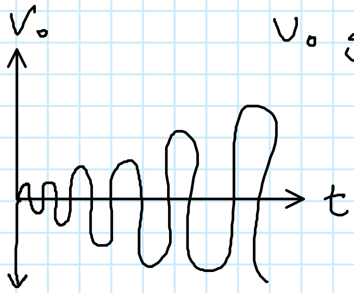
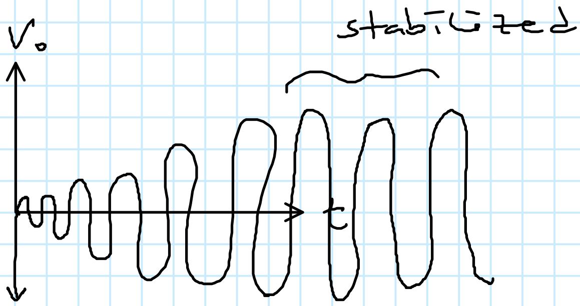




V_o grows inside the loop until the transistors in the amplifier start to approach SAT region where the gain A is reduced. Thus $AB \neq 1$ but $AB < 1$ and the oscillation is stabilized.

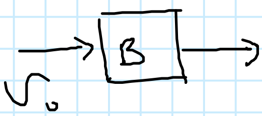


- The frequency of oscillation is determined by the B circuit.

B - Circuit (Feedback Circuit)

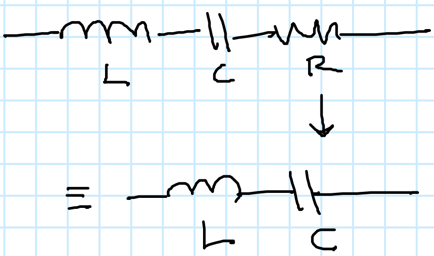
B circuit is a filter or frequency selective circuit with R, L and C components.

Frequency selective:

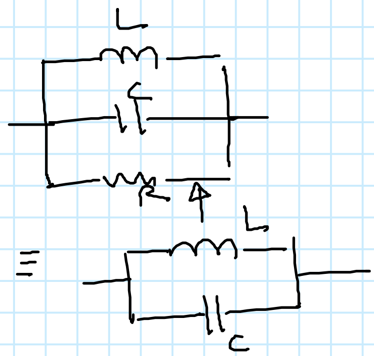


$V_f = BV_o$ for certain frequencies

Typically,



or



(Resonator circuit)

(Ring circuit, tank circuit)

(LC - Resonator)

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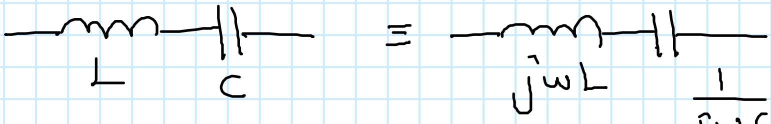


$$\frac{1}{j\omega C} = \frac{-j}{\omega C}$$

$$Z_{Total} = j\omega L + \frac{1}{j\omega C} = \frac{1-\omega^2 LC}{j\omega C} \quad (\Omega).$$

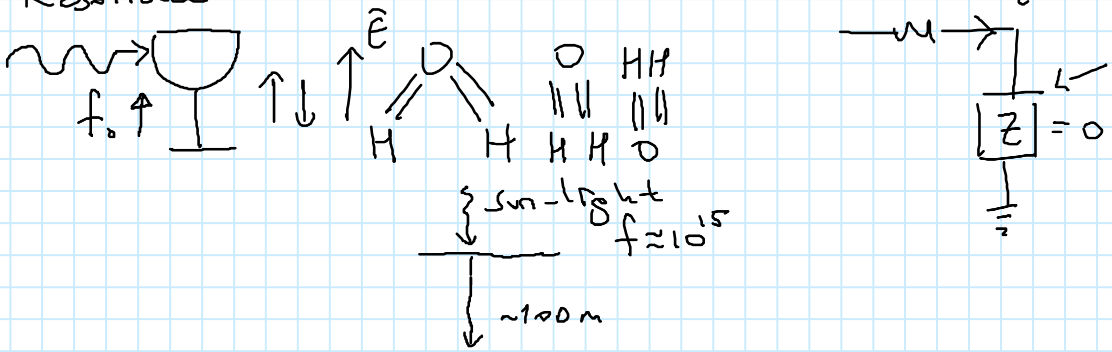
When the impedance is zero, this is called "resonance".

Resonance: Resistance of a quantity = 0.

Structural Resonance

Molecular resonance

Circuit Resonance ...



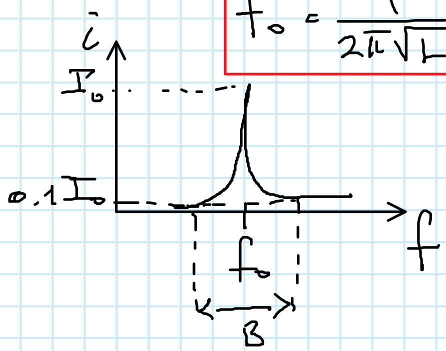
It absorbs all current

$1-\omega^2 LC = 0$ is the condition for resonance.

$\Rightarrow \omega^2 LC = 1$

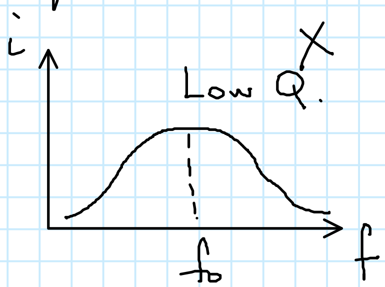
$\Rightarrow \omega_0 = \frac{1}{\sqrt{LC}}$ (rad/s) (resonance frequency)

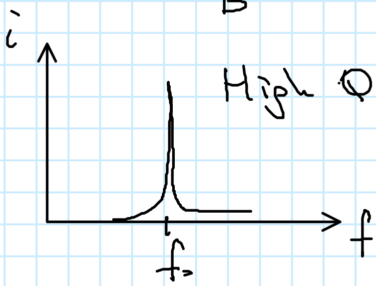
$$\boxed{f_0 = \frac{1}{2\pi\sqrt{LC}} \ (Hz)}$$



B = Bandwidth (10% cross value)

Define quality factor: $Q = \frac{f_0}{B}$





High Q filter (circuit)

Q > 10

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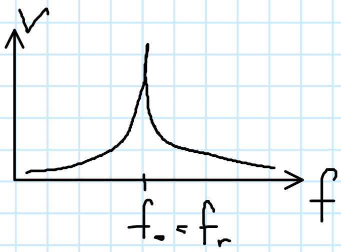
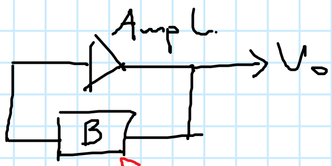
- $Q > 10$ is considered as high.
- For an LC-resonator, $Q > 10$
- The parallel LC-resonator has the same characteristics as the series circuit except, the voltage and current are reversed.

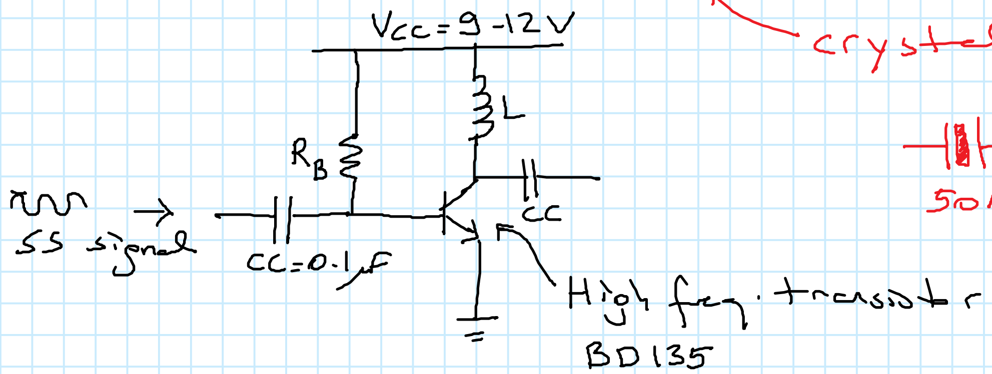


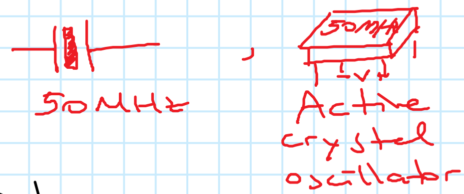
→ Parallel LC-resonator circuit.

Electronic Implementation of the Oscillator:

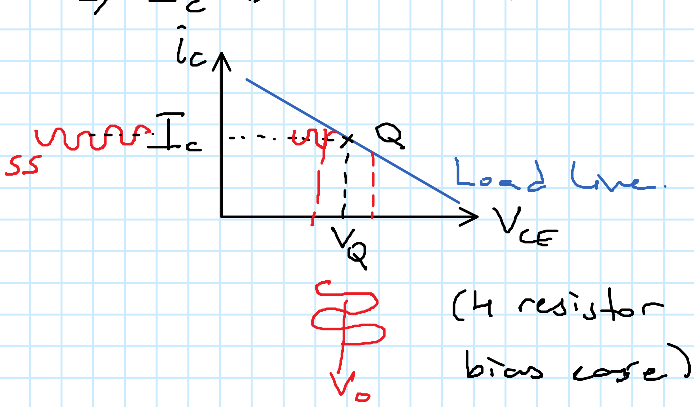
The block diagram:

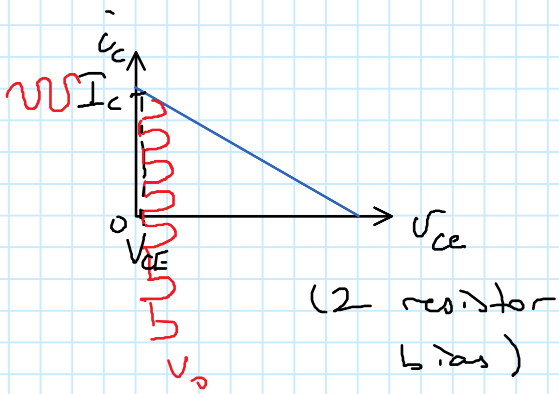






- R_B is used to bias the transistor.
  - ⇒ I_c is established





- The inductor L is used to charge during the + cycle and release its energy during the − cycle, completing a full cycle output.

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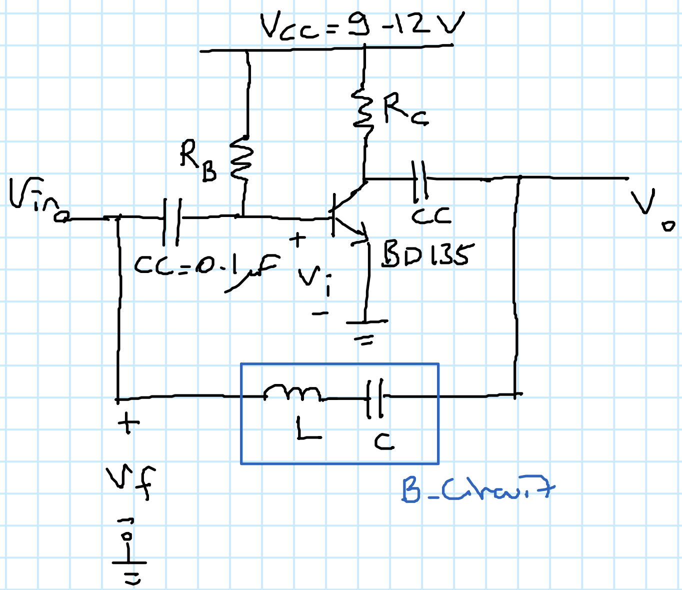
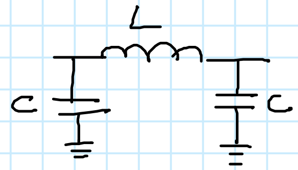


$V_f = V_i$ (steady state)

$V_i = V_{in} + V_f$

- In practice, modified resonators are used for the feedback circuit. Because they have better (more) Q-factor.

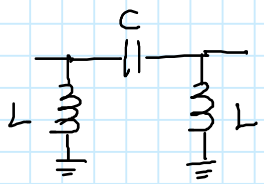
a-) Colpitts Oscillator.



$$f_r = \frac{1}{2\pi\sqrt{LC_{eff}}}$$

$$C_{eff} = \frac{C}{2}$$

b-) Hartley oscillator.

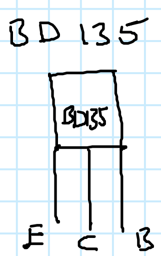


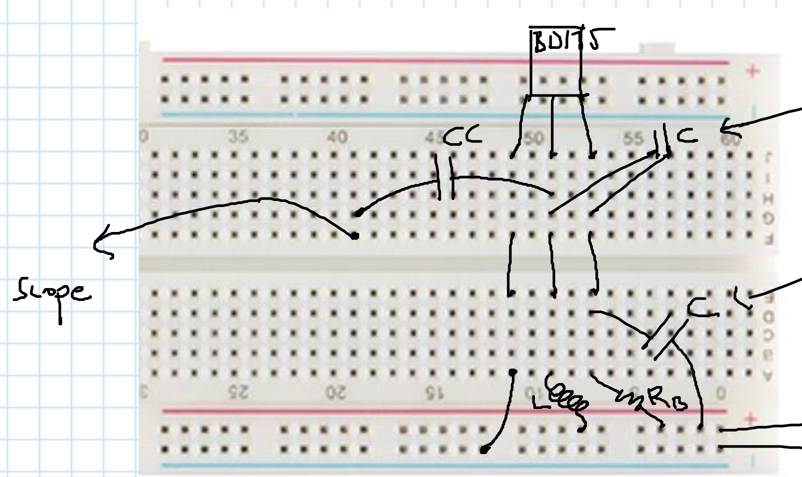
$$f_r = \frac{1}{2\pi\sqrt{L_{eff}C}}$$

where

$$L_{eff} = 2L$$

Board Implementation:





60-100 pF

To increase Q.
60-100 pF

+
V_{cc}
−

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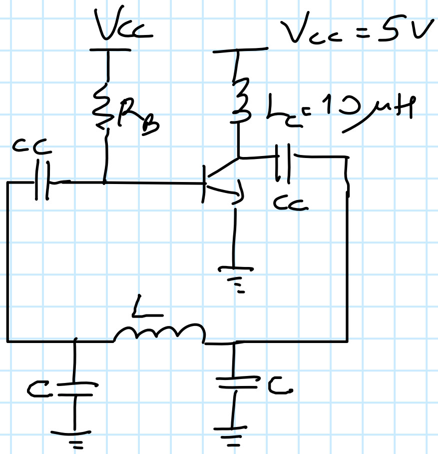
Ex:

Design a Colpitts oscillator at 433 MHz frequency. Draw the circuit schematics.

Ans:

$R_B = 5.6k - 10k.$

$cc = 0.1 \mu F.$



$$f_r = \frac{1}{2\pi\sqrt{L\frac{C}{2}}} = 433 \times 10^6$$

Let $L = 5\mu H$

$$\sqrt{(5\times10^{-6})\frac{C}{2}} = \frac{1}{2\pi \cdot 433} \times 10^{-6}$$

Taking the Square both sides gives

$$5 \times \cancel{10^{-6}} \cdot \frac{C}{2} = \left(\frac{1}{2\pi \cdot 433}\right)^2 \times \cancel{10^{-12}}^{\,-6}$$

$$\Rightarrow C = \underbrace{\frac{2}{5}\left(\frac{1}{2\pi \cdot 433}\right)^2 \times 10^{-6}}$$

$$C = 5.4 \times 10^{-14} \Rightarrow 0.054 pF$$

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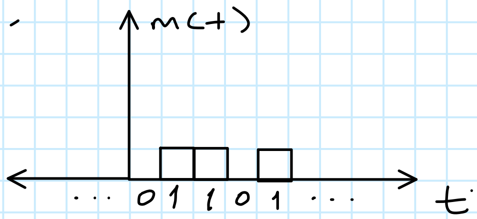
– Modulation –

- A signal that carries information is usually called the "message signal", $m(t)$.
- $m(t)$ is usually a digital signal

$$m[n] = [\cdots 0, 1, 1, 0, 1, \cdots] = \text{sequence}.$$

In time graph,



Any signal (or function), $m(t)$ can be expressed in terms of summations

$$m(t) = \sum_{k=-\infty}^{\infty} c_k \cdot \phi(kt)$$

Constant coefficients.

$\phi(kt)$ = Basis function.

$\phi(kt)$ must be an orthogonal function.

$$\underbrace{\int_{-\infty}^{\infty} \phi(kt)\,\phi^*(kt)\,dt = 1}_{\text{Dot product of functions.}}$$

If $\phi(kt) = (t-a)^n$ (Taylor series)

$= e^{jn\omega_0 t}$ (Exponential series)

$= \cos(n\omega_0 t)$ (Fourier series) → We use this function for telecomm.

$= \vdots$ $\vdots$

$$\Rightarrow m(t) = \sum_{k=-\infty}^{\infty} c_k \cos(n\omega_0 t) \quad \text{(Fourier series)}$$

For a non-periodic $m(t)$

$$m(t) = \frac{1}{2\pi} \int_{-\infty}^{\infty} M(\omega) \cos(n\omega_0 t)\, d\omega$$

$$M(\omega) = \int_{-\infty}^{\infty} m(t) \cos(n\omega_0 t)\, dt \quad \text{(Fourier transform)} \equiv C_k.$$

- We analyze signals in frequency domain (spectral analysis) by plotting C_n's versus frequency $n\omega_0$

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Modulation can be written in terms of multiplication

$$g(t) = m(t) \times f(t)$$

where

$m(t)$ = message signal, usually in lower frequencies, kHz

and

$f(t)$ = carrier signal used for radiation at high frequencies

$g(t)$ = modulated signal.

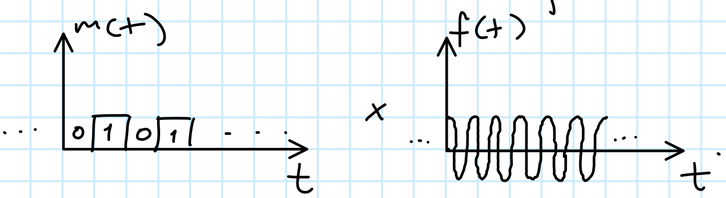
ASK Modulation (ON-OFF Keying):

$$m(t) = [\dots, 0, 1, 0, 1, \dots]$$

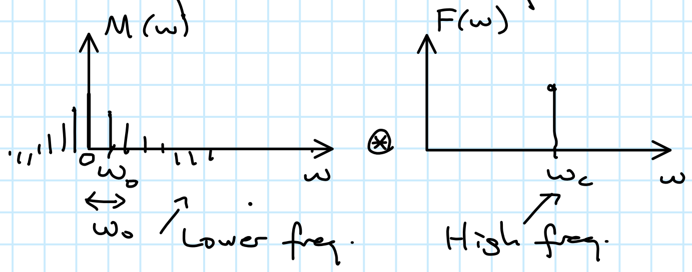
$$f(t) = A\cos(\omega_c t), \quad \omega_c = \text{Carrier frequency.}$$

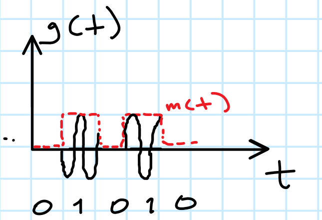
$$g(t) = m(t) \times f(t) = [\dots, 0, 1, 0, 1, \dots] \times A\cos(\omega_c t)$$

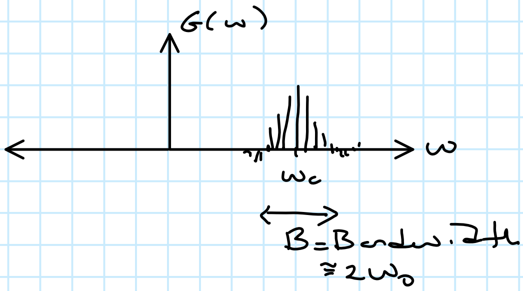
Time Domain Interpretation



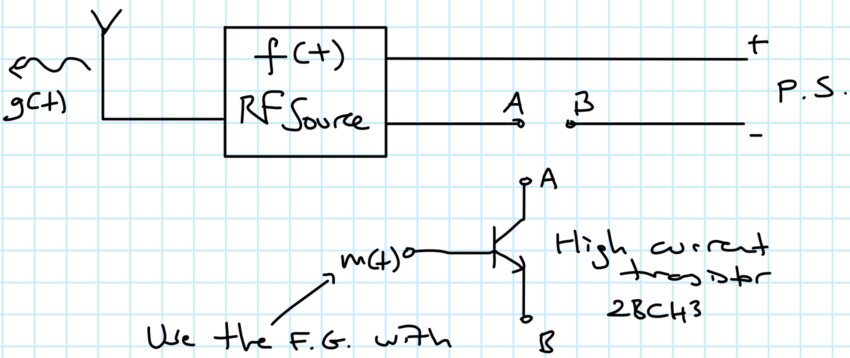
Freq. Domain Interpretation

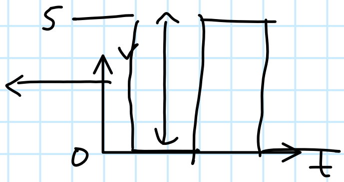






Physical Implementation:





Amplitude $5\,V_{pp}$, and freq. 100 Hz (Square Wave)

2.5V offset

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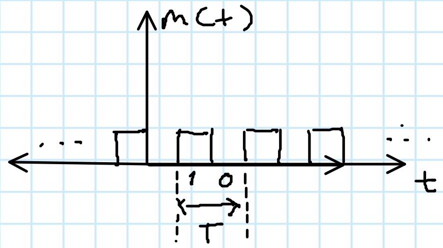
Transmission Bandwidth: is the frequency of $m(t)$.

- First, all modern electronic systems such as phones, computers, video satellite decoders, etc... use digital signals. Because digital signals have advantages over analog signals such as better noise immunity.
  Thus, we always assume $m(t)$ is digital.
- The transmission bandwidth determines how fast the information is transfered.
  For example if B = Transmission bandwidth = 1 kHz = 1000 means that in 1 sec. we have <u>2000</u> bits



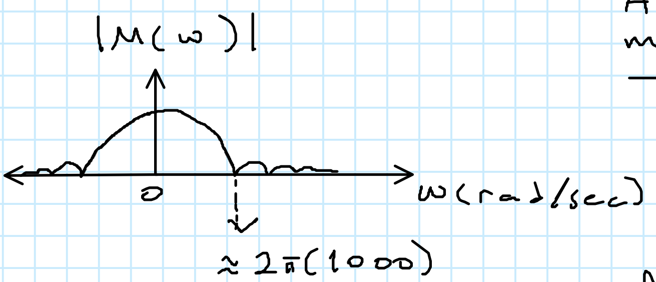
each cycle has 2 bits.
$\Rightarrow$ for 1 kHz trans. bandwidth we have 2000 bits.
or

Transmission rate $= 2 \frac{\text{kbits}}{\text{sec}}$.

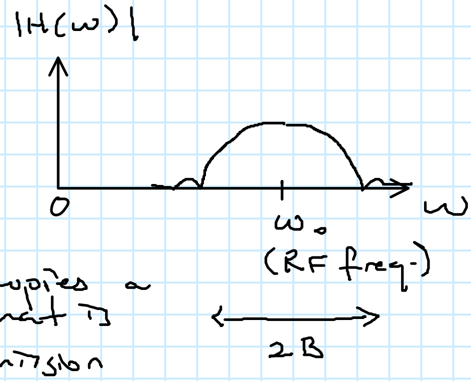
- If B is high, we have faster transmission (or more data transmission in unit time)
- The downside of having high transmission bandwidth is to occupy frequency band which is costly

<u>Ex:</u>

Let us assume $m(t)$ have 1 kHz bandwidth
Then, in the spectrum analysis:



After ASK modulation $\longrightarrow$



(It occupies a frequency band that is twice the transmission bandwidth.)

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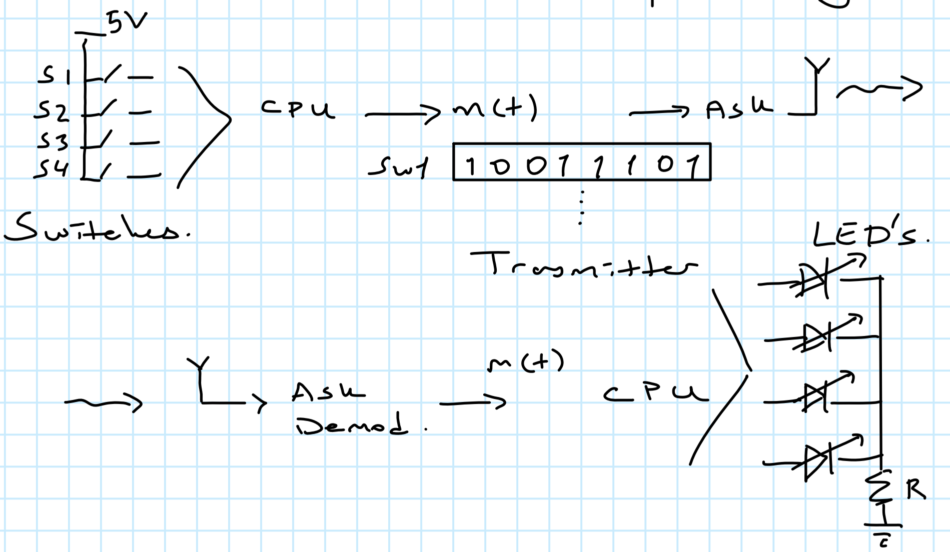
- Bandwidth is valuable. One must pay to use bandwidth.

Ex

Suppose that we have the following telecomm. system:



For simplicity, one switch will be on at a time.

For our case, we want to turn LED's on and off

$m(t) = 8$ bits what transmission bandwidth is suitable?

$f = 10\,Hz$, $f = 100\,Hz$, $f = 1\,kHz$ which one is the best choice? explain why?

Ans:

For $f = 10\,Hz$, $B = 2f$ bits/sec $= 20$ bits/sec.

1 sec $\longrightarrow$ 20 bits $x = \frac{8}{20} = 0.4$ sec. $\sim \frac{1}{2}$ sec.

$x \longrightarrow 8$ bits

$\frac{1}{2}$ sec. is a significant delay. Thus, it is not accepted.

For $B = 100\,Hz$ ✓, $t.r. = 200\,\frac{bit}{sec}$, delay $= x = \frac{8}{200} = 0.04$ sec $= 40$ ms.

40ms delay is not detectable by our senses.

Thus, it is suitable.

For $B = 1\,kHz$ means $2000\,\frac{bits}{sec}$, delay $= 4$ms.

Thus, this is not accepted, because the cost is high.

—o—

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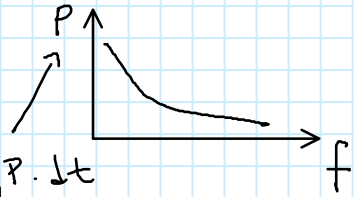
Carrier Frequency Selection

Parameters that effect the carrier frequency selection:

1-) Antenna dimensions: as f increases, antenna dimensions decrease. This is usually a good property.

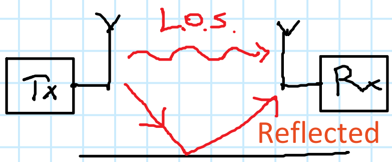
2-) Power (RF): As frequency increases, power decreases

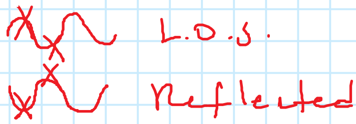


$E = \int_T P \, dt$

3-) Fading: (Multipath).

– Cancellation of out of phase signals coming from different paths at the receiver.





The phase term $\quad \bar{E} = E_0 e^{\underbrace{-jkz}_{\text{phase}}} \qquad k = \frac{2\pi}{\lambda} \Rightarrow kz = 2\pi \frac{z}{\lambda}$

If $\frac{z}{\lambda}$ is high $\Rightarrow$ phase deviation is high (sensitive) $\Rightarrow$ Prone to fading

If $\frac{z}{\lambda}$ is low $\Rightarrow$ phase " " low (less sensitive)
↳ Immune to fading.

$\Rightarrow$ Fading is higher for high frequencies

f > HF band. then fading begins.

↓

3-30 MHz

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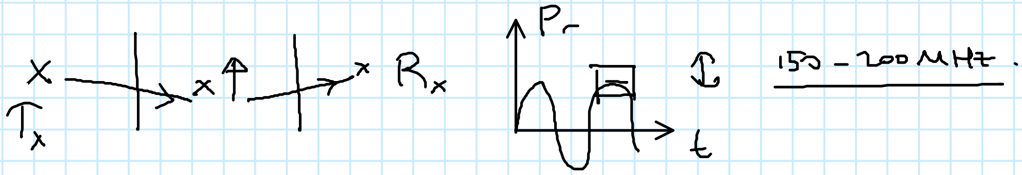
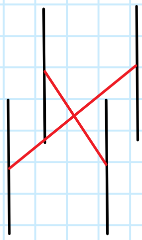
- Generally fading is undesired, but sometimes it is useful in some applications such as motion detectors



Motion Detection

In the case of base stations



(Antenna arrangement to minimize fading)

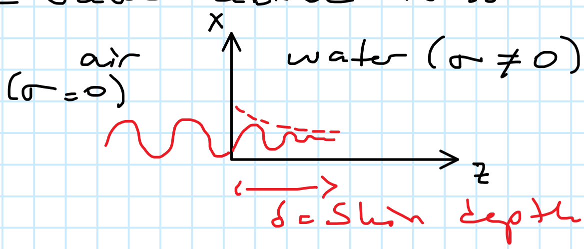
4-) Stray Effects (Electromagnetic interference or EMI)

At high frequencies, small conductors act as radiators and couples energy with nearby conductors This is called interference. Interference is unwanted and causes circuit operation to failure.

In order to overcome interference, one must use guided structures such as transmission lines when implementing circuits

5-) Wave Penetration:

Skin depth = Depth at which the wave looses its amplitude value above 70 %



$$\delta \propto \frac{1}{f}$$

6-) Signal Processing:

As frequency increases, signal processing becomes more difficult The remedy is to use mixers.

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Frequency Bands

- Extremely Low Frequency (ELF): 3-3kHz
- Very Low Frequency (VLF): 3-30kHz (100k-10k wavelength)
  - Difficult to have portable antennas.
  - Usually compact antennas are used.
  - Ship and aircraft guidance beacons.
  - High penetration → underwater comm. relies on sound waves.
- LF (Low Freq.) 30kHz-300kHz (10k-1km)
  - Difficult to have portable antennas.
  - Ship and aircraft beacons.
  - High penetration.
- MF (Medium Freq.): 300kHz-3MHz (1km-100m)
  - Antennas are very big, mounted on towers and/or masts.
  - Long range comm. through sky waves.
  - AM broadcasting.
  - HAM radio. (Amateur radio)
  - High penetration.
  - Low fading.
  - Antennas are somewhat portable (not very portable.)

HF (High Freq.): 3MHz-30MHz (100m-10m)

- Broadcasting.
- Ship comm.
- Ham radio.
- Long range comm. through sky waves:

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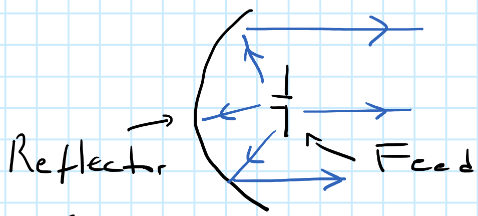
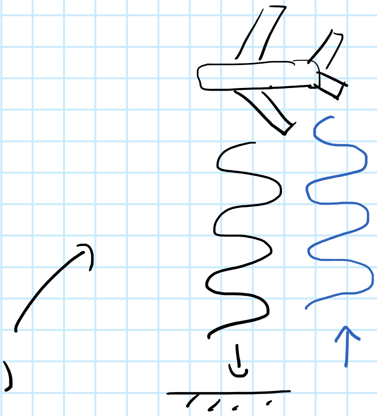
- Antenna sizes are practical but long, usually wires are extended over towers or buildings to set up antennas.
- Good penetration through walls.

VHF (Very High Freq.): 30 MHz – 300 MHz (10 m – 1 m).
- FM broadcasting.
- TV "
- Government, millitary comm.
- Ham. radio.
- Portable antennas.
- Good penetration
- High fading. (multiple transmitters or circular polarization can be used to overcome fading).

UHF (Ultra High Freq.): 300 MHz – 3 GHz (1 m – 10 cm)
- Antenna sizes are small enough to make directive antenna such as reflectors





- Police radars
- TV broadcasting.
- Mobile phones.
- Altitute radars (cw radars)
- High fading.
- Somewhat good penetration.

SHF (Super High Freq.) 3 GHz – 30 GHz (0.1 m – 0.01 m)
- Astronomy and space research.
- Sattelite broadcasting.
- Radars.
- Electronic comm. (doppler radars, motion detectors, etc..)

~~Ama~~ ateur wireless.
- Bad penetration
- High fading
- Small antennas with array structure.

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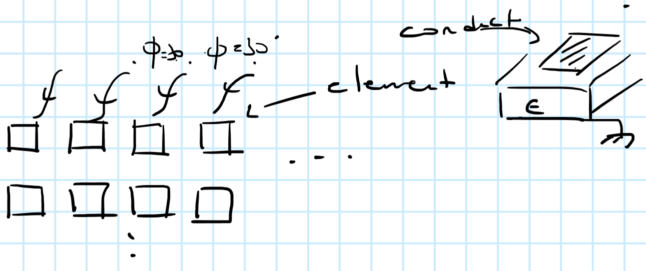
EHF (Extremely High Freq.): 30 GHz − 300 GHz. (0.01m − 0.001m)

- Sattelite comm.
- Terrestrial comm.
- High fading.
- Bad penetration.
- Very small antennas
- Antenna arrays can be used to have very high gain antennas



SLF (Submilli Light Freq.): $f = 300$ GHz − 3 THz

(λ = 1mm − 0.1mm)

- Remote sensing
- Laser comm.
- Optical comm.

Ex:

Which of the following carrier frequencies is suitable for an audio communication (walkie-talkies). Explain why?

a-) MF b-) HF c-) VHF d-) UHF

Ans:

Properties: 1-) Antenna size, Smallest

	1	0		
	UHF	VHF	~~HF~~	~~MF~~
	↓	↓	↓	↓
	5 cm	0.5 m = 50 cm	5 m	50 m

2-) Power, VHF = 1, UHF = 0

3-) Fading, VHF = 1, UHF = 0

4-) EMI, VHF = 1, UHF = 0

5-) Penetration, VHF = 1, UHF = 0

6-) DSP, VHF = 1, UHF = 0

VHF ✓

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Ex:

Which of the following carrier frequencies is suitable for an mobile phone communication. Explain why?

a-) MF b-) HF c-) VHF d-) UHF

Ans:

1-) Antenna size : Smallest UHF, VHF, ~~HF~~, ~~MF~~

$\lambda = 10cm$ $\lambda = 1m$ $\lambda = 10m.$ $\lambda = 100m$

$\frac{\lambda}{2} = 5cm$ $\frac{\lambda}{2} = 50cm$ $\frac{\lambda}{2} = 5m.$ $\frac{\lambda}{2} = 50m.$

This is a strong condition, thus the answer is UHF.

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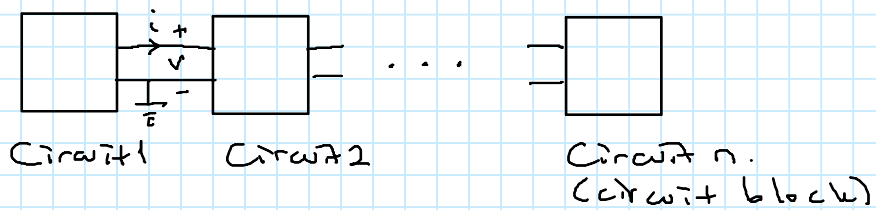
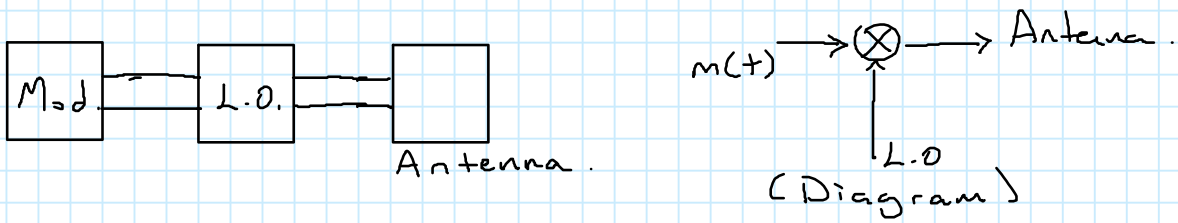
- Impedance Matching -

Generally, electronic systems are connected in series (cascaded).

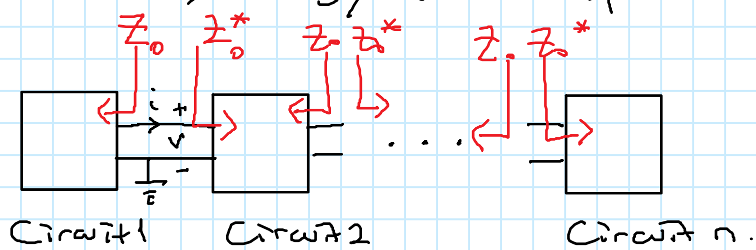
For example,



In the transmitter, we have



- Between each circuit pair, we want maximum power transfer. Otherwise, energy is lost for the remaining blocks.



- For maximum power transfer

$$\boxed{Z_o = Z_o^*} \qquad Z_o = R_o \mp jX_o \ , \quad Z_o^* = R_o \pm jX_o$$

For real impedance (resistor)

$$\boxed{R_o = R_o}$$

Usually $R_o \neq R_o$ for any two blocks, or $Z_o \neq Z_o^*$. Then, what can we do?

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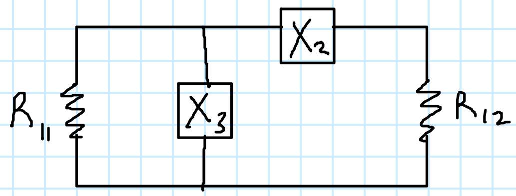
- Inserting an extra resistor is a waste of energy. thus we use "LC-matching" technique.

LC - Matching:

Given the circuit:



- $R_{11} > R_{12}$
- X_2, X_3 are reactive componed
- X_2 can be a capacitor or an inductor
- X_3 must be the opposite of X_2.

$$\boxed{X_2 = \mp\sqrt{R_{12}(R_{11}-R_{12})}} \quad , \quad \boxed{X_3 = \pm R_{11}\sqrt{\frac{R_{12}}{R_{11}-R_{12}}}}$$

—o—

Ex

Match 75Ω modulator block to a 50Ω antenna using an LC-matching circuit ($f = 20$ MHz)

Ans:

For this example, $R_{11} = 75\Omega$, $R_{12} = 50\Omega$.

$$\Rightarrow \quad X_3 = -75\sqrt{\frac{50}{75-50}} = -75\sqrt{2} \approx -113$$

and

$$X_2 = \sqrt{50(75-50)} \approx 36.$$

Since X_3 is negative,

$$-113 = -\underbrace{\frac{1}{\omega C}}_{\text{capacitor reactance}} \Rightarrow C = \frac{1}{(2\pi f)(113)} = \frac{1}{(2\pi\times 20\times 10^{6})(113)} = 0.0734 \text{ nF}$$

Similarly,

$$36 = \underbrace{\omega L}_{\text{inductor reactance}} \Rightarrow L = \frac{36}{2\pi\times 20\times 10^{6}} = 0.3\,\mu H$$

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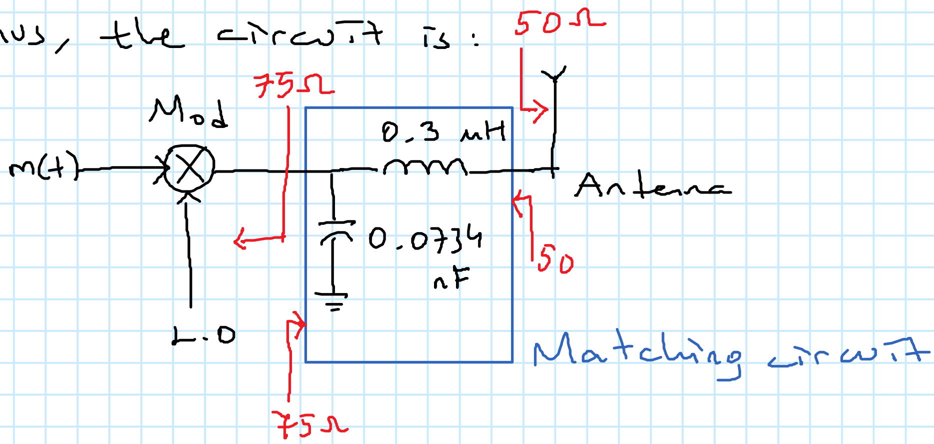
Thus, the circuit is:



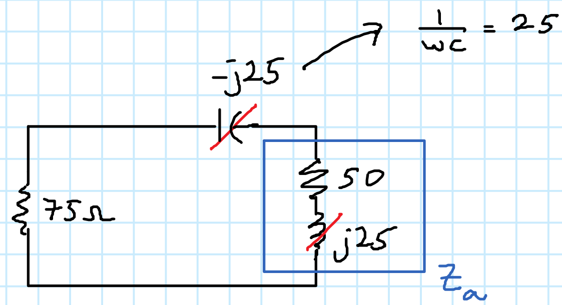
—o—

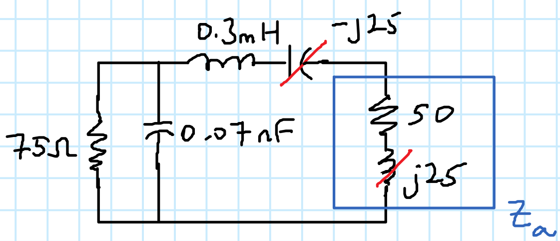
- In practice, there is a 50Ω impedance standart meaning all electronic circuits have 50Ω impedance. This way, we can connect them is cascade without the necessity of using a matching circuit.

Ex:

Match 75Ω modulator to a $Z_a = 50 + j25$ antenna using LC-matching ($f = 20$ MHz)

Ans:





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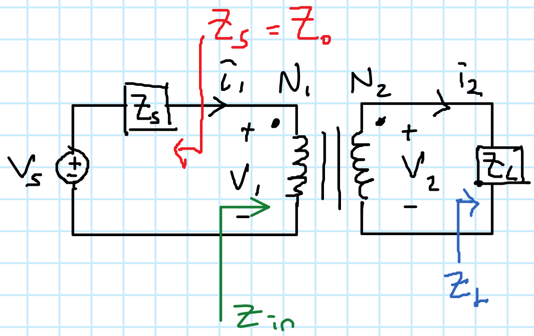
Transformer Matching:

Consider the following circuit.



$\boxed{V_1 = \dfrac{V_2}{a}}$ and $\boxed{i_1 = a\, i_2}$, $a = \dfrac{N_2}{N_1}$

The impedance seen by the source is

$$Z_{in} = \frac{V_1}{i_1} = \frac{1}{a^2} \underbrace{\frac{V_2}{i_2}}_{Z_L} = \frac{1}{a^2} Z_L .$$

$$\Rightarrow \boxed{Z_{in} = \frac{1}{a_2} Z_L}$$

Ex:

Match 50Ω line to 200Ω antenna using a transformer.

Ans:

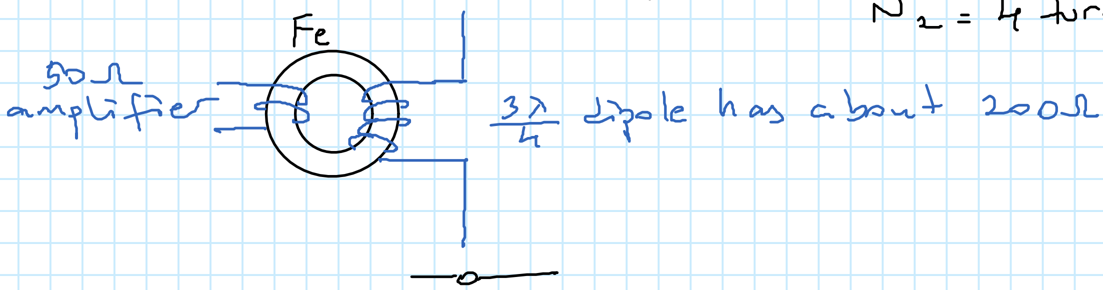
$$a = \frac{i_1}{i_2} = \frac{V_2}{V_1} = \frac{N_2}{N_1} \qquad \text{and} \qquad Z_{in} = \frac{1}{a^2} Z_L$$

$$50 = \frac{1}{\left(\frac{N_2}{N_1}\right)^2} \cdot (200)$$

$$\Rightarrow \left(\frac{N_2}{N_1}\right)^2 = \frac{20\cancel{0}}{5\cancel{0}} = 4$$

and $\dfrac{N_2}{N_1} = 2 \Rightarrow N_1 = 2$ turns

$N_2 = 4$ turns.



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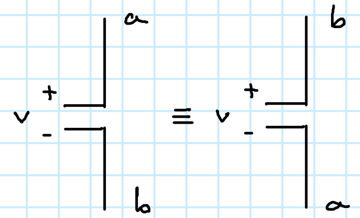
– Balun (Balanced to Unbalanced) –

– A balun is a transformer.

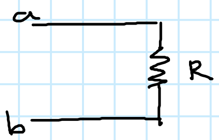
– Balanced circuit = when we rotate the circuit in reciprocal, the circuit does not change.



Dipole antenna is a balanced circuit

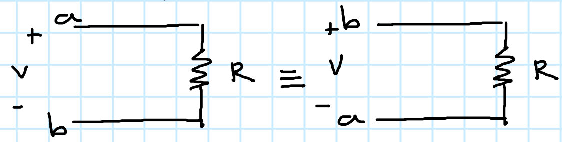
Ex.

Is the following circuit balanced?

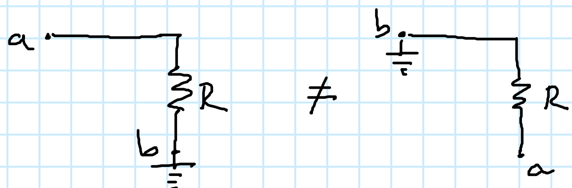


Ans.

Yes, it is balanced, because

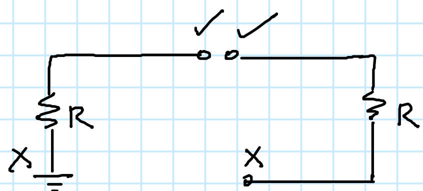


– Unbalanced circuit. When we take the reciprocal of the circuit, it is no longer the same.



– We can connect balanced to balanced or unbalanced to unbalanced circuits easily

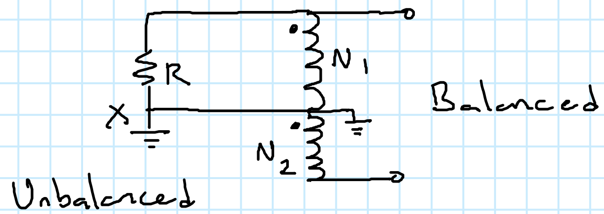
– When we connect balanced circuit to unbalanced circuit we get a problem:



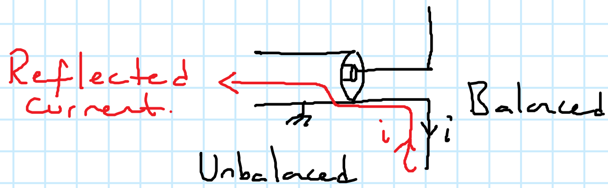
↳ This connection is problematic, becaus

this point is not ground.

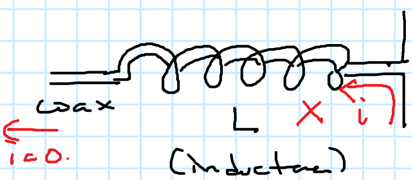
- The solution is to use "Balun".



- The use of baluns are necessary for antennas, because the dipole is balanced and coaxial cable is unbalanced.



- The reflected current flows through the ground lines, and cause unwanted radiation.
- N_1 and N_2 are chosen according to line and antenna impedances as before.
- If $Z_S = Z_{ant} = 50\Omega \Rightarrow$ 1:1 balun must be used.
- If this 1:1 balun is not possible to find, then use an air balun



—o—

- Receiver Design -

- Designing the receiver is much harder than the transmitter.
- A good receiver must have the following properties:
  1-) High sensitivity.
  2-) Stability
  3-) Low bit error rate (BER)
- Receiver sensitivity refers to the ability of receiving small amplitude (weak power) signals out of noise.
- This also implies that receiver can operate at low SNR levels easily

SNR = Signal to noise ratio.

$$SNR = \frac{S}{N} = \frac{\text{Signal power}}{\text{noise power}}.$$

- SNR is usually given in dB.

Ex:

Let us assume $N = -70$ dB. If P_r = Received power = 0.1 nW.
Evaluate the $SNR_{dB} = ?$

Ans

We have $SNR = \frac{S}{N} = \frac{P_r}{N}$

In dB:

$$SNR_{dB} = S_{dB} - N_{dB}$$

$$\Rightarrow S_{dB} = 10\log_{10} 0.1\times10^{-9} = 10\log_{10} 10^{-10} = -100 \text{ dB}.$$

$$\Rightarrow SNR = -100 - (-70) = -30 \text{ dB}. \quad \text{(bad SNR)}$$

If the receiver is highly sensetive, it may be able to operate with weak power signals.

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Noise: is a random fluctuations in voltage and/or current that exists at all frequencies for temperatures > 0 K. (−270°)

Noise affects SNR, and this is why it is important for telecommunication.

SNR > 10 dB is required for acceptable reception.

SNR ≈ 20 − 25 dB is a good reception.

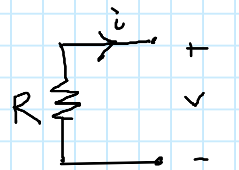
SNR ≈ 40 − 45 dB or greater is considered as very good.

Noise Power:

There are 3 sources of noise

Thermal noise ✓ — Shot noise ✗ — Flicker noise ✗

− Suppose that we have a resistor:



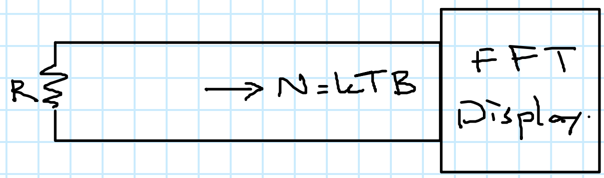
$$\boxed{N = kTB} \quad (W)$$

where k = Boltzmann's constant $= 1.38 \times 10^{-23}$

T = Temperature in Kelvin.

B = Bandwidth in hertz

− If we take a resistor R, and connect it to a spectrum analyzer, we can observe its FFT for noise.



− At $T = 0$ K $\Rightarrow N = 0$.

− At $T = T_0 = 290$ K (room temp) $\Rightarrow N = k(290).B$

− We can adjust the bandwidth by using a filter right before the FFT display device (spectrum analyzer)

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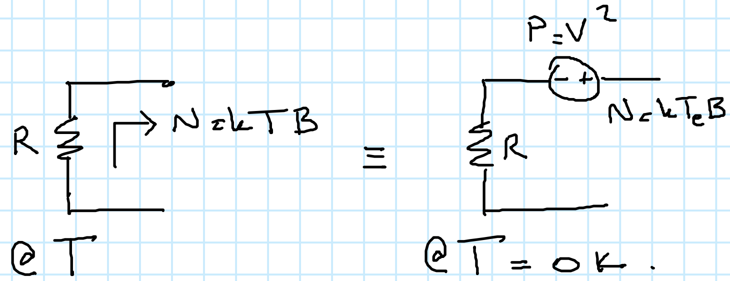
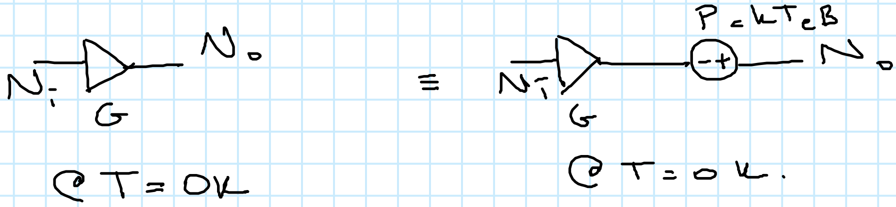
Equivalent Noise Temperature:

Suppose we have a resistor



$\Rightarrow kT_eB = N \quad \Rightarrow \boxed{T_e = \frac{N}{kB}}$ (Temp. of the power source when R is noiseless.)

- In case of an amplifier,



$\Rightarrow G.kT_eB = N_o$

$\Rightarrow \boxed{T_e = \frac{N_o}{GkB}}$ (T_e = Noise temp. at T = 0K)

- Noise Factor and Noise Figure -

By definition,

Noise Factor = $\boxed{F = \frac{S_i/N_i}{S_o/N_o}}$

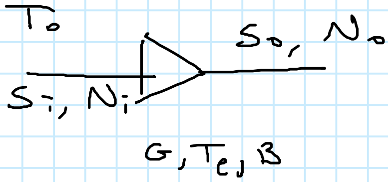
- If $T_e = 0\,K$ for the amplifier, this means $F = 1$ (means the amplifier does not heat up.)
- But, in reality, $T_e > 0K$. $\Rightarrow F > 1$

F close to 1 is desired.

Define the noise figure as:

$$\boxed{NF = 10 \log_{10} F \quad (dB)}.$$

For a given amplifier:



$$\Rightarrow F = \frac{\frac{S_i}{N_i}}{\frac{S_o}{N_o}} = \frac{\frac{S_i}{kT_oB}}{\frac{GS_i}{\underbrace{GkT_oB}_{G.N_i} + \underbrace{GkT_eB}_{G.N_{int}}}} = \frac{\cancel{S_i}}{kT_oB} \cdot \frac{GkT_oB + GkT_eB}{G.\cancel{S_i}}$$

The noise that is generated by the amplifier itself. (N_{int})

$$F = \frac{GkT_oB + N_{int}}{kT_oBG} = 1 + \frac{N_{int}}{kT_oBG}$$

where $N_{int} = \cancel{G}\cancel{k}T_e\cancel{B} = \cancel{k}(F-1)T_o\cancel{B}\cancel{G}$

$$\Rightarrow \boxed{T_e = (F-1)T_o} \quad \text{or} \quad \boxed{F = 1 + \frac{T_e}{T_o}}$$

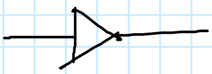
—o—

Ex:

The power gain of an amplifier is 20 dB in the freq. band 10 to 12 GHz. If its noise figure is 3.5 dB, find the output noise power in dBm.

Ans:

$$F = 3.5\,dB = 10^{0.35} = 2.2387$$



$$G = 20\,dB = 100$$

$$B = (12-10)\,GHz = 2\,GHz = 2 \times 10^9$$

The output noise power N_o:

$$N_o = GkT_oB + GkT_eB$$

$$= GkB(T_o + \underbrace{T_e}_{(F-1)T_o}) = GkB[T_o + (F-1)T_o]$$

$$= GkB[\cancel{T_o} + T_oF - \cancel{T_o}]$$

$$= GkBT_oF = (100)(1.38 \times 10^{-23})(2 \times 10^9)(290)(2.2387)$$

$$= 1.791 \times 10^{-9}\,W. \quad \Rightarrow$$

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$N_o(\text{dB}) = 10\log_{10}(1.7919\times10^{-9})$, $N_o(\text{dBm}) = N_o(\text{dB}) + 30$

$= -87.4669\ \text{dB}.$ $= -57.5\ \text{dBm}.$

– Noise Figure of a Cascaded System –

Connected in series

Suppose we have

$$\xrightarrow[T_i]{N_i} \boxed{G_1, F_1, T_{e_1}} \xrightarrow{N_1} \boxed{G_2, F_2, T_{e_2}} \longrightarrow N_o$$

$$\equiv \xrightarrow[T_i]{N_i} \boxed{G, F, T_e} \longrightarrow N_o$$

– The noise power at the output of the 1st system is

$$N_1 = G_1 k T_i B + G_1 k T_{e_1} B \quad \text{——(1)}$$

and

$$N_o = G_2 N_1 + G_2 k T_{e_2} B \quad \text{——(2)}$$

Substituting (1) into (2)

$$N_o = G_1 G_2 k B \left(T_i + T_{e_1} + \frac{T_{e2}}{G_1}\right)$$

$$= G_2\left[G_1 k B (T_i + T_{e_1})\right] + G_2 k T_{e_2} B$$

or

$$N_o = G_1 G_2 k B (T_e + T_i) = G k B (T_e + T_i)$$ (From the single equivalent system)

Equating the two equations and after simplifications.

$$T_e = T_{e_1} + \frac{T_{e2}}{G_1}$$

Also, $T_{e_1} = (F_1 - 1)T_i$, $T_{e_2} = (F_2 - 1)T_i$, $T_e = (F-1)T_i$

Substituting all the variables,

$$F = F_1 + \frac{F_2 - 1}{G_1}$$

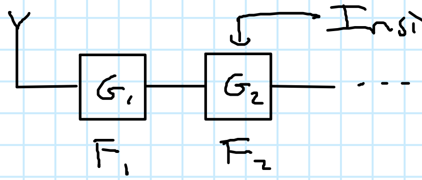
The equations T_e and F can be generalized as

For n-cascaded systems:

$$\boxed{T_e = T_{e_1} + \frac{T_{e_2}}{G_1} + \frac{T_{e_3}}{G_1 G_2} + \cdots + \frac{T_{e_n}}{G_1 G_2 \cdots G_{n-1}}}$$

$$\boxed{F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \cdots + \frac{F_n - 1}{G_1 G_2 \cdots G_{n-1}}}$$

– Note that the overall noise factor is dominantly determined by the 1st network (stage).



Insignificant in terms of the overall F.

This stage determines the predominantly the overall noise performance of the entire system.

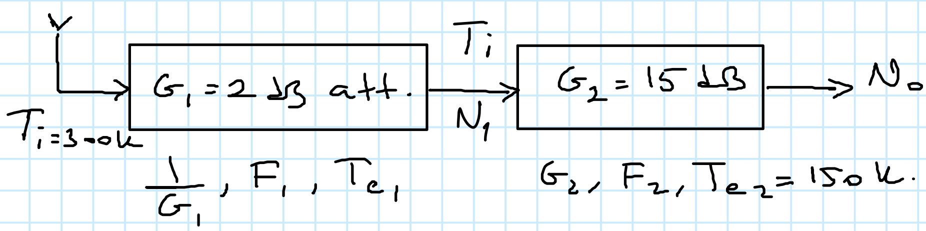
<u>Ex:</u>

A receiving antenna is connected to an amplifier through a transmission line (coaxial cable) which has an attenuation of 2 dB. The gain of the amplifier is 15 dB, and its noise temperature is 150 K over a bandwidth of 100 MHz. All the components are at an ambient temperature of 300 K.

a-) Find the noise figure of the cascaded system.

b) What would be the noise figure if the amplifier were placed before the transmission line.

<u>Ans</u>



$T_o = 290$ K. , $B = 100$ MHz

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We need to find F_1.

Consider the transmission line:

$$N_1 = G_1 \cdot (kT_i B) + G_1 N_{int}.$$

$$\Rightarrow N_{int} = \frac{1}{G_1}(1-G_1)kT_i B = kT_{e_1} B$$

$$\Rightarrow T_{e_1} = \left(\frac{1}{G_1} - 1\right) T_i$$

$$\Rightarrow F_1 = 1 + \frac{T_{e_1}}{T_i} = 1 + \left(\frac{1}{G_1} - 1\right)\frac{\cancel{T_i}}{\cancel{T_i}} = \underset{\substack{\uparrow \\ \text{att.}}}{\frac{1}{G_1}} = \frac{1}{\frac{1}{G_1}} = \frac{1}{\frac{1}{10^{0.2}}} = 1.58$$

$\Rightarrow F_1 \approx 1.6$

$NF_1 = 2.05\ dB$

To find F_2.

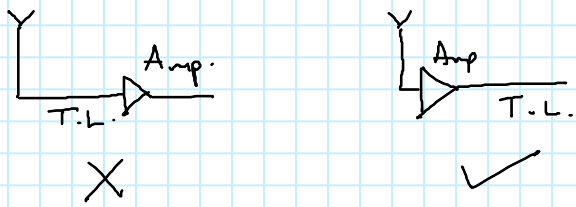
$G_2 = 10^{1.5} = 31.6228$

$F_2 = 1 + \frac{150}{300} = 1.5 \Rightarrow NF_2 = 10\log_{10} 1.5 = 1.8\ dB.$

a-) $F = F_1 + \frac{F_2 - 1}{G_1} = 1.6 + \frac{1.5 - 1}{\frac{1}{1.58}} = 2.42 = 3.84\ dB.$

b-) $F = F_{amp} + \frac{F_{line} - 1}{G_{amp}} = 1.5 + \frac{1.6 - 1}{31.6228} = 1.5363 = 1.865\ dB.$

—o—



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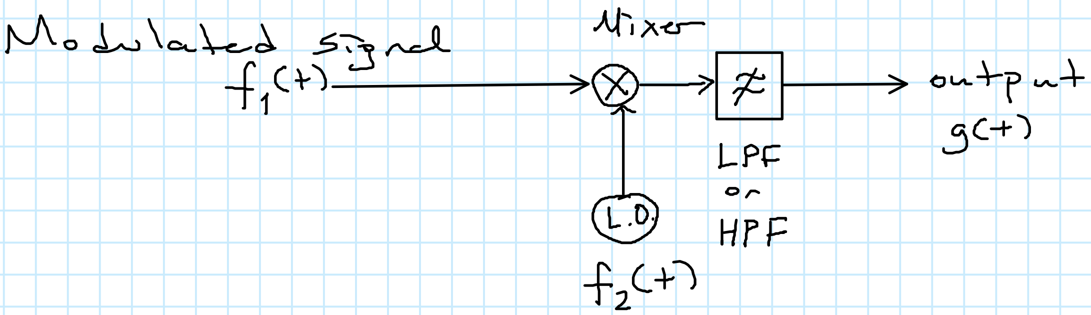
– Mixers –

– Mixer are RF circuits that are used to multiply a modulated signal or any RF signal by a local oscillator.



Let $f_1(t) = A\cos(\omega_1 t)$

and $f_2(t) = A\cos(\omega_2 t)$

$\Rightarrow f_1(t)\, f_2(t) = A^2 \cos(\omega_1 t)\cos(\omega_2 t)$

Using the Identity

$$\cos A \cdot \cos B = \frac{1}{2}\left[\cos(A+B) + \cos(A-B)\right]$$

$$\Rightarrow f_1(t) \cdot f_2(t) = \frac{A^2}{2}\left[\cos(\omega_1+\omega_2)t + \cos(\omega_1-\omega_2)t\right]$$

After filtering, one of these two terms is eliminated.

– If we use a LPF, then the 1st term is cancelled. This called "down conversion"

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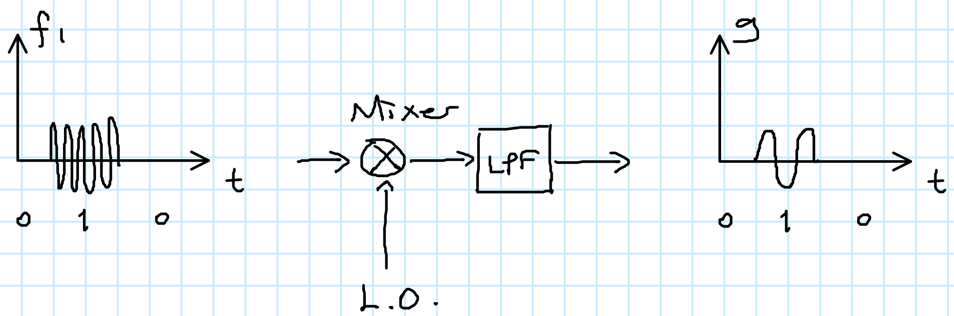
– If we use a HPF, then the 2^{nd} term is cancelled. This is called "up-conversion"

– Down-conversion mixers are usually used in receivers to decrease the carrier frequency.

– Up-conversion mixers are usually used in transmitters to increase the carrier frequency.

– The circuit implementation contains RF transistors.

– In receivers, several mixer stages are used to down-convert the carrier frequency so that the signal processing can be possible.

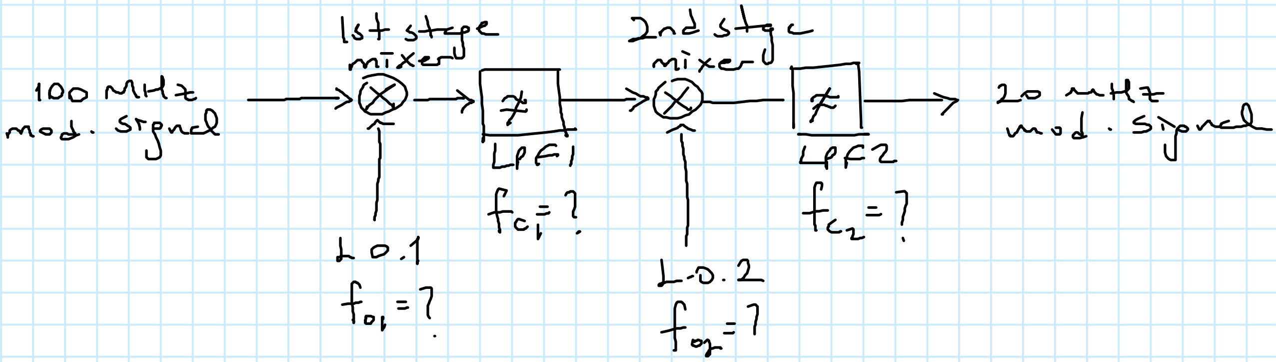


– Such receivers with several downconverting mixer are called "superheterodyne receiver". All modern receivers are this type.

<u>Ex:</u>

Having a 100MHz modulated signal, use 2 stage mixer circuits to downconvert the carrier to 20MHz. Design the mixers.

<u>Ans:</u>



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1^{st} Stage Design:

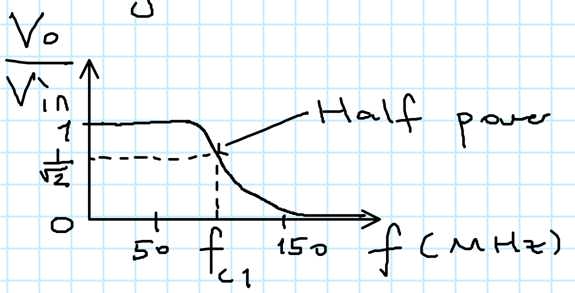
Let $\boxed{f_{o1} = 50\ MHz}$ (we select this arbitrarily)

Output of the mixer 1:

frequency → $(100+50)\ MHz = 150\ MHz$ ✗ cancelled by LPF.

frequency → $(100-50)\ MHz = 50\ MHz$ ✓

LPF1 design:



⇓ the cut-off frequency

$$\Rightarrow \boxed{f_{c1} = \frac{f_H + f_L}{2}}$$

where $f_H = 150\ MHz$

$f_L = 50\ MHz$

$$\boxed{f_{c1} = \frac{200}{2} = 100\ MHz}$$

2^{nd} Stage Design:

$\boxed{f_{o2} = 30\ MHz}$ (Because of $50\ MHz - f_{o2} = 20\ MHz$)

LPF cut-off freq. (2^{nd} stage)

$$f_{c2} = \frac{f_H + f_L}{2}, \quad \text{where } f_H = 50+30 = 80\ MHz. \text{ ✗ LPF.}$$

$$f_L = 50 - 30 = 20\ MHz$$

$$\boxed{f_{c2} = \frac{80+20}{2} = 50\ MHz}$$

Electromagnetic Wave Propagation:

In general, there are three types of waves:

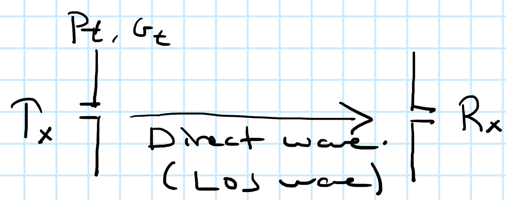
1-) Direct wave (Line Of Sight - LOS)

2-) Sky wave (Ionospheric wave)

3-) Ground wave (surface wave)

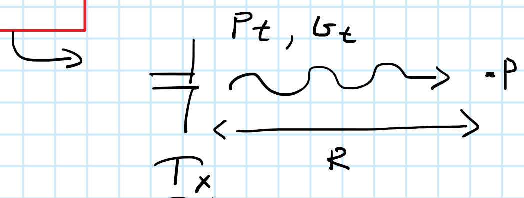
1-) Direct Wave

Transmitter and receiver antennas are alined without any obstacles in btw. them. The waves travel in a straight path from the Transmitter to the receiver. No reflection occurs.



As far as the power density is concerned:

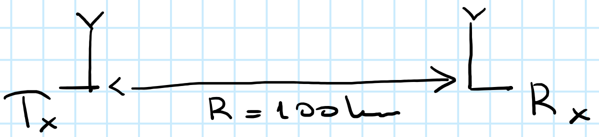
$$\boxed{P = P_t \cdot G_t \cdot \frac{1}{4\pi R^2} \quad (W/m^2)}$$



Ex:

At R = 100 km away from the transmitter, a receiver antenna is located with dimensions 2m x 1m. The trans. ant. has a gain of 5 dB and 100 W of a radiated power. Evaluate the SNR at the receiver ant. with N = 0.1 mW noise power?

Ans:



P_r = Received power (W).

$G_t = 5$ dB.

$P_t = 100W = 20$ dB.

Area = $2 m^2$

$SNR = \frac{P_r}{N} = ?$?

$P_r = P \cdot (\text{Area})$

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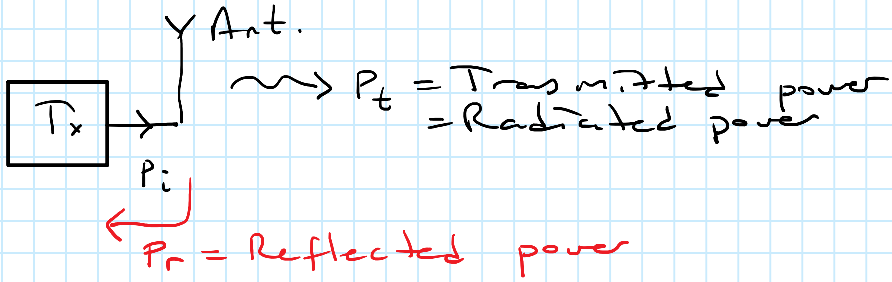
$$P = P_t \cdot G_t \cdot \left(\frac{1}{4\pi R^2}\right) = 100\,(10^{0.5})\left[\frac{1}{4\pi (10^5)^2}\right] = 2.5\ nW/m^2$$

$$P_r = P\cdot(\text{Area}) = 2.5\ \frac{nW}{\cancel{m^2}}\cdot(2\,\cancel{m^2}) = 5\,nW.$$

$$SNR = \frac{P_r}{N} = \frac{5\,\cancel{nW}}{0.1\,\cancel{nW}} = 50 \Rightarrow SNR_{dB} = 10\log\frac{50}{10} \cong 17\ dB. \Rightarrow \text{poor SNR.}$$

Voltage Standing Wave Ratio at the transmitter.

Consider a transmitter



Assuming that antenna efficiency $\epsilon = 1$, which means that there is no loss of power due to heat dissipation on the antenna, if the T_x system and the antenna are not in impedance match, then some power (energy) reflects from the antenna to the transmitter.

$$\Rightarrow \boxed{P_t = P_i - P_r}$$

We want $P_r = 0$ (perfect match!)

Define the reflection coefficient as

$$\boxed{\Gamma = \frac{P_r}{P_i}} \quad \text{(Power reflection coeff.)}$$

$$\Rightarrow \boxed{\Gamma_{voltage} = \frac{\text{Voltage wave reflected}}{\text{Voltage wave incident}} = \frac{V_r}{V_i} = \Gamma_v}$$

$$\boxed{VSWR = \frac{1+\Gamma_v}{1-\Gamma_v}}$$

When $\Gamma_v = 1$ (total reflection).

$\Rightarrow VSWR = \infty$

When $\Gamma_v = 0$ (perfect match)

$\Rightarrow VSWR = 1.$

$1 < VSWR < \infty$

Usually in dB :

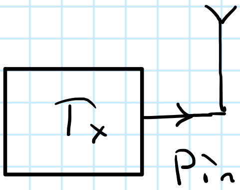
$1 < VSWR_{dB} < \infty$

> **Note:** $VSWR > 2$ is considered to be a good match

Ex:

A T_x system has $P_{in} = 5\,kW$ to the antenna and assuming $\epsilon = 1$ (perfect efficiency), calculate the radiated power if VSWR = 3 dB.

Ans:



$\rightsquigarrow P_t = P_{rad} < P_{in}$ $\hookrightarrow = ?$

$P_{in} = 5\,kW.$

$$VSWR = 3\,dB = 10^{0.3} = 2.$$

$$\Rightarrow \frac{1+\Gamma_v}{1-\Gamma_v} = 2$$

$$\Rightarrow 1+\Gamma_v = 2 - 2\Gamma_v$$

$$3\Gamma_v = 1$$

$$\Rightarrow \Gamma_v = \frac{1}{3}$$

Then, we find Γ as

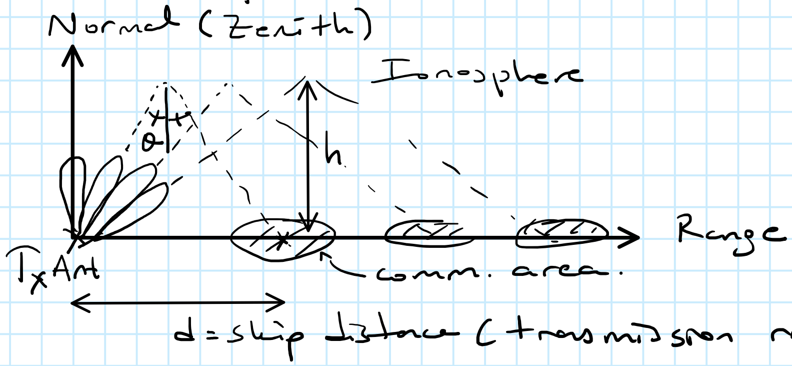
$$\Gamma = \frac{P_r}{P_i} = \frac{V_r^2/\cancel{2R}}{V_i^2/\cancel{2R}} = \left(\frac{V_r}{V_i}\right)^2 = \left(\frac{1}{3}\right)^2 = \frac{1}{9}$$

$$\Rightarrow \frac{P_r}{P_i} = \frac{1}{9} \qquad \Rightarrow P_r = \frac{P_i}{9} = \frac{5000}{9} = 555.5\ W.$$

$$\Rightarrow P_t = P_i - P_r = 5000 - 555.5 = 4444.5\ W.$$

2-) Sky Wave (Ionosphere wave):

As waves travel through the ionosphere, they reflect from height h, and come back to earth at a distance d from the transmitter.



- Define maximum usable frequency (MUF)

Any E.M. wave whose frequency is below MUF reflects from ionosphere from heigh h. Waves with frequency above MUF escape to space.

$$\boxed{MUF = \frac{CF}{\cos\theta}}$$, where CF = Critical angle

θ = Angle of incidence.

- Define Optimum working frequency = 0.85 MUF.

Also, $\boxed{CF = 9\sqrt{N_{max}} = f_c}$

where N_{max} = Maximum e^- density

Ex:

Given the maximum e^- density in ionosphere as $N = 5\times10^4 \frac{e^-}{cm^3}$ and $\theta = 70°$. Find MUF.

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Ans:

$N_{max} = 5\times10^{4}\, e^-.cm^{-3} = 5\times10^{10}\, e^-.m^{-3}$

$\Rightarrow f_c = 9\sqrt{5\times10^{10}} = 9.\sqrt{5}.10^5 = 2012500\ Hz. \approx 2\ MHz.$

$\Rightarrow MUF = \dfrac{2\ MHz}{Cos(70°)} = 5.884\ MHz. \approx 6\ MHz.$

$OWF = 0.85.(5.884\ MHz) = 5\ MHz.$

- As a rule of thumb, MUF is about 3 times of fc.
- F-layer reflection has max. N as $N = 5\times10^5\ \dfrac{e^-}{cm^3}$

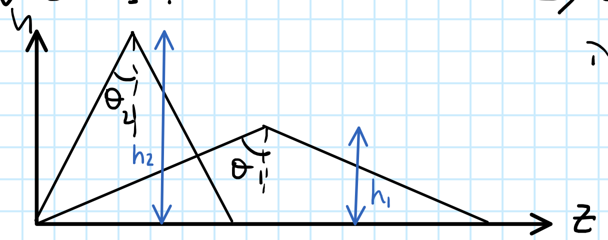
$\Rightarrow f_c = 9\sqrt{5\times10^{11}} = 6.3\ MHz$

$\Rightarrow MUF\Big|_{\theta=70°} = \dfrac{6.364\ MHz}{Cos(70°)} = 18.6\ MHz.$

or

$MUF\Big|_{\theta=80°} = 36.649\ MHz.$

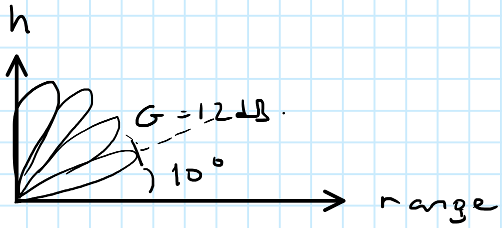
This means:

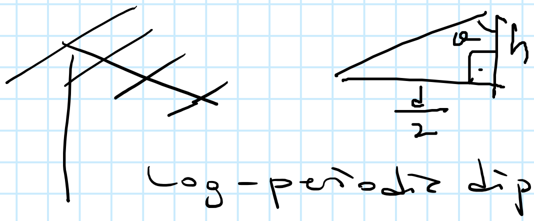


$\Rightarrow$ Skywave comm. is possible in HF band.

Ex:

For an horizontal polarized log-periodic dipole antenna, with 1000 W of input power at VSWR = 2 dB has a radiation pattern as shown below.





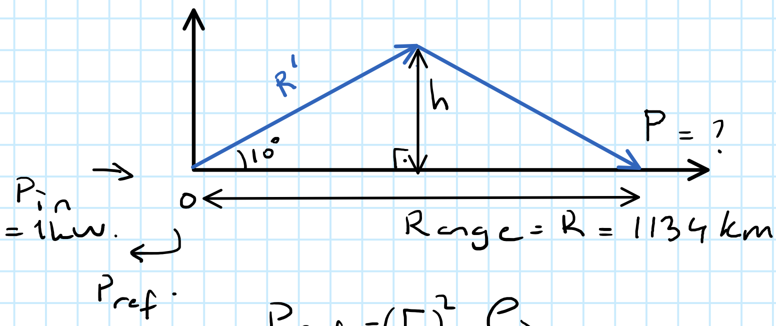
$\tan\theta = \frac{d/2}{h}$

$\tan\theta = \frac{d}{2h}$

Evaluate the max. comm. range through sky waves at a single hop of the smallest angle beam, and evaluate the power density at this distance? (h = 100 km, E-layer reflection)

Ans:

$$\text{Range} = \frac{2h}{\tan\theta} = \frac{2(10^5)}{\tan(10^\circ)} = \frac{200000}{0.1763} = 1134 \text{ km}$$



$P_{ref} = (\Gamma_v)^2 \cdot P_{in}$.

$$VSWR = \frac{1+\Gamma_v}{1-\Gamma_v} = 10^{0.2} = 1.58489$$

$\Rightarrow \Gamma_v = 0.22627$

$P_{ref} = (\Gamma)^2 \underbrace{P_{in}}_{1000} = 51.2 \text{ W}$ is reflected.

$\Rightarrow P_{rad} = P_{in} - P_{ref} = 1000 - 51.2\text{W} = 948.8 \text{ W}$.

To find P:

$$P = \underbrace{P_t}_{P_{rad} = 948.8\text{W}} \cdot \overbrace{G_t}^{10^{1.2}} \cdot \frac{1}{4\pi R^2} \quad (W/m^2)$$

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To find R:

$$\cos\theta = \frac{\frac{R}{2}}{R'} = \frac{\frac{1134}{2}}{R'} \text{ km.} \Rightarrow R' = \frac{1134 \text{ km}/2}{\cos 10°} = 575.751 \text{ km}$$

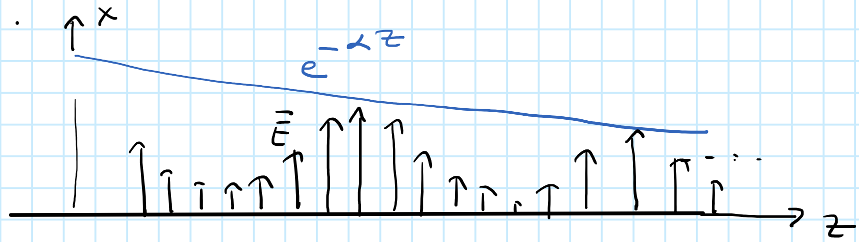
Total range the wave travels is $2R' = 2(575.751 \text{ km})$
$= 1151$ km.

$$\Rightarrow P = (948.8) \cdot (10)^{1.2} \cdot \frac{1}{4\pi(1151000)^2} \cong 0.9 \text{ nW}/m^2$$

- Note that modern receivers can operate with $5 \frac{pW}{m^2}$ of power density in standart noise power.

3-) Ground Wave Propagation :

Ground waves are generated when the E.M. waves hit the surface of the ground. The surface waves (ground waves) are parallel to the ground and propagate through the surface subjected to an attenuation.



- Because of the attenuation, the comm. range is short.
- The electric field can be written as

$$E = \hat{a}_x E_o e^{-\alpha z} e^{-j\beta z} \quad \text{(Phasor)}$$

or

$$E(z,t) = \hat{a}_x E_o e^{-\alpha t} \cos(\omega t - \beta z) \quad \text{(time)}$$

α: Attenuation constant. ($\frac{\text{Nepers}}{m}$)

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Ex:

For a ground wave, if $\alpha = 4 \frac{Np}{m}$, evaluate the attenuation at $z = 0.5$ m away from the source?

Ans:

$$\text{Attenuation factor} = e^{-\alpha z} = e^{-\cancel{4}^{2} \cdot \frac{1}{\cancel{2}}} = e^{-2} = 0.13$$

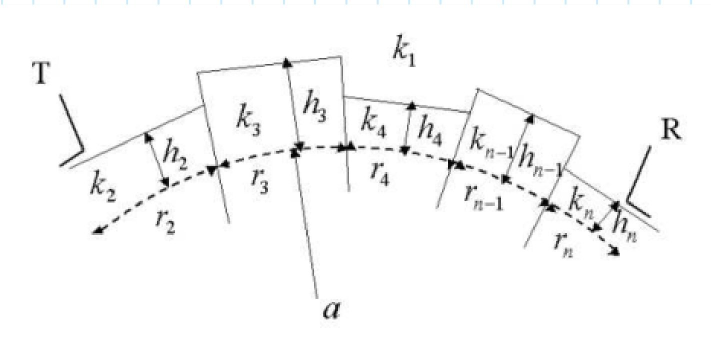
Thus, the electric field is reduced to 13% of its initial value.

—o—

Many times, direct wave comm. is not possible and for short comm. range, ground waves are used.

For example,

Ex:



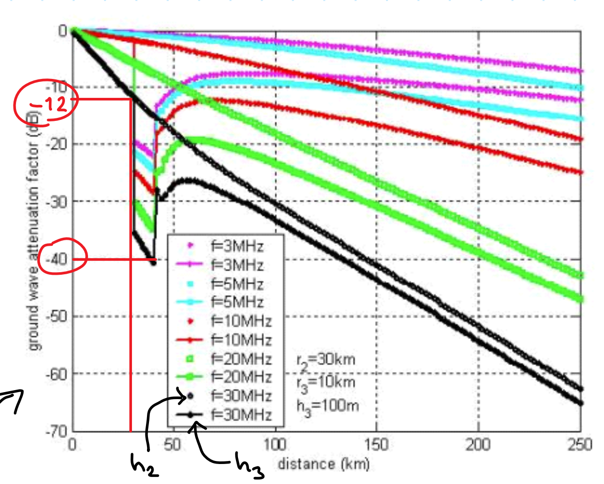


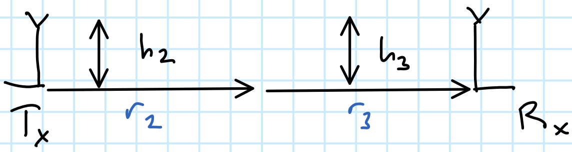
Figure 3. The variation of the ground wave attenuation factor with distance in the HF band for different frequencies in the presence of a single island ($h_2 = h_4 = 0$m).

$e^{-\alpha z}$ = Attenuation factor

α = Attenuation constant. $\left(\frac{Np}{m}\right)$

$$1\ dB = 0.115\ Np.$$

Given the above graph, find the attenuation factor at



$r_2 = 30km$, $r_3 = 10km$, $h_3 = 100m$, $h_2 = 0$.

$f = 30\ MHz$ (HF band)

$$\text{Atten. fact} = e^{-\alpha z}, \quad z = r_2 + r_3$$

Ans:

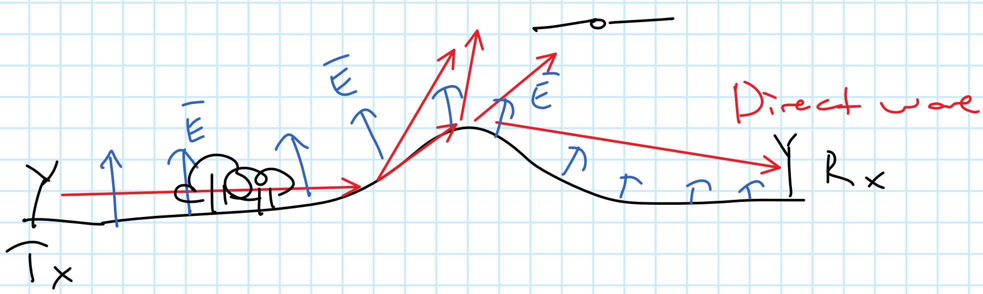
At r_2:

$r_2 = 30km$, $h_2 = 0$, $\Rightarrow$ Atten. factor $= -12\ dB$

At r_3:

$r_3 = 10km$, $h_3 = 100m$, $\Rightarrow$ Atten. factor $= -40\ dB$

Total Atten. factor $= -12 - 40\ dB = -52\ dB$.



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