Part III Microwave Radio Communications

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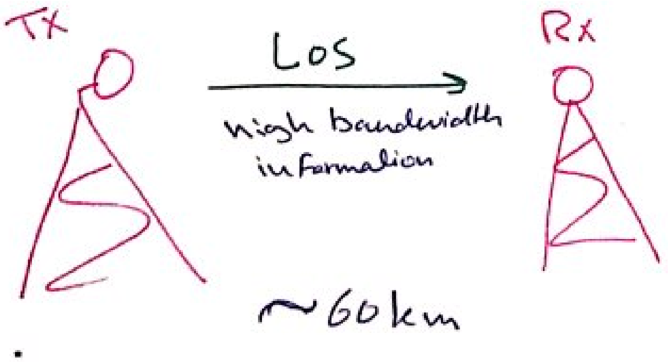
Microwave Radio Communications

Introduction

- Frequency range⇒500 MHz - 300 GHz, i.e., relatively short wavelengths (0.1 cm - 60 cm)
- Table 1 lists some of the microwave radio-frequency bands available in the United State
- Full-duplex (two-way) operation is generally required in microwave communications systems⇒ each frequency band is divided in half with the lower-half identified as the low band and the upper-half as the high band.
- Capacity range⇒ 12 to more than 22000 voice-band (VB) channels.
- Followed Multiplexing techniques:
  - Early microwave systems carried FDM VB circuits and used conventional, noncoherent frequency modulation techniques.
  - More recently developed microwave systems carry PCM-TDM VBcircuits and use more modern digital modulation techniques; PSK and QAM.



FDM + analog modulation
FM vs AM

PCM - TDM + digital modulation
PSK
QAM

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Table.1: Microwave Radio Frequency Assignment

Service	Frequency (MHz)	Band
Military	1710–1850	L
Operational fixed	1850–1990	L
Studio transmitter link	1990–2110	L
Common carrier	2110–2130	S
Operational fixed	2130–2150	S
Operational carrier	2160–2180	S
Operational fixed	2180–2200	S
Operational fixed television	2500–2690	S
Common carrier and satellite downlink	3700–4200	S
Military	4400–4990	C
Military	5250–5350	C
Common carrier and satellite uplink	5925–6425	C
Operational fixed	6575–6875	C
Studio transmitter link	6875–7125	C
Common carrier and satellite downlink	7250–7750	C
Common carrier and satellite uplink	7900–8400	X
Common carrier	10,700–11,700	X
Operational fixed	12,200–12,700	X
Cable television (CATV) studio link	12,700–12,950	Ku
Studio transmitter link	12,950–13,200	Ku
Military	14,400–15,250	Ka
Common carrier	17,700–19,300	Ka
Satellite uplink	26,000–32,000	K
Satellite downlink	39,000–42,000	Q
Satellite crosslink	50,000–51,000	V
Satellite crosslink	54,000–62,000	V

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Brief History

- On August I7 ,1951, the first transcontinental microwave radio system began operation.
- The system was comprised of 107 relay stations spaced an average of 30 miles apart (between New York and San Francisco and 40 million dollar cost
- By 1954, there were over 400 microwave stations scattered across the United States
- By 1958, microwave carriers were the dominate means of long distance communications as they transported the equivalent of 13 million miles of telephone circuits.

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General microwave system layout

- Fig.1 shows a microwave radio link comprised of two terminal stations (one at each end) that are interconnected by three repeater stations.
- As the figure shows, the microwave stations must be geographically placed in such a way that the terrain (lakes, mountains, buildings, and so on) do not interfere with transmissions between stations ⇒ LOS required.
- This sometimes necessitates placing the stations on top of hills, mountains, or tall buildings

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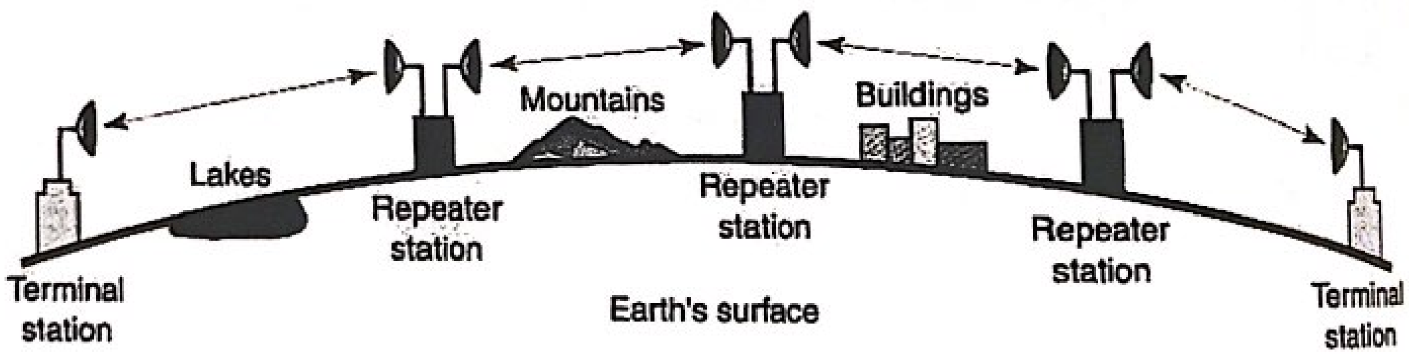
Fig.1: General microwave system layout



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Some advantages:

- Large quantity of information (BW$\simeq$0.1f_c).
- Small antennas required (because the wavelengths are short).
- Fewer repeaters are necessary for amplification.
- Minimum delay times (speed of light).
- Increased reliability and less maintenance (no need for physical facilities such as coaxial cables or optical fibers).
- Does not require a right-of-way acquisition between stations (small area of land just needed).

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Some disadvantages

- It is more difficult to analyze and design circuits at microwave frequencies.
- Measuring techniques are more difficult to perfect and implement at microwave frequencies.
- It is difficult to implement conventional circuit components (resistors, capacitors, inductors, and so on) at microwave frequencies
- Microwave frequencies propagate in a straight line, which limits their use to LOS applications.

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Analog vs Digital Microwave

- A vast majority of the existing microwave radio systems are frequency modulation (which is analog).
- Recently, however, systems have been developed that use either PSK or QPS which are forms of digital modulation.
- Here, we deal primarily with conventional FDM/FM microwave radio systems.

FM versus AM

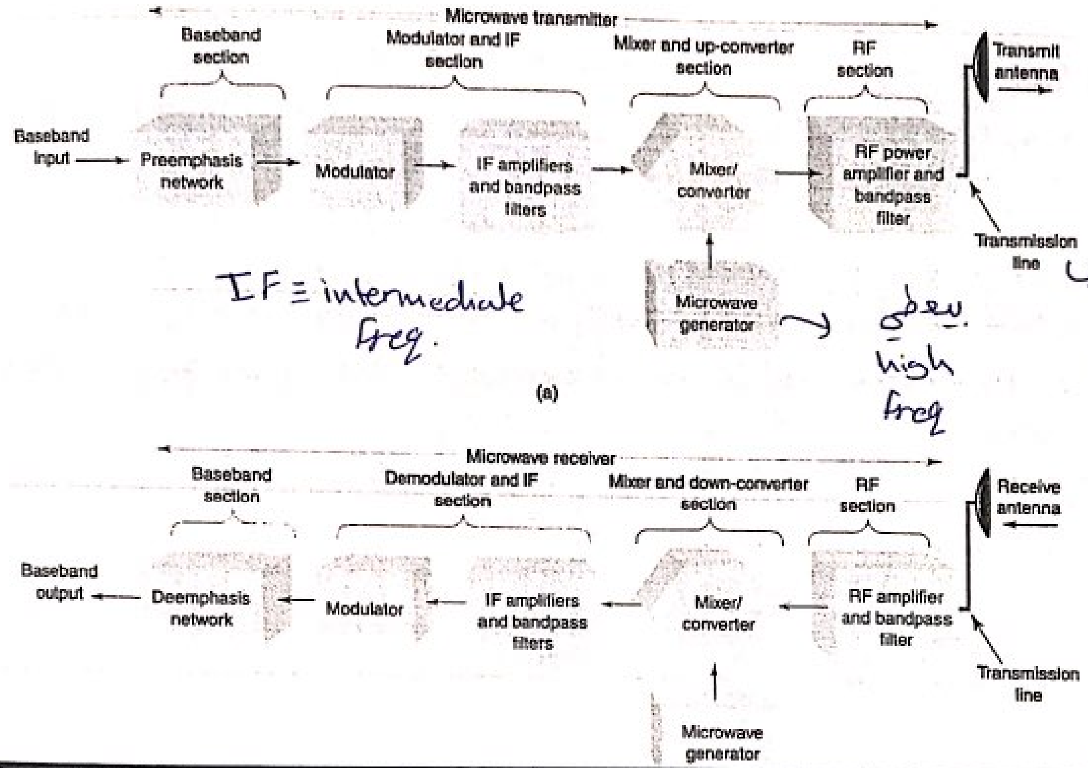
- FM is used in microwave radio systems rather than AM because:
  - AM is sensitive to amplitude nonlinearities in wideband microwave amplifiers, while FM signals are relatively insensitive.
  - AM is sensitive to random noise (noise affects the amplitude), and thus, it requires more transmit power than FM signals.

Frequency-modulated (FM) Microwave Radio Systems

- They provide flexible, reliable and economical point-to-point communication using free-space.
- Their capacity range: Few narrowband voice channels up to thousands of voice and data channels.
- Can be configured to carry high-speed data or commercial TV.
- More economical.

Microwave radio Communication

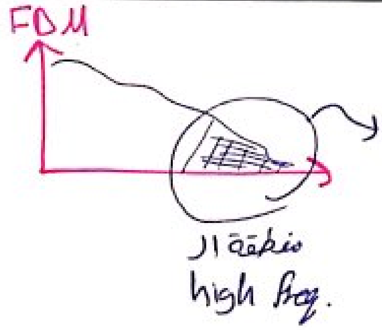
Fig.2:A simplified block diagram of an FM microwave radio system



IF ≡ intermediate freq.

Microwave generator → يعني high freq

Transmission line ↳ practically we use Coaxial Cable

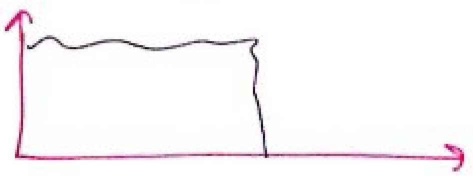


منطقة ال high freq.

'HPA'
'LNA'
Low noise amplifier

Analog ⇐ Signal طبيعة ال

⇓



وظيفة ال preemphasis

- Baseband < 2MHz
- If : 60 - 80 MHz

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FM Microwave Radio Systems: The Transmitter

- The baseband is the composite signal that modulates the FM carrier and may comprise one or more of the following:
  - Frequency-division-multiplexed voice-band channels
  - Time-division-multiplexed voice-band channels
  - Broadcast-quality composite video or picturephone.
- The preemphasis network boosts the amplitude in the higher baseband frequencies
- IF carrier frequency: 60 - 80 MHz (most common is 70 MHz).
- RF carrier frequency: 6 GHz.

FM Microwave Radio Systems: The Receiver

- The bandpass filter, AM mixer, and microwave oscillator down-convert the RF microwave frequencies to IF frequencies and pass them on to the FM demodulator
- The FM demodulator is a conventional.noncoherent FM detector (i.e., a discriminator or a PLL demodulator).
- At the output of the FM detector, a deemphasis network restores the baseband signal to its original amplitude-versus-frequency characteristics.

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FM Microwave Radio Repeaters

- Typical distance between FM microwave Tx and Rx is between 15 - 40 miles.
- The distance depends on:
  - علاقة طردية Transmit power
  - Rx sensitivity
  - Terrain
  - Atomspheric conditions (fading)
- With systems that are longer than 40 miles or when geographical obstructions, such as a mountain, block the transmission path, repeaters are needed.

Note

$P_{th} = -90\ dBm$

$P_{in} = -120\ dBm$

Microwave radio Communication

Fig.3: Microwave Repeaters

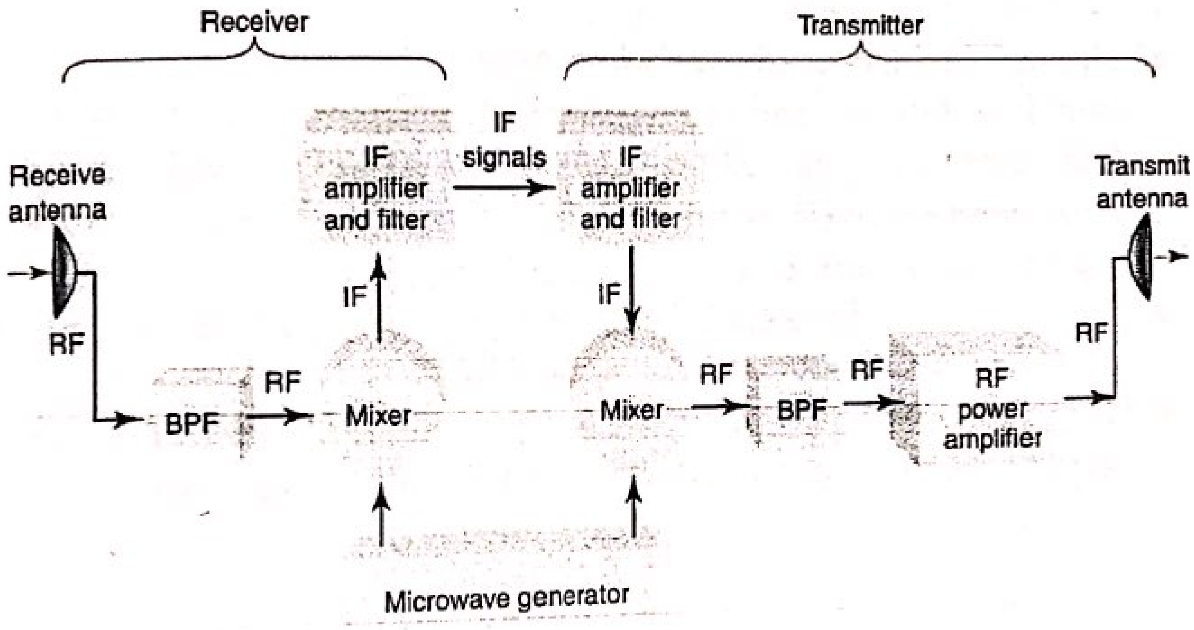
- Def a microwave repeater is a receiver and a transmitter placed back to back or in tandem with the system.
- The repeater station
  receives a signal, amplifies and reshapes it, and then retransmits it to the next repeater or terminal station down line from it.
- The repeater location is greatly influenced by the nature of the terrain between and surrounding the sites
- Repeater types: there are three types of microwave repeaters: IF, baseband, and RF

Microwave radio Communication: FM

IF Repeaters

- With an IF repeater, the received RF carrier is down-converted to an IF frequency, amplified, reshaped, up-converted to an RF frequency, and then retransmitted.
- The signal is never demodulated below IF.
- Consequently, the baseband intelligence is unmodified by the repeater.

Fig.4: IF Repeater



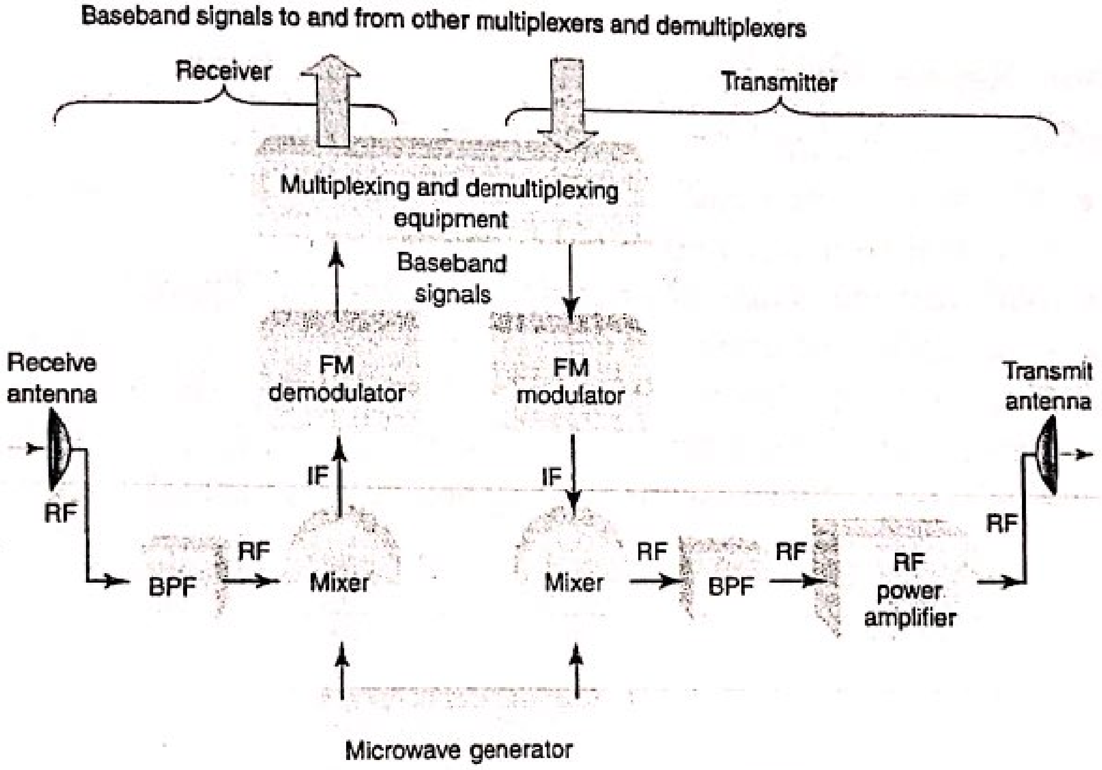
Microwave radio Communication: FM

Baseband Repeaters (two configurations)

- configuration 1 (Fig.5a):
  - The received RF carrier is down-converted to an IF frequency, amplified, filtered, and then further demodulated to baseband.
  - The baseband signal, which is typically frequency-division-multiplexed voice-band channels, is further demodulated to a mastergroup, supergroup, group, or even channel level.
  - This allows the baseband signal to be reconfigured to meet the routing needs of the overall communications network.
  - Once the baseband signal has been reconfigured, it FM modulates an IF carrier, which is up-converted to an RF carrier and then retransmitted.

Microwave radio Communication: FM

Fig.5a: Baseband Repeater (configuration 1)

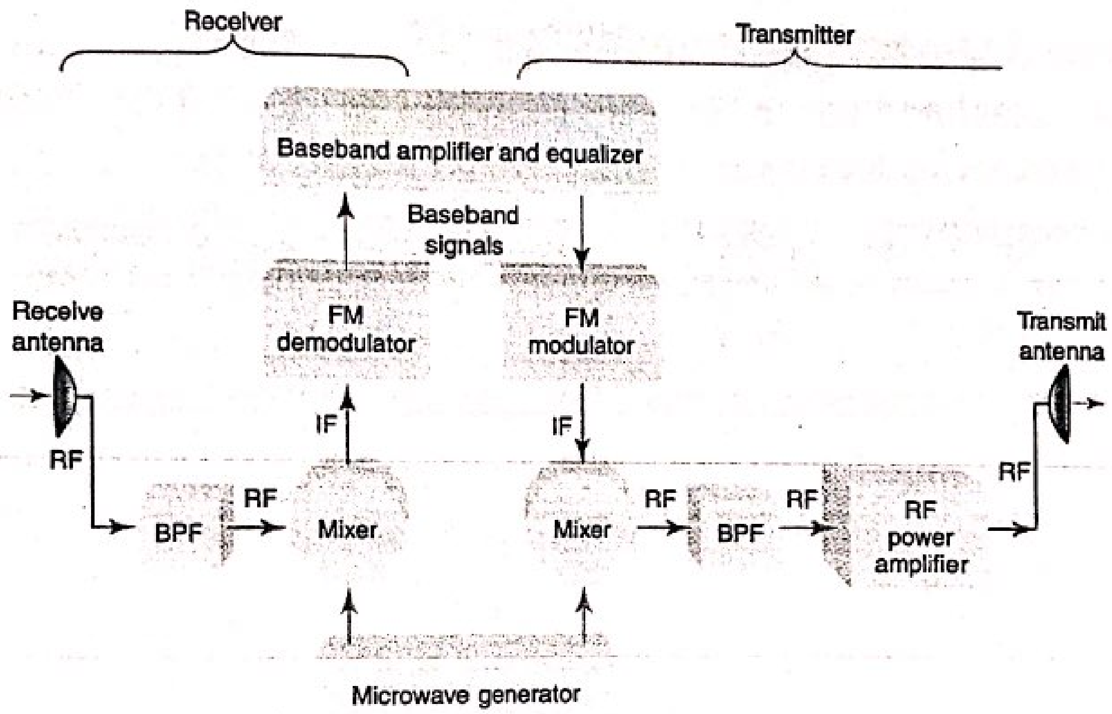


Baseband Repeaters

- configuration 2 (Fig.5b):
  - The repeater demodulates the RF to baseband, amplifies and reshapes it, and then modulates the FM carrier.
  - With this technique, the baseband is not reconfigured.
  - Essentially, this baseband configuration accomplishes the same thing that an IF repeater accomplishes. The difference is that in a baseband configuration, the amplifier and equalizer act on baseband frequencies (<9 MHz) rather than IF frequencies (60 - 80 MHz).

Microwave radio Communication: FM

Fig.5b: Baseband Repeater (configuration 2)



Microwave radio Communication: FM

Baseband-Repeater-configuration-2 vs IF-repeater

- The baseband frequencies are generally less than 9 MHz, whereas the IF frequencies are in the range 60 MHz to 80 MHz.
- Consequently, the filters and amplifiers necessary for baseband repeaters are simpler to design and less expensive than the ones required for IF repeaters.
- However, the disadvantage of a baseband configuration is the addition of the FM terminal equipment.

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RF Repeaters

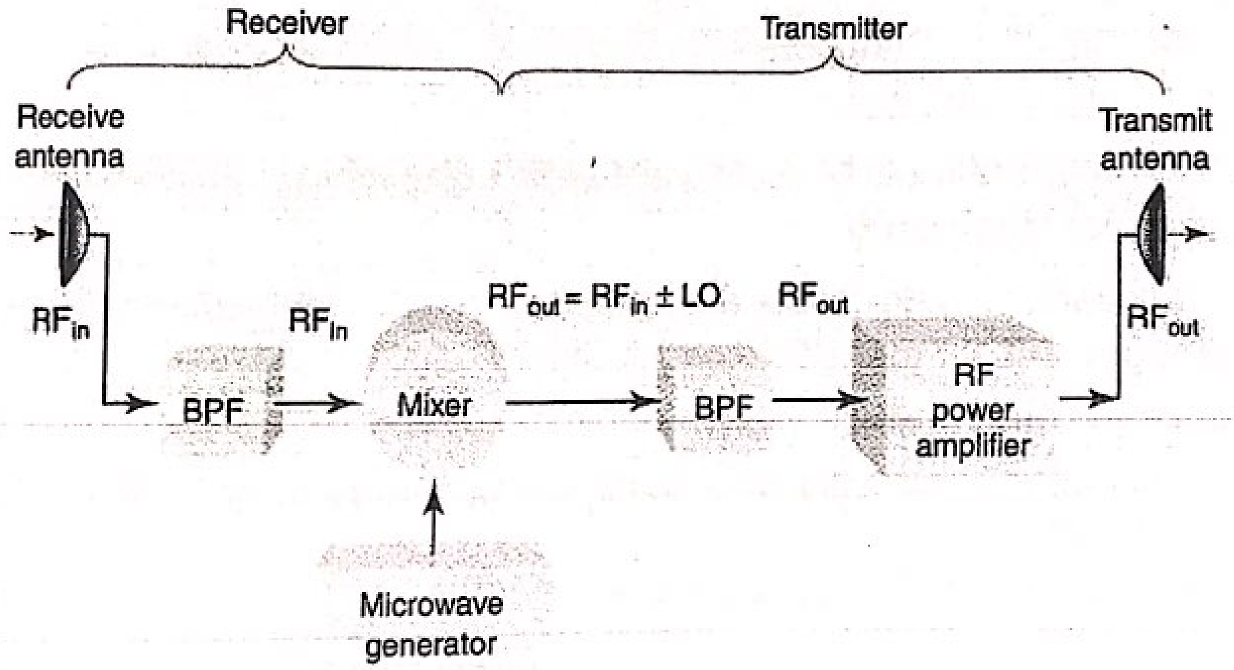
- the received microwave signal is not down-converted to IF or baseband; it is simply mixed with a local oscillator frequency in a nonlinear mixer.
- The output of the mixer is tuned to either the sum or the difference between the incoming RF and the local oscillator frequency, depending on whether frequency up- or down-conversion is desired.
- For example, an incoming RF of 6.2 GHz is mixed with a 0.2-GHz local oscillator frequency producing sum and difference frequencies of 6.4 GHz and 6.0 GHz. to avoid interference.
- For frequency up-conversion, the output of the mixer would be tuned to 6.4 GHz, and for frequency down-conversion, the output of the mixer would be tuned to 6.0 GHz.

RF Repeaters

- With RF-to-RF repeaters, the radio signal is simply converted in frequency and then reamplified and transmitted to the next down-line repeater or terminal station. Reconfiguring and reshaping are not possible with RF-to-RF repeaters.

Fig.6: RF Repeater

high freq على Amplification بعمل + disadvantag



Diversity

- Microwave systems are LOS transmission; therefore a direct signal path must exist.
- If the signal path undergoes a severe degradation, a service interruption will occur.
- Over time, radio path losses vary with atmospheric conditions that can vary significantly.
- This leads to a corresponding reduction in the Rx signal-strength of 20,30, or 40 or more dB (i.e., fading)
- How to address this:
  - AGCC ← Automatic gain control circuits: can compensate for fades of 25 dB to 40 dB.
  - Diversity: for fades in excess of 40 dB.

Microwave radio Communication

→ it exists in any system espically wireless systems

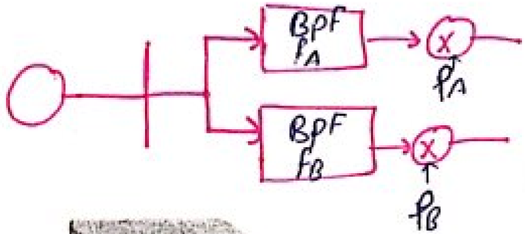
What is Diversity?

- More than one transmission path or method of transmission between Tx and Rx are created in order to increase the system reliability and its availability
- Most common methods of diversity:
  - Frequency diversity
  - Space diversity
  - Polarization diversity
  - Hybrid diversity
  - Quad diversity

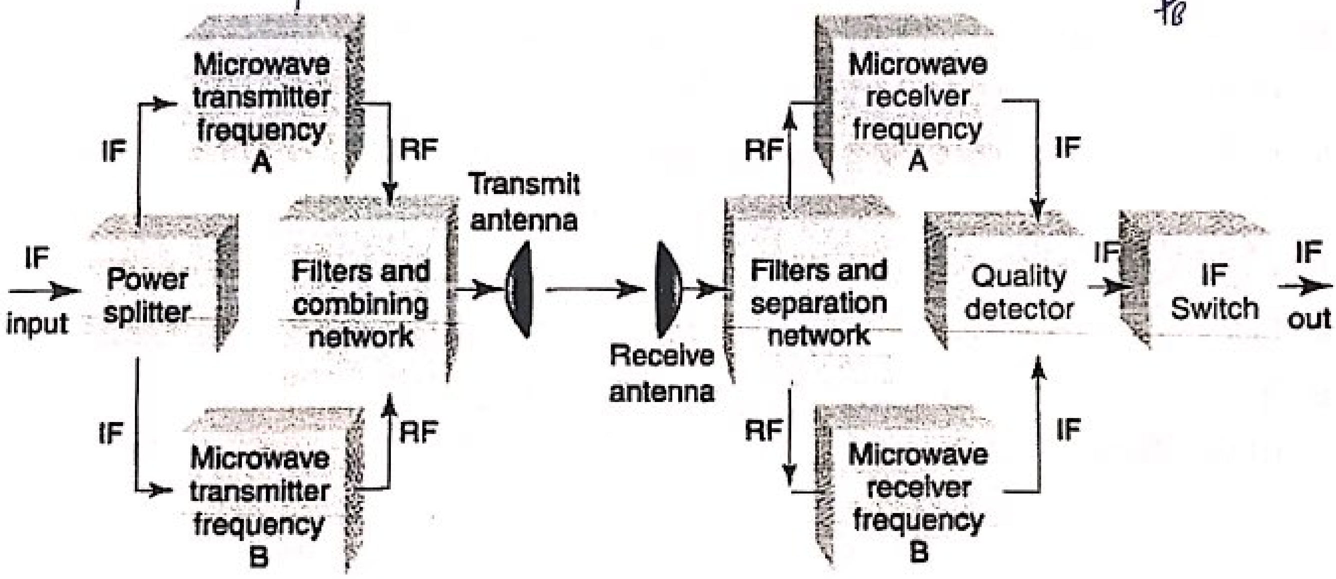
Frequency Diversity

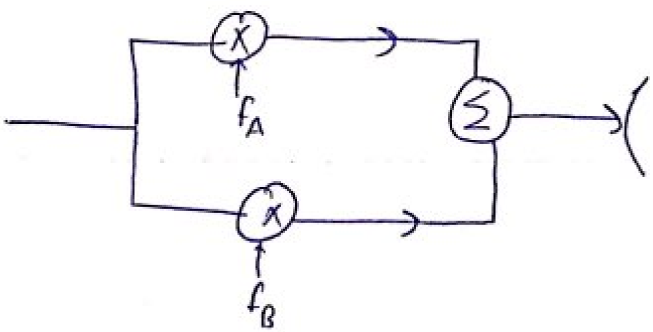
- Modulating two different RF carrier frequencies with the same IF intelligence, then transmitting both RF signals to a given destination (see Fig.7).
- At the destination, both carriers are demodulated, and the one that yields the better-quality IF signal is selected.
- Many of the temporary atmospheric conditions that degrade an RF signal are frequency-selective; they may degrade one more than another. Therefore, over a given period of time, the IF switch may switch back and forth from receiver A to receiver B and vice versa many times.
- Freq. diversity disadvantage: doubles the amount of frequency spectrum and equipments.

Fig.7: Frequency Diversity



→ up Conversion





dis. adv.

① زاد ال B.W

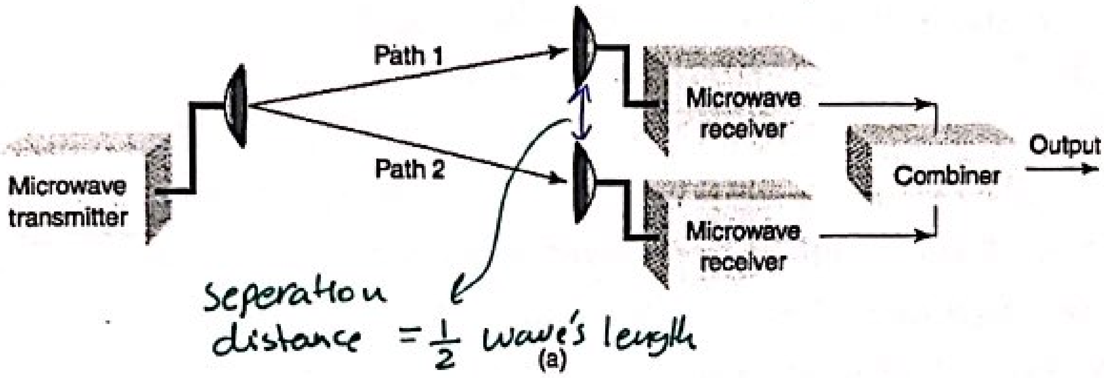
② devices الكثير

Space Diversity

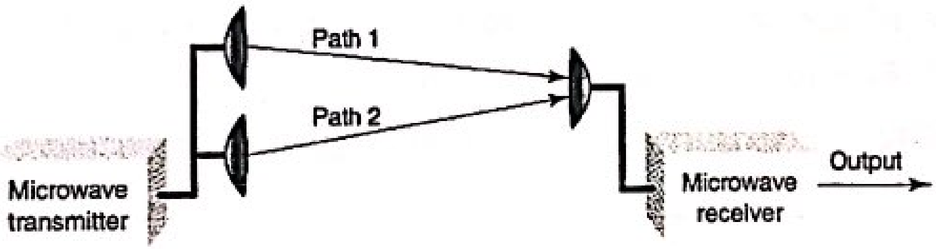
- The output of a transmitter is fed to two or more antennas that are physically separated by an appreciable number of wavelengths.
- Similarly, at the receiving end, there may be more than one antenna providing the input signal to the receiver.
- If multiple receiving antennas are used, they must also be separated by an appreciable number of wavelengths.
- Fig.8a: shows space diversity system using two transmit antennas.
- Fig.8b: shows space diversity system using two receive antennas.
- The rule is to use two transmit antennas or two receive antennas but never two of each.

Fig.8: Space Diversity

we use multiple Antenna

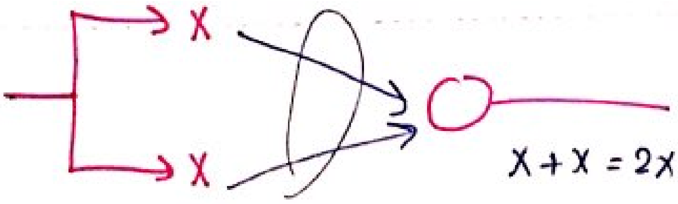


(a)



(b)

* كل ما زادت عدد ال Antennas بيتحسن ال diversity



orthognal (space time coding)

Note :- current system are (Massive MIMO)

Space Diversity

- When space diversity is used, it is important that the electrical distance from a transmitter to each of its antennas and to a receiver from each of its antennas is an equal multiple of wavelengths long.
- This is to ensure that when two or more signals of the same frequency arrive at the input to a receiver, they are in phase and additive.
- If received out of phase, they will cancel and, consequently, result in less received signal power than if one antenna system were used
- Disadvantage: more expensive than frequency diversity because of the additional antennas and waveguides.
- Advantage: provides efficient frequency spectrum usage.

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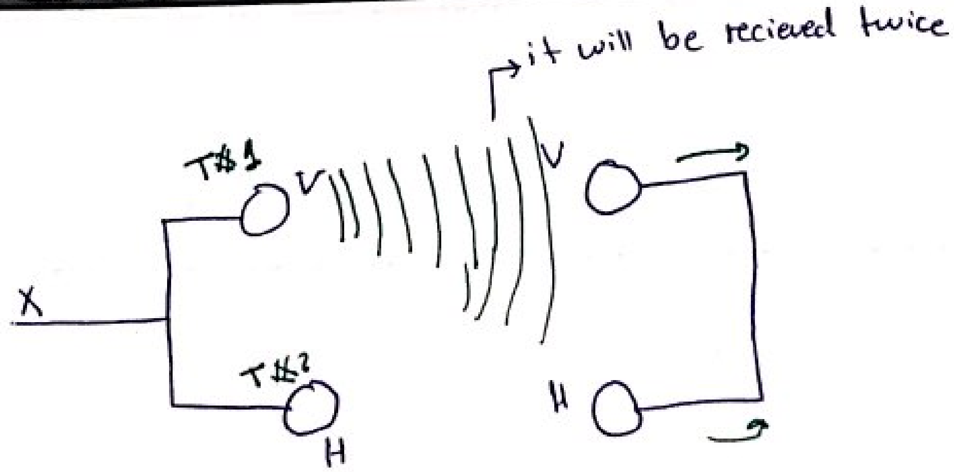
Polarization Diversity

- A single RF carrier is propagated with two different electromagnetic polarizations (vertical and horizontal)
- One transmit/receive antenna pair is vertically polarized, and the other is horizontally polarized
- Electromagnetic waves of different polarizations do not necessarily experience the same transmission impairments
- Polarization diversity is generally used in conjunction with space diversity



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Hybrid Diversity

- It consists of standard frequency diversity and space-diversity.

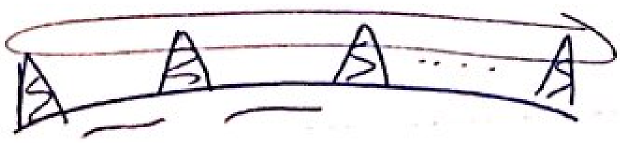
Quad Diversity

- It combines frequency, space, polarization diversity into one system.

Protection Switching Arrangements (PSA)

- Target: to avoid a service interruption during periods of deep fading or equipments failures.
- How: alternate facilities are temporarily made available.
- Diversity Vs PSA:
  - Diversity: provides protection for single microwave link & and single channels
  - PSA: used for much larger section of the system and several channels may share it.

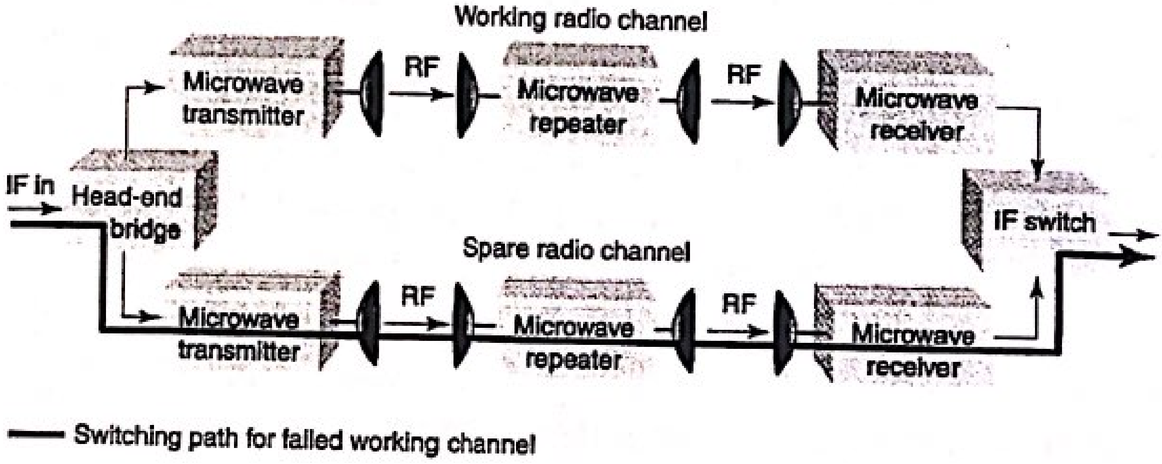
PSA



Hot Standby PSA (see Fig.9)

- At the transmitting end, the IF goes into a head-end bridge, which splits the signal power and directs it to the working and the spare (standby) microwave channels simultaneously. Consequently, both the working and the standby channels are carrying the same baseband information. At the receiving end, the IF switch passes the IF signal from the working channel to the FM terminal equipment. The IF switch continuously monitors the received signal power on the working channel and, if it fails, switches to the standby channel. When the IF signal on the working channel is restored, the IF switch resumes its normal position.

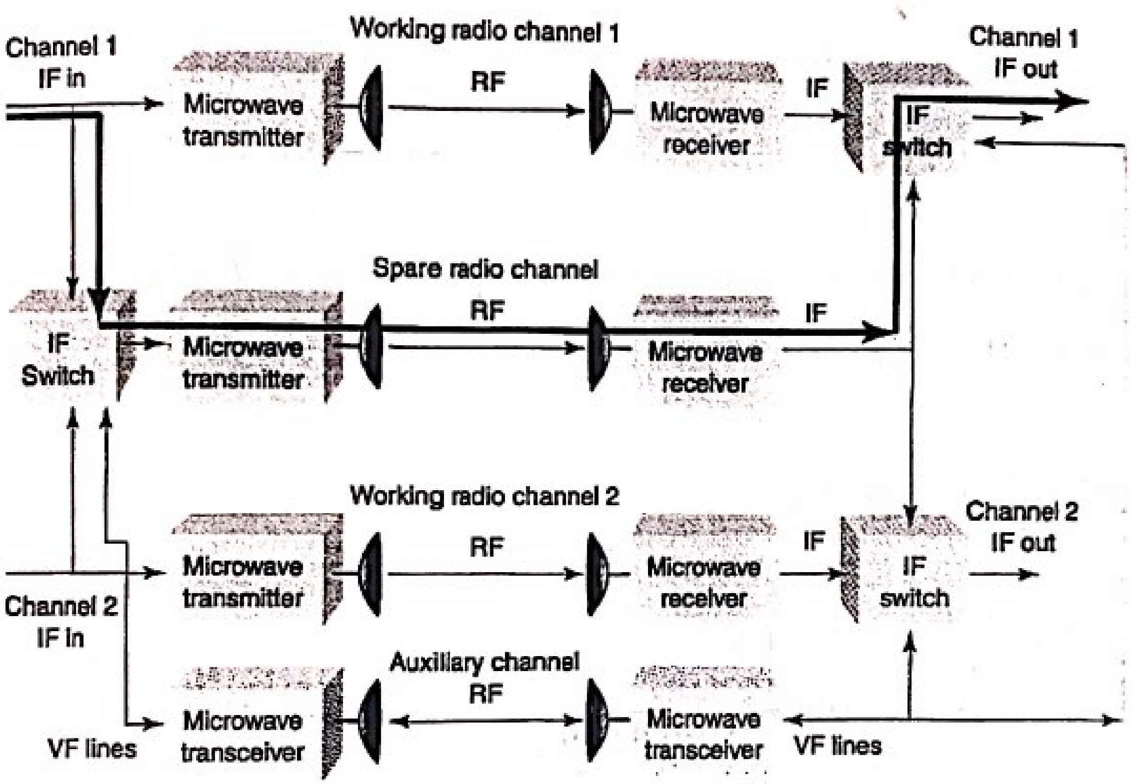
Fig.9: Hot Standby PSA



Diversity PSA (see Fig.10)

- This system has two working channels (channel 1 and channel 2), one spare channel, and an auxiliary channel. The IF switch at the receive end continuously monitors the receive signal strength of both working channels. If either one should fail, the IF switch detects a loss of carrier and sends back to the transmitting station IF switch aYF (voice frequency) tone-encoded signal that directs it to switch the IF signal from the failed channel onto the spare microwave channel. When the failed channel is restored, the IF switches resume their normal positions. The auxiliary channel simply provides a transmission path between the two IF switches. Typically, the auxiliary channel is a low-capacity low-power microwave radio that is designed to be used for a maintenance channel only..

Fig.10: Diversity PSA

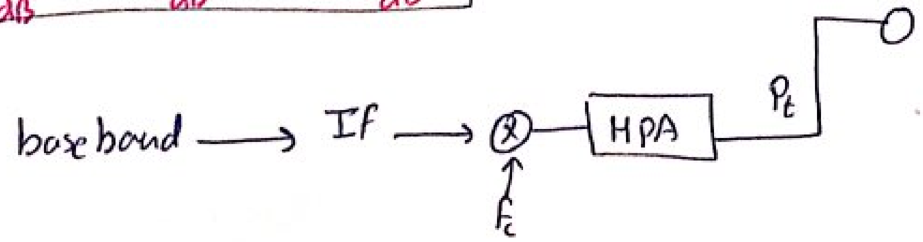


⑪ system gain :- G_s

Is the difference between the nominal output power (P_t) of Transmitter and minimum received power required by a receiver (C_{min}).

$$\underset{dB}{G_s} = \underset{dBm}{P_t} - \underset{dBm}{C_{min}}$$

$$\underset{dB}{G_s} = \underset{dB}{\text{losses}} - \underset{dB}{\text{gains}}$$



losses :-

1) L_b : branching or coupling losses (dB)
2) L_F : Feeder losses (dB)
3) L_p : Free space loss

$$L_p = 20 \log\left(\frac{4\pi d}{\lambda}\right) = 20 \log\left(\frac{4\pi F d}{c}\right)$$

4) F_m : Fade margin [dB]

gains :-

A_t : Tx antenna gain

A_r : Rx antenna gain

⇓ ex:-

for parabolic Antenna :-

$$A = 10 \log \left(5.4 \left(\frac{D}{\lambda}\right)^2\right)$$

D : Diameter

ex:- A space-diversity microwave system operating at 1.8 GHz. Each station has a 2.4m diameter parabolic antenna that is fed by 100m of air filled Coaxial cable. The system has a path loss of 129.55 dB (d = 40 km) and a fade margin of 31.4 dB. Find the system gain G_s in dB

Sol:-

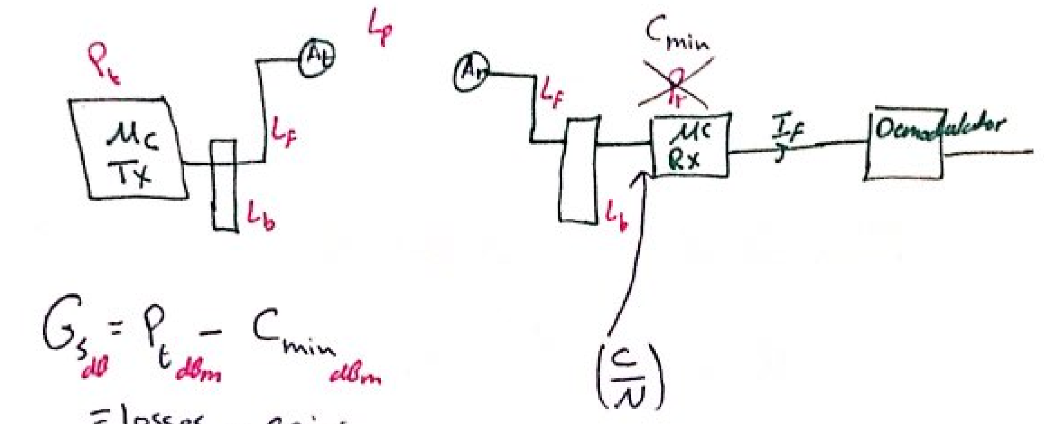
(→ from the table: L_p)

$$G_s = \text{losses} - \text{gain} = (L_b + L_F + L_p + F_m) - (A_t + A_r)$$

$$= (2 + 2 + \underbrace{5.4}_{Tx} + \underbrace{5.4}_{Rx} + 129.55 + 31.4) - (31.2 + 31.2) = 113.35\ dB$$

$$P_t - C_{min} = 113.35\ dB$$

System gain :-



$$G_{s_{dB}} = P_{t_{dBm}} - C_{min_{dBm}}$$

$$= \text{losses} - \text{gains}$$

losses → L_f, L_b, L_p, F_m

gains → A_t, A_r

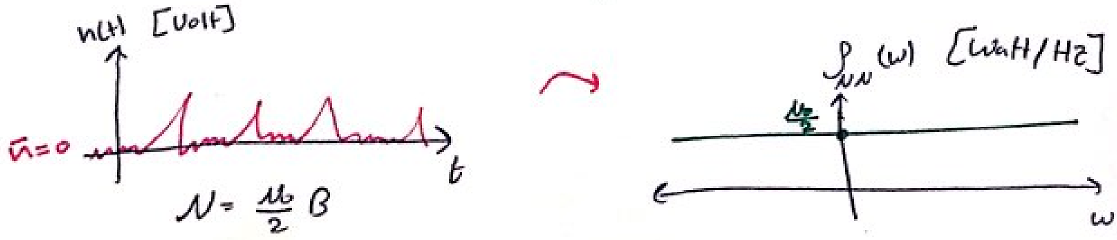
$\left(\frac{C}{N}\right)$: wideband carrier power to noise-power Ratio at the input to the Rx.

Noise sources & power :-

$y(t) = h\,x(t) + n(t)$

↑ AWGN R.process

$P(hx(t)) = P_r$



Noise :-

External

1) industrial effects
motors, generators, Radio systems
2) solar systems
3) atmospheric electric charges

Internal

↳ caused by the Rx electronic components

passive / active

"Thermal noise"

Thermal Noise :-

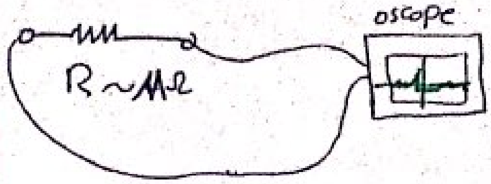
T [kelvin]

Random electric motion causes a Random current

$V_n = R\, i_n \sim \mu V, nV$

↑ Random noise Voltage

experiment: -



Noise power : $\boxed{N = kTB}$ [W] $\Rightarrow \frac{N_o}{2} = kT$

↑ Johnson's formula

k : Boltzman's constant $= 1.38 \times 10^{-23}$ J / kelvin

T : Temprature [kelvin]

B : system Bandwidth [Hz]

$$N_{[dBm]} = 10 \log \left(\frac{KTB}{0.001} \right) = 10 \log \frac{kT}{0.001} + 10 \log (B)$$

For $T = 290°$ kelvin

$$N_{dBm} = -174_{dBm} + 10 \log (B)$$

(B in Hz)

$\Rightarrow$ For $B = 10$ MHz

$$N_{dBm} = -174 + 10 \log (10^7)$$

$$= -104 \text{ dBm}$$

$$\left(\frac{C}{N}\right)_{dB} = C_{min} - N$$

C_{min} [dBm], N [dBm]

C_{min} [dBw], N [dBw]

Ex:- a microwave system with system gain of 113.35 dB & Carrier-to-noise-power Ratio of 24 dB. B = 10 MHz, Find P_t ?!

$$G_s = P_t - C_{min} \Rightarrow P_t = 113.5 + C_{min}$$

$$\left(\frac{C}{N}\right) = 24\,dB = C_{min\,[dBm]} - N_{[dBm]}$$

$$\Rightarrow C_{min\,[dBm]} = 24 + N_{dBm} = 24 + (-104\,dBm)$$
$$= 80\,dBm$$

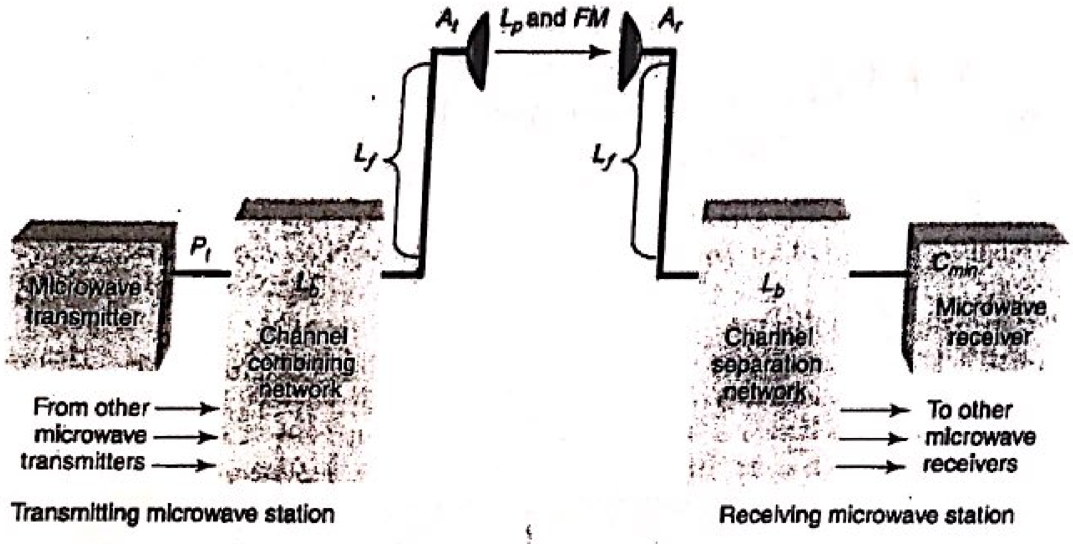
$$\Rightarrow P_t = 113.5 - 80 = 33.35\,dBm$$
$$\triangleq 10^{3.335}\,mW$$

$N_0/2 = kT$ watt/Hz

System Gain

- $\sigma_N^2 = \frac{N_0}{2} B =$ Ac. Power.
- Total power $= \sigma_N^2 + \bar{N}^2 = \sigma_N^2 = \frac{N_0}{2}$.
- $P_n = kTB = \frac{N_0}{2} B$

System Gain Parameters



	Feeder Loss (L_f)		Branching Loss (L_b) (dB)		Antenna Gain (A_t or A_r)	
Frequency (GHz)	Type	Loss (dB/100 Meters)	Diversity Frequency	Diversity Space	Diameter (Meters)	Gain (dB)
1.8	Air-filled coaxial cable	5.4	4	2	1.2	25.2
					2.4	31.2
					3.0	33.2
					3.7	34.7
					4.8	37.2
7.4	EWP 64 elliptical waveguide	4.7	3	2	1.2	37.1
					1.5	38.8
					2.4	43.1
					3.0	44.8
					3.7	46.5
8.0	EWP 69 elliptical waveguide	6.5	3	2	1.2	37.8
					2.4	43.8
					3.0	45.6
					3.7	47.3
					4.8	49.8

$f \uparrow \Rightarrow G \uparrow$

$D \uparrow \Rightarrow G \uparrow$

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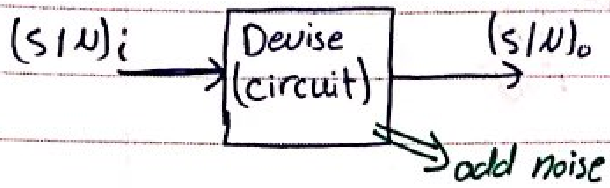
Noise factor & figure of used to indicate how much the SNR deteriotes as the signal passes through a circuit or seires of circuits.



$(S/N)_o < (S/N)_i$

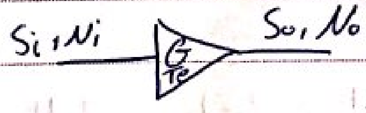
$F = \frac{(S/N)_i}{(S/N)_o} \geq 1$; $= 1 \Rightarrow$ if the devise is noiseless then $(S/N)_o = (S/N)_i$

$\Rightarrow$ Noise figure, $NF = 10 \log_{10}(F)$ dB

if $NF = 0$ dB $\rightarrow$ noisless

For power amplifiers

$\left(\frac{S}{N}\right)_i = \frac{S_i}{N_i}$



G = amplification gain
T_e = equivalent temprature

$N_o = (N_i + N_d)\, G$

$N_i = kTB$

$N_d = kT_eB$

$S_o = G\, S_i$

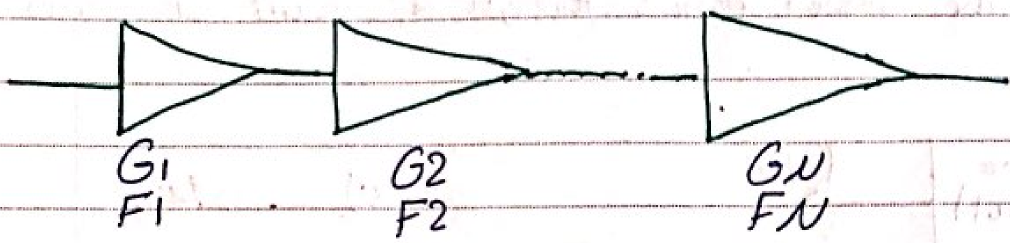
$(S/N)_o = \frac{S_o}{N_o} = \frac{G S_i}{G(N_i + N_d)} = \frac{S_i}{N_i + N_d}$

$= \frac{S_i}{kTB + kT_eB} = \frac{S_i}{kB(T+T_e)} \times \frac{T}{T}$

$\left(\frac{S}{N}\right)_o = \left(\frac{S}{N}\right)_i \cdot \frac{T}{T+T_e}$ $\Rightarrow F = \frac{(S/N)_i}{(S/N)_o} = \frac{T+T_e}{T} = 1 + \frac{T_e}{T}$

No.

Fris Formula :-



$$G_T = G_1 G_2 \cdots G_N = G_{1dB} + G_{2dB} + \cdots + G_{N dB}$$

$$F_T = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \cdots + \frac{F_N - 1}{G_1 \cdots G_{N-1}}$$

example :- A sub system consists of 3 amplifiers with equal power gain $G_1 = G_2 = G_3 = 10\,dB$, and equal noise figure $NF1 = NF2 = NF3 = 3\,dB$, Find the total gain and the total NF

Sol :-

$$G_T = G_1 + G_2 + G_3 = 10^3 = 30\,dB$$

$$F_T = 2 + \frac{2-1}{10} + \frac{2-1}{100} = 2.11$$

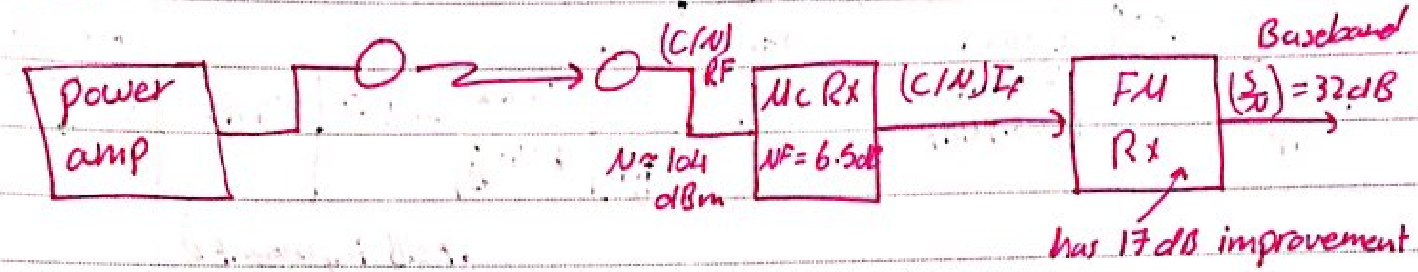
$$NF_T = 10 \log (2.11) = 3.24\,dB$$

$$F1 = 1 + \frac{Te1}{290} \Rightarrow Te = 290^\circ$$

$$FT = 1 + \frac{TeT}{290} \Rightarrow TeT = (1.11)\,290$$

No.

Ex 8-



Find P_t ?!

$\left(\frac{C}{N}\right)_{IF} = 32\,dB - 17\,dB = 15\,dB$

$NF = \left(\frac{C}{N}\right)_{RF} - \left(\frac{C}{N}\right)_{IF}$

$\left(\frac{C}{N}\right)_{RF} = 6.5\,dB + 15 = 21.5\,dB$

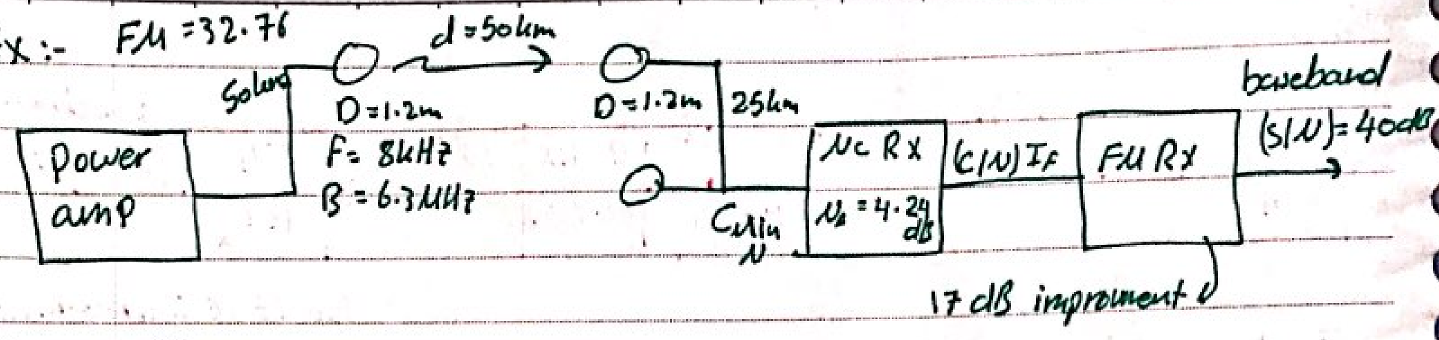
$\left(\frac{C}{N}\right)_{RF} = C_{min} - N \Rightarrow C_{min} = 21.5\,dB - 104\,dBm = -82.5\,dBm$

$G_s = P_t - C_{min}$

$P_t = 112\,dB + -82.5\,dBm = 29.5\,dBm$

No.

Ex:-



Find P_t ?!

$\left(\frac{C}{N}\right)_{IF} = 40\,dB - 17\,dB = 23\,dB$

$\left(\frac{C}{N}\right) = 27.24\,dB$

$N_{dBm} = -174 + 10\log(6.3 \times 10^6) = -106\,dBm$

$C_{min} = \left(\frac{C}{N}\right) + N = 27.24 - 106 = -78.76\,dBm$

$G_s = P_t - C_{min}$

$G_{s_{dB}} = \text{losses} - \text{gains} = (L_{ft} + L_{fr} + L_{bt} + L_{br} + L_p + F_m) - (A_t + A_r)$

$= 3.25 + \frac{6.5}{4} + 2 + 2 + 20\log\left(\frac{4\pi \times 50 \times 10^3 (8 \times 10^9)}{3 \times 10^8}\right) + 32.76$

$- (37.8 + 37.8)$

$P_t = G_s + G_{min} = 110.475\,dB + -78.76\,dBm = 31.715\,dBm$