SRI MUTHUKUMARAN INSTITUTE OF TECHNOLOGY

(Approved by AICTE, Accredited by NBA and Affiliated to Anna University, Chennai)

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

EC8701 – ANTENNA AND MICROWAVE ENGINEERING
(REGULATION – 2017)

YEAR: IV **SEM: VII**

UNITI:-INTRODUCTION TO ANTENNA AND MICROWAVE SYSTEMS

PART-A

1. Definemicrowave.

Microwaves are electromagnetic waves (EM) with wavelength ranging from 1cm to1mm. The corresponding frequency range is 1 GHzto 300GHz. Therefore, signals of highfrequencieshave relativelyshortwavelengths,hence the name "micro"waves.

2. What arethemajorbandsavailablein microwavefrequencies?

The microwave frequencies span the following three major bands at the highest end ofRFspectrum.

Ultra High Frequency (UHF) 0.3 to 3
GHz.Super High Frequency (SHF) 3 to 30
GHz.ExtraHighFrequency(EHF)30to300GH
z.

3. Enumeratethebasicadvantageofmicrowaves.)

- Fewerrepeatersaresufficientforamplification.
- Minimalcrosstalkexistsbetweenvoicechannels.
- Increasedreliabilityand lessmaintenance.
- Increasedbandwidthavailability

4. Writetheapplicationsofmicrowaves.(

- Microwavebecomesaverypowerfultoolin microwaveradiospectroscopyforanalysis.
- Microwavelandingsystem(MLS),usedtoguideaircrafttolandsafetyatairports.
- Specialmicrowaveequipmentknownasdiathermymachinesareusedinmedicinefo rheatingbodymusclesand tissueswithout hurting theskin.
- Microwaveovensareacommonapplianceinmostkitchenstoday.

5. DefineAntenna. (R)

Antennaisastructureassociatedwiththeregionoftransitionbetweenguidedwaveandfreesp ace waveandviceversa

6. **DefineanIsotropicAntenna. (R)(Nov /Dec '14)(May/June'06)**

AnIsotropicAntennaistheonewhichradiateenergyuniformly inalldirections.

7. **WhataredBianddBd?Writetheirsignificances?(R)(Nov/Dec'13)**

dBi – Decibel with respect toisotropic antenna. dBd– decibel with respect todipoleantenna.dBiisameasurementthatcomparesthegainofanantennawithrespecttoan isotropic radiator. dBd compares the gain of an antenna to the gain of a reference dipoleantenna.

8. **DifferentiateradianandSteradian. (U)(Nov/Dec'17)**

Radian	Steradian
Measurementofplanarangleisradian.	MeasurementofsolidangleisSteradian.
1Circlecontains2πradians	1Spherecontains4πSteradians.
$1Sr=1rad^2$	

9. **DefineRadiation pattern. (R)**

AntennaRadiationpatternisa3dimensionalgraphwhichshowsthevariationinactualfieldstrengthofEMFatallpointswhichare atequaldistancefromtheantenna.

10. **Whatare and patterinantennaradiationpattern?(R) (Nov/Dec'13)**

and farfield.(R)(May/June'07)/(Apr/May'15)

Induction field (Near field): The field which predominates at the points closer to the currentelement where r is small is known as induction field. The near field is inversely proportionaltosquareofthedistance (1/r2).Itisoflessimportance.

Radiation field (Far field): The radiation fieldis farfield and itvaries inversely withdistance(1/r).Thisfieldcontributestotheflowof energy awayfrom thesource.Thisradiation fieldorfarfieldisofgreatimportance atlarge distance.

14. **The radial component of the radiated power density of an antenna is given by**

$W_{rad} = a_r A_0 \sin\theta / r2$ (W/m2). Determine the total radiated power. (R) (Nov/Dec'16)

$U = W_{rad} \times r^2 = A_0 \sin\theta$

$P_{rad} = \int\int U \sin\theta \, d\theta \, d\phi = A_0 \int\int \sin^2\theta \, d\theta \, d\phi = \pi^2 A_0$ Watts

$= \int\int A_0 \sin\theta \cdot \sin\theta \, d\theta \, d\phi = 2\pi A_0$

15. DefineRadiationresistanceofantenna. (R) (May/June'09)

Radiationresistanceisdefinedasa'Virtualresistancethatdoesnotexistphysicallybutisaquantitycouplingtheantennatodistantregionsofspaceviaatransmissionline'.

16. Theradiationresistanceofanantennais72Ωandlossresistanceis8Ω.Whatisthedirectivity (indB)ifthe powergainis 15.(R)(Nov/Dec'16)

$$\eta = \frac{R_r}{R_r + R_l} = 0.9$$

$$\eta = \frac{G}{D} \Rightarrow D = \frac{G}{\eta} = \frac{15}{0.9} = 16.67$$

D(indB)=10log D = 10log 16.67=12.22dB

17. Writetheimportanceof radiation resistanceofanantenna.(R)(Apr'15)/(Apr'14)

21. DefineDirectivityofAntenna.(R) (May/June'12)&(Nov/Dec'09)

Directivity isdefinedastheratioof Radiationintensity of testantennain agivendirectiontoradiationintensityofisotropicantenna.D=U/U_0

WhereU=RadiationintensityoftestantennaU_0=Radiationintensityofisotropicantenna

Itisalsoexpressedas $D = \frac{4\pi U}{P_{rad}}$

22. Definegainofanantenna.Whatistherelationbetweengainandapertureofanantenna? (R)(Nov /Dec '16)/(April/May'17)

GainisdefinedastheratioofRadiationintensityoftestantennainagivendirectionto radiationintensityofisotropic antenna,assuming sameinputpower.G =U/U_0

WhereU=Radiation intensityoftest antenna

U_0=RadiationintensityofIsotropicantenna

Therelationbetweengainandapertureis, $G = \frac{4\pi}{\lambda^2}(A_e)_{max}$

23. Distinguishbetweenpowergainanddirectivegain.(U)(Nov/Dec'14)

Both power gain and directive gain refers to the ratio of Radiation intensity of testantenna in a given direction to radiation intensity of isotropic antenna. But power gain ismeasuredbyconsideringsameinputpowerwhereasdirectivegainismeasuredbyconsideringradiatedpower.

24. What isfront tobackratio? (R)

FronttoBackRatio(FBR)isdefinedastheratioofpowerradiatedinthedesireddirectiontothe powerradiatedintheopposite direction

ie.FBR=powerradiatedindesireddirection/powerradiatedinoppositedirection

28. DefineEffectiveapertureofanantenna.(R) (May/June'12)&(Nov/Dec'12)

Effectiveapertureisdefinedastheratioofpowerreceivedattheantennaloadterminaltothepointingvector(powerdensity)oftheincidentwave.ItsunitisW/m^2.

29. Whatisthe relationshipbetweeneffectiveapertureanddirectivity? (R)

Therelationshipbetweeneffectiveapertureanddirectivityis $D = 4\pi \frac{A_e}{\lambda^2}$

30. What isthesignificanceofapertureofan antenna?(R) (Apr/May'15)

Apertureofanantennaisausefulparameterthatcalculatesthereceivepowerofanantenna.Itdescribeshow muchpoweriscapturedfroma givenplane wave.

31. Writetheantennafieldzoneswiththeboundariesofanantennaundertest.(R) (Nov/Dec '04)

Thespacesurroundinganantennaisdividedinto3regions.

Theyarea)Reactive nearfield

b) Radiationnearfield(Fresnel)and

c) Radiationfarfield(Fraunhofer)

The outer boundary of Reactive near field is at a distance R< $0.62\sqrt{D^3/\lambda}$Theinnerboundaryofradiationnearfield (Fresnel)isgiven by

$R \geq 0.62\sqrt{D^3/\lambda}$ anditsouterboundaryisR< $2D^2/\lambda$

The inner boundary of far field is given by R>= $2D^2/\lambda$Where,D=largestdimensionofthe antenna

λ=wavelengthinmeter

32. Whatdoyou meantby effective length ofthe antenna? (R)

The term effective length of an antenna represents the 'effectiveness of an antenna asradiator or collector of electromagnetic wave energy'. For a receiving antenna, it is defined asthe ratio of induced voltage at the terminals of the receiving antenna under open circuitconditiontothe incidentelectricfieldstrengthE.

Effectivelength,$l_e$orh=V/E(meterorwavelength)

33. Whatdoyoumeantbyselfimpedance? (R)

Selfimpedanceisdefinedastheratioofvoltagetocurrentatapair ofterminals.

$Z_{11}=R_{11}+jX_{11}$

where,R_{11}=Radiationresistance,X_{11}=Selfreactance

34.Whatismutualimpedance? (R)

Itisdefinedasthenegativeratioofemf inducedinoneantennatothecurrentflowingintheantenna.

MutualImpedance,$Z_{21}=-V_{21}/I_1$(or) $Z_{12}=-V_{12}/I_2$

35. WhatisBalun? (R)

A Balun is a device that joins a balanced line (one that has two conductors, with equalcurrents in opposite directions, such as a twisted pair cable) to an unbalanced line (one thathas just one conductor and a ground, such as a coaxial cable). A typical use for a balun is in atelevisionantenna.The termisderivedbycombiningbalancedandunbalanced.

PART-B

UNITIINTRODUCTIONTOMICROWAVESYSTEMSAND ANTENNAS

1). Explain the electromagnetic spectrum and microwave frequency bands,

Electromagneticspectrum:

Electromagnetic spectrum

Microwaves occupy a place in the electromagnetic spectrum with frequency above ordinary radio waves, and below infrared light:

Electromagnetic spectrum			
Name	Wavelength	Frequency (Hz)	Photon energy (eV)
Gamma ray	< 0.02 nm	> 15 EHz	> 62.1 keV
X-ray	0.01 nm – 10 nm	30 EHz – 30 PHz	124 keV – 124 eV
Ultraviolet	10 nm – 400 nm	30 PHz – 750 THz	124 eV – 3 eV
Visible light	390 nm – 750 nm	770 THz – 400 THz	3.2 eV – 1.7 eV
Infrared	750 nm – 1 mm	400 THz – 300 GHz	1.7 eV – 1.24 meV
Microwave	1 mm – 1 m	300 GHz – 300 MHz	1.24 meV – 1.24 μeV
Radio	1 m – 100 km	300 MHz – 3 kHz	1.24 μeV – 12.4 feV

MicrowaveFrequencyBands:

Microwaves Frequency Bands

Band	Frequency range
HF Band	3 to 30 MHz
VHF Band	30 to 300 MHz
UHF Band	300 to 1000 MHz
L Band	1 to 2 GHz
S Band	2 to 4 GHz
C Band	4 to 8 GHz
X Band	8 to 12 GHz
Ku Band	12 to 18 GHz
K Band	18 to 27 GHz
Ka Band	27 to 40 GHz
V Band	40 to 75 GHz
W Band	75 to 110 GHz
mm Band	110 to 300 GHz

b) Explain the physical concepts of radiation.

PhysicalConcept ofRadiation(Radiation Mechanism)

One of the first questions that may be asked concerning antennas would be "how is radiation accomplished?"

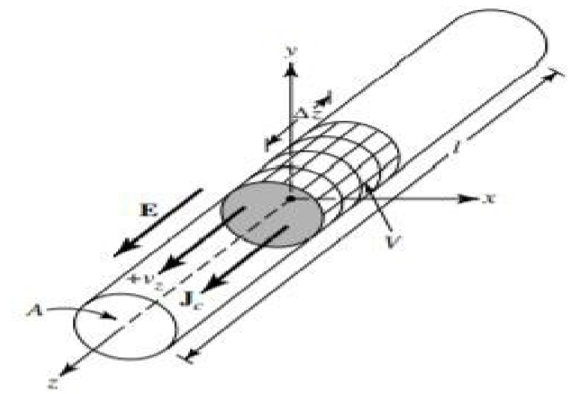
In otherwords, how arethe electromagneticfields generated by the source, contained and guided within the transmission line and antenna, and finally "detached" from the antenna to form a free-space wave?

Letus firstexaminesomebasic sourcesof radiation.

RadiationfromSingleWire

Conducting wires are material whose prominent characteristic is the motion of electric charges and the creation of current flow.

Let us assume that an electric volume chargedensity, represented by q_v(coulombs/m3), is distributed uniformly in a circular wire of cross-sectional area A and volume V, as shown in Figure.



Charge uniformly distributed in a circular cross section cylinder wire.

The total charge Q with in volume V is moving in the z direction with a uniform velocity v_z(meters/sec). It can be shown that the current density J_z(amperes/m2) over the cross section of the wire is given by

$$J_z=q_v v_z \qquad (1a)$$

Ifthewireismadeofanidealelectricconductor,thecurrentdensityJ_s(amperes/m)resides on the surface of the wire and it is given by

$$J_s=q_s v_z \qquad (1b)$$

whereq$_s$(coulombs/m2)isthesurfacechargedensity.

Ifthewireisverythin(ideallyzeroradius),thenthecurrentinthewirecanberepresented by

$$I_z=q_l v_z \qquad (1c)$$

whereq$_l$(coulombs/m)isthechargeperunitlength.Insteadofexaminingallthreecurrent densities,wewillprimarilyconcentrateontheverythinwire.Theconclusionsapplytoall three.

Ifthecurrent istime varying,thenthe derivativeof thecurrentof (1c)canbewritten as

$$dI_z/dt=q_l dv_z/dt=q_l a_z \qquad (2)$$

where$dv_z/dt=a_z$(meters/sec^2)istheacceleration.Ifthewireisoflengthl,then(2)can be written as

$$l dI_z/dt=l q_l dv_z/dt= l q_l a_z \qquad (3)$$

Equation (3) is the basic relation between current and charge, and it also serves as the fundamental relation of electromagnetic radiation.

It simply states that to create radiation, there must be a time-varying current or an acceleration (or deceleration) of charge. We usually refer to currents in time-harmonic applications while charge is most often mentioned in transients. To create charge acceleration (ordeceleration)thewiremust be curved, bent, discontinuous, orterminated. Periodicchargeacceleration(ordeceleration)ortime-varyingcurrentisalsocreatedwhen charge is oscillating in a time-harmonic motion.

ImportantConclusions:

(i) Ifachargeisnotmoving,currentisnotcreatedandthereisnoradiation.

(ii) Ifchargeis moving with auniformvelocity:

(a) Thereis no radiation ifthewireis straight,andinfinite in extent.

(b) Thereisradiationifthewireiscurved,bent,discontinuous,terminated,or truncated, as shown in Figure

(iii) Ifchargeisoscillating inatime-motion, itradiates evenif the wireis straight.

A qualitative understanding of the radiation mechanism may be obtained by considering a pulse source attached to an open-ended conducting wire, which may be connected to the ground through a discrete load at its open end, as shown in Figure (d).

When the wire is initially energized, the charges (free electrons) in the wire are set in motionbytheelectricallinesofforcecreatedbythesource.Whenchargesareaccelerated inthesource-endofthewireanddecelerated(negativeaccelerationwithrespecttooriginal motion) during reflection from its end, it is suggested that radiated fields are produced at each end and along the remaining part of the wire.

Stronger radiation with a more broad frequency spectrum occurs if the pulses are of shorter or more compact duration while continuous time-harmonic oscillating charge produces,ideally,radiationofsinglefrequencydeterminedbythefrequencyofoscillation.

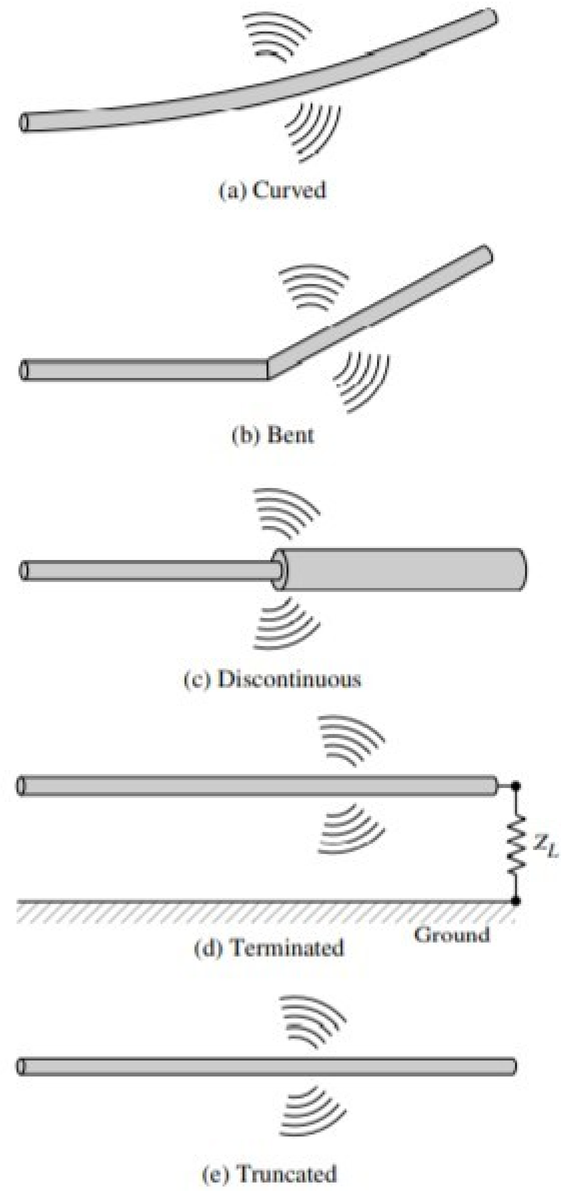


Figure Wire configurations for radiation.

Theaccelerationofthechargesisaccomplishedbytheexternalsourceinwhichforces setthechargesinmotionandproducetheassociatedfieldradiated.Thedecelerationofthe charges atthe end ofthe wireis accomplishedby theinternal (self) forces associated with the induced field due to the build up of charge concentration at the ends of the wire. The internalforces receiveenergyfromthechargebuildupas itsvelocityis reducedto zeroat theendsofthewire.**Therefore,chargeaccelerationduetoanexcitingelectricfieldand deceleration due to impedance discontinuities or smooth curves of the wire are mechanisms responsible for electromagnetic radiation.**

RadiationfromTwo-Wires

Letusconsideravoltagesourceconnectedtoatwo-conductortransmissionlinewhich is connected to an antenna. This is shown in Figure. Applying a voltage across the two-conductor transmission line creates an electric field between the conductors. The electric field has associated with it electric lines of force which are tangent to the electric field at eachpointandtheirstrengthisproportionaltotheelectricfieldintensity.Theelectriclines of force have a tendency to act on the free electrons (easily detachable from the atoms) associated with each conductor and force them to be displaced. The movement of the chargescreatesacurrentthatinturncreatesamagneticfieldintensity.Associatedwiththe magneticfieldintensityaremagneticlinesofforcewhicharetangenttothemagneticfield.

Wehaveacceptedthatelectricfieldlinesstartonpositivechargesandendonnegative charges.Theyalsocanstartonapositivechargeandendatinfinity,startatinfinityandend on a negative charge, or form closed loops neither starting or ending on any charge. Magnetic field lines always form closed loops encircling current-carrying conductors because physically there are no magnetic charges.

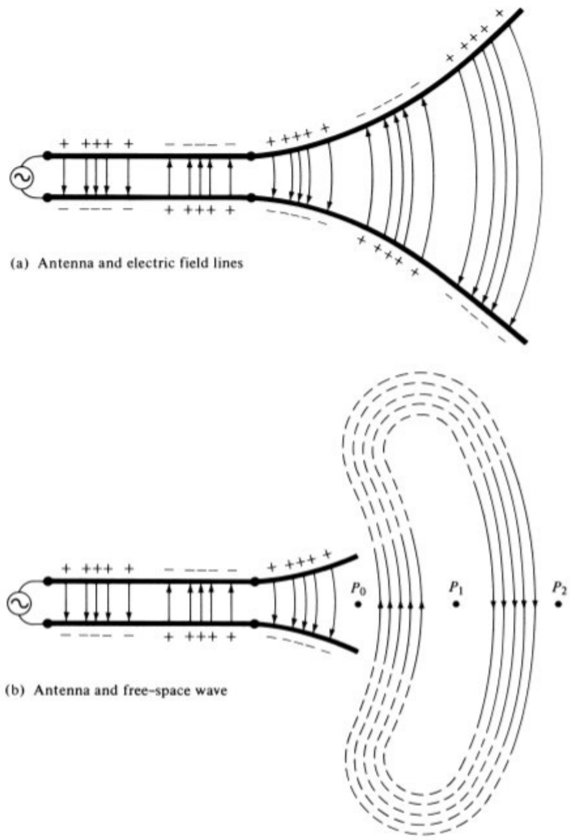


Figure Source, transmission line, antenna, and detachment of electric field lines.

The electric field lines drawn between the two conductors help to exhibit the distribution of charge. If we assume that the voltage source is sinusoidal, we expect the electric field between theconductors to also besinusoidal with aperiod equal to that oftheapplied source. Therelativemagnitudeoftheelectricfieldintensityisindicatedbythedensity(bunching)of the lines of force with the arrows showing the relative direction (positive or negative). The creation of time-varying electric and magnetic fields between the conductors forms electromagnetic waves which travel along the transmission line, as shown in Figure (a).

The electromagnetic waves enter the antenna and have associated with them electric charges and corresponding currents. If we remove part of the antenna structure, as shown in Figure(b),free-spacewavescanbeformedby“connecting”theopenendsoftheelectriclines (shown dashed).

Thefree-spacewavesarealsoperiodicbutaconstantphasepointP_0movesoutwardlywith thespeedoflightandtravelsadistanceof$\lambda/2$(toP_1)inthetimeofone-halfofaperiod.Ithas been shownthat close to the antenna the constant phase point P_0moves faster than the speed of light but approaches the speed of light at points far away from the antenna (analogous to phase velocity inside a rectangular waveguide).

free-spacewavesandwaterwaves-analogy

The question still unanswered is how the guided waves are detached from the antenna to create the free-space waves that are indicated as closed loops. Before we attempt to explain that,letusdrawaparallelbetweentheguidedand free-spacewaves,andwaterwavescreated by the dropping of a pebble in a calm body of water or initiated in some other manner.

Oncethedisturbance in thewaterhas been initiated,waterwaves arecreated which begin to travel outwardly. If the disturbance has been removed, the waves do not stop or extinguish themselves but continue their course of travel. If the disturbance persists, new waves are continuously created which lag in their travel behind the others. The same is true with the electromagnetic waves created by an electric disturbance.

If the initial electric disturbance by the source is of a short duration, the created electromagneticwavestravelinsidethetransmissionline,thenintotheantenna,andfinallyare radiated as free-space waves, even if the electric source has ceased to exist (as was with the water waves and their generating disturbance). If the electric disturbance is of a continuous nature, electromagnetic waves exist continuously and follow in their travel behind the others.This is shown in Figure for a biconical antenna. When the electromagnetic waves are withinthetransmissionlineandantenna,theirexistenceisassociatedwiththepresenceofthe charges insidethe conductors. However, when thewaves are radiated, they form closedloops and there are no charges to sustain their existence. This leads us to conclude that electric charges are required to excite the fields but are not needed to sustain them and may exist in their absence. This is in direct analogythe water waves.

Isotropic,Directional,andOmnidirectional Patterns

An isotropic radiator is defined as "a hypothetical lossless antenna having equal radiation in all directions." Although it is ideal and not physically realizable, it is often taken as a reference for expressing the directive properties of actual antennas.

A directional antenna is one "having the property of radiating or receiving electromagneticwavesmoreeffectivelyinsomedirectionsthaninothers".Exampleofantenna with directional radiation patterns is shown in Figure.

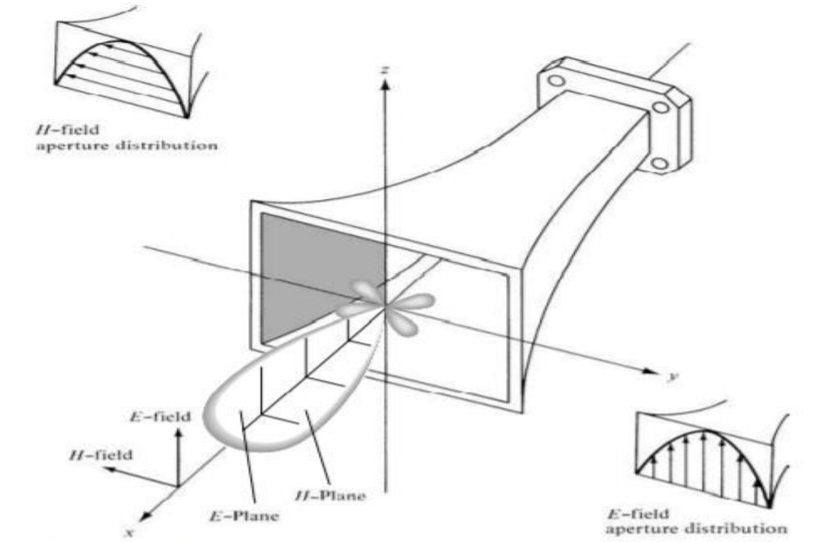


Figure Principal E- and H-plane patterns for a pyramidal horn antenna.

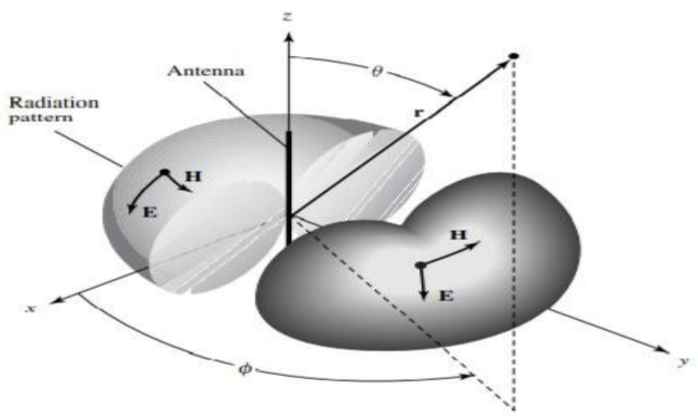


Figure Omnidirectional antenna pattern.

2.(a) Explain the following antenna parameters.

Antennanearandfarfield(FieldRegions of Antenna)

Thespacesurroundingan antennais usuallysubdivided intothreeregions:

(a) reactivenear-field,

(b) radiatingnear-field(Fresnel)and

(c) far-field(Fraunhofer)regionsasshowninFigure.

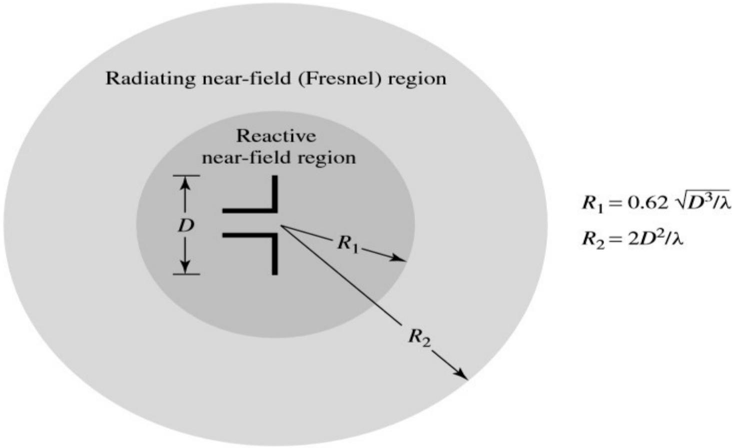


Figure Field regions of an antenna.

These regions are so designated to identify the field structure in each. Although no abrupt changes in the field configurations are noted as the boundaries are crossed, there are distinct differences among them.

Reactivenear-field region

Reactive near-field region is defined as "that portion of the near-field region immediately surrounding the antenna wherein the reactive field predominates." For most antennas,theouterboundaryofthisregioniscommonlytakentoexistatadistance $R < 0.62\sqrt{D^3/\lambda}$ fromtheantennasurface,whereλisthewavelengthandDisthelargestdimension oftheantenna."Foraveryshortdipole,orequivalentradiator,theouterboundaryiscommonly taken to exist at a distance λ/2π from the antenna surface."

Radiatingnear-field(Fresnel) region

Radiatingnear-field(Fresnel)regionisdefinedas"thatregionofthefieldofanantenna between the reactive near-field region and the far-field region wherein radiation fields predominateandwhereintheangularfielddistributionisdependentuponthedistancefromthe antenna.

Iftheantennahasamaximumdimensionthatisnotlargecomparedtothewavelength, this region may not exist. For an antenna focused at infinity, the radiating near-field region is sometimes referred to as the Fresnel region on the basis of analogy to optical terminology. If theantennahasamaximumoveralldimensionwhichisverysmallcomparedtothewavelength, thisfieldregionmaynotexist."Theinnerboundaryistakentobethedistance $R \geq 0.62\sqrt{D^3/\lambda}$ andtheouterboundarythedistance $R < 2D^2/\lambda$ whereDisthelargest*dimensionoftheantenna. This criterion is based ona maximum phase error of π/8. In this region the field pattern is, in general, a function of the radial distance and the radial field component may be appreciable.

∗Tobevalid,D mustalso be largecompared tothewavelength(D>λ)

Far-field(Fraunhofer)region

Far-field(Fraunhofer)regionisdefinedas"thatregionofthefieldofanantennawhere theangularfielddistributionisessentiallyindependentofthedistancefromtheantenna.Ifthe antennahasamaximum*overalldimensionD,thefar-fieldregioniscommonlytakentoexist at distances greater than $2D^2/\lambda$ from the antenna, λ being the wavelength.

The far-field patterns of certain antennas, such as multibeam reflector antennas, are sensitive to variations in phase over their apertures. For these antennas $2D^2/\lambda$ may be inadequate. In physical media, if the antenna has a maximum overall dimension, D, which is large compared to $\pi/|\gamma|$, the far-field region can be taken to begin approximately at a distance equal to $|\gamma|D^2/\pi$ from the antenna, γ being the propagation constant in the medium.

For an antenna focused at infinity, the far-field region is sometimes referred to as the Fraunhofer region on the basis of analogy to optical terminology." In this region, the field componentsareessentiallytransverse andtheangulardistributionisindependentoftheradial distance where the measurements are made. The inner boundary is taken to be the radial distance $R = 2D^2/\lambda$ and the outer one at infinity.

Theamplitudepatternofanantennain differentregions

The amplitude pattern of an antenna, as the observation distance is varied from the reactive near field to the far field, changes in shape because of variation of the fields, both magnitude and phase.

Atypicalprogressionoftheshapeofanantenna,withthelargestdimensionD,isshown inFigure.Itisapparentthatinthereactivenearfieldregionthepatternismorespreadoutand nearly uniform, with slight variations. As the observation is moved to the radiating near-field region(Fresnel), the pattern begins to smooth and form lobes. In the far-field region (Fraunhofer), the pattern is well formed, usually consisting of few minor lobes and one, or more, major lobes.

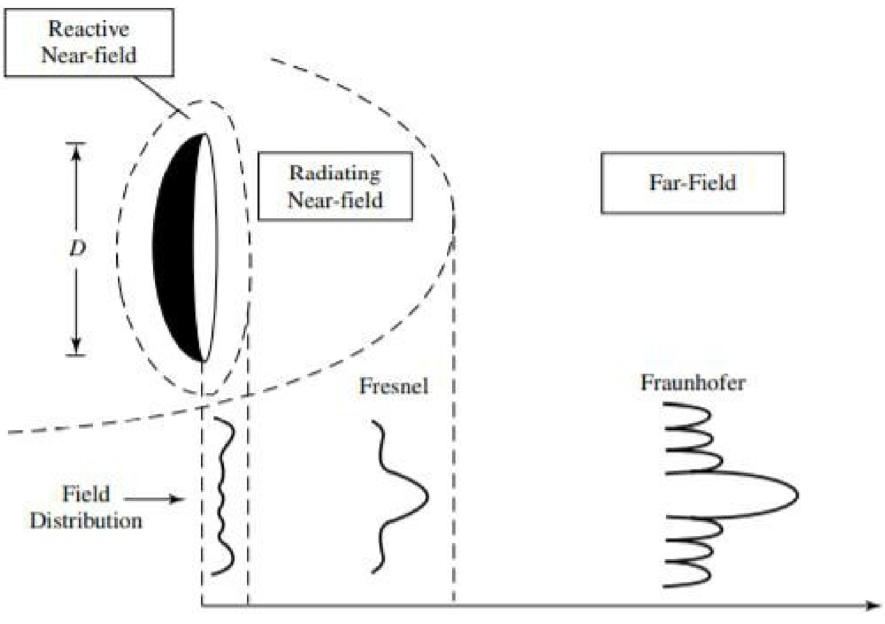


Figure:Typicalchangesofantennaamplitudepatternshapefromreactivenearfield toward the far field

3.Explain and detail about following antenna parameters.

AntennaParameters

(a) Radiation pattern.

The radiation pattern of an antenna is a plot of the magnitude of the far-zone field strength versus position around the antenna, at a fixed distance from the antenna.

Thus the radiation pattern can be plotted from the pattern function $F_\theta(\theta,\varphi)$ or $F_\varphi(\theta,\varphi)$, versuseithertheangleθ(foranelevationplanepattern)ortheangleφ(foranazimuthalplane pattern).The choiceof plottingeither$F_\theta$or$F_\varphi$isdependent onthepolarizationof theantenna.

(b) main lobe, side lobe, minor lobe and back lobe with reference to antenna radiationpattern.

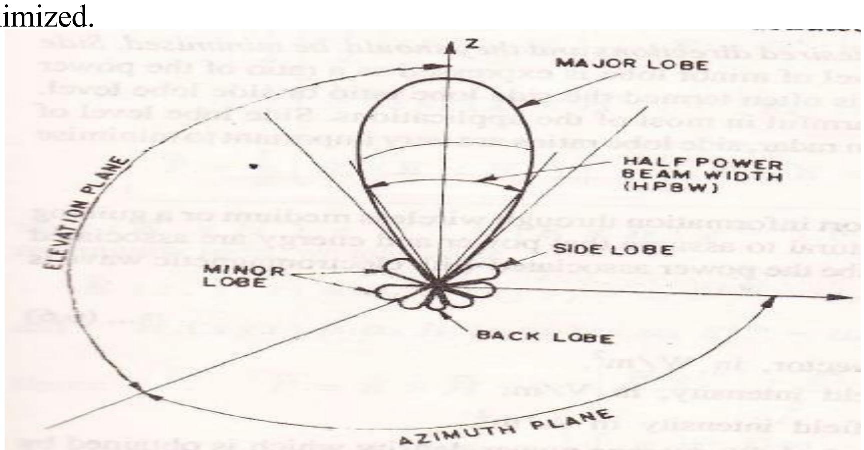
Major Lobe:Major lobe is also called as main beam and is defined as "the radiation lobe containingthedirectionofmaximumradiation".Insomeantennas,theremaybemorethan one major lobe.

Minorlobe: Allthelobesexcept themajorlobes arecalled minor lobe.

Sidelobe: Asidelobe isadjacent tothe main lobe.

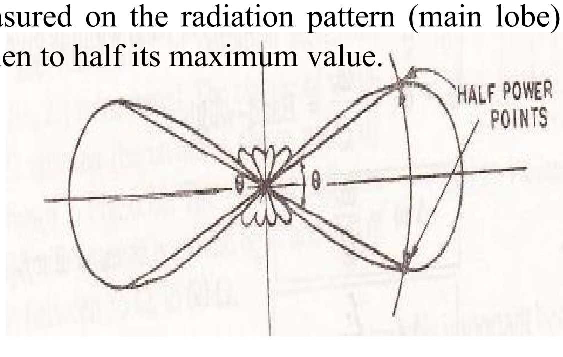
Backlobe:Normallyreferstoaminorlobethatoccupiesthehemisphereinadirection opposite to that of the major(main) lobe .

- Minorlobesnormallyrepresentsradiationinundesireddirectionsandtheyshouldbe minimized.



(c) Half PowerBeamWidth (HPBW) ofanantenna.

Half Power Beam Width is a measure of directivity of an antenna. It is an angular width in degrees, measured on the radiation pattern (main lobe) between points where the radiated power has fallen to half its maximum value.



(d) beam solidangle

Thebeamareaorbeamsolidangle Ω_A forantennaisgivenbyintegralofthe normalizedpowerpatternoverasphere.

$$\Omega_A = \int_0^{2\pi}\int_0^{\pi} P_n(\theta,\phi)\, d\Omega \quad steradian$$

$P_n(\theta,\phi) = Normalized\ power\ pattern$

Beamsolidangleisalsogivenapproximately by

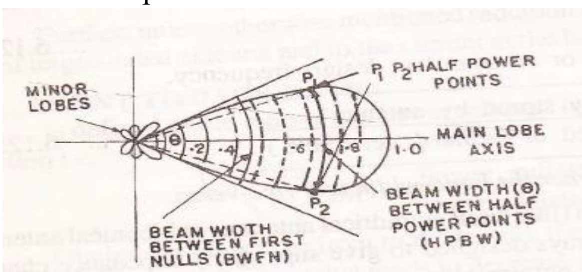
$\Omega_A = \theta_{HP}\phi_{HP}$ *steradian*

$\theta_{HP} = HPBW in\ E plane or\ \theta$ *plane*

$\phi_{HP} = HPBW in\ H plane or\ \phi$ *plane*

(e) Beam WidthbetweenFirst Null

Beamwidthbetweenfirstnull(BWFN)istheangularwidthindegrees,measuredon the radiation pattern between first null points on either side of the main lobe.



(f) Radiation Intensity

RadiationIntensity$U(\theta,\emptyset)$ingiven direction is defined asthe power perunitsolid angle in that direction.

- Thepower radiated perunitareainanydirection isgivenby pointingvector P.
- FordistantfieldforwhichEandHareorthogonalinaplanenormaltotheradius vector,

Thepowerflowper unit areais given by $P = \frac{E^2}{\eta_v}$ *watts/sqm*

- Therearer^2 squaremetersof surfaceareaperunit solid angle(or steradian).
- $U(\theta,\emptyset) = r^2 P = \frac{r^2 E^2}{\eta_v}$ $watts/unitsolidangle$

The radiation intensity gives the variation in radiated power versus position around the antenna.WecanfindthetotalpowerradiatedbytheantennabyintegratingthePoyntingvector over the surface of a sphere that encloses the antenna. This is equivalent to integrating the radiation intensity over a unit sphere.

$$P_{rad} = Powerradiated = \int_{\emptyset=0}^{2\pi}\int_{\theta=0}^{\pi} U(\theta,\emptyset)\, sin\theta d\theta d\emptyset$$

(g) Directivity ofan antenna

Thedirectivity(D)of an antenna is defined as the ratio of the maximum value of the power radiated per unit solid angle to the average power radiated per unit solid angle. Thatis,directivityisratioofthemaximumradiationintensityinthemainbeamtotheaverage radiation intensity over all space.

$$D=\frac{U_{max}}{U_{avg}}=\frac{U_{max}}{P_{rad}/4\pi}=\frac{4\pi U_{max}}{\int_{\emptyset=0}^{2\pi}\int_{\theta=0}^{\pi}U(\theta,\emptyset)\,sin\theta d\theta d\emptyset}$$

Thus,thedirectivitymeasureshowintenselytheantennaradiatesinitspreferreddirectionthan an isotropic radiator would when fed with the same total power.
Directivity is a dimensionless ratio of power, and is usually expressed in dB as D(dB) = 10log(D)

directivityofisotropic radiator:

An isotropic radiator is a hypothetical loss less radiator having equal radiation in all directions.

U(θ,φ)=1forisotropicantenna.Applyingtheintegralidentity, $\int_{\emptyset=0}^{2\pi}\int_{\theta=0}^{\pi}sin\theta d\theta d\emptyset=4\pi$, wehave,

$$D=\frac{4\pi U_{max}}{\int_{\emptyset=0}^{2\pi}\int_{\theta=0}^{\pi}U(\theta,\emptyset)\,sin\theta d\theta d\emptyset}=1$$

Thedirectivity of anisotropic antennaisD =1,or0 dB.

RelationshipbetweenDirectivityandbeamwidth

Beamwidthanddirectivityarebothmeasuresofthefocusingabilityofanantenna:anantenna patternwithanarrowmainbeamwillhaveahighdirectivity,whileapatternwithawidebeam will have a lower directivity.

Approximate relation between beam width and directivity that apply with reasonable accuracyfor antennas with pencil beam patterns is the following:

$D\cong\frac{32,000}{\theta_1\theta_2}$ where θ_1 and θ_2 arethebeamwidthsintwoorthogonalplanesofthemain beam,indegrees.Thisapproximationdoesnotworkwellforomnidirectionalpatternsbecause there is a well-defined main beam in only one plane for such patterns.

(h) radiationefficiency ofantenna

Radiation efficiency of an antenna is definedas the ratio of the radiated output power to the supplied input power.

$$\eta_{rad}=\frac{P_{rad}}{P_{in}}=\frac{P_{in}-P_{loss}}{P_{in}}=1-\frac{P_{loss}}{P_{in}}$$

where P_{rad} is the power radiated by the antenna, P_{in} is the power supplied to the input of the antenna,and P_{loss} isthepowerlostintheantenna(dissipativelosses)duetometalconductivity or dielectric loss with in the antenna.

(i) Gain of an antenna

Thegainoftheantennaiscloselyrelatedtothedirectivity,itisameasurethattakesinto account the efficiency of the antenna as well as its directional capabilities.

Antennagainis definedas theproductof directivityand efficiency:

$Gain=G=\eta_{rad}\times D.$

Thus,gainis alwayslessthanorequalto directivity.

(j) Aperture efficiency

Apertureefficiencyisdefinedastheratiooftheactualdirectivityofanapertureantennatothe maximum directivityof aperture antenna.

The maximumdirectivitythatcanbeobtainedfromanelectricallylargeapertureofareaAis given as, $D_{max} = \frac{4\pi A}{\lambda^2}$

$\eta_{ap} = apertureefficieny = \frac{D}{D_{max}}$

(k) Effectiveaperturearea

Receivedpowerisproportionaltothepowerdensity,orPoyntingvector,oftheincidentwave. SincethePoyntingvectorhasdimensionsofW/m2,andthereceivedpower,P_r,hasdimensions of W, the proportionality constant must have units of area.

Wehave,$P_r = A_e \times S_{avg}$

where$A_e$isdefinedastheeffectiveapertureareaofthereceiveantenna.Theeffectiveaperture area has dimensions of m^2, and can be interpreted as the "capture area" of a receive antenna, intercepting part of the incident power density radiated toward the receive antenna.

relationbetweeneffectiveapertureareaandDirectivity(gain)

The maximum effective aperture area of an antenna is related to the directivity of the antenna as,

$$A_e = \frac{D\lambda^2}{4\pi}$$

Themaximumeffective apertureareaasdefinedabovedoesnotincludetheeffectoflossesin the antenna, which can be accounted for by replacing D with G, the gain, of the antenna.

$$A_e = \frac{G\lambda^2}{4\pi}$$

(l) AntennaBrightnesstemperature

Whentheantennabeamwidthisbroadenoughthatdifferentpartsoftheantennapatternsee differentbackgroundtemperatures,theeffectivebrightnesstemperatureseenbytheantenna can be found by weighting the spatial distributionof background temperatureby the pattern function of the antenna.

Mathematicallywecan writethebrightnesstemperature$T_b$seenbytheantennaas

$$T_b = \frac{\int_{\emptyset=0}^{2\pi}\int_{\theta=0}^{\pi} T_B(\theta,\emptyset)D(\theta,\emptyset)sin\theta d\theta d\emptyset}{\int_{\emptyset=0}^{2\pi}\int_{\theta=0}^{\pi} D(\theta,\emptyset)sin\theta d\theta d\emptyset}$$

Where $T_B(\theta,\emptyset)$is the distribution of the background temperature, and $D(\theta,\emptyset)$ is the directivity (or the power pattern function) of the antenna. Antenna brightness temperature is referenced at the terminals of the antenna. Observe that when $T_B$is a constant,$T_b = T_B$

(m) AntennaNoise Temperature

Ifareceivingantennahasdissipativeloss,sothatitsradiationefficiencyη_{rad}islessthan unity,thepoweravailableattheterminalsoftheantennaisreducedbythefactorη_{rad}fromthat intercepted by the antenna (the definition of radiation efficiency is the ratio of output to input power).

Thisreductionappliestoreceivednoisepower,aswellasreceivedsignalpower,sothe noisetemperatureoftheantennawillbereducedfromthebrightnesstemperaturebythefactor η_{rad}.

Inaddition,thermalnoisewillbegeneratedinternallybyresistivelossesintheantenna, and this will increase the noise temperature of the antenna. We can find the resulting noise temperature seen at the antenna terminals as,

$$T_A = \eta_{rad}T_b + (1 - \eta_{rad})T_p.$$

The equivalent temperature $T_A$is called the antenna noise temperature, and is a combination of the external brightness temperature seen by the antenna and the thermal noise generated by the antenna.

Note:Thistemperatureisreferencedattheoutputterminalsoftheantenna. T_A = $T_b$for a lossless antenna with η_{rad}= 1.

Iftheradiationefficiencyiszero,meaningthattheantennaappearsasamatchedloadanddoes notseeanyexternalbackgroundnoise,thenT_A=T_p,duetothethermalnoisegeneratedbythe losses.

(n)G/T ratio

Useful figure of merit for receive antennas is the G/T ratio, defined as 10 log(G/ T_A) dB/K,where G is the gain of the antenna, and T_A is the antenna noise temperature.

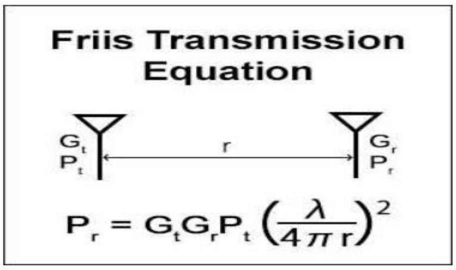
This quantity is important because, the signal-to-noise ratio (SNR) at the input to a receiverisproportionaltoG/T_A.TheratioG/Tcanoftenbemaximizedbyincreasingthegain of the antenna, since this increases the numerator and usually minimizes reception of noise from hot sources at low elevation angles. Of course, higher gain requires a larger and more expensive antenna, and high gain may not be desirable for applications requiring omnidirectional coverage (e.g., cellular telephones or mobile data networks), so often a compromise must be made.

Note: that the dimensions givenfor 10 log(G/T) are not actually decibels per degree kelvin, but this is the nomenclature that is commonly used for this quantity

4(a)DeriveFRIIStransmissionformulaandexplainitssignificance.(Apr/May'18)

FriisTransmissionFormula

Thisformulagivesthepowerreceived over aradiocommunication link.



Let the transmitter feed a power $P_t$to a transmitting antenna of effective aperture A_{et}.At a distance r areceiving antenna of effective aperture A_{er}, intercepts some of the power radiated by the transmitting antenna and delivers it to the receiver.

Assuming that the transmitting antenna is isotropic, the power per unit area at the receiving antenna is

$$S_r = \frac{P_t}{4\pi r^2} \quad \text{(W)--------1}$$

IfthetransmittingantennahasgainG$_t$,thepowerperunitareaatthereceivingantennawillbe increased in proportion as given by,

$$S_r = \frac{P_t G_t}{4\pi r^2} \quad \text{(w)------------2}$$

Now,the powercollected bythe receivingantennaofeffective apertureA$_{er}$is,

$$P_r = A_{er} S_r = \frac{A_{er} P_t G_t}{4\pi r^2} \quad \text{(w)} \quad 3$$

Thegainof thetransmittingantennacanbe expressed as,

$$G_t = \frac{4\pi A_{et}}{\lambda^2}$$ -----4a

$$G_r = \frac{4\pi A_{er}}{\lambda^2}$$ ------4b

Substitutingforgainin equation3,wehave,

$$P_r = \frac{A_{er} P_t A_{et} 4\pi}{4\pi r^2 \lambda^2} = \frac{A_{er} P_t A_{et}}{r^2 \lambda^2}$$ -------5a

Intermsofantennagain,receivedpowercanbe expressedas,

$$P_r = \frac{G_r P_t G_t \lambda^2}{4\pi \times 4\pi r^2} = \frac{G_r P_t G_t \lambda^2}{(4\pi r)^2}$$ --------5b

Equation5isFriistransmission formula

$$P_r = \frac{G_r P_t G_t \lambda^2}{(4\pi r)2}$$

(b)Explain in detail about Link budget and LinkMargin..

LinkBudget andLink Margin

The various terms in the Friis formula are often tabulated separately in a link budget, where each of the factors can be individually considered in terms of its net effect on the received power.

Additionallossfactors,suchaslinelossesorimpedancemismatchattheantennas,atmospheric attenuation, and polarization mismatch can also be added to the link budget.

One of the terms in a link budget is the path loss, accounting for the free-space reduction in signal strength with distance between the transmitter and receiver.

Pathloss=Transmittedpower-Receivedpower=P_t-P_r

Assumingunitygain antennas,path lossis givenas(usingFriis formula)

$$pathloss(dB)=20log(\frac{4\pi r}{\lambda})$$

Wecan writethebudgetasshown inthefollowing link budget:

Transmit power	P_t
Transmitantennalineloss	$(-)L_t$
Transmitantennagain	G_t
Pathloss(free-space)	$(-)L_0$
Atmosphericattenuation	$(-)L_A$
Receiveantennagain	G_r
Receiveantennalineloss	$(-)L_r$
Receivepower	P_r

We have also included loss terms for atmospheric attenuation and line attenuation. Assuming that all of the above quantities are expressed in dB (or dBm, in the case of P_t), we can write the receive power as

$$P_r(dBm)=P_t-L_t+G_t-L_0-L_A+G_r-L_r$$

If the transmit and/or receive antenna is not impedance matched to the transmitter/ receiver(ortotheirconnectinglines),impedancemismatchwillreducethereceivedpowerby the factor $(1 - |\Gamma|2)$ where Γis the appropriate reflection coefficient.

Theresultingimpedance mismatchloss,

$$L_{imp}(dB)=-10log(1-|\Gamma|2)\geq 0,$$

canbeincluded inthelinkbudget toaccountfor thereduction inreceivedpower.

Another possible entry in the link budget relates to the polarization matching of the transmit and receive antennas, as maximum power transmission between transmitter and receiver requires both antennas to be polarized in the same manner.

Ifatransmitantennaisverticallypolarized,forexample,maximumpowerwillonlybe deliveredtoaverticallypolarizedreceivingantenna,whilezeropowerwouldbedeliveredtoa horizontally polarized receive antenna, and half the available power would be delivered to a circularly polarized antenna.

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Link Margin

In practical communications systems it is usually desired to have the received power level greater than the threshold level required for the minimum acceptable quality of service (usually expressed as the minimum carrier-to-noise ratio (CNR), or minimum SNR).

This design allowance for received power is referred to as the link margin, and can be expressed as the difference between the design value of received power and the minimum threshold value of receive power:

Linkmargin (dB) =LM=$P_r - P_r$(min)>0,whereall quantities arein dB.

Link margin should be a positive number; typical values may range from 3 to 20 dB.Havingareasonablelinkmarginprovidesalevelofrobustnesstothesystemtoaccountfor variables such as signal fading due to weather, movement of a mobile user, multipath propagation problems, and other unpredictable effects that can degrade system performance.

Link margin for a given communication system can be improved by increasing the received power (byincreasing transmit power or antennagains), orby reducing theminimum thresholdpower(byimprovingthedesignofthereceiver,changingthemodulationmethod,or by other means)

Fademargin.

Signalfadingoccurduetoweather,movementofamobileuser,multipathpropagation problems,andotherunpredictableeffectsthatcandegradesystemperformanceandqualityof service.Linkmarginthatisusedtoaccountforfadingeffectsissometimesreferredtoasfade margin.

5.Explain in detail about Noise characterization of a microwave receiver.

NoiseCharacterizationofaMicrowaveReceiver

(i) NOISEFIGUREandEQUIVALENTNOISETEMPERATUREofaSYSTEM

(Generalconcepts)

The signal-to-noise ratio is the ratio of desired signal power to undesired noise power, and so is dependent on the signal power.

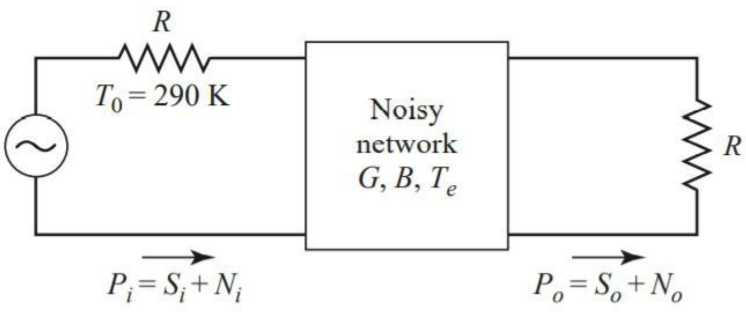
Whennoiseandadesiredsignalareappliedtotheinputofanoiselessnetwork,bothnoiseand signal will be attenuated or amplified by the same factor, so that the signal-to-noise ratio will be unchanged.

However,ifthenetworkisnoisy,theoutputnoisepowerwillbeincreasedmorethantheoutput signal power, so that the output signal-to-noise ratio will be reduced.

Thenoisefigure,F,isa measureof thisreductioninsignal-to-noiseratio,andisdefined as,

$$F=\frac{S_i/N_i}{S_o/N_o} \geq 1 \text{--------------------------(1)}$$

where S_i, N_i are the input signal and noise powers, and S_o, $N_o$are the output signal and noise powers. By definition, the input noise power is assumed to be the noise power resulting from a matched resistor at T_0= 290 K; that is, N_i= kT_0B.



Determining the noise figure of a noisy network.

ConsiderFigureshownabove,whichshowsnoisepowerN$_i$andsignalpowerS$_i$beingfedinto a noisy two-port network.

Thenetworkischaracterizedbyagain,G,abandwidth,B,andanequivalentnoisetemperature, T_e.

TheinputnoisepowerisN$_i$=kT$_0$B,andtheoutputnoisepowerisasumoftheamplifiedinput noise and the internally generated noise: $N_o = kGB(T_0 + T_e)$.

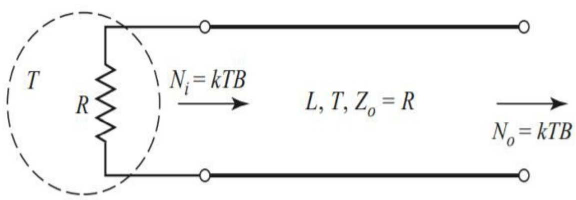
Theoutput signal poweris$S_o = GS_i$. Usingtheseresults in (1)gives thenoise figureas,

$$F = \frac{S_i}{kT_oB} \frac{kGB(T_o+T_e)}{GS_i} = 1 + \frac{T_e}{T_o} \geq 1 \text{--------------(2)}$$

$$T_e = (F-1)T_o \text{------------------------(3)}$$

Itisimportanttokeepinmindtwothingsconcerningthedefinitionofnoisefigure:noisefigure is defined for a matched input source, and for a noise source equivalent to a matched load at temperature $T_0 = 290$ K. Noise figure and equivalent noise temperatures are interchangeable characterizations of the noise properties of a component.

An important special case occurs in practice for a two-port network consisting of a passive, lossy component, such as an attenuator or lossy transmission line, held at a physical temperature T . Consider such a network with a matched source resistor that is also at temperature T , as shown in Figure



Determining the noise figure of a lossy line or attenuator with loss L and temperature T.

Thepowergain,G,ofalossynetworkislessthanunity;thelossfactor,L,canbedefinedasL =1/G >1. Becausetheentiresystem is in thermal equilibrium at thetemperatureT,and has a driving point impedance of R, the output noise power must be $N_o = kTB$. However, we can also think of this power as coming from the source resistor (attenuated by the lossy line), and from the noise generated by the line itself. Thus we also have that

N_o=kTB =GkTB + GN_{added}--------------------(4)

Where$N_{added}$is the noise generated by the line, as if it appeared at the input terminals of the line. Solving (4) for this power gives

$N_{added} = \frac{(1-G)}{G} kTB = (L-1)kTB$-----------------(5)

Then (5) shows that the lossy line has an equivalent noise temperature (referred to the input) given by,

$T_e = (L-1)T$-----------------(6)

Noisefigureis,

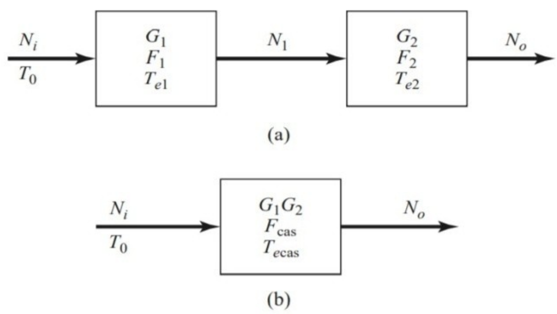
$F = 1 + \frac{(L-1)T}{T_o} \geq 1$----------(7)

<u>NoiseFigureofaCascaded System</u>

In a typical microwave system the input signal travels through a cascade of many different components, each of which maydegradethesignal-to-noiseratio to somedegree. If weknow the noise figure (or noise temperature) of the individual stages, we can determine the noise figure (or noise temperature) of the cascade connection of stages.

We will see that the noise performance of the first stage is usually the most critical, an interesting result that is very important in practice.

Consider the cascade of two components, having gains G_1, G_2, noise figures F_1, F_2, and equivalent noise temperatures T_{e1}, T_{e2}, as shown in Figure.



Noise figure and equivalent noise temperature of a cascaded system. (a) Two cascaded networks. (b) Equivalent network.

Wewishtofindtheoverallnoisefigureandequivalentnoisetemperatureofthecascade,asif it were a single component. The overall gain of the cascade is G_1G_2.

Usingnoisetemperatures,wecanwritethenoisepoweratthe outputofthefirststageas N_1=

$G_1kT_0B + G_1kT_{e1}B$-------------------------(8)

sinceN_i=kT_0Bfornoisefigurecalculations.Thenoisepoweratthe outputofthesecondstage is

N_o=G_2N_1+$G_2kT_{e2}B$

$N_o = G_1 G_2 k T_o B + G_1 G_2 k T_{e1} B + G_2 k T_{e2} B$

$N_o = G_1 G_2 kB(T_o + T_{e1} + \frac{T_{e2}}{G_1})$-----------(9)

Fortheequivalent system wehave,

$N_o = G_1 G_2 kB(T_o + T_{cas})$----------(10)

Where,

$T_{cas} = T_{e1} + \frac{T_{e2}}{G_1}$ ---------(11)

Using(3)toconvertthetemperaturesin(11)tonoisefiguresyieldsthenoisefigureofthe cascade system as,

$F_{cas} = F_1 + \frac{(F_2 - 1)}{G_1}$ --------(12)

Equations(11)and(12)showthatthenoisecharacteristicsofacascadedsystemaredominated by the characteristics of the first stage since the effect of the second stage is reduced by the gain of the first (assuming G1 > 1).

Thus, for the best overall system noise performance, the first stage should have a low noise figure and at least moderate gain. Expense and effort should be devoted primarily to the first stage, as opposed to later stages, since later stages have a diminished impact on the overall noise performance.

Equations(11)and(12) can begeneralized toan arbitrary numberof stages, as

(ii) **NoiseCharacterizationof Receiver**

We can now analyze the noise characteristics of a complete antenna–transmission line–receiverfrontend,asshowninFigure.Inthissystemthetotalnoisepowerattheoutputofthe receiver, N_o, will be due to contributions from the antennapattern, the loss in the antenna, the loss in the transmission line, and the receiver components.

This noisepowerwill determinethe minimum detectable signal level for thereceiver and, for a given transmitter power, the maximum range of the communication link.

ThetransmissionlineconnectingtheantennatothereceiverhasalossL_T,andisataphysical temperature T_p.

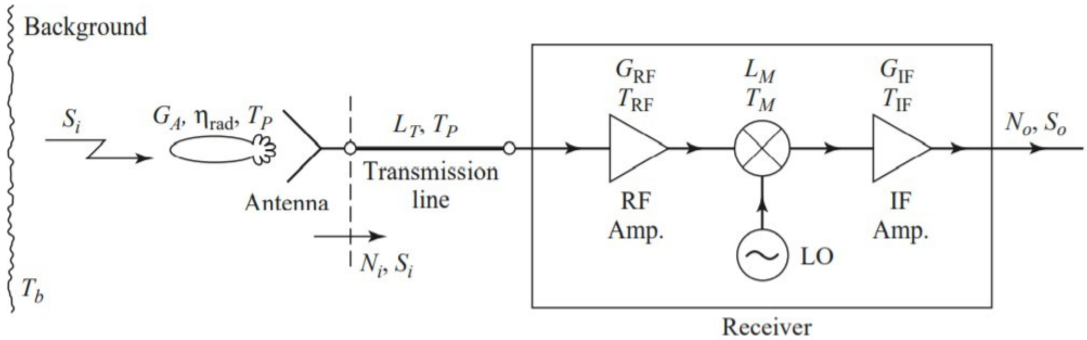


FIGURE 14.14 Noise analysis of a microwave receiver front end, including antenna and transmission line contributions.

ThereceivercomponentsinFigureconsistofanRFamplifierwithgainG_{RF}andnoise temperatureT_{RF},amixerwithanF
,andanIFamplifierwithgainG_{IF}andnoisetemperatureT_{IF}.
Thenoiseeffectsoflaterstagescanusuallybeignoredsincetheoverallnoisefigureis dominated by the characteris
Thecomponentnoisetemperaturescanberelatedtonoisefiguresas$T=(F-1)T_0$. The equivalent noise temperatur

$$T_{REC} = T_{RF} + \frac{T_M}{G_{RF}} + \frac{T_{IF} L_M}{G_{RF}} \quad \text{-(1)}$$

So, its equivalent noise temperature is

$$T_{TL}=(L_T-1)T_p \text{-----------------------(2)}$$

Wecanfindthatthenoisetemperatureofthetransmissionline(TL)andreceiver(REC) cascade is

$$T_{TL+REC}=T_{TL} + L_T T_{REC}=(L_T-1)T_p+L_T T_{REC} \text{----(3)}$$

This noise temperature is defined at the antenna terminals (the input to the transmission line). The entire antenna pattern can collect noise power. If the antenna has a reasonably high gain withrelativelylowsidelobes,wecanassumethatallnoisepowercomesviathemainbeam,so that the noise temperature of the antenna is given by,

$$T_A=\eta_{rad}T_b + (1-\eta_{rad})T_p \text{---------------------(4)}$$

where $\eta_{rad}$is the efficiency of the antenna, $T_p$is its physical temperature, and $T_b$is the equivalent brightness temperature of the background seen by the main beam.

The noise power at the antenna terminals, which is also the noise power delivered to the transmission line, is

$N_i = kBT_A = kB[\eta_{rad} T_b + (1-\eta_{rad}) T_p]$--------------------(5)

whereBisthesystembandwidth.If$S_i$isthereceivedpowerattheantennaterminals,thenthe input SNR at the antenna terminals is S_i/N_i.

Theoutput signalpoweris,

$$S_o = \frac{S_i G_{RF} G_{IF}}{L_T L_M} = S_i G_{SYS} \quad \text{------(6)}$$

whereG_{SYS}hasbeendefinedasasystempowergain. The

output noise power is,

$N_o = (N_i + kBT_{TL+REC}) G_{SYS}$

$N_o = (kBT_A + kBT_{TL+REC}) G_{SYS}$

$No = kB(TA + TTL + REC) GSYS = kBTSYSGSYS$---(7)

whereT_{SYS}hasbeendefinedastheoverallsystemnoisetem