

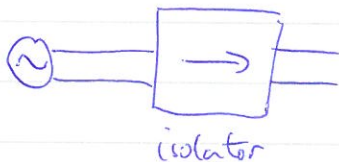
After we use circular waveguide with TE_{01} mode, because give very high Q-factor (and so very specific for frequency)

$$Q = \frac{\text{energy stored}}{\text{energy lost}}$$

$\therefore$ low wall skin losses good.

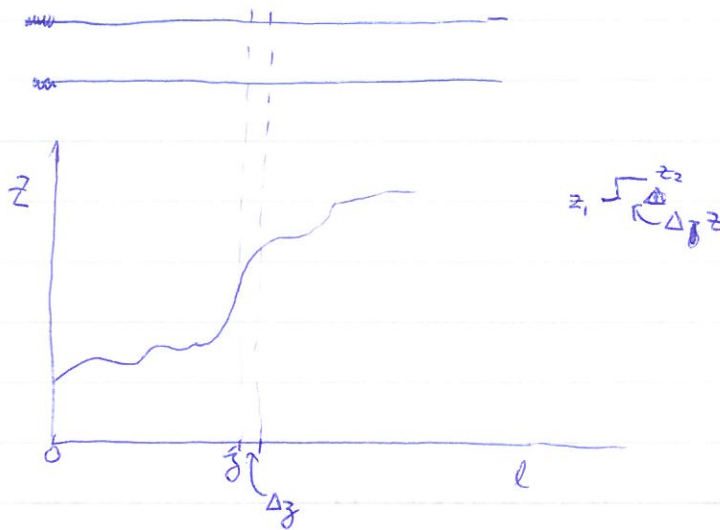
Faraday isolator

Get 45° rotation through in first direction. On return through the isolator by reflection ^{get another 45° ro,} when the wave reaches the rectangular waveguide its electric field is polarised along the larger dimension, so it is cut off. Hence isolation & reflection elimination. May give 30-50 dB of isolation.



Also the properties of an isolator a pure reactance to the return wave.

Non-Uniform Transmission Line



Reflection coefficient at some z is

$$\frac{z_2 - z_1}{z_2 + z_1} \rightarrow \frac{\Delta z}{2z} \quad \text{as } \Delta z \rightarrow 0$$

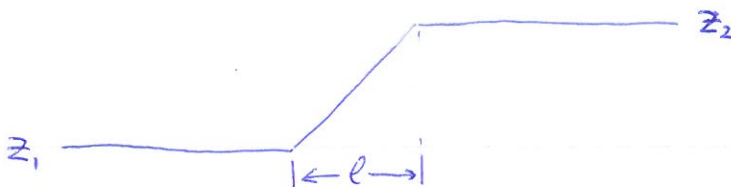
and $z = z(z)$

The reflection coefficient at $z=0$

(assuming $\beta = \text{const}$)

$$\begin{aligned} \rho &= \int_0^l \frac{1}{2z} \frac{dz}{dz} dz e^{-j2\beta z} \\ &= \int_0^l \frac{1}{2z} \frac{dz}{dz} e^{-j2\beta z} dz \end{aligned}$$

Example



$$\text{so } \frac{dz}{dz} = \frac{z_2 - z_1}{l}$$

and $\bar{z} \cong \frac{z_1 + z_2}{2}$ ray, and take $\beta = \text{const.}$

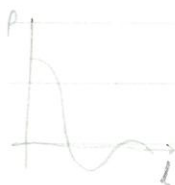
$$\begin{aligned} \text{then } f &\cong \frac{1}{z_1 + z_2} \int_0^l \frac{z_2 - z_1}{l} e^{-z\beta} dz \\ &= \frac{z_2 - z_1}{z_1 + z_2} \cdot \frac{1}{l} \int_0^l e^{-z\beta} dz \end{aligned}$$

finish this
(rem: $\beta = \frac{2\pi}{\lambda}$)

if $l \ll \lambda$,

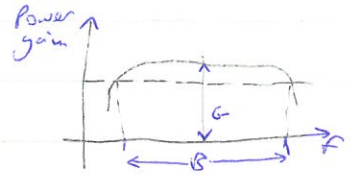
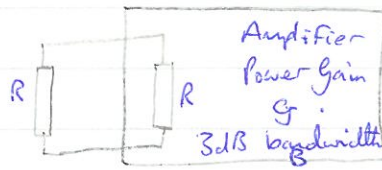
$$f \approx \frac{z_2 - z_1}{z_1 + z_2}$$

if $l \approx \lambda$,
get cancellation.



Noise in Systems

Noise arises from the random movement of electrons - depends on temperature



Max noise power delivered by a resistor R at temperature T (K)

ie when matched, is

$$P = KTB$$

where K is Boltzmann's const $= 1.38 \times 10^{-23} \text{ J/K}$

B = bandwidth

T = temperature (room = 290K)

Defⁿ:

Noise figure $F = \frac{\text{Signal to noise power ratio at input}}{\text{" " " " " " output}}$

$$= \frac{S_{in} / N_{in}}{S_{out} / N_{out}}$$

see diag above,
 G = power gain

$$= \frac{N_{out}}{G N_{in}}$$

But $N_{out} = G N_{in} + \Delta N$ $\rightarrow$ noise added by amplifier

$$N_{in} = KTB$$

$$N_{out} = F KTB G$$

$$F = \frac{KTB G + \Delta N}{KTB G}$$

$= 1$ if $\Delta N = 0$
 > 1 otherwise

$$= 1 + \frac{\Delta N}{KTB G}$$

$$\therefore \Delta N = (F-1) kTBG$$

$$T \text{ usually } T_0 = 290K$$

$$\text{then } kT \approx 4 \times 10^{-21} \text{ W/Hz}$$

Defⁿ

Effective noise temperature T_e is that temperature at the input of the network which could produce the added noise ΔN at the output. Thus

$$\Delta N = kT_e BG$$

$$\therefore F = 1 + \frac{T_e}{T_0}$$

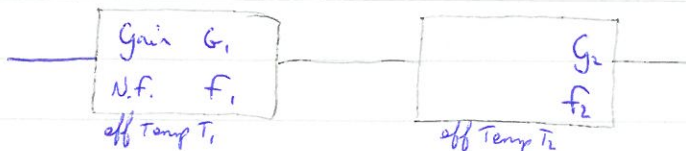
$T_0 = \text{standard room temp.}$

$$\Rightarrow T_e = (F-1)T_0$$

So for a noise figure of 3dB, $F=2$, $T_e=290K$

10dB, $F=10$, $T_e=2610K$

Networks in Cascade



Bandwidth B

Overall noise figure F_n :

in terms of F , output noise is $FkT_0BG_1G_2$

= noise from ① at output of ② + noise introduced by ②

$$= F_1 kT_0 B G_1 G_2 + (F_2 - 1) kT_0 B G_2$$

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

rest cancels.

If first stage is high gain, low noise, it nullifies the effect of the second device.

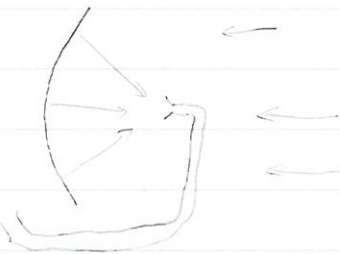
If cascade more devices

$$F = F_1 + \frac{(F_2 - 1)}{G_1} + \frac{(F_3 - 1)}{G_1 G_2} + \dots + \frac{(F_n - 1)}{G_1 G_2 \dots G_{n-1}}$$

Key

Hence the need for a high gain, low noise amplifier at the front end of a receiver chain. PREAMPLIFIER.

if have a
parabolic
antennae,
followed
by a feeder,



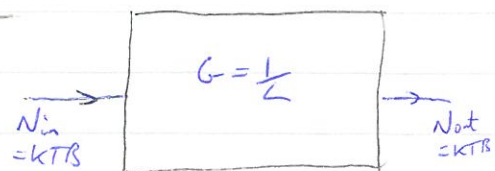
may actually have a loss (see later)

Using the effective noise temperature concept, overall

$$T = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + \frac{T_4}{G_1 G_2 G_3} + \dots + \frac{T_n}{G_1 \dots G_{n-1}}$$

Noise Figure of an Attenuator

$$F_{att} = \frac{N_{out}}{G N_{in}} = \frac{1}{1/2} = 2$$



alternatively,

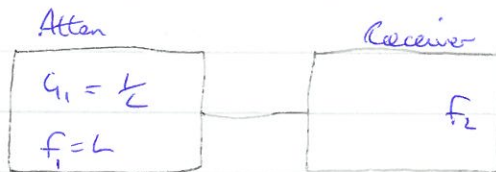
$$N_{out} = G N_{in} + \Delta N$$

$$= \frac{1}{L} N_{in} + \left(1 - \frac{1}{L}\right) N_{in}$$

$$= N_{in}$$

$$f = \frac{N_{out}}{G N_{in}} = \frac{1}{L} = L$$

absorbed power must go somewhere. if constrain temperature, must go in noise.



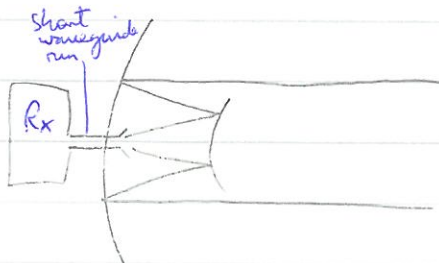
overall noise figure

$$F = F_1 + \frac{f_2 - 1}{G}$$

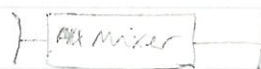
$$= L + L(f_2 - 1)$$

blends deleterious effects of a long waveguide connection from ~~ant~~ antenna to receiver.

As a result, may use a hyperboloid + paraboloid antenna system (called Cassegrain double reflector antenna)



May go into mixer



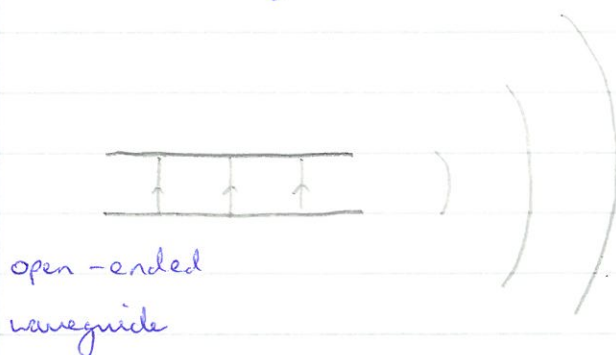
Radiators and Receptors of e/m Waves

Elementary radiator:



Direction of propagation is $\perp$ to wavefront, $E + H$ are at right angles to it. Thus locally has the properties of a plane wave.

Currents give rise to radiative fields.



guided fields (waves) give rise to radiated fields (waves).

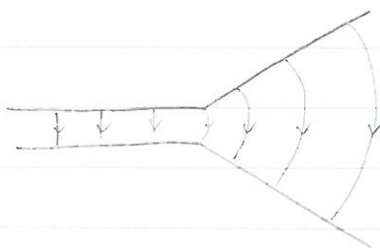
Not very good radiator, much better if can get a match. For dipole, make element $\frac{1}{2}\lambda$ long, for waveguide, shape end to give a good transition.

Improved matching gives more efficient radiation.



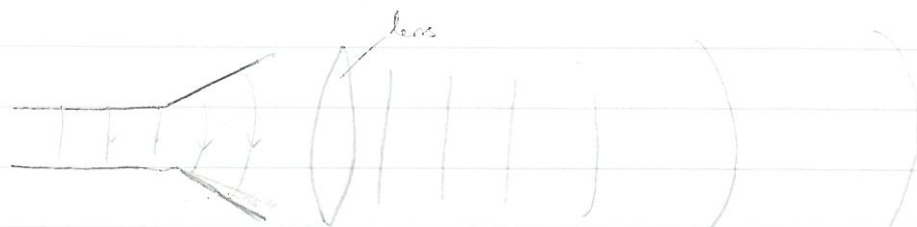
half-wave dipole. Resonance effect gives impedances of $73 + j0 \Omega$

electromagnetic
for microwave horns



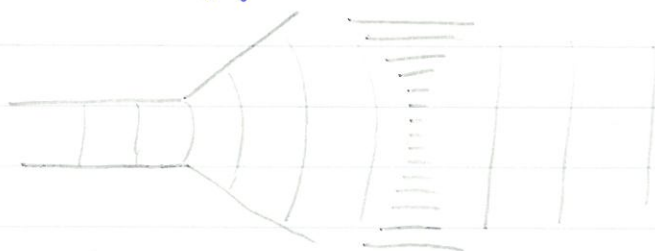
transition section improves
match.

horn - lens combination.



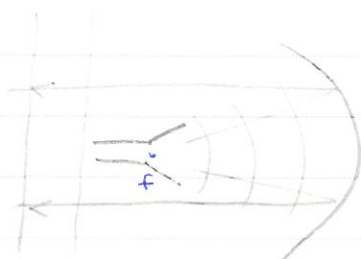
Gives a local plane wave & doesn't remain plane very long
(diffraction): tends to spread, and degenerates to a spherical wavefront
(Huygens' principle). Also is fragile.

Can use artificial ~~wave~~ dielectric lens - just a stack of
waveguides: phase vely higher in waveguide than air so actually
works (less fragile)



But both give reflection

Better still to use a parabolic reflector with horn-source
at focus



As receiver, with a plane wave incident



Current is induced in the dipole



Field is set up in waveguide and travels down to receiver.

Reciprocity: if no non-reciprocal element involved, the aerial transmits and receives in exactly the same way.

Reciprocity with transmission is expected and obtained.

Propagation in Free Space (Uniform, unbounded medium)

The radiated field: if P_T is the power delivered to a loss-free, isotropic* radiator, the power flux density S at distance r is:

* isotropic
= same in
all directions

$$S = \frac{P_T}{4\pi r^2} \quad (\text{W/m}^2)$$



Allow for non-isotropic character of the radiation,

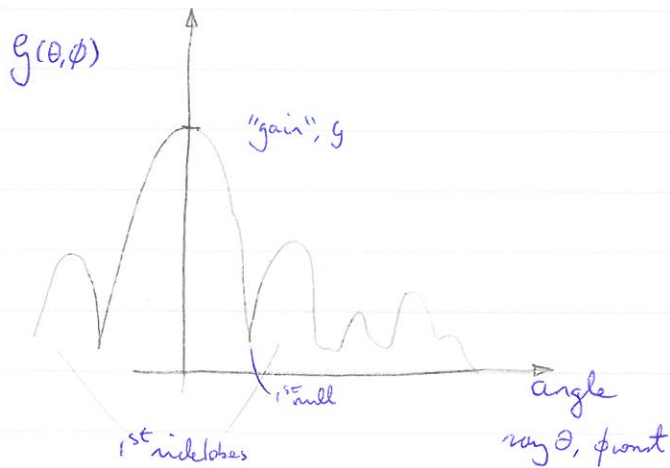
$$S = \frac{P_T G_T}{4\pi r^2}, \quad G_T \text{ is the gain in the direction } TR.$$

Definition the "gain function" of an antenna is the ratio

$$G(\theta, \phi) = \frac{\text{Power flux at distance } r \text{ in direction } (\theta, \phi)}{\text{Power flux at distance } r \text{ from isotropic antenna}}$$

Convention: The "gain" is the value of $G(\theta, \phi)$ in a particular direction of interest, or the maximum value of $G(\theta, \phi)$, usually expressed in dB's

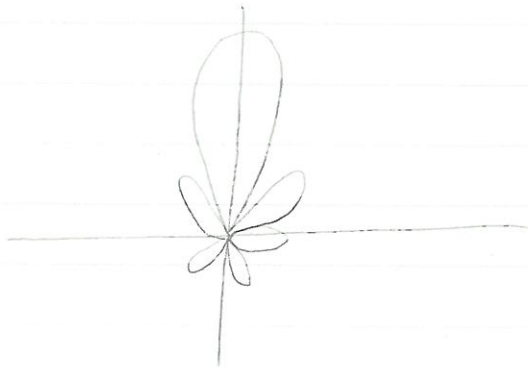
Gain Function : $G(\theta, \phi)$



Get an interference pattern, with secondary maxima known as "lobes".

Sidelobes and nulls occur.

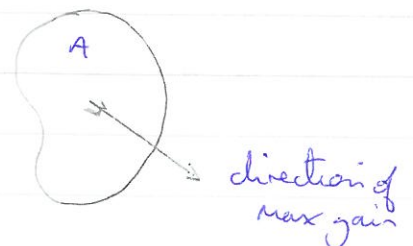
polar plot



Example : A Uniformly Illuminated Aperture
i.e. amplitude & phase constant

Can show that

$$G = \frac{4\pi A}{\lambda^2}, \quad \lambda = \text{wavelength}$$



This gain is the maximum obtainable from aperture of area A . This is a useful design upper bound.

Antenna as a Receiver

Defⁿ :



The "effective receiving area" of an antenna is :

$$A_{\text{eff}}(\theta, \phi) = \frac{\text{Power delivered to the receiving antenna}}{\text{Power density in plane wave from } (\theta, \phi)}$$

when the antenna is "polarisation matched" to the incoming plane wave.

It can be shown that, from the reciprocity theorem,

$$A_{\text{eff}}(\theta, \phi) = \frac{\lambda^2}{4\pi} G(\theta, \phi)$$

Note that in the ~~ex~~ example,

$$A_{\text{eff}}(\theta, \phi) = \frac{\lambda^2}{4\pi} \times G = A, \text{ the physical area.}$$

Aperture Efficiency, η

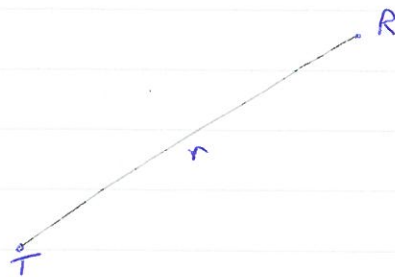
If $\max [A_{\text{eff}}(\theta, \phi)] = A_e$,
then η is defined as $A_e = \eta A$ ($\eta \leq 1$)

$$\text{Thus the gain (ie } \max [G(\theta, \phi)]) = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi \eta A}{\lambda^2}$$

$$\text{ie } G \leq \frac{4\pi A}{\lambda^2}$$

Direct Transmission Equation

If r is large, the wavefront at the receiver R is essentially plane,



hence

$$P_R = \frac{P_T G_T A_R}{4\pi r^2}$$

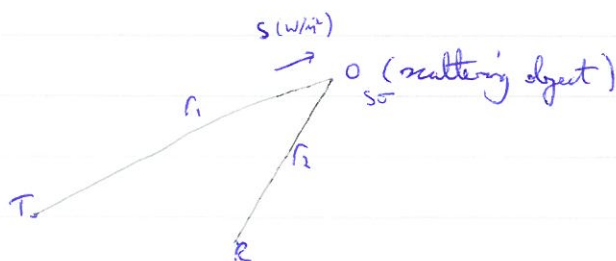
where A_R is the effective receiving area of R in direction RT and G_T = gain of transmitting antenna in direction TR

$$= \frac{P_T G_T G_R \lambda^2}{(4\pi r)^2}$$

G_R = gain of receiving antenna in direction RT .

The Radar Equation

Definition: the scattering cross-section σ of a target is the imaginary area which intercepts a power S_0 from the plane wave incident upon it and scatters the power isotropically such that the power flux incident on the receiver is that observed



$$P_R = \frac{P_T G_T}{4\pi r_1^2} \sigma \frac{1}{4\pi r_2^2} A_R$$

for this "bistatic" configuration.

In a "monostatic" (the usual) configuration, T and R are coincident and are the same antenna

$$P_R = \frac{P_T G_T \sigma A_R}{(4\pi)^2 r^2} \quad (r_t = r_r = r)$$

$$= \frac{P_T G_T G_R \sigma \lambda^2}{(4\pi)^2 r^4 \times 4\pi}$$

Note: r^{-4} dependence

: σ is a function of angles of incidence, observation and polarization.

Nature of the Radiated Field

At large distances, when $r > \frac{2a^2}{\lambda}$

the radiated field is basically a spherical wave

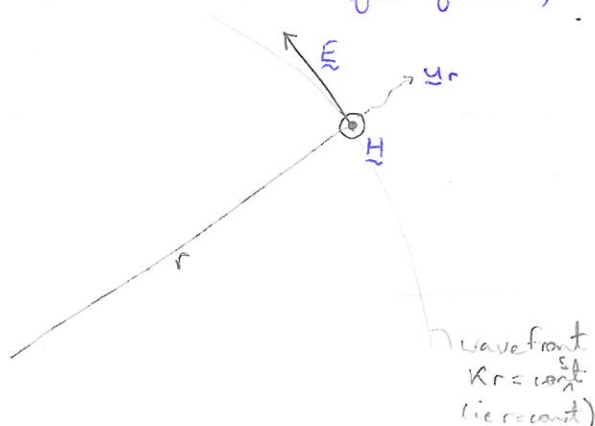
ie Rayleigh distance,
a is the largest
antenna aperture
dimension

$$\underline{E}(r, \theta, \phi) = \underline{e}(\theta, \phi) \underbrace{\exp(-jkr)}_{\text{spherical wave function}}$$

phasor vector
electric field vector
pattern
function

$$k = \omega \sqrt{\mu \epsilon}$$

This is the far field, or Fraunhofer field



The direction of electric field defines polarization.

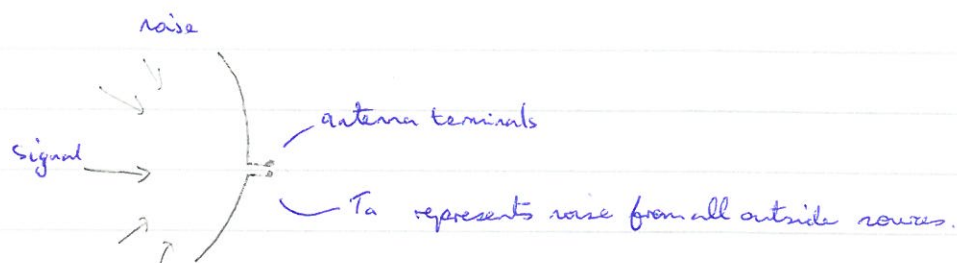
The far field is locally a plane wave, ie., $\underline{E}$, $\underline{H}$ and $\underline{u}_r$ form a right hand set, and

$$\frac{\underline{E}}{\underline{H}} = \underline{Z}$$

Attenuation in the Atmosphere

Due to absorption at resonances of constituent gas and water molecules.

Noise



Can represent noise as an antenna effective noise temperature.

Antenna Effective Noise Temperature

Sources of Noise

Cosmic noise - greatest from galactic centre < UHF

Absorption noise - from ground and atmospheric ~~also~~ absorption
UHF >

Atmospheric noise - due to lightning strikes < VHF

Man-made noise - eg. car ignition

Discrete radio sources - sun, radio stars

Linear and Circular Polarization

A linearly polarized plane wave, eg.

$$\underline{E} = \underline{u}_x E_0 \exp(-jkz)$$

$\swarrow$ direction of $\underline{E}$ $\swarrow$ peak amplitude $\swarrow$ z = direction of propagation

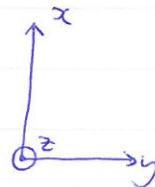
A circularly polarized plane wave eg.

$$\underline{E} = (\underline{u}_x - j\underline{u}_y) E_0 \exp(-jkz)$$

In plane $z=0$ therefore,

$$E_x = E_0 \text{ (assumed real)}$$

$$E_y = -jE_0$$

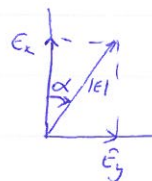


Explicit time dependence

$$E_x(t) = \text{Re}(E_0 e^{j\omega t})$$

$$= E_0 \cos \omega t$$

$$E_y(t) = E_0 \sin \omega t$$



Magnitude $|E| = E_0$
= constant

$$\text{Angle } \alpha = \tan^{-1} \frac{E_y}{E_x} = \omega t$$

hence E rotates at ω radians/sec.

$$\text{so } \underline{E}_{\text{RHC}} = (\underline{u}_x - j\underline{u}_y) E_0 e^{-jkz}$$

12

RHC
= right
hand
circular

$$\text{1 } \underline{E}_{\text{LHC}} = (\underline{u}_x + j\underline{u}_y) E_0 e^{-jkz}$$

11