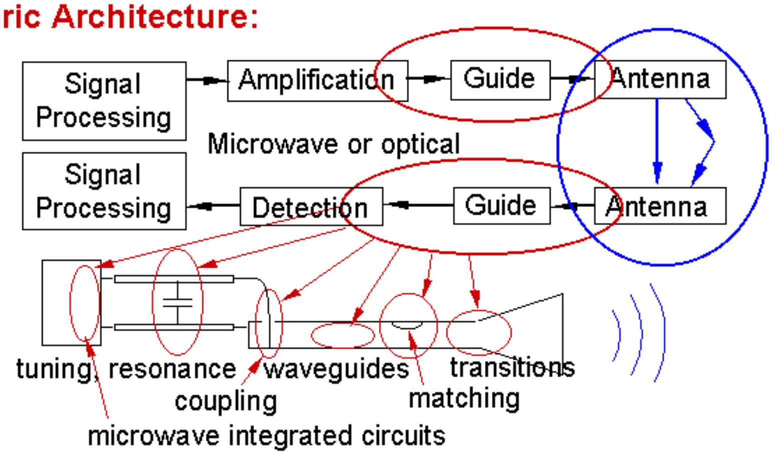
MICROWAVE COMMUNICATIONS AND RADAR

Generic Architecture:



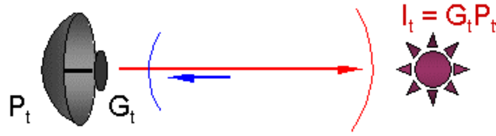
Signal Processing
Amplification
Guide
Antenna
Microwave or optical
Signal Processing
Detection
Guide
Antenna
tuning
resonance
waveguides
transitions
coupling
matching
microwave integrated circuits

Communications, bi-static radar—separately located systems
Radar, lidar, data recording—co-located systems
Passive sensing—uses receiver side only

Systems fail at the weakest link, therefore understand all parts

RADAR, LIDAR, AND PASSIVE SYSTEMS

Radar (Lidar) Equation:



$I_t = G_tP_t/4\pi r^2$ [W/m^2] (target intensity)

σ_s target cross-section [m^2]

$I_r = I_t\,\sigma_s/4\pi r^2$ [W/m^2] (received intensity)

$P_r = A_rI_r = [A_r][G_tP_t/4\pi r^2][\sigma_s/4\pi r^2]$ Watts, where $A_r = G_t\lambda^2/4\pi$

Therefore: $\boxed{P_r = P_t\sigma_s(G_t\lambda/4\pi r^2)^2/4\pi \ \text{Watts}}$ **Radar Equation**

Atmospheric absorption by oxygen and water vapor is important
mostly above 40 GHz, rain can dominate above ~3 GHz (neglected here)

Target Scattering Cross-Section σ_s:

Assumes isotropic scattering; referenced to the receiver
Therefore retro-reflectors can have σ_s >> physical cross-section

Radar Measures:

Range r, σ_s, and Doppler shift Δf (Hz)

RADAR, LIDAR, AND PASSIVE SYSTEMS

Radar Example: Radar Equation $P_r = P_t\sigma_s(G_t\lambda/4\pi r^2)^2/4\pi$ [W]

Killer asteroids > 300-m diameter; range = ?

Assume $P_t = 1$ Mw, $G_t = 10^8$, $\lambda = 0.1$ m, $\sigma_s \cong 10^4$ m^2

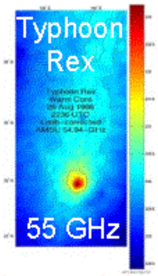
$P_r = kT_sB = 1.38 \times 10^{-23} \times 10 \times 1$ watts

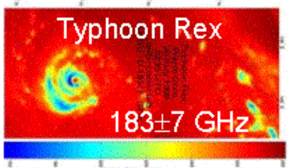
Then: $r = [P_t\sigma_s(G_t\lambda/4\pi)^2/4\pi P_r]^{1/4}$ meters (for S=N)

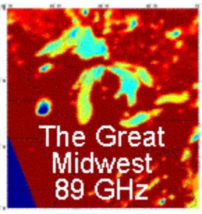
$\cong 10^6\ 10^4\ (10^8\ 0.1/4\pi)^2/(4\pi \times 1.38 \times 10^{-22})]^{1/4}$

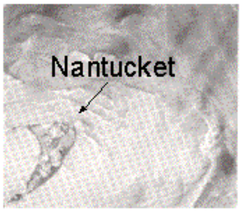
$\cong 4 \times 10^7$ km $\cong$ 0.3 Astronomical Units

(~distance to Venus; ⇒ ~2-3 weeks warning)









Thermal Sensing:

Target ⇒ kT_BB watts into antenna, (T_B is brightness temperature)

System noise ⇒ kT_SB watts

Sensitivity (K,rms) = T_S/(# Degrees of Freedom that are averaged)$^{0.5}$

DoF = $2B\tau$ (time-bandwidth product), [1 sec, 1 MHz ⇒ DoF = 2×10^6]

Example: RMS Sensitivity(K) = $T_S/(\tau B)^{0.5}$ [e.g. $500/(1 \times 10^8)^{0.5} = 0.05$K]

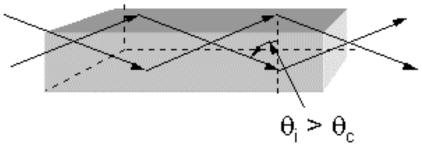
GUIDED WAVES

Trapped Plane Waves:

TEM Mode

Bouncing Waves—parallel-plate waveguide

Bouncing Waves—rectangular waveguide



Waves Guided by Dielectrics:

Bouncing Waves—dielectric slab waveguide

Optical Fibers

Standing Waves ⇒ Waveguide Modes:

Null planes parallel to plates (see above) ⇒ TE_m, TM_m modes

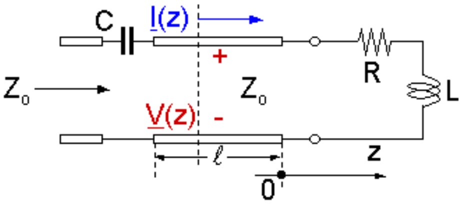
Rectangular waveguides, null planes in two dimensions

⇒ $TE_{m,n}$ and $TM_{m,n}$ modes

Optical fibers—similar; fields characterized by Bessel functions

IMPEDANCE, IMPEDANCE TRANSFORMATIONS

TEM Mode (at ω):



Impedance: $\underline{Z}(z) = \underline{V}(z)/\underline{I}(z)$

Where: $\underline{V}(z) = \underline{V}_+e^{-jkz} + \underline{V}_-e^{+jkz}$ volts (recall plane waves at ω)
$\underline{I}(z) = Y_o(\underline{V}_+e^{-jkz} - \underline{V}_-e^{+jkz})$ amperes

Impedance Transformations:

Therefore: $$Z_o \frac{\underline{V}_+e^{-jkz} + \underline{V}_-e^{+jkz}}{\underline{V}_+e^{-jkz} - \underline{V}_-e^{+jkz}} = Z_o \frac{1+\underline{\Gamma}(z)}{1-\underline{\Gamma}(z)}$$

Where: $\underline{\Gamma}(z) = (\underline{V}_-/\underline{V}_+)e^{2jkz}$
Yields: $\underline{Z}(z) = \pm jX$ (for any X, if line is losslessly terminated (e.g. shorted)
Enables: Microwave integrated circuits to emulate wired ones

Matching Impedances Losslessly:

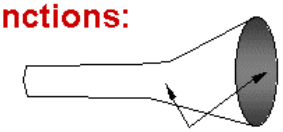
Just position proper C or L in series or parallel at proper ℓ,

Or, insert a section of line with different impedance ⇒ transformer
(ALL incident power is then dissipated in load resistance)

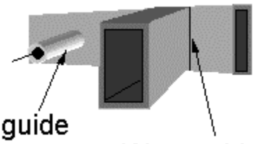
L14-5

JUNCTIONS AND MODAL COUPLING

Junctions:



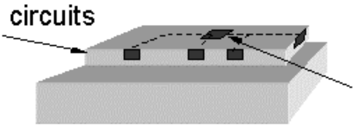
e.g. Antenna feeds



Cable-waveguide

Waveguide-waveguide

Optical and microwave integrated circuits



Active elements

Parasitic Reactances (L or C):

Find average energy storage: $w_e < w_m \Rightarrow L$; $w_e > w_m \Rightarrow C$

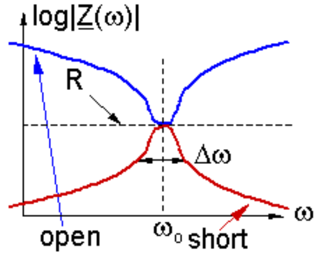
Modal Coupling:

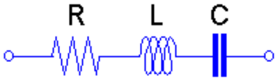
Single-mode to one or more single-mode guides
Multi-mode to multi-mode guides
$\underline{\mathbf{S}}_{ij}$ scattering matrix, $\underline{\mathbf{Z}}_{ij}$ impedance matrix

L14-6

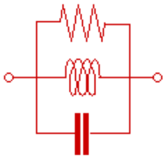
RESONANCE AND RESONATORS

RLC Resonators:





Series resonance



Parallel resonance

$\omega_0/\Delta\omega = Q$

$\omega \to 0 \Rightarrow j\omega L \to 0,\ \ 1/j\omega C \to \infty$

$\omega \to \infty \Rightarrow j\omega L \to \infty,\ 1/j\omega C \to 0$

Critical Coupling:

Perfect coupling (no reflection) at ω_0 if $Z_0 = R$

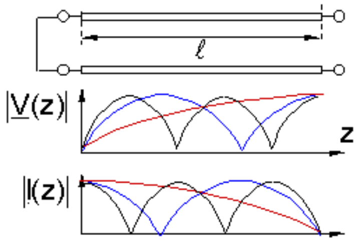
TEM Resonators:

Example, λ_n:

$(2n-1)(\lambda_n/4) = \ell$

$n = 1,2,3,\ldots$

(ℓ is an odd number of quarter wavelengths)



MICROWAVE COMMUNICATIONS AND RADAR

Outline of Section:

Applications and overview of issues
Generalized TEM line, complex impedance $\underline{Z}(z)$
Impedance transformations, gamma plane
Smith chart, tuning, quarter-wave transformers
RLC and TEM resonators, ω_0, Q, coupling
TE, TM parallel-plate waveguides
Rectangular waveguides
System examples