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微波工程講義

Microwave Engineering Notes

http://cc.ee.ntu.edu.tw/~thc

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General Introduction

1.Class: Fri. 9:10-12:00 am, Room 225

2.Textbook: Radio-frequency and microwave communication circuits-analysis and design, D.K. Misra, John Wiley, 2001, 全華代理

3.Scopes: microwave basics, principles of passive and active microwave components, microwave communication applications from electronic circuits point of view

4.Contents:

Ch.1 Introduction
Ch.2 Communication systems
Ch.3 Transmission lines
Ch.4 Resonant circuits
Ch.5 Impedance matching networks
Ch.6 Impedance transformers
Ch.7 Two-port networks
Ch.8 Filter design

Ch.9 Signal-flow graphs and applications
Ch.10 Transistor amplifier design
Ch.11 Oscillator design
Ch.12 Detectors and mixers

5. Total class hours: 51 hours
6. Grades: homework 20%, midterm exam. (Ch.1-Ch.7) 40%, final exam. (Ch.8-Ch.12) 40%
7. Office hour: Mon. 2:00-3:00, room 541
8. Reference books

Collin, R.E., *Foundations for Microwave Engineering*, McGraw Hill, 1992

Chapter 1 Introduction

- General description of microwaves
  related history, frequency bands, factors favor for RF and microwaves, propagation, passive and active devices, applications

1.1 Microwave transmission lines
  types and general description of RF and microwave transmission lines

General description of microwaves

1. Related history

- 19th century

  1846 - earliest talk on EM wave, "Thoughts on ray vibrations," Michael Faraday (1791-1867)

  1864 - "Maxwell's equations," James Clark Maxwell (1831-1879)

  1887 - first microwave-like experiment, "electric spark at λ~10cm induces at a distant wire loop," Heinrich Rudolf Hertz (1857-1894)

  1895 - wireless telegraphic communication and 1900 trans-Atlantic Ocean telegraph, Guglielmo Marconi (1874-1937)

- 20th century

  1921 - magnetron, A. W. Hull

  1930 - wave propagation in waveguide, George C. Southworth

  1937 - klystron, Russell Varian, Sigurd Varian and William Hansen

  World War II – radar, MIT Radiation Laboratory

  ~1950 - coaxial cables for radio communication

  ~1960 - satellite communication

~1980 - remote sensing satellite, DBS (direct broadcast satellite)
~1990 - PCN/PCS (personal communications network/personal communication services), GPS (global positioning system), VSAT (very small aperture terminals)
~2000 - Digital DBS, WLL (wireless local loop), GII (global information initiative) using mobile satellite network, fibers, cables and wireless

- *IEEE Transactions on Microwave Theory and Techniques*, vol.32, no.9, Sept. 1984

2. Frequency bands

• Commercial broadcasting

	channels	frequency (Hz)	wavelength
AM	107	535~1605k	186.92~560.75m
TV(VHF)	2-4	54~72M	4.7~5.56m
	5-6	76~88M	3.41~3.95m
FM	100	88~100M	2.78~3.41m
TV(UHF)	7-13	174~216M	1.39~1.72m
	14-83	470~890M	33.7~63.83cm

• RF band

band	frequency (Hz)	wavelength	
VLF	3~30k	10~100km	
LF	30~300k	1~10km	
MF	300k~3M	100m~1km	
HF	3~30M	10~100m	
VHF	30~300M	1~10m	microwaves
UHF	300M~3G	10cm~1m	microwaves
SHF	3~30G	1cm~10cm	microwaves
EHF	30~300G	0.1cm~1cm	microwaves

• Microwave band

band	frequency (GHz)	waveguide dimension * (in)	cutoff frequency (GHz)
UHF	0.5~1	18×9, WR-1800, 0.41-0.62GHz 15×7.5, WR-1500, 0.49-0.75GHz 11.5×5.75, WR-1150, 0.64-0.98GHz	0.33 0.39 0.51
L	1~2	7.7×3.85, WR-770, 0.96-1.46GHz 6.5×3.25, WR-650, 1.74-1.73GHz 5.1×2.55, WR-510, 1.45-2.2GHz	0.77 0.91 1.16
S	2~4	4.3×2.15, WR-430, 1.72-2.61GHz 3.4×1.7, WR-340, 2.17-3.3GHz 2.84×1.34, WR-284, 2.6-3.95	1.37 1.74 2.08
C	4~8	1.87×0.872, WR-187, 3.94-5.99GHz 1.372×0.622, WR-137, 5.38-8.17GHz	3.15 4.3
X	8~12.4	0.9×0.4, WR-90	6.57
Ku	12.4~18	0.622×0.311, WR-62	9.49
K	18~26.5	0.42×0.17, WR-42	14.08
Ka	26.5~40	0.28×0.14, WR-28	21.2

* p562, table A3.3

3. Factors favor to microwaves

- antenna size

as antenna size ~ λ, it radiates efficiently

$\rightarrow$ f ↑ , λ ↓ , size ↓ , radiation efficiency ↑

- channel bandwidth

as f ↑ , available spectrum bandwidth ↑

$\rightarrow$ f ↑ for wider information bandwidth transmission, especially digital video transmission

e.g.,

1% BW of AM radio @1MHz gives 1channel of 10kHz audio bandwidth

0.1% BW of C-band satellite communication @6GHz gives 1 channel of 6MHz video bandwidth

- propagation through atmosphere

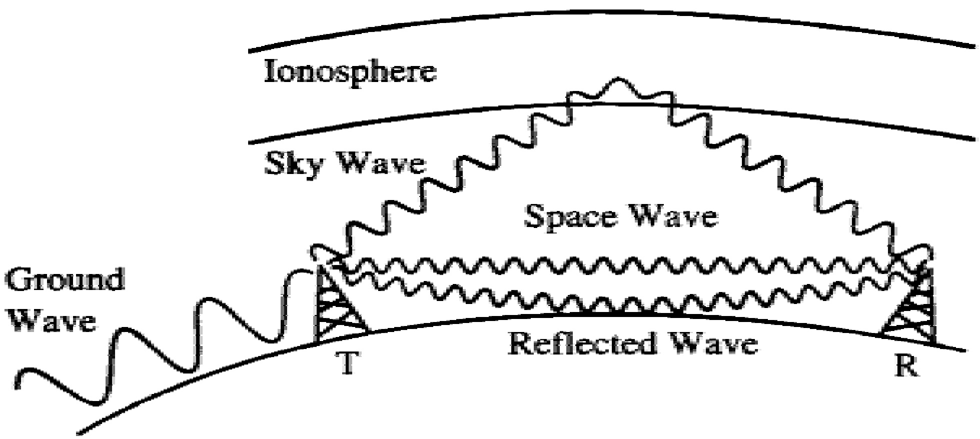
ground wave (LF band, 30-300KHz) travels over and near the earth surface $\rightarrow$ ground absorption loss, especially for h-polarization $\rightarrow$ AM radio uses vertical polarization, sky wave (HF band, 3-30MHz) performs refraction (signal bending) in ionosphere, plasma frequency ~ 9MHz → short-wave radio

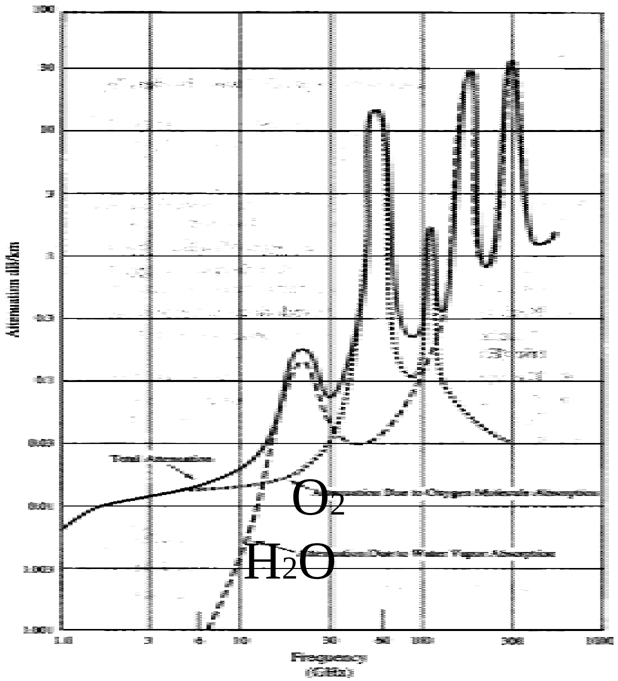
space wave (VHF, UHF and microwave, 30M-300GHz)

direct wave (line-of sight, LOS) and reflected wave → interference or multipath phenomenon

low atmospheric attenuation and unaffected by rain and cloud

→ wireless, mobile, terrestrial and satellite communication





4. Microwave devices

- In general, input/output matching is inherently required for microwave components over the operating band.
- passive devices (without DC bias)
  diplexer, filter, coupler, power divider/combiner, isolator, circulator, attenuator, adapter, terminator, cable, transmission line, waveguide, resonator, detector, mixer, phase shifter, lumped R, L, C, antenna,…
- active devices (with DC bias)
  amplifier, oscillator, switch, mixer, frequency multiplier, active antenna, ….
- vacuum tube devices

linear beam type		cross-field type
EM cavity type	slow-wave circuit type	
klystron amplifier, oscillator	TWT (traveling wave tube) amplifier	magnetron

• Solid-state devices

junction effect	field effect	transfer electron	avalanche effect	lasing effect
BJT HBT Tunnel diode Schottky-barrier diode PIN diode	JFET MESFET HEMT MOSFET NMOS, PMOS, CMOS	Gunn diode LSA diode InP diode CdTe diode	IMPATT diode TRAPATT diode BARITT diode parametric devices	laser mixing maser

HBT:hyterojuction bipolar transistor
MESFET:metal-semiconductor field-effect transistor
HEMT:high electron mobility transistor
MOSFET:metal-oxide-semiconductor field-effect transistor
CMOS:complementary metal-oxide-semiconductor transistor
IMPATT diode:impact ionization avalanche transit-time diode
TRAPATT diode:trapped plasma avalanche triggered transit-time diode
BARITT diode:barrier injected transit-time diode
maser:microwave amplification by stimulated emission of radiation
LSA diode:limited space-charge accumulation mode of the Gunn diode

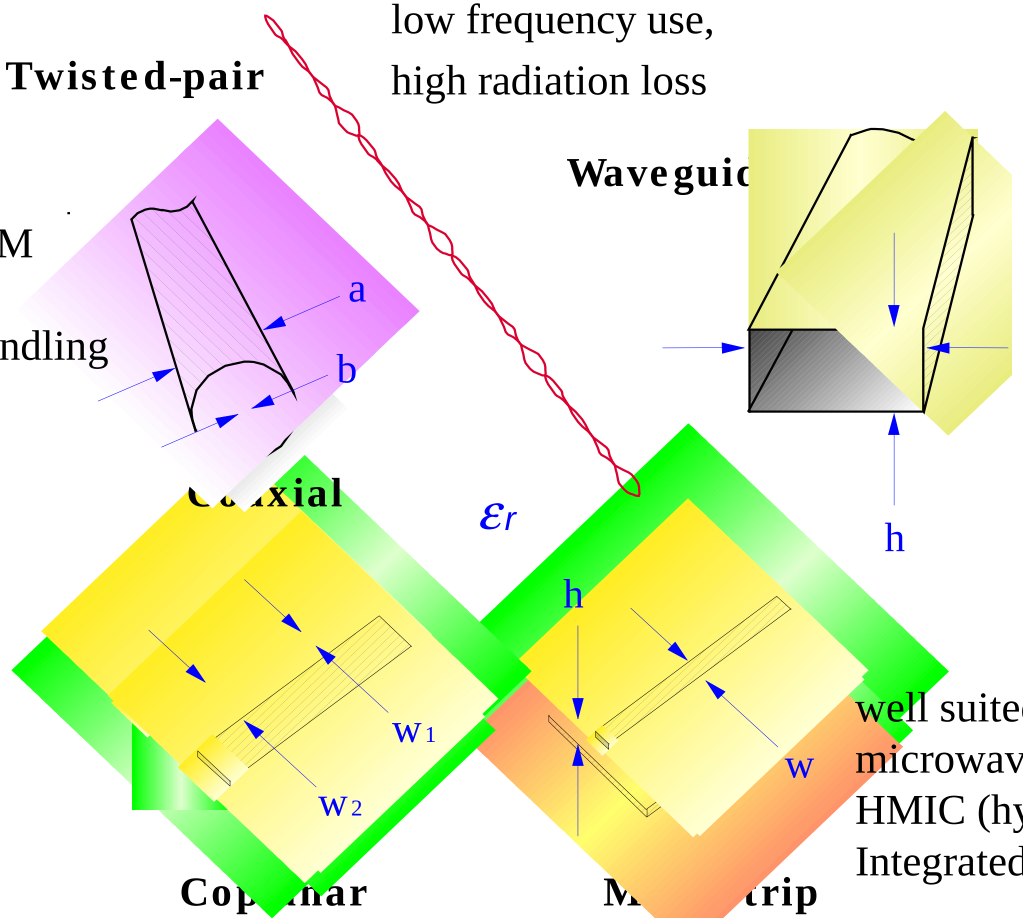
- Vacuum tube technology finds its applications in high power (W-MW) and high frequency (200MHz-200GHz)
  e.g., magnetron: kW CW source in microwave oven, MW pulsed source in radar,
  traveling wave tube amplifier: >10 W power amplifier in satellite,
  klystron: local oscillator in receiver.
- Microwave solid-state devices are low cost, low power supply, low noise, small, light weight, easy cooling, reliable and long life time compared with microwave tubes.

5. Microwave applications

communication	radar		Industrial, scientific and biomedical
	civilian	military	
broadcasting WLAN cordless phone RFID cellular terrestrial Satellite GPS	air traffic control aircraft navigation ship safety law enforcement	surveillance navigation weapon guidance electronic warfare C^3	drying, curing heating cooking process control imaging hyperthermia patient monitoring remote sensing radio astronomy power transmission particle acceleration

- Growth and expansion of microwave technology move from military and satellite applications into information and entertainment applications.

1.1 Microwave transmission lines



low frequency use,
high radiation loss

wideband TEM operation,
low power handling capability

good all-around characteristics, but difficult in integration with other microwave components

well suited for MMIC(monolithic microwave integrated circuit) or HMIC (hybrid microwave Integrated circuit)

	coaxial line	waveguide	microstrip
mode: preferred other	TEM TM, TE	TE_{10} TM, TE	quasi-TEM Hybrid TM, TE
dispersion	none	medium	low
bandwidth	high	low	high
loss	medium	low	high
power capacity	medium	high	low
physical size	large	large	small
easy of fabrication	medium	medium	easy
integration with other components	hard	hard	easy