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# 微波工程講義

# Microwave Engineering Notes

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# General Information

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

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

## 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

Grading policy: Midterm: 40%, final: 40%, homework: 20%

References:


1. Collin, R.E., Foundations for Microwave Engineering, McGraw Hill, 1992.
2. Pozar, D.M., Microwave Engineering, John Wiley, 2/e, 1998.


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# 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

# 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 $\lambda$~10cminduces 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 | (US)107<br>(TW)133 | 535~1605K<br>522~1710K | 186.92~560.75m |
| TV(VHF) | 2-4 | 54~72M | 4.7~5.56m |
| | 5-6 | 76~88M | 3.41~3.95m |
| FM | 100 | 88~108M | 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 |
| UHF | 300M~3G | 10cm~1m |
| SHF | 3~30G | 1cm~10cm |
| EHF | 30~300G | 0.1cm~1cm |

} microwaves (VHF, UHF, SHF, EHF)

• Microwave band

| band | frequency (GHz) | waveguide dimensions * (in.) | cutoff frequency (GHz) |
|---|---|---|---|
| UHF | 0.5~1 | 18×9, WR-1800, 0.41-0.62GHz<br>15×7.5, WR-1500, 0.49-0.75GHz<br>11.5×5.75, WR-1150, 0.64-0.98GHz | 0.33<br>0.39<br>0.51 |
| L | 1~2 | 7.7×3.85, WR-770, 0.96-1.46GHz<br>6.5×3.25, WR-650, 1.74-1.73GHz<br>5.1×2.55, WR-510, 1.45-2.2GHz | 0.77<br>0.91<br>1.16 |
| S | 2~4 | 4.3×2.15, WR-430, 1.72-2.61GHz<br>3.4×1.7, WR-340, 2.17-3.3GHz<br>2.84×1.34, WR-284, 2.6-3.95 | 1.37<br>1.74<br>2.08 |
| C | 4~8 | 1.87×0.872, WR-187, 3.94-5.99GHz<br>1.372×0.622, WR-137, 5.38-8.17GHz | 3.15<br>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 ~ $\lambda$, it radiates efficiently

→ f ↑, $\lambda$ ↓, size ↓, radiation efficiency ↑

• channel bandwidth

as f ↑ available spectrum bandwidth ↑

→ 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

→ ground absorption loss, especially for h-polarization

→ AM radio uses vertical polarization,

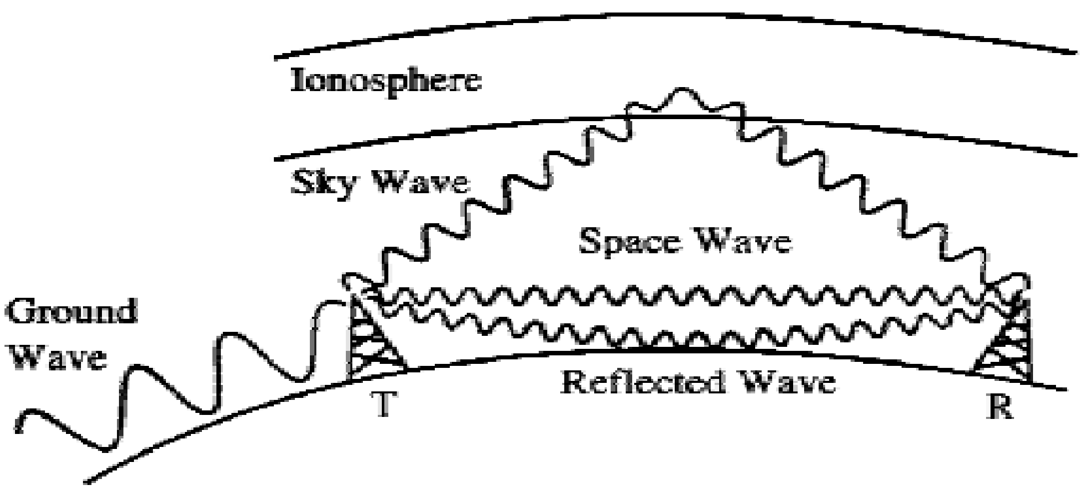
sky wave (HF band, 3-30MHz) performs refraction (signal bending) in ionosphere,

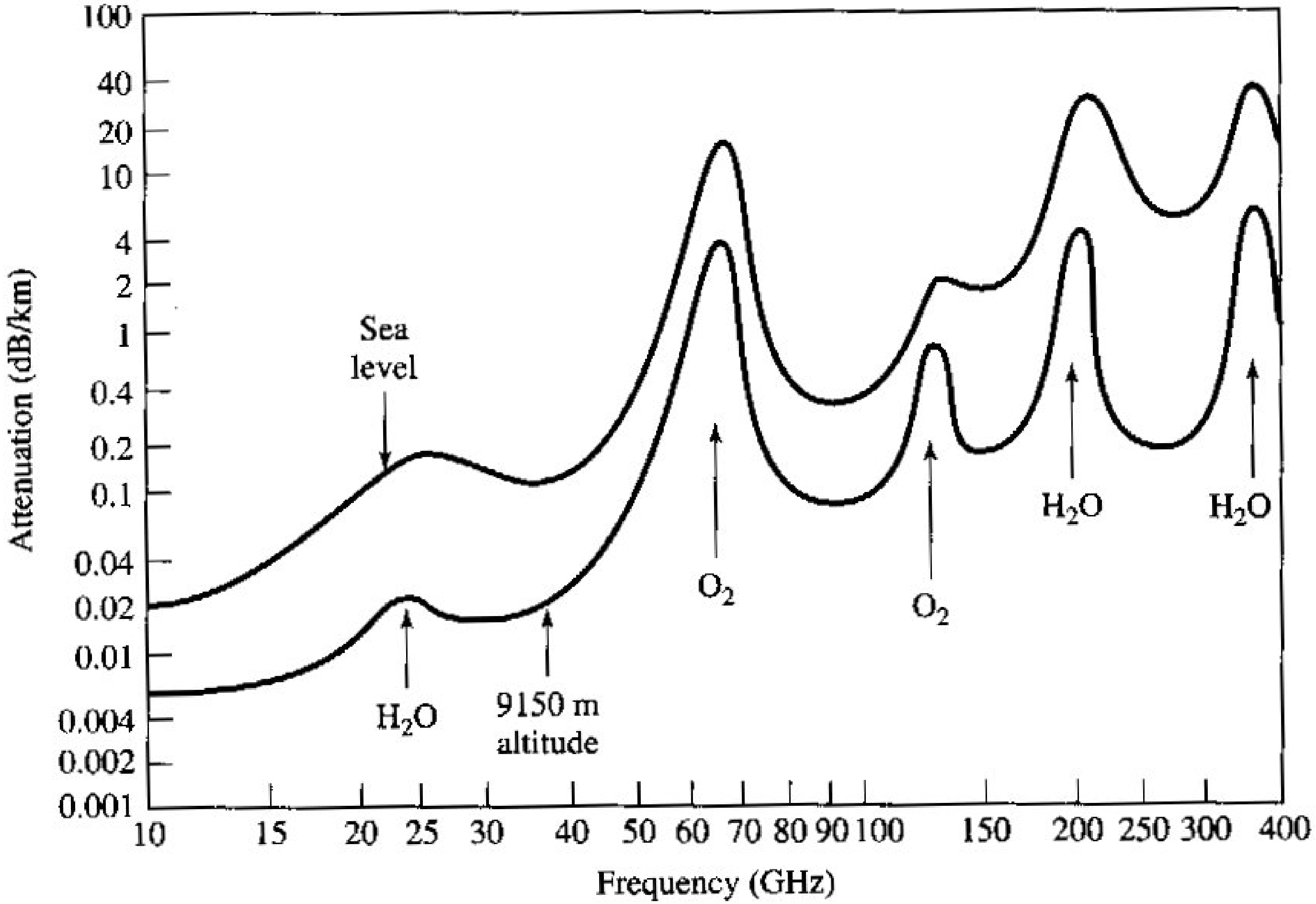
plasma frequency ~ 9MHz → short-wave radio

space wave (VHF, UHF and microwave, 30M-300GHz) direct wave (line-of sight, LOS) and reflected wave → interference or multi-path phenomenon

low atmospheric attenuation and unaffected by rain and cloud

→ wireless, mobile, terrestrial and satellite communication





100
40
20
10
4
2
1
0.4
0.2
0.1
0.04
0.02
0.01
0.004
0.002
0.001
Attenuation (dB/km)
Sea level
$H_2O$
9150 m altitude
$O_2$
$O_2$
$H_2O$
$H_2O$
10 15 20 25 30 40 50 60 70 80 90 100 150 200 250 300 400
Frequency (GHz)

## 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

<table>
<tr><th colspan="2">linear beam type</th><th rowspan="2">cross-field type</th></tr>
<tr><th>EM cavity type</th><th>slow-wave circuit type</th></tr>
<tr><td>klystron amplifier, oscillator</td><td>TWT (traveling wave tube) amplifier</td><td>magnetron</td></tr>
</table>

• Solid-state devices

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

HBT: heterojuction 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<br>WLAN<br>Cordless phone<br>RFID<br>Cellular<br>Terrestrial<br>Satellite<br>GPS | air traffic control,<br>aircraft navigation,<br>ship safety,<br>law enforcement | surveillance,<br>navigation,<br>weapon guidance,<br>electronic warfare<br>$C^3I$ (command,<br>control,<br>communication,<br>information) | drying, curing,<br>heating,<br>cooking process<br>control,<br>imaging,<br>hyperthermia,<br>patient monitoring,<br>remote sensing<br>radio astronomy,<br>power<br>transmission ,particle<br>acceleration |

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

## 1.1 Microwave transmission lines

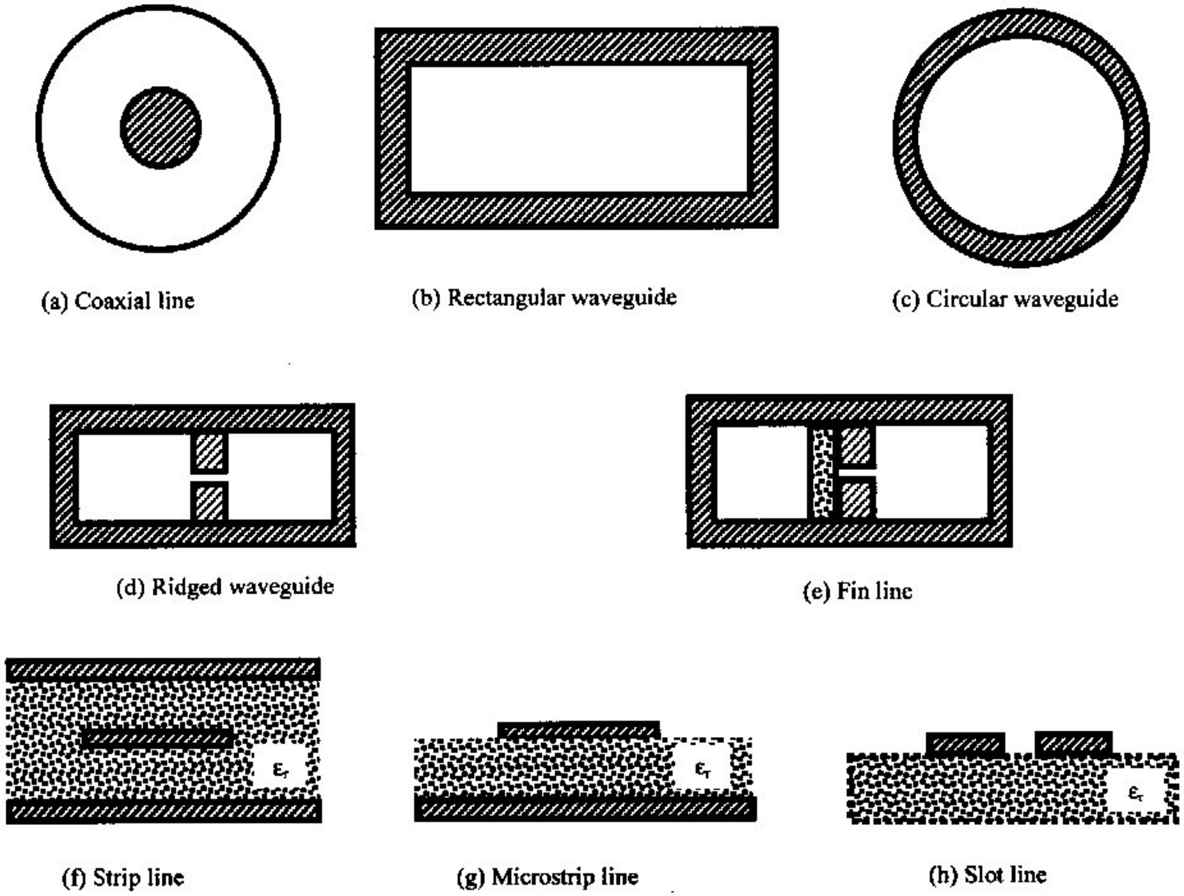



**Figure 1.6** Transmission lines used in RF and microwave circuits.

| | coaxial line | waveguide | microstrip |
|---|---|---|---|
| mode: preferred<br>other | TEM<br>TM, TE | TE10<br>TM, TE | quasi-TEM<br>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 |