Transmission Lines
(Chapter 7)
Ideal transmission line:
1. No losses
2. No radiation (TX)/no reception (RX)
3. Constant characteristics
Transmission line has a **characteristic impedance** (Z₀), measured in ohms (Ω).

The complex sum of line’s R + XL + XC is determined by **spacing**, **thickness** of wires, and **dielectric** between.

Z₀: if used to terminate the line, will give an SWR of 1:1 and **maximum** power transfer.

**Practical result**: TX/RX Zout should match trans. line Z₀, which should match antenna Z.

Common trans. line Z: **50, 72, 300, 450, 600 Ω**

**50Ω**: all amateur and most commercial radios

**72Ω**: most TV/video cellular phone radios
(V)SWR: (Voltage) Standing Wave Ratio

\[ VSWR = \frac{VF + VR}{VF} - VR \]

A measure of Z mismatch or reflected RF power

If \( Z_0 = 50\Omega \) and \( Z_{ANT} = 50\Omega \) \( \Rightarrow \) SWR = 1:1.0
\( Z_{ANT} = 100\Omega \) \( \Rightarrow \) SWR = 1:2.0
\( Z_{ANT} = 25\Omega \) \( \Rightarrow \) SWR = 1:2.0
\( Z_{ANT} = 12.5\Omega \) \( \Rightarrow \) SWR = 1:4.0
\( Z_{ANT} = 500\Omega \) \( \Rightarrow \) SWR = 1:10
Antenna tuner: matches Z of transmission line to transmitter

It DOES NOT tune the antenna!

Often power/SWR meter, dummy load, balun, antenna switch included
Balanced Transmission Lines

- 2 parallel wires, unshielded
- signals 180° out-of phase

\[ Z_0 = 276 \log_{10} 2(S/d) \]

S = distance between 2 wires
d = diameter of 2 wires

Advantages
- very low losses
- takes high voltage, power, SWR
- cheap

Disadvantages
- influenced by nearby metal
- ant. tuner must be balanced or have balun
- flaps/fatigues in wind
How a balanced transmission line rejects noise (and is prevented from being an antenna)!

Unbalanced Circuit

Balanced Circuit

Noise on output

Noise cancelled

Noise
Balanced Feedline Types

- Low-loss dielectric
- Insulating spacers
- Two wires
- Braided shield
- Rubber cover
- Dielectric
Balun (Balanced: Unbalanced) transformers

Balanced line

M4-M6 Bolts
Insulator
Soldered joint
RG Coaxial cable
Enclosure Case
Balun Transformer
(ferrite doughnut)
Crimp Joint
SO-239 Chassis Mount

Unbalanced (co-ax) line

Figure 2  4:1 Balun Wiring diagram

Figure 5
Balun may have:
- air core
- Ferrite toroidal core
- Ferrite rod core

Ferrite, powdered iron cores can saturate, overheat; air core cannot

Big core, heavy wire for high power!

**Current balun**: forces same current (I) in both sides of antenna or balanced line

**Voltage balun**: forces same voltage (E) in both sides of antenna or balanced line
Coaxial cable “choke balun”

- forces coax to be balanced
- keeps RF off outside of coax shield
- reduces RF in shack
- maintains antenna pattern
- reduces transmission + reception by co-ax
- sometimes these effects important, often not
- ”scramble-wound” coil not the best

10-20 turns =>
Unbalanced (Coaxial) Transmission Lines

- 2 conductors on same axis
- center conductor + shield

\[ Z_0 = \frac{138}{\sqrt{e}} \cdot \log \frac{D}{d} \]

\( e = \) dielectric constant
\( D = \) outer conductor diameter
\( d = \) inner conductor diameter

**Velocity factor:** transmission speed in trans. line as a fraction of \( c \)
  : typical 0.66, 0.82 (coax), 0.99 (balanced line)

**Advantages**
- Unaffected by nearby conductors
- Waterproof
- Easy to install

**Disadvantages**
- More lossy than balanced
- Special connectors
- Ruined by water
- \( Z \) matching more important
El Cheapo!
Specific cable line losses. Losses greater with any mis-match!!
Common Coaxial Connector Types

"BNC"

"N" Type

SO-239 => "UHF" Type

PL-259 => "UG" adaptors
The “F” connector family (usually 72Ω)

RCA connector family: now some for audio, some for RF
Halifax Amateur Radio Club Licensing Course

Antennas
(Chapter 8)

de Fred Archibald VE1FA
What does an antenna do??

The perfect antenna:
1. **100% efficient**
2. **Highly directional (high gain)**
3. **Pointable at any location**
7. **Poor receiver of natural radio noise**
8. **Cheap and easy to erect, lasts forever!**

To design, set up, or most efficiently use a good radio antenna, one must understand some basic radio wave physics.
- **Electrostastic** (electric) (E) field 90° from **electromagnetic** (magnetic) (H) field

- Both 90° from direction of travel

- **Electrostatic** (electric) field determines polarization

- Vertical antenna => **vertically polarized RF**

- Horizontal antenna => **horizontally polarized RF**

- If RX = TX polarization: optimal reception

- Circular polarization?
Antenna impedance (Z): complex combination of R + XL or XC

When antenna XL = XC, X=0, and therefore Z = R, and antenna is resonant.

Antenna most efficient at its resonant frequency.

Antenna behaves like an L+C resonant circuit.

Every antenna has a resonant frequency.

Antenna will have XL if applied freq > than antenna resonant freq.

Antenna will have XC if applied freq. < than resonant freq.
Antenna properties

**Feedpoint Z**: often designed to be around 50 ohms

\[ P = I^2 (R + R_0) \]

**Resonant dipole antenna** =>
(Z=50 Ω at resonance and 0.5λ above ground!)

**Bandwidth**: frequency range giving reasonable SWR (standing wave ratio)

**Directivity**: Gain in a particular direction, and front: back (F:B) ratio (in db)

Gain compared to theoretical isotropic radiator

**Efficiency**: % of RF power radiated as signal (can be 90+% to 0%)
(Voltage) Standing Wave Ratio (SWR or VSWR) = Vmax/Vmin

SWR=1.0: perfect Z match!
  1.5: max mismatch tolerable by many modern transceivers
>1.5: need a TX to line matching device “antenna tuner”
>2.0: coaxial transmission line losses and voltages increase greatly!
Half-Wave (\(\lambda/2\)) Antenna E + I Distribution at Resonance

- Changes with frequency!

- Changes with antenna dimensions!

- Why would this antenna be fed at its center??
Calculating the lengths of resonant antennas

-works for loops, verticals, dipoles, etc

-ground, nearby conductive objects will affect the exact length giving resonance

-therefore, cut long, trim to desired frequency!

\[ \lambda = \frac{c}{F} \text{ (m/s)/F (Hz)} \quad \frac{\lambda}{2} = 492 \text{ feet/F (MHz)} \quad \text{...in free space} \]

\[ \frac{\lambda}{2} = 468' \quad \text{or} \quad 143 \text{m/F (MHz)} \quad \text{...for dipole 0.5}\lambda \text{ above ground*} \]

Example: 40m dipole at 0.5\lambda \text{ above ground}

\[ \frac{\lambda}{2} = \frac{468'}{7.1 \text{ MHz}} = 65.9' \quad \text{(length of 7.1 MHz dipole)} \]

* Ground effect makes dipole seem around 5% longer
Antenna Radiation Patterns and Directivity

- All antennas **directive** (except isotropic)
- Directivity measured in “**db gain**” and **Front:Back (F:B) ratio** (in db)
- Effective Radiated Power (ERP)
- NEC and related programs (EZNEC, MINNEC) calculate antenna patterns
- Also known as “antenna modeling”:
- Must enter data on: **height**, **ground conductivity**, **antenna design/dimensions**, and **frequency**
- Millions of calculations usually required!
- Must think in 3D to enter antenna to be analyzed
- Projections in **Azimuth, Elevation**, or **3-D**
Elevation Antenna Radiation Plot

0 dB = 2.76 dBd

53.750 MHz
EZNEC 3D radiation model of 40m dipole at 69°
Effect of height above ground on a dipole (elevation proj.)
## Broadside Dipole Gain

<table>
<thead>
<tr>
<th>Takeoff angle</th>
<th>15°</th>
<th>25°</th>
<th>45°</th>
<th>90°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dipole at</td>
<td>dbi</td>
<td>dbi</td>
<td>dbi</td>
<td>dbi</td>
</tr>
<tr>
<td>20'</td>
<td>-2.2</td>
<td>+1.8</td>
<td>+3.8</td>
<td>+5.8</td>
</tr>
<tr>
<td>35'</td>
<td>-0.1</td>
<td>+2.9</td>
<td>+5.6</td>
<td>+6.0</td>
</tr>
<tr>
<td>52' (3/8 λ)</td>
<td>+5.0</td>
<td>+7.0</td>
<td>+3.0</td>
<td>-5.0</td>
</tr>
<tr>
<td>69' (1/2 λ)</td>
<td>+5.5</td>
<td>+7.5</td>
<td>+4.5</td>
<td>-7.0</td>
</tr>
<tr>
<td>86.6' (5/8 λ)</td>
<td>+6.9</td>
<td>+7.9</td>
<td>-1.5</td>
<td>+4.9</td>
</tr>
</tbody>
</table>
Standard Dipole Construction
Dipole-derived antennas
(center-fed, half-wavelength long)

Dipole shortcomings:

1. Usually single band
2. Needs 2-3 supports
3. Low gain/no gain

FP = feedpoint for RF
T = trap LC tuned circuit
L = loading coil (makes antenna seem longer)
ATU = antenna tuning unit
Inverted Vee dipole

Note pulley/halyard setup: very convenient!

Note coaxial cable RF choke =>
EZNEC patterns for vertical Delta loop fed at two different points

Middle bottom fed=>

1/4λ down side fed=>
Horizontal Loop Antenna
-relatively quiet (low QRN)
-good for all frequencies above resonance
-good radiation pattern on higher bands
requires multiple supports and room

My Loop
-3-sided (Delta), fed at corner
-height =52’
circumference =486’
good from 160m-10m
-high power balun+tuner
-450-ohm balanced line
even good for LF RX
-low-angle radiation patterns above 40m
Vertical Antennas

- single band
- low takeoff angle (good for DX!)
- noisy
- radials needed
Yagi or beam antenna

Parasitic elements

Driven (active)

Dir. (all)

Ref.

Hidetsugu Yagi, inventor in 1920s

VHF, UHF: small size makes multi elements easy

Characteristics:
- Band: 144-146 MHz
- Raport data: - space = 20 dB, Deg = 46
- Gain = 11 dB
- Adaptation: 689 mm
- Impedance: Z = 75 ohm
Yagi azimuth pattern

Yagi elevation pattern

Beamwidth measured at 3 db points

13-20—At A, horizontal radiation pattern at 1 meter height over average ground for the NW3Z/3FET 40-meter Yagi. The patterns are for 7.05 MHz. Lowering the value of the loading reactance from 138 to 32 Ω improves the F/B performance.
3-element 3-band yagi (Mosley CL-33)

VERY popular

10-15-20 meters

Aircraft aluminum tubing construction
Boom = 18'
Elements = 27-29' long
Weight 40 lbs.
Front:back ratio: 20-25 db
Forward gain: 7-8.5 dbd
9.1-10.6 dbi

SWR curves for this “Tri-bander” 📈
Cubical Quad Directive Antenna

- Quiet
- Directive
- Easily multi-banded
The cubical quad...not great in wind + ice!
Stacked yagis after an ice storm
Improvised/expedition antennas

-Correct wire lengths dependent on operating frequency!
DX-pedition antennas on 40’ “TV” tower
Parabolic antennas for very high gain

- High F/B ratio
- Highly directional
- The “spotlight” of the RF spectrum
- Dipole, feedhorn, and preamplifier at focus
- Great for UHF => up
- The higher the freq., the more precise the parabola must be
- Mechanically very difficult for low frequencies
Antenna-Related Equipment

Antenna/SWR analyzer

Field-strength meter

RF Power : SWR meter

Artificial antenna or dummy load (pure resistance)

100 WATT DUMMY LOAD 50 OHMS

PT-DL1000
1,000 WATTS DUMMY LOAD
Antenna Safety

Climbing towers, trees, roofs
- safety belt, harness for towers
  - safe equipment (quality ropes, ladders, etc)
- at least two people!
- training for tower climbing
- experience for tower put-up, tear-down
- quality tower components

Electric shock
- lightning protection for high masts, towers, aerials
  (good grounding, safety antenna disconnect)

**AVOID POWER LINES!** No wire or metallic antenna parts above, below, or near commercial power lines

Non-ionizing radiation (RF fields):
- unclear whether any real risk to humans,
  but should set up station to minimize RF near radio
- also tends to minimize interference on radio
END
Of Transmission Lines and Antennas

Questions??
Fig 23—Nominal matched-line attenuation in decibels per 100 feet of various common transmission lines. Total attenuation is directly proportional to length. Attenuation will vary somewhat in actual cable samples, and generally increases with age in coaxial cables having a type 1 jacket. Cables grouped together in the above chart have approximately the same attenuation. Types having foam polyethylene dielectric have slightly lower loss than equivalent solid types, when not specifically shown above.
**Specification and Performance Data**

**CL-33-M**

- **Forward Gain:**
  - 10 Meter: 8.5 dbd.
  - 15 Meter: 8.1 dbd.
  - 20 Meter: 7.3 dbd.

- **Front-to-Back:**
  - 10 Meter: 20 db.
  - 15 Meter: 23 db.
  - 20 Meter: 25 db.

- **Power Rating:**
  - CW: 1.9 KW
  - SSB: 2.6 KW

- **SWR at resonant frequency:** 1.0:1

- **Boom Length:** 2" x .126 x .18'

- **Turning Radius:** 16 ft.

- **Recommended Mast Size:** 2 in.

- **Maximum Element Length:** 27 ft.

- **Assembled Weight (approx.):** 42 lbs.

- **Wind Surface Area (in sq. ft.):** 6.0 ft.²

- **Wind Load (EIA standard 80 M.P.H.):** 120 lbs.

- **Shipping Weight (approx.):** 47 lbs.

- **Warranty:** 2 Yrs.

**NEW! Master CL-33-WARC Kit**

Convert your CL-33 to a CL-33-WARC with our "NEW" CL-33-WARC-KIT. This is an easy mod that will give you an even "Hotter" CL-33. Conversion will give the above performance!

Once your conversion is completed you get an add 40 Meters with a 7A-40-MK!
The Perfect Antenna

1. 100% Efficient: 100W RF AC $\Rightarrow$ 100 W RF photons + 0 W heat.

2. Optimal $\triangle$ of radiation.

3. 100% of photons focussed in beam in desired direction.

Real-World losses

Antenna resistive losses
Transmission line losses
Ground losses
Tuner losses