Course 703

Basics of Line Sweeping with Anritsu®/Wiltron Site Master®

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Contents of Course 703

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The Basics of Antenna Testing

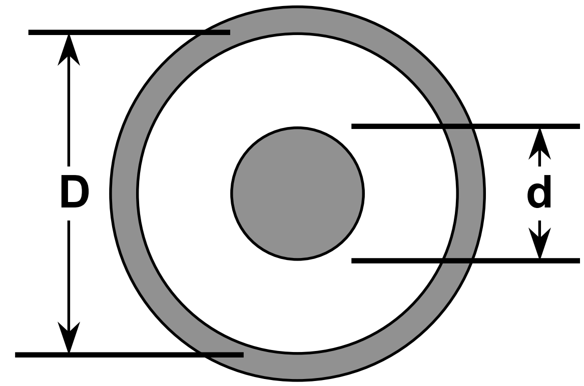
Testing Communications Feedlines and Antennas

- AC power wiring and voice telephone wiring do not require extremely critical wiring practices
  - just make sure the connections and insulation are good, heat is not allowed to build up, and you'll have good results
  - AC power frequencies and audio signal frequencies have wavelengths of many miles
    - a few feet of wire won't radiate much energy
- High frequency RF wiring practice is much more critical since signal wavelengths are only a few inches or feet
  - any bend or protruding bit of wire can serve as an unintentional antenna, "leaking" energy
  - even splices and connections can leak energy unless their shape and dimensions are closely controlled
  - abrupt changes in cable shape "reflect" energy back down the transmission line, causing many problems
- Precisely shaped cables and connectors, careful installation and accurate testing are required to avoid significant antenna system performance problems

Important Characteristics of Transmission LInes

Transmission Lines are chosen for:

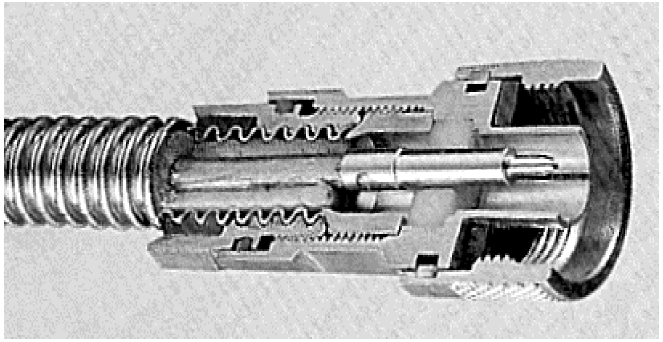
- Attenuation (signal absorption)
  - Varies with frequency, size, dielectric characteristics of insulation
  - Usually specified in **dB/100 ft** and/or **dB/100 m**
- Characteristic impedance $\mathbf{Z_0}$ (50 ohms is the wireless standard; 75 ohms for cable TV)
  - determined by inner/outer diameter ratio and characteristics of the insulation
  - Connectors must preserve constant impedance throughout (see cutaway)
- Velocity factor (speed of signal in the cable)
  - Expressed as a fraction of the speed of light in empty space
  - determined mainly by insulation density
- Power-handling capability
  - determined by the resistance and size of the conductors, and the heat and arc-over characteristics of the insulation



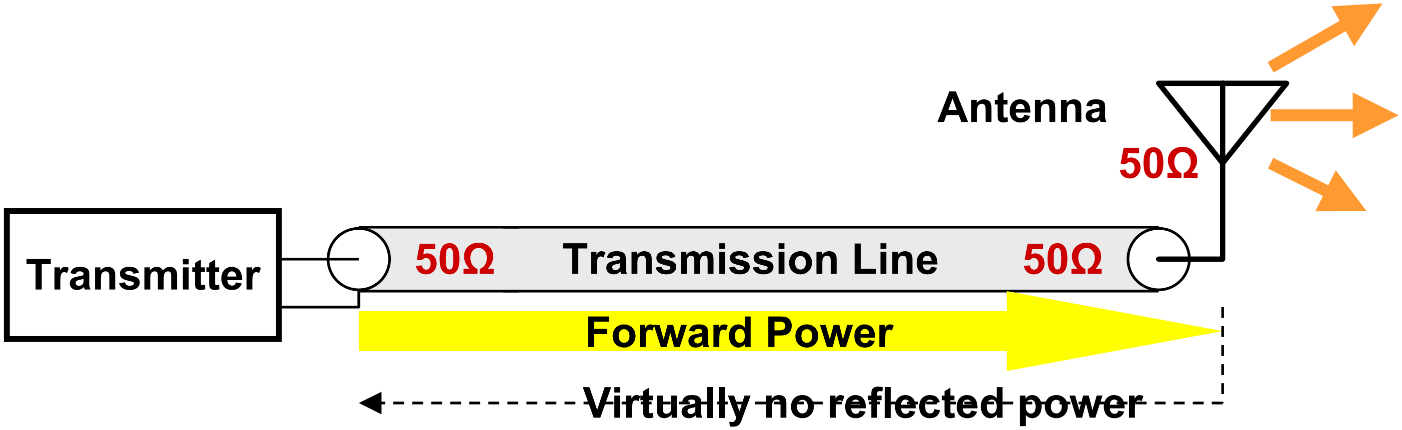
Characteristic Impedance of a Coaxial Line

$Z_o = (138 / (\varepsilon^{1/2})) \mathrm{Log}_{10} (D / d)$

ε = Dielectric Constant
= 1 for vacuum or dry air

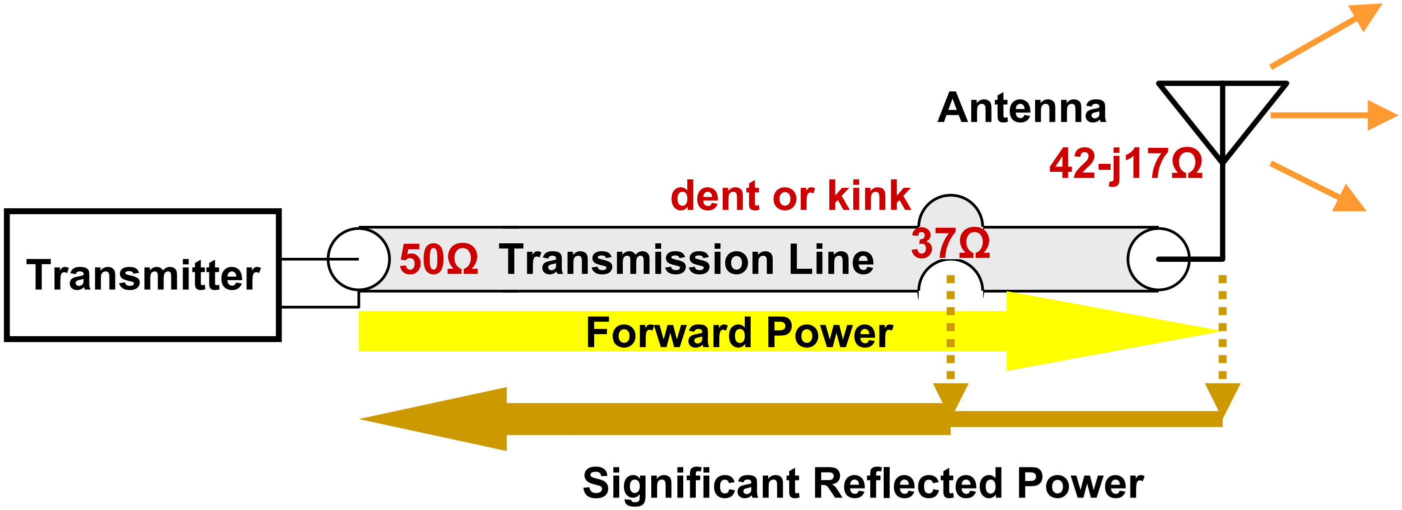


Forward and Reflected Energy



- In a perfect antenna system, the transmission line and the antenna have the same impedance
  - we say they are “impedance matched”
- All the energy from the transmitter passes through and is radiated from the antenna
  - virtually no energy is reflected back to the transmitter

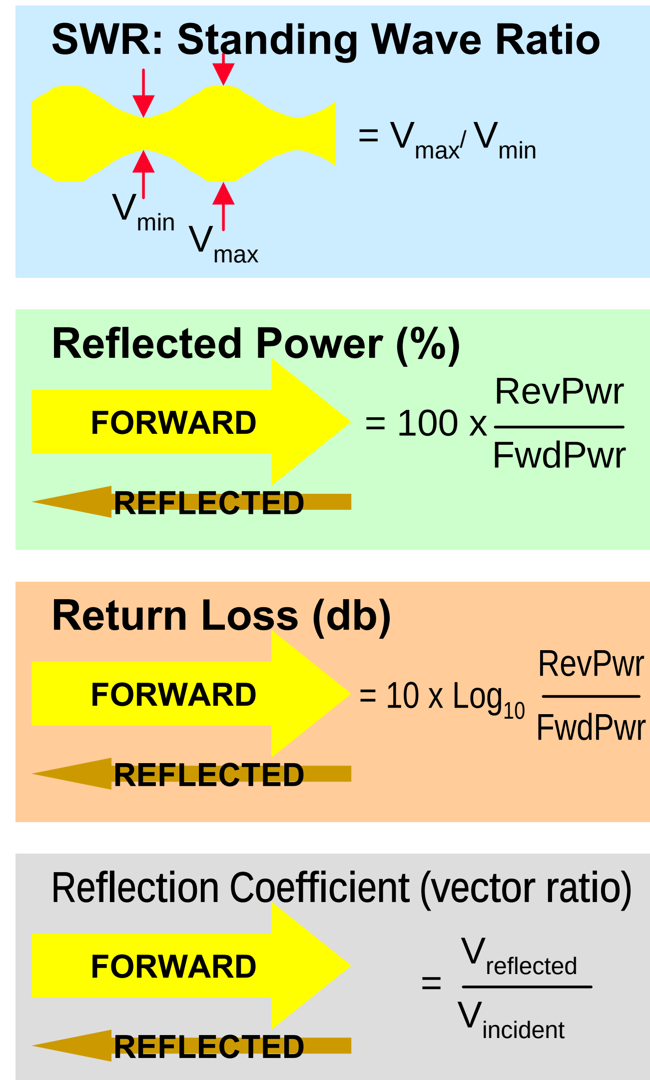
Forward and Reflected Energy



- In a damaged antenna system, the impedance match is not good
  - there could be a dent, kink, or a spot with water in the transmission line
    - the different impedance in the line at this spot will cause some of the energy to be reflected backwards
  - the antenna could be damaged or dangling, causing it to have an altered impedance
    - the antenna's different impedance will reflect some of the energy backwards down the line
- The Site Master® Distance-To-Fault mode will be helpful in finding the location of the damage

How Much Reflection? Four Ways to Say It

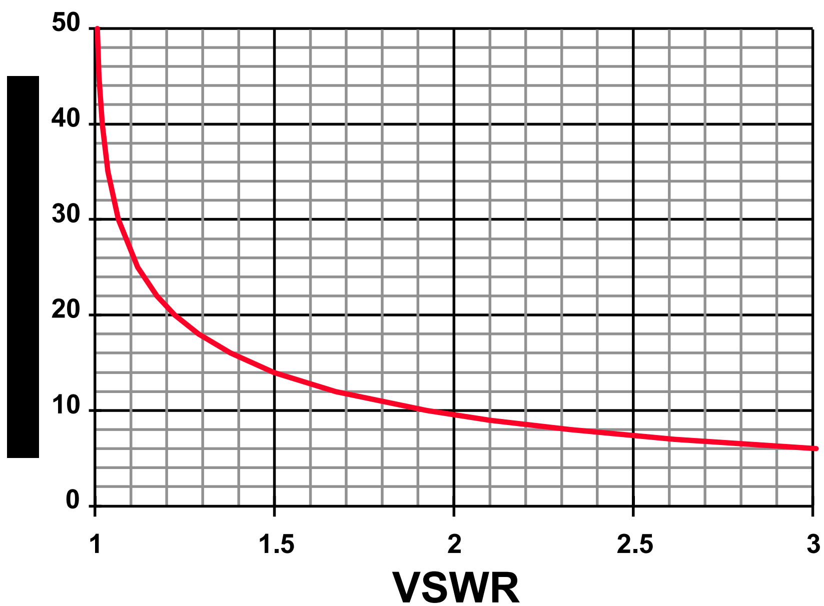
- There are four ways of expressing how much energy is being reflected
  - different users like different methods
- Voltage Standing Wave Ratio (VSWR) (used by hobbyists and consumers)
  - the reflected voltage is in phase with the incident voltage at some places and out of phase at others
  - VSWR is the ratio of Vmax/Vmin
- Reflected Power as % of Forward Power (used by field personnel in some industries)
  - just divide Rev by Fwd, use percent
- Return Loss (used by field personnel)
  - how many db weaker is the reflected energy than the forward energy
- Reflection Coefficient (academic users)
  - vector ratio of reflected/incident voltage or current
  - usually expressed as a polar vector, with magnitude and phase



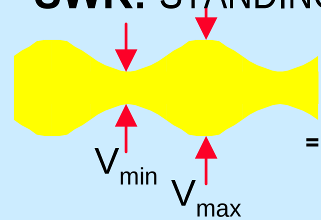
Comparing Reflection Reports in Different Forms

- Reflection expressed in one form can be converted and expressed in the other forms
- For example, consider a VSWR of 1.5 : 1
  - this is 4% reflected power
  - this is a return loss of 14 db
  - to calculate the reflection coefficient, the phase of the reflection is also needed

VSWR vs. Return Loss

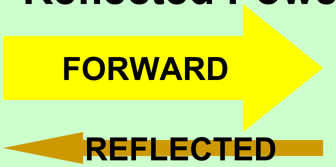


SWR: STANDING WAVE RATIO



$$= V_{max} / V_{min} = \frac{1 + \sqrt{\frac{\text{Reflected Power}}{\text{Forward Power}}}}{1 - \sqrt{\frac{\text{Reflected Power}}{\text{Forward Power}}}}$$

Reflected Power (%)



$$= 100 \times \frac{RevPwr}{FwdPwr}$$

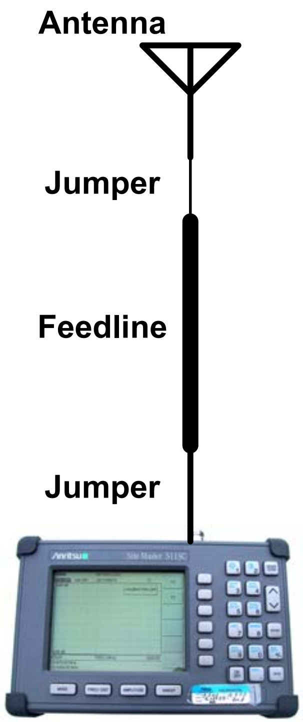
Return Loss (db)

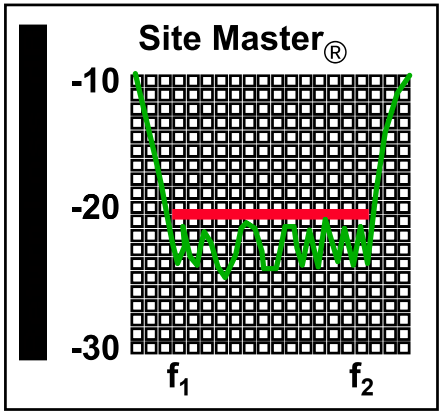
$$= 10 \times \mathrm{Log}_{10} \frac{RevPwr}{FwdPwr}$$

Reflection Coefficient (vector ratio)

$$= \frac{V_{reflected}}{V_{incident}}$$

Swept Return Loss and TDR Measurements





- It's a good idea to take swept and TDR return loss measurements of a new antenna at installation and to recheck periodically
  - maintain a printed or electronically stored copy of the analyzer output for comparison
  - most types of antenna or transmission line failures are easily detectable by comparison with stored data

What is the maximum acceptable value of return loss as seen in sketch above?

<u>Given:</u>

- Antenna VSWR max spec is 1.5 : 1 between f1 and f2
- Transmission line loss = 3 dB.

<u>Consideration & Solution:</u>

- From chart, VSWR of 1.5 : 1 is a return loss of -14 dB, measured at the antenna
- Power goes through the line loss of -3 db to reach the antenna, and -3 db to return
- Therefore, maximum acceptable observation on the ground is -14 -3 -3 = **- 20 dB.**

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What's a Site Master® ?

The Anritsu®/Wiltron Site Master®

The Site Master® is a "combination" instrument not much larger than a cigar box. In the field, it provides the functions of a spectrum analyzer with tracking sweep generator, directional coupler, and power meter. In the past, a trunk full of instruments were required to test communications antenna systems. Today, a Site Master® can even be carried to the tower top if needed.

- The Site Master® is one of the most convenient and popular "combination" instruments for testing communications feedlines and antennas
- Built Into a Site Master® are:
  - sweep signal generator
  - directional coupler
  - signal detector
  - processing software to display return loss and distance to fault
  - Optional: Spectrum Analyzer
  - Optional: Power Meter
  - Battery and charging circuit

Get Acquainted with the Site Master® Top Panel

Battery Charging LED

Port for external RF detector and attenuator to make power measuements.

Optional RF Input port for optional spectrum analyzer capabilities

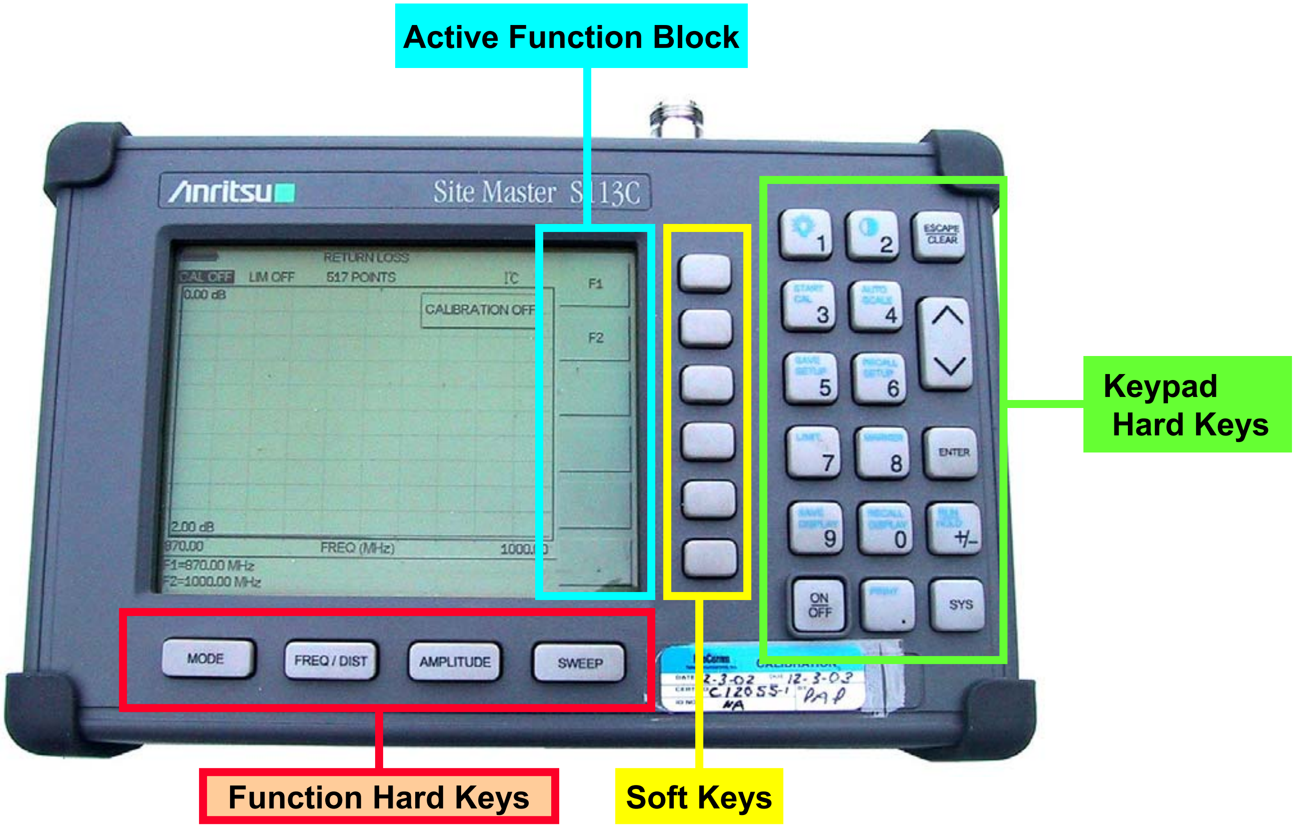
Serial Interface for direct printing and transferring traces to or from a PC.

RF input/output port for transmission line tests (VSWR, return loss, DTF)

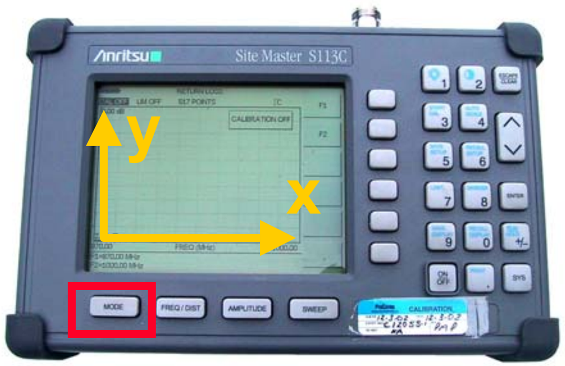
External Power jack. Accepts DC input 11-15 VDC, 1.2A max. Note! The inner pin is positive and the sleve is negative.

Power ON LED

Introducing the Site Master® Front Panel

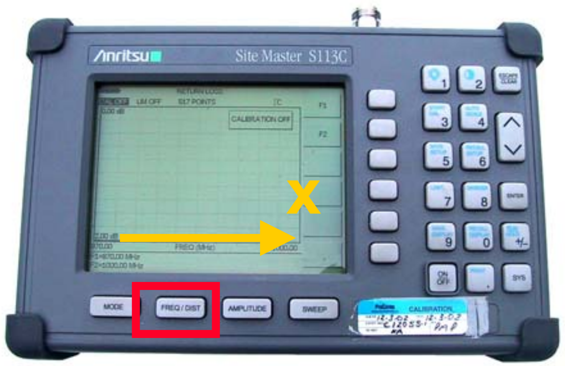


Setting the Mode: What Will Be Displayed



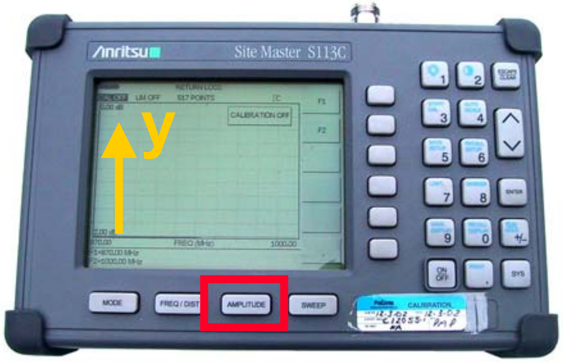
- The **MODE** button selects what will be displayed by the Site Master®:
  - Frequency on the X-Axis, along with
    - SWR on the Y-Axis, or
    - Return Loss on the Y-Axis, or
    - Cable Loss (one-port) on Y-Axis
  - Distance-to-Fault (DTF) on the X-Axis, with
    - SWR on the Y-Axis, or
    - Return Loss on the Y-Axis
  - Power Monitor
    - unit displays power level using optional Power Monitor and an attenuator
- In the Frequency and Distance-to-Fault (DTF) modes, the two top softkeys allow entry of the upper and lower frequency limits for the sweep using the keypad or the up-down control
  - active function block shows key labels

Setting Freq/Dist: x-Axis Units



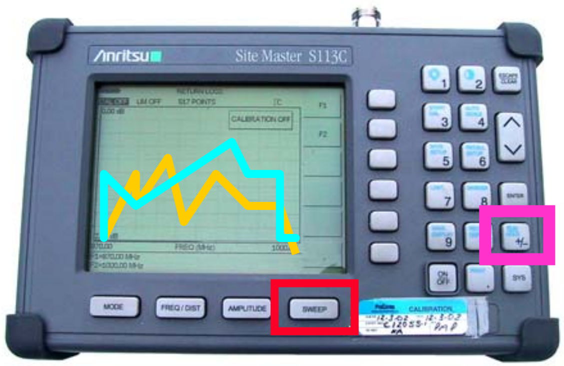
- In Frequency mode, the **FREQ/DIST** button selects the frequency range to be swept.
  - Press F1 softkey, select the low-end sweep frequency, press ENTER
  - Press F2 softkey, select the high-end sweep frequency, press ENTER
- In Distance-to-Fault mode, the **FREQ/DIST** button selects the distance range to be tested, and allows entry of necessary information about the line being swept
  - Press D1 softkey, select starting distance for sweep, press ENTER
  - Press D2 softkey, select maximum distance for sweep, press ENTER
  - Press DTF AID softkey for a window to guide selection of line or manual entry of line characteristics, OR
  - Press MORE softkey to individually enter the loss, velocity, type, and window desired

Setting AMPLITUDE: y-Axis Units



- In Frequency and Distance-to-Fault modes, the **AMPLITUDE** button allows entry of y-axis scale values:
  - Press the top softkey, set the desired top y-axis value, then press ENTER
    - you can key in the value or scroll with the up/down button
  - Press the second-from-top softkey, set desired bottom y-axis value, ENTER

Setting SWEEP: What Will Be Displayed



- The **SWEEP** button selects how the Site Master® will sweep and display its measurements:
  - Resolution can be set to 130, 259, or 517 bins on the x-axis
  - Single-Sweep will stop the normal continuous sweeping, and run one sweep each time the **RUN/HOLD** keypad button is pressed
  - Trace Math can add or subtract the immediate measurements to the measurements seen on the previous sweep, thereby showing a running delta
  - Trace Overlay will display a previously stored trace as an overlay for visual comparison with the current measurement
    - – the stored trace must have the same settings as the presently-measuring trace

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Site Master® Setup and Calibration

Site Master® Accessories

- The tough fabric carrying case provides travel protection and is a comfortable holder for the Site Master® when measuring
  - a pouch and zippered foam-lined carrier hold power supplies, terminations and adaptors
- The extension cable can be used to place the official reference point at the end of the cable
- Between-series adaptors can be used to connect the native Type-N connector with any other family of adapters.

Powering Up and Calibrating Before Use

- To provide reliable readings, Site Master® should be calibrated immediately prior to making important measurements
- When first powered up, Site Master® will show a welcome screen as it completes a self-test.
  - When prompted, press ENTER to begin normal operation, or wait five seconds and normal operation will begin automatically
  - If the internal battery is low, connect external DC power
- If the unit displays “CAL OFF”, recalibration is required before measuring
- Decide which location you wish to use as the “reference point” for the measurements: the top panel port of the Site Master®, or the end of a phase-stable extension cable
  - Site Master® must be calibrated using the “OSL” method: a reference open, reference short, and reference load connected to the reference point during calibration as requested in screen prompts
  - Calibration is also required if the temperature varies substantially, if the reference point is changed, or the measurement frequency is changed

Site Master® Accessories Used In Calibration

- If you will use an extension cable as the reference point, attach it now
- The most convenient calibration process uses the Anritsu® InstaCal fixture.
  - This device automatically presents an open, short, and load in response to automatic triggers during calibration
- If a recently certified InstaCal is not available, the manual calibration process must be used
- Press START CAL and follow the prompts, attaching the reference loads when requested
- At conclusion, you should see the CAL ON message displayed at the top of the screen

InstaCal Module

Precision Short & Open

Precision Load

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Site Master® Exercises

Exercise 1: Calibration using InstaCal

- Power up Site Master®
- Attach the phase-stable extension cable
- Set the frequency range as wide as your instrument allows
- Begin calibration and use the InstaCal device when prompted
- Observe the return loss for InstaCal in the termination mode

Example 2: Manual Calibration

- Power up Site Master®
- Attach the phase-stable extension cable
- Set the frequency range as wide as your instrument allows
- Begin calibration and use manual devices when prompted
  - Precision Open
  - Precision Short
  - Precision Termination
- Observe the return loss for the precision termination

Exercise 3: Return Loss of a Jumper

- Install the phase-stable extension cable
  - its far end will be the reference point for this session
- Ensure that calibration is valid (CAL ON)
- Test a jumper cable by attaching it to the reference port
  - Measure return loss over the band – does it pass?
  - Measure insertion loss over the band – is it acceptable?
  - Observe the return loss in the DTF mode
    - – do you detect the end of the cable at the correct distance?

Exercise 4: Sweep a Real Antenna

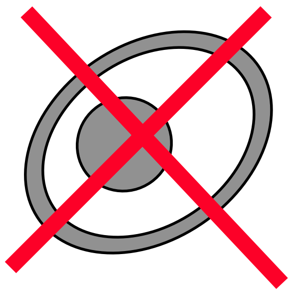
- Install the phase-stable extension cable
  - its far end will be the reference point for this session
- Ensure that calibration is valid (CAL ON)
- Test the entire feedline and antenna system by attaching it to the reference port
  - Measure return loss over the cellular band – does it pass?
  - Measure insertion loss over the cellular band – is it acceptable?
  - Observe the return loss in the DTF mode
    - – do you detect the end of the cable at the correct distance?

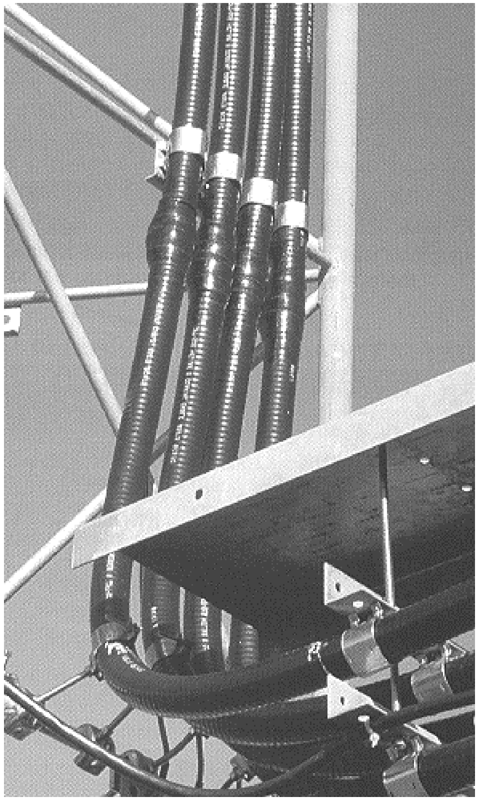
Course 703

Installation Practices and Other System Elements

Transmission Lines
Important Installation Practices

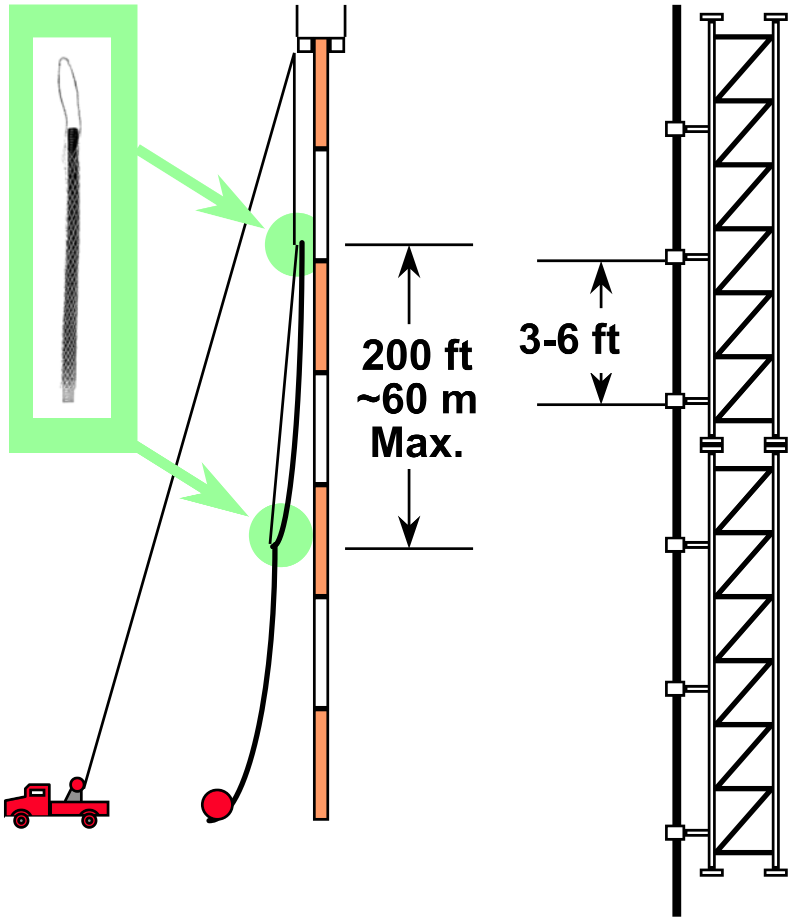
- Respect specified minimum bending radius!
  - Inner conductor must remain concentric, otherwise $\mathbf{Z_o}$ changes
  - Dents, kinks in outer conductor change $\mathbf{Z_o}$
- Don't bend large, stiff lines (1-5/8" or larger) to make direct connection with antennas
- Use appropriate jumpers, weatherproofed properly.
- Secure jumpers against wind vibration.





Transmission Lines
More Important Installation Practices

- During hoisting
  - Allow line to support its own weight only for distances approved by manufacturer
  - Deformation and stretching may result, changing the Z_o
  - Use hoisting grips, messenger cable
- After mounting
  - Support the line with proper mounting clamps at manufacturer's recommended spacing intervals
  - In the long term, strong winds can set up damaging metal-fatigue-inducing vibrations



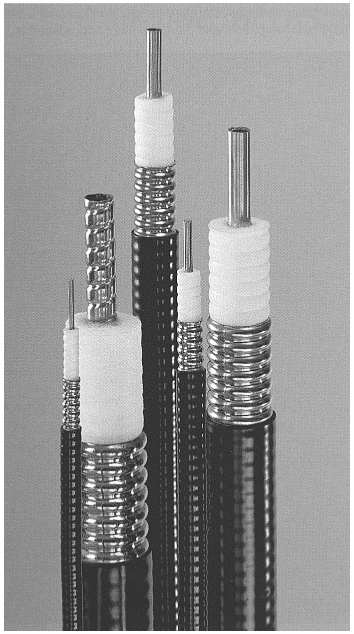
Types Of Transmission Lines

Physical Characteristics

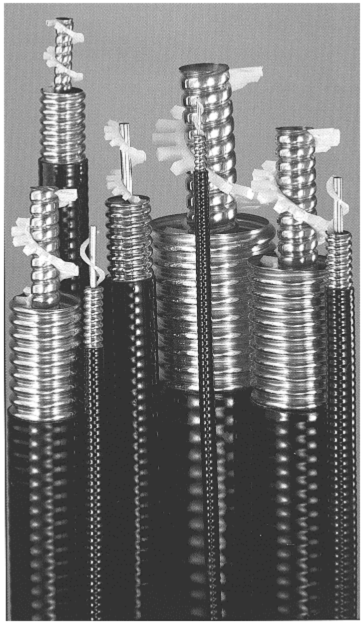
- Type of line
  - Coaxial, stripline, open-wire
  - Balanced, unbalanced
- Physical configuration
  - Dielectric:
    - air
    - foam
  - Outside surface
    - unjacketed
    - jacketed
- Size (nominal outer diameter)
  - 1/4”,1/2”, 7/8”, 1-1/4”, 1-7/8”, 2-1/4”, 3”

Typical coaxial cables

Used as feeders in wireless applications



Foam Dielectric

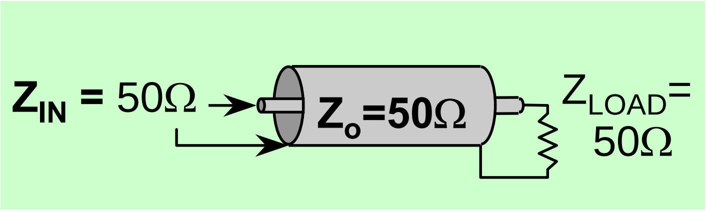


Air Dielectric

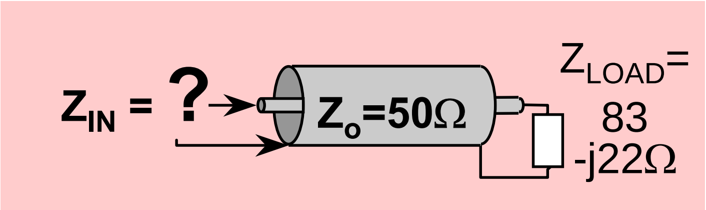
Transmission Lines
Special Electrical Properties of Quarter-Wave Sections

- Transmission lines have impedance-transforming properties
  - When terminated with same impedance as $\mathbf{Z_o}$, input to line appears as impedance $\mathbf{Z_o}$
  - When terminated with impedance different from $\mathbf{Z_o}$, input to line is a complex function of frequency and line length. Use Smith Chart or formulae to compute
- Special case of interest: Line section one-quarter wavelength long has convenient properties useful in matching networks
  - $\mathbf{Z_{IN} = (Z_o^2)/(Z_{LOAD})}$

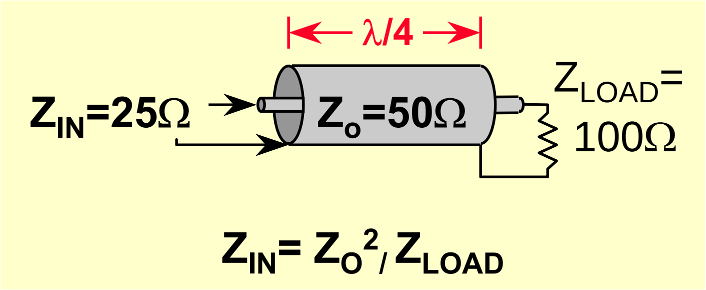
Matched condition



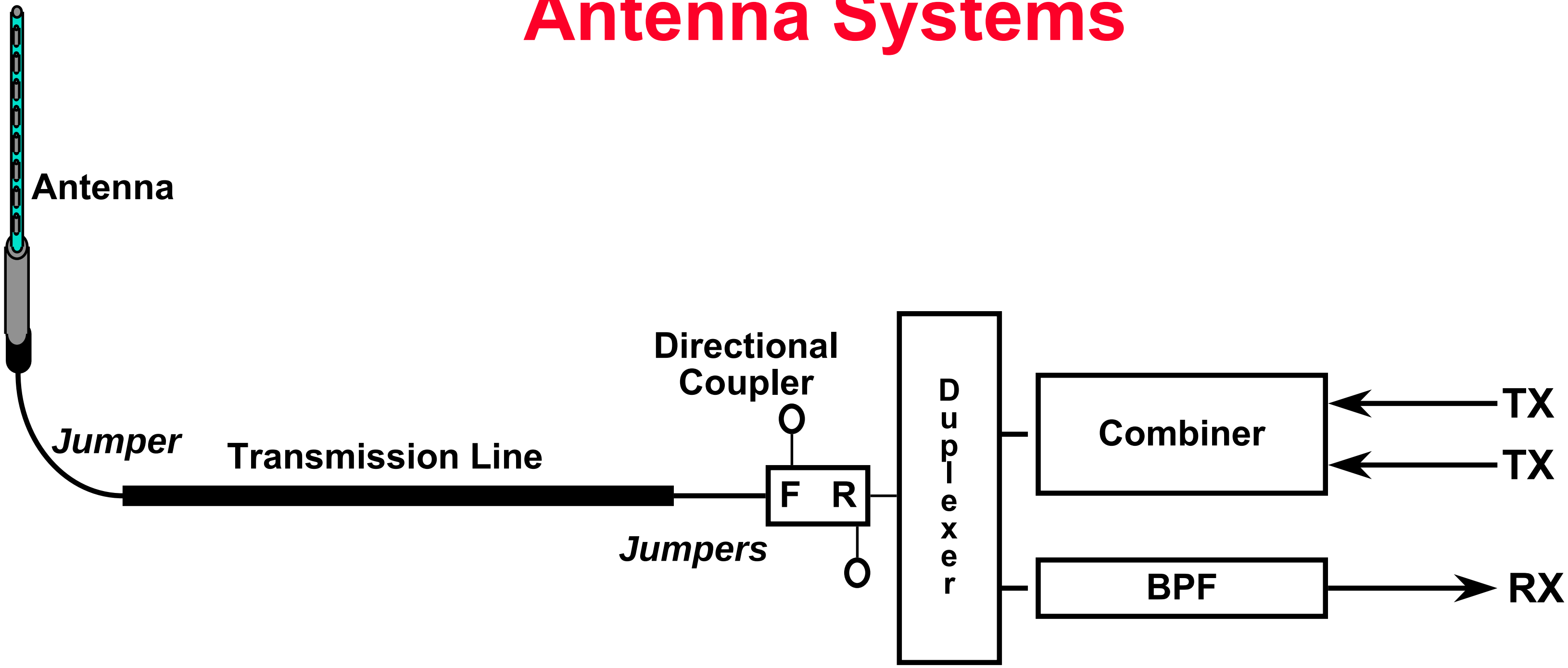
Mismatched condition



Deliberate mismatch for impedance transformation



Antenna Systems



- Antenna systems include more than just antennas
- Transmission Lines
  - Necessary to connect transmitting and receiving equipment
- Other Components necessary to achieve desired system function
  - Filters, Combiners, Duplexers - to achieve desired connections
  - Directional Couplers, wattmeters - for measurement of performance
- The BTS Manufacturer's system may include some or all of these items
  - Remaining items are added individually as needed by system operator

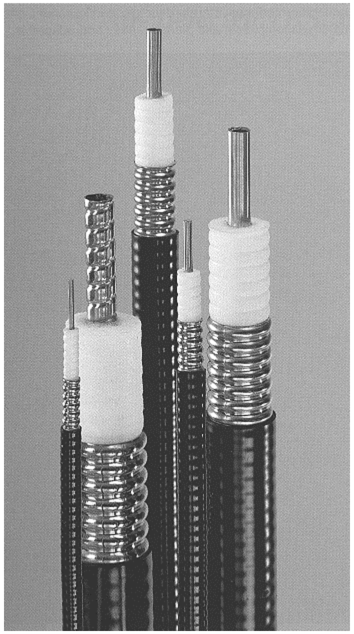
Characteristics Of Transmission Lines

Physical Characteristics

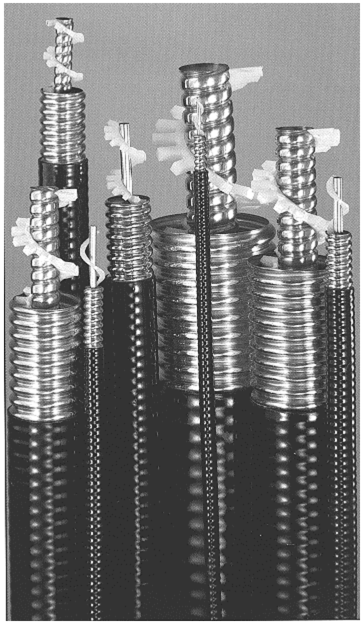
- Type of line
  - Coaxial, stripline, open-wire
  - Balanced, unbalanced
- Physical configuration
  - Dielectric:
    - air
    - foam
  - Outside surface
    - unjacketed
    - jacketed
- Size (nominal outer diameter)
  - 1/4”,1/2”, 7/8”, 1-1/4”, 1-5/8”, 2-1/4”, 3”

Typical coaxial cables

Used as feeders in wireless applications



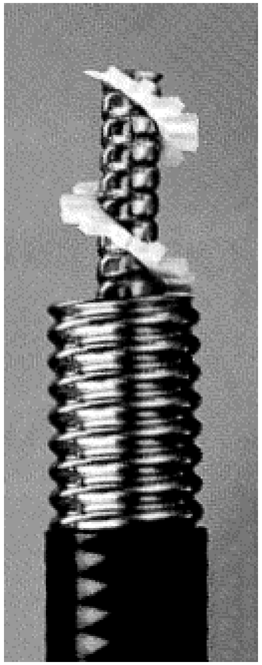
Foam Dielectric



Air Dielectric

Transmission Lines
Some Practical Considerations

- Transmission lines practical considerations
  - Periodicity of inner conductor supporting structure can cause VSWR peaks at some frequencies, so specify the frequency band when ordering
  - Air dielectric lines
    - lower loss than foam-dielectric; dry air is excellent insulator
    - shipped pressurized; do not accept delivery if pressure leak
  - Foam dielectric lines
    - simple, low maintenance; despite slightly higher loss
    - small pinholes and leaks can allow water penetration and gradual attenuation increases



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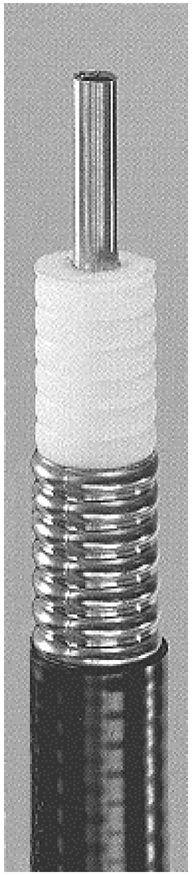
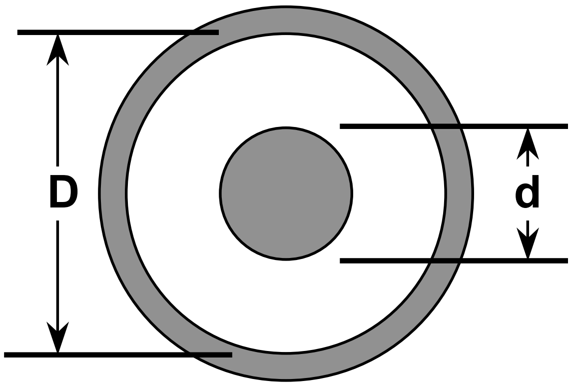


Foam Dielectric

Characteristics Of Transmission Lines, Continued

Electrical Characteristics

- Attenuation
  - Varies with frequency, size, dielectric characteristics of insulation
  - Usually specified in **dB/100 ft** and/or **dB/100 m**
- Characteristic impedance $\mathbf{Z_0}$ (50 ohms is the usual standard; 75 ohms is sometimes used)
  - Value set by inner/outer diameter ratio and dielectric characteristics of insulation
  - Connectors must preserve constant impedance (see figure at right)
- Velocity factor
  - Determined by dielectric characteristics of insulation.
- Power-handling capability
  - Varies with size, conductor materials, dielectric characteristics



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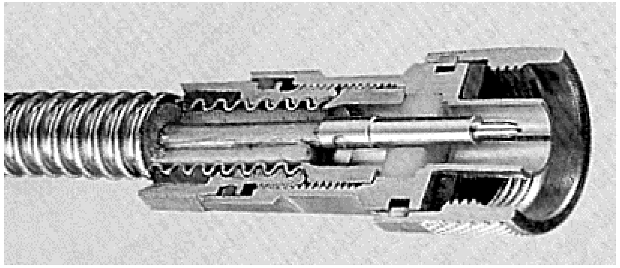

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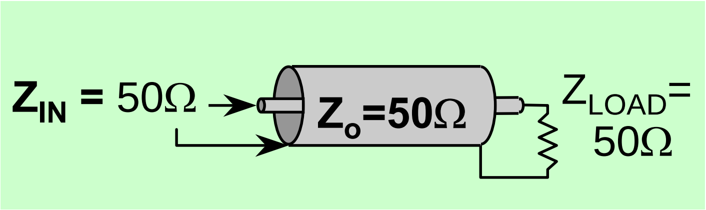
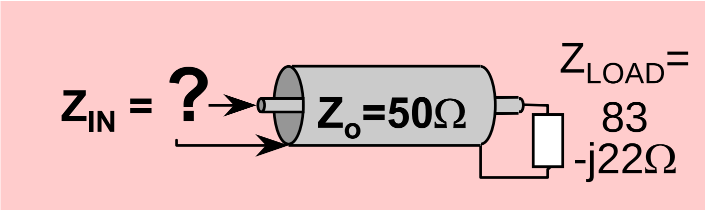
Matched condition



Mismatched condition



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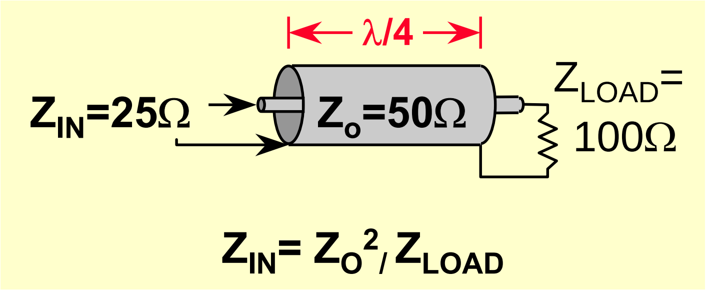

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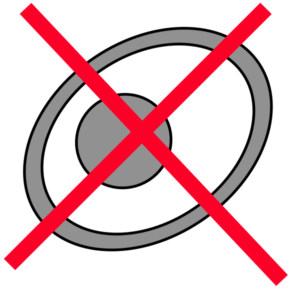
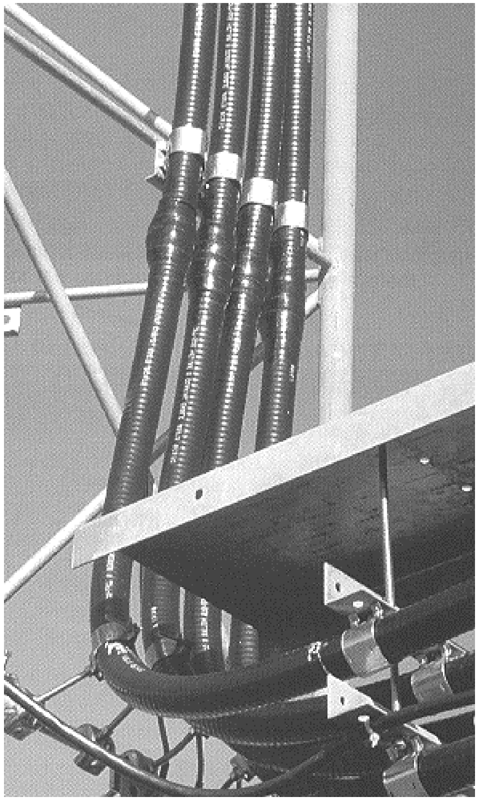
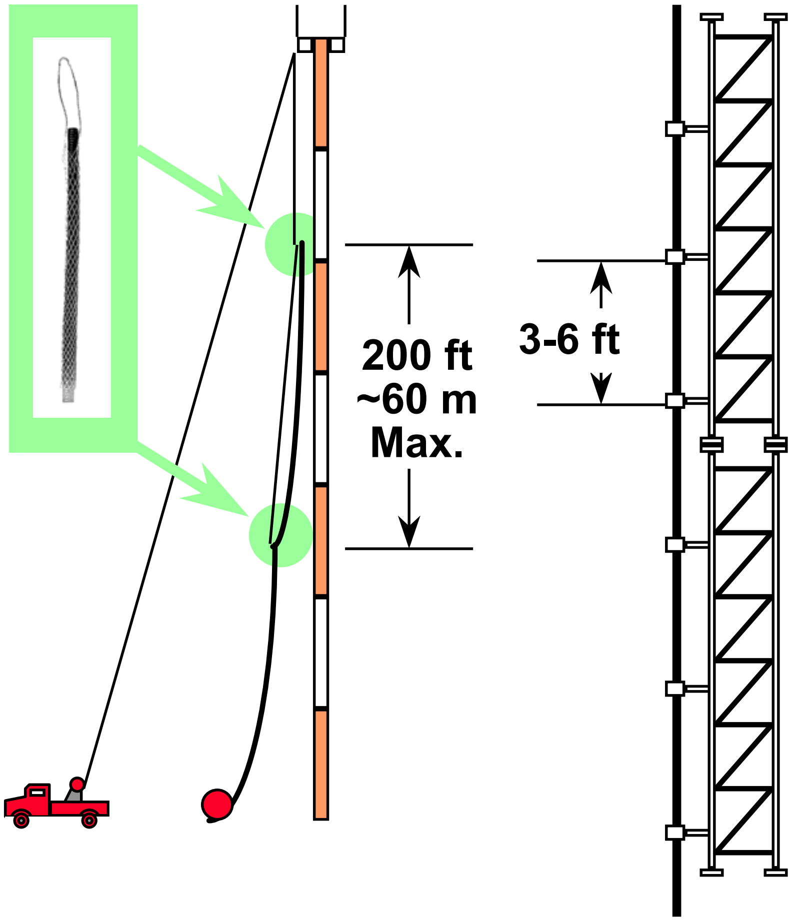
- Use appropriate jumpers, weatherproofed properly.
- Secure jumpers against wind vibration.





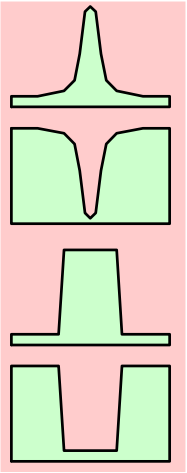
Transmission Lines
Important Installation Practices, Continued

- During hoisting
  - Allow line to support its own weight only for distances approved by manufacturer
  - Deformation and stretching may result, changing the Z_o
  - Use hoisting grips, messenger cable
- After mounting
  - Support the line with proper mounting clamps at manufacturer's recommended spacing intervals
  - Strong winds will set up damaging metal-fatigue-inducing vibrations

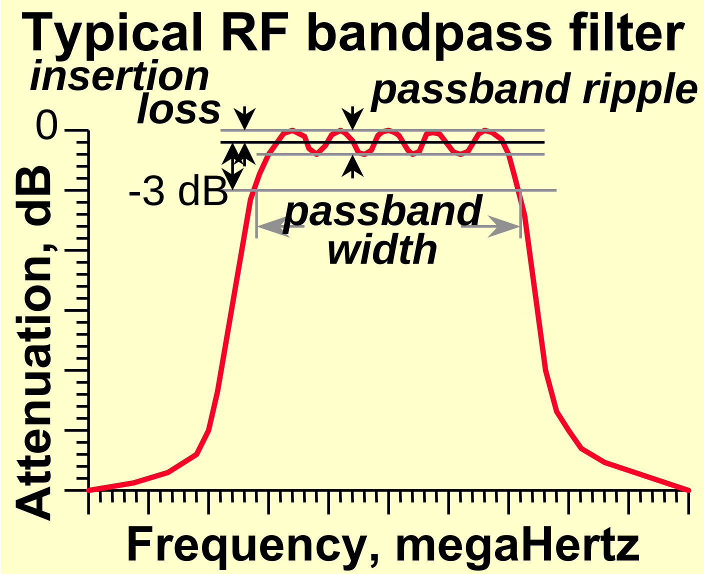


RF Filters
Basic Characteristics And Specifications

- Types of Filters
  - Single-pole:
    - pass
    - reject (notch)
  - Multi-pole:
    - band-pass
    - band-reject



- Key electrical characteristics
  - Insertion loss
  - Passband ripple
  - Passband width
    - upper, lower cutoff frequencies
  - Attenuation slope at band edge
  - Ultimate out-of-band attenuation

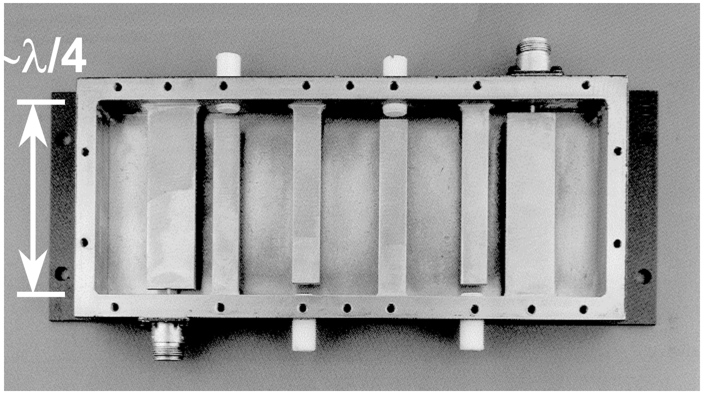


Typical bandpass filters have insertion loss of 1-3 dB. and passband ripple of 2-6 dB.
Bandwidth is typically 1-20% of center frequency, depending on application. Attenuation slope and out-of-band attenuation depend on # of poles & design

RF Filters
Types And Applications

- Filters are the basic building blocks of duplexers and more complex devices
- Most manufacturers' network equipment includes internal bandpass filters at receiver input and transmitter output
- Filters are also available for special applications
- Number of ***poles*** (filter elements) and other design variables determine filter's electrical characteristics
  - Bandwidth rejection
  - Insertion loss
  - Slopes
  - Ripple, etc.

Typical RF Bandpass Filter



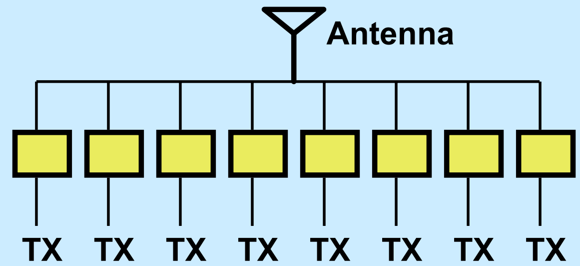
Notice construction: RF input excites one quarter-wave element and electromagnet fields propagate from element to element, finally exciting the last element which is directly coupled to the output.

Each element is individually set and forms a pole in the filter's overall response curve.

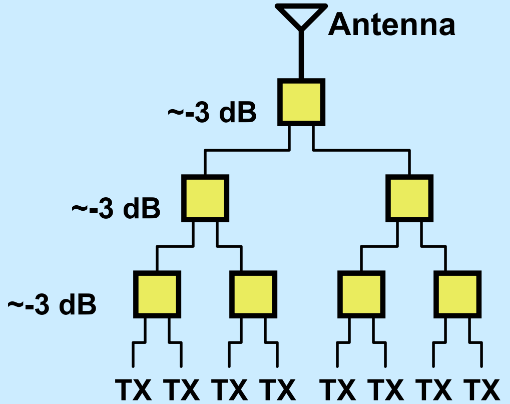
Basics Of Transmitting Combiners

- Allows multiple transmitters to feed single antenna, providing
  - Minimum power loss from transmitter to antenna
  - Maximum isolation between transmitters
- Combiner types
  - Tuned
    - low insertion loss **~1-3 dB**
    - transmitter frequencies must be significantly separated
  - Hybrid
    - insertion loss **-3 dB** per stage
    - no restriction on transmitter frequencies
  - Linear amplifier
    - linearity and intermodulation are major design and operation issues

Typical tuned combiner application

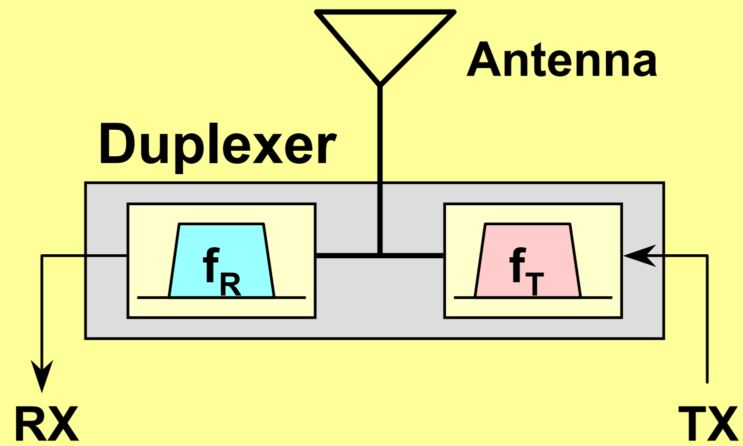


Typical hybrid combiner application



Duplexer Basics

- Duplexer allows simultaneous transmitting and receiving on one antenna
  - Nortel 1900 MHz BTS RFFEs include internal duplexer
  - Nortel 800 MHz BTS does not include duplexer but commercial units can be used if desired
- Important duplexer specifications
  - TX pass-through insertion loss
  - RX pass-through insertion loss
  - TX-to-RX isolation at TX frequency (RX intermodulation issue)
  - TX-to-RX isolation at RX frequency (TX noise floor issue)
  - Internally-generated IMP limit specification



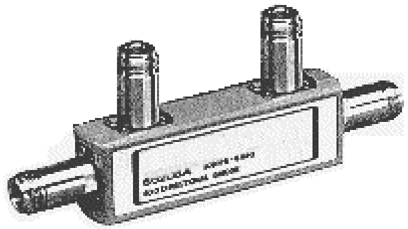
Principle of operation

Duplexer is composed of individual bandpass filters to isolate TX from RX while allowing access to antenna for both. Filter design determines actual isolation between TX and RX, and insertion loss TX-to-Antenna and RX-to-Antenna.

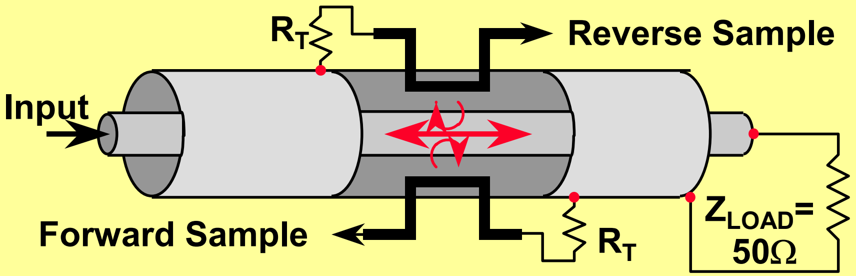
Directional Couplers

- Couplers are used to measure forward and reflected energy in a transmission line; it has 4 ports:
  - Input (from TX), Output (to load)
  - Forward and Reverse Samples
- Sensing loops probe E& I in line
  - Equal sensitivity to E & H fields
  - Terminations absorb induced current in one direction, leaving only sample of other direction
- Typical performance specifications
  - Coupling factor **~20, ~30, ~40 dB**., order as appropriate for application
  - Directivity **~30-~40 dB., f($)**
    - defined as relative attenuation of *unwanted* direction in each sample

Typical directional coupler

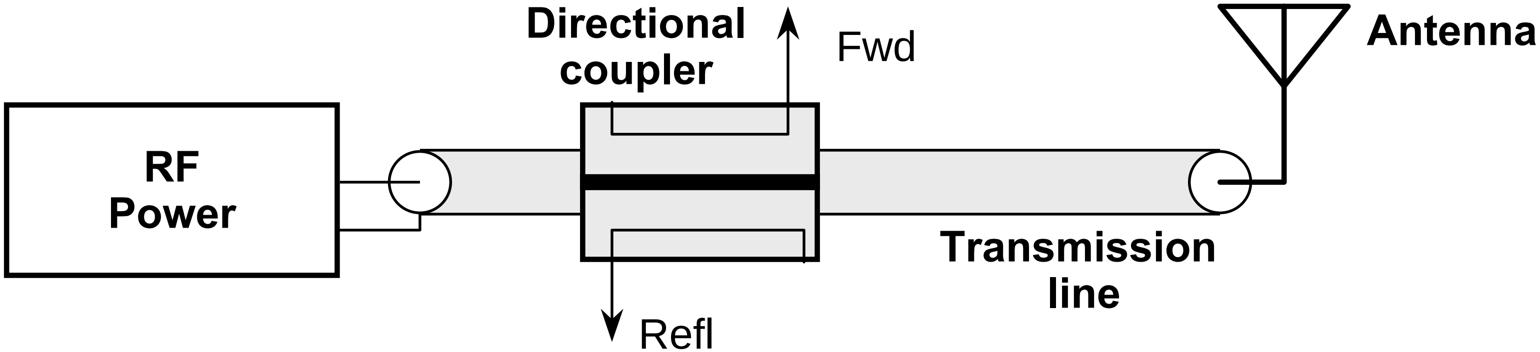


Principle of operation



Main line's E & I induce equal signals in sense loops. E is direction-independent, but I's polarity depends on direction and cancels sample induced in one direction. Thus sense loop signals are directional. One end is used, the other terminated.

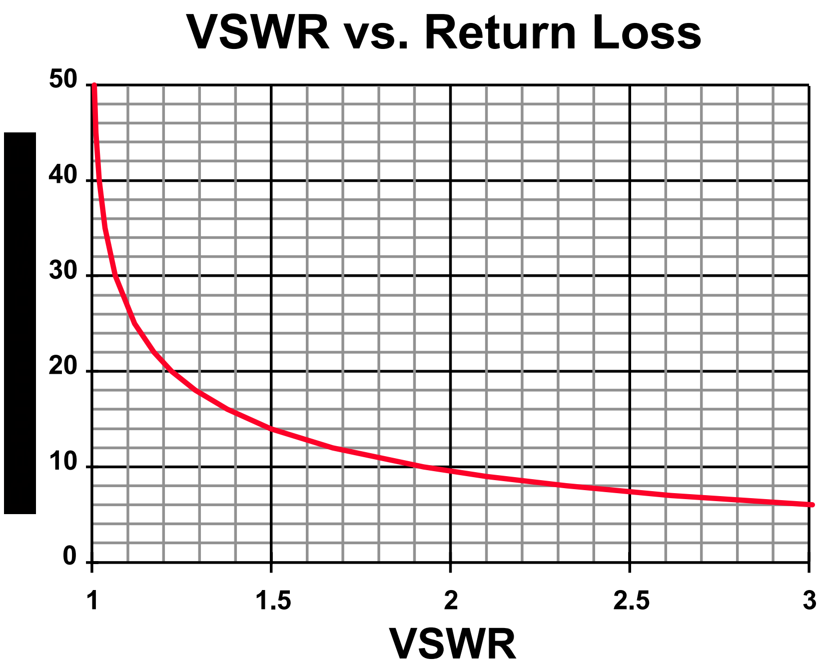
Return Loss And VSWR Measurement



A perfect antenna will absorb and radiate all the power fed to it

- Real antennas absorb most of the power, but reflect a portion back down the line
- A Directional Coupler or Directional Wattmeter can be used to measure the magnitude of the energy in both forward and reflected directions
- Antenna specs give maximum reflection over a specific frequency range
- Reflection magnitude can be expressed in the forms *VSWR*, *Return Loss*, or *reflection coefficient*
  - VSWR = Voltage Standing Wave Ratio

Return Loss and VSWR



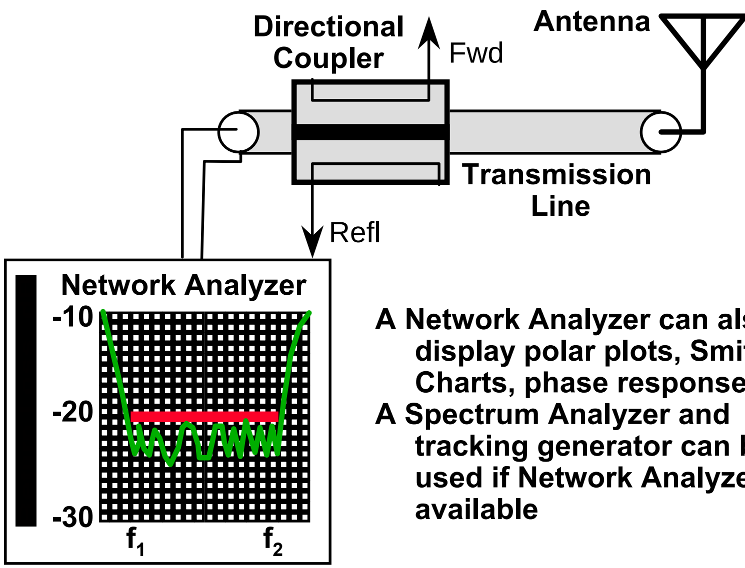
Forward Power, Reflected Power, Return Loss, and VSWR can be related by these equations and the graph.

- Typical antenna VSWR specifications are 1.5:1 maximum over a specified band.
- **VSWR 1.5 : 1**
  = 14 db return loss
  = 4.0% reflected power

$$\text{Return Loss, dB} = 10 \times \text{Log}_{10}\left(\frac{\text{Reflected Power}}{\text{Forward Power}}\right)$$

$$\text{VSWR} = \frac{1 + \sqrt{\frac{\text{Reflected Power}}{\text{Forward Power}}}}{1 - \sqrt{\frac{\text{Reflected Power}}{\text{Forward Power}}}}$$

Swept Return Loss Measurements



A Network Analyzer can also display polar plots, Smith Charts, phase response
A Spectrum Analyzer and tracking generator can be used if Network Analyzer not available

- It's a good idea to take swept or TDR return loss measurements of a new antenna at installation and to recheck periodically
  - maintain a printed or electronically stored copy of the analyzer output for comparison
  - most types of antenna or transmission line failures are easily detectable by comparison with stored data

What is the maximum acceptable value of return loss as seen in sketch above?

<u>Given:</u>

- Antenna VSWR max spec is 1.5 : 1 between f1 and f2
- Transmission line loss = 3 dB.

<u>Consideration & Solution:</u>

- From chart, VSWR of 1.5 : 1 is a return loss of -14 dB, measured at the antenna
- Power goes through the line loss of -3 db to reach the antenna, and -3 db to return
- Therefore, maximum acceptable observation on the ground is -14 -3 -3 = **- 20 dB.**