Reflected Power Control in Contemporary Transmission Systems

Karl D. Lahm, P.E.

Broadcast Transmission Services, LLC

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Presentation Contents

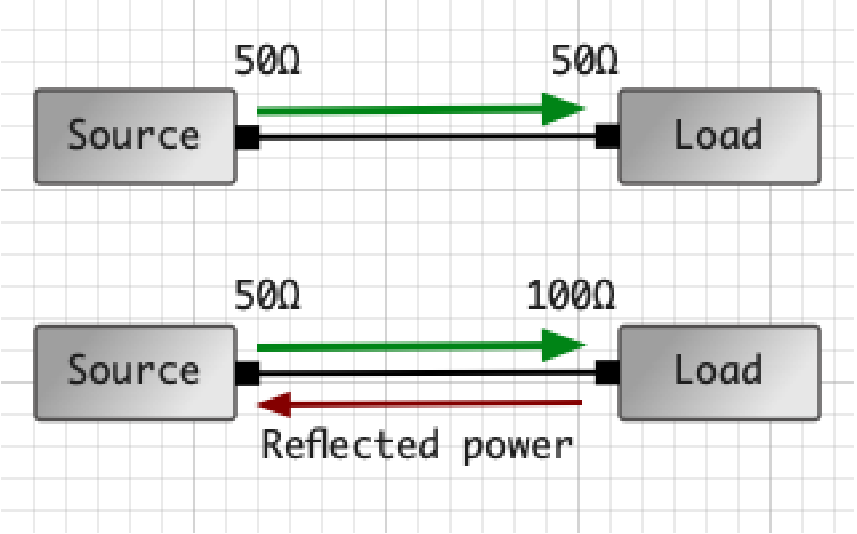
- Basic theory of forward and reflected power, VSWR, etc.
- Causes of excessive reflected power
- Transmitter reflected power monitoring & control features
- Methods of limiting excessive reflected power
- Contemporary transmitter topology and implications
- Testing of reflected power control functions

Forward & Reflected Power Basics

- Forward power
- Reflected power
- Reflection causes
- SWR, reflected power, VSWR equivalence
- Threshold of concern

Basic Definitions

- Forward Power
  - Delivered from transmitter into transmission line
    - Antenna input + transmission line loss + reflected
- Reflected Power
  - Caused by downstream mismatch/discontinuity
  - Absorbed by transmitter system



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- Power Reflection Sources
  - Discontinuities within transmission lines
  - Mismatch at antenna input or within internal antenna elements & feed lines

Causes of Excessive Reflected Power

- Environmental
  - Ice buildup on antenna
  - Lightning strike damage
  - Falling ice damage
  - Moisture on antenna
  - Static electricity buildup
- Deterioration
  - RF switch internal fault
  - Antenna/line corrosion
  - Inner connector wear
- Latent Design/Installation Defects
  - Split inner connectors (bullets)
  - Improper inner connector sizing (thinwall vs thickwall)
  - Loose line junctions
  - Insufficient power rating
- Pressurization loss
  - Dehydrator failure or empty gas tank
  - Vandalism - gun bullet penetration of line
- Other
  - Vehicle/animal collision

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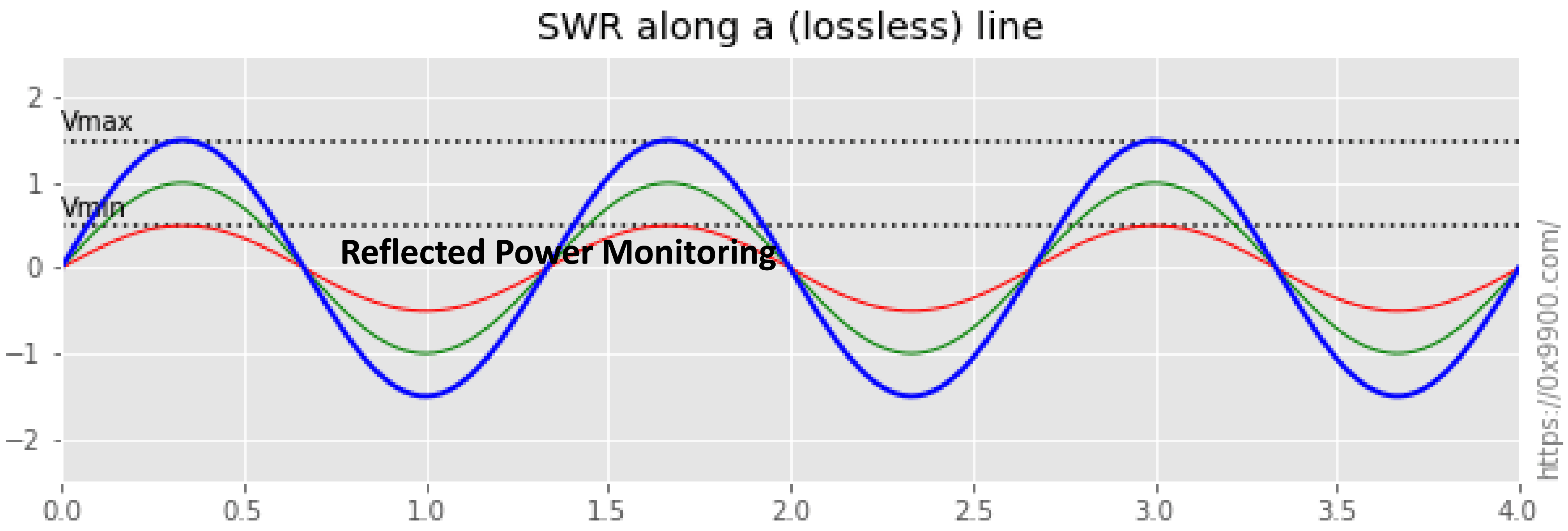
When Reflected Power Isn’t Controlled!

Reflection Measures

- Standing wave ratio SWR/VSWR
  - Directly measured by network analyzers
  - Often measured by transmitters etc.
- Power ratio (reflected/forward)
  - Directly measured by power meters, via directional couplers
  - Often measured by transmitters, etc.
- Reflection coefficient p
  - Directly measured by network analyzers
  - Seldom measured by transmitters etc.
- Impedance Z
  - Directly measured by network analyzers
  - Seldom measured by transmitters, etc.

Standing Wave Pattern with Reflected Signal



Green = Forward, incident wave   Red = Reflected wave   Blue = Composite wave

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Reflection Measure Relationships

- Reflection Coefficient
  - $p = \left(\frac{Z-Zo}{Z+Zo}\right)$
  - $p = \sqrt{({}^{P_{refl}}/{}_{P_{fwd}})}$
  - $p = {}^{(SWR-1)}/{}_{(SWR+1)}$
- Standing Wave Ratio
  - $SWR = {}^{Z}/{}_{Z_o}$
  - $SWR = {}^{(1+\sqrt{\frac{P_{refl}}{P_{fwd}}})}/{}_{(1-\sqrt{\frac{P_{refl}}{P_{fwd}}})}$
  - $SWR = {}^{(1+p)}/{}_{(1-p)}$
- Power Ratio
  - $\frac{P_{refl}}{P_{fwd}} = \left(\frac{Z-Zo}{Z+Zo}\right)^2$
  - $\frac{P_{refl}}{P_{fwd}} = p^2$
  - $\frac{P_{refl}}{P_{fwd}} = \left(\frac{SWR-1}{SWR+1}\right)^2$

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Typical Reflection Thresholds of Concern
(specified by equipment manufacturers)

- Reflected Power
  - 1 to 4 percent
- SWR/VSWR
  - 1.2:1 to 1.5:1
- Reflection Coefficient
  - 0.1 to 0.2
  - -20 dB to -14 dB
- Impedance
  - 41 to 33 and 61 to 75 Ohms in 50 Ohm systems
  - 61 to 50 and 92 to 112 Ohms in 75 Ohm systems

Essential Principles of Reflected Power Control

- Detection & control schemes cannot prevent excessive reflected power
  - Physical damage initiates discontinuity and reflection
  - Physical damage cannot be anticipated/avoided
  - Damage is proportional to energy – magnitude of reflection and time

- Control schemes can limit damage once excessive reflected power has been detected
  - Operation can be interrupted and/or ceased
  - Power can be reduced
  - Fast response speed is essential

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Reflected Power Monitoring & Control

- External devices
  - Directional coupler segments with built-in detectors
  - Sensors that connect to existing directional couplers
  - Transmitter remote control system
- Transmitter output monitoring & output control
  - Internal directional coupler & detector
- Multistage output monitoring & transmitter interface
  - External directional coupler(s)
  - Internal or external detectors
- External test signal injection & monitoring
  - Dielectric “RF Hawkeye” system

Forward & Reflected Power Sampling

- 2-port directional coupler(s)
  - Forward & reflected samples
- Detector circuit
  - Typically part of transmitter
  - Rectifier/filter
  - RF to DC converter chips

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Directional Couplers with Detector

For All Radio & Digital Television Broadcast Applications

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Plug-In RF Sensor

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Reflected Power Monitoring Methods

- Absolute Reflected Power
  - Longstanding monitoring method
  - Independent of reflected/forward ratio, SWR, etc.
  - Control threshold value set to limit physical damage
- Reflected/Forward Ratio
  - Independent of power level
  - Facilitated by contemporary logarithmic detector chips
  - Control threshold value set to preserve transmitter performance

Transmitter Reflected Power Control Methods

- RF output disabled when absolute limit exceeded

- RF output disabled & re-enabled (a/k/a restrike)
  - Full power re-enabled
  - Reduced power re-enabled
  - Shutdown after 3 faults

- SWR foldback: holding reflected power at a limiting value

- Combinations of these features

Reflected Power Control Method Comparison

RF Output Interruption

Interrupts OTA signal
Extinguishes arc(s)
Prevents additional deterioration
OTA glitch impacts viewers

Power Foldback

Maintains OTA signal
May maintain arc(s)
Allows additional deterioration
Slows heating
Most useful with icing etc.

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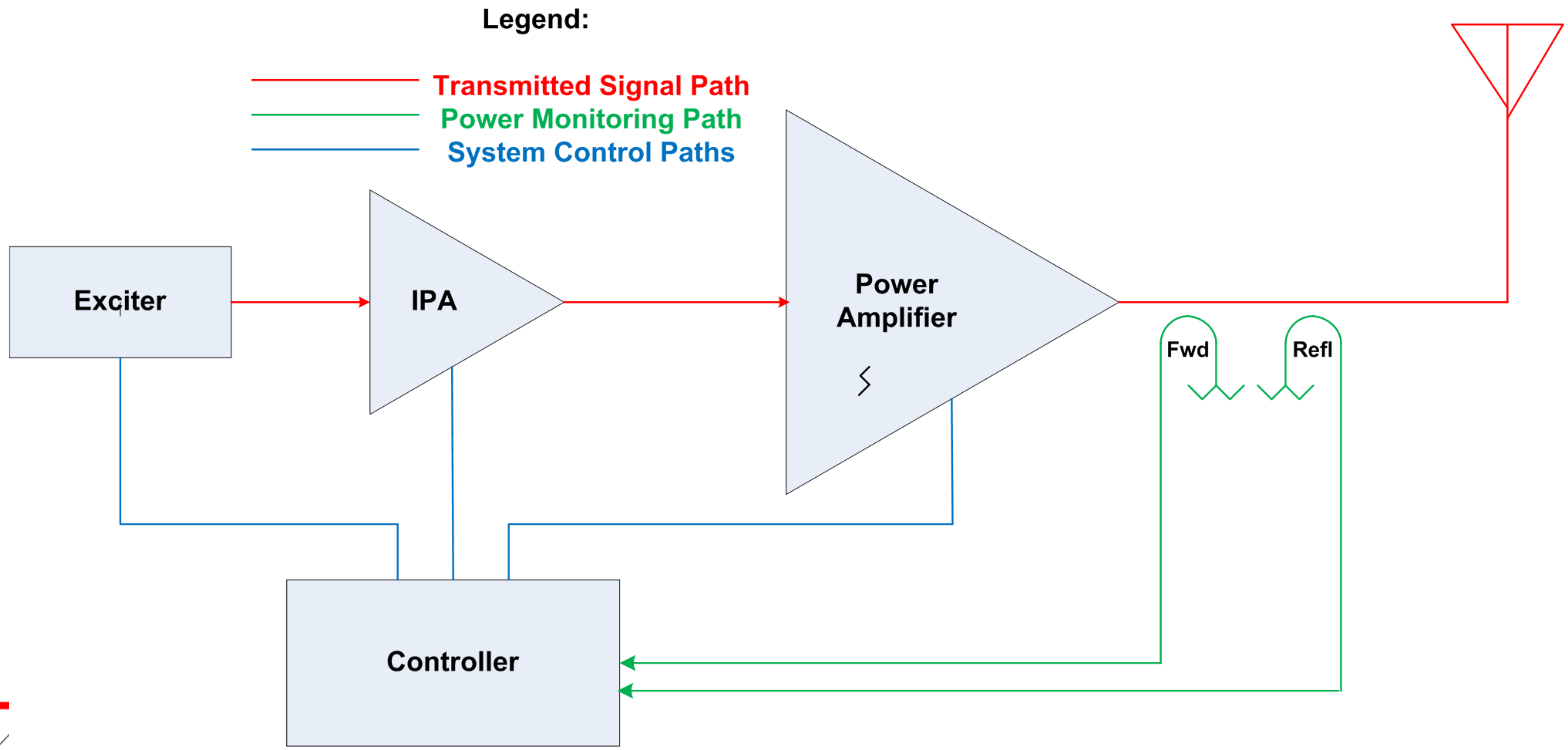
SWR Foldback Behavior (2% threshold)

	Power		Current		Peak
SWR	Reflected	Forward	RMS	Maximum	Voltage
	(Watts)	(Watts)	(Amperes)	(Amperes)	(Volts)
1	0	10,000	14.1	14.1	1000
1.1	23	10,000	14.8	15.6	1050
1.2	83	10,000	15.4	17.0	1100
1.3	170	10,000	16.0	18.4	1150
1.33	200	9,970	16.1	18.8	1163
1.4	200	7,200	14.0	16.8	1018
1.5	200	5,000	12.0	15.0	884
1.6	200	3,756	10.7	13.9	797
1.7	200	2,976	9.7	13.1	736
1.8	200	2,450	9.0	12.6	693
1.9	200	2,077	8.4	12.2	661
2	200	1,800	8.0	12.0	636

Simple Transmitter



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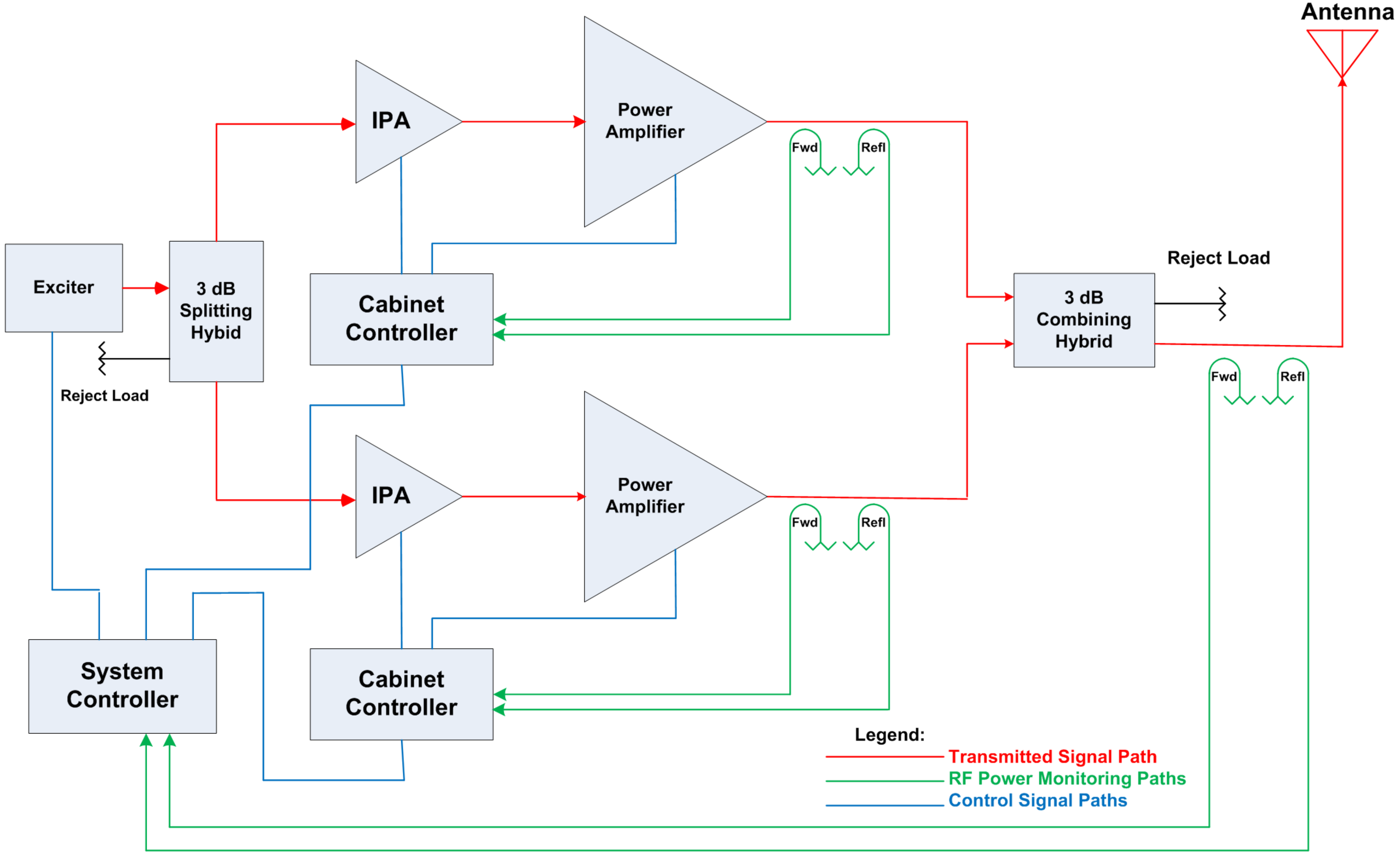
Two-Cabinet Transmitter



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Contemporary Transmitter Topology

- Massively paralleled amplifiers
  - Amplifier tray of multiple amplifier pallets
  - “Power Block” of multiple amplifier trays
  - Cabinets of multiple “Blocks” or amplifier trays
  - Two or more power-combined cabinets
- Power combiners used at all stages
  - Power combiners have reject loads
  - Significant reflected power is dissipated in reject loads
  - Reflected power decreases dramatically as location backs up the combining chain

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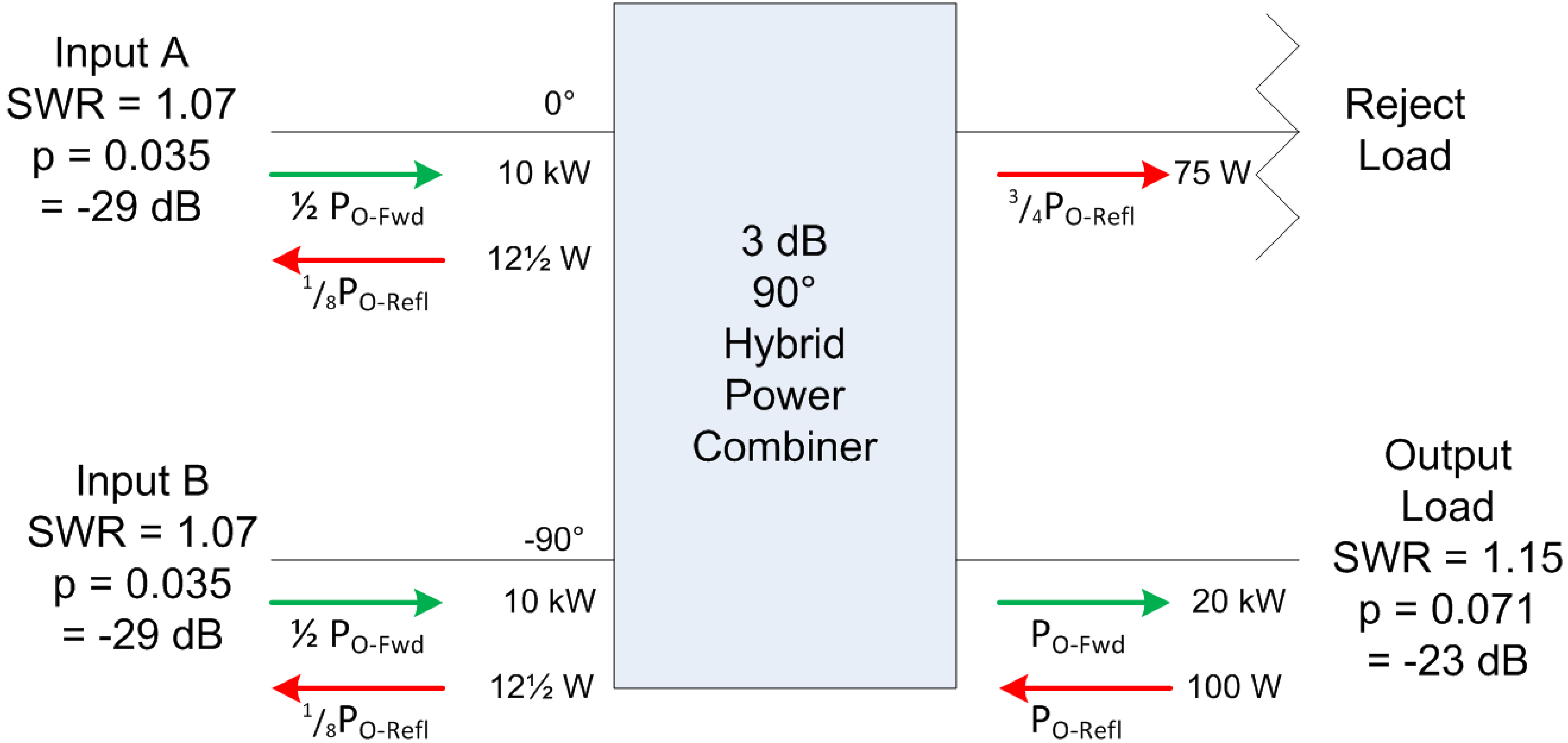
Basic 4-port Combiner



References: M/A-Com Application Note M560, V2.00, Table III, p.10-8
Whittaker, Jerry, Power Vacuum Tubes Handbook, 2nd. Ed., chapter 7.4.2, p.391

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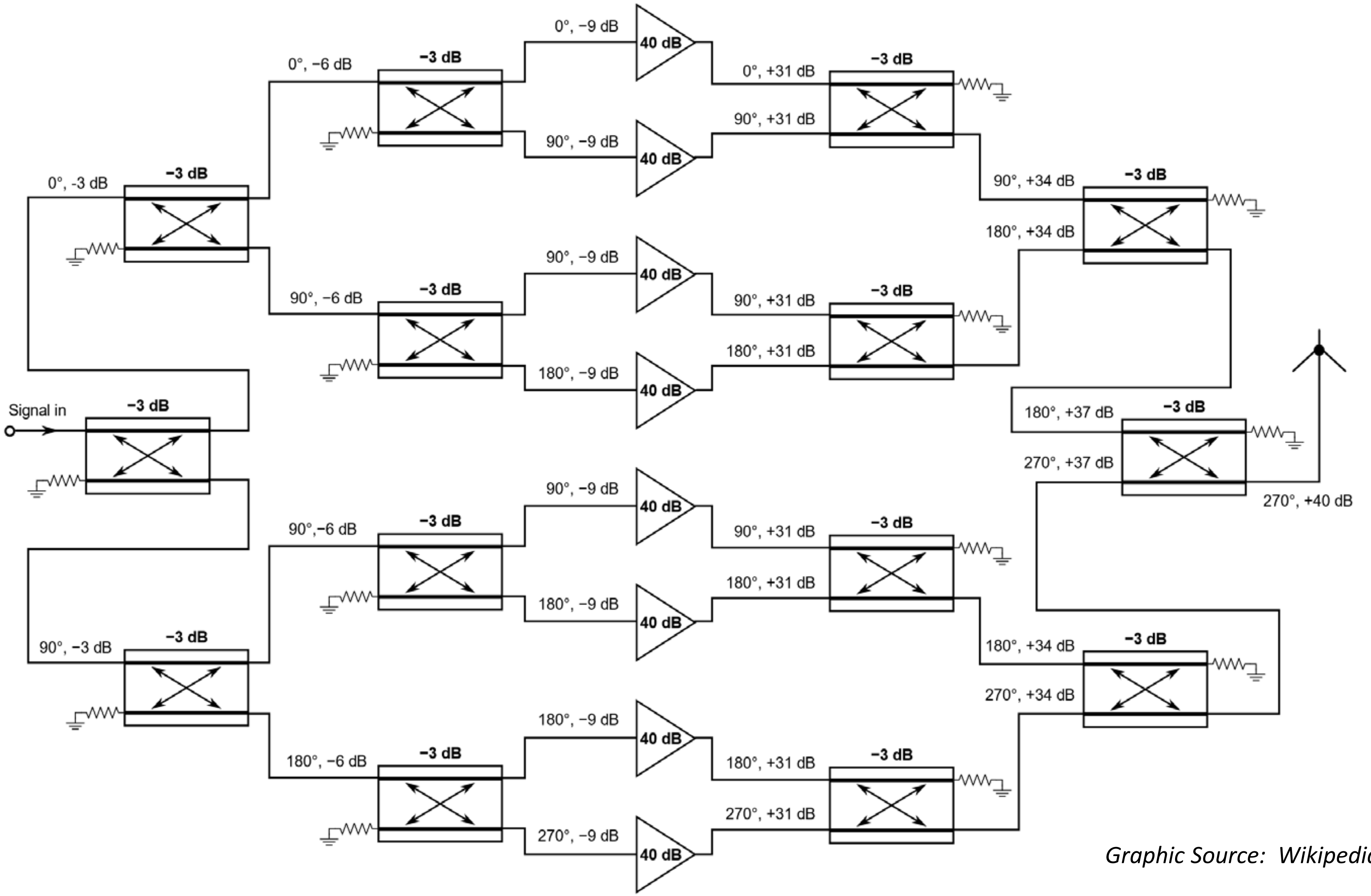
Generic 8-Amplifier Combined Block



Graphic Source: Wikipedia/Courtesy Spinningspark

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Reflected Power Control in Paralleled Amplifier Transmitters (1)

- Final Combined Output Monitoring & System Control
  - Limits upstream damage to output combining and filtering equipment
  - Limits downstream damage to transmission line, antenna, etc.
  - Threshold set based on tolerable system output mismatch
- Cabinet and/or Power Block Monitoring & Control
  - Limits upstream damage to cabinet and/or power block combiners
  - Limits downstream damage to next combining stage
  - Threshold set based on tolerable cabinet/block output mismatch
- Amplifier Tray Monitoring & Control
  - Limits upstream damage to amplifier tray pallet combiners & networks
  - Limits downstream damage to next combining stage
  - Threshold set based on tolerable amplifier output mismatch

Reflected Power Control in Paralleled Amplifier Transmitters (2)

- Monitoring after final combiner is essential to limiting power dissipated in faulty filter, line and/or antenna.
  - Monitoring upstream of combiner(s) will see only a fraction of reflected power at the output.
  - Reducing trip threshold upstream to compensate for reflected power dissipated in reject load may cause nuisance trips when cabinet/block is operating within design range.

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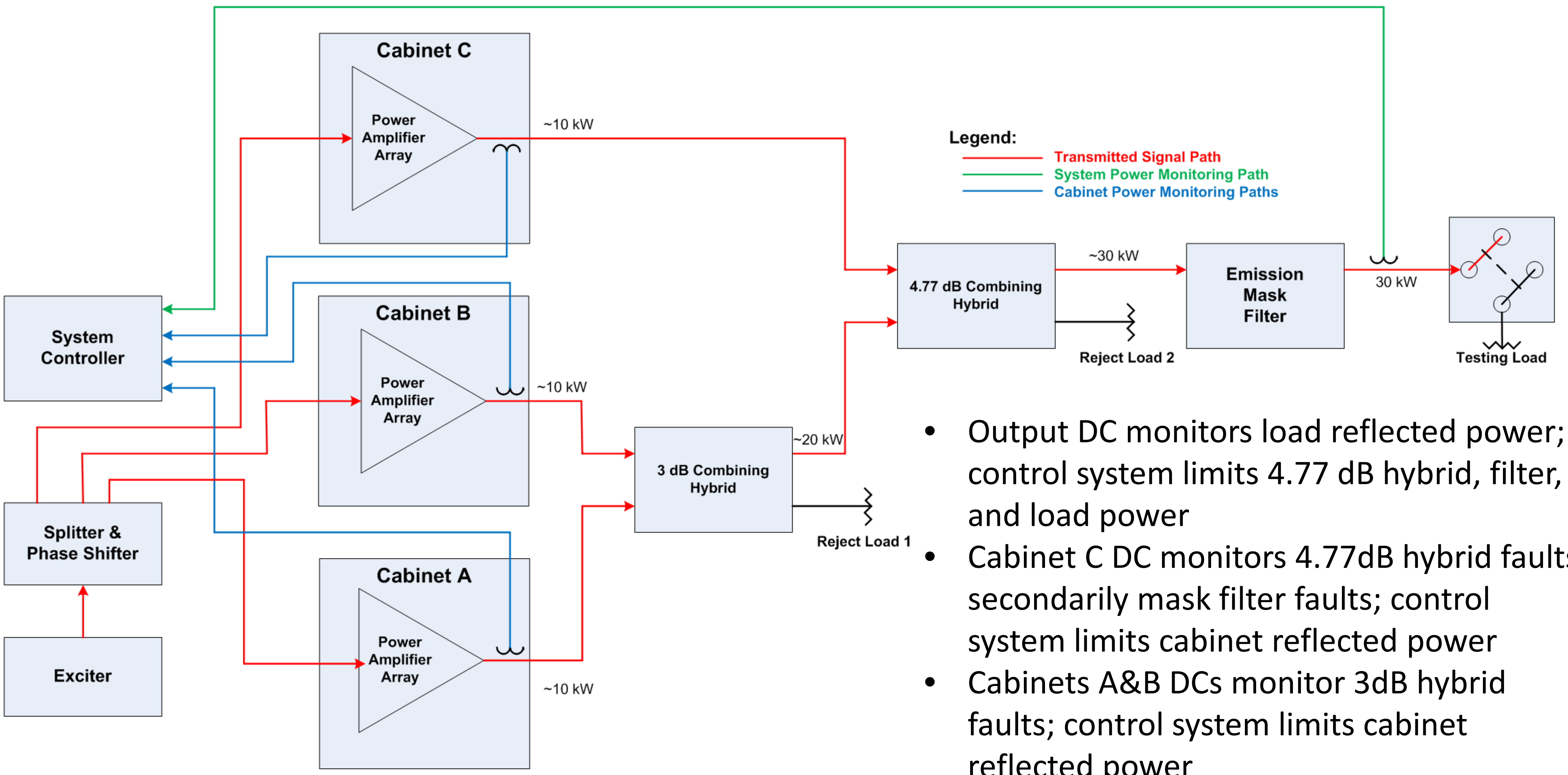
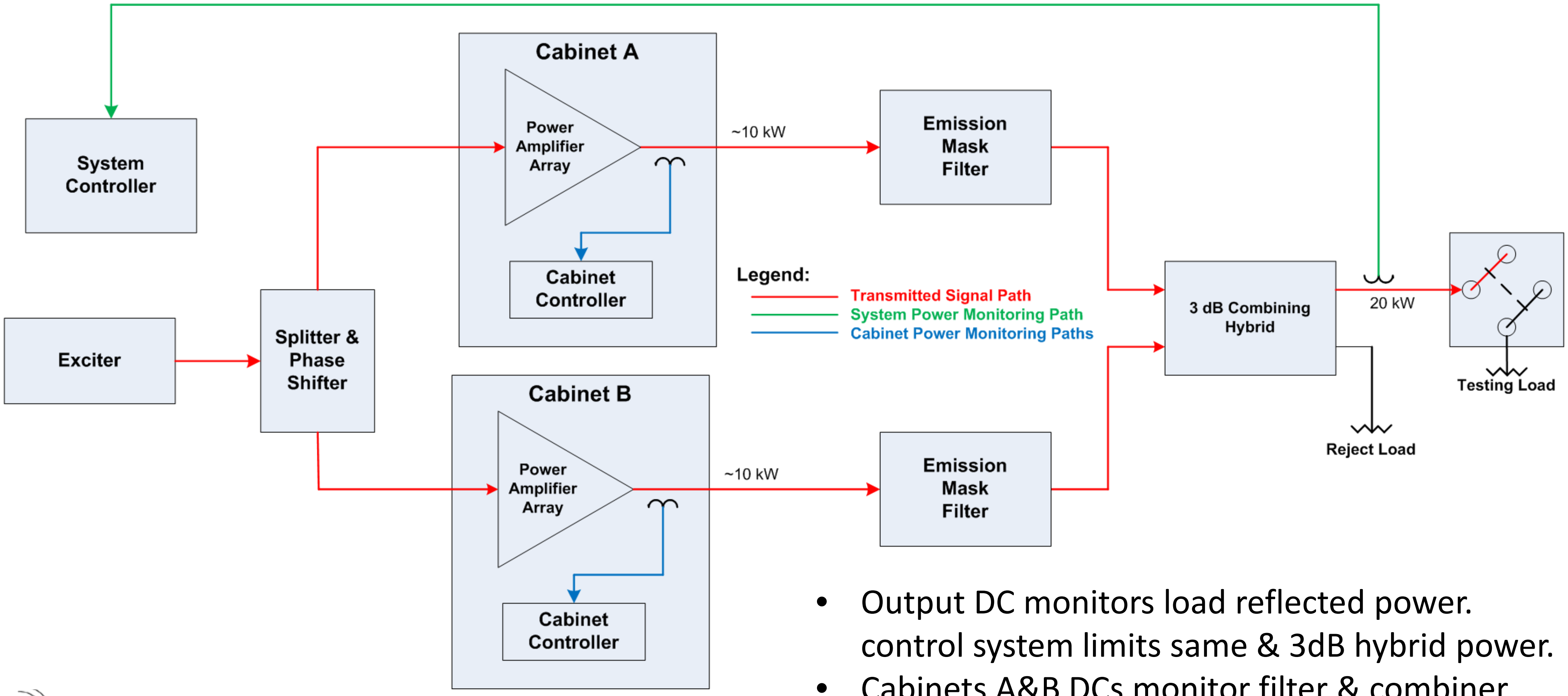
Generic Topology DTV Transmitter



- Output DC monitors load reflected power; control system limits 4.77 dB hybrid, filter, and load power
- Cabinet C DC monitors 4.77dB hybrid faults, secondarily mask filter faults; control system limits cabinet reflected power
- Cabinets A&B DCs monitor 3dB hybrid faults; control system limits cabinet reflected power

GatesAir ULXT Topology DTV Transmitter



- Output DC monitors load reflected power. control system limits same & 3dB hybrid power.
- Cabinets A&B DCs monitor filter & combiner reflected power; control systems limit cabinet & filter power.

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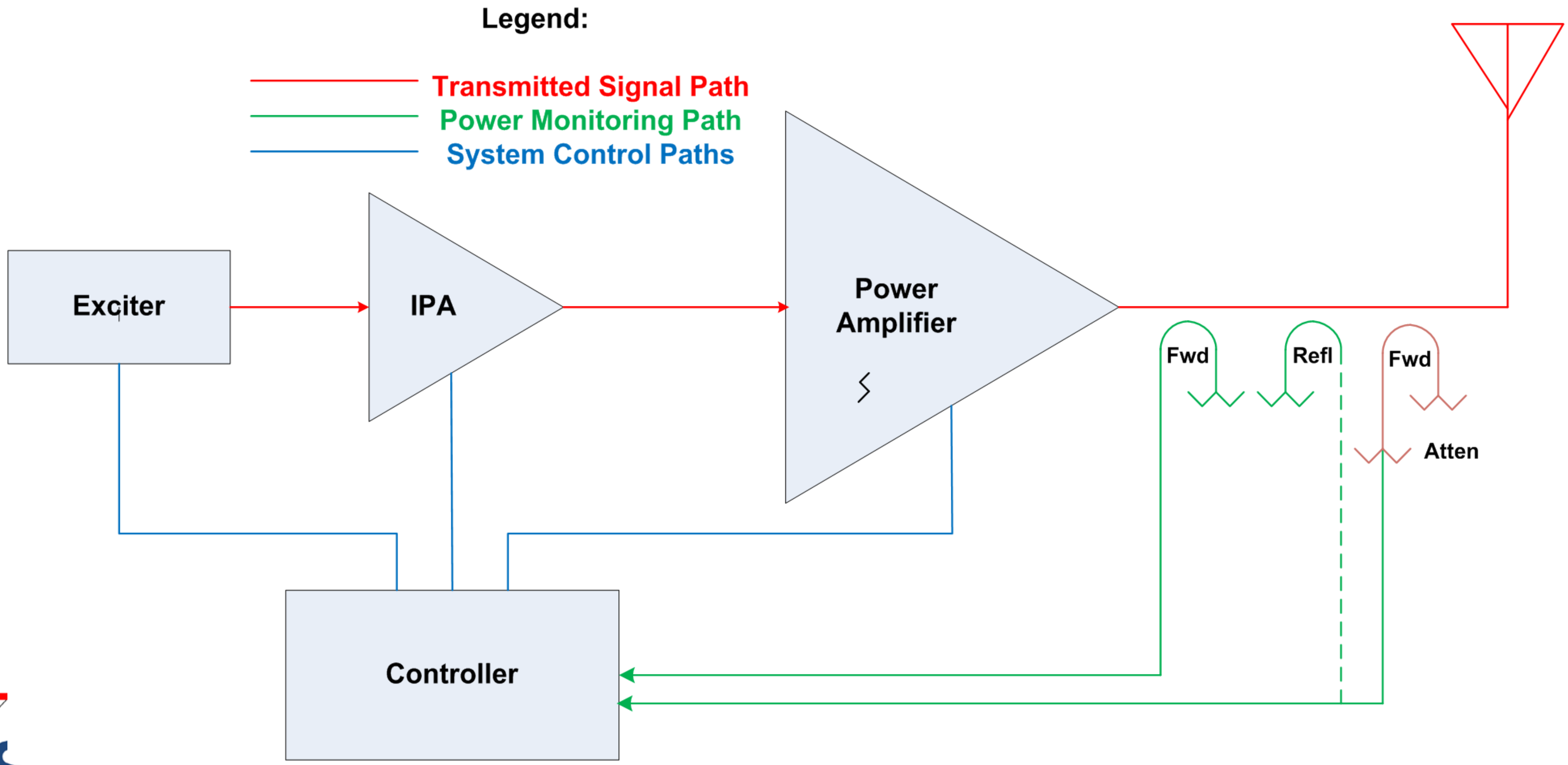
Reflected Power Control Testing

- Test at least annually.
- Review manufacturer’s maintenance manual for test procedure
- If not in manual, contact manufacturer’s customer service staff
- If guidance unavailable, simulate excessive reflected power:
  - Find an open directional coupler forward port
  - Connect input of coaxial attenuators to open forward port
  - Connect reflected power sample line to output of attenuators
  - Power control should activate when sample connected
  - Reduce/increase attenuator by 1 dB to check threshold operation

Reflected Power Test Connection



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Testing Step 1: Reflected Power Attenuation

$$A_o = 10 * \log({}^{P_r}/_{P_f})$$

- -20 dB for 1%
- -17 dB for 2%
- -15.2 dB for 3%
- -14 dB for 4%

Testing Step 2: Calculate Total Attenuation

- Find coupling ratios of system forward & reverse power DC ports
- Find coupling ratio of open DC forward port
- Calculate total attenuation from coupling ratios & basic attenuation
- $A_t = Ao + (A_{dcr} - Adc_t)$

  where:

  - A_t = total test attenuation
  - A_o = reflected power ratio attenuation
  - A_{dcr} = reverse power coupler attenuation
  - A_{dct} = test port power coupler attenuation

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Test Attenuator Example

- 2% reflected power action threshold
- -40 dB reverse power coupling ratio
- -51 dB test port power coupling ratio

- $A_o = 10 * \log(0.02) = -17$ dB
- $A_t = -17 + (-40 + 51)$

  = -6 dB

Typical RF Attenuators

SMA

BNC

N

Available from Mouser, Mini-Circuits, Pasternack, etc.

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Test Port Power Calculation Example

	Transmitter Test Ports		
Measure	Forward	Reflected	Test
Transmitter Power Output (kW)	10.0	0.2	10.0
TPO, dBk	10.0	-7.0	10.0
dBk to dBmW Conversion	30.0	30.0	30.0
TPO, dBmW	40.0	23.0	40.0
DC Coupling Factor, dB	-50.0	-40.0	-51.0
Attenuator, dB	0.0	0.0	-6.0
Detector Input, dBmW	-10.0	-17.0	-17.0

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Summary

- Excessive reflected power is a primary threat to contemporary transmitter system reliability, as other fault sources fade
- Know how your transmitter detects and controls reflected power
  - Study the manual
  - Attend training classes
- Ensure that reflected power monitoring/logging is enabled on remote control systems
- Transmitter reflected power detection and control features must be tested and maintained
  - Follow manufacturer guidance & procedures
  - Test at least annually

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