TWT vs a Modern SSPA Architecture for Very High Power

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Topics

- Expertise Overview
- Evolution into the Modern Architecture
- Modern Architecture – High Level Description
- Major System Elements
  - The RF Drawer - aka Booster
  - Digital Features in the Amplifier
  - Combining Considerations
- Scalability
- Availability
- Effective MTBF
- Total Cost of Ownership
  - With a model
- Concluding Remarks and Q & A Session

Expertise Overview

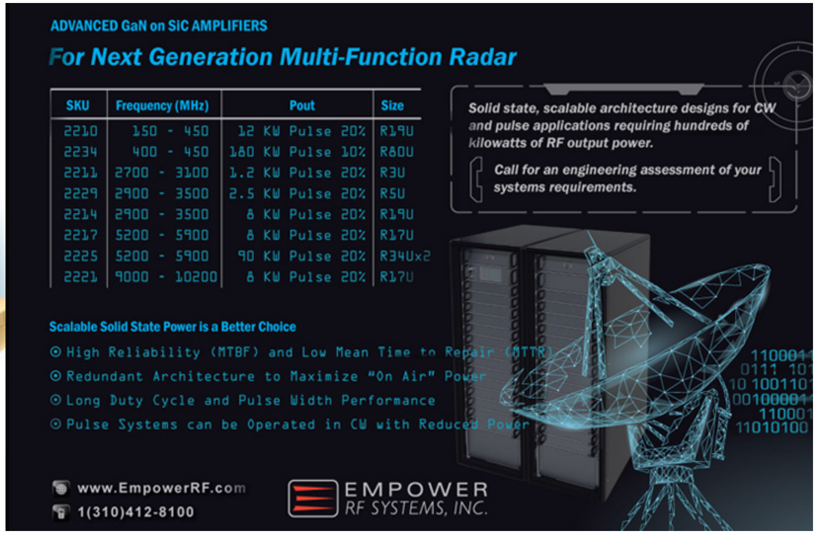
- Pulse and CW SSPAs
- HF to X Band

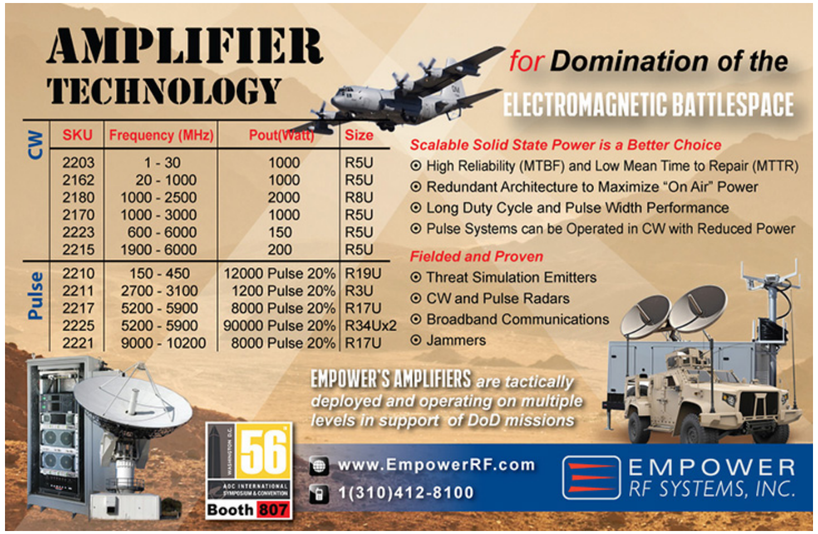
- EW
- Radar
- Product Testing
- Communications

- Modules
- Air cooled Systems
- Liquid Cooled Transmitters

Evolution – The Multi-mode and Interoperable Power Amplifier

- Today's topic is the result of planned roadmap of technology implementation
- The first generation of Solid State Multi-mode and Interoperable Power Amplifier is mature As seen in our Next Gen family of air cooled system amplifiers
  - *Multimode* Power Amplifier is an amplifier that can operate in all modes required for its application
  - *Interoperable* Power Amplifier is an amplifier that requires no change in hardware to operate in any mode
  - *Why do we care?* A single unit is capable of Multi-Domain applications. Designed to stay ahead of the increasing complexities of the signals environment.





Air Cooled Evolution

A Smart, User Configurable, Scalable Power Amplifier Architecture for Fielding More Advanced, Future Proof, Multi-Domain EW, Radar, Satcom, and Communications Systems.

150 MHz to 450 MHz, 12 KW Pulse
2.9 GHz to 3.5 GHz, 8 & 10 KW Pulse
5.2 GHz to 5.9 GHz, 8 KW Pulse
9.2 GHz to 10 GHz, 8 KW Pulse

scalable power
"system of systems"

Threat Simulation Network Amplifiers - 2 MHz to 6 GHz coverage

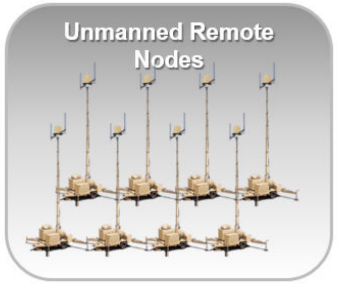
17.5" x 21" x 22"

2 MHz – 3 GHz Switch Filters
Central Controller

1 – 3 GHz 250W PA
2 – 6 GHz 25W PA + Switch Filter

Power Supplies

2 – 30 MHz 250W PA
30 – 1000 MHz 250W PA



17.5" x 12.25" x 22"

2 MHz – 1 GHz Switch Filters
Central Controller

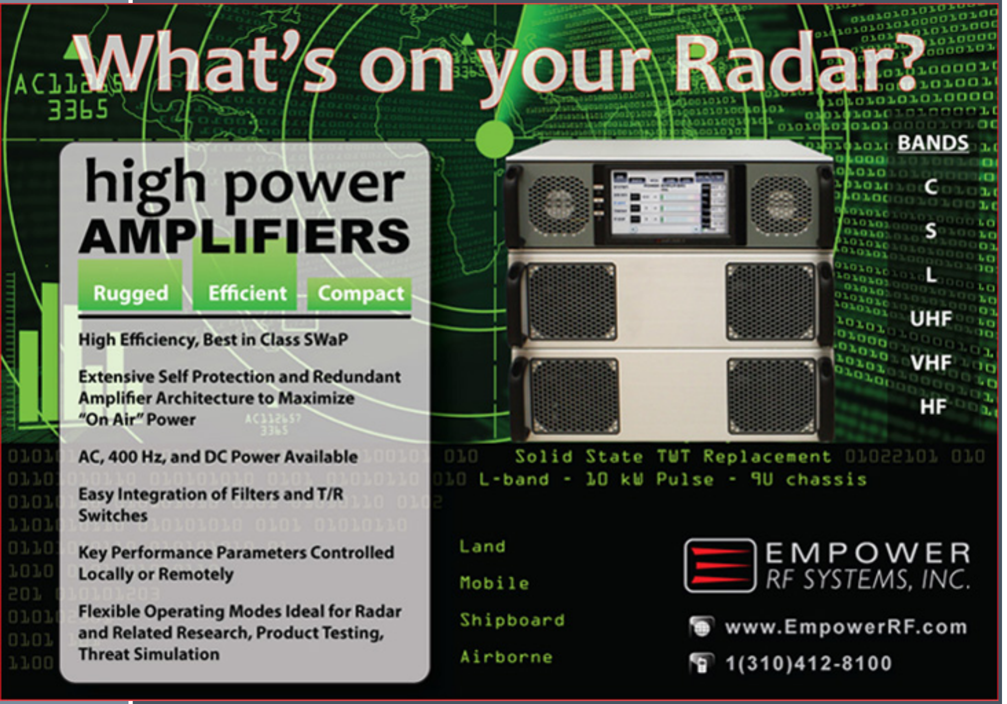
Power Supplies

2 – 30 MHz & 30 to 1000 MHz 25W PA's
1 – 3 GHz & 3 – 6 GHz 25W PA's
Switch Filters

BEYOND GAN

BEYOND OPERATING CLASS

THE ARCHITECTURE MATTERS



Contemporary SSPA manufacturers have not taken advantages of the newest technology

- High speed ADC & DACs
- RF silicon integrated into FPGA fabric
- Fiber Optics
- DSP

Advantages across multiple dimensions – Additional benefits vs traditional SSPA architecture

Reliability/Availability

Fidelity

Wave Form Flexibility

- Long Pulse Widths and Duty Cycles

Total Lifetime Cost of Ownership

Integration Features

- Web API for M2M

Scalability

Additional Operational Capabilities

- Precise Control with Short Latencies
- Accurate Complex Waveform Power Management
- Broader Instantaneous Detection Bandwidth
- Faster Frequency Hopping
- "On the Fly" Mode and Operational Profile changes

Evolution Commonality - “Platform-driven” Approach

Our recurring and consistent RF deck architecture, along with common power supplies, is used across all platforms.

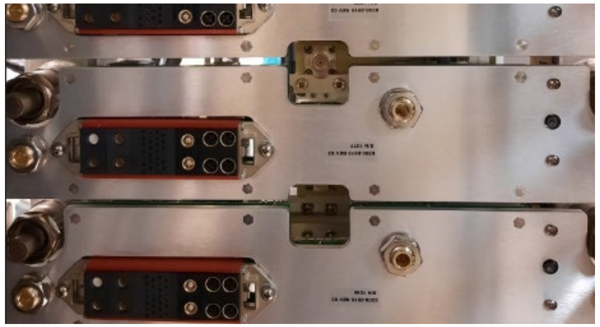
Important to understand the intentionality of evolution. The RF Deck for our new Scalable, Hot Swappable, Liquid Cooled architecture is unchanged.

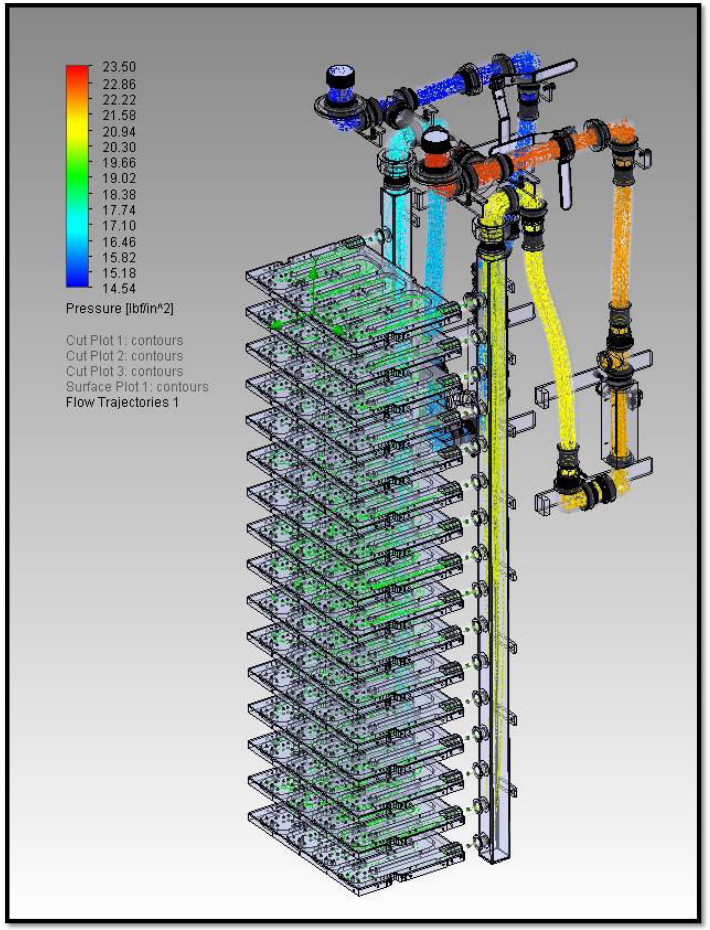
Air Cooled RF Deck

Liquid Cooled RF Deck

A Modern Architecture – High Level Description

Scalable, Liquid Cooled, Hot Swapping



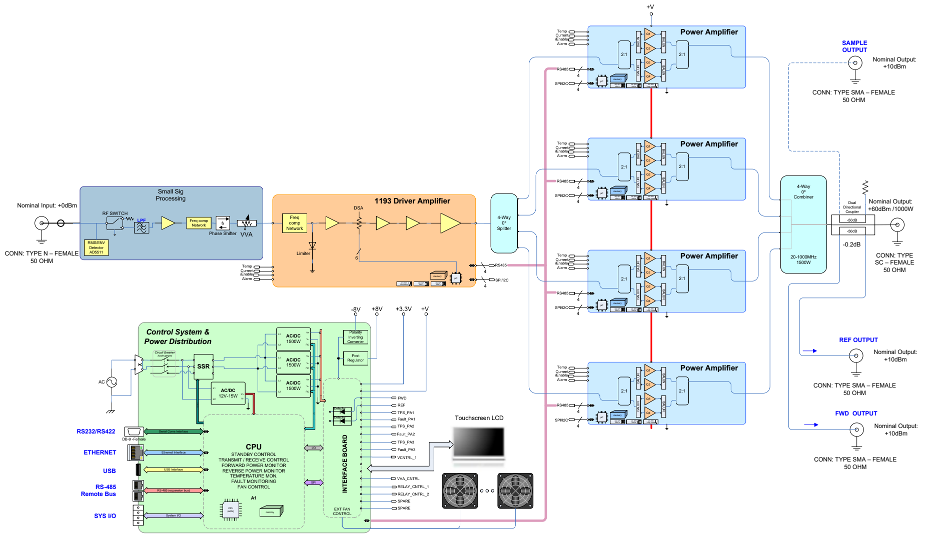


MAJOR SYSTEM ELEMENTS

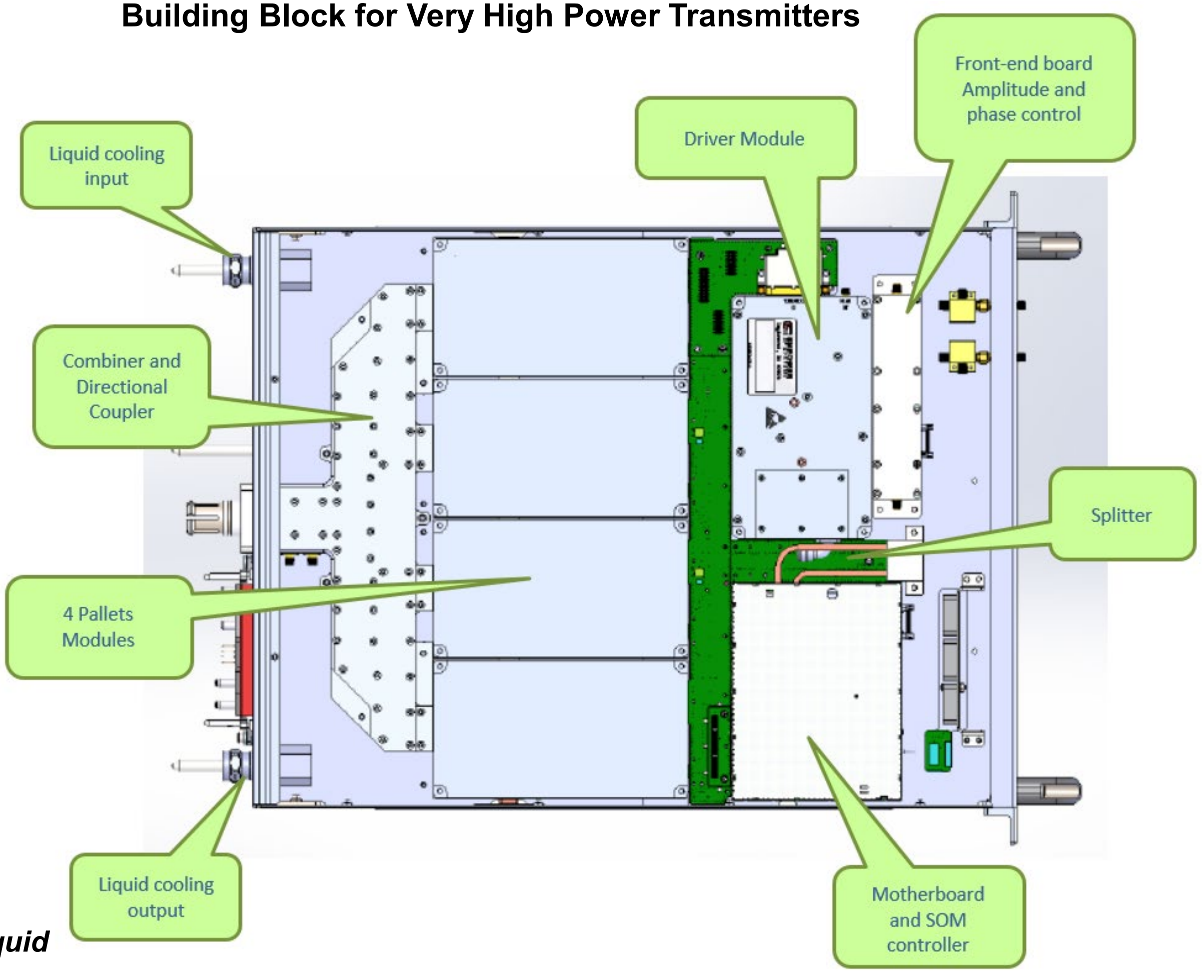
- **Fully integrated, liquid cooled SSPA amplifier building block**
- **System Controller**
- **Backplane Implementation, No External Cabling**
- **Waveguide Combiner**
- **Liquid Cooling Manifolds**
- **Optical Fiber Data Bus**

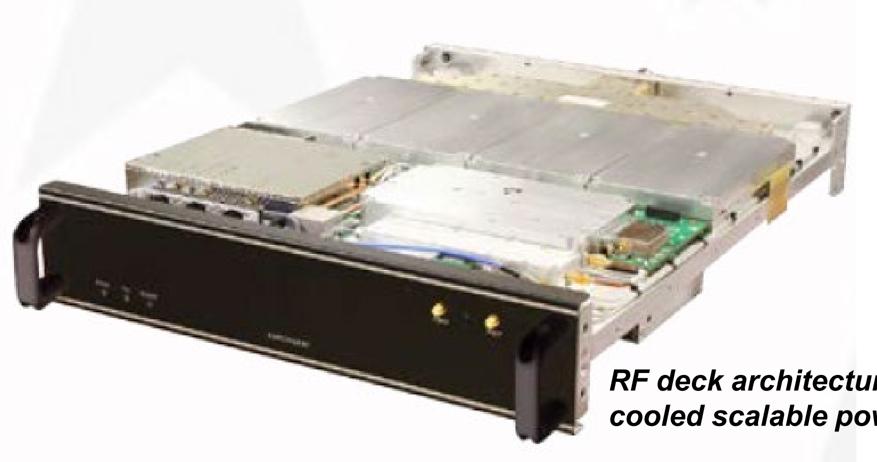
The RF Drawer - aka Booster

- The basic building block is a fully integrated RF deck with power supply
- Distributed RF and power supply design provides system redundancies and eliminates single points of failure



Liquid Cooled, 2U chassis Amplifier Drawer – The scalable Building Block for Very High Power Transmitters

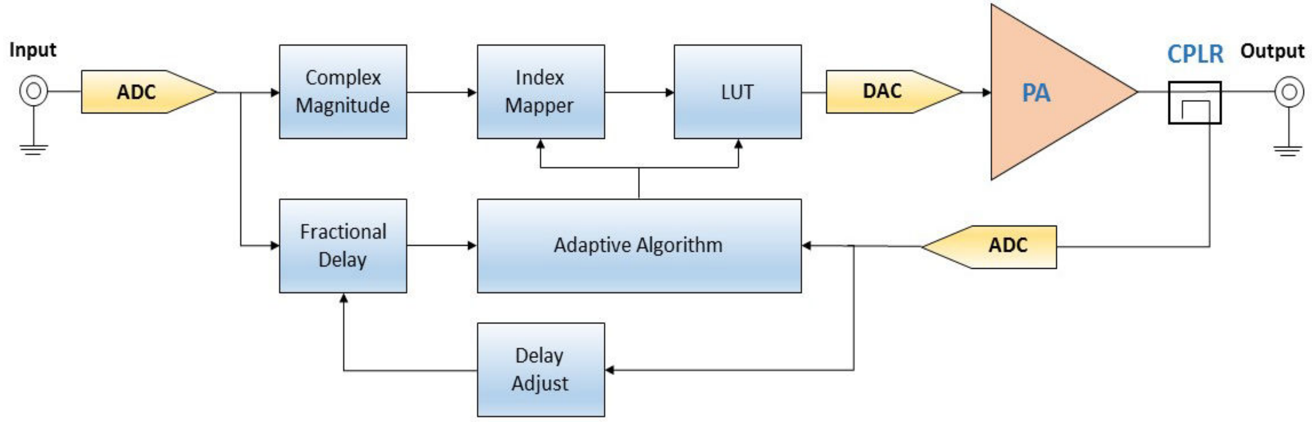




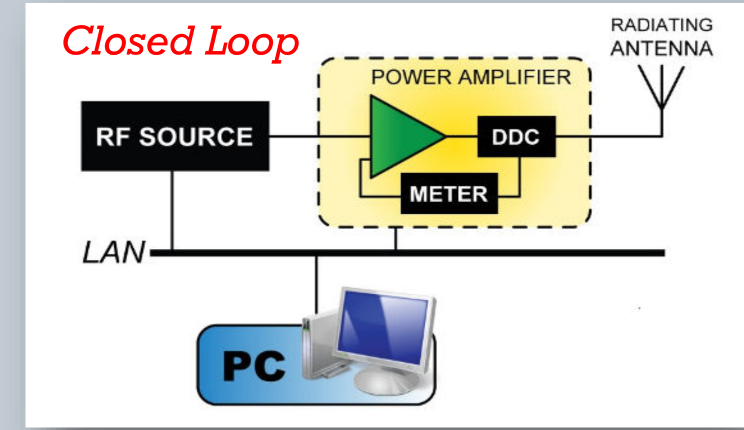
RF deck architecture is consistent across all liquid cooled scalable power transmitter designs.

Digital Features in the Transmitter

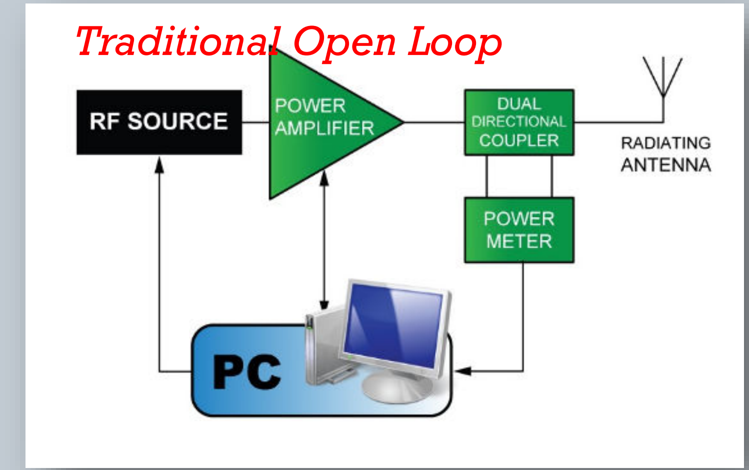
A Step Towards Closed Loop Inside the System Amplifier, Where it Belongs



- **Digital Detection – What is it?**
- **Benefits of Digital Detection**
- **Fiber Optics – High Speed Data**

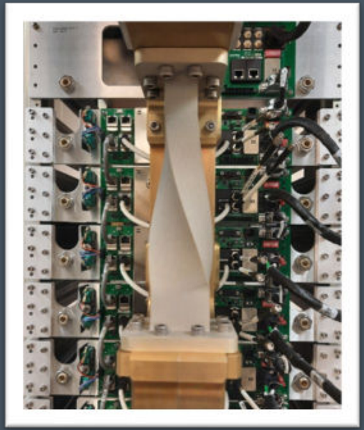


How the Typical System Amplifier has Been Integrated for Decades



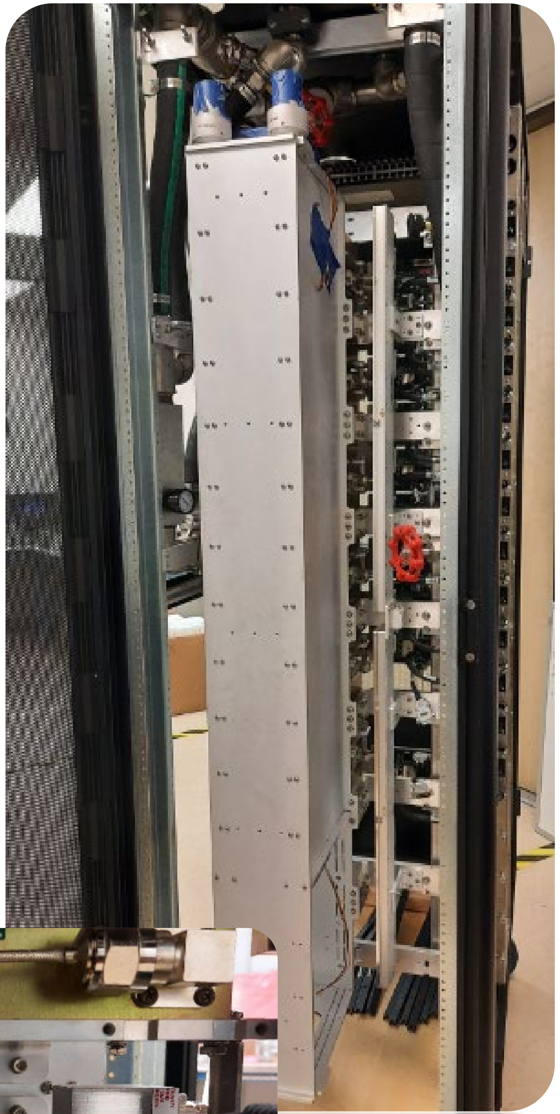
COMBINING CONSIDERATIONS

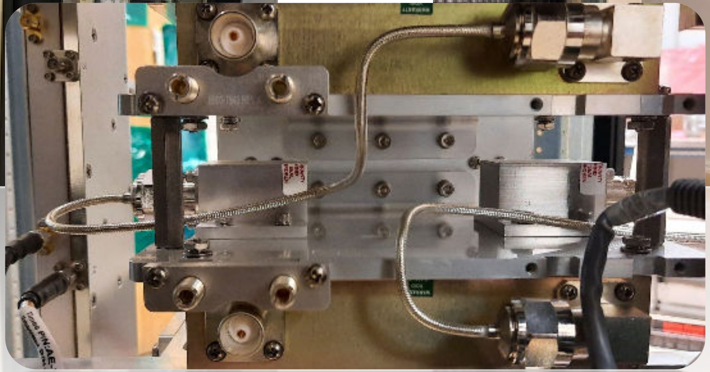
- Reducing Insertion Loss
- VSWR & Arcing
- Isolated Loads
- Adjustable Gain and Phase



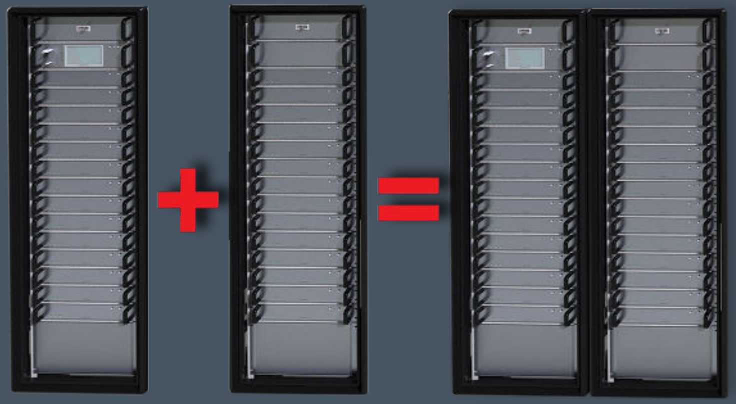
C Band

UHF





SCALABILITY



SSPA's and System Controller

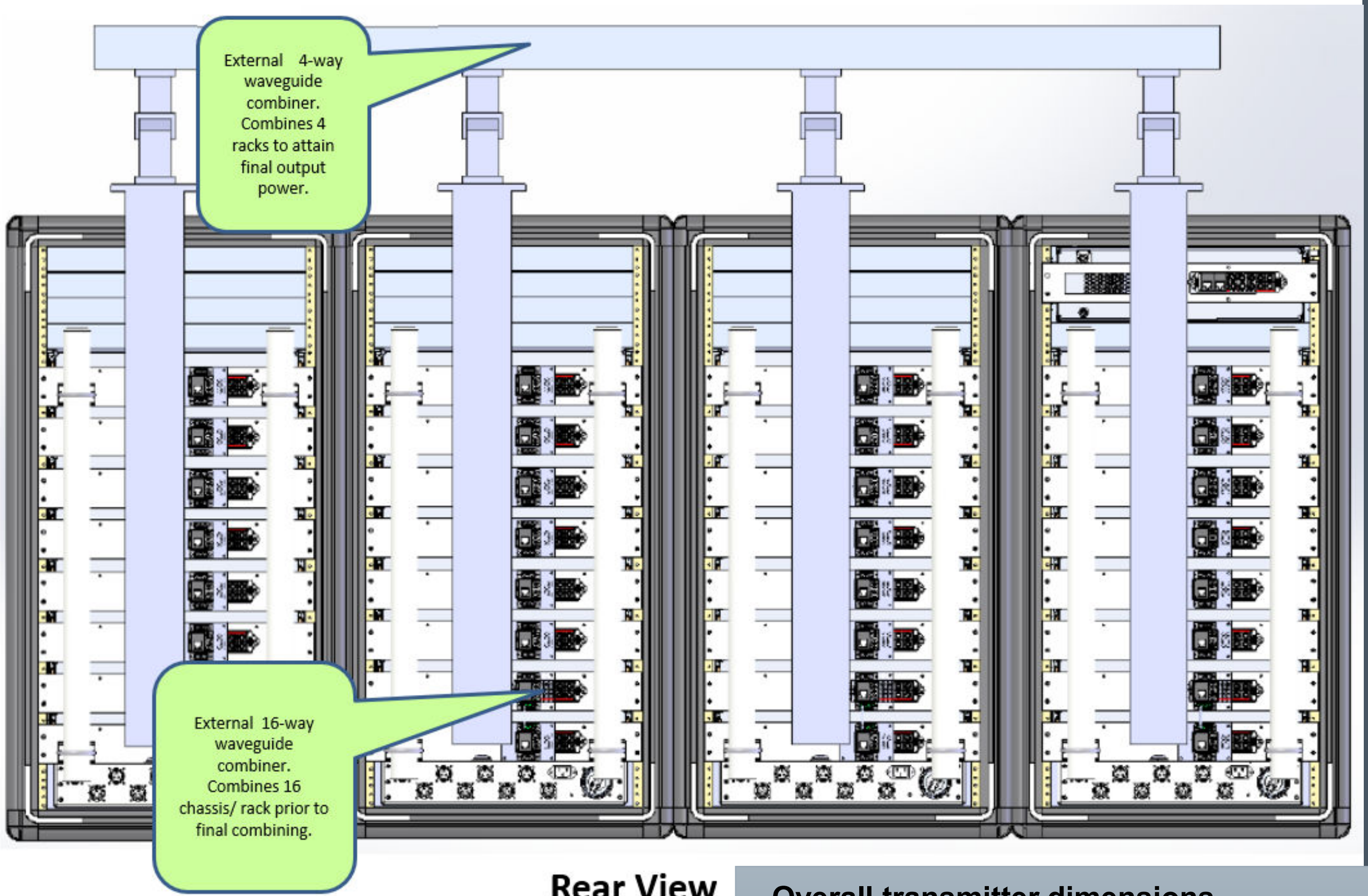
Multiple SSPA's to be combined into a higher power configuration

Two or more racks integrated into a single, higher power configuration - control chassis in Rack #1 managing all amplifiers.

1. **Scalability at the Rack Level**
2. **2U Drawer Level**
3. **Longer PW & Duty cycle**

Example

2.9 to 3,5 GHz, **310 KW peak,** 16% duty cycle
PW 20 – 1000 µsec, Rise / Fall time 10nS



Rear View

Overall transmitter dimensions
8' (wide) x 7' (high) x 4' (deep)
additional clearance required for combiners
liquid cooling system housed separately

Availability

Mission Critical on Air Availability

- Reduced Points of Failure
- Distributed Architecture with Isolated Loads
  - At the module Level, 2U Drawer level, and Rack Level
- Hot Swapping

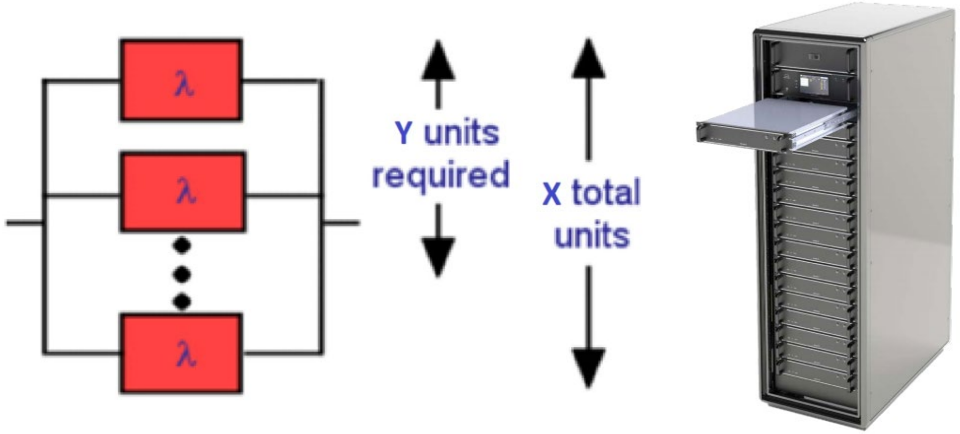
The Amplifier Remains on Air

- At Reduced Output
- Component Failure, Drawer Failures, Cabinet Failure
- Exception is the Controller Failure. 15 minute MTTR

The Result: Traditional MTBF Definition Not Useful

	100KW Rack with 16 Drawers	
# of Drawer Failures	Maximum Power Available (W)	dB Loss Rated Power
1	93750	-0.280287236
2	87500	-0.57991947
3	81250	-0.901766303
4	75000	-1.249387366
5	68750	-1.627272975
6	62500	-2.041199827
7	56250	-2.498774732
8	50000	-3.010299957

Effective MTBF



Effective MTBF is based off effective failure rate of (X) parallel units which need (Y) operational for meeting application or mission success.

Subsystem	MTBF (note 1)	Failure Rate Per Million Hours (of booster)	MTTR	# Of Parallel Units	# That Can Fail	Effective Failure Rate of System Per Million Hours	Effective MTBF (note 2)
2U Booster	20,400	49	0.5	16	0	784	1,275
2U Booster	20,400	49	0.5	16	1	.14	6,900,000

(note 1) MTBF calculated with MIL-HDBK-217F, single 2U booster

(note 2) Exponential model

From the table it is obvious a type of redundancy is required for such a high power SSPA. But the surprising outcome is that with the proper architecture extremely high availability is intrinsic, literal redundancy is not required and therefore not an added cost. Only minimal fractional sparing is required.

Total Cost of Ownership (TCO)

Initial Amplifier Cost

- Typically higher for SSPA. Include cost of external hardware such as filters and isolators that may not be required for SSPA implementation. Some mission critical applications require redundant system with baseball switch.

Reliability MTBF

- TWT Failures within 2.5 years very common but varies with use case. Adjust with your use case data.

MTTR

- Effects spare strategy and quantities
- Mission down time
- Higher MTTR implies specialized Tech training

Maintenance Cost

- Includes rebuilds for cathode degradation
- ~60% of tube cost

Major Repair

- New Tube 70% of new amp cost
- How often? 1 to 5 years?

Annual Electrical Power Costs

- Need efficiency data related to power at antenna

Equipment Spares

- Use case showed 3X more spares required for TWT over SSPA for a non redundant SSPA
- Modular, distributed SSPA architecture allow "fractional" sparing, changing the TCO dramatically.

Intangibles

- Availability
- SWaP – in some cases
- Fidelity
- Technician Training
- Safety

Warning from two Major Tube Suppliers User Manuals

WARNING

HIGH VOLTAGE — VOLTAGES REQUIRED FOR OPERATION OF THIS DEVICE ARE EXTREMELY DANGEROUS TO LIFE; EQUIPMENT MUST BE DESIGNED WITH PROTECTIVE INTERLOCK CIRCUITS TO MAKE PHYSICAL CONTACT WITH THESE VOLTAGES IMPOSSIBLE. SEE "OPERATING HAZARDS" SECTION.

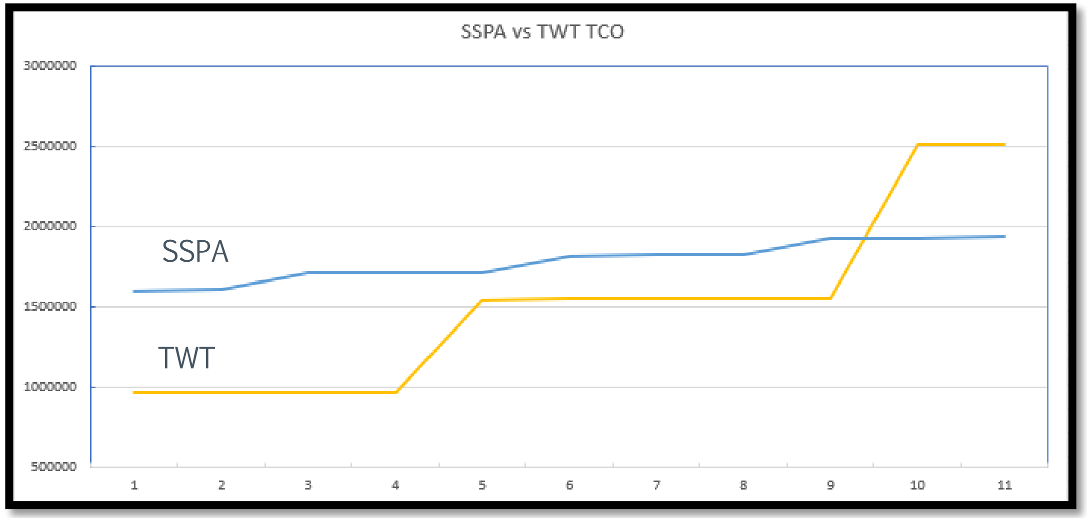
Lethal Voltages up to 15,000 Volts are present in this amplifier when it is operating. USE EXTREME CAUTION when inside the unit.

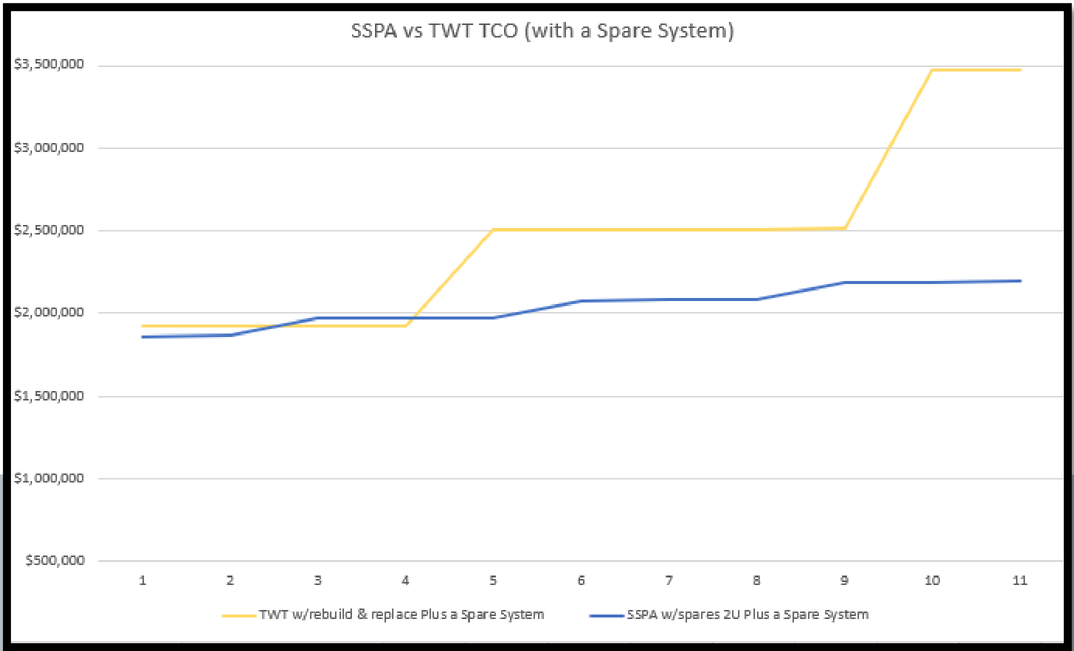
Total Cost of Ownership – Generic Case

TWT Cost	$960,000
SSPA Cost	$1,600,000
TWT rebuilds at 60% every 5 years	$576,000
TWT replacement 10 years	$960,000
TWT Spare Cost	$960,000
SSPA Drawer Cost	$100,000
SSPA Controller Spare Cost	$60,000
Nominal Energy Cost Monthly	$2,000
SSPA Spare System 1 Controller 2 Drawers	$260,000
TWT Spare System	$960,000

Delta	$582,667
Percentage	130.1%

Delta	1,282,667
Percentage	158.5%





Intangibles ☐

- ☐ Availability
- ☐ SWaP
- ☐ Fidelity
- ☐ Technician Training
- ☐ Safety
- ☐ *Multi-mode*
- ☐ *System Integration*
- ☐ *Scalable*
- ☐ *Web API*
- ☐ *Latency*
- ☐ *Pulse Flexibility*

Concluding Remarks and Q & A Session

- Lower Total Cost of Ownership than Non Modular Architectures
- Always "On Air" Architecture
- Extreme Effective MTBF
- Upgradable
- Pulse Fidelity, Random Pulse Width and Duty Cycle, High PRF's
- Waveform Flexibility
- Signal Processing Functions on the Roadmap
- SWaP Better in Many Cases
- Integration Features
- Plus a Long List of Intangible Benefits

More Questions? Send them to Sales@EmpowerRF.com