Benefits of Liquid Cooling for High Power FM Digital Transmitters

WBA Broadcasters Clinic

TUESDAY, OCTOBER 11, 2016

Tim Anderson, CPBE
GatesAir Manager, Radio Product Development

SBE CHAPTER 24, Inc., MADISON WISCONSIN USA

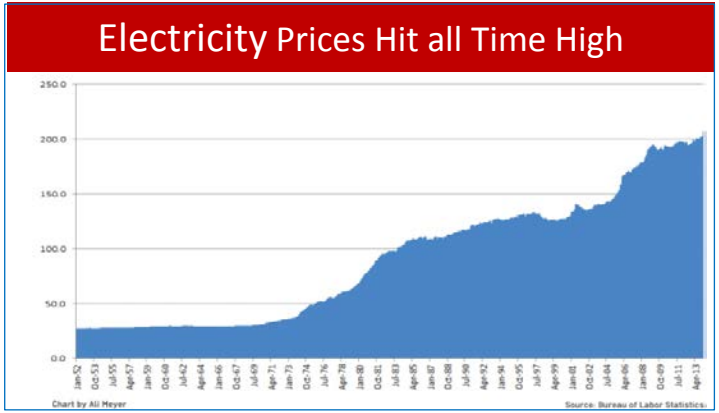
WBA ON AIR WISCONSIN BROADCASTERS ASSOCIATION

Issues Customers are Facing

Rising Cost of Energy

- World electricity prices have increased by an average of 6.6% per year for the past 5 years
- Projected to continue to rise throughout the world - 60% increase by 2030

Electricity Prices Hit all Time High



Carbon Taxes

- Some countries are imposing taxes based on energy usage, example Australia from 2012-14:

Financial Year	Price* (USD $)
2012–13	23.00
2014	24.15
1 July 2014 onwards	Revoked

Source: Clean Energy Regulator - per ton of emitted CO_2

Issues Customers are Facing

Pressure to Reduce Operating Expenses

- **Opex** (people, plant, spares, energy) **= 5x the cost of initial investment in the transmitter** over the system lifetime
  - Purchase price is only 20% of the cost to deliver services
- Deploying people to a site is costly
- Aging technology is very costly to maintain – parts and people/skills harder to find

Factors Affecting TCO

- When purchasing, or replacing a transmitter, Total Cost of Ownership is more important than just the purchase price alone
- Some of the items that must be considered:
  - Equipment acquisition cost (inc. taxes/duties/shipping, etc.)
  - Financing/Loan/Payment Terms (if applicable)
  - Building space requirements (own, lease, purchase)
  - Shipping to site, Installation and commissioning costs
  - Operational cost of the equipment, including:
    - AC power costs
    - Personnel training
    - Routine maintenance costs / site visits
    - Repair costs
    - Upgrades
    - Warranty and other factors

TCO versus Efficiency

- **TCO is what is really important to a transmission operator:**
  - It's the total cost to own and operate the transmitter system over time
  - Includes initial equipment cost and delivery
  - Includes the installation/commissioning cost
  - Includes routine and unscheduled maintenance costs
  - Repair/replacement and other operational costs
- **AC power consumed by the transmitter is important**
  - However, other factors also affect the system efficiency:
    - AC transformers and voltage regulators
    - Heat load to the room (HVAC costs)
    - RF system losses (often significant)
    - RF feeder losses
      - ex: 100.1MHz, 500ft, 3-1/8" Heliax, energy loss = 15%
    - Non-optimal antenna pattern (throwing RF energy away)

Technologies & TCO

- At GatesAir we are constantly updating designs to improve efficiency and lower TCO:
  - Higher Efficiency RF Devices & PA Module design
  - Higher Efficiency Power Supplies
  - Optimized Energy Efficient Cooling Systems
  - Broadband, future-proof designs
  - Improved up-time and reduced maintenance costs
  - Modular designs with Faster MTTR (Mean Time To Repair)
  - Higher Power Density for reduced floor space
  - User-friendly designs, easier to understand and operate

What is PowerSmart® ?

PowerSmart® is the on-going GatesAir design initiative to create the most efficient transmitter designs and products. GatesAir leverages the most sophisticated tools to develop cost, energy, and space efficient solutions.

Television

The Maxiva™ family of UHF transmitters led this initiative with the first 50V LDMOS device-driven transmitter in the industry setting a new benchmark for power density and efficiency.

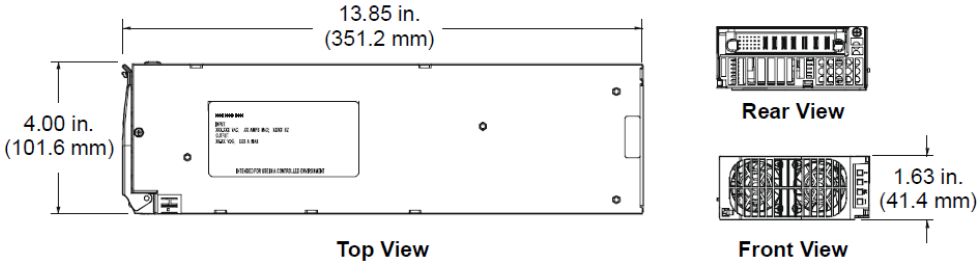
Radio

The Flexiva™ family of FM transmitters set new benchmarks with operating efficiencies of up to 72%, the first FM design to use 50V LDMOS devices, and the smallest footprint at 10kW and higher power levels.

Power Supply Technology

- Improvements in Power density/weight
- Very high conversion efficiency
  - 96.3% versus 84% only a few years ago
- With 48-50V DC requirement, can leverage the Telecomm industry:
  - Very high MTBF (900,000hrs)
  - High volume part
  - Widely available Worldwide
- Versatile
  - Use same part in FM and TV products

2,725 Watt high-efficiency power supply (weight 2kg)

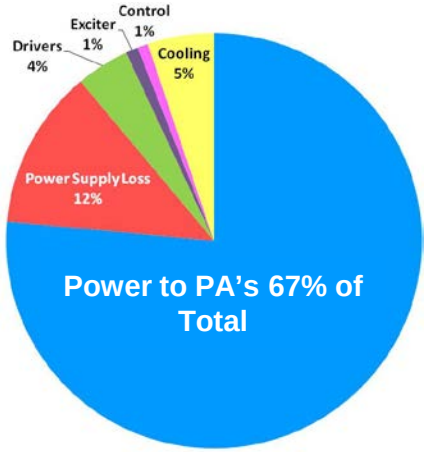


Reliability (calculated)		900,000		Hours	At ambient of 25°C at full load per Telcordia SR-332, issue 2, Reliability Prediction for Electronic Equipment, Method I Case III.

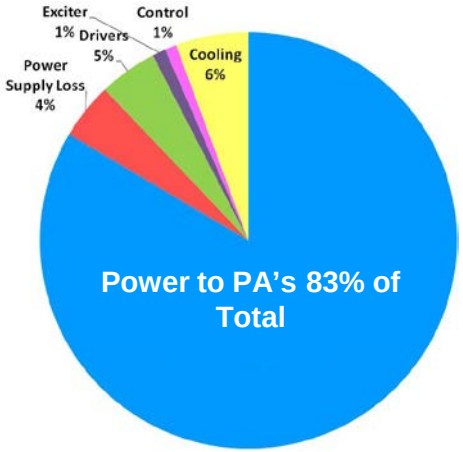
Every Part of The Transmitter Matters

Effect of power supply efficiency on overall system efficiency

	Tx with older PS	Tx with new High Eff. PS
RF Power Output (kW)	10.00	10.00
Power Amplifier Efficiency	76%	76%
DC Power to PA's	13.16	13.16
Power Supply Efficiency	84%	96%
AC Power to PA's	15.59	13.65
Power Supply Loss	2.43	0.49
Drivers	0.60	0.60
Exciter	0.14	0.14
Control	0.12	0.12
Cooling	0.75	0.75
Total AC Input (kW)	19.63	15.75
Overall Tx Efficiency	51%	63%



Distribution of Power Usage with Older Technology Power Supplies

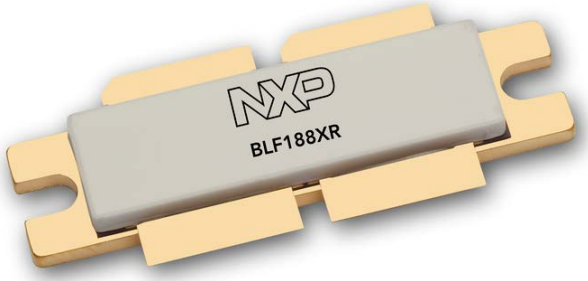


Distribution of Power Usage with High Efficiency Power Supplies

Power Supplies make 13% difference!

RF Device Technology

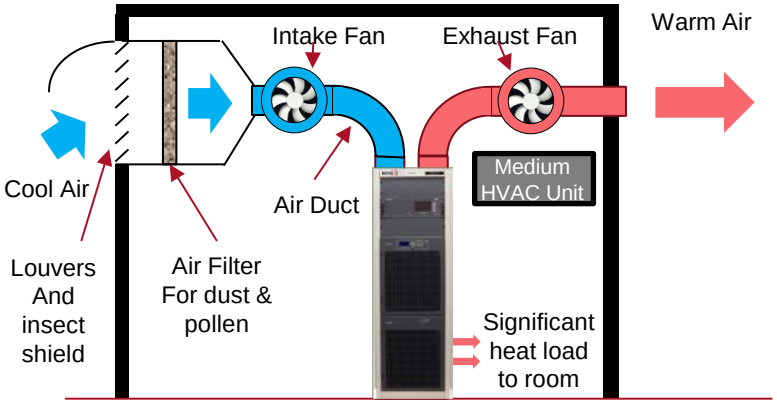
- **New 50V LDMOS devices introduced that dramatically increase power density, efficiency and reliability**
  - 1400W peak power
  - High Gain (> 22dB)
  - High DC-RF Efficiency (> 82%)
  - Improved thermal transfer
  - Rugged
  - Very High MTF (> 20K years)



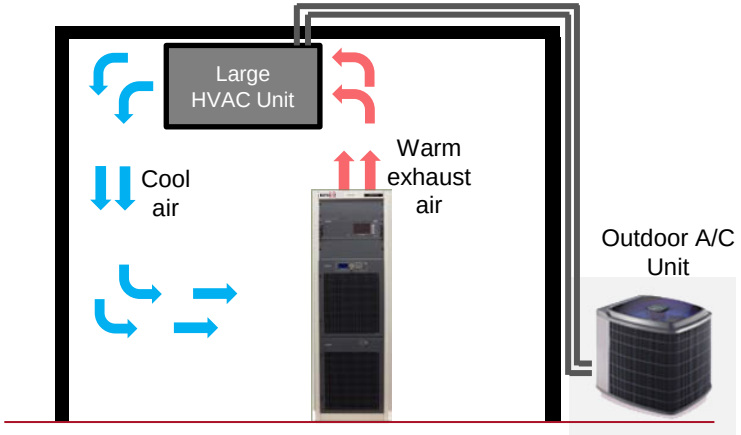
BLF188XR Features and benefits (from data sheet):

- High power
- High power gain
- High efficiency
- Designed for broadband operation (HF to 600 MHz)
- Excellent ruggedness (VSWR > 65 : 1 through all phases)
- Excellent thermal stability
- Integrated ESD protection
- Internal input matching for ease of use
- Designed for broadband operation (HF to 600 MHz)

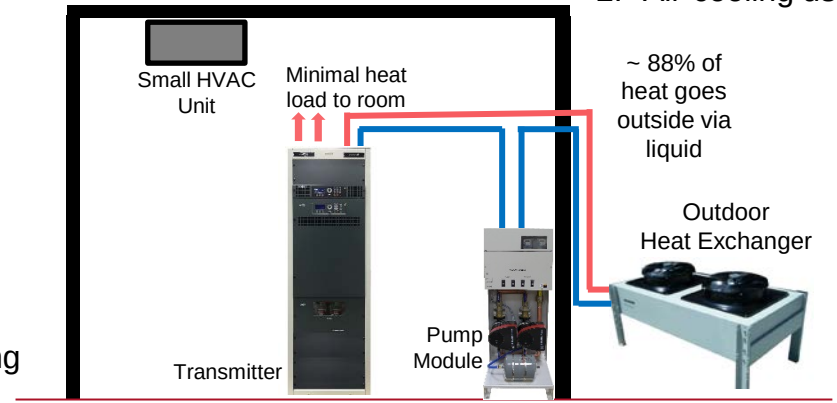
Three Ways to Cool the Transmitter



1. Air-cooling using outside air



2. Air-cooling using inside air and Air-Conditioning



3. Liquid-cooling

Cooling Comparison

Item	Air-Cooled (outside air)	Air-Cooled (HVAC)	Liquid Cooled
Energy cost	Low	High	Low
Maintenance	Very High	Medium	Low
Installation cost	High	Medium	Medium/Low
Site visits	Frequent	Infrequent	Infrequent
Humidity control	None	Excellent	Excellent
Dust & dirt	Filter dependent	Excellent	Excellent
Reliability	Medium	Medium	Medium/Excellent
TCO Rank	**3**	**2**	**1**

Flexiva™ FLX Liquid-Cooled FM Transmitters

NEW! Flexiva™ FLX Liquid-Cooled FM Transmitters

- 88% overall heat dissipation to liquid transfer efficiency
- Internal or external redundant pump modules
- Two 10kW transmitters with dual exciters, in a single rack
- 20kW with dual exciters in a single rack

PowerSmart®

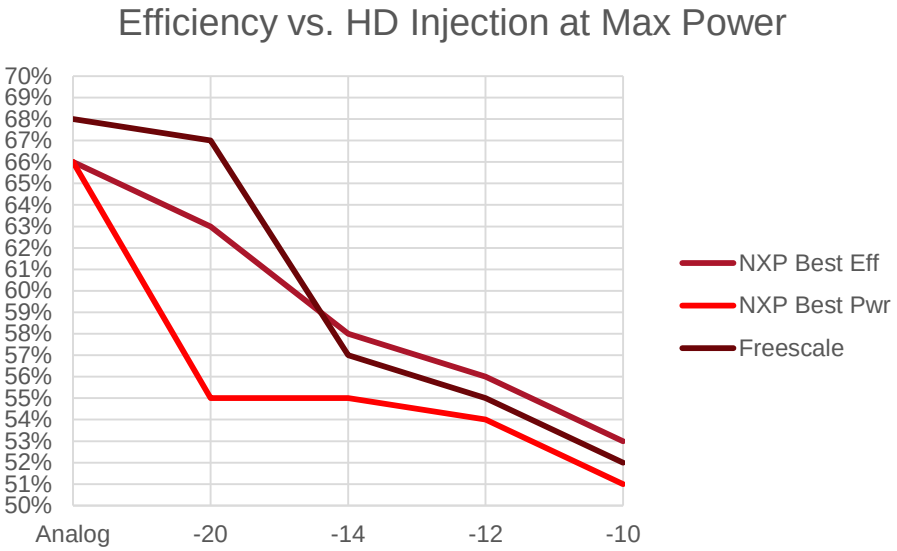
Flexiva™ FLX Liquid-Cooled FM Transmitters

Scalable 10kW - 80kW Liquid Cooled

Liquid Cooling
Power & Heat Load Discussions

Maximum Power Available Optimized for Best Efficiency

Best efficiency is established by adjusting the PA Voltage to the lowest achievable (44V) while maintaining acceptable peak-to-average-power-ratio (PAPR) and pre-correct-ability at ~2dB PA saturation.

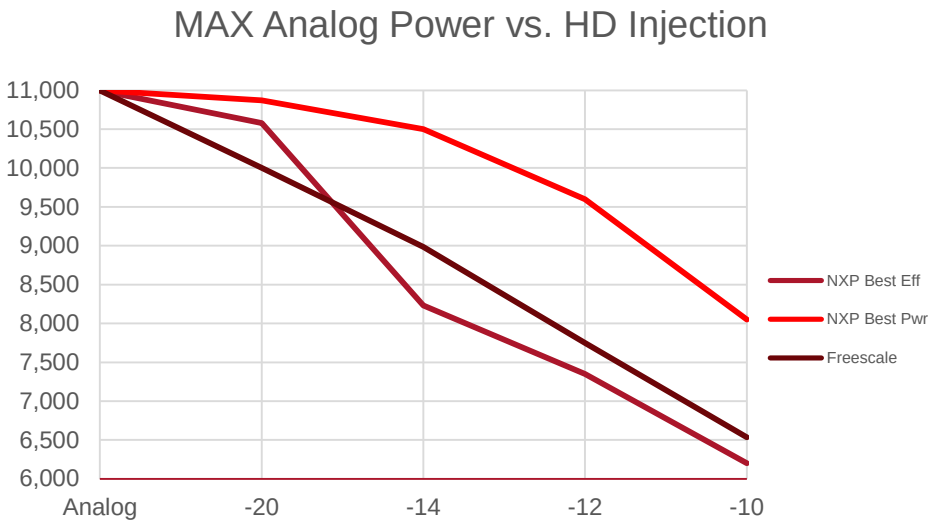


Best Efficiency Flexiva FLX (NXP BLF188XR) PA		FLXT10K	FLXT20K	FLXT30K	FLXT40K
Analog Only (44v)	Max Power[1]	11,000	22,000	33,000	44,000
	Typical Efficiency	66%	65%	65%	65%
Analog @ -20 dBc HD (44v)	Max Power[1]	10,578	21,156	31,734	42,312
	Typical Efficiency	63%	65%	65%	65%
Analog @ -14 dBc HD 44v)	Max Power[1]	8,230	16,460	24,690	32,920
	Typical Efficiency	58%	58%	58%	58%
Analog @ -12 dBc HD (44v)	Max Power[1]	7,350	14,700	22,050	29,400
	Typical Efficiency	56%	56%	56%	56%
Analog @ -10 dBc HD (44v)	Max Power[1]	6,200	12,400	18,600	24,800
	Typical Efficiency	53%	53%	53%	53%

Published Flexiva FAX Freescale PA		FLXT10K	FLXT20K	FLXT30K	FLXT40K
Analog Only (44v)	Max Power[1]	11000	22000	33000	44000
	Typical Efficiency	68%	68%	68%	68%
Analog @ -20 dBc HD (50v)	Max Power[1]	10000	20000	30000	40000
	Typical Efficiency	67%	67%	67%	67%
Analog @ -14 dBc HD (52v)	Max Power[1]	8985	17970	26955	35940
	Typical Efficiency	57%	57%	57%	57%
Analog @ -12 dBc HD (52v)	Max Power[1]	7750	15500	23250	31000
	Typical Efficiency	55%	55%	55%	55%
Analog @ -10 dBc HD (52v)	Max Power[1]	6534	13068	19602	26136
	Typical Efficiency	52%	52%	52%	52%

Maximum Power Optimized for Best Power

Best Power is established by adjusting the PA Voltage to either the maximum available or the lowest practical value where maximum power can still be achieved at reasonable efficiency while maintaining acceptable peak-to-average-power-ratio (PAPR) and pre-correct-ability at ~2dB PA saturation.



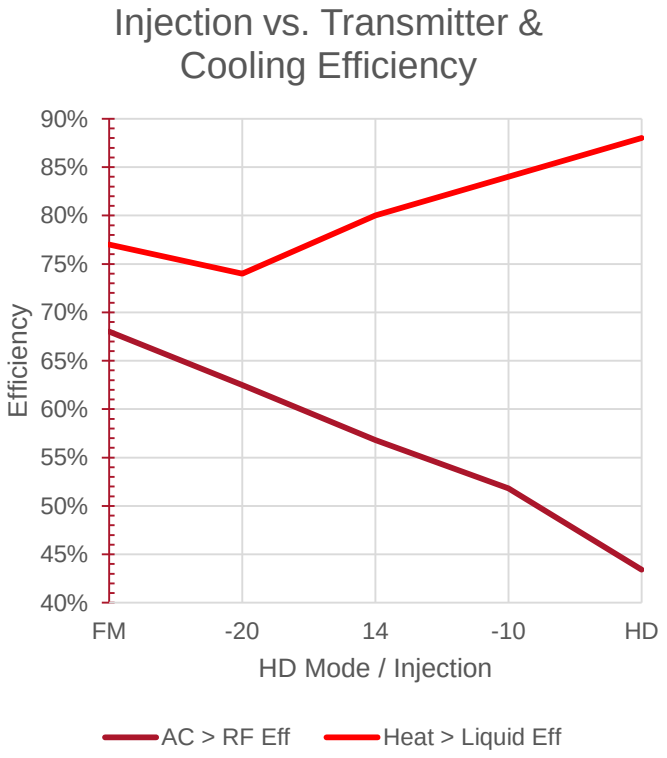
Best Power Flexiva FLX (NXP BLF188XR) PA		FLXT10K	FLXT20K	FLXT30K	FLXT40K
Analog Only (44v)	Max Power[1]	11,000	22,000	33,000	44,000
	Typical Efficiency	66%	65%	65%	65%
Analog @ -20 dBc HD (47v)	Max Power[1]	10,870	21,740	32,610	43,480
	Typical Efficiency	55%	55%	55%	55%
Analog @ -14 dBc HD (50v)	Max Power[1]	10,500	21,000	31,500	42,000
	Typical Efficiency	55%	55%	55%	55%
Analog @ -12 dBc HD (50v)	Max Power[1]	9,600	19,200	28,800	38,400
	Typical Efficiency	54%	54%	54%	54%
Analog @ -10 dBc HD (50v)	Max Power[1]	8,050	16,100	24,150	32,200
	Typical Efficiency	51%	51%	51%	51%

Published Flexiva FAX Freescale PA		FLXT10K	FLXT20K	FLXT30K	FLXT40K
Analog Only (44v)	Max Power[1]	11000	22000	33000	44000
	Typical Efficiency	68%	68%	68%	68%
Analog @ -20 dBc HD (50v)	Max Power[1]	10000	20000	30000	40000
	Typical Efficiency	67%	67%	67%	67%
Analog @ -14 dBc HD (52v)	Max Power[1]	8985	17970	26955	35940
	Typical Efficiency	57%	57%	57%	57%
Analog @ -12 dBc HD (52v)	Max Power[1]	7750	15500	23250	31000
	Typical Efficiency	55%	55%	55%	55%
Analog @ -10 dBc HD (52v)	Max Power[1]	6534	13068	19602	26136
	Typical Efficiency	52%	52%	52%	52%

Power, Cooling and efficiency

FLX Power Cooling & Efficiency					
Operating Mode:	**FM**	**-20**	**14**	**-10**	**HD**
TPO	11,000	11,000	10,500	9250	5,500
PAV	43V	43V	46.9V	49.8V	49.8V
Dissipation	16,176	17,590	18,470	17,870	12,680
AC > RF Eff	68%	63%	57%	52%	43%
Heat > Liquid	3,832	4,709	6,231	7,105	6,140
Heat > Air	1,145	1,681	1,539	1,315	840
Total Heat	4,976	6,390	7,770	8,420	6,980
Heat > Liquid Eff	77%	74%	80%	84%	88%

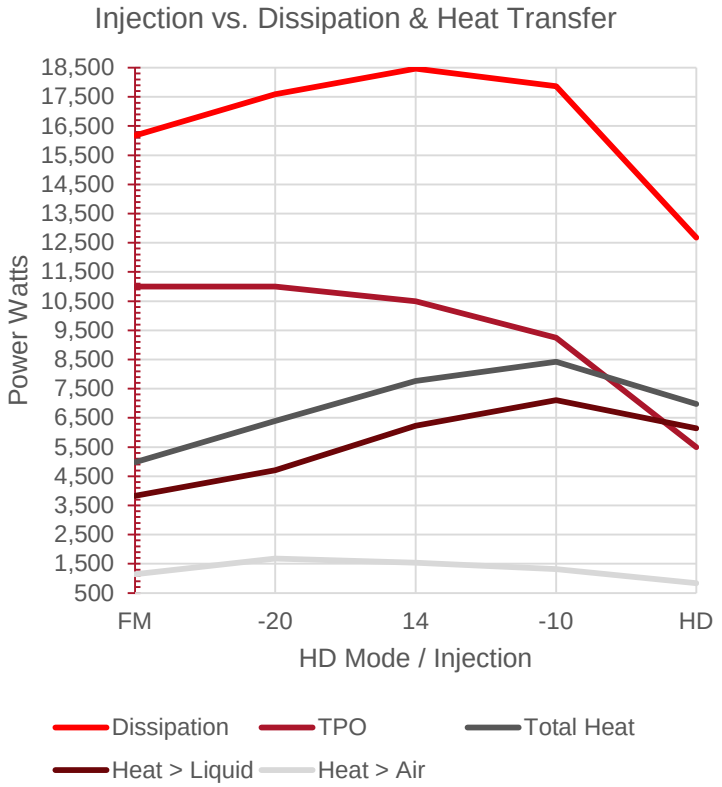
This chart is extrapolated from data taken by measuring air and liquid flows and temperature deltas to compute heat to air and heat to liquid transfer and comparing this numbers with the theoretical model.



Power, Cooling and efficiency

FLX Power Cooling & Efficiency					
Operating Mode:	**FM**	**-20**	**14**	**-10**	**HD**
TPO	11,000	11,000	10,500	9250	5,500
PAV	43V	43V	46.9V	49.8V	49.8V
Dissipation	16,176	17,590	18,470	17,870	12,680
AC > RF Eff	68%	63%	57%	52%	43%
Heat > Liquid	3,832	4,709	6,231	7,105	6,140
Heat > Air	1,145	1,681	1,539	1,315	840
Total Heat	4,976	6,390	7,770	8,420	6,980
Heat > Liquid Eff	77%	74%	80%	84%	88%

This chart is extrapolated from data taken by measuring air and liquid flows and temperature deltas to compute heat to air and heat to liquid transfer and comparing this numbers with the theoretical model.

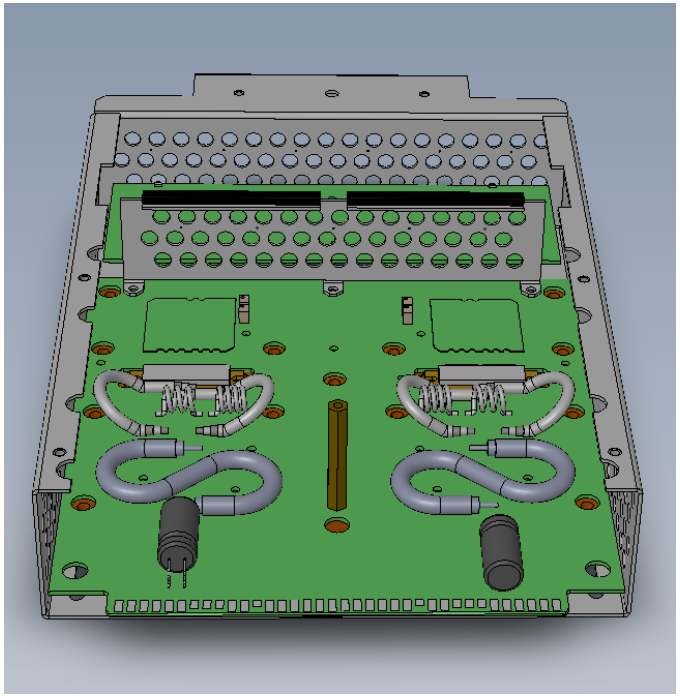


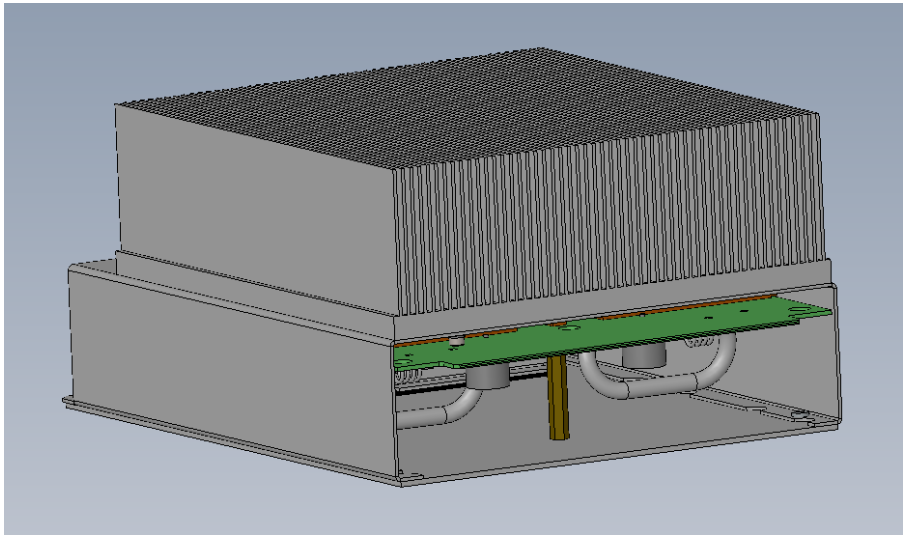
Conclusions

- As PA efficiency increases, the ratio of heat-to-liquid vs. heat-to-air efficiency decreases.
- As TPO decreases, efficiency decreases as well as overall dissipation BUT, heat to liquid transfer efficiency increases.
- FM mode at full power being most efficient, exhibits lowest overall dissipation BUT, the worst case heat-to-liquid efficiency resulting in the highest room heat load.
  - FM+HD @ -14 is the worst case number that should be used to calculate Air Conditioning sizing.
  - Air Conditioning and TX system power consumption should be calculated based on the intended operating mode and TPO for TCO calculations.

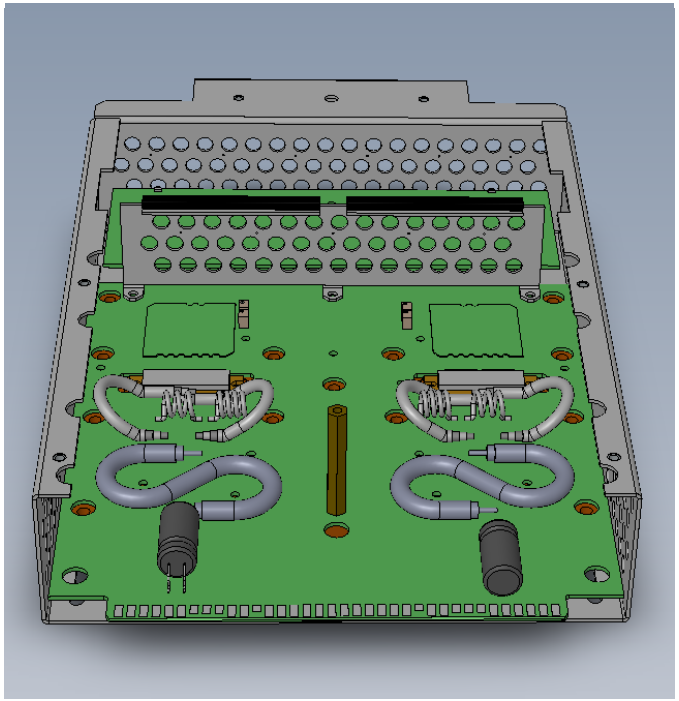
Flexiva FLX Liquid Cooled Transmitter System Architecture

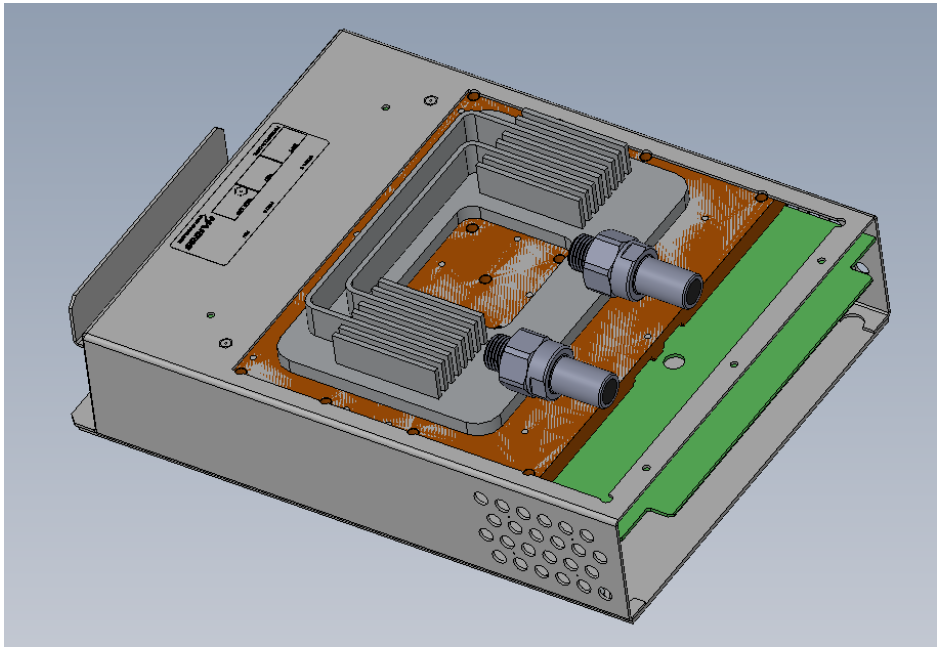
FAX Air Cooled PA Module





FLX Liquid Cooled PA Module with Chiller Plate



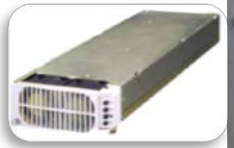


Flexiva High Power FM Transmitters

10kW Power Block

Integrated IPA switching
(Automatic drive chain redundancy)

Hot-Swappable, Hot Pluggable 2750W High Efficiency PS
1 to 1 PS to PA Ratio



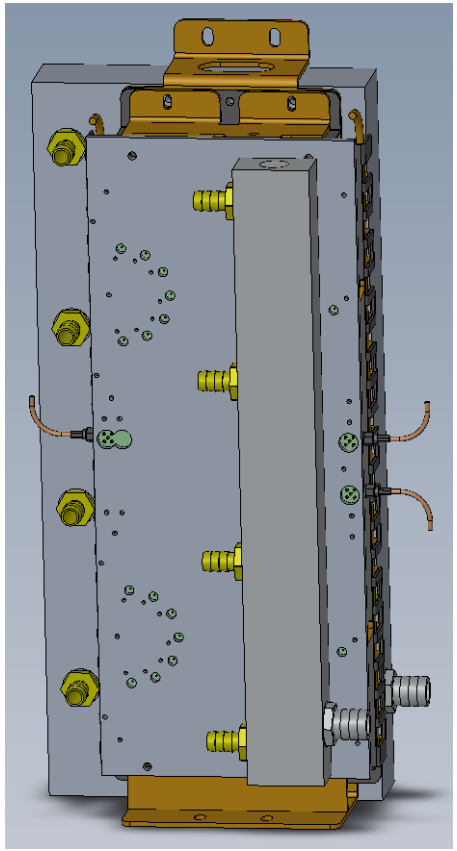
Hot Pluggable Dual IPA module Same module as PA

Seven Hot-Pluggable, Hot Swappable 1750 Watt PA modules for redundancy

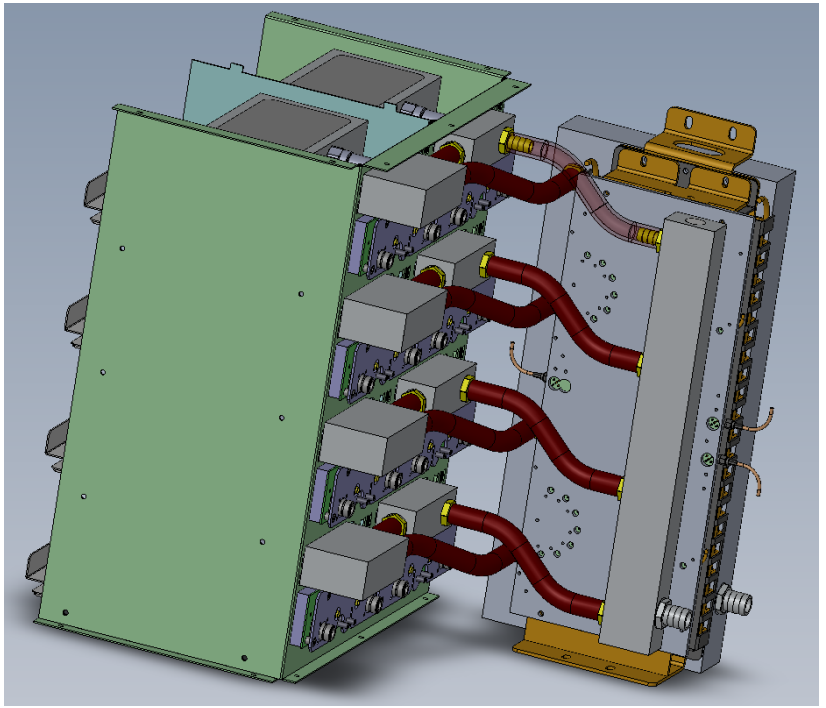
Microcontroller for Local Display, Remote Web Interface, SNMP Support

Hardware based controller with backup controller & life-support maintains basic functions and provides system operation without reliance on the microprocessor

Flexiva™ FLX Liquid-Cooled FM Transmitters

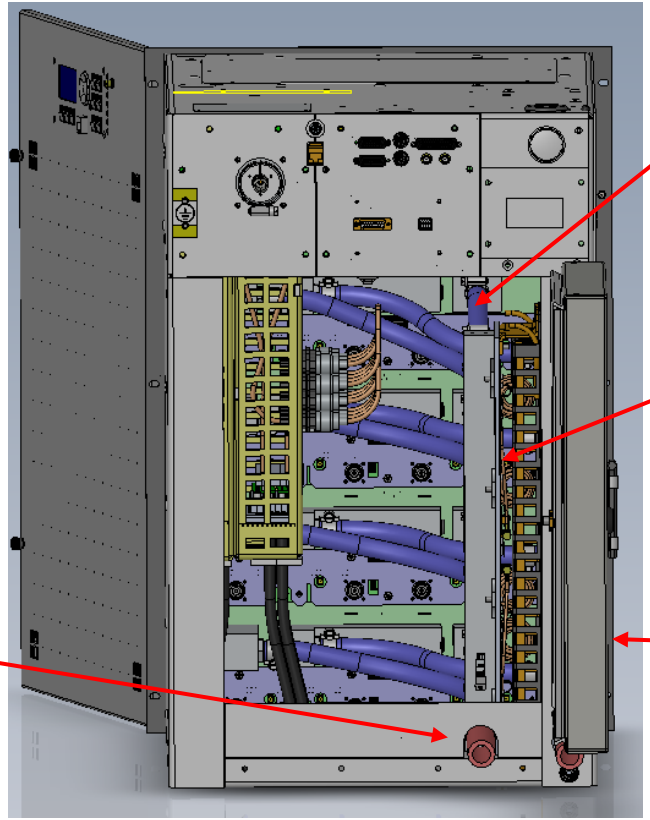


Liquid cooled 14-Way Splitter & ISO-Loads



Liquid Cooling Distribution System

Flexiva™ FLX Liquid-Cooled FM Transmitters



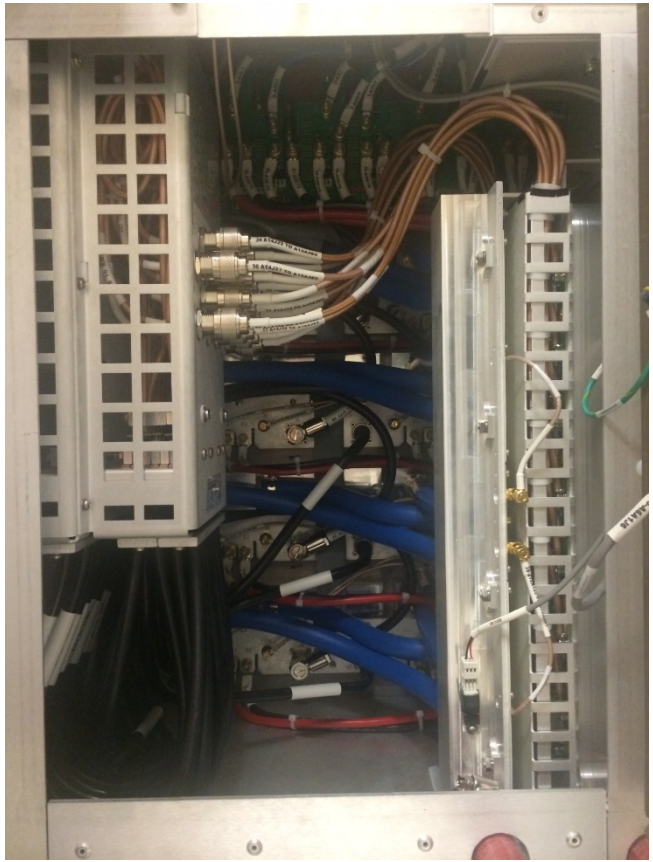
Glycol distribution system

Chiller plate for Combiner reject loads

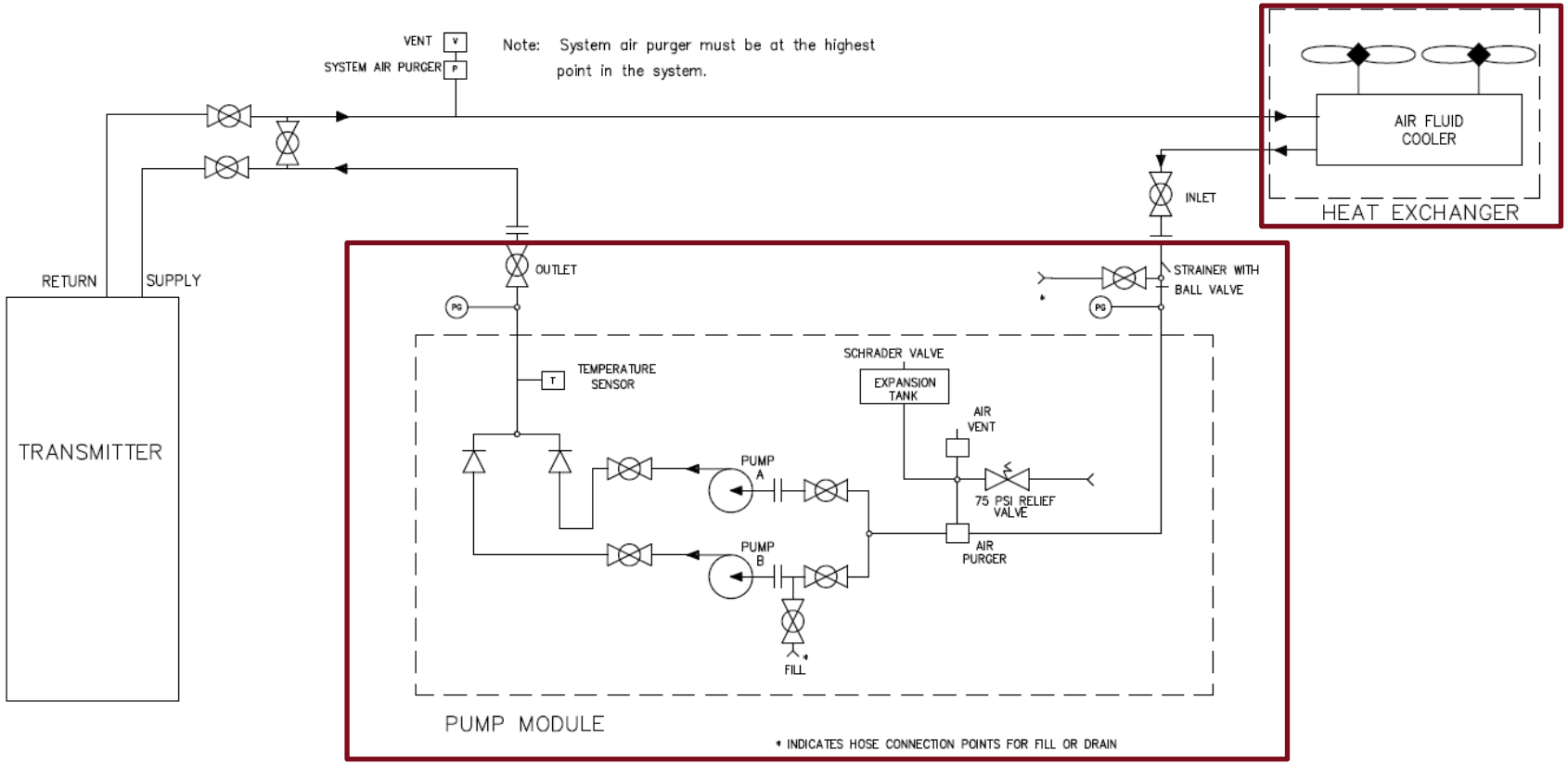
Variable speed flushing fans reduced from 4 to 2

Input/output from pump modules

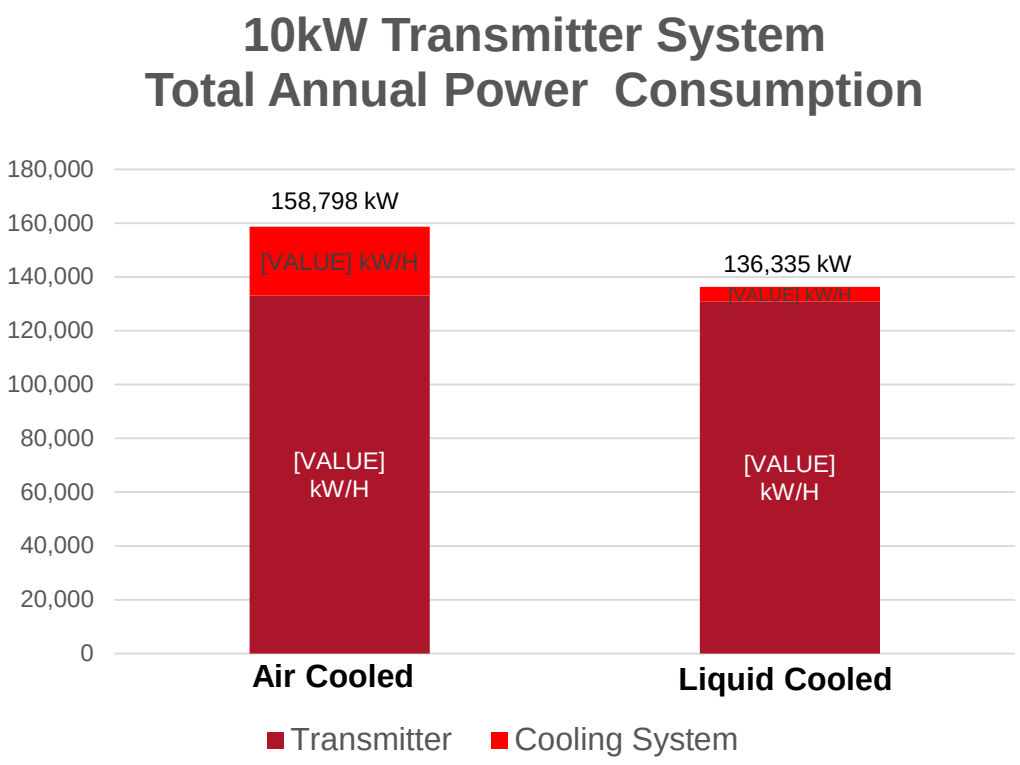
Flexiva™ FLX Liquid-Cooled FM Transmitters

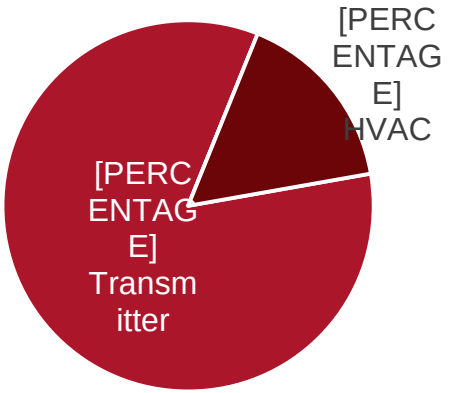


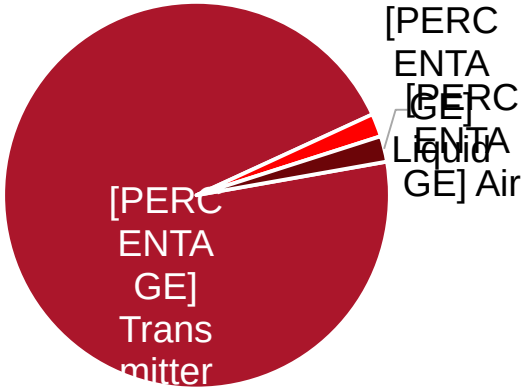
COOLING SYSTEM BLOCK DIAGRAM



HVAC vs. Liquid Cooled Consumption







High Efficiency Pump Module

- GatesAir design and manufacture
- 3rd generation – Optimized for High Efficiency
- Small physical size
- 2 Pumps, with auto/manual changeover
  - Low-noise, high efficiency pumps
  - Replace a pump during on-air operation!
- Low maintenance, closed-loop pressurized system
- Quiet – Designed for indoor installation
- Pump speed adjustable to optimize flow rate and efficiency

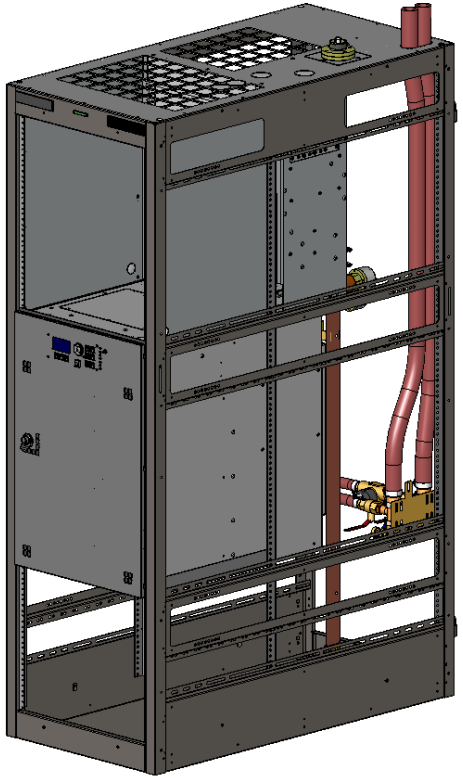
High Efficiency Heat Exchanger

- GatesAir manufacture
- Dual fans - on-air replacement
- Low noise, high-efficiency fan blades
- Speed controlled for maximum efficiency
- Vertical or horizontal airflow (mounting can be adapted on site for either configuration)
- Two sizes available 20kW & 50kW heat dissipation

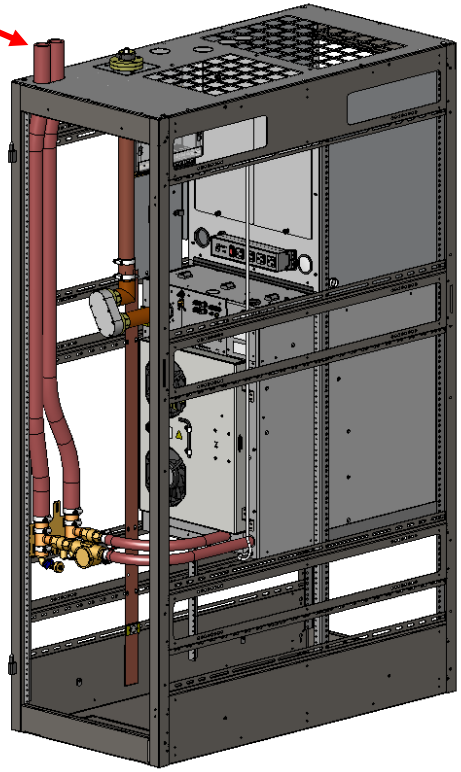
Vertical Air Flow

Horizontal Air Flow

FLX10K Transmitter



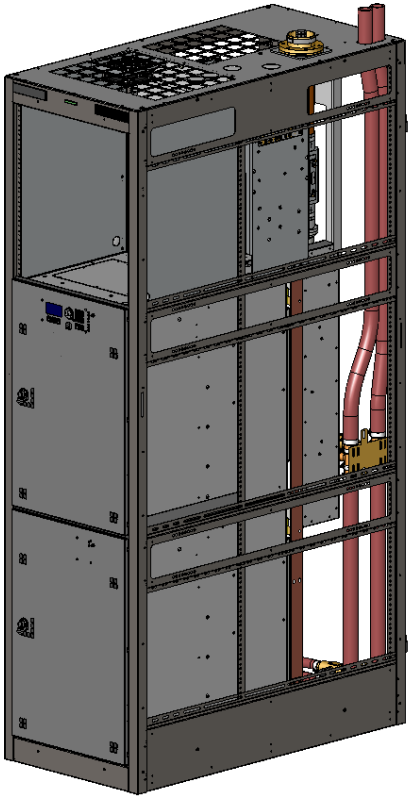
Supply/Return



Xmtr Size

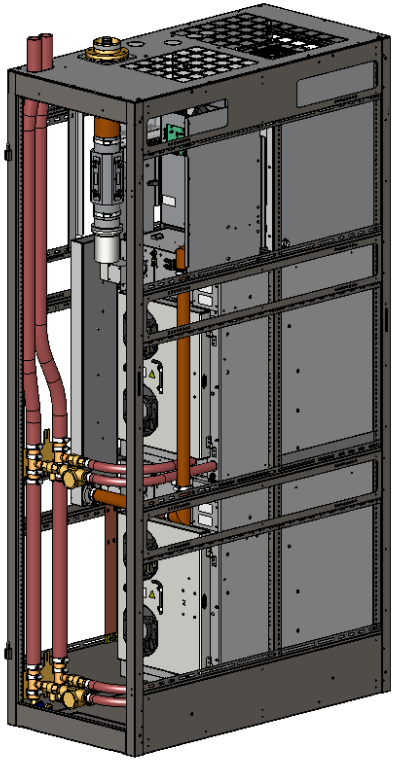
- 23.51 wide
- 71.00 tall
- 45.75 deep with doors
- 44.43 deep without doors

FLX20K Transmitter

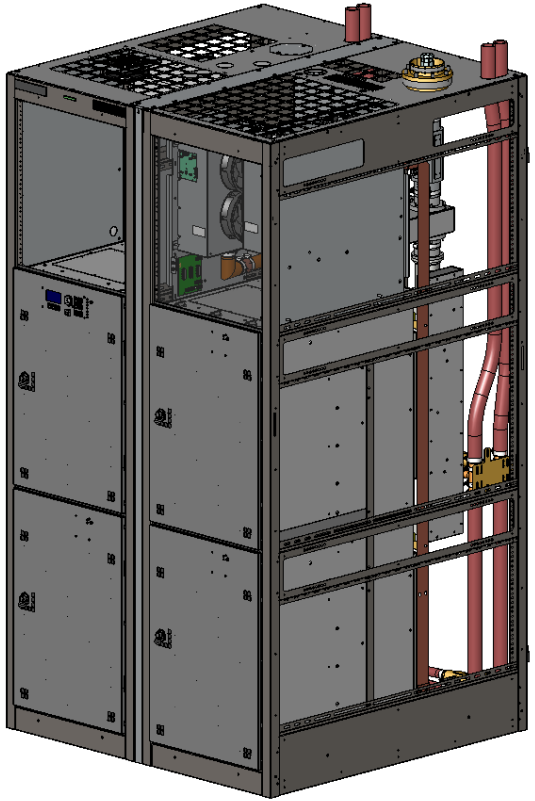


Xmtr Size

- 23.51 wide
- 83.25 tall
- 45.75 deep with doors
- 44.43 deep without doo

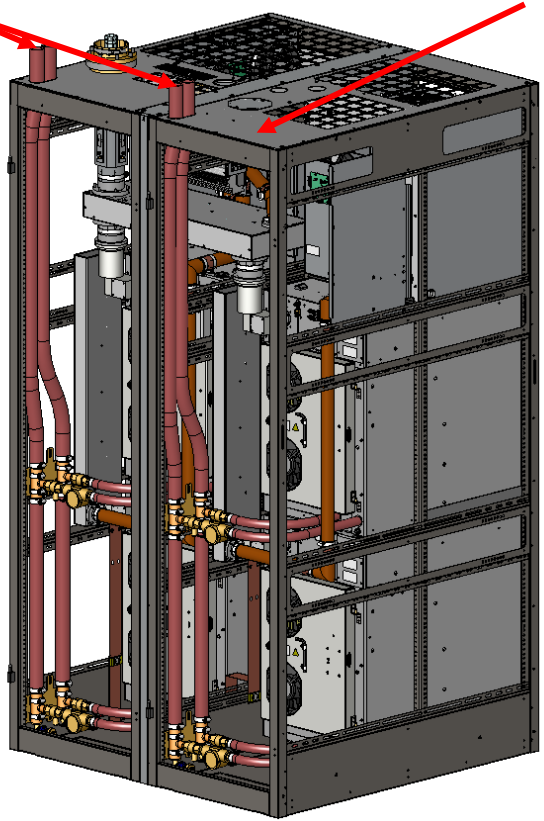


FLX40K Transmitter



Supply/Return

PWA, Pump
Diode Gating



Xmtr Size

- 47.09 wide
- 83.25 tall
- 45.75 deep with doors
- 44.43 deep without doors

FLX40K Transmitter

Thank you!

Questions?