FM TRANSMITTER COOLING TECHNOLOGIES AND TRADEOFFS

Jeff Welton

Regional Sales Manager, Central US

Nautel

Typical Efficiency ~2002-05

2002-2005	FM (Class C)	Hybrid -20 (Class AB)	Digital Only
Solid State <10 kW	60-64%	40-55%	30-35%
Tube >20 kW	64-67%	Not available	Not available

High-level combined systems increased power consumption about 20 to 25%.

Common-amp systems at the time could increase power consumption up to 50% or more!

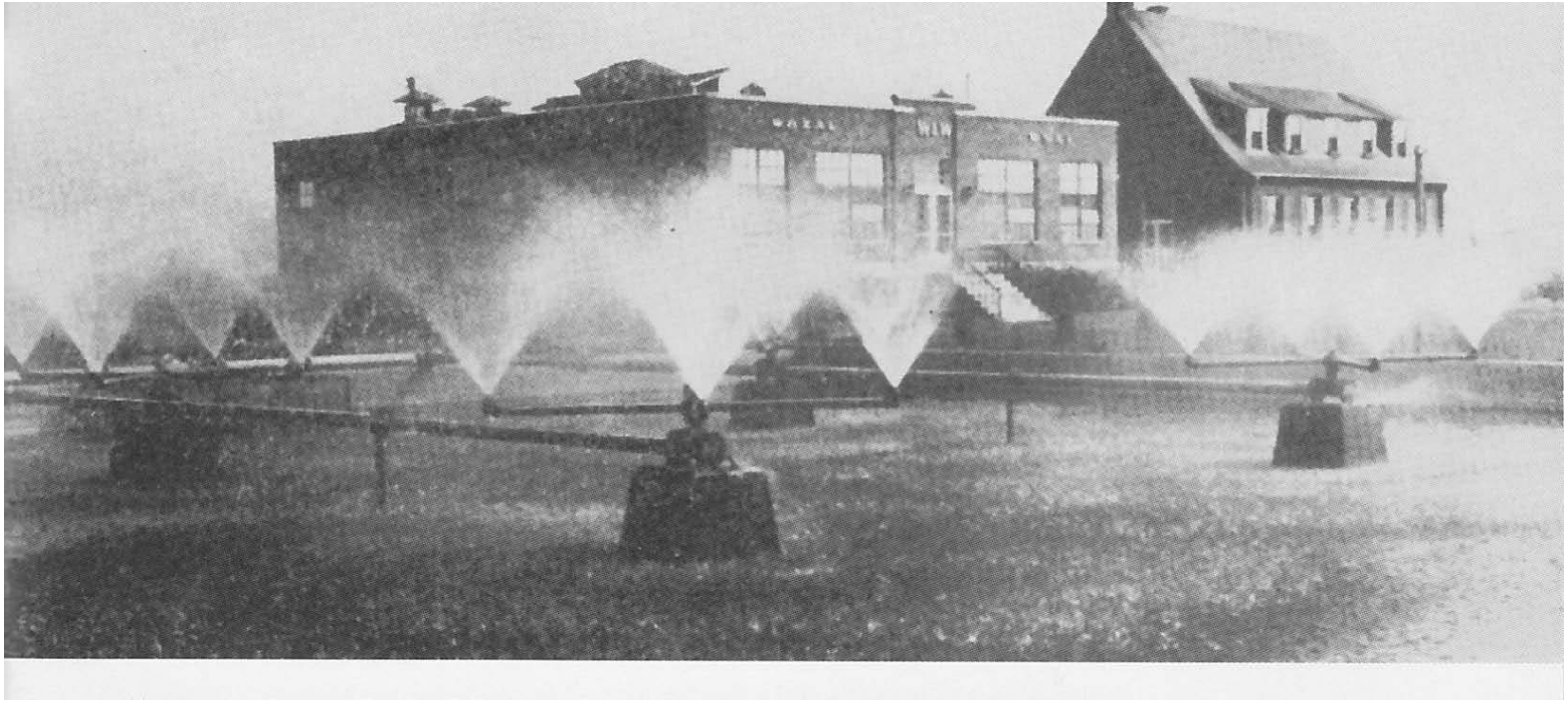
Solid State and Tube Solutions

- Initially, only solid state available <10 kW (really 8 kW)
- Continental – first tube digital hybrid transmitter, for TPOs 10-22 kW (employing Nautel's M50 exciter)
- Harris and BE followed with hybrid versions of their analog tube models:
  - Concerns with max plate dissipation and anode temperature
  - Workaround was sometimes needed to use different tube
- But, what about the prospect of -10 dBc operation?

A new 40 kW Transmitter

- -10 dBc would make high-level/mid-level obsolete
- Tougher cooling (and mask) challenges for manufacturers
- For Nautel, a clean slate to start
  - Solid State, the easy part
  - Must be 40 kW to allow for digital de-rating
  - Liquid cooled or air cooled? (not so easy)

Liquid Cooling History



“The Fountain” –Cooling spray pond at 500 kW WLW (1932)

Transmitter Cooling Challenges

- TUBE – Keep plate structure at reliable operating temperature to avoid failure of ceramic and metal seals.
- SOLID STATE– Keep heat source (FET) junction temperatures within their range. Could be hundreds of devices in the transmitter.
- MTBF for silicon and other electronic components improves significantly for every 10°C reduction in operating temperature.

Physics of Heat Transfer

Temp rise of media =

$$\frac{\text{Power (W)}}{\text{(Specific Heat x Mass Density x Flow Volume)}}$$

- Air must flow about 3000 times faster, in terms of volume, than water to remove the same amount of heat (due to the relative mass densities of water and air).

Heat Sink Design

$$Q = H \times A \times \Delta t$$

Where Q = heat removed (watts)

H = Heat transfer coefficient (heat per square meter)

A = Surface area in square meters

Δt= rise in temperature of media

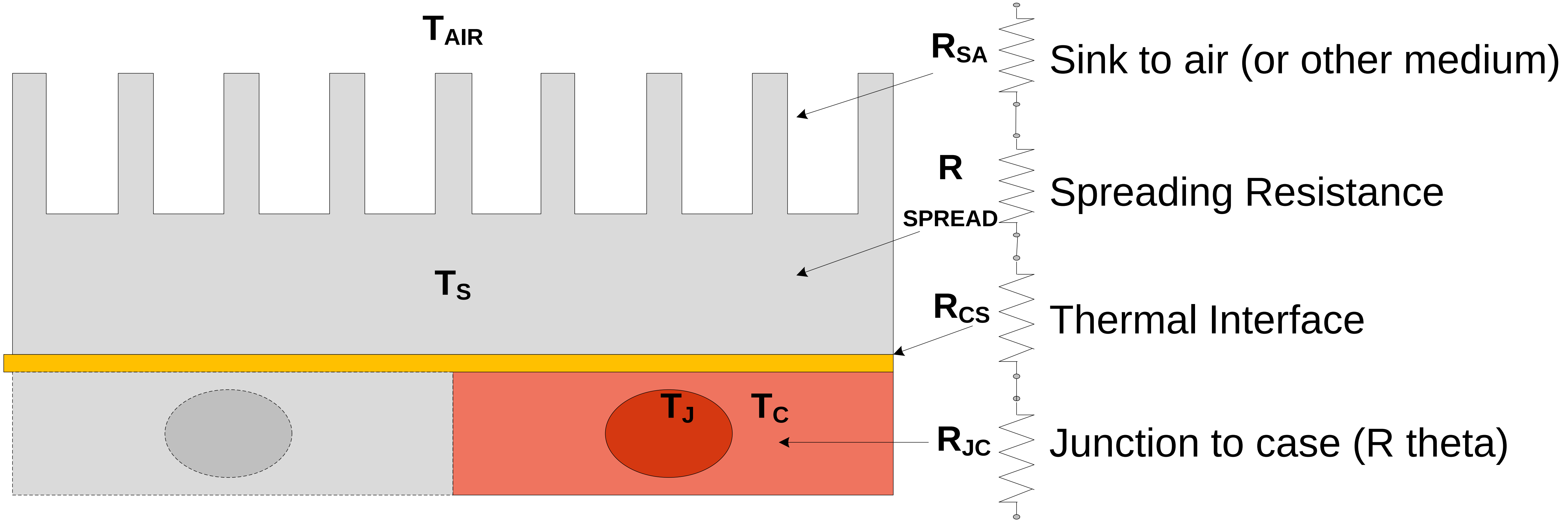
- Water has advantage of much higher H, so surface area required for a water-cooled heat sink can be much smaller.

Thermal Resistance Circuit

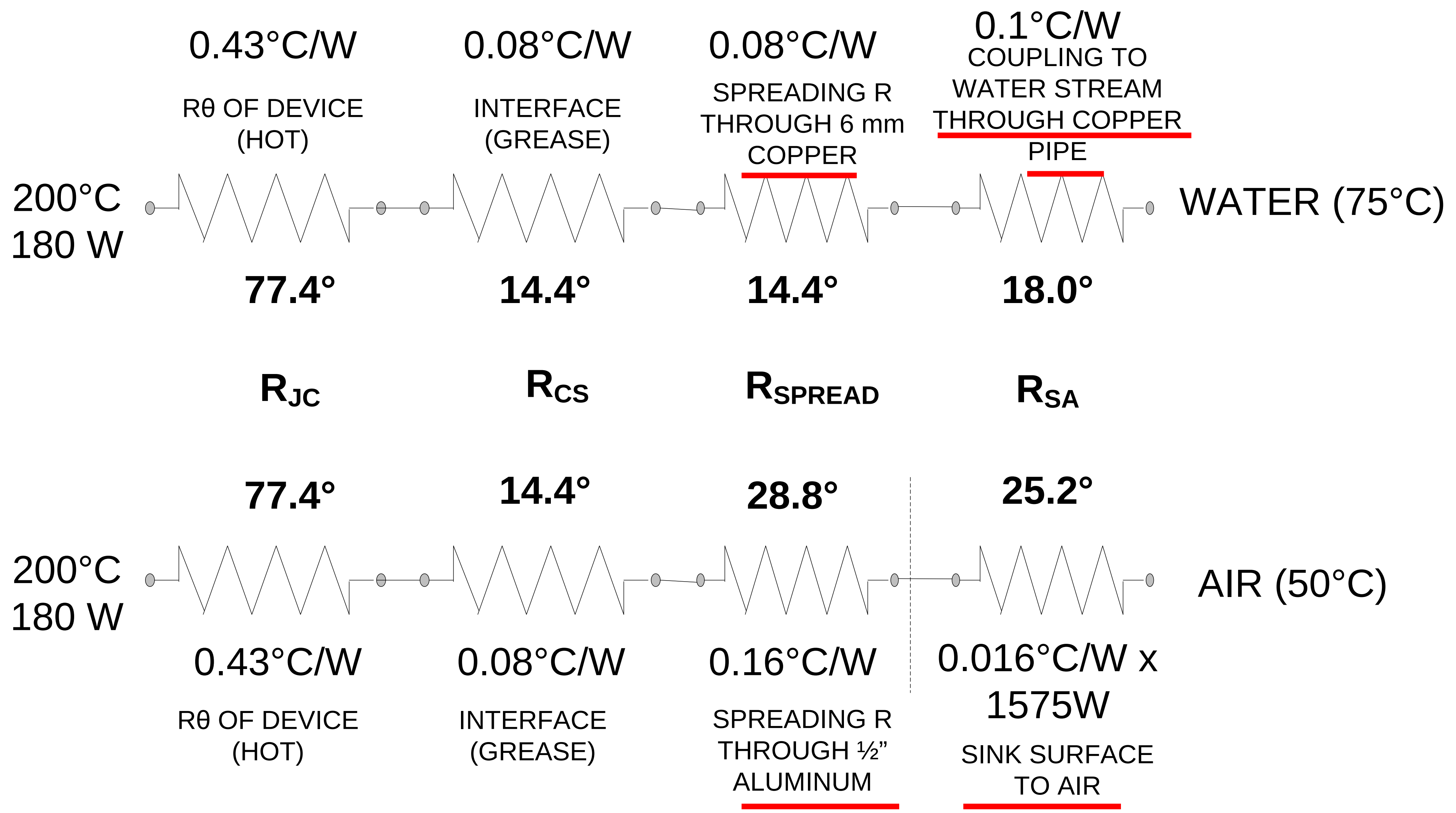
Heat from a cooled semiconductor traverses a path through solid materials before reaching the cooling medium. This path comprises a ***thermal resistance circuit***.

1. Device junction to its own case (R theta)
2. Case to heat sink (thermal interface)
3. “Spreading” resistance of the heat sink
4. Heat sink to the cooling medium (air or water)

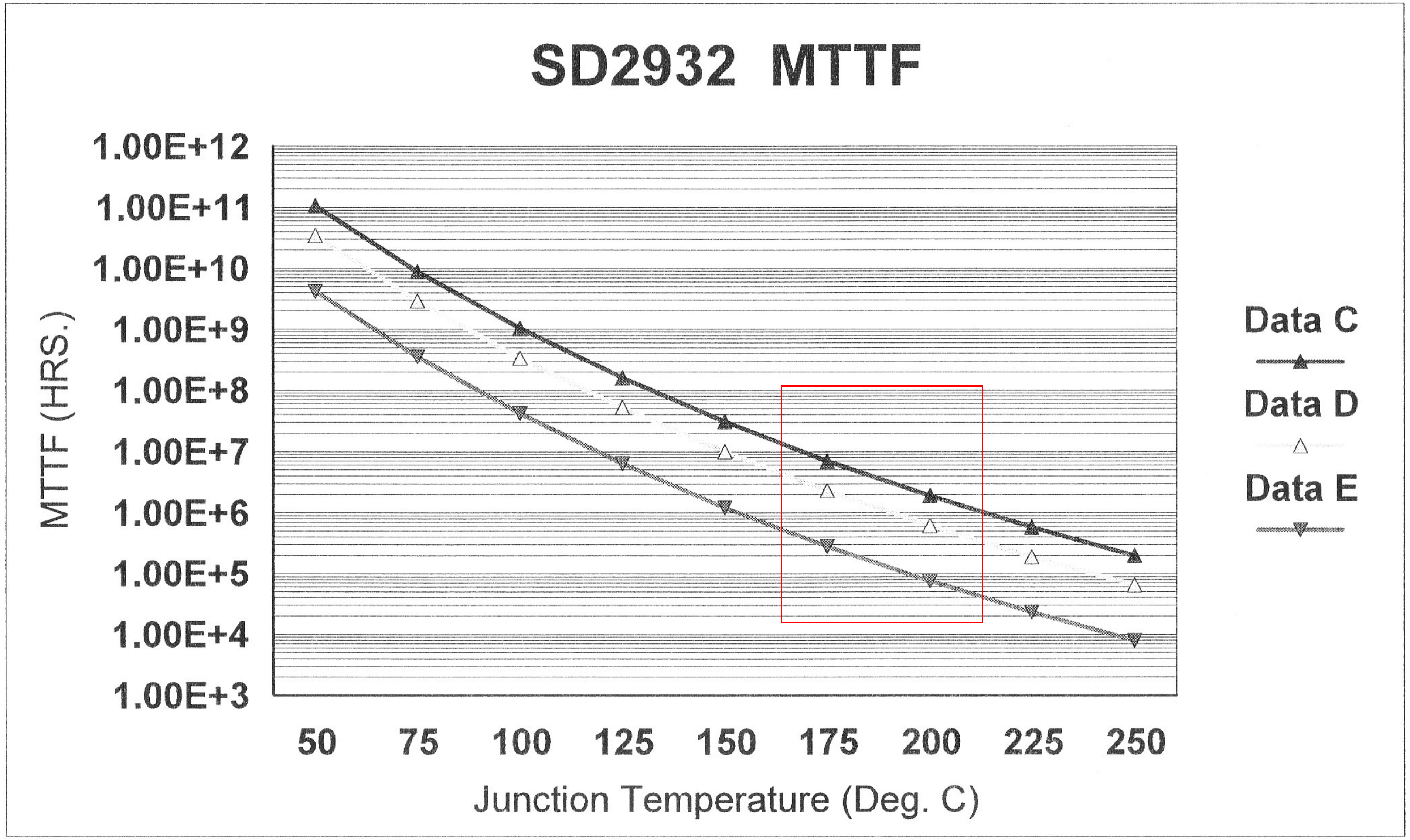
Thermal Resistance to Air



Calculations through water and air



Junction Temperature and MTBF



MTBF: SD FET in Mixed Ambient T

% of time	Ta	Tj	MTBF
5	50	180	2E6
60	40	170	4E6
35	30	160	8E6

Weighted failure rate=

0.05/2E6 + 0.60/4E6 + 0.35/8E6 =2.19E-7

MTBF= 1 / 2.19E-7 =4.57E6 hours or 1.9% in 10 years

% of time	Ta	Tj	MTBF
5	50	190	0.6E6
60	40	180	2E6
35	30	170	4E6

Tj max increased by 10°C

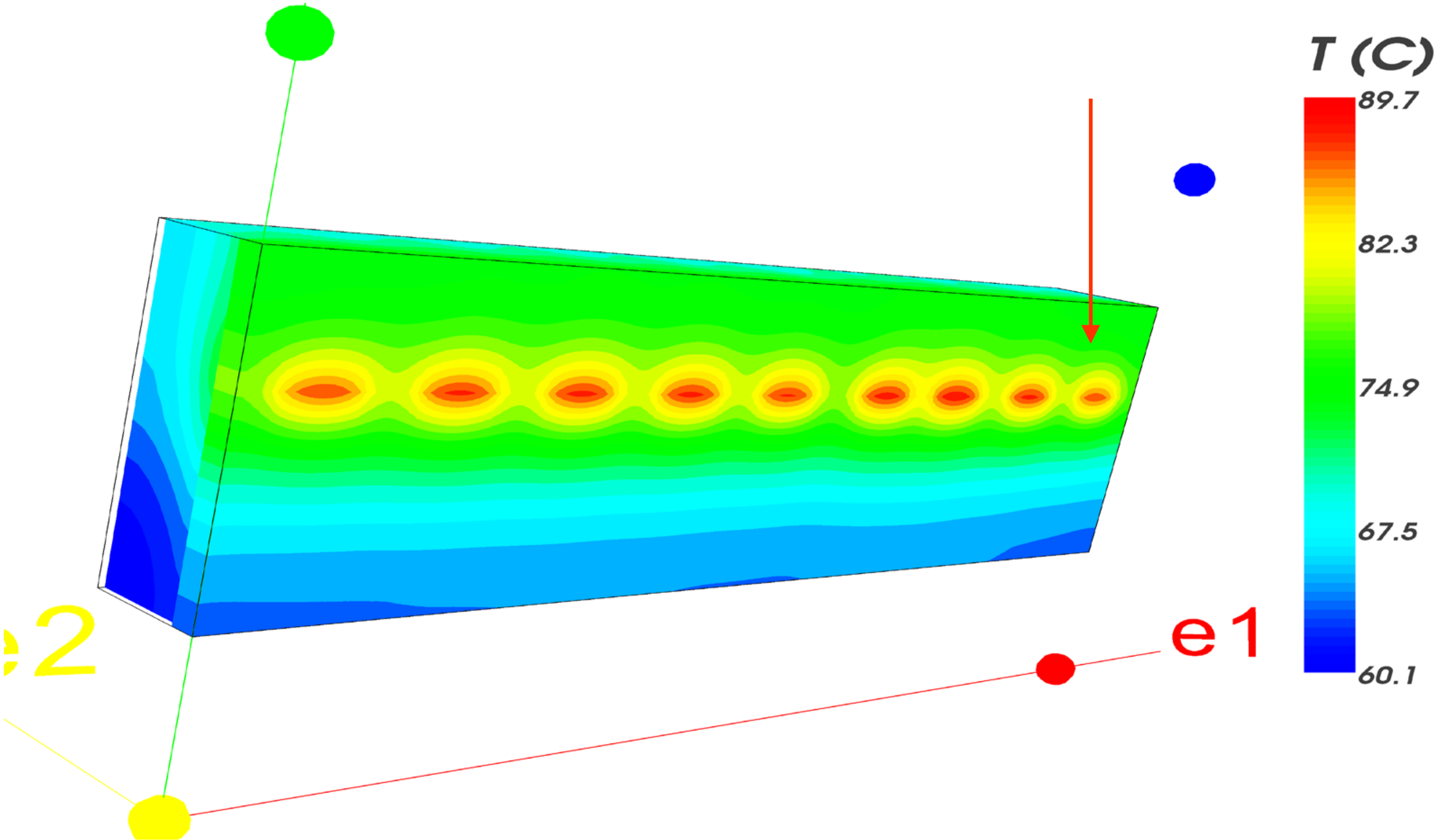
0.05/0.6E6 + 0.60/2E6 + 0.35/4E6 =4.71E-7

MTBF= 2.12E6, or 4% failure in 10 years.

Heat sink design “handles”

- R theta is a fixed parameter for the device.
- R_{CS} Thermal Interface (grease) also essentially fixed.
- R_{SPREAD} is a function of cross sectional boundaries where heat flows from one solid to another.
- R_{SA} the sink-to-air (or other cooling medium) resistance can be manipulated with number, surface area, and fin count of the heat sink, but only to a point of diminishing returns.
- T_{AIR} may or may not be controllable depending on the operating environment.

Spreading Resistance

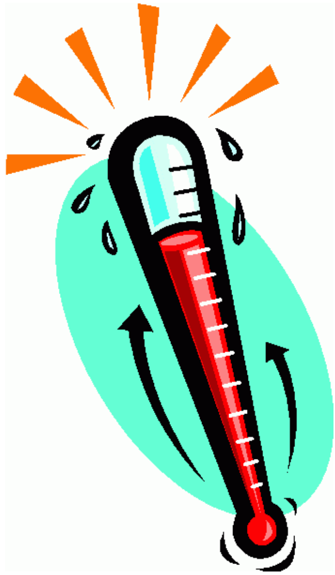


Cooling-Practical Design Limits

- Whether air or liquid, the practical range of control of the junction temperature is limited to about 25°C.
- In an air system, user control of ambient air temperature (e.g. 50°C to 40°C) can yield order of magnitude improvement in FET MTBF.
- In liquid cooled system, limits are more a function of heat exchanger design, if water chilling is used, etc.
- Both types of systems are equally capable of maintaining desired junction operating temperatures, if properly designed.

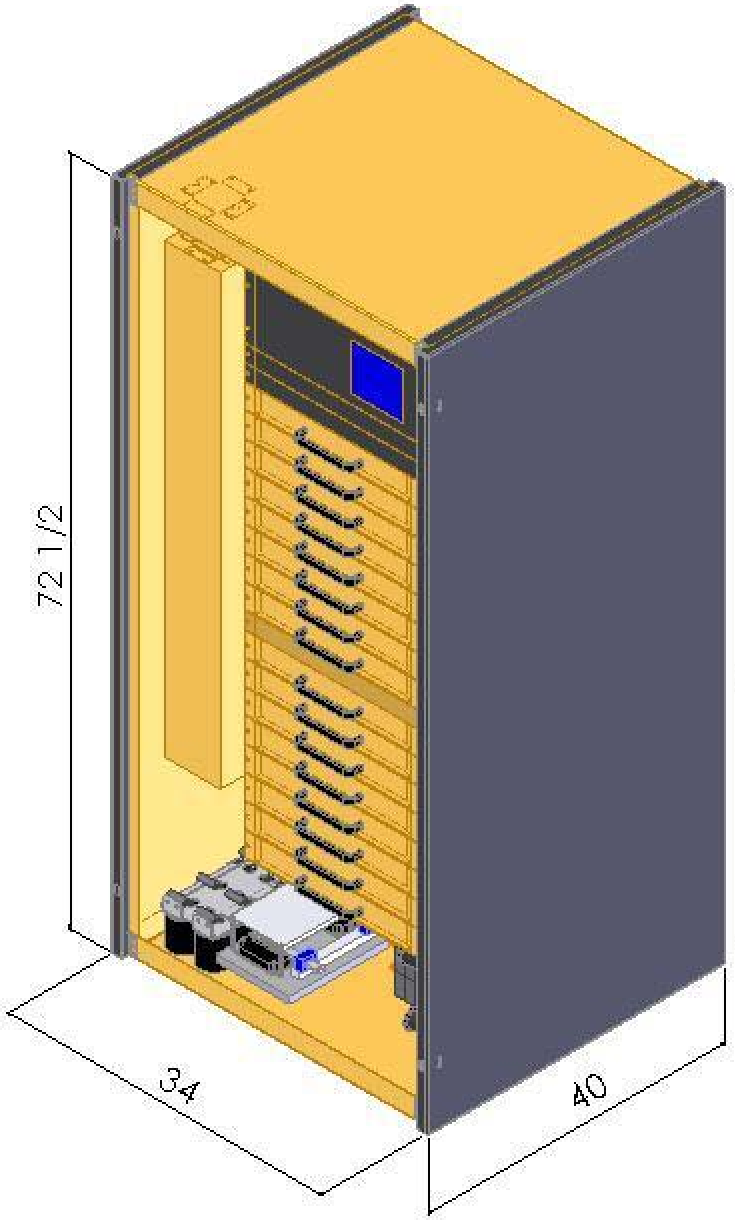
Operating Environment

- Most transmitters are designed for 50°C
- Significant improvement in device life can be achieved for each 10 degree reduction in ambient temperature



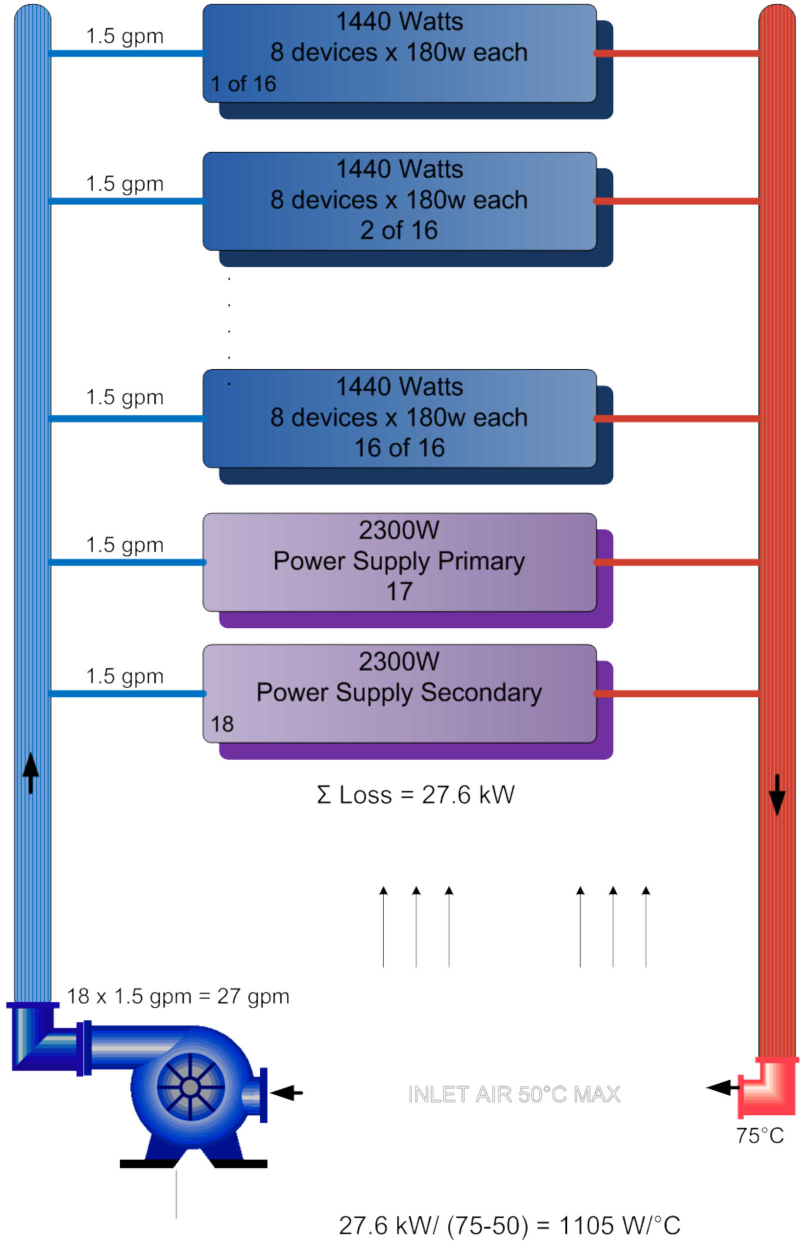
°C	°F
50	122
40	104
30	86
20	68

The Nautel Prototype



- Power modules oriented horizontally and stacked vertically
- Allows for vertically oriented manifold pipes at corners- with RF cubes and water cooled power supplies between them.
- Smaller footprint than final product (not including heat exchanger)
- Coolant – propylene glycol mix, single loop, single pump design

Coolant flow for proto design



Each module: 8 devices x 180 watts each = 1440 watts dissipated

16 modules x 1440 watts + 2 modules (PS) x 2300 watts = 27.6 kW total dissipation (40 kW FM Class C)

1.5 GPM flow in each module x 18 modules = 27 GPM pump/ heat exchanger flow.

More aggressive design would be needed for higher digital injection cooling.

WNCI, Columbus, OH

Decision: Water vs. Air

1. Initial Cost: Water cooled about 10% higher than air. Redundant heat exchangers/ backup pumps add to cost. **Advantage: Air.**
2. Installation Cost and Time: System complexity is higher for a liquid cooled system, requiring plumbing, pumps, heat exchanger installation, which must be coordinated with transmitter installation. High rise buildings may not accept risk of fluid leaks. Air may require HVAC or upgrade of existing HVAC, more readily accepted by landlord. **Advantage: Air**.

Water vs. Air

3. Operating Cost: Water cooled requires smaller HVAC system, but still will require SOME HVAC for modern computer controlled rack equipment. **Advantage: water-cooled**.

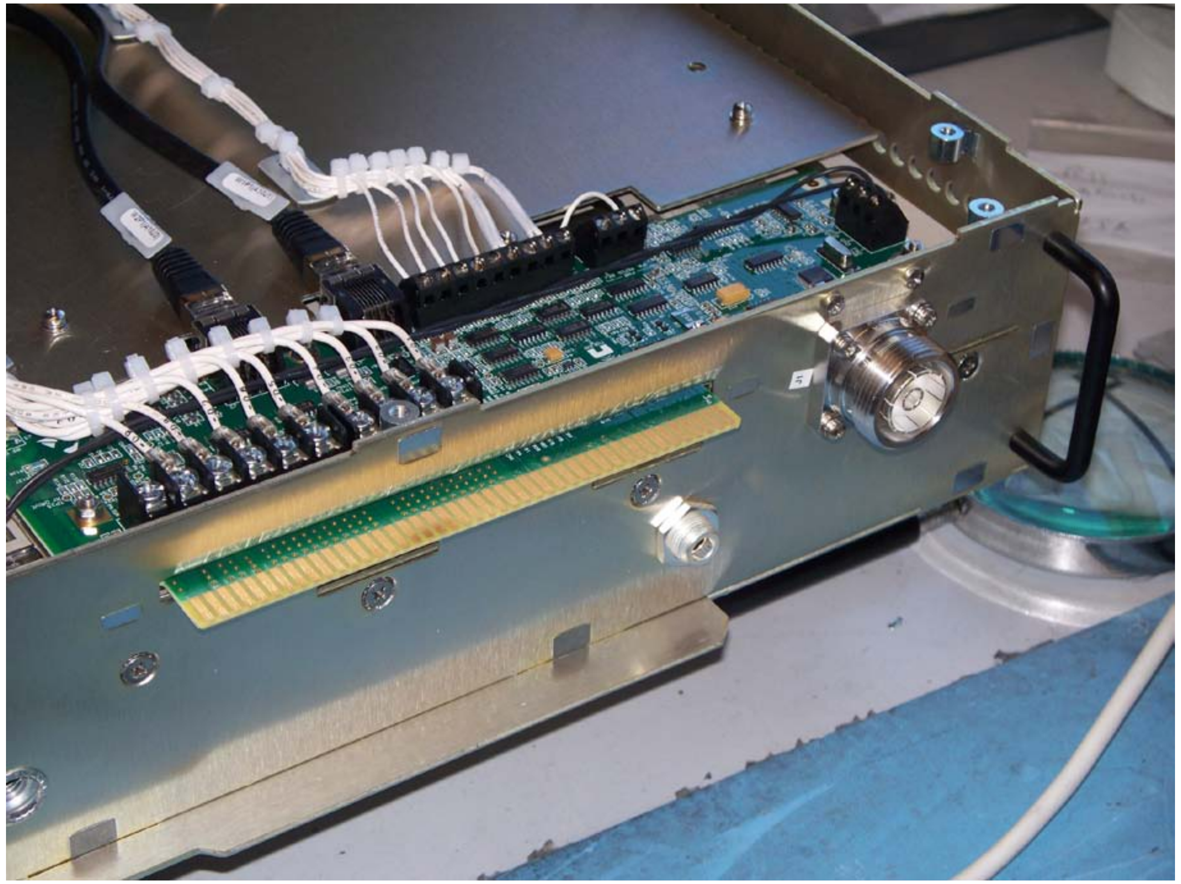
4. Noise: Water cooled systems have no high volume air passing across heat sink fins. Ambient noise is low level hum of pump(s). **Advantage: water-cooled**.

Water vs. Air

5. <u>Redundancy:</u> Single points of failure in a water-cooled system may include pumps, hoses, and potential leak points. Redundancy can be added but at additional cost. Air system, with multiple small DC-powered fans, eliminates these risks. **<u>Advantage: Air-cooled</u>**.

Water vs. Air

6. <u>Hot pluggable Modules:-</u>Easy to design for air system (blind-mating), without need for user to “make” or “break” connection. Designing a similar system for a module circulating water would be significantly more expensive. **<u>Advantage: Air-cooled</u>**.



Water vs. Air

7. Maintenance:

Air System: Periodic Inspection, cleaning, filter change, all performed while on-air.

Water cooled System: Monitor and trending of parameters-- pressure, temperatures, water levels, and water purity

Periodic flush and change of coolant, inspection of heat exchanger coils, hoses, piping, and pumps.

Water and glycol replenishment, storage, transport, and availability

Advantage: Air-cooled.

Water vs. Air

8. <u>Environmental Contamination:</u>
   – Harsh Environments- salt, sand, dust, corrosive industrial air, dirt

   <u>Advantage: Water-cooled.</u>

9. <u>Scalability:</u>

   -- Re-use of design at lower power levels, down to 3.5 kW
   Commonality of parts helps both manufacturing and customer familiarization. **<u>Advantage: Air-cooled.</u>**

Water vs. Air

10. Customer Resources and Training:

--Learning curve for water cooled systems

--Do stations have adequate engineering resources for the maintenance required?

--What about contract engineered stations, or stations with NO engineer until there is a problem?

--Are savings from lower building cooling costs worth the additional maintenance time?

Advantage: Air-cooled.

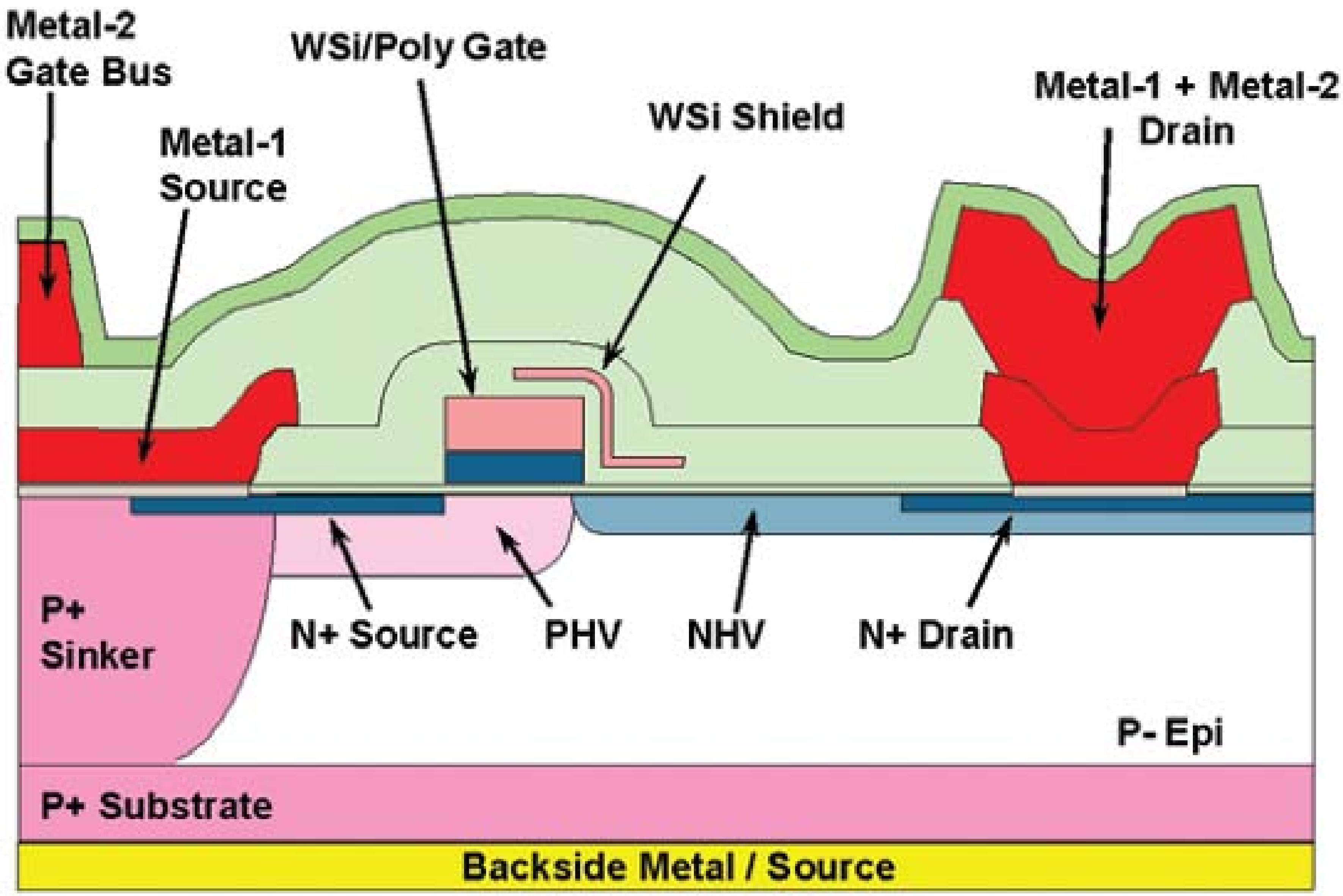
Matrix Summary

	WATER	*AIR*
Initial cost		✓
Installation Cost and Time		✓
Operating Cost	✓	
Noise	✓	
Redundancy		✓
Hot Pluggable Modules		✓
Maintenance		✓
Environmental Contamination	✓	
Customer Resources and Training		✓
Scalability		✓

A Promising Future: LDMOS Devices

- 50 Volt LDMOS now shipping in newer product
- Slightly higher efficiency
- Higher gain translates to fewer stages
- Significant thermal resistance benefits

LDMOS Device[1]



1. White Paper – 50V LDMOS, Freescale Semiconductor

Conclusions

- The broadcast industry traditionally has preferred air-cooling except where they cannot provide sufficient cooling capacity.
- When “reaching” to some formerly unattainable power level, water cooling is considered a means to that end, until an air cooled equivalent becomes a viable alternative.
- Customer preference may be strongly influenced by specific site conditions, by available maintenance resources, and “comfort level” with a particular technology.
- LDMOS Technology offers promise to lighten the heat load for both air and liquid cooled systems.

Thank you!

Questions?

Jeff Welton
Regional Sales Manager, Central US
Toll-Free: 877-662-8835, ext. 5127
jwelton@nautel.com