



Immersion Cooling of RF Amplifiers

Enhanced Amplification with Higher Duty Cycles

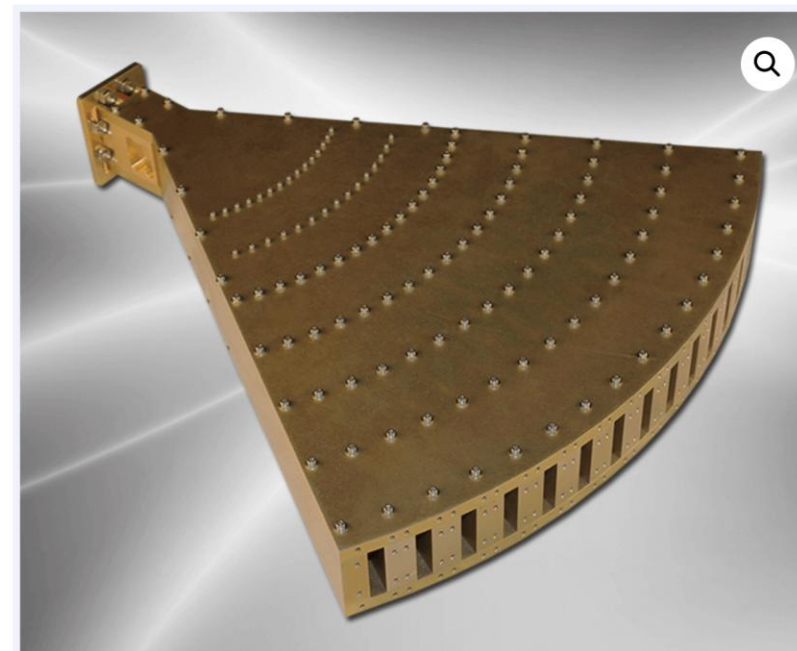
Gary Testa, President & CEO

Background

- In May 2024 Engineered Fluids, Inc. and Integra Technologies Inc. partner to test immersion cooling of high voltage GaN RF Amplifiers.
- Engineered Fluids provided the test tank and its ElectroCool EC-110 Dielectric Coolant to Integra. Integra utilized its 3.6kW 805 MHz GaN PA for testing.
- Testing indicated a small amount of RF distortion was caused by the difference in the dielectric constant between the EC-110 Coolant and Air, however the difference was small enough that pre-distortion could be applied to the initial input signal to correct.
- Amplifier performance increased from 3.6kW to >7kW with an increase in duty cycle from 5ms to 100ms without any modification to the amplifier IC.
- Currently awaiting approval from US Navy to fund additional testing to increase performance, duty-cycle, and lifecycle testing.

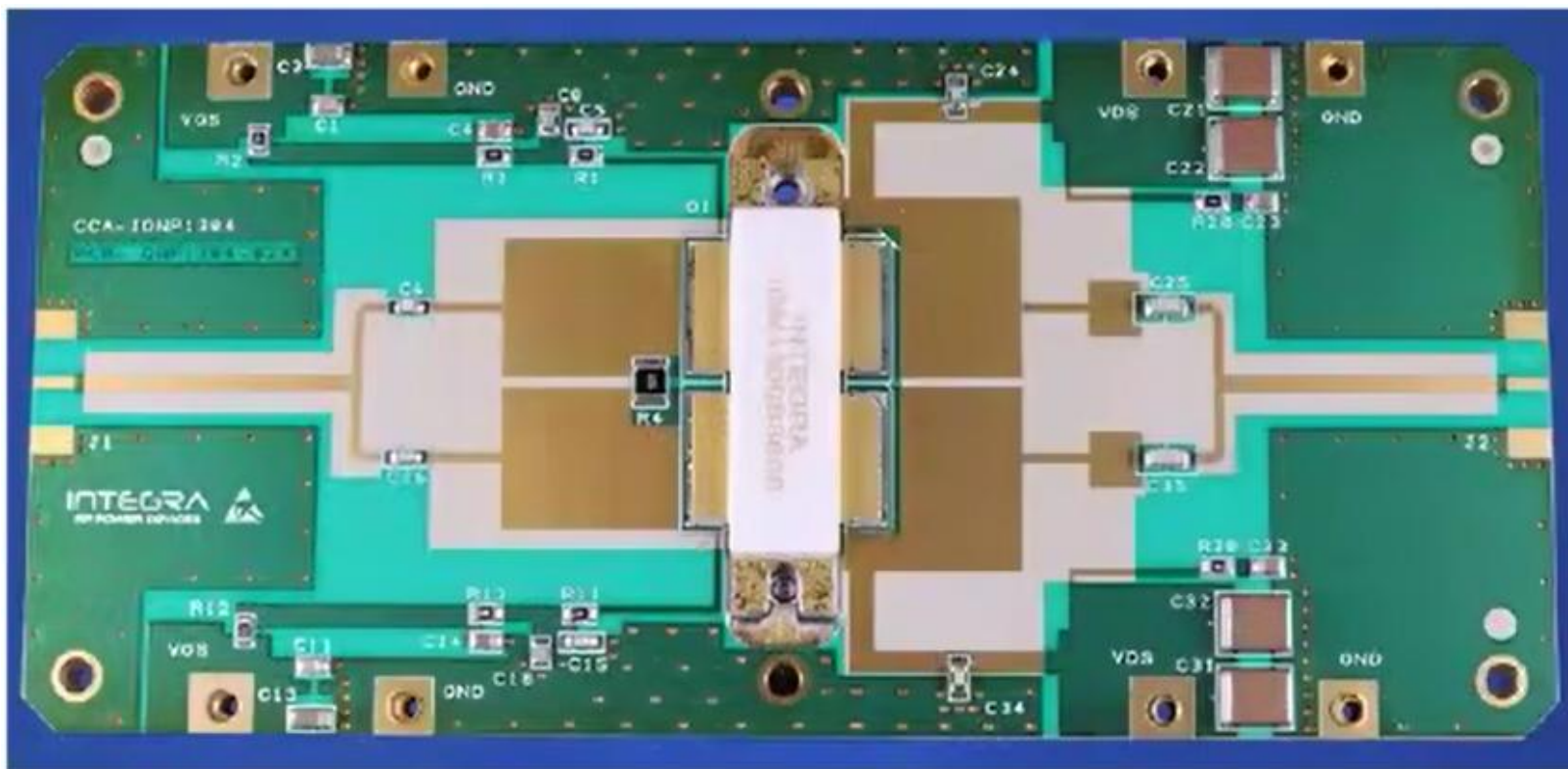
Benefits of Immersion Cooling to RF Amplifiers

- No modification of amplifier chip was required.
- Doubling of amplification through better thermal management achieves the targeted output power without design or chip changes:
 - Reduces the energy loss required for the same level of amplification
 - Reduces the number of wave combiners in system
 - Reduces system complexity, thus increasing MTBF
 - Reduces overall system size and weight
 - Simplifies cooling and eliminates water use
- Increase in amplifier duty cycle through better thermal management reduces the number of amplifiers required to achieve the necessary pulse duration:
 - Reduces complexity of coordination for timed pulses
 - Reduces the number of wave combiners and complexity of wave combiners
 - Reduces overall system size and weight



Integra Amplifier: 3.6kW 805 MHz GaN PA

- Existing standard product was utilized for testing, no modifications were made to the amplifier chip or pallet
- Entire pallet was immersed in Engineered Fluids EC-110 Dielectric Coolant
- Dielectric Coolant was not circulated or cooled during this testing



Applications benefiting from High Voltage GaN



Avionics/ATC



Early Warning
Radar



Weather
Radar



Directed
Energy



High Power
Microwave



Particle
Accelerators



Agriculture



Broadband
Jamming



Naval Radar TWT
Replacement



Industrial
Drying



Medical

Engineered Fluids, Inc.

Specialized developer of Single-phase Liquid Immersion Cooling Solutions

High-Performance Biodegradable, Non-Toxic, Non-Corrosive Dielectric Coolants

BitCool® - Dielectric Immersion Coolants designed specifically for ASIC based miners

- Supports all ASIC Crypto-mining devices

ElectroCool® - Dielectric Immersion Coolants for Semiconductors and Servers

- Server / CPU / GPU / SSD / DRAM
- Lasers / LEDs / RF Amplifiers / RF Transceivers / Processors / RADAR
- Battery / Fuel Cell cooling for Power Generation (Solar / Wind / Conventional) in stationary electrical storage applications

AmpCool® - Dielectric Immersion Coolants for Batteries, Electric Motors and Hydraulics

- Electric motors & motor controllers
- Hydraulic power transmission and actuator systems
- Battery and Fuel Cell cooling in hybrid and electric vehicles

SubmergeDeep® - Dielectric Pressure Compensation Fluids and Coolants for Subsea Applications

- Remote Operated Vehicles, Submarine Cables, Subsea Oil and Gas Downhole rigging
- Battery, chargers, electric motor, LED lighting, and hydraulic manipulators.

Products for protecting and cleaning electronic equipment during and after immersion

VoltCool® Additives - Highly Concentrated Transformer Oil Protection

- Power & Distribution Transformers, Switch Gear, AC & DC feeder lines
- Anti-oxidation and Corrosive Sulfur Stop Additives for use with hydrocarbon transformer oils

Dielectric Solvents - Safe and Effective Removal of Dielectric Fluids and Mineral Oils

- Fully dielectric solvents for use with all electronics and immersion cooling systems

What is **SLIC** for Electronics Cooling

SLIC : Single-phase, Liquid Immersion Cooling

The full immersion of electrical devices directly into single-phase dielectric heat transfer fluid that is either passively circulated by the natural convection of the heated coolant or actively circulated by pumping the dielectric coolant through and around the electrical device being cooled.

Single-phase

- A single-phase coolant does not boil or undergo a phase change at anytime during the cooling process. This eliminates all pressure, fumes, vapors, and corrosion due to micro-cavitation created by a coolant's state transition from liquid to gas.

Liquid

- The coolant is a Newtonian fluid and can be circulated and transported within the system at very low pressure and low flow rates using standard inexpensive hoses, pipes, pumps, and cooled with radiators, dry coolers, or heat exchangers.

Immersion

- Direct immersion of electronics in a non-electrically conductive (dielectric) engineered coolant such that no protective cover, enclosure, coatings, or other means of insulation is required to be applied to the electrical circuits, chips, or device.

Cooling

- The removal of thermal energy from a device through absorption by a dielectric coolant and transfer to a heat rejection device or heat reuse appliance through the circulation of the coolant without the use of compressors or phase change.

SLIC is simply the most efficient and cost-effective means to cool all high-power electronics.

Over 11,000 Customers in Production Today

Electric Vehicles



Servers / Data Centers



Batteries / Other



ElectroCool® Dielectric Coolants

ElectroCool Dielectric Coolants are the highest performance biodegradable, non-toxic dielectric thermal management fluids available.

ElectroCool Coolants feature the broadest material compatibility, highest safety, and widest useful temperature range.

Download Information on ElectroCool:

- [Technical Data Sheets](#)
- [Safety Data Sheets](#)
- [Characteristics by Temperature](#)

CHARACTERISTICS OF ELECTROCOOL DIELECTRIC COOLANTS

Product ID	EC-110	EC-120	EC-122	EC-130	EC-140
Typical Application	General Electronics Cooling	High Temperature Electronics	Lowest Viscosity, Microchannels & Actuators	Higher flash point offers an extra safety margin	Extreme Temp Semiconductor & highest flash point
Appearance	Clear				
Fluid Behavior	Non-Compressible, Isotropic, Newtonian				
Dielectric Strength	>60kV				
Acid Value, mg KOH/g	<0.01 (pH = neutral)				
Resistivity (ohm-cm)	>1x10 ¹⁴				
Dielectric Constant	2.100	2.200	2.100	2.104	2.220
Refractive Index n _D ²⁰	1.441	1.453	1.442	1.458	1.462
Pour Point (°C)	-60	-60	-65	-58	-54
Flash Point (°C)	203	228	157	260	285
ISO 4406 Particle Count	17/15/12	17/15/12	17/15/12	17/15/12	17/15/12
Total Sulfur (ppm)	0	0	0	0	0
Density, g/cc @ 20°C	0.82	0.82	0.81	0.83	0.84
Coefficient of Thermal Expansion, Vol/°C	0.00067	0.00065	0.00067	0.00065	0.00063
Kinematic Viscosity (cSt)	0°C	33.1	109.4	18.9	290
	40°C	7.25	16.10	5.02	36.10
	60°C	4.44	8.72	2.9	18.14
	100°C	2.22	3.70	1.7	6.80
Thermal Conductivity (W/m*K)	0°C	0.1397	0.1459	0.1383	0.1480
	40°C	0.1374	0.1439	0.1359	0.1467
	60°C	0.1363	0.1430	0.1342	0.1460
	100°C	0.1340	0.1411	0.1325	0.1446
Specific Heat (kJ/kg°C)	0°C	2.0608	2.0608	2.06	2.0610
	40°C	2.2121	2.2119	2.21	2.2030
	60°C	2.2877	2.2877	2.32	2.2877
	100°C	2.4390	2.4390	2.44	2.4390
Global Warming Potential	0	0	0	0	0
Biodegradability ¹	Readily Biodegradable (D5864 / OECD 301B)				Inherently Biodegradable
Materials Compatibility Warranty	Yes	Yes	Yes	Yes	Yes
Product Operational Warranties (Yrs) ²	1, 5, 10	1, 5, 10	1, 5, 10	1, 5, 10	1, 5, 10
Shelf Life (Yrs) ³	25	25	25	25	25

¹⁾ Biodegradation is stated for a 28-Day Test Period. Biodegradation continues to occur after the initial test period.

²⁾ See product specific warranty statement for terms and conditions.

³⁾ Shelf-Life duration is stated for an original sealed steel container, Shelf-life period is included in the warranty period.

ElectroCool® Dielectric Coolants

High Performance Coolants designed for general cooling of electrical devices

Industries & Applications for Dielectric Coolants:

Aerospace

- Aeronautic and space instrumentation and radar cooling

Automotive & Robotics

- Electric motors & EM controller cooling & lubrication
- Battery cooling and thermal runaway suppression
- Kinetic Energy Recovery Systems (KERS) cooling and hydrostatic energy transfer
- Undersea pressure compensation and lubrication for submersibles

Power and Transmission Engineering

- Transformer Cooling

Semiconductor & Communications

- Electronics Immersion Cooling - CPU / GPU / FPGA / SSD and servers
- Amplifiers, Power Vacuum Tubes, & RF Transmitter cooling
- Optical & Laser Diodes cooling



For more information...

Engineered Fluids, Inc.

2233 3rd Ave S, St. Petersburg, FL 33712

tel: +1. 725.218.1955

email: sales@engineeredfluids.com