“Miniaturization and Performance Improvement of Electronic Systems by Utilizing Embedded Thin-Film Resistors and Gap Capacitors”

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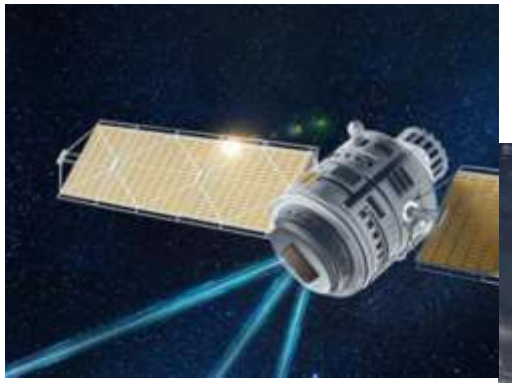
Agenda

- Trends in Military and Space Electronics
- Why embedded resistors and capacitors?
- Overview of embedded resistors
  - Fabrication Process
  - Designing with Embedded Resistors
- Applications
- Technology Roadmap
- Overview of Gap Capacitors for Embedding
- Summary

Trends in Military and Space Electronics

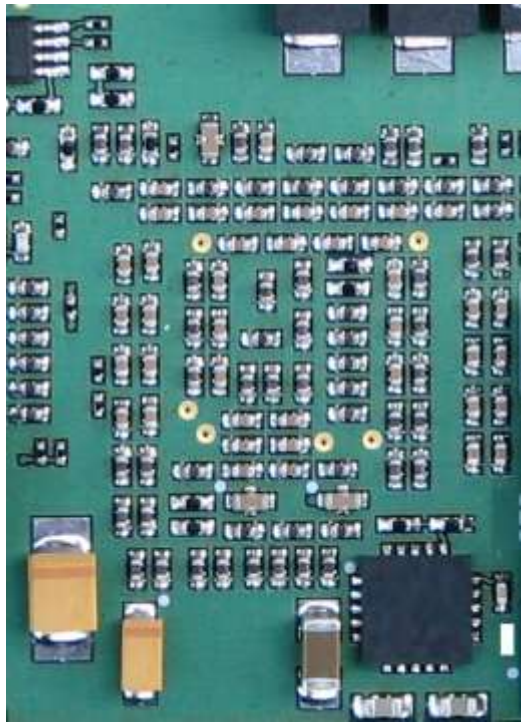
- Higher Data Rates
  - Requires Advanced Antenna Designs (Phased Array) with higher frequencies
- More onboard computing, including AI.
  - Requires High-performance IC Packaging
- Advanced Sensor Technology
  - Requires higher integration
- Use of SmallSats/CubeSats
  - Requires higher component density



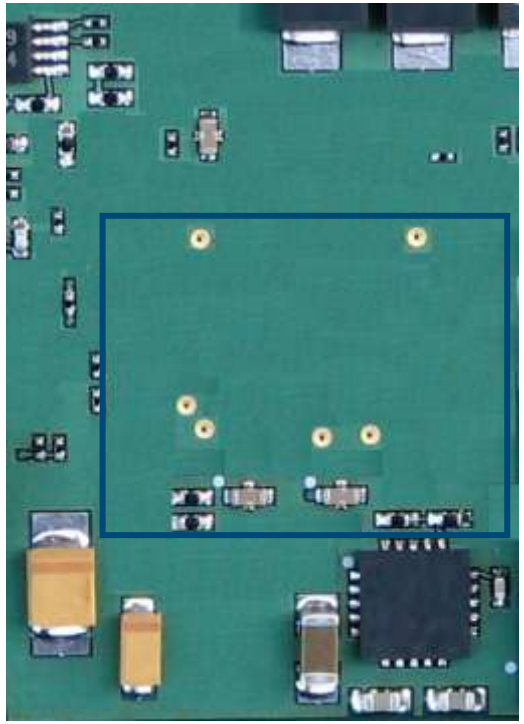
All these require SWaP improvements!

Embedded Passive Technology

- Resistor copper foil allows etched resistors to be formed on PCB layers
- Embedded capacitor material allows the removal of numerous caps
- Space available to add alternate components or shrink the printed circuit board



Surface Mount

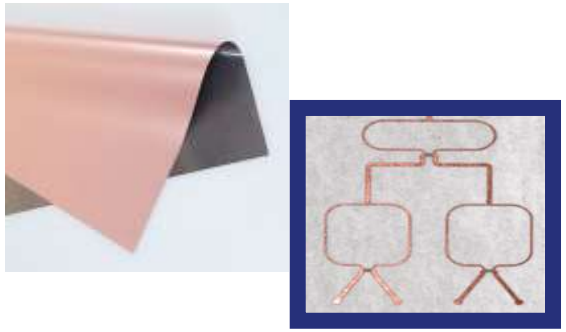


Embedded

Surface Mount Embedded

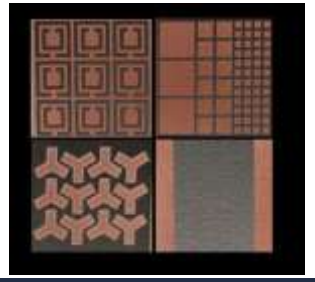
Embedded Resistor Overview

Thin-Film Embedded Resistors – The Platform for Performance in Mission-Critical Applications



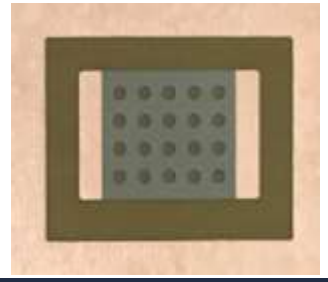
- Thin-Film resistors act like a resistive ‘blank slate’ which enables design engineers to create the innovative, robust, and feature-rich circuitry that modern applications demand.
- Thin-Film resistors have reduced parasitic inductance and capacitance which improve electrical performance over discrete resistors.
- Partnered with leading OEMs to deliver best-in-class electronics for aerospace and defense, consumer electronics, computer, medical and telecommunications markets to embed resistors within circuit board.

EM Absorber / Structured



Wilkinson Power Dividers

Circuit Foil Heaters



Electronic Packaging

Embedded Resistor Technology

Product Overview

- Resistive copper foil used by PCB hardware designers to embed planar resistors into a layer of the PCB
- Embedded resistors are used over surface discrete resistors when there is a need to miniaturize a PCB foot-print, increase density, improve signal integrity or electrical performance, and increase reliability
- The resistive alloy can also be used for a very efficient heater element within a PCB or as a HIS / FSS / R-card Absorber

Technical Advantages

- Provides Greater Packaging Density
  - Free up board surface area
  - Reduce board size or add functionality
- Electrical Performance Enhancement
  - Shorter electrical connections
  - Lower inductance
  - Reduced EMI
- Improved Reliability and Manufacturability
  - Fewer solder joints
  - Stable over temperature and frequency
  - Potential for single-sided assembly
- Weight Reduction

Quantic Ohmega-Ticer Enabling PCB Designs over the Decades

High Reliability – RF – Improved Electrical Performance – Miniaturization – Higher Frequencies

1972
Mica Corp. develops OhmegaPly

1973
First Major application

1983
Ωhmega Technologies Founded

2002
Gould develops TCR

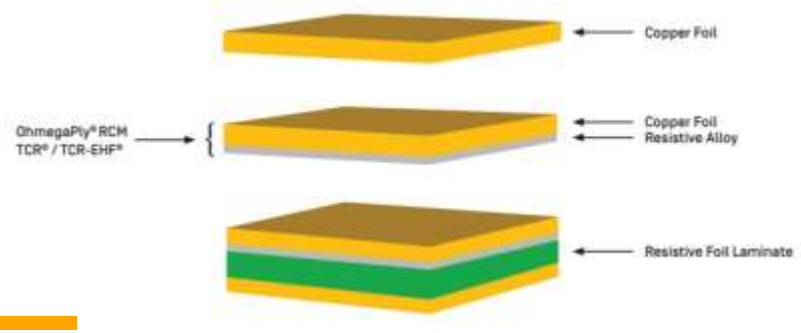
2006
Ticer Technologies Founded

2021
Quantic acquires Ohmega and Ticer

Resistor Foil Products

Resistive Blank Slate

- Quantic Resistive Foils, OhmegaPly® and Ticer TCR ® are manufactured in wide web, roll to roll format
- The thin film metal alloy/copper foil combination is called RCM [Resistor-Conductor Material]
- The RCM is laminated to a dielectric material, like any other copper foil, and subtractively processed to produce copper circuitry and planar resistors



OhmegaPly® RCM

- Proprietary Electrodeposited non-magnetic NiP
- CCL Customers: Rogers, AGC, Isola, Others
- 21K ft^2 manufacturing facility, Culver City, CA

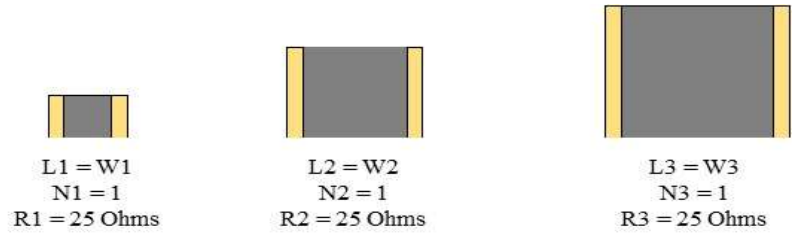
Substrates:
- Rigid
- Flex
- Rigid-Flex

Ticer TCR®, TCR-EHF®

- Proprietary Sputtered non-magnetic NiCr, NCAS, CrSiO
- CCL Customers: Rogers, AGC, Isola, Panasonic, DuPont
- 14K ft^2 manufacturing space: Windsor, CT + Chandler, AZ

Ohms Per Square What?

- Sheet resistivity (stated in Ohms per square) is dimensionless
- A square area of resistive material = sheet resistivity of resistive material E.g., a 25 Ω/□ (Ohms/Square) sheet resistance; simply adjust the length to width ratio to change the resistor value

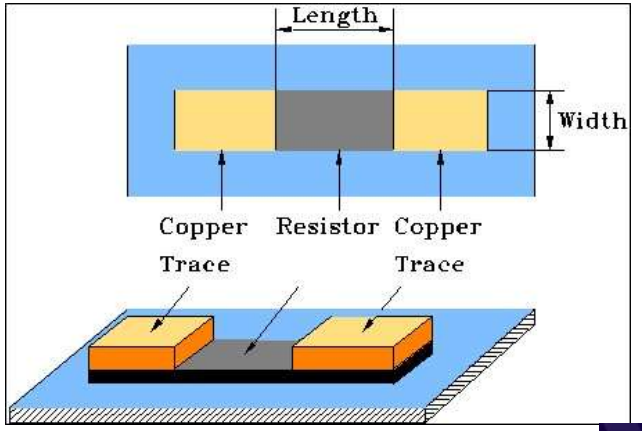


- Resistor value = sheet resistivity x ratio of element length to width
- E.g., a 25 Ω/□ sheet resistivity
  - Length = 0.5 mm
  - Width = 0.25 mm
  - Resistor value = 50Ω

$$R = R_s \left(\frac{L}{W}\right)$$

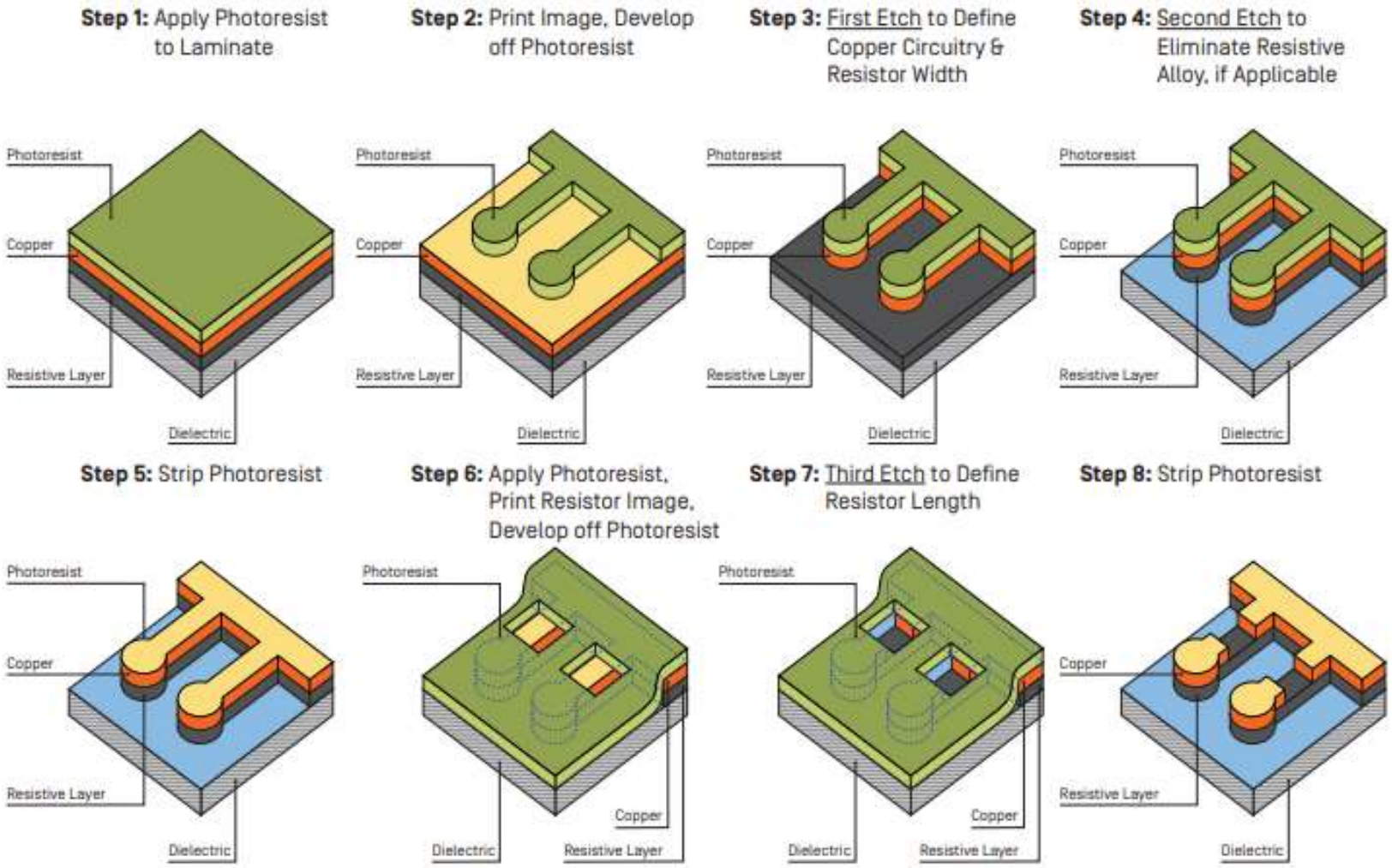
$$R = 25\ \Omega/\square \left(\frac{0.50}{0.25}\right)$$

$$R = 50\ \Omega$$



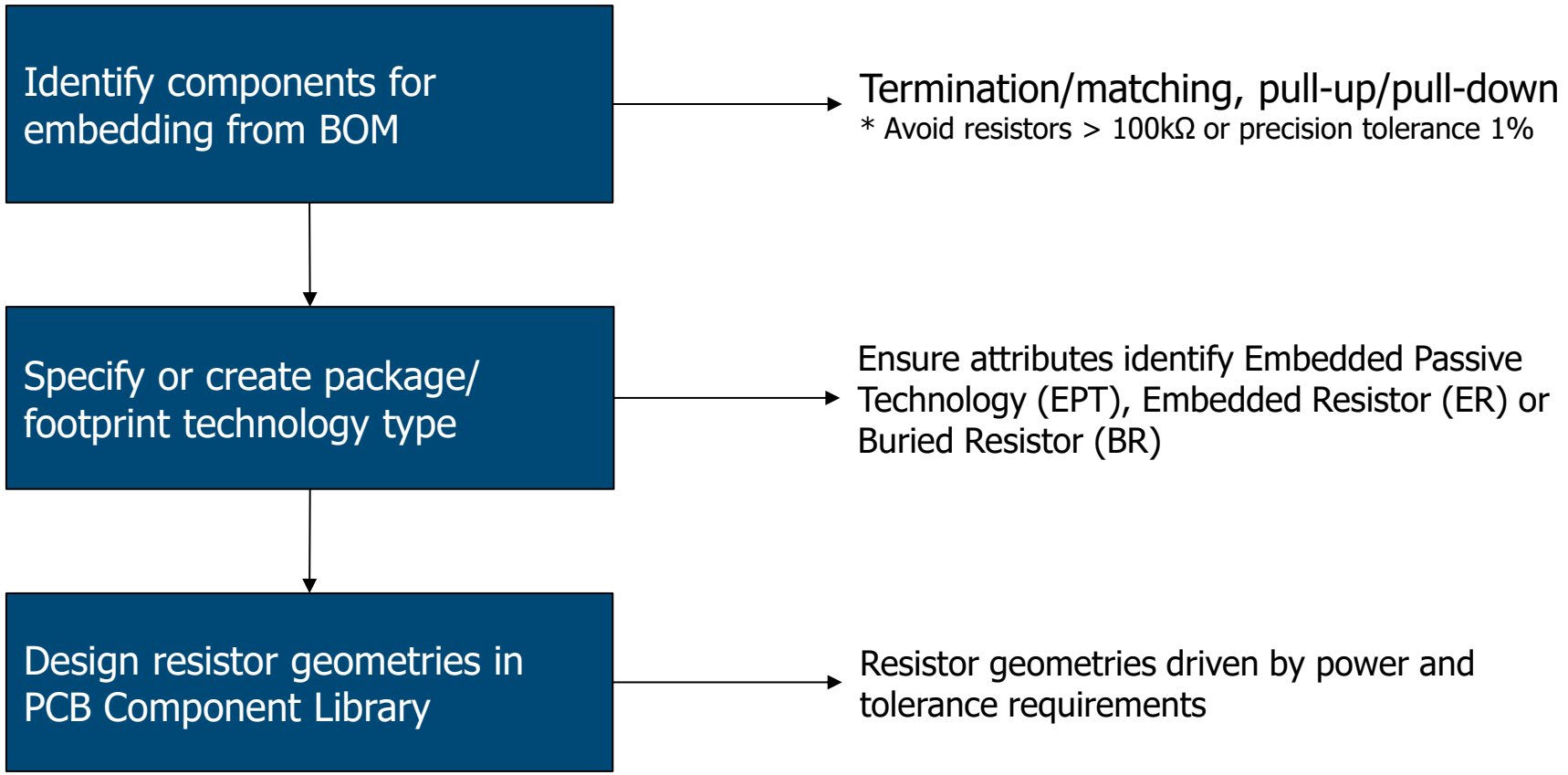
- Smaller resistors are expected to have higher resistor tolerance

Resistor Foil Subtractive Etch Processing



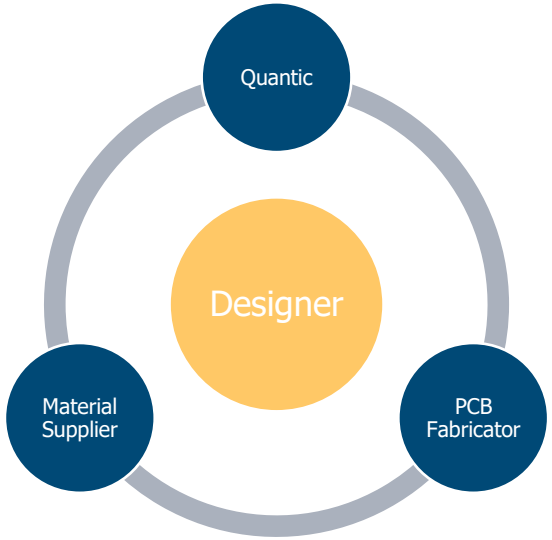
- Ticer TCR® NiCr does not require Step 4.
- Typically resistors are designed for use on internal layers of PCBs
- Extra precaution needs to occur when resistors are on external layers:
  - Resistor Shift –Add'l Processing
  - Handling
  - Mechanical Stresses
  - Soldermask Over Resistor

Embedded Resistor Design Flow



Designer Tools & Considerations

- Dielectric Material Selection
  - Resistive Foil Offering (OhmegaPly or Ticer TCR)
  - Stack-up Considerations
    - Predominantly used on PCB innerlayers; use on outerlayers is possible, but more challenges occur at PCB fabricator
    - Not recommended on layers with plated or filled vias, unless you speak with your fabricator and have a process defined
    - PCB Fabricator Registration tolerances
- Simulation Parameters to be used in modeling tools available from Quantic Ohmega
- Layout
  - Ohmic Value Shifts
    - Characterized shifts will occur after high temperature lamination (PTFE, Polyimide lamination, etc.)
    - PCB processing contribution
  - Power Rating
    - Resistor Calculator available
  - Tolerances
    - Size of resistor correlates to tolerances; larger resistor has improved tolerance
    - Consider PCB fabrication registration tolerances
  - Design Guideline Available
- PCB Fabricator List Available



Quantic Ohmega Ticer

Resistive Foils Applications

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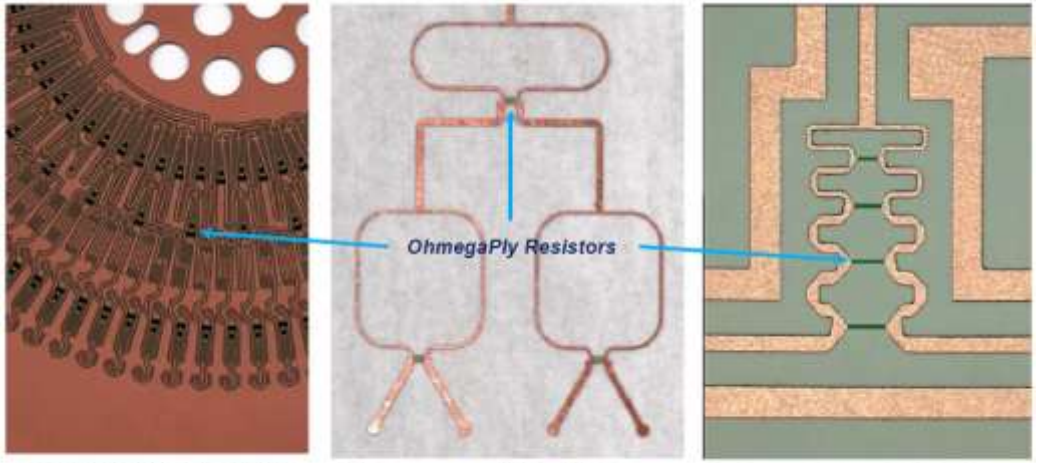
Trends Driving Adoption of Embedded Resistors

RF / mmWave – AESA Radar

- Long standing use of resistor foil in RF and microwave circuits; including those operating beyond 50 GHz
- Stable resistance values over frequency, time and temperature (MIL-STD-202-304 -55°C to 125°C)
  - Reduced parasitic inductance and capacitance
  - Fewer solder joints
  - Greater packaging densities for smaller form-factor

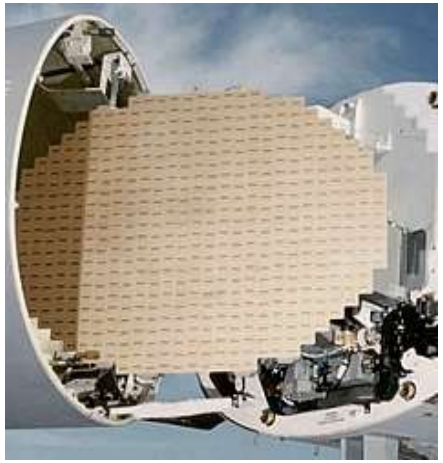
Typical Applications
- Power Dividers/Combiners
- Terminations
- Resonators



▲ OhmegaPly® power dividers in Globalstar antenna

▲ 16-way power divider with 50 Ω/sq OhmegaPly® resistors

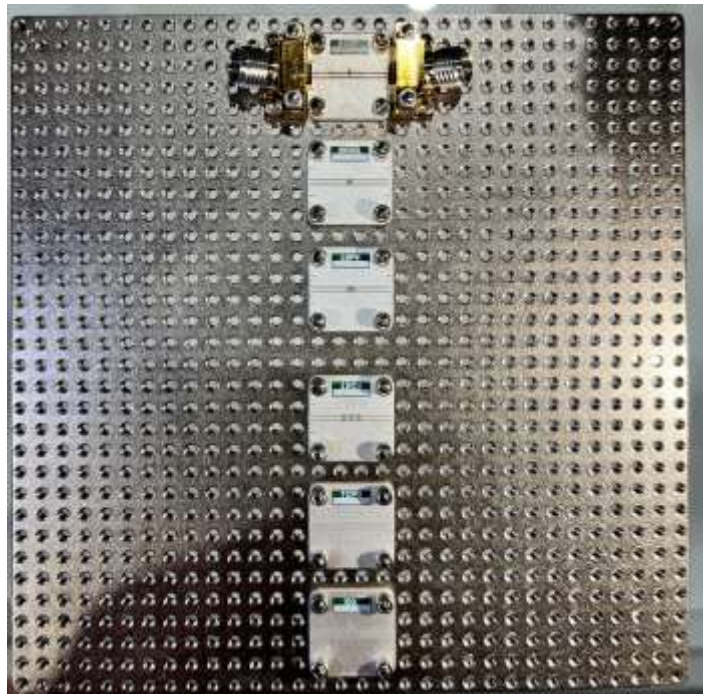
▲ Power divider with 25 Ω/sq OhmegaPly®

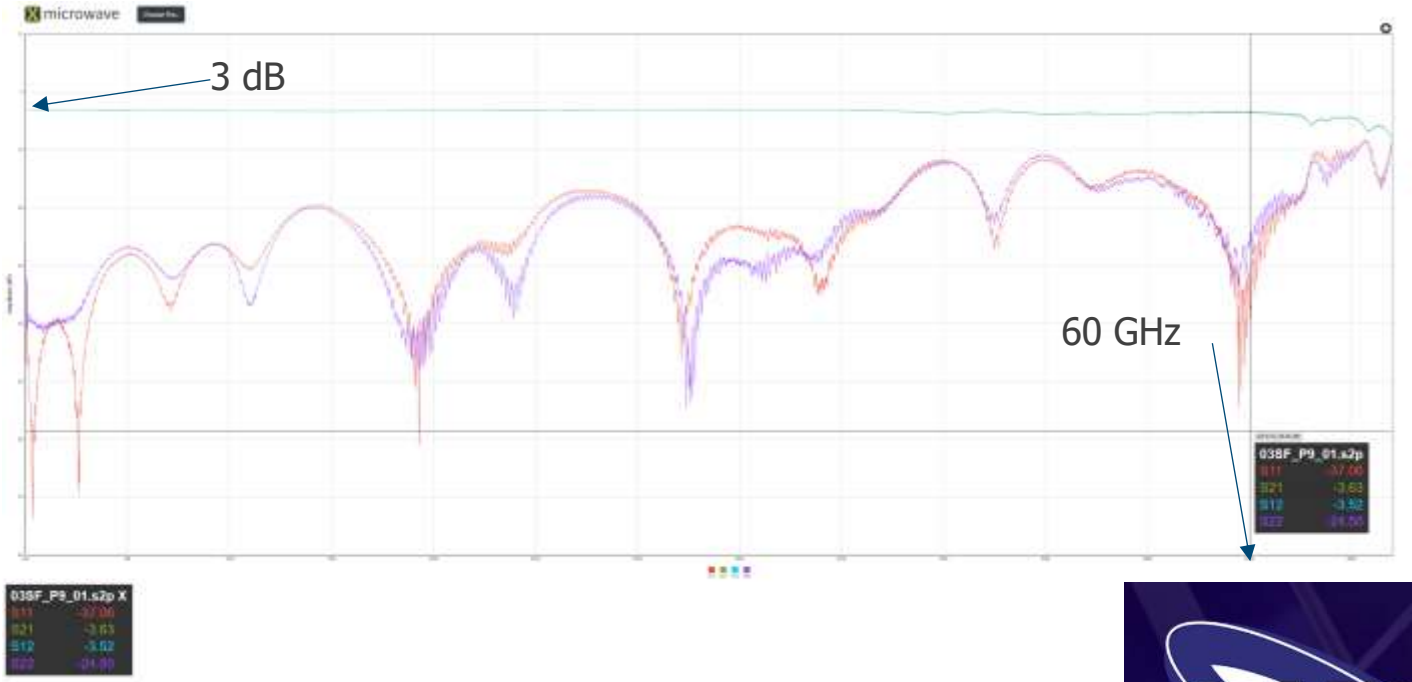


Structured RF Elements

- Joint project with Quantic X-Microwave
- Attenuator utilized 3 resistor design (2 in series and 1 to ground)
- Designed for 3 dB up to 60 GHz
- Simulated and actual performance in agreement with excellent results

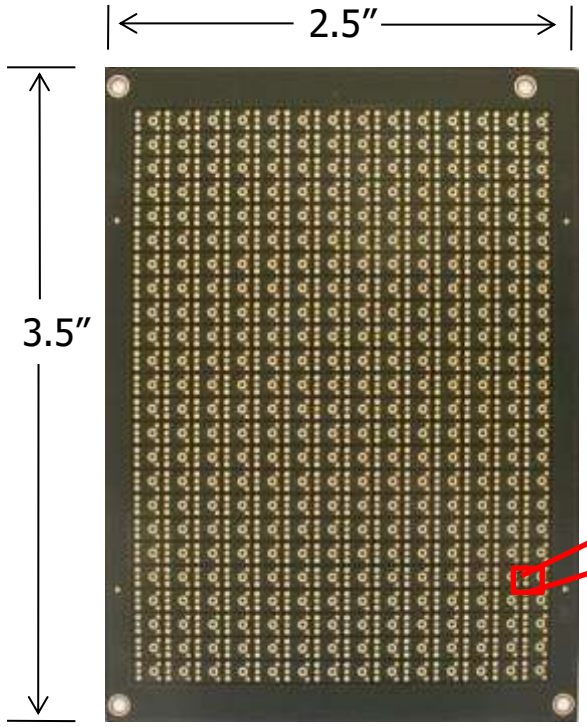
- Benefits at high frequency-
- Replacing expensive specialty resistors
- Better electrical performance due to removal of vias and solder joints





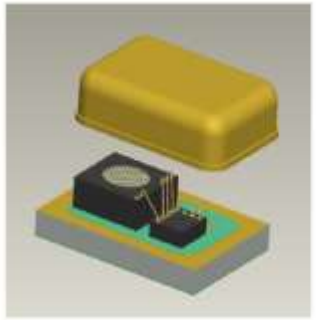
COTS Application

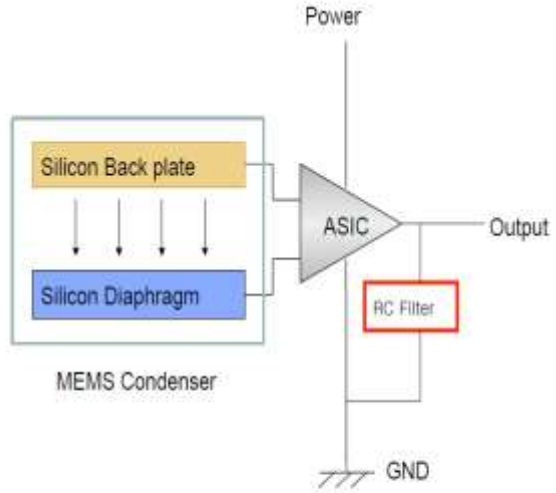
Smartphone – MEMS Microphone Packaging



336 PCBs

Well-established supply chain in Asia!



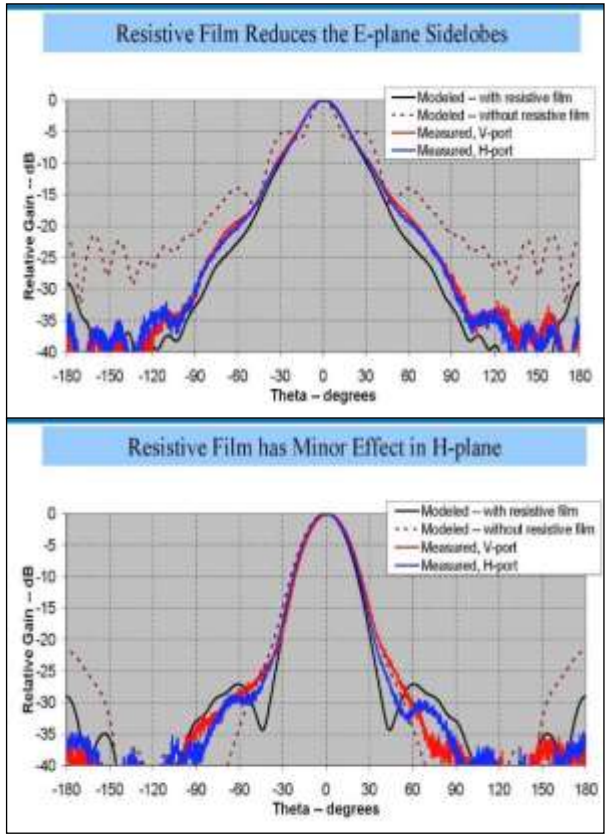


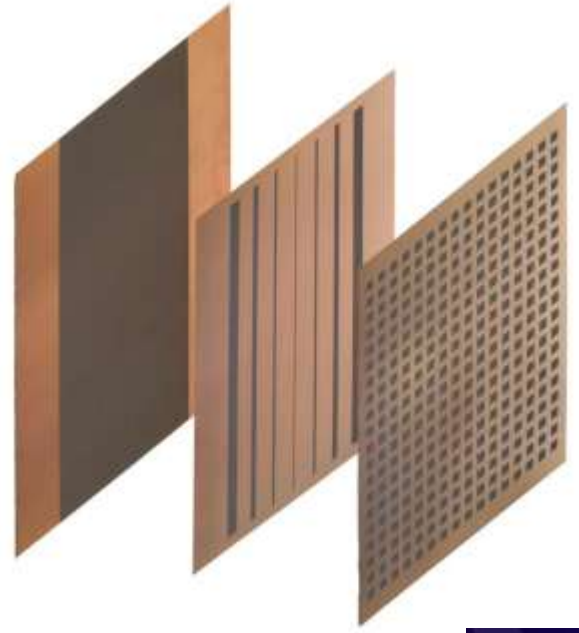
EMC@217Hz &1KHz improved 20dBV from 500 to 2800MHz

Resistive Elements Applications

Radar Absorbing Materials (RAM), Resistive Cards(R-cards), High Impedance Surfaces (HIS) and Frequency Selective Surfaces (FSS)

OhmegaPly® resistive cards (R-card)





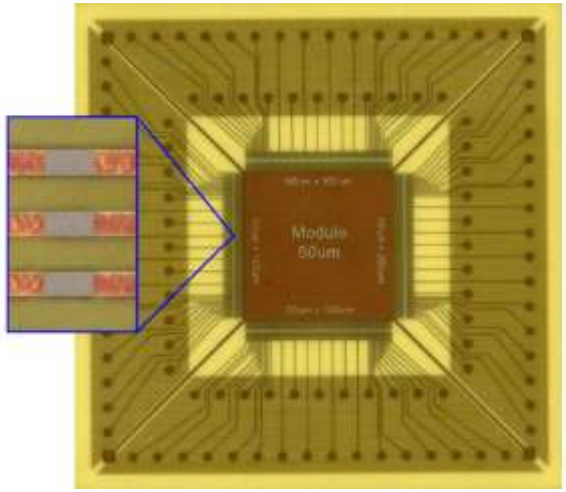
Example R-Card – Absorber Patterns

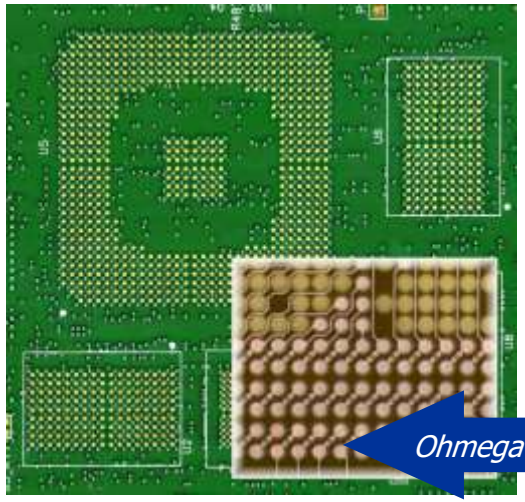
* Data Courtesy of Toyon Research Corporation

HDI PCBs, Semiconductor Packaging and Test

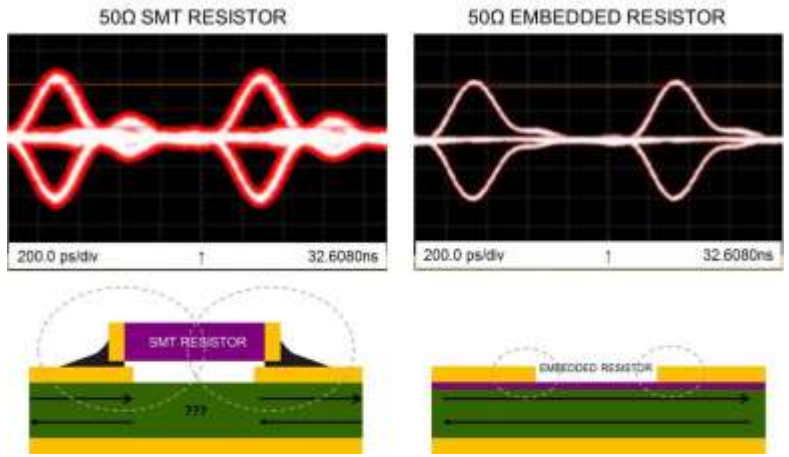
Commercial Electronics - Interposer, Probe Card, SLPCB

- OhmegaPly® is being used by some of the most advanced PCB & Substrate Fabricators for fine line and space applications to solve signal integrity and routing density challenges
  - Improved electrical performance
  - Elimination of vias and solder joints
  - Embedded passive technology on rigid and flexible dielectrics
  - Creative placement of resistive elements





Embedded Thin Film Resistors
SI Improvement



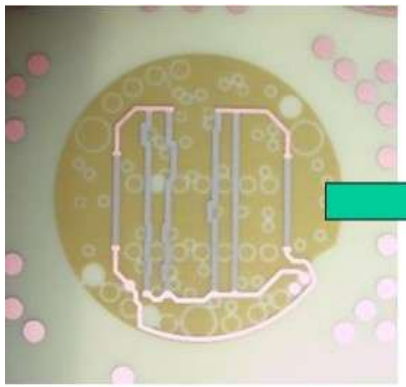
Eye diagrams show 30% reduced noise at 1 Gb/s using thin film resistor

Courtesy of Applied Laser Technology

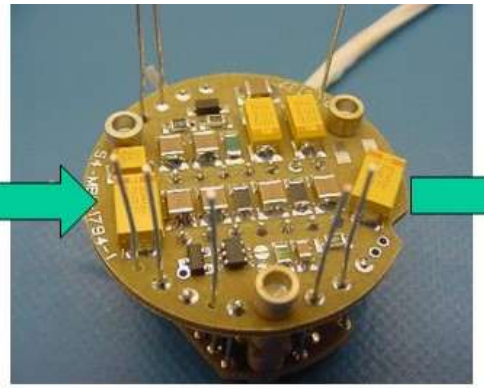
Heater Applications

Mars Beagle 2 Lander

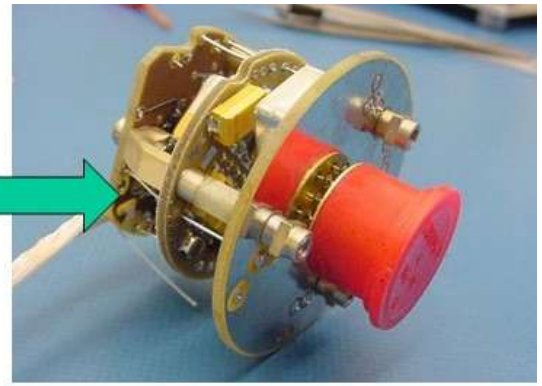
Application shows a heater used to bring the X-Ray Spectrometer (XRS) biasing and pre-amplification electronics to -50°C



Inner Layer Heater



Assembled board



Assembled XRS unit

Images Courtesy of the University of Leicester Space Research Centre and the Beagle2 Consortium

Embedded Resistor Roadmap

- **Product & Application Trends**
  - Increasing Frequencies
    - → K → Ka → mmWave bands
    - Drives the use of lower profile matte side copper surface roughness
  - **Micro-Electronics**
    - Finer feature sizes and faster response times
    - Drives thinner copper foils, a lower profile matte side copper surface roughness, and a closer proximity of passives.
  - **Space-Based Electronics**
    - Requires Low Resistance Temperature Change (RTC)
    - Must be compatible with specialty dielectric offerings

Quantic™ Eulex

Embedded GAP Capacitors

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Overview

Quantic™ Eulex

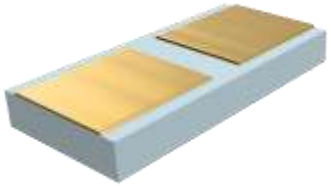
Ceramic Capacitors for the Most Demanding High Frequency, Microwave & Millimeter-wave Applications

Key Applications

- 5G and next generation telecoms
- Test and measurement
- AI & machine learning, new high-speed architecture
- Automotive, mm-wave / vision sensing / C-V2X
- Military & aerospace radar / sat-coms

Company & Product Highlights

- Patented Technology – Unmatched Performance
- Focus on Innovation
- Domestic Manufacturing Capability
- High Reliability
- Full Suite of High Frequency Ceramic Products
- Co-Founders 30+ Years in MLCC & SLC



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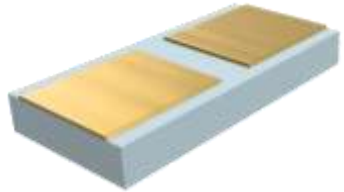
Patented Gap Capacitor

Patented technology allows our Gap Capacitors to be manufactured with up to 20x capacitance

Advantages

- Up to 20x capacitance
- Fewer Dielectrics
- True Single Layer (no vias)
- High Reliability
- No Wire-Bond
- Simpler Part Selection
- Ultra-High Q Dielectrics
- Range of Voltages



Gap Capacitor

Gap capacitor mounted face-down on strip-line

Note: Requires a cavity in prepreg sheets

	Maximum Capacitance / pF															
	100 Volt				50 Volt				16 Volt				6.3 Volt			
	P	NP0	X7R	Max	P	NP0	X7R	Max	P	NP0	X7R	Max	P	NP0	X7R	Max
ATC	X	1.0	82	120	X	X	X	X	X	X	X	X	X	X	X	X
AVX	X	X	X	X	X	X	X	*1400	X	X	X	X	X	X	X	X
Knowles	X	X	X	X	0.2	1.5	68	*250	X	X	X	X	X	X	X	X
Passive Plus	0.2	2	68	*820	0.3	2.7	68	*1200	X	X	X	X	X	X	X	X
Eulex	3.3	47	1400	5800	3.9	56	1700	6800	5.6	80	2400	10000	8.7	120	3600	15000

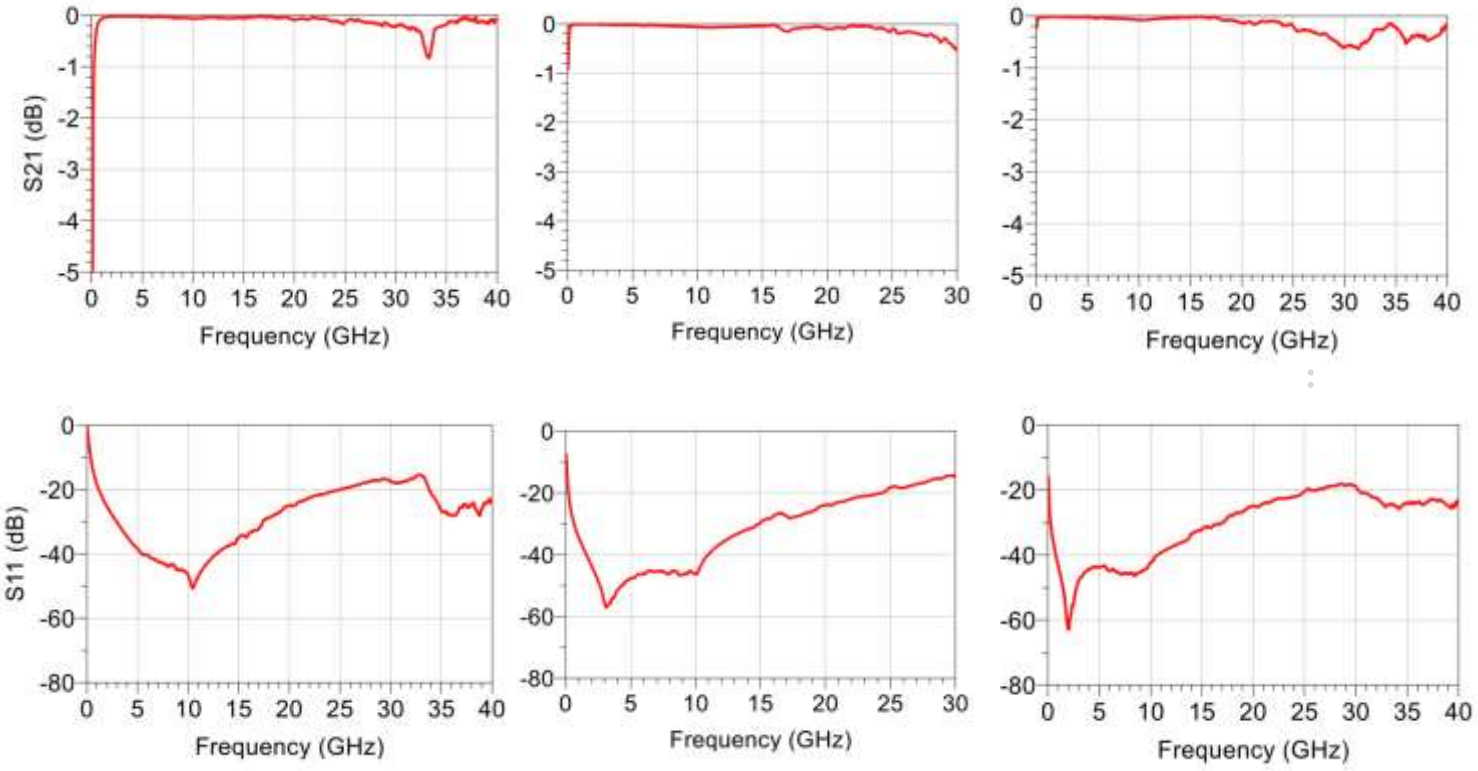
Competitor Comparison (Based on 0804 size device)

* Uses GBBL dielectric

Patented Gap Capacitor (cont.)

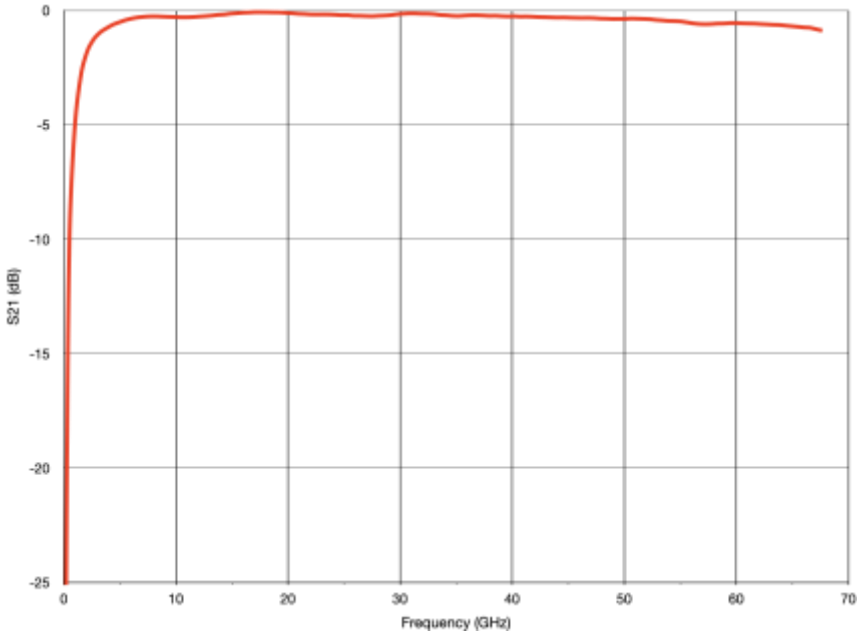
Gap Capacitor – Performance Data

XGE40Q130K **XGE40N750K** **XGE40C271K**



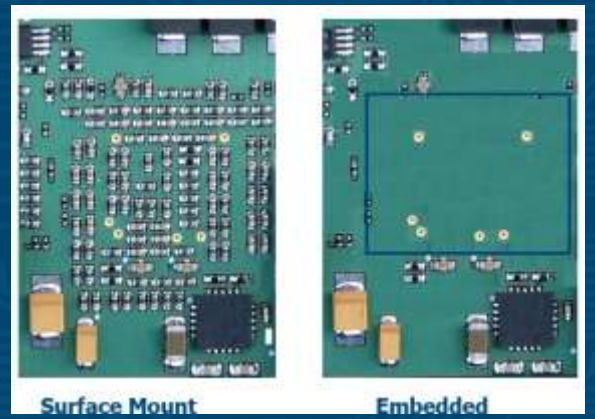
Data Courtesy of Modelithics®

XGE15P1R3B



Data Courtesy of Quantic X-Microwave

Embedded Passives Technology Summary



- The combination of Quantic Ohmega & Quantic Ticer leverages two leading product technologies for resistor foils.
- Embedded resistors lead to improved electrical performance/reliability and space/weight savings.
- Embedded Resistors are made using standard PCB processes and have decades of utilization in the most demanding, mission-critical systems.
- Embedded capacitors decrease the need for discrete SMT capacitors on the surface, improve signal integrity, and can reduce board size and thickness.
- The Gap Capacitors from Eulex offer the highest capacitance density and excellent high-frequency performance.

Quantic Ohmega Quantic Ticer

Quantic Ohmega Ticer

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Thank You!

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