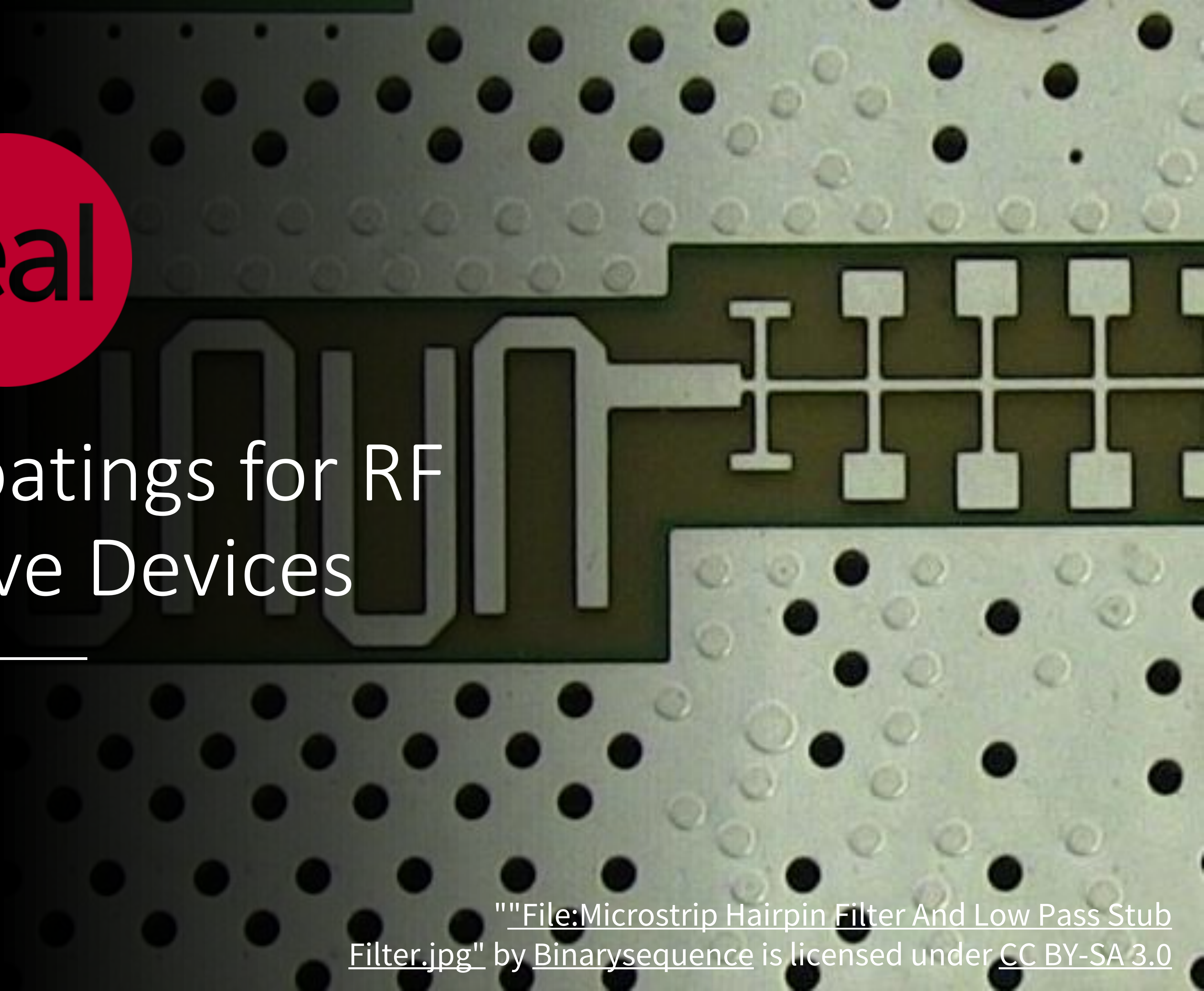
SignalSeal

Conformal Coatings for RF and Microwave Devices

GVD

GVD Corporation



Agenda

- GVD Overview
- Challenges for conformal coating use on RF circuits
- SignalSeal conformal coating system
- Case studies of conformal coatings on high frequency RF circuits
- Masking and rework considerations

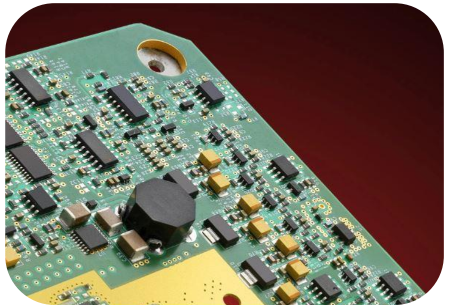
History

- Spinout from MIT based on Dr. Karen Gleason's polymer coating technology
- 20 years of polymer coating innovation
- Expanded our application into a variety of industries

Business Model

- Coating services (R&D and Production level)
- Multiple Production coating locations in the US and globally
- Technology licensing (case-by-case basis)

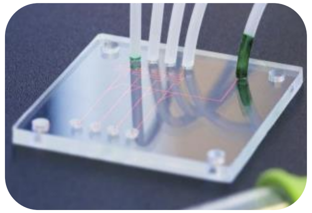
Our Commercial Products



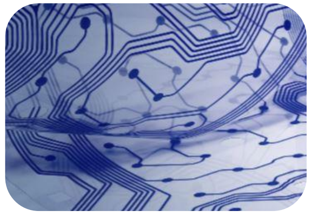
Electronics Protection

Mold Release

Lubricious Surface Modification



Electrowetting



Multilayer Barrier

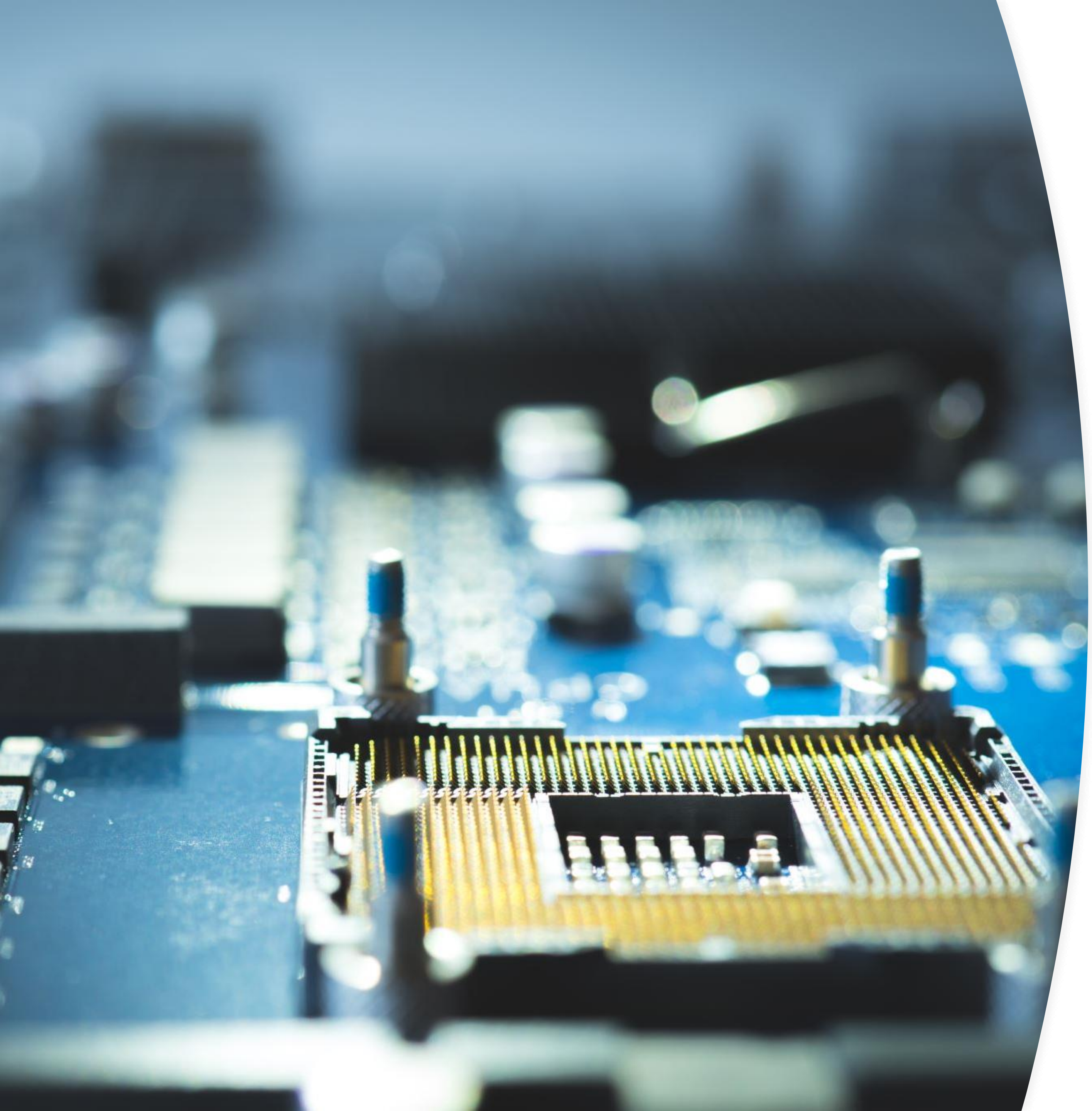
Our Government Research Work

Modern High-Performance Electronics Challenges

- EW and military communications moving toward higher frequencies
- Ongoing optimization of size, weight, power, & cost (SWaP-C)
- PCBs are increasingly more complex and densely-populated
- Progressively wider variety of materials used in processing and final products
- Systems must be modular, light-weight, and easily repairable
- High cost, long-development cycle projects must meet the most stringent industrial and military environmental specifications

The industry need:

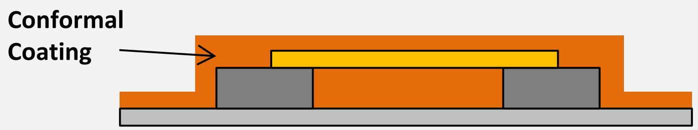
Reliable, highly robust, protective coating suitable to high frequency applications and compatible with modern trends in device & system size, weight, power, modularity, and complexity.



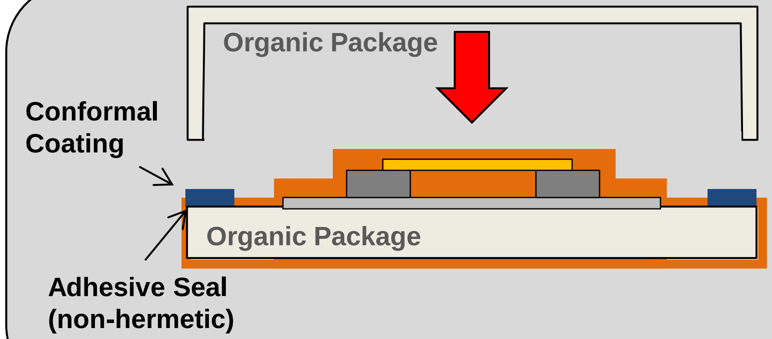
Traditional Conformal Coating Uses

- Environmental and mechanical protection of ICs and PCBs:
  - during processing, or
  - once they are installed in a housing or assembly.
- Primarily aimed at RF frequencies of less than 8 GHz
  - Higher frequency applications traditionally rely on hermetic packaging, or forgo environmental protection altogether
- Traditional coating materials present challenges on modern high-frequency and high-speed digital circuits
- An ultra-thin, rugged protective coating can enable wider applicability of modern technologies

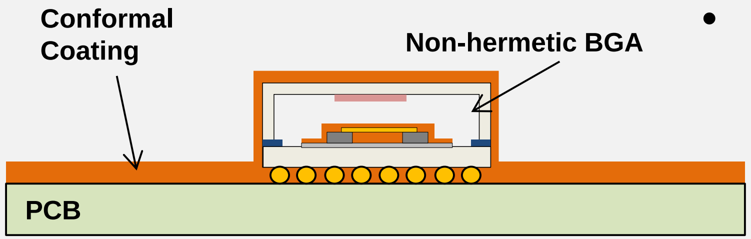
Application of Conformal Coatings



- Level 1: Chip-Level Protection
  - Protects bare die from Foreign Object Debris
  - Provides Structural Support for air bridges



- Level 2: Package-Level Protection
  - Non-Hermetic seals and materials reduce weight/cost of packaging
  - Protective Layer to provide extra reliability w/o hermeticity



- Level 3: Board-Level Protection
  - Protective Layer for environmental protection of board traces (RF and otherwise)

Thickness

Dielectric Constant

Dissipation Factor

Dielectric Strength

Environmental Protection

Thermal Properties

Coating Material Considerations for RF & Microwave Circuits

Dielectric Constant (Relative Permittivity)

Dissipation Factor (Loss Tangent)

Dielectric Properties of Coatings

- RF circuit traces & planar transmission lines are designed with the expectation that the dielectric on the outer surface of the waveguide is air
  - k ~1; very low loss tangent
- Legacy coating materials, such as epoxy or silicone, exhibit a relative permittivity > 4
  - Exacerbates parasitic capacitance between conductive traces & features
  - Causes degradation in RF performance of ICs and PCBs with an already stringent performance budget
- Traditional coatings' dielectric properties rarely scale well with frequency

- Military, aerospace, and naval applications require protection under extreme conditions
  - Typically -55°C to +125°C operating conditions
  - Exposure to harsh chemicals and wear
  - Commonly include salt fog and moisture-rich environments
- Accelerated stress tests help assess how a coated device may perform under regular stress over extended periods of time
  - A 1000 hours of continuous 85°C at 85% RH exposure can predict up to 25 years of operation
- Crucial for high-frequency applications that the behavior of a coating remains consistent over the lifetime of the circuit
  - a derated coating may lead to early failure
- Critical application communication and sensing circuits are typically built of high-power transmitters and extremely sensitive receivers
  - any loss in transmitter, receiver, interconnect, or antenna performance directly contributes to a loss of range, resolution, throughput, or reliability.

Coating's Environmental Performance Dictates its Applicability

- Coating’s performance can change with temperature
  - potential to delaminate, change phase, permanently change dimensionally, discolor, oxidize, or otherwise degrade at temperatures > 100°C
- Coefficient of thermal expansion (CTE) difference between a coating and PCB board or die must be considered
  - Mismatch could lead to a loss of adhesion between the coating and board/die;
  - Coating deformation could have a substantial impact on the electrical performance of high frequency surface traces
  - Even minor nonconformity leads to impedance changes in RF circuits and planar transmission lines with surface traces
- Coating’s thermal conductivity may have an impact on the process design
  - Materials with a lower bulk thermal conductivity and greater thickness will add to the thermal resistance of the stack and will need to be accounted for during the thermal management design
- Choosing coatings with poor thermal properties can add to costs and complications during rework, limit applications

Thermal Properties and Considerations

Ultra-thin Environmental Coating: GVD SignalSeal

SignalSeal

- Novel siloxane polymer developed as an encapsulant for sensitive electronic neural implants
- Explored for use on RF circuits through collaboration with & support from US NAVY and DARPA
- Provides very thermally stable environmental protection at thickness of only 1um
    - Adhesion of SignalSeal inhibits the formation of conductive aqueous films below the coating that lead to device failure via electrochemical corrosion.

SignalSeal Environmental Protection	
Maximum Temperature	+265^{o}C
85°C / 85% RH Exposure	1000 hours JESD22-A101C
Salt Fog Exposure	min. 500 hours ASTM B117
Thermal Cycling -70°C to + 225°C	10 cycles MIL-STD-810G
Thermal Cycling -75°C to + 125°C	50 cycles MIL-I-46058C

SignalSeal Electrical Properties	
Parameter	**Value**
Dielectric Constant* (@ 1 MHz)	2.62
Dissipation Factor* (@ 1 MHz)	<0.001
Dielectric Withstanding Voltage (V/mil)	7,200
Volume Resistivity (ohm•cm, 23°C, 50% RH)	4.0 x 10^{15}

SignalSeal shows negligible impact on gain, isolation, and return loss before and after 8 days environmental exposure at 85°C/85%RH (test to 20 GHz). **Demonstrated suitable for applications to at least 100 GHz**

Show little change in RF performance with temperature

* *further investigation is in progress to provide broadband RF characterization to 40 GHz and higher in the future.*

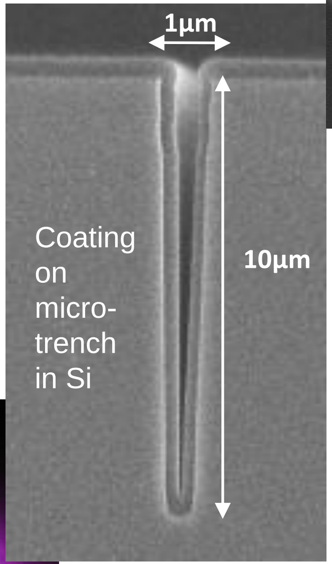
SignalSeal Electrical Properties

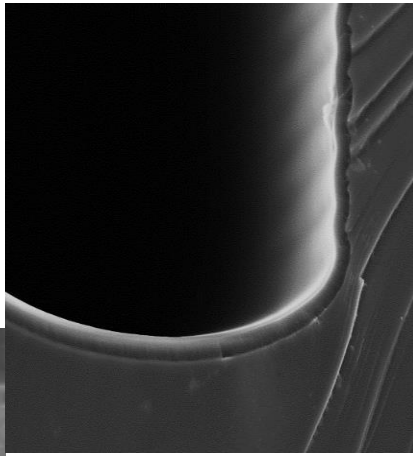
Coating Application Technology: Chemical Vapor Deposition (CVD)

- Coating process is performed:
  - in specialized vacuum chambers
  - at low or room temperature
  - without solvents or surfactants
  - via a contact-free, gentle application
  - by precisely controlling process conditions

- Coatings are:
  - formed directly on the substrate from vapor phase, on any exposed surface
  - fully polymerized after deposition and typically do not require any post-processing

- Advantages:
  - Produces ultra-thin, pinhole free films
  - Results in molecular level coverage & surface modification
  - Can coat complex, micro features without plugging cavities
  - Dramatically more uniform and conformal than wet-applied coatings
  - Coating thickness is controlled and verifiable

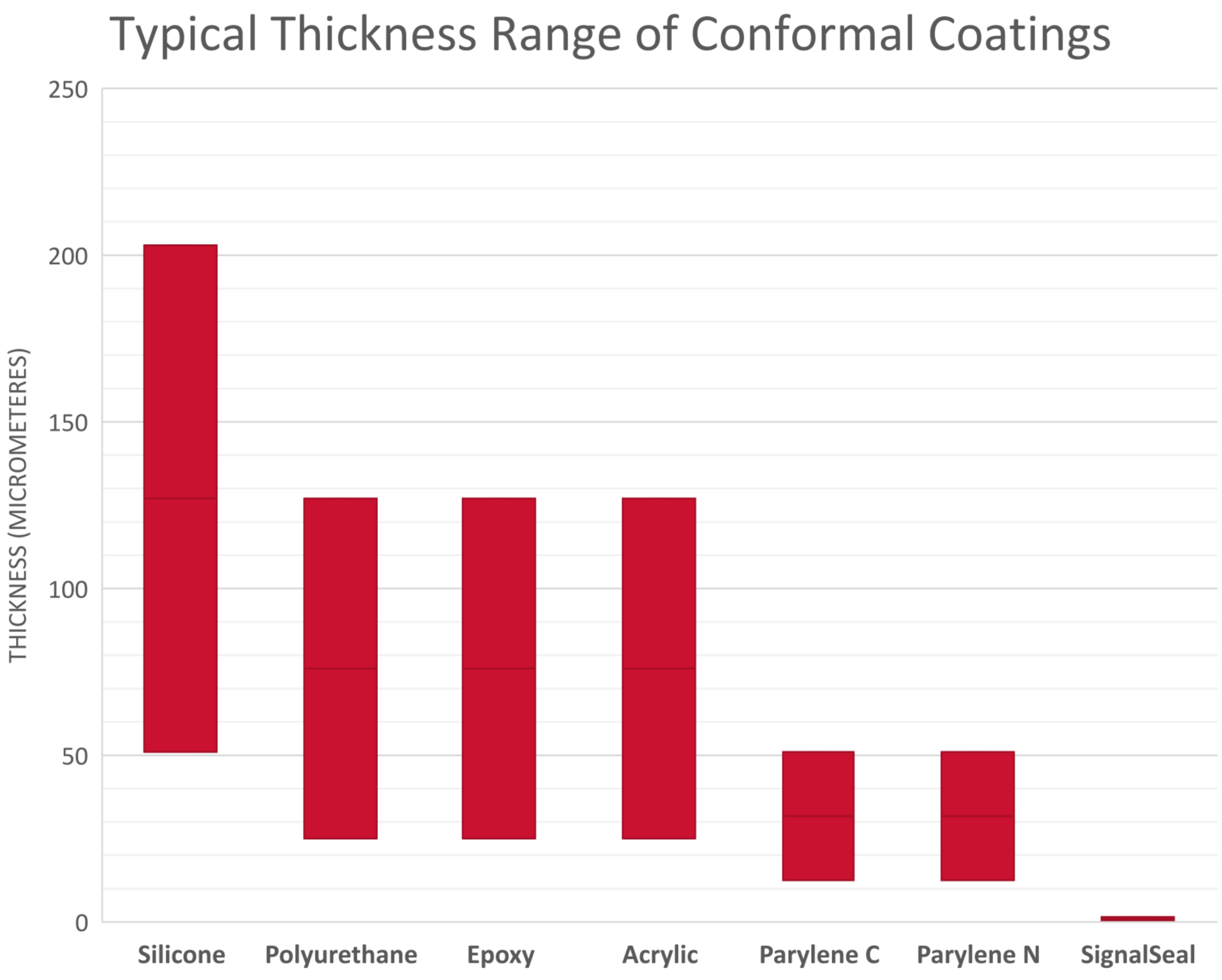




Coated 17:1 trench feature

Coating Thickness

- Affects:
  - Environmental protection
  - RF performance
- Directly relates to the high frequency performance of planar transmission lines & surface traces
- Each material requires a particular critical thickness in order to protect in harsh environments
  - established in standards, such as IPC J-STD-001, IPC-A-610, MIL-I-46058, NASA-STD 8739.1, etc.

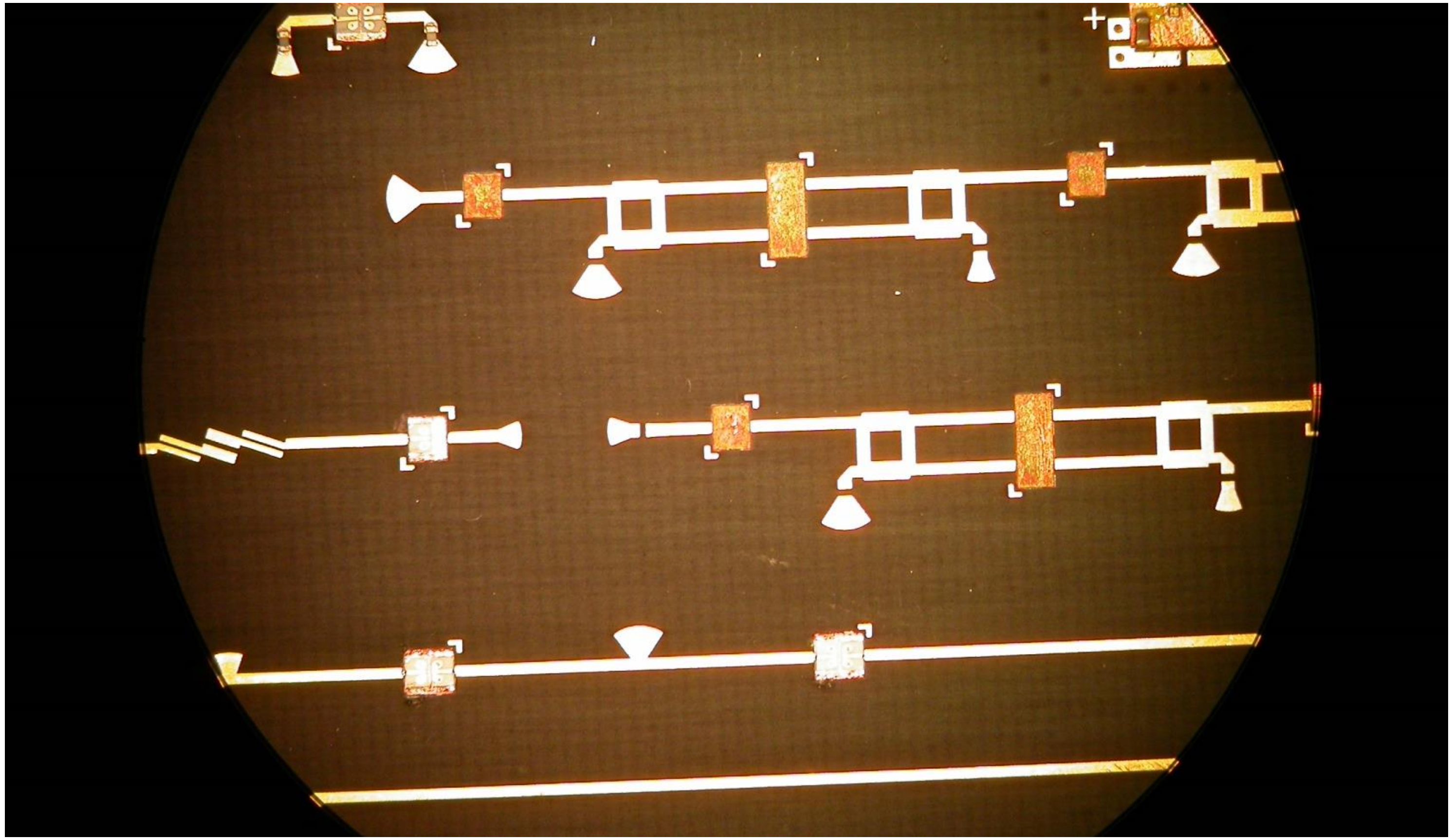


According to MIL-I-46058, IPC-CC-830, and NASA-STD 8739.1 standards

Performance of Conformal Coatings

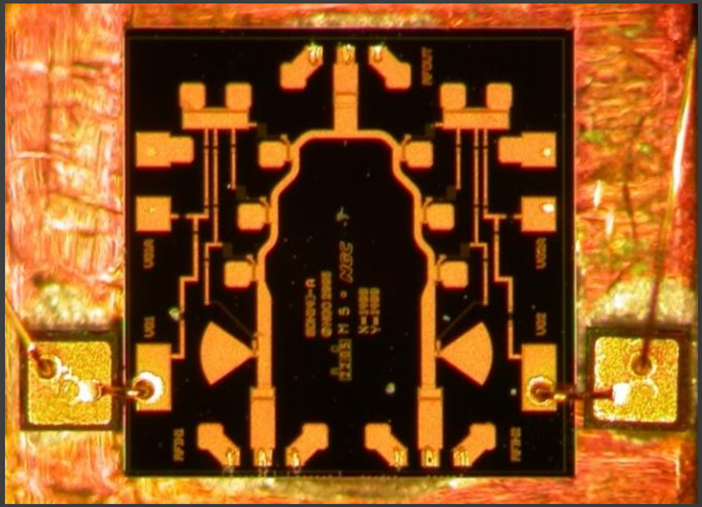
Coating Type	Dielectric Constant (@ 1MHz)	Dissipation Factor (@ 1MHz)	Typical Thickness (microns)	Maximum Continuous Operating Temperature	RF and mW Performance	Environmental Protection	Reworkability
SignalSeal	2.62	<0.001	1	225°C	★★★★	★★★★	★★★★
Parylene N	2.65	0.0006	12.5-51	60°C	★★★★	★★	★★
Parylene C	2.95	0.013	12.5-51	80°C	★★	★★★★	★★
Acrylic	2.7-3.2	0.02-0.03	25-127	82°C	★	★★	★★
Epoxy	3.1-4.2	0.004-0.006	25-127	177°C	★	★★★★	★
Polyurethane	3.8-4.4	0.068-0.074	25-127	121°C	★	★★	★★
Silicone	3.1-4.0	0.003-0.006	51-203	260°C	★	★★★	★★★

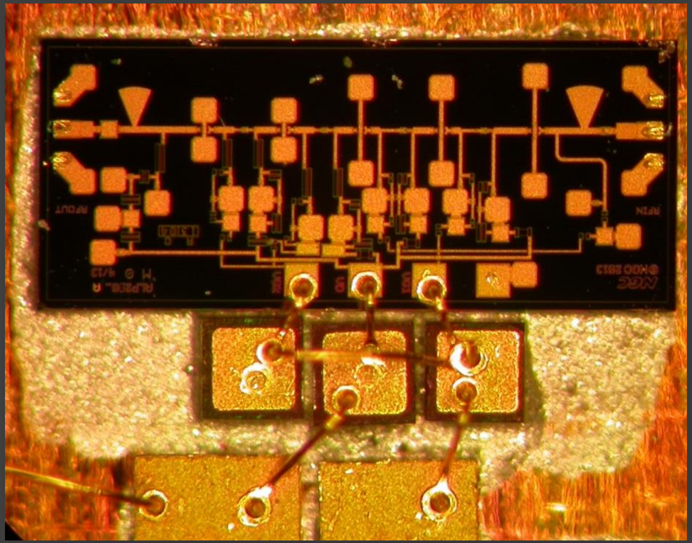
Test Case – RF Impact of SignalSeal Coatings at 100 GHz



- Two RF MMIC test devices designed to operate up to 100 GHz were fabricated with standard micro-assembly techniques for active and passive circuitry

- GVD coatings were applied at two different thicknesses, covering the entire substrate including bond wires, MMIC devices and traces.
  - Thicknesses used were 150% - 300% greater than standard SignalSeal thickness of 1 um





MMIC LNA devices show reasonable degradation in gain.

MMIC SPDT switches showed minor insertion loss increases with bandwidth degradation.

W-Band MMIC SPDT Switch

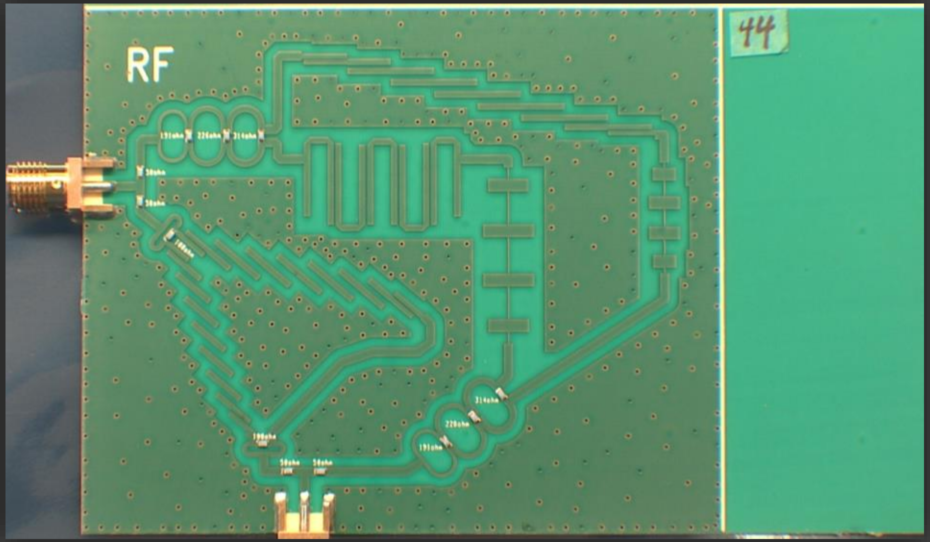
Measured Parameter	Test Freq. (GHz)	NO Coating Measured Value	Applied Coating Measured Value	
			1.5 µm Thickness	3 µm Thickness
Insertion Loss Test Ckt # 1	100	-3.3 dB		-4.0 dB
Switch Isolation Test Ckt # 1	100	-32.5 dB		-28.6 dB
Insertion Loss Test Ckt # 2	100	-3.35 dB	-4.0 dB	
Switch Isolation Test Ckt # 2	100	-32.8 dB	-28.5 dB	

W-Band MMIC LNA

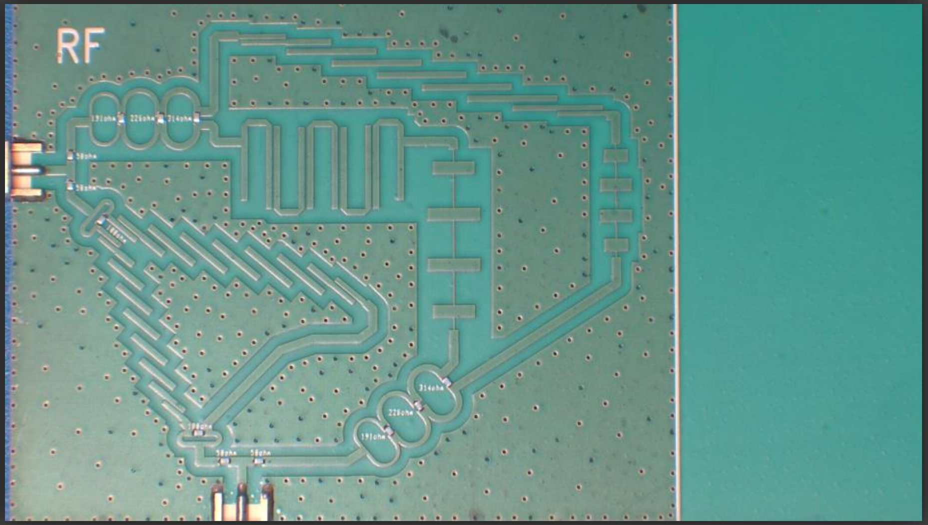
Measured Parameter	Test Freq. (GHz)	NO Coating Measured Value	Applied Coating Measured Value	
			1.5 µm Thickness	3 µm Thickness
Gain Test Ckt # 1	100	28.5 dB		26.3 dB (-2.2)
Gain Test Ckt # 2	100	31.2 dB	29.9 dB (-1.3)	

Parylene-C Environmental Performance

Initial

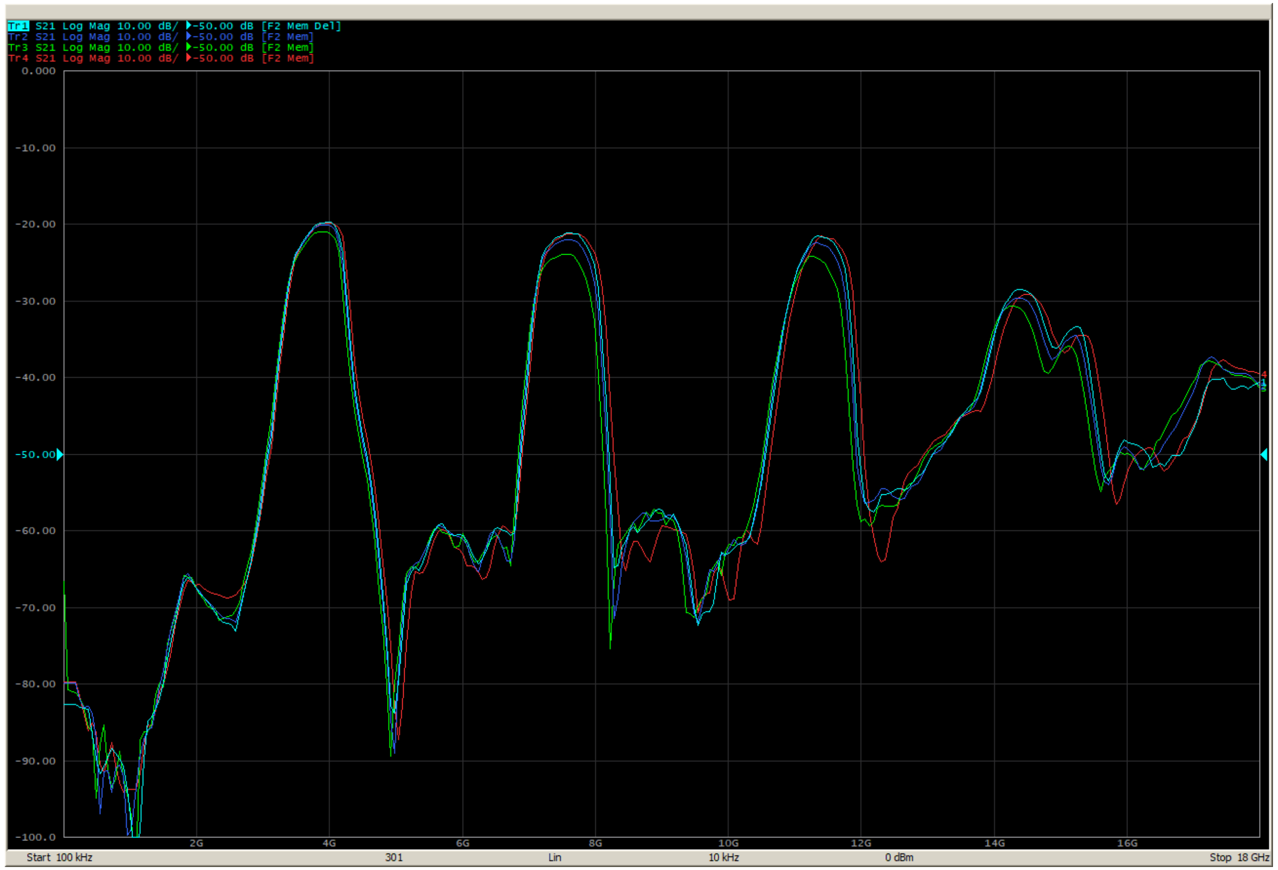


250 hr 85 /85



0.5mil coating applied by external vendor

Sample subjected to 250 hours of 85% RH @ 85C

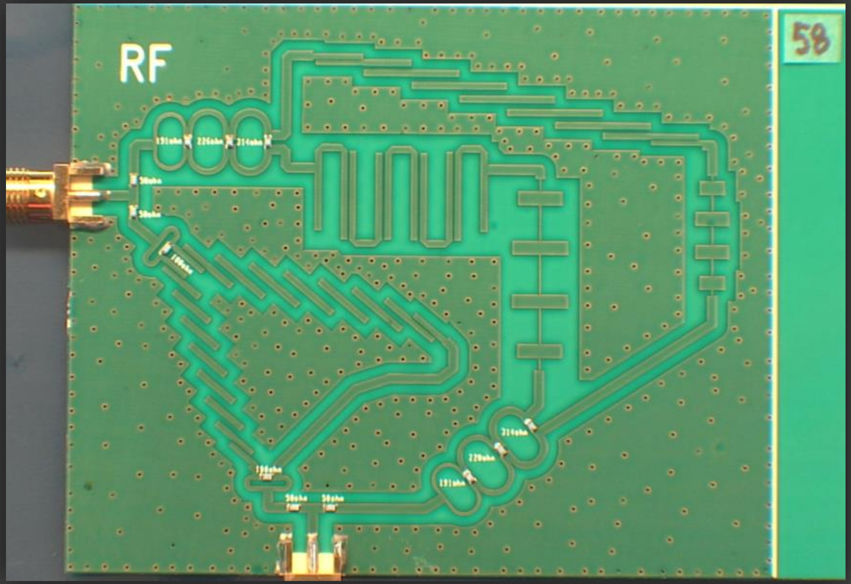


Performance change with environmental exposure

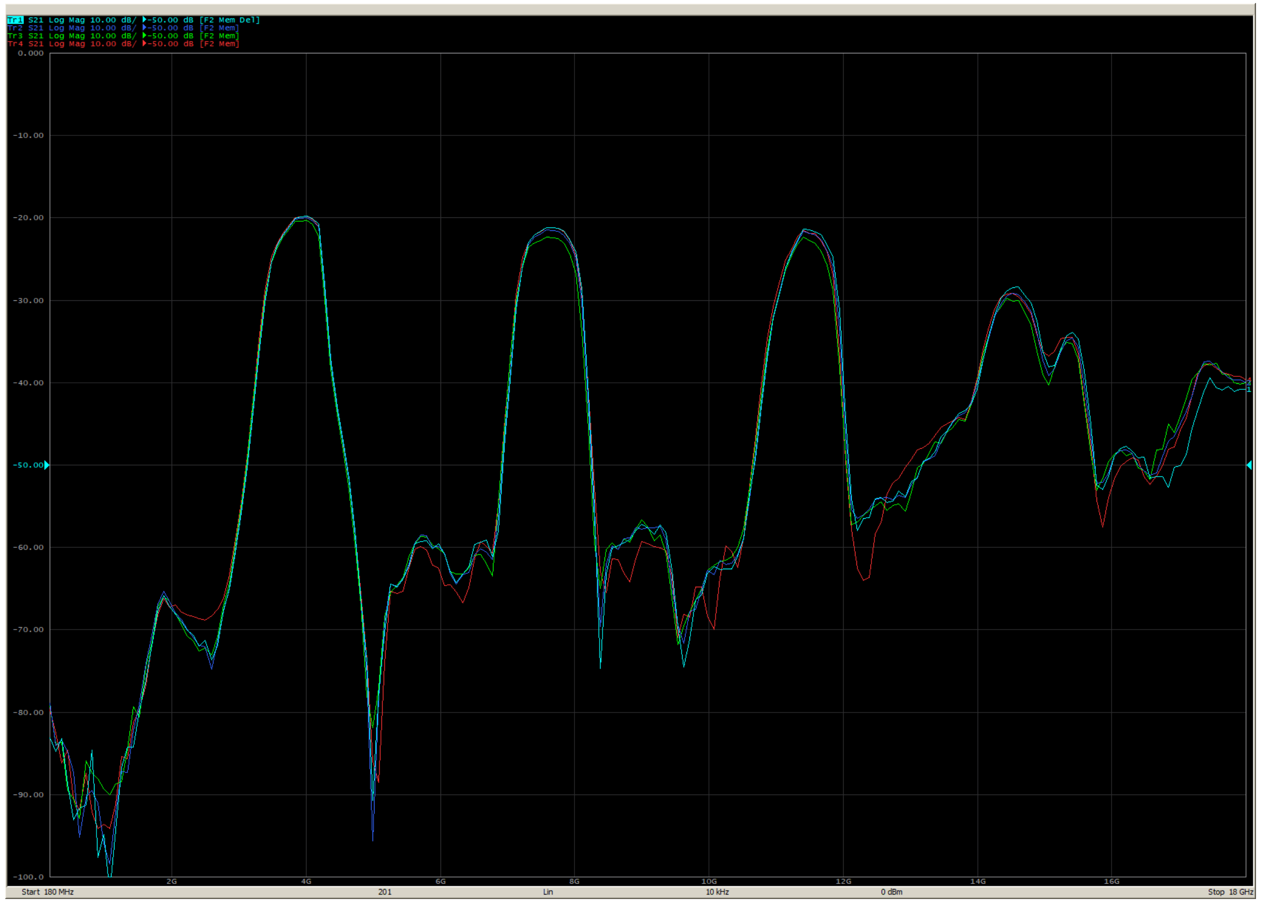
	4 GHz	8 GHz	12 GHz
Passband broadening @ 250 hr (GHz)	0.01	-0.03	-0.04
Center frequency shift @ 250 hr (GHz)	-0.07	-0.11	-0.18
Insertion loss change @ 250 hr (dB)	-2.03	-4.62	-4.77

SignalSeal Environmental Performance

Initial



250 hr 85 /85



Performance change with environmental exposure

	4 GHz	8 GHz	12 GHz
Passband broadening @ 250 hr (GHz)	0.00	0.00	0.03
Center frequency shift @ 250 hr (GHz)	0.00	0.00	-0.04
Insertion loss change @ 250 hr (dB)	-0.65	-1.09	-1.32

Change in RF Parameters with Environmental Exposure

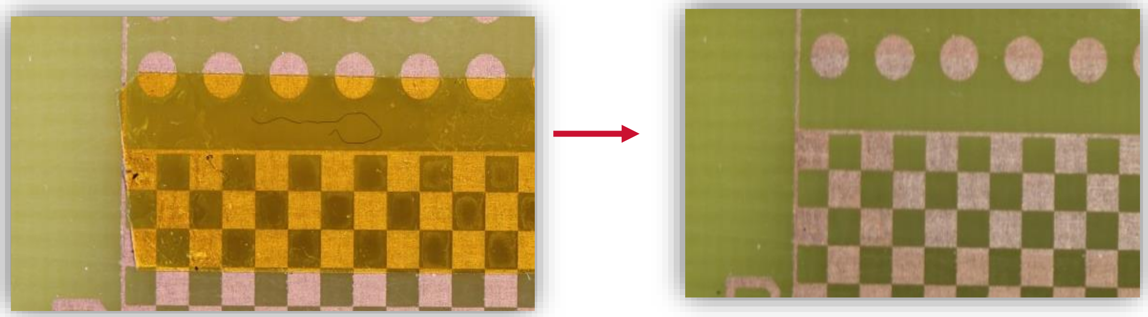
- Parylene shows a significant shift in insertion loss, center frequency and passband across all frequencies
- The shifts are comparable (within margin of error) between SignalSeal and an uncoated PCB

	Filter	Uncoated	SignalSeal	Parylene-C
Insertion loss (dB)	4 GHz	-0.60	-0.47	-2.03
	8 GHz	-1.58	-1.04	-4.62
	12 GHz	-1.87	-1.12	-4.77
Center frequency (GHz)	4 GHz	-0.02	-0.02	-0.07
	8 GHz	-0.03	0.00	-0.11
	12 GHz	-0.07	-0.06	-0.18
Passband (GHz)	4 GHz	0.03	0.03	0.01
	8 GHz	0.00	0.00	-0.03
	12 GHz	-0.03	0.00	-0.04

Coating Challenges During Processing & Rework

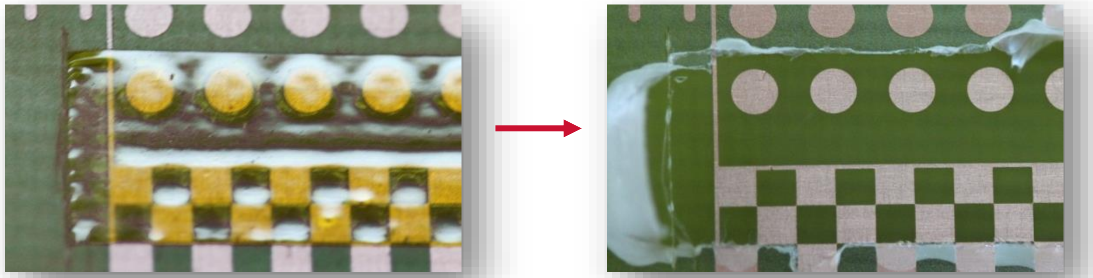
- Thick coatings require scoring to achieve a clean mask separation
  - Risk of peelback and delamination
  - Additional touch-up is needed post-coating for areas prone to lifting & tearing
  - Legacy coatings' toughness make it difficult to make localized repairs
- Coating removal often involves aggressive mechanical methods:
  - scraping, micro blasting, or sanding
  - pose a risk of damage to the part
  - result in additional expenses and longer processing times
- Thin, highly adhesive coatings much easier to mask/de-mask and rework

SignalSeal (1 µm or 0.04 mils)



Clean de-masking line with no scoring

Parylene-C (20 µm or 0.8 mils)



Peelback and delamination after Kapton tape removal

SignalSeal Coating Enables New Possibilities

Withstands Harsh Environments

Ultrathin pinhole free, conformal coating provides military grade environmental protection at only 1 micron thickness.

Results in Minimal RF Signal Impact

Coating exhibits electrical characteristics ideal for high-speed and high-frequency applications to 100 GHz with negligible impact on signal integrity.

Uniformly Adheres to the Most Complex & Delicate Devices

The deposition method ensures total coverage, and the highly adhesive coating is surface agnostic.

Easy To Mask, Demask & Rework

Coated components can be removed without the need to strip the coating first. No scoring required during demasking, minimizing the chance of damage.