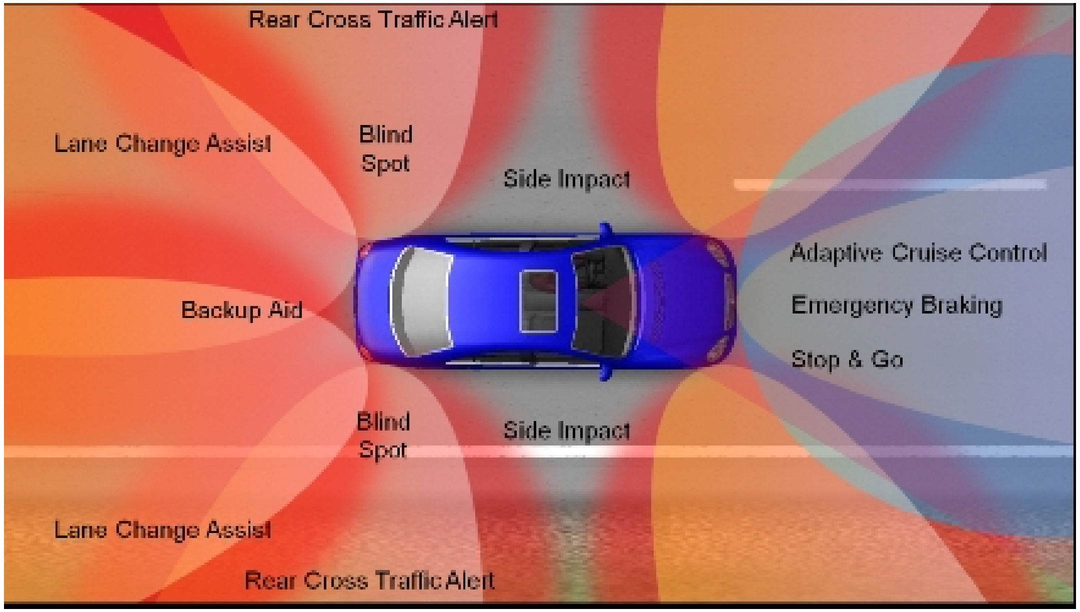
Enabling Lower Cost Advanced Automotive Safety Systems Through Hybrid PCB Construction

Outline

- Printed Circuit Board (PCB) requirements for advanced automotive safety systems
- Hybrid PCB construction and benefits
- PCB material processing requirements for hybrid constructions
- Material availability in industry
- Summary

Advanced Automotive Safety Systems

Active Safety Systems



Radar Sensor Portfolio

- 25 GHz Ultra-wide Band Radars
- 24 GHz Narrow-band Radars
- 77 GHz Multi-mode Radars

Supporting

- Blind Spot Detection
- Rear Cross-traffic Alert
- Lane Change Assist
- Forward Collision Warning
- Autonomous Emergency Braking
- Adaptive Cruise Control

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Vehicle Radar Classification

- **Long Range Radar (LRR)**
  - Range up to 250 m
  - Vehicle velocity above 30 km/h to 250 km/h
  - Narrow beams to control driving path in front of the car to determine distance of vehicle driving ahead for maintaining minimum safety distance
  - Bandwidth below 1 GHz and typical spatial resolution 0.5 m

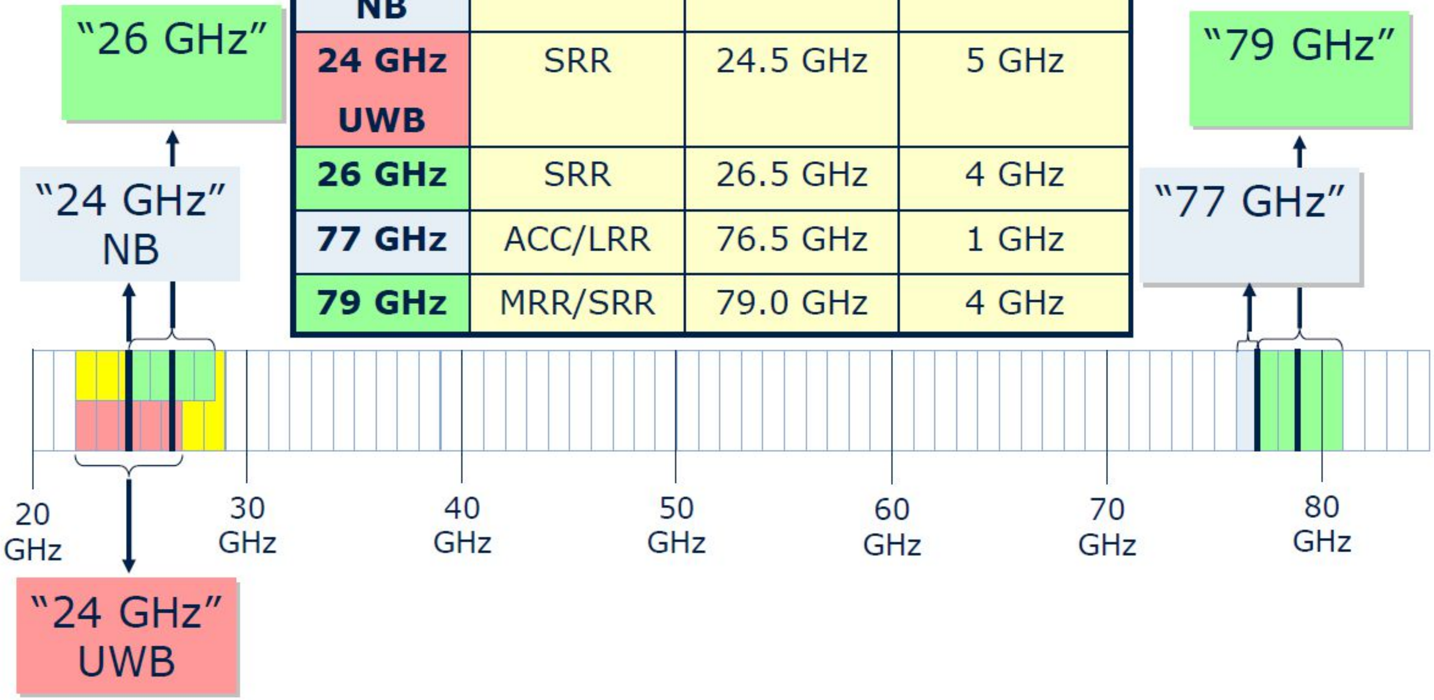
- **Short Range Radar (SRR)**
  - Range up to 30 m
  - Speed range from 5 km/h to 150 km/h
  - Wide field of view
  - Bandwidth below 5 GHz and typical spatial resolution 0.1 m

RADAR Resolution Requirements

- **Scenarios Requiring High Resolution (wide bandwidth)**
  - Side Impact
  - Cross Traffic Alert
  - Narrow Pass Assistant
  - Evasion Maneuver
  - Pedestrian Protection
  - Front Collision Warning
  - Proximity Warning and Parking Assistant
- **Scenarios Needing Lower Resolution (narrow bandwidth)**
  - Adaptive Cruise Control – long range
  - Lane Change Assist – 24 GHz

Frequency Bands for Automotive Radar

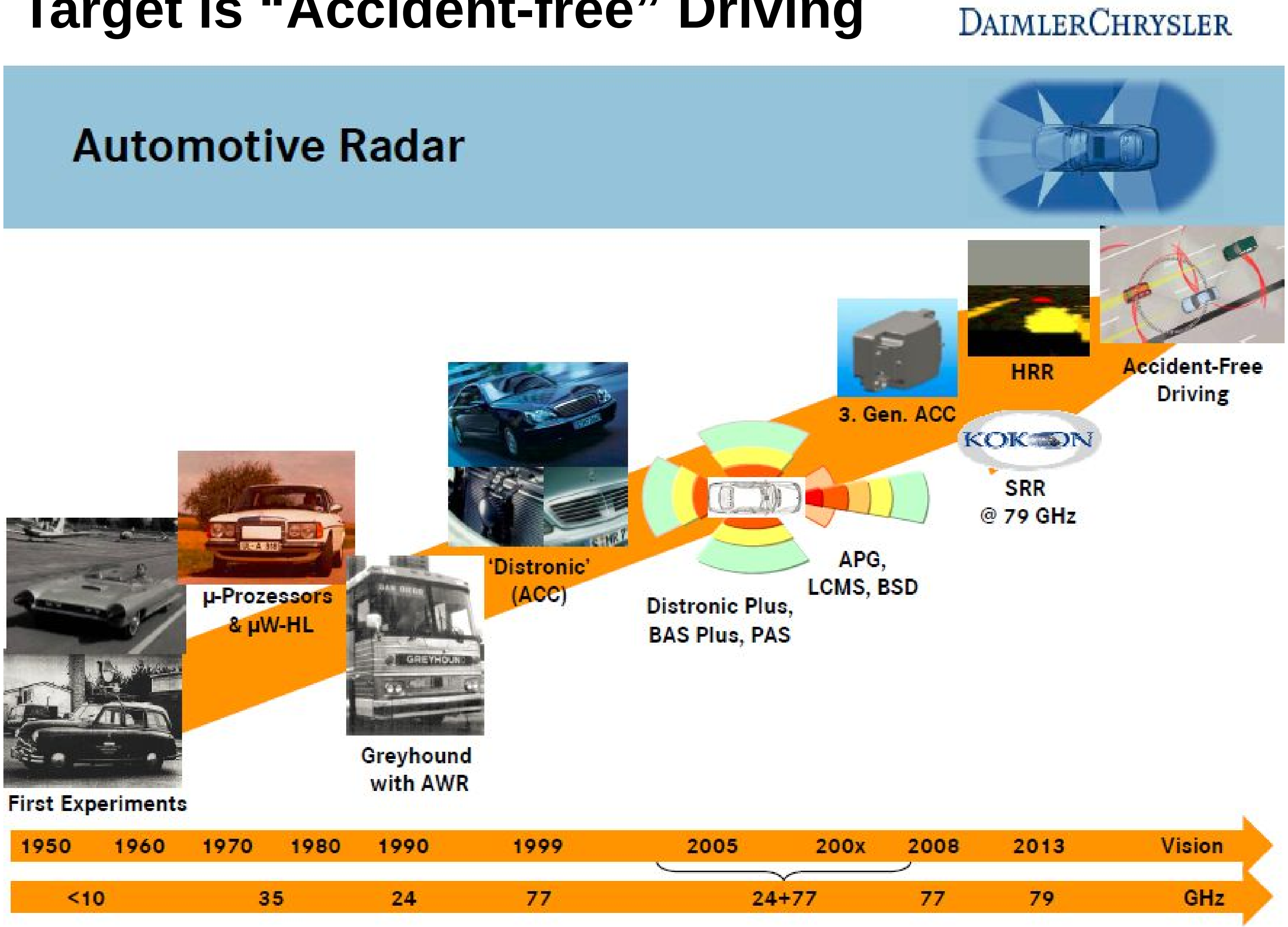
	Application	Center Frequency	Band Width
24 GHz NB	ACC	~24.2 GHz	0.2 GHz
24 GHz UWB	SRR	24.5 GHz	5 GHz
26 GHz	SRR	26.5 GHz	4 GHz
77 GHz	ACC/LRR	76.5 GHz	1 GHz
79 GHz	MRR/SRR	79.0 GHz	4 GHz



Source: Infineon

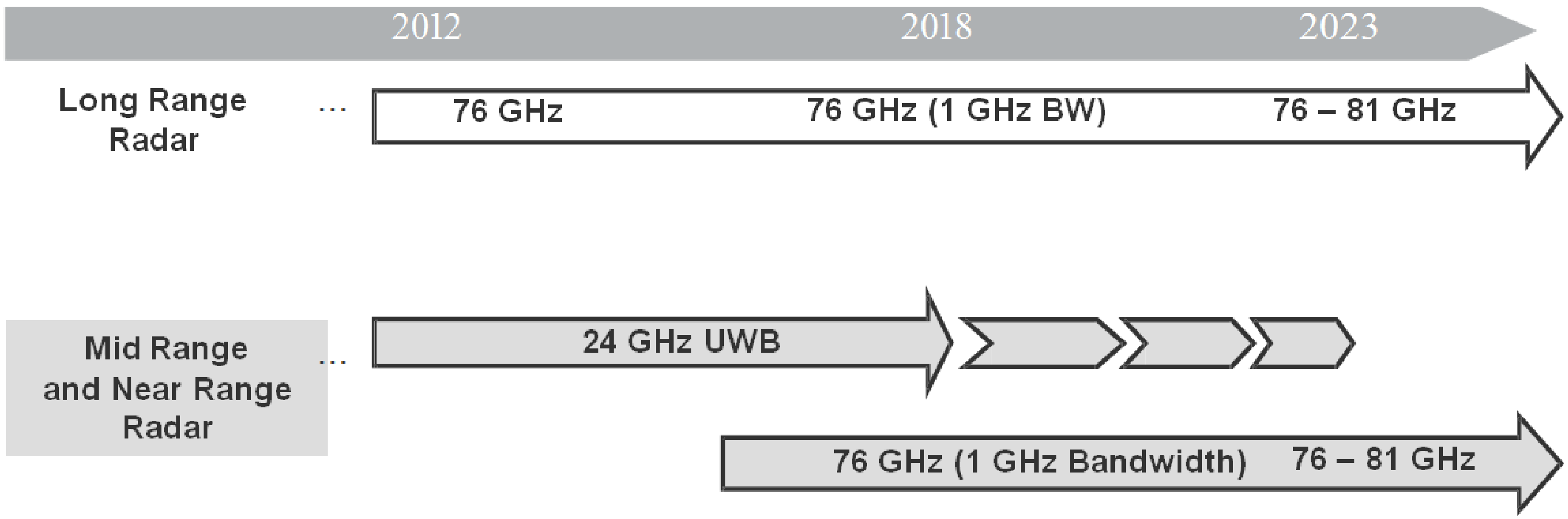
Automotive Radar Development

Target is "Accident-free" Driving



Source: IWPC

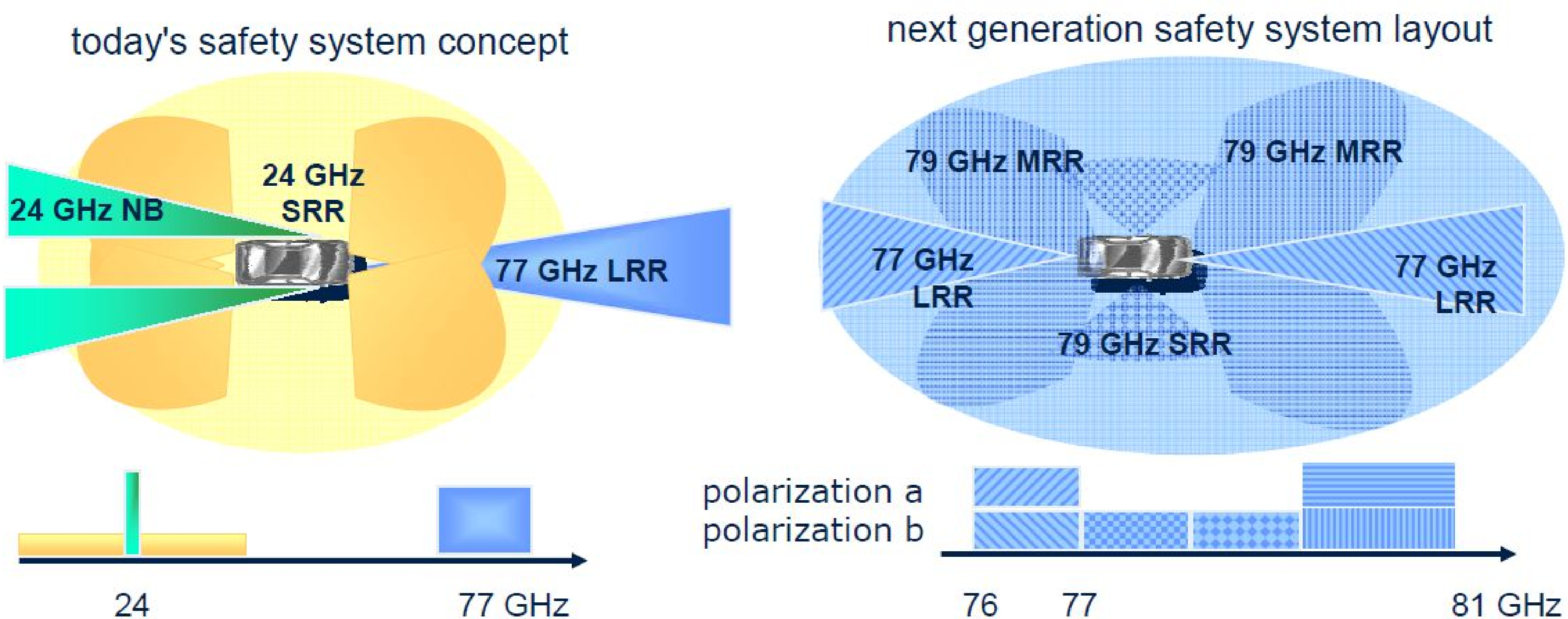
Mercedes-Benz Frequency Strategy



It is clear that all systems will migrate to the 76 – 81 GHz band in the short to medium term

Source: IWPC

Active Safety System Development



Source: Infineon

Systems are migrating to higher frequencies

- **Change in frequency allocation**
- **Improved performance**
- **Reduced size and improved affordability**

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Active Safety System Trends

- **Shift to higher frequencies**
  - 76 GHz to 81 GHz
  - Development ongoing at 140 GHz
- **Integration of multiple system functions in one chipset**
  - Radar front end
  - Microcontroller
- **Reduction in system size**
  - Smaller size offers more options for integration into vehicle front and rear fascia
- **Increasing demand for system cost reductions for a widening target market**

Desirable PCB Electrical Properties

- **Low dissipation factor, Df = tanδ**
  - Maximize power delivered to antenna
  - Achieve desired effective isotropic radiated power (EIRP) with lower input power, P_{in}
  - Better s_{11} characteristics at resonance
- **Low dielectric constant, Dk**
  - Allows rapid signal propagation
- **Consistent Df, Dk over operating bandwidth of SRR and LRR**
  - Provides consistent transmission line impedance
  - Prevents phase distortion of waveform (due to frequency dependence on phase velocity)
- **Consistent Df, Dk over temperature of operation (-40°C to 85°C) and varying humidity**
  - Eliminates need for compensation for impedance mismatch and attenuation changes over operating range of vehicle

Additional PCB Attributes

- **Material must have consistent physical properties**
  - Uniform electrical properties
  - Consistent physical properties – thickness, Dk, Df
  - Uniformity batch-to-batch and within batch

- **Ease of processing**
  - Minimum amount of special material treatment for PCB fabrication
  - Single cure cycle with parameters consistent with mature products, well established at board shops

- **Low cost as possible**
  - Choose *sufficient* material to satisfy requirements
  - Choose material process-compatible with Hybrid PCB construction

Sources of Loss in PCB

- Dielectric Loss
- Conduction Loss

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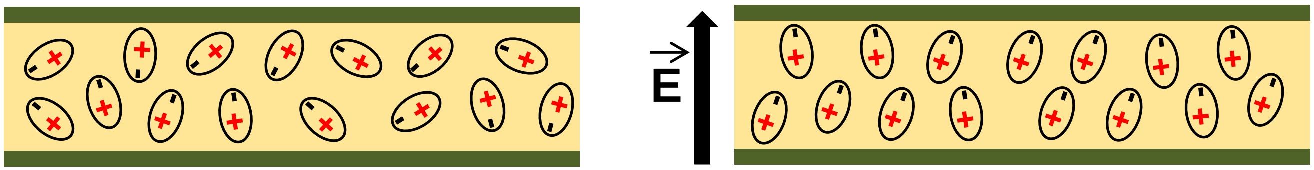
PCB Material Dielectric Loss

- **Dielectric materials have polarized molecules that move when subjected to the electric field of a digital signal**



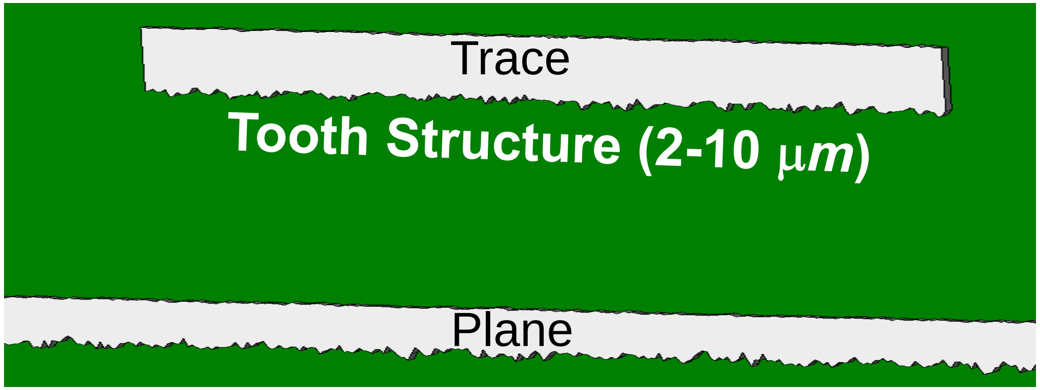
- **This motion produces heat loss**
- **Loss results in signal attenuation that increases in direct proportion to signal frequency**

PCB Material Conduction Loss

- The copper contributes to overall loss through the metal’s resistive losses
- At high signal frequencies, the current in PCB copper is concentrated within a small depth near its surface (skin effect)
- Reduction in effective cross-sectional area increases the effective resistance

Conductor Surface Roughness

- Conductors on PCBs do not have perfectly smooth surfaces
- Rough copper improves peel strength of laminate
- Maximum peak-peak tooth size varies ~ 2-10 microns
- Surface roughness increases bulk copper resistance 10-50%
- Electrical impact of conductor roughness increases with increasing frequency



Frequency	Skin Depth (Copper)
50 Hz	9.3 mm
10 MHz	21 μm
100 MHz	6.6 μm
1 GHz	2.1 μm
10 GHz	0.66 μm

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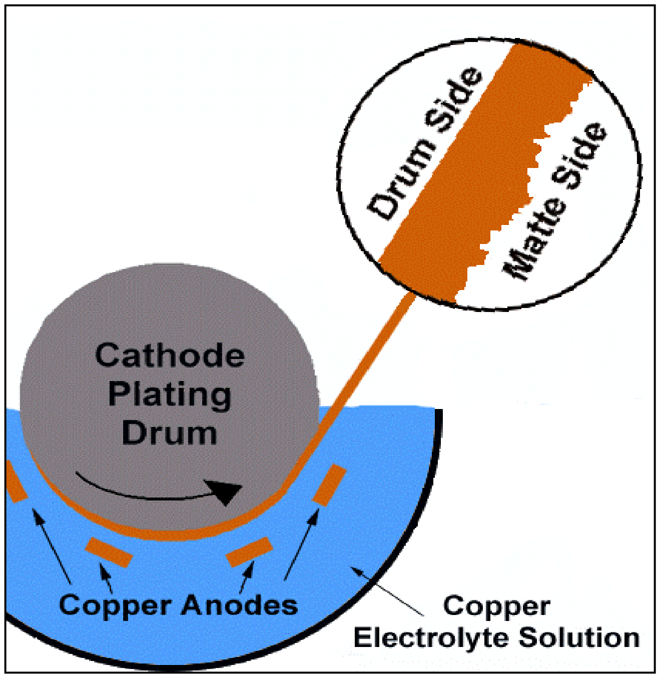
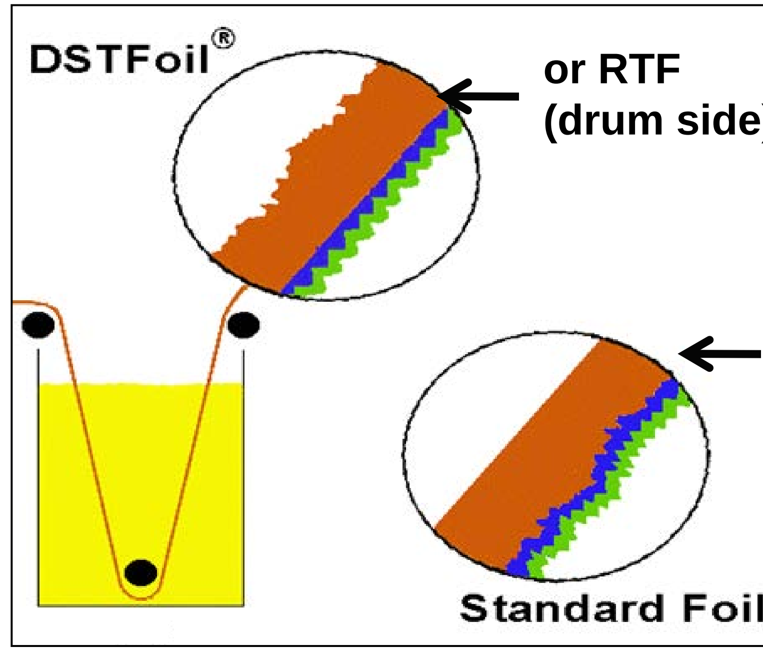
Copper Foil Plating

Foil is fabricated by plating copper on a drum



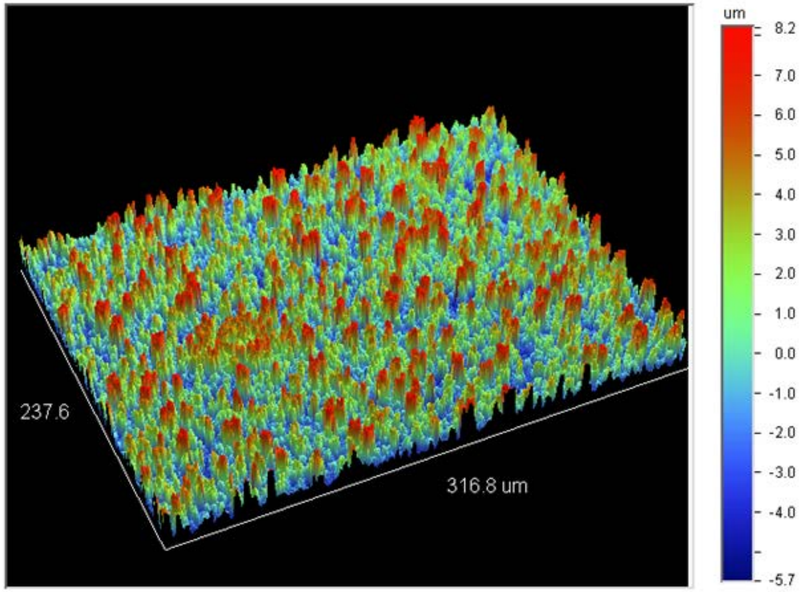
Foil Treatment



RTF and VLP Copper Profiles

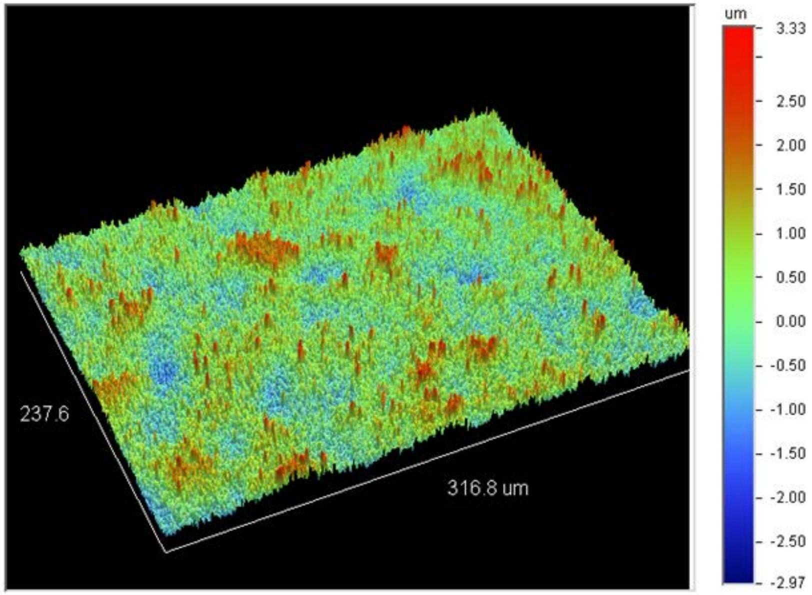
RTF

Rq=2.6 um, RF=1.85



VLP

Rq=0.68 um, RF=1.3



- Roughness parameters measured with profilometer

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Effects of Surface Roughness

- **Increase in capacitance due singular electric fields on surface spikes**

- **Increase in signal group delay over perfectly smooth**

- **“Apparent” increase in Dk to match group delay vs frequency characteristics**

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Automotive Radar PCB Conclusions

- **Dissipation factor, Df is typically specified in the range of 0.002 – 0.005 over frequency of operation**
- **Low profile copper such as VLP2 is necessary to reduce overall loss and eliminate group delay effects versus frequency**
- **Materials with these attributes come at a premium cost**

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Hybrid PCB Construction

Hybrid PCB Construction

- **Multi-layered PCB using dissimilar materials**
  - FR4 plus HSD optimized material
  - FR4 plus RF optimized material

- **Reasons to use hybrid construction include**
  - Reduction in overall system cost
  - Optimization of electrical properties
  - Improvement in reliability* and manufacturability

- **Application areas where hybrids are used**
  - Power amplifiers for cellular base stations
  - Ku band low noise block down converters
  - High-speed data channels – PCI Gen 3,4 for example
  - Advanced automotive safety systems

Reliability Concerns

- **Laminates having good electrical properties for RF/Microwave applications can have high CTE relative to other materials in construction**

- **This high CTE will cause problems when PCB experiences thermal cycling**
  - High CTE material expands at different rate than copper causing delamination
  - Plated through holes undergo stress causing cracking

- **Materials in hybrid construction should have well-matched CTEs, reasonably close to that of copper**

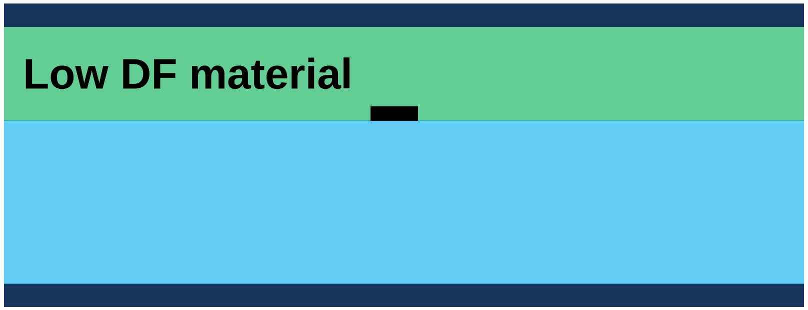
Cost Savings

- Material for best radar performance comes at a cost premium, so use it only on critical layers
- Hybrid material mix must be compatible and not increase fabrication cost and complexity or reduce yield
- Fortunately, high performance materials are available that make hybrid builds straightforward using well established processes

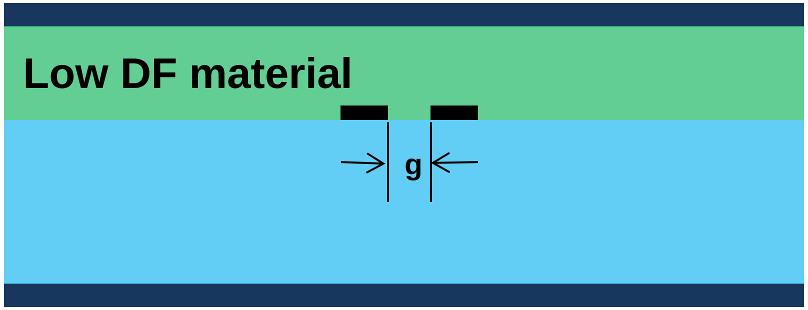
Process for Maximum Cost Savings

- **To realize the greatest cost savings, use materials that process most closely to FR-4**
- **Additional or more complex steps required in processing can consume cost savings associated with hybrids**
  - Plasma etch for microvia plating
  - Use of multiple plasma surface treatment cycles
  - Plasma desmear
  - Time-constrained electroless and soldermask processes
  - Plasma to promote bond of photo resist for secondary imaging

Transmission Line Guidelines



- For asymmetric stripline it is best to have the thinnest layer being low loss



- Asymmetric stripline can be more susceptible to cross-talk if Dks differ. This is mitigated by slight increase in gap, g

- Microstrip takes full advantage of low-loss materials

Hybrid Construction for Automotive Radar

Layer	Type	Structure (Stack up)	Cu weight (oz)	Construction	Thickness after lam (mil)
1	TOP		0.5 + plating		2.1
	core			Astra 5mil	5.0
2	V2		0.5		0.6
	prepreg			370HR	7.2
3	V3		1		1.3
	core			370HR	18.0
4	V4		1		1.3
	prepreg			370HR	7.2
5	V5		0.5 + plating		2.1
					44.7

This hybrid structure utilizes high performance material where necessary and standard process-compatible materials to reduce cost

This construction processes like standard FR-4

Conclusions

- Hybrid constructions offer significant cost savings when the correct materials are used
- The savings realized is more than just material costs as processing costs can be different depending on the high performance PCB material utilized
- For best results consult the PCB manufacturer for guidance