BENCHMARK STUDY OF RF PERFORMANCE IN ADVANCED COMPOSITES DESIGN

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ABSTRACT

Radio frequency (RF) characterization is an important aspect of designing components in close proximity to transmitting or receiving antennas. For components comprised of anisotropic composites, designing for RF functionality is particularly complex due to morphology and boundaries between the composite materials. Phenomena resultant from these material aspects greatly affect RF transmission and reception.

This paper discusses experiments conducted on ARRIS materials (ARRIS-GF50-BK-001 and ARRIS-CF45-BK-001) to characterize the RF response of multi-material composites with different fiber orientations. These results were compared to data available in literature and used to demonstrate an example of the design process.

The structurally optimized ARRIS components meet RF requirements for next-generation devices—thinner and lighter weight composite parts with significantly improved mechanical performance versus metals and plastics.

INTRODUCTION & MOTIVATION

Numerous markets are adopting composites as a replacement for plastics and metals used by critical structural components, including unmanned aerial vehicles (UAVs), also known as drones, augmented reality (AR), or virtual reality (VR) devices, portable electronics, and wearable devices. A common motivation of these markets is to minimize the weight and volume of structural components and to maximize available weight and volume for electronics and supporting hardware systems. Reducing structural allocation must also meet the functional criteria of relevant application assemblies.

THE INCREASING PREVALENCE OF DIGITAL COMMUNICATION COMPONENTS MEANS RF PERMITTIVITY IS A FUNCTIONAL PRIORITY MORE THAN EVER

In consumer and industrial electronics, applications benefit from structural components that possess the minimum viable weight while meeting mechanical and electronic hardware functionality criteria. A structural component's corner-to-corner stiffness, for example, must meet a minimum value while constrained to only allocate material in regions free of electronics. Mobile devices utilizing metal for structural backing, primarily aluminum, must incorporate gaps through which RF signals can be transmitted, as relevant metals drastically attenuate RF wavelengths. Such structural gaps are usually comprised of plastic, through which antennas can achieve connectivity. These gaps, however, present weakened interfaces that inhibit drop impact resistance and other mechanical performance requirements. To replace such metal casings, a monolithic backing without weakened antenna gap interfaces must provide equivalent RF functionality.

AN INCREASING NEED EXISTS FOR NOVEL PROCESSES ENABLING RF PERMITTIVITY & SPECIFIC STIFFNESS IN PORTABLE ELECTRONIC DEVICES

By engineering RF and mechanical functionality into increasingly lightweight structural components, devices will become stiffer and lighter while still able to communicate across the networks they rely on. This study addresses this need by using ARRIS technologies, methods, and materials to simultaneously meet structural performance and RF functionality requirements at reduced weight in a redesigned case plate for a consumer or enterprise-level mobile device.

APPROACH

RF MATERIAL TESTING

Because ARRIS materials are inherently anisotropic, understanding the effect these internal material boundaries have on the dielectric properties of the effective material is essential. The ARRIS materials tested are continuous fiber composites where the different material properties of the two constituents, fiber and resin, combine to exhibit effective behaviors at the parts and component level.

Additionally, because the reinforcing fiber pattern is uniform, the composites exhibit unique material properties relative to the fabrication pattern. Properties that extend along the fibers are commonly known as 'axial' properties, and properties that extend across the fibers are known as 'transverse' (Figure 1). The materials discussed in this study have been evaluated for directional dielectric material response.

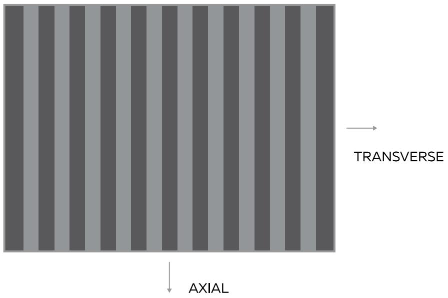

Figure 1: Top-Down View of A Uni-Directional (UD) Composite Lamina

Figure 2: Cross-Ply Laminate: Where Half Of The Layers Are At 0 Degrees From The X-Axis & Half Are At 90 Degrees For The X-Axis

MULTIFUNCTIONAL DESIGN

The demonstrated design is made up of three primary objectives:

1. The radio frequency loss of the transmitting and receiving antennas should be within 5.0% compared to the control.
2. The overall phone case stiffness should be greater than or equal to the stiffness of the control.
3. The weight of the phone case should be less than or equal to the weight of the control.

ARRIS-GF50-BK-001 ///
PC Matrix with Glass Fibers At 50% Fiber by Volume, Dyed Black
ARRIS-CF45-BK-001 ///
PC Matrix with Carbon Fibers At 45% Fiber by Volume, Dyed Black

The control, in this study, is the case plate that is shipped with the phone from the current supplier. This control part is comprised of an unknown plastic, likely polycarbonate (PC) or polypropylene (PP). To assess these objectives, the control was compared to a full composite case plate and topology optimized back plate of the same geometry. The full composite case is comprised entirely of ARRIS-GF50-BK-001, while the topology optimized case is comprised of ARRIS-CF45-BK-001, ARRIS-GF50-BK-001, and neat PC in specific regions.

The design process involves meeting and balancing all stated objectives. Divergent trade-offs do exist between radio frequency loss and material thickness and stiffness. By evaluating a range of consumer electronics grade materials, most of these materials notably exhibit an inverse relationship between RF permittivity and stiffness. This is also the case for ARRIS materials.

STRUCTURAL DESIGN & VALIDATION

The structural design involved an initial approximation using 1-dimensional hand calculations. The flexural testing procedure was then identified, and initial testing was conducted on the control samples to inform the design.

A digital twin or computer simulation was then constructed to simulate the testing conditions virtually. This computer simulation was used to input ARRIS patent-pending anisotropic topology optimization software. This design step was run concurrently with the following design step, and minimum RF windows and total weight were used as an initial envelope for the topology optimized case plate.

RF DESIGN & VALIDATION

The radio frequency design involved calculating an initial approximation for the control sample. The range of loss versus frequency was calculated for a small subset of suspected material compositions. The actual material for the control is unknown. A Composite RF Calculator, developed by ARRIS via existing literature, was then used to estimate RF transparency. This software was calibrated with the material data available below in the RF Test Results section. The difference in losses for the various ARRIS materials and local part thicknesses were taken into consideration during the design.

The final designs were manufactured and validation testing was conducted using standard over the air (OTA) testing for Total Radiated Power (TRP) and Total Isotropic Sensitivity (TIS). Eight discrete frequencies between the ranges 800 MHz to 6 GHz were tested.

The test chamber was a MAPS (Multi Axis Positioning System) with a single stationary measurement antenna. The measurement was taken using the great circle cut method. The model was an ETS-Lindgren manufactured AMS-8500. The software used was ETS-Lindgren EMQuest. All test equipment satisfies CTIA requirements and satisfies ISO 17025 standards.

DISCUSSION

RF TEST RESULTS

All material characterization testing was done on flat samples. Test data is for radio signal frequencies ranging from 500MHz to 6 GHz. The tests were conducted at 22 degrees C and with a relative humidity of less than 70%. The test was VNA was calibrated and the calibration was verified with known materials prior to testing.

Based on the test data for multiple layups and configurations it was determined that the material ARRIS-GF50-BK-001 behaves isotropically when exposed to RF signals in this frequency range. Isotropic behavior significantly simplifies the expected signal loss calculations. The resulting dielectric constant and tan delta for ARRIS-GF50BK-001 can be seen in Figures 3 and 4.

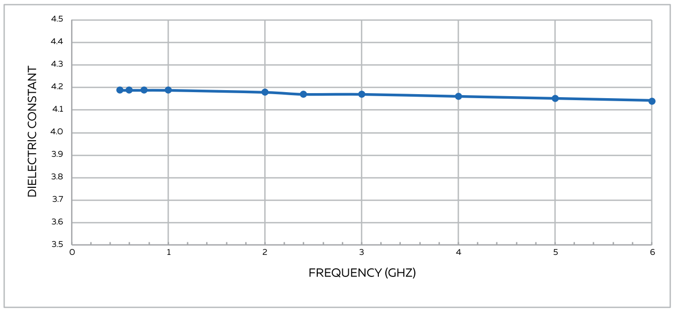

Figure 3: ARRIS-GF50-BK-001 Dielectric Constant

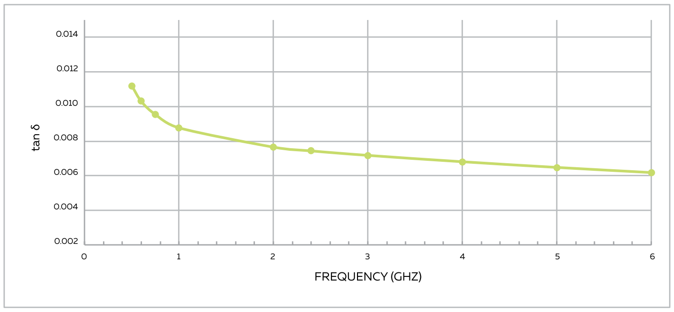

Figure 4: ARRIS-GF50-BK-001 Tan Delta

In contrast, based on the test data for multiple layups and configurations, it was determined that the material ARRIS-CF45-BK-001 exhibits highly orthotropic behavior. This means that the fiber directionality and layup are important for considering in the dielectric design. The uni-directional (UD) configuration of the ARRIS-CF45-BK-001 material dielectric constant and tan delta, where the signal is applied in the axial direction or parallel to the fiber, can be seen in Figures 5 and 6.

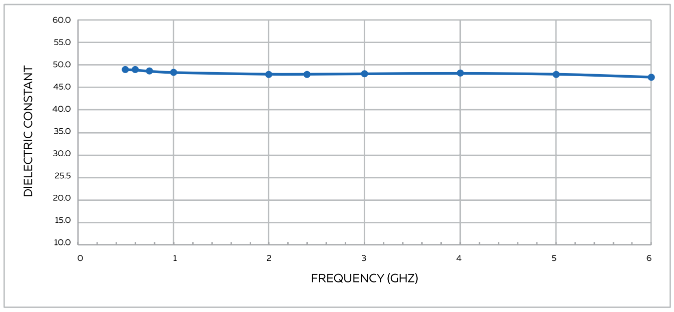

Figure 5: ARRIS-CF45-BK-001 Dielectric Constant For A Uni-Directional Layup With The RF Signal Oriented Axial To The Fiber

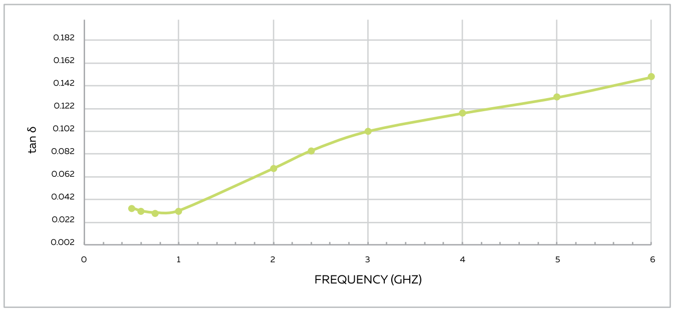

Figure 6: ARRIS-CF45-BK-001 Tan Delta For A Uni-Directional Layup With The RF Signal Oriented Axial To The Fiber

The UD configuration of the ARRIS-CF45-BK-001 material dielectric constant and tan delta, where the signal is applied in the transverse direction or perpendicular to the fiber, can be seen in Figures 7 and 8.

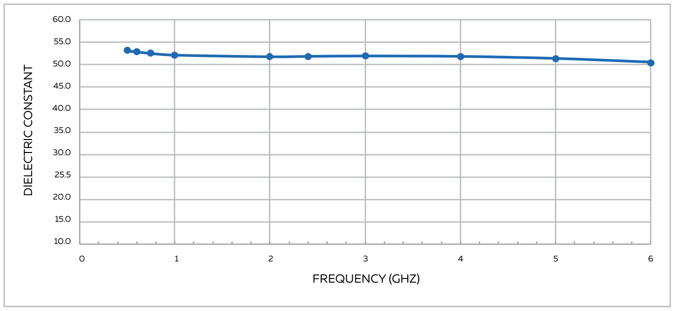

Figure 7: ARRIS-CF45-BK-001 Dielectric Constant For A Uni-Directional Layup With The RF Signal Oriented Transverse To The Fiber

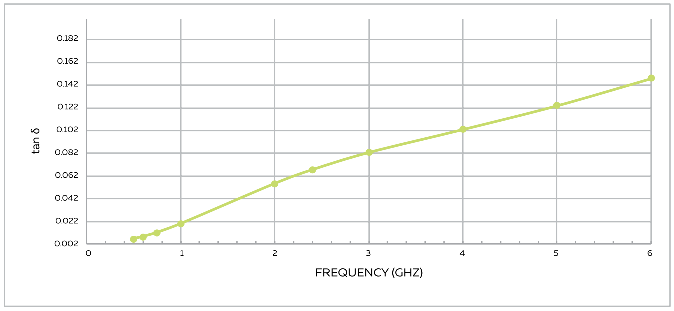

Figure 8: ARRIS-CF45-BK-001 Tan Delta For A Uni-Directional Layup With The RF Signal Oriented Transverse To The Fiber

The cross-ply configuration (see Figure 2) of the ARRIS-CF45-BK-001 material dielectric constant and tan delta can be seen in Figures 9 and 10. Due to the pattern of the cross-ply signals applied in the axial and transverse directions should yield the same response. The results supported this assumption. There was no difference between the response in the axial and transverse directions for the cross-ply configuration.

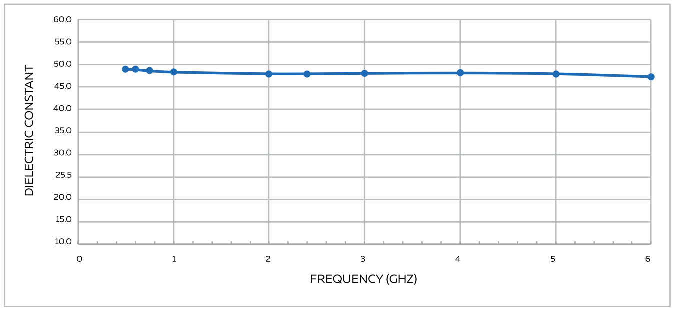

Figure 9: ARRIS-CF45-BK-001 Dielectric Constant For A Cross-Ply Layup

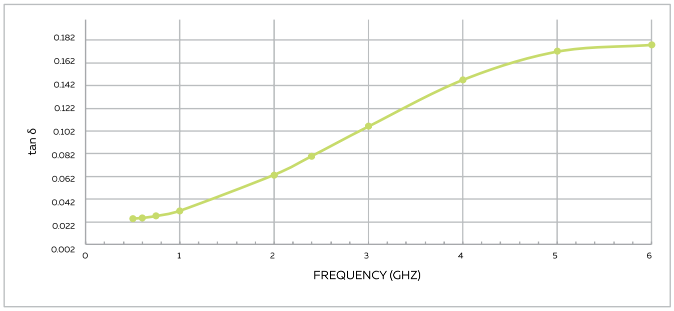

Figure 10: ARRIS-CF45-BK-001 Tan Delta For A Cross-Ply Layup

As expected, the CF45-BK-001 material exhibited approximately a ten-fold increase in dielectric constant when compared with the GF50-BK-001 material. Where GF50-BK-001 is in the range of most consumer electronic case materials. It is worth noting that the CF45-BK-001 cross-ply configuration has a lower dielectric constant than the UD configuration in the frequency ranges above 4 GHz. The tan delta for the GF50-BK-001 is roughly constant across the frequency range tested, while the tan delta for the CF45-BK-001 material increases as frequencies increases over 1 GHz.

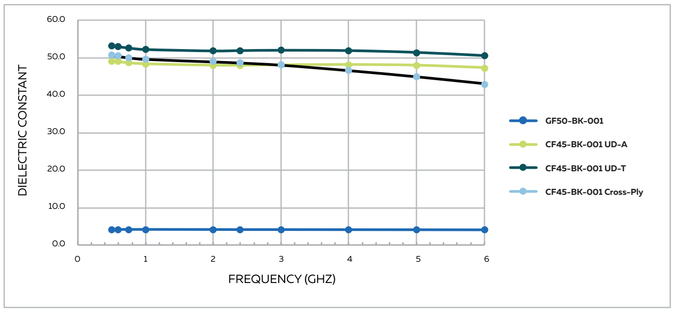

Figure 11: Summary of Dielectric Constants For The ARRIS Materials Included In This Study

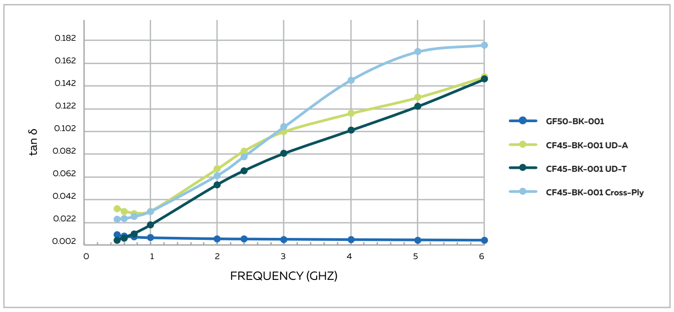

Figure 12: Summary of Tan Deltas For The ARRIS Materials Included In This Study

RESULTING COMPONENT

The multi-objective optimization that included structural and radio frequency considerations yielded the following component shown in Figures 14 and 15. Because of the unique Additive Molding^{TM} method and materials technology, multi-material parts can be manufactured seamlessly.

The resulting topology optimized case plate utilizes both ARRIS-CF45-BK-001 and ARRIS-GF50-BK-001, as well as neat PC resin. Using neat PC as a window for the smartphone's multiple radio frequency receivers in the corner areas, shown in Figure 13, and the other two materials to increase specific stiffness in the bezel and panel locations creates an optimal configuration that meets all design objectives.

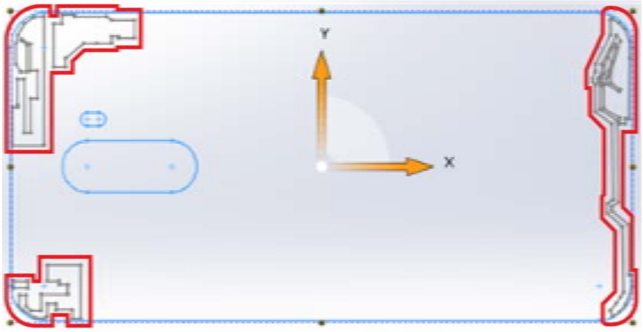

Figure 13: Artistic Rendering of Antenna Locations (In Red)

STRUCTURAL DESIGN & CALCULATIONS

The initial design was estimated with hand calculations based on the expected modulus of elasticity of the control phone case material. A virtual setup of the flexural test was built in a finite element simulation. Initial radio frequency windows were included to initialize the ARRIS topOpt software (Figure 14). The resulting optimization and fiber mapping can be seen in Figure 15.

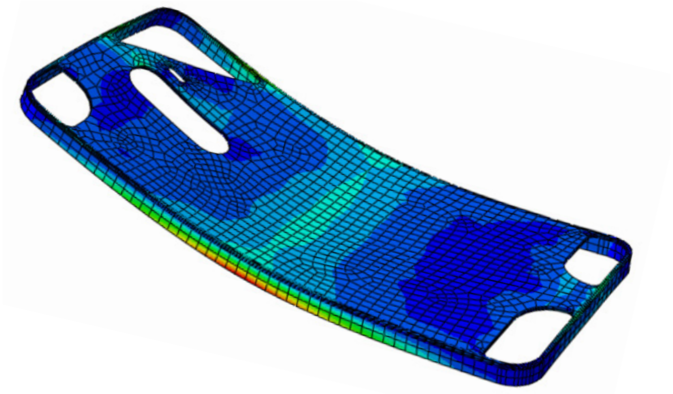

Figure 14: Render Image of Finite Element Analysis (FEA)

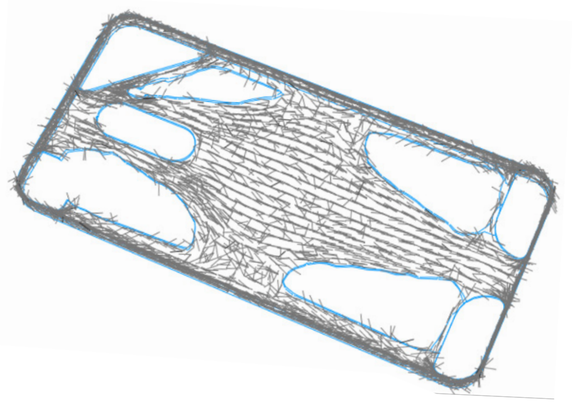

Figure 15: Image of TopOpt Analysis/Results (Grey: Local Fiber Orientation, Blue: Material Edges)

RF DESIGN & CALCULATIONS

The loss through the control was approximated using material data available in the literature and the ARRIS Composite RF Calculator, Figure 16. Using the ARRIS Composite RF Calculator, the assumption that the weight of the current design would be a limiting parameter, the wall thickness was limited to 0.7mm. The final thickness of 0.68mm was selected based on fabrication and processing constraints. Based on the initial estimate, Figure 17, the expected loss is within the above-mentioned design criteria.

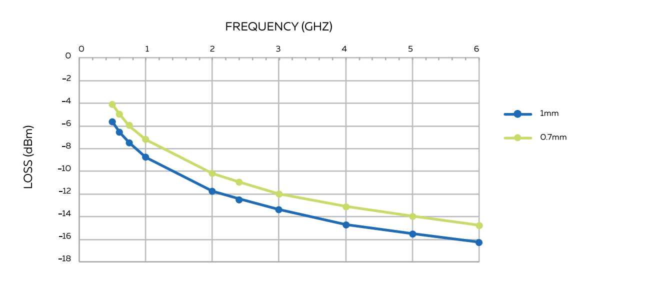

Figure 16: Estimated Loss Through The Control Sample: Polarization of The Signal Is Not Accounted

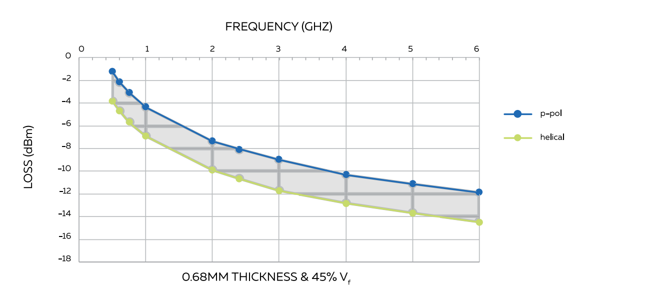

Figure 17: Calculated Loss For 0.68mm Thickness Of ARRIS-GF50-BK-001

FLEXURAL TEST RESULTS & VALIDATION

All flexural testing was conducted on finished samples using the test setup method discussed above. An average of three samples was used for both the control (Figure 18) and the topology optimized design (Figure 19, blue curve). Notably, the topology optimized case plate meets the design criteria and further significantly outperforms the control back in flexural stiffness.

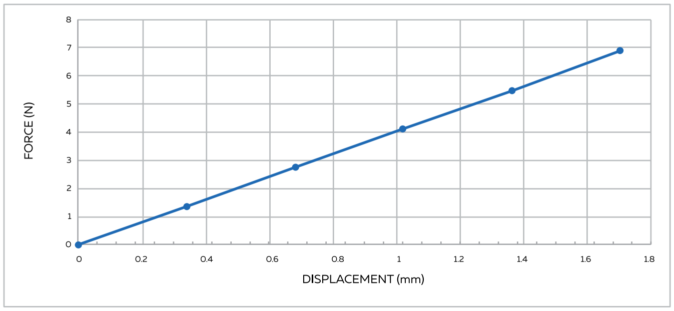

Figure 18: Load In Newtons Vs. Mid-Span Deflection In Millimeters For Control Back Three-Point Bend Test

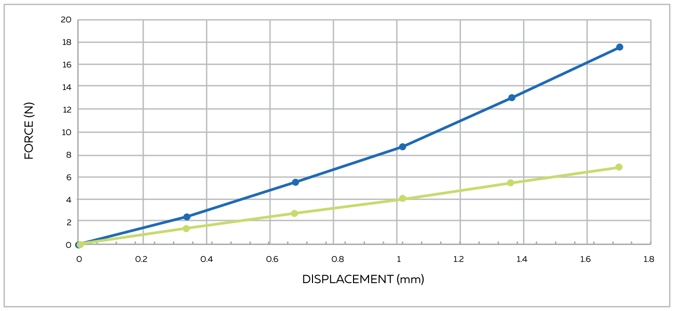

Figure 19: Load In Newtons Vs. Mid-Span Deflection In Millimeters For Current Design (Blue) And Control Back (Green) Three-point Bend Test

OTA TEST RESULTS & VALIDATION

All testing was conducted on finished samples using the test setup methods discussed in the section above for TIS and TRP. The full composite ARRIS-GF50-BK-001 case was considered in addition to the topology optimized case. Compared to the default control case, the degradation difference is plotted against a range of signal frequencies in Figures 20 and 21.

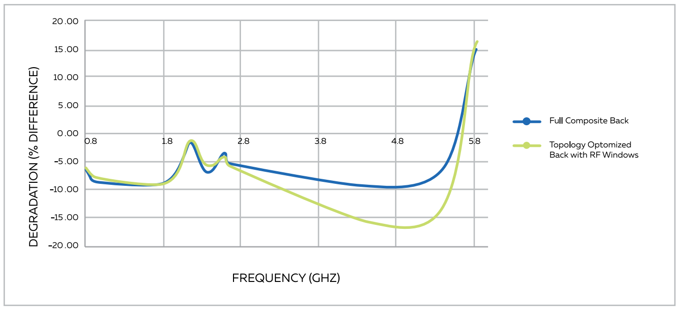

Figure 20. Results From TRP Plotting Degradation Percent Difference From The Default Case vs. Frequency For The Full Composite Case (Blue) and Topology Optimized Case (Green)

Both full composite and topology optimized cases subjected to OTA testing showed similar degradation compared to the default control back case of the smartphone company, as shown by Figures 20 and 21. Both cases show moderate degradation compared to the control case at lower frequencies, which increases at higher frequencies. These trends are in line with those predicted by the RF calculator.

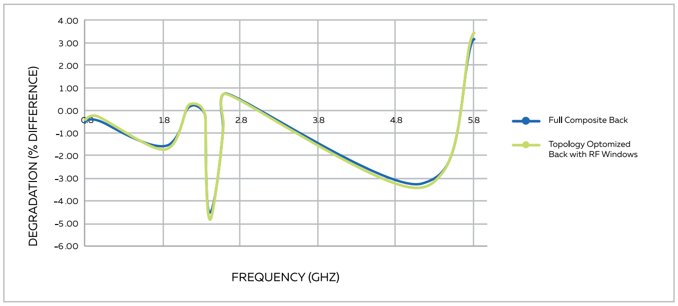

Figure 21. Results From TIS Plotting Degradation Percent Difference From The Default Case vs. Frequency For The Full Composite Case (Blue) and Topology Optimized Case (Green)

Potential for error in the test method is possible, which is attributable to slight geometric inconsistencies between the control and full composite and topology optimized cases. The default case has the inherent benefit of RF engineering internal to the smartphone company and will thus interface optimally with the antennas, whereas the composite geometries may vary slightly from the default, resulting in a less precise antenna interface. Any difference in spatial gap or contact between the case and antenna will affect results to a degree of 0.5-1.0 dBm.

The control sample weighed 14.81g, the full composite case weighed 15.67g, and the topology optimized case weighed 13.48g. The multifunctional design approach thus yielded a topology-optimized case comparable to the default in terms of RF permittivity but with increased stiffness and reduced mass.

CONCLUSION

As with all multifunctional structures, multiple material responses must be considered in the design process for composite components within devices requiring RF functionality. To maximally enable next-generation mobile electronics, structural components must minimize weight while maintaining or increasing mechanical performance and RF functionality. In this study, test data and analysis have been presented for the RF response of ARRIS' flagship materials (ARRIS-CF45-BK-001 and ARRIS-GF50-BK-001).

This data was then used for validation of an RF calculator, which was subsequently used to predict performance and specify criteria for a redesigned mobile phone case, in addition to ARRIS' topology optimization software.

A multifunctional design process informed by the RF test data and optimization software has been discussed as a demonstration component, the topology optimized case, comprised of both carbon and glass fibers in specific regions. This redesigned case was subjected to bending stiffness and OTA testing for comparison against the control case.

THE **ARRIS TOPOLOGY OPTIMIZED CASE WAS LIGHTER & 3X STIFFER** THAN THE CONTROL WHILE ACHIEVING COMPARABLE RF PERFORMANCE

A similar ARRIS-enabled design process can be adopted for other mobile electronics components to deliver RF functionality at reduced weight and increased mechanical performance.

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