WHITE PAPER

Concealment Material Performance for 3.45 GHz, 3.5 GHz (CBRS) & 3.7 GHz (C-Band) Networks

BACKGROUND

The recent auctions in the 3.55 to 3.98 GHz frequency range (CBRS / C-Band) provide valuable blocks of spectrum for US operators. The 100's of MHz made available in these auctions dramatically increases the pool of sub-6 GHz spectrum for 5G networks. The superior propagation characteristics of this "mid-band" spectrum compared to mmW enables larger coverage areas per cell and improved building penetration. Initial deployments will likely focus on coverage utilizing massive MIMO arrays deployed on existing macro sites. Capacity / hole filling sites will follow shortly thereafter deployed at "street level" with lower power radios and lower order MIMO arrays. Street level deployments often require some level of concealment to improve the aesthetics of antennas and radios to achieve site approval. ConcealFab has extensive experience designing street level concealment solutions for antenna systems up to 40 GHz. This paper presents measurements showing how ConcealFab's concealment materials perform over the CBRS / C-Band frequency range and presents several concealment designs manufactured using these materials.

SPECTRUM AUCTIONS

CBRS is the frequency band from 3.55 to 3.70 GHz, a 150 MHz block of spectrum that is divided into fifteen 10 MHz Time Division Duplex (TDD) channels. The 15 channels are split between licensed (PAL) and unlicensed (GAA) blocks as shown in Figure 1. The CBRS spectrum is shared with incumbents (government and commercial) and is managed through a Spectrum Access System (SAS).

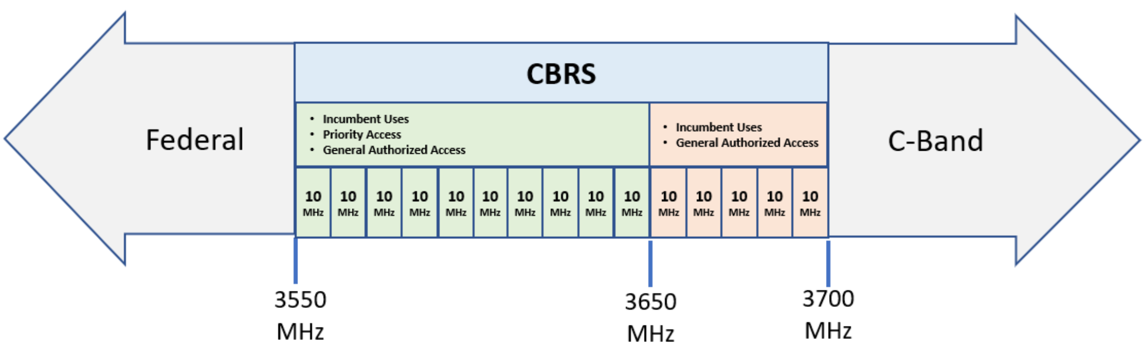


Figure 1: CBRS Spectrum

For US wireless operators C-band is the range of frequencies for 3.70 to 3.98 GHz, a 280 MHz block of spectrum that is divided into fourteen 20 MHz TDD channels as shown in Figure 2. Historically C-band is a generic designation given by the IEEE for the 4 GHz to 8 GHz frequency range. A major commercial use of this frequency band has been satellite communications with uplink from 5.925 to 6.425 GHz and downlink from 3.70 to 4.20 GHz. The lower portion of the downlink spectrum (3.70 to 3.98 GHz) has been re-allocated for 5G terrestrial use via FCC Auction 107. Satellite operators have agreed to accelerated clearing of this spectrum, re-packing their existing operations into the 4.0 to 4.2 GHz range. The first 120 MHz will be cleared in 46 Partial Economic Areas (PEA) by December 5, 2021 with the remaining spectrum to be cleared by December 5, 2023.

ConcealFab® Corporation
10205 Federal Drive, Building B • Colorado Springs, CO 80908 719.599.3400 www.concealfab.com

Updated: April 9, 2021

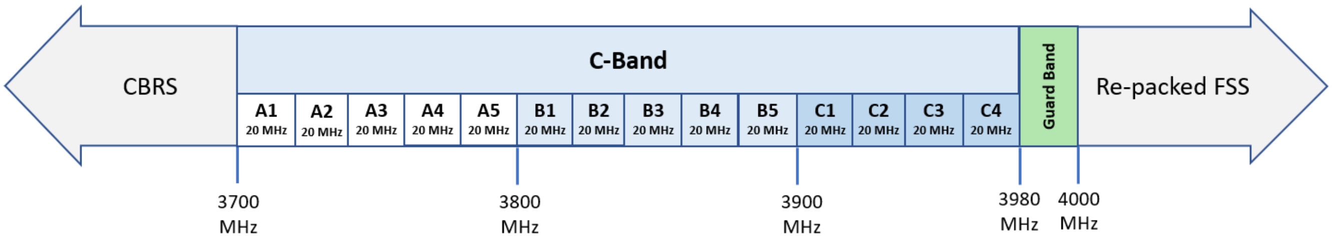


Figure 2: C-Band Spectrum

The FCC has recently announced that 100 MHz of "Federal" spectrum directly below the CBRS band, 3.45 to 3.55 GHz, will be auctioned in ten 10 MHz blocks in October 2021 (Auction 110). Like AWS-3 there will be sharing with DoD frequencies around certain US military installations.

RADOME/CONCEALMENT BASICS

Wireless antennas (panels, cylinders, etc.) come with a protective cover or radome made of a RF transparent dielectric material. When an antenna is hidden behind a concealment, the concealment material acts as a second radome to the antenna. The RF energy lost through a concealment is due to reflection and absorption that varies with frequency, distance, angle, and polarization. Key properties of a concealment material are its dielectric constant, loss tangent (dissipation factor), composition, and its thickness. "Electrically thin" concealments have a thickness ≤0.1 wavelength and offer low loss over a wide range of incidence angles and polarizations. "Electrically thick" concealments have a thickness >0.1 wavelength and have higher loss compared to "electrically thin" concealments. Another key factor impacting antenna performance is the distance between the antenna and the Radome/Concealment as it's typically in the near field of the antenna and has a "lensing" effect on the antenna.

Table 1 shows the ratio of thickness to wavelength for a typical 0.25-inch-thick concealment with dielectric constant equal to 3 over a range of frequency bands. The wavelength in a material is calculated by dividing the free space wavelength by the square root of the material dielectric constant. For this 0.25-inch-thick concealment example, the transition between electrically thin and electrically thick occurs in the 2600 MHz range. At 3500 MHz, this concealment is just above the electrically thin threshold, suggesting that materials used for concealments in the 3.45 – 3.98 GHz frequency range should be tested to verify their suitability.

FREQUENCY (MHZ)	700	850	1900	2100	2600	3500	5500	28000
Free Space wavelength (in)	16.86	13.98	6.21	5.62	4.54	3.37	2.15	0.42
Wavelength in material (in) (Dielectric Constant = 3)	9.73	8.02	3.59	3.24	2.62	1.95	1.24	0.24
Thickness to wavelength ratio in the material	0.03	0.03	0.07	0.08	0.10	0.13	0.20	1.03

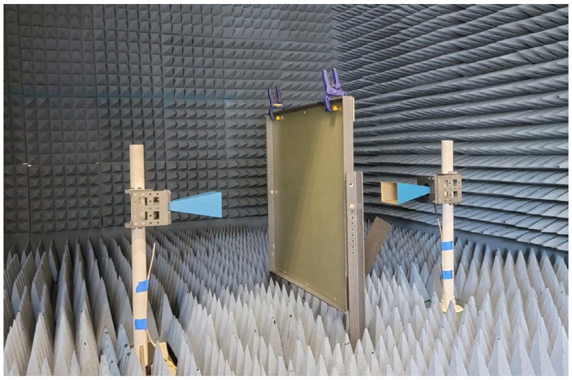
Table 1: Thickness to wavelength ratio of 0.25-inch-thick concealment (Dielectric Constant =3)

ConcealFab® Corporation
10205 Federal Drive, Building B • Colorado Springs, CO 80908 719.599.3400 www.concealfab.com
Updated: April 9, 2021

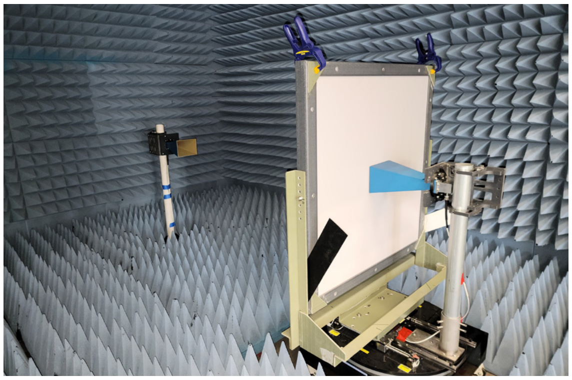
CONCEALFAB MATERIAL TESTING

ConcealFab has an inhouse anechoic chamber and the necessary RF / mmW test equipment to evaluate concealment materials from sub-6 GHz to mmW frequency bands. Tests performed by ConcealFab to evaluate the performance of CBRS/C-Band concealment materials include:

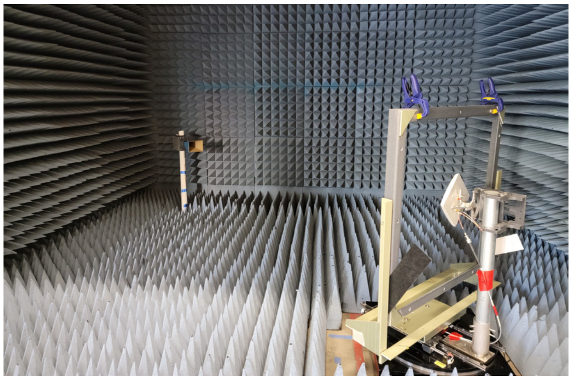
- **FAR FIELD TRANSMISSION LOSS VS FREQUENCY**
  Measured on 3-FT x 3-FT samples with the material at a fixed far field distance between horn antennas. Measurements are made at incidence angles of 0°, 30°, 60° for both perpendicular and parallel polarizations.



- **NEAR FIELD TRANSMISSION LOSS VS FREQUENCY VS DISTANCE**
  Measured on 3-FT x 3-FT samples with the material located 0mm (touching the antenna) to 180mm in 1mm increments away from one of the horn antennas. This distance covers approximately two wavelengths at 3.45 GHz which is the lowest frequency (longest wavelength) of the CBRS/C-Band spectrum. The transmission loss vs frequency measurements at each distance are plotted together to create a family of curves that ConcealFab has named a "Cyclone Plot." The cyclone plot shows the loss variation vs. frequency that can result when the concealment material is installed close to a site antenna.



- **ANTENNA PATTERNS**
  Measured at 3.6 GHz using a 40° beamwidth panel antenna. Far field azimuth patterns are measured with and without a 3-FT x 3-FT sample of the concealment material placed in front of the antenna. Patterns are compared to evaluate the impact on pattern shape, sidelobe levels, backlobe levels and main beam loss.

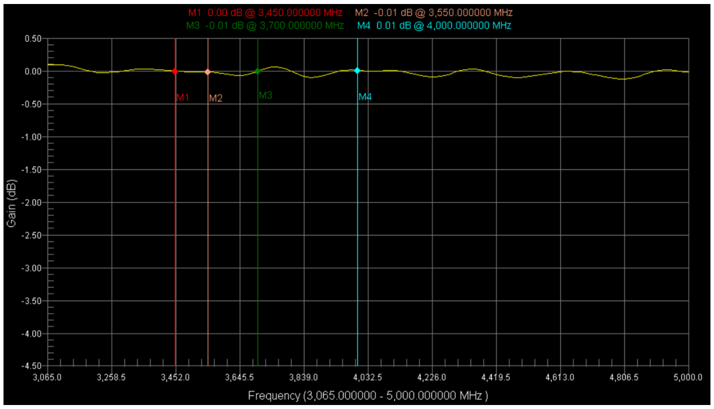


TEST RESULTS

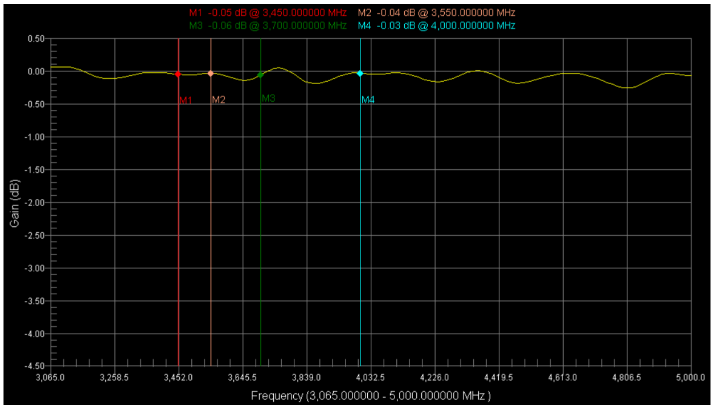
Test results are presented for materials that ConcealFab currently uses to manufacture concealment solutions for small cells and other street level deployments. Commonly used in the industry, FRP is also included for comparison. Table 2 shows a summary of results and provides an over-all ranking for each concealment material.

FAR FIELD TRANSMISSION LOSS VS FREQUENCY

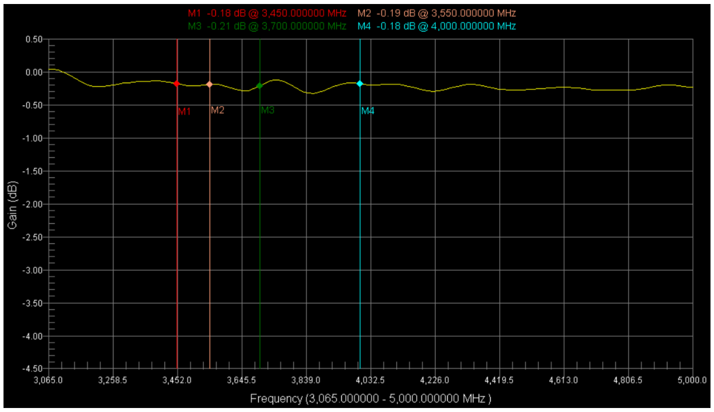
Shown below are the transmission loss plots for Parallel Polarization at 0° incidence:



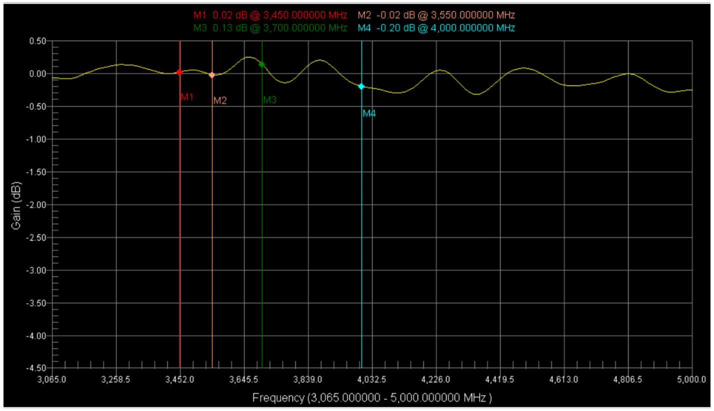
clearWave™ S140



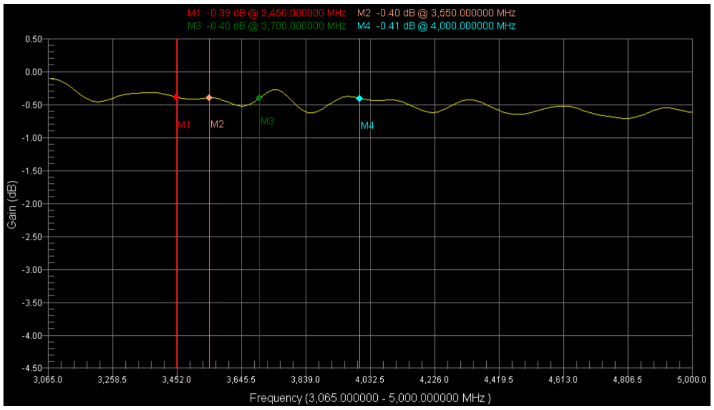
clearWave™ S240



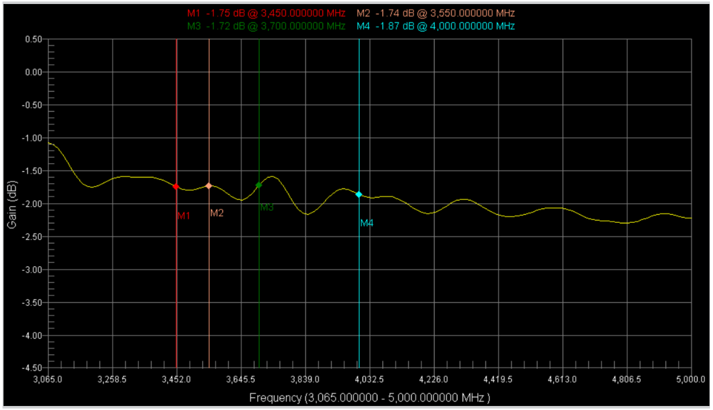
clearWave™ S500



EXTRUDED PVC .125



PVC .187

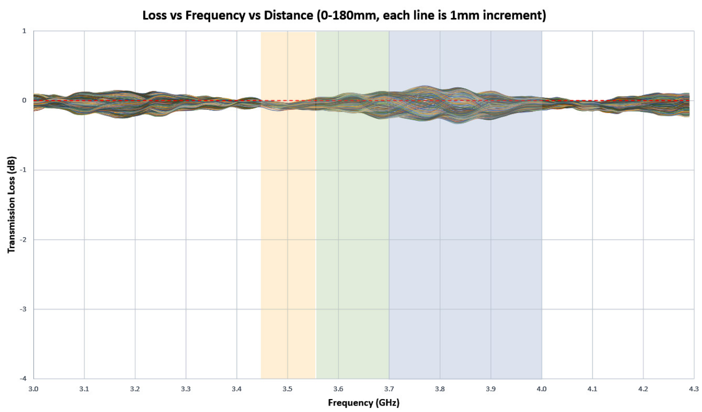


FRP .250 (for reference only)

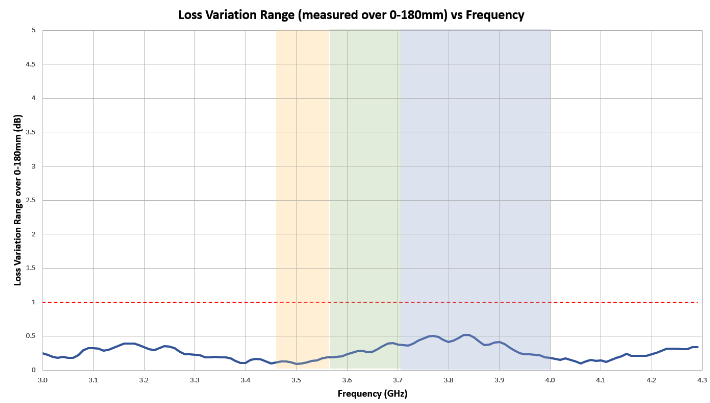
ConcealFab® Corporation
10205 Federal Drive, Building B • Colorado Springs, CO 80908 719.599.3400 www.concealfab.com

Below is the cyclone plot for ConcealFab's clearWave™ S140 material. The blue shaded region is C-Band, the green shaded region is CBRS, and the orange shaded region is the soon to be auctioned 3.45 GHz band. The loss variation vs frequency plot shows the difference between the maximum and minimum loss value measured at each frequency over all distances tested. The average loss vs frequency plot shows the average of all loss measurements at each frequency over all distances tested. The average loss vs frequency measurement compares favorably with the Far Field transmission loss measurement. This plot is included for the clearWave™ S140 material for reference only to show the comparison and will be omitted for other materials measured.

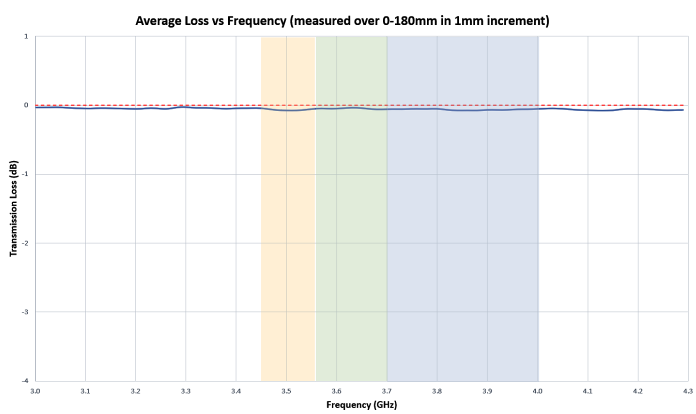
It is interesting to note on the Cyclone chart that there are frequency / distance combinations showing "gain" when the concealment material is placed in the near field in front of the antenna. This "gain" is caused by the concealment material creating a lens effect on the antenna at that specific frequency / distance combination, resulting in a distortion of the antenna pattern.



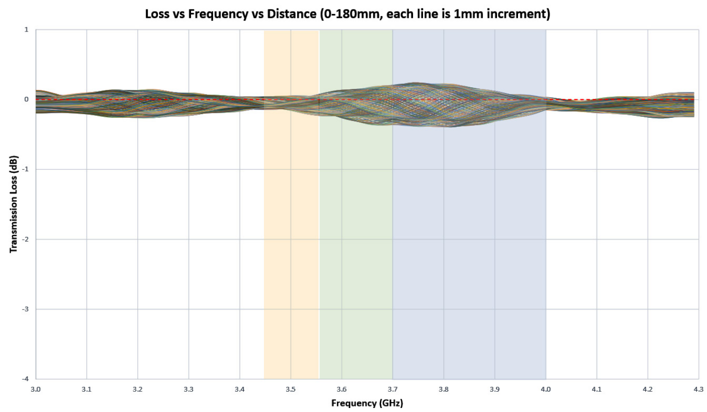
clearWave™ S140: Loss vs Distance vs Frequency (Cyclone Plot)

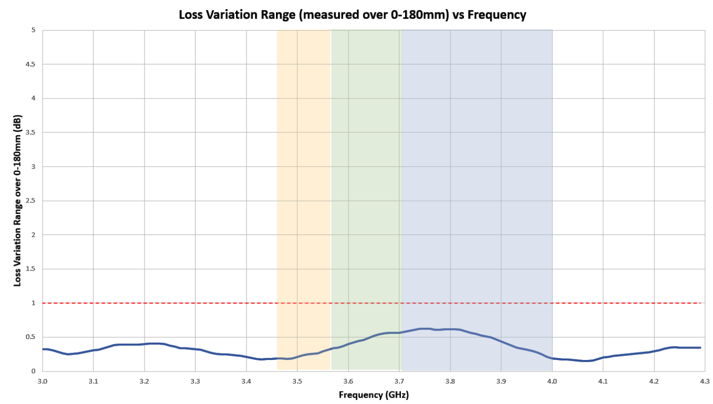


clearWave™ S140: Loss Variation vs Frequency

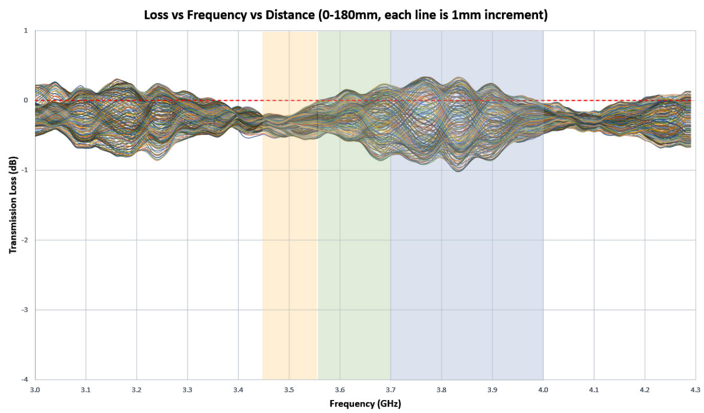


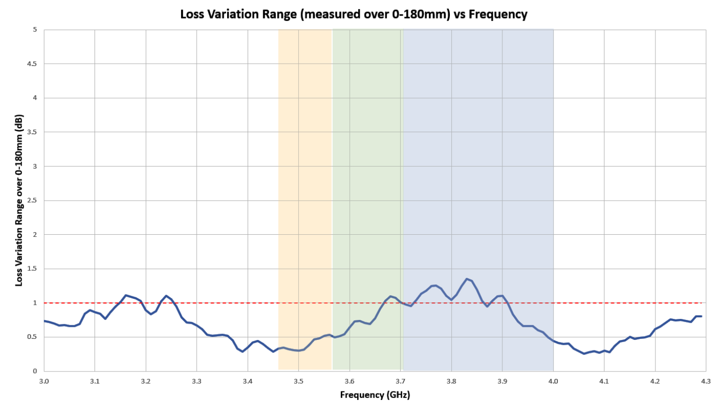
clearWave™ S140: Average Loss vs Frequency



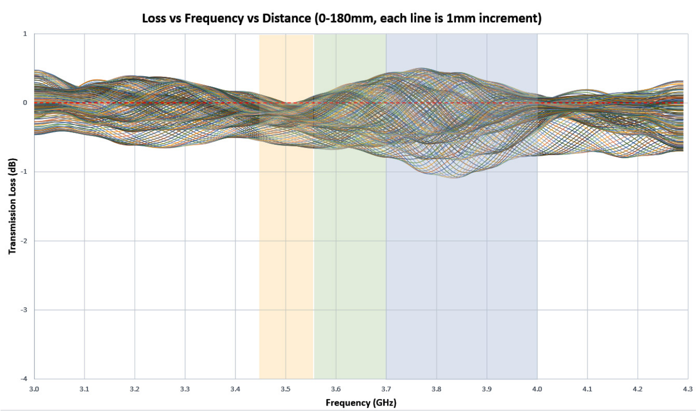


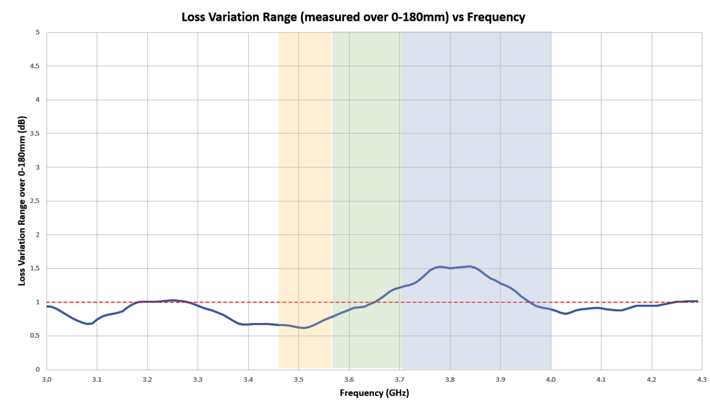
clearWave™ S240



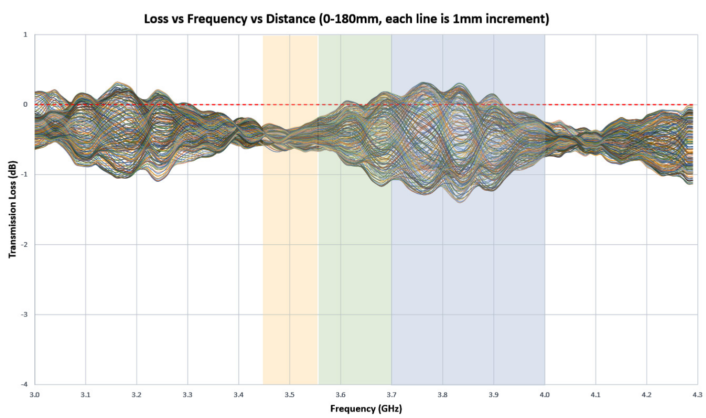


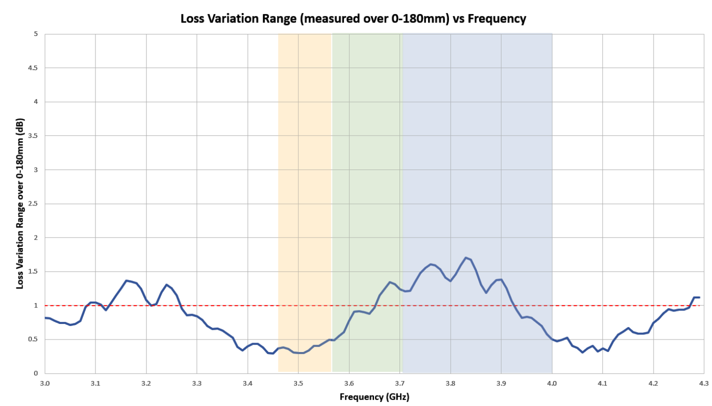
clearWave™ S500





EXTRUDED PVC .125

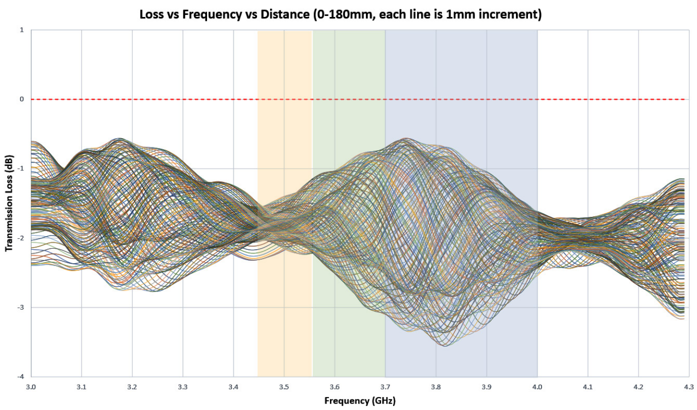


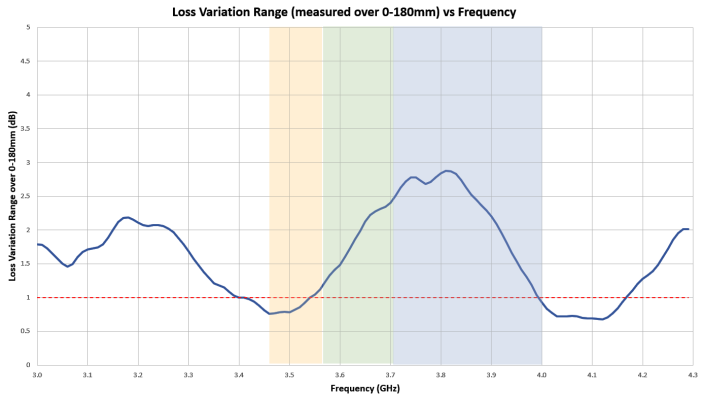


PVC .187

ConcealFab® Corporation
10205 Federal Drive, Building B • Colorado Springs, CO 80908 719.599.3400 www.concealfab.com

Updated: April 9, 2021





FRP .250 (FOR REFERENCE ONLY)

SUMMARY OF TEST RESULTS

Table 2 summarizes the results for both Far Field and Near Field transmission loss measurements. Based on the results the concealment materials are assigned an RF performance ranking for the CBRS/C-Band frequency range. The standard materials used by ConcealFab for concealment solutions range from excellent to fair performance. FRP has poor performance and should be avoided for CBRS/C-Band concealments.

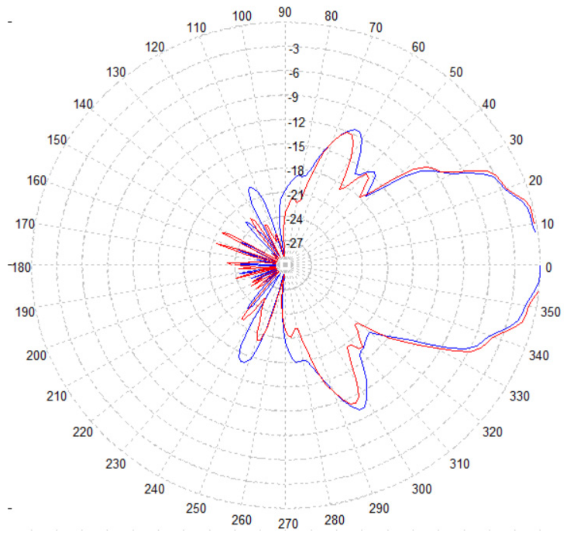
MATERIAL	AVERAGE LOSS AT 3.45 – 4.0 GHZ (DB)	MAX LOSS VARIATION AT 3.45 – 4.0 GHZ (DB)	RF PERFORMANCE RANKING
clearWave™ S140	0.10	0.50	Excellent
clearWave™ S240	0.10	0.70	Excellent
clearWave™ S500	0.25	1.25	Good
Extruded PVC	0.20	1.50	Good
PVC .187	0.50	1.70	Fair
FRP .250 (for comparison only)	1.90	2.80	Poor

Table 2: Concealment material measurements with RF performance ranking

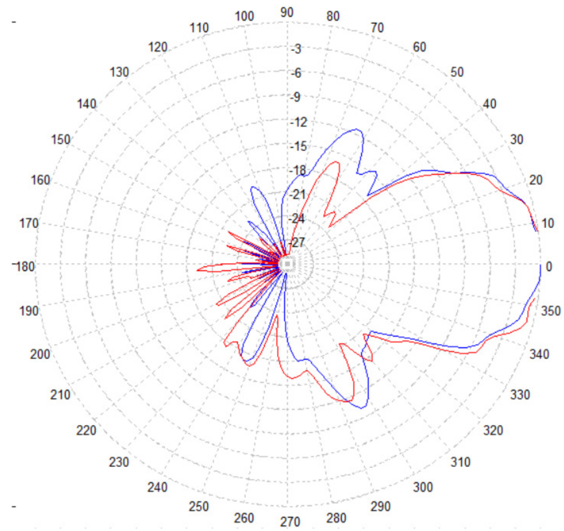
ConcealFab® Corporation
10205 Federal Drive, Building B • Colorado Springs, CO 80908 719.599.3400 www.concealfab.com
Updated: April 9, 2021

ANTENNA PATTERN MEASUREMENTS

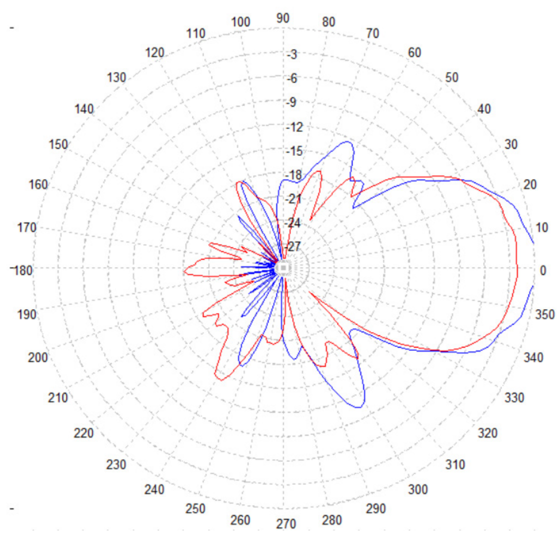
The final test for evaluating concealment materials is to evaluate their impact on antenna pattern performance. Shown below are antenna patterns measured at 3.6 GHz for clearWave™ S240 (ranked **EXCELLENT**), Extruded PVC .125 (ranked **GOOD**), and FRP .250 (ranked **POOR**). On each plot the **BLUE** trace is the baseline pattern with no material in front of the antenna and the **RED** trace is the pattern with the concealment material in front of the antenna.



clearWave™ S240



EXTRUDED PVC .125



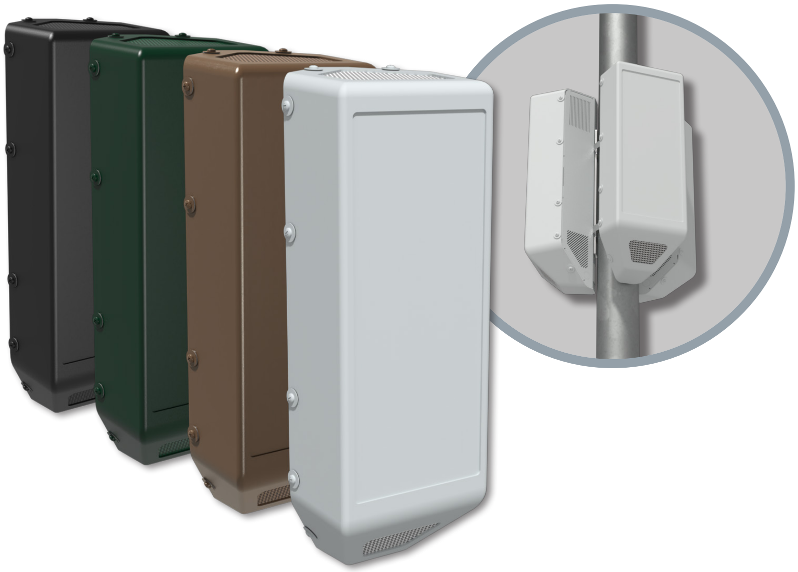
FRP .250

The clearWave™ S240 has minimal impact to the overall antenna pattern. The Extruded PVC .125 also has very low impact to the mainlobe, some reduction in the sidelobes, and slight growth in the backlobes. The FRP .250 has a significant degradation with 2-3 dB of loss in the main lobe and increased backlobes indicating significant reflected energy. This antenna pattern data confirms the rankings of the concealment materials and reinforces that FRP should not be used for CBRS/C-Band concealments.

ConcealFab® Corporation
10205 Federal Drive, Building B • Colorado Springs, CO 80908 719.599.3400 www.concealfab.com
Updated: April 9, 2021

CONCEALFAB CONCEALMENT SOLUTIONS

ConcealFab has extensive experience designing concealments for the wireless industry. In addition to meeting RF requirements, concealment solutions must also be designed to meet environmental requirements, structural integrity, and thermal performance. ConcealFab has the engineering expertise to design concealment solutions needed for CBRS / C-Band deployments. ConcealFab's investment in RF testing capability allows new concealment solutions to be tested in-house for rapid evaluation and prototyping. The following section shows examples of the concealment solutions suitable for CBRS / C-Band deployments using the materials tested in this report.



MODULAR SHROUDS

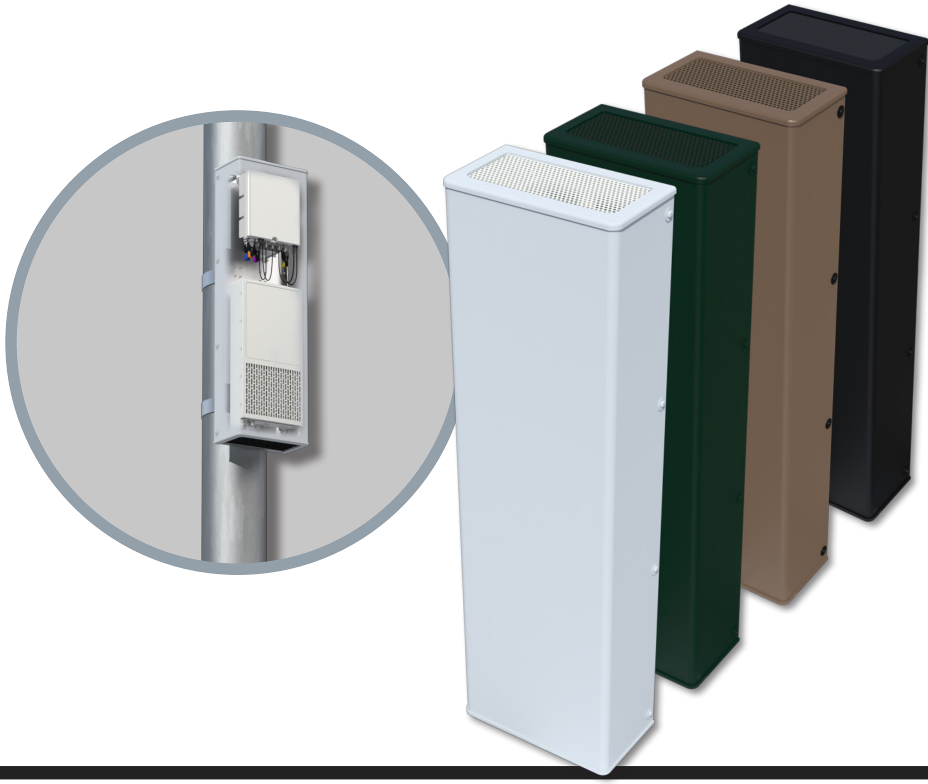
ConcealFab's Modular Shrouds are enclosures designed to cover the top, bottom and sides of a CBRS/C-Band integrated radio to hide cables and mounting hardware from view. Vent holes are included in the enclosure design to allow air flow across the radio heat sink fins for cooling. The enclosure includes a vacuum molded plastic frame with clearWave™ S140 or clearWave™ S240 material in front of the radiating portion of the integrated radio.

POLE TOP CONCEALMENTS

Pole Top Shrouds are produced using ConcealFab's Extruded PVC .125 material with cut-out sections allowing air, to flow to enclosed radio equipment. The cut-out sections are covered with perforated PVC panels that permit air, but are small enough to exclude insects from entering the enclosure. Pole Top Shrouds provide a functional yet aesthetically pleasing enclosure to house a variety of sub-6 GHz radio equipment on a variety of pole types.

MID POLE "PHOENIX" CONCEALMENTS

ConcealFab's "Phoenix" concealment can be manufactured using either clearWave™ S140 or clearWave™ S240 material to house CBRS/C-Band and mmW radio equipment in an enclosure that resembles a standard sub-6 GHz panel antenna. This shape allows operators to remove an existing sub-6 GHz panel antenna and replace it with a concealment that contains upgraded radio equipment.



VERTEX CONCEALMENT POLES

The Vertex portfolio is a multi-operator / multi-technology solution designed to house a variety sub-6 GHz and mmW radio equipment. Vertex poles include a power bay at the bottom with multiple radio equipment and antenna bays above. Panels manufactured from clearWave™ S500 are used to cover the antenna bays. The pole's clean aesthetics, custom luminaire, and smart city functionality make it an ideal solution for hard-to-permit locations.