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Araştırma Makalesi / Research Article

Mobil Haberleşme Combo Antenleri için Genişband Elektromanyetik Sönümlendirici

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Anahtar kelimeler
5J; 4J; 3J; Elektromanyetik Dalga Sönümleme; Baz İstasyonu; Mobil Haberleşme.

Özet

Mobil Şebeke İşletmecileri (MŞİ) farklı jenerasyon mobil teknolojilerinin farklı sıklık aralıklarında düzgün çalışmasını sağlamak zorundadırlar. Öte yandan, elektromanyetik (EM) kirlilik, ki daha çok mobil telefonlar ve mobil baz istasyonları tarafından kaynaklanır, toplumda sağlık kaygıları yaratmaktadır. Bu sebeple, MŞİler birçok anten çubuğunu tek bir radomeda saklayan combo antenleri kullanmaktadırlar. Bu çalışmada, araştırmacılar mobil şebeke baz istasyonu combo antenleri için genişband bir elektromanyetik sönümlendirici önermektedirler. Araştırmacılar bunun için çok katmanlı Jaumann sönümlendirme (JS) ve Salisbury ekranlama prensiplerini mikrometrik ve milimetrik grafit ve nonametrik karbon siyahı malzemeleri üzerine uygulamıştır. Buna ek olarak, ileri teknoloji gümüş ve nikel kaplanmış seramik kürecikler de sönümlendirici kalınlığını azaltmak üzere EM saçılımını arttırmak ve sönümlenmeyi iyileştirmek için kullanılmıştır. Son olarak, gümüş kaplı naylon kumaş da salisbury ekranlamasının en yenilikçi şekli ile sönümlendiriciye dik iplikçiklerle yerleştirilerek ısınma sorununu çözmüştür. Laboratuvar testlerinden sonra, sönümlendirici sahada test edilmiştir. Doksan milimetre kalınlığındaki bir sönümlendirici uygulaması istenmeyen radyo frekans (RF) sinyalini mobil şebekenin çalışmasını engellemeden ve anten yayınım şeklini değiştirmeden 18 dB azalmiştir. Bu tip bir sönümlendirici istenmeyen elektromanyetik dalgaların yayılmasını engellemeye yardımcı olabilir ve bütün mobil şebeke RF gürültüsünü ve EM kirliliğini her iki yayın yönünde de azaltabilir.

A Broadband Electromagnetic Absorber for Mobile Telecommunication Combo Antennas

Keywords
5G; 4G; 3G; Electromagnetic Wave Absorption; Base Station; Mobile Telecommunication.

Abstract

Mobile network operators (MNOs) have to sustain the interworking of different generations of mobile technologies in different frequency bands. On the other hand, electromagnetic (EM) pollution, which is caused mainly by the mobile devices and mobile network base stations, also raises public health concerns. Thus, MNOs use combo antennas, which encapsulate multiple antenna rods in a single radome. In this study, the authors propose a broadband electromagnetic absorber for the mobile network base station (BS) combo antennas. They have merged the multi-layer Jaumann absorber (JA) and Salisbury screen principles along with the merits of off-the-shelf micrometric and millimetric graphite and nanometric carbon black. Advanced silver and nickel coated nanometric cenospheres were also used to decrease the absorber thickness and to improve EM scattering and absorption. And finally, silver fabric was used as the salisbury screen with novel perpendicular threads into the absorber body as heat sink. After the laboratory tests, the absorber has also been tested in the field. The application of the absorber has reduced the unwanted radio frequency (RF) signal around 18 dB in the tested frequency range without any network affecting disturbances or without any noticeable antenna pattern deformation with only a thickness of ninety millimeters. Such an absorber may also help containing the unwanted spread of electromagnetic waves from BS antennas; and, in return, decrease the overall mobile network RF noise and electromagnetic pollution both in uplink and downlink frequency bands.

1. Introduction

The mobile telecommunication has become an essential part of our daily life. With the increasing number of users, the mobile network operators (MNOs) have to use more mobile base stations (BS). The mobile technology has also advanced parallel to increasing demands of users. Thus, MNOs have deployed newer mobile technologies over the existing ones further increasing the number of BS antennas broadcasting in different spectrum bands [1]. On the other hand, this increasing use of wireless technologies has raised public health concerns [2-14].

There has been extensive research performed on the EM shielding and absorption [7-21]. Compact devices with multiple EM transmitters are available, and there can be EM interferences between them and with other devices. So, it becomes more important to contain the unwanted signals, and the EM absorbers gain popularity [9].

In our BS case, the urban sites are generally co-located with other MNOs. MNOs also have to use more than one mobile technology because of financial, regulatory, and compliance reasons. Therefore, there are clusters of antennas in each urban site. These clusters may interact with each other and with other antennas on different sites negatively affecting the performance of the overall mobile radio network.

The MNOs use different technologies in different parts of the spectrum. A single BS antenna does not necessarily cover the entire spectrum, and in general, different antennas are used to broadcast in different bands. For these reasons, the number of antennas per urban site dramatically increases. So, the MNOs use combo antennas, where three or more antenna pairs are encapsulated within a single radome. In order to avoid these disruptive interactions, EM absorbers can be used to limit the spread of unwanted EM signals. Such an EM absorber should, therefore, be able to operate over the range of all those frequencies that the combo antenna operates [1].

Materials with high enough complex dielectric coefficients are preferable for the absorption of the electromagnetic (EM) energy and for converting it into heat. These materials are used for wide-band EM energy absorption applications such as in anechoic chambers [22]. But in mobile BS case, there are different constraints for an EM absorber such as wind load, weight, thickness, and cost.

In this study, authors propose a broadband EM absorber, which can operate with multiple rod combo antennas and upcoming massive multi-input multi-output (MIMO) 5th generation mobile telecommunication antennas without overheating.

2. EM Absorption

There are two fundamental loss mechanisms in shielding theory: reflection loss and absorption loss. An EM plane wave arriving on a uniform slab obstacle can undergo reflection, absorption, and transmission. When such a plane wave comes across the slab, the transmitted and the reflected parts of electrical and magnetic components are the same [7]. But there is a serious difference here to note that the primary transmission of the magnetic component occurs at the initial interface while the primary transmission of the electrical component occurs at the final interface. In other words, it is much easier to reflect the electrical component in the first boundary, and that makes dielectric absorption not an easy task, at all.

2.1 Magnetic and dielectric loss mechanisms

The electromagnetic radiation in mobile telecommunication spectrum can be absorbed by its dielectric and magnetic components. The absorber domain should be designed in order to allow the EM waves in, and attenuate them as the waves penetrate further. The waves will have propagation constant in the absorber domain as Equation 1:

$$\gamma = (j\omega\mu^* (\sigma + j\omega\varepsilon^*))^{1/2} \qquad (1)$$

where μ^* is the magnetic permeability; ε^* is electrical permittivity; σ is the conductivity (1/m or "mhos/m"); ω is radial frequency, $\omega = 2\pi f$ (f frequency in Hz) [7]. The main factors affecting the absorption of the EM waves are the absorber domain complex permittivity ($\varepsilon^* = \varepsilon' - \varepsilon''$), the complex permeability ($\mu^* = \mu' - \mu''$), and EM impedance match, which is related with former two factors and the conductivity σ [7]. The real parts of the complex permittivity and permeability represent the energy storage capacity of the absorber domain, whereas the imaginary parts show the loss of electric and magnetic energy in the absorber domain [7]. Therefore, the ratio of imaginary to real part for the absorber material's permittivity and permeability shows the capacity of absorption for electric and magnetic parts, respectively.

2.2Salisbury screen mechanism

The Salisbury screen mechanism is a narrowband applicable shielding method working with the principle of out of phase cancellation of the incoming wave through a single absorber layer followed by a good conductor. In order to have the reflecting wave to be in totally out of phase with the incoming wave, the thickness of the absorber should be carefully arranged to the quarter wave effective inside the absorber. The propagating wave within the absorber will have the wavelength as such Equation 2:

$$\lambda = \frac{\lambda_o}{\sqrt{|\varepsilon||\mu|}} \tag{2}$$

where λ_o is the wavelength in free space, and $|\varepsilon|$ and $|\mu|$ are the modulus of permittivity and permeability of the absorber material, respectively [10]. This mechanism can be applied within the range of 0.25-0.30 λ in practical applications with dielectric absorbers [10, 22].

2.3 Jaumann absorber mechanism

The JA uses the mechanism of multiple layers of absorbers tuned to return minimum reflection. The wave would attenuate both by the transmission through multiple absorber layers as well as the multiple in-bound reflections within these absorber layers. Another important property of JA mechanism is that the layers are arranged with increasing dielectric values focusing waves into the axis perpendicular to the absorbers' axis. This is a great benefit for the absorption of waves with different polarizations and incoming directions and provides a wider absorption range [10].

The JA layers are generally followed by a good conductor and the total thickness is arranged for the effective quarter wave length depth in order to benefit from the Salisbury screen mechanism. For a designated range of frequencies, this thickness can be arranged for the lowest operating, or the dominant frequency of operation of the Jaumann absorber, or any other preference in design [10, 23].

3. Material Development of Dielectric Absorbers

Our design steps included a narrowband absorber development followed by a broadband absorber development. We preferred a dielectric only absorber design in order keep our design simple and our cost low in order to fulfil our constraint set for the telecom mobile radio network.

3.1 Narrowband Absorber Development

We have chosen polyester free form acoustic sponge with open-cell structure as our matrix material. This material has the following advantages: low cost; ease of reach; easy to shape; easy to impregnate, and most importantly it comes in almost all sizes.

The designated frequency range greatly affects the size and dimensions of a narrowband absorber [23]. We have chosen micrometric, millimetric, and nanometric carbon as our base materials having good properties for impregnation. A micrometric and millimetric graphite (G) and nanometric carbon black (CB) mixture is prepared using a water-based binder; and, the matrix material is soaked with this mixture. So, having two different carbon materials with different properties, one can choose between the high thermal and electric conductivity of the graphite, and radiation absorption and electrical conductivity of carbon black [24].

We have made lab measurements on a Rohde&Schwarz ZVA 40 vector network analyser (VNA) using ridged microwave antennas from 2.3 to 2.6 GHz band with sweep on 1 MHz steps with time domain gating (Figure 1). The measurements were all done in close proximity to resemble our field test conditions. Time domain gating used according to VNA vendor specification in order to avoid multipath reflections and wrap around energy release.

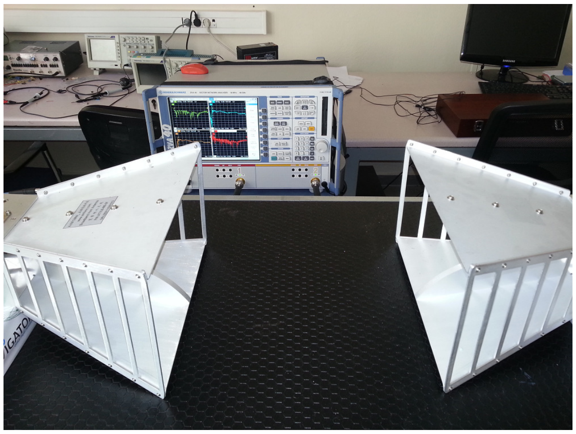

Figure 1. Measurement set-up with R&S ZVA 40 vector analyser with ridged horn antenna pair.

Using matrix sponge with planar and pyramid shapes and different mixtures, 1 set (5 pieces) and 1 set with Chebyshev pyramids (3 pieces) with increasing loading were prepared, respectively. The loading ratios for the planar set were as follows: 1%-0%; 1.5%-0%; 1%-1%; 1.5%-1%; 2%-1%, CB-G by weight. The loading ratios for the pyramidal set were as follows: 1%-0%; 1%-1%; 2%-1%, CB-G by weight. The pyramid shapes had λ/4 height tuned for 2.45 GHz at 3cm with 1 cm base thickness.

The first set has provided the benefits of a gradual dielectric change while the second set provided the benefits of gradual surface change. S_{11} and S_{22}values represent the reflection amounts back to transmitter while S_{12} and S_{21} values represent the transmission amounts in Figure 2, Figure 3, and Figure 4 [9,17]. The absorption (A) is related with the transmission (T) and the reflection (R) with the equation: A=1-R-T, where R and T can be determined by $R=|S_{11}|^2$ and $T=|S_{21}|^2$, respectively [17]. So, one should minimize both the reflection and the transmission values at the same time [25].

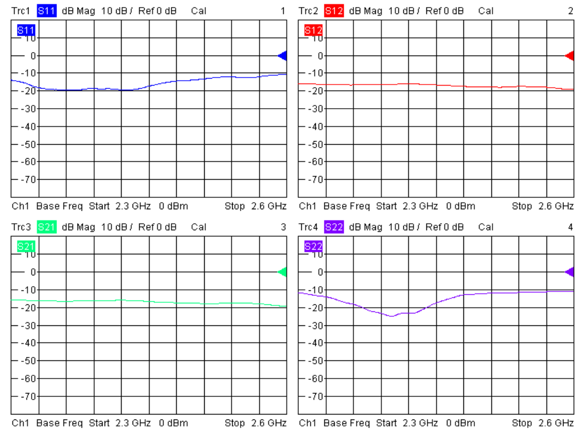

Figure 2.1% CB loaded flat layer.

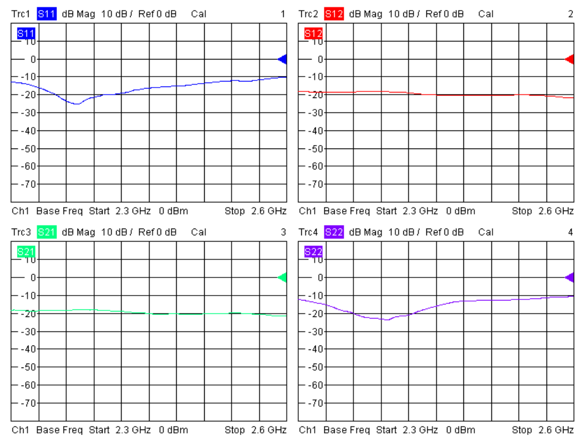

Figure 3.1% CB and 1% G loaded flat layer.

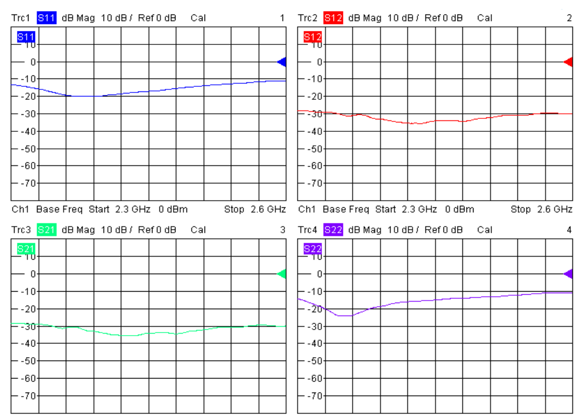

Figure 4.2% CB and 1% G loaded flat layer and Chebyshev pyramid structure together.

The 1% CB loaded flat layer (Figure 2) was approximately 3 dB better on the average than the nominal free transmission in S_{11} and S_{21}. The 1% CB and 1% G loaded layer (Figure 3) was approximately 5 dB better on the average than the nominal in S_{11} and S_{21}. The mutual effect of Chebyshev pyramids together with a flat layer was approximately 15 dB better on the average than the nominal in S_{21} when both were 2% CB and 1% G loaded (Figure 4).

We have tested the Chebyshev pyramid model in a 5 kW commercial 2.45 GHz operating microwave (MW) oven.The material has shown good load properties minimizing the reflections back to magnetron. This test also demonstrated the importance of the homogeneity of the materials based on the observations of the temperature distribution after a short exposure (Figure 5). Non-homogeneous parts were hotter and one hot spot has also suffered thermal runaway. The commercial MW oven has also been used to test and the load/impedance match of the overall model.

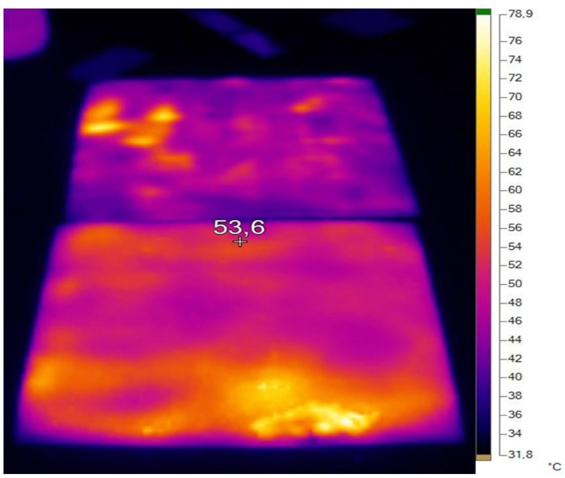

Figure 5. Thermal picture of pyramid absorbers in bottom-up formation in commercial MW oven after a short exposure (temperature scale in degrees Celcius).

3.2 Broadband Absorber Development

For a good broadband absorber performance, good attenuation should be attained while keeping a gradual change of dielectrics to avoid reflection of the electrical field in the designated frequency band. Having these two constraints in mind, a multilayer strategy and gradually changing dielectric constant with depth strategy was chosen at the same time. Other granular materials were used either to maximize the attenuation of the wave or to increase the scattering of the wave within the absorber matrix.

Combo antennas range from 700 MHz up to 3.5 GHz and can support 2nd, 3rd, and 4th generation mobile telecommunication technologies, concurrently. This can readily explain the need for the broad band performance. Another issue in the absorption performance is the source to absorber distance. Our absorber antenna distance falls in the near field range in our case.

Multiple layers with gradual change of dielectrics with nanometric CB and micrometric and millimetric graphite are used with our initial experience. Silver and nickel cenospheres were added between the layers to increase the scattering and increase magnetic attenuation, respectively.

CB provides attenuation across all frequencies. Its nanometric scale does not increase the conductivity of the composite material significantly, whereas micrometric and millimetric graphite pieces may add up to the conductivity, if used in high amounts. These two materials are used in layers in increasing amounts. Stacking the different layers, the best performance has been tuned by the help of commercial MW oven reflection measurements both for impedance match and minimum reflection. As a final surface, silver coated nylon mesh fabric was used as a flexible conductor with a shielding effectiveness of 66 dB at 900 MHz according to IEEE STD-299 (Figure 6).

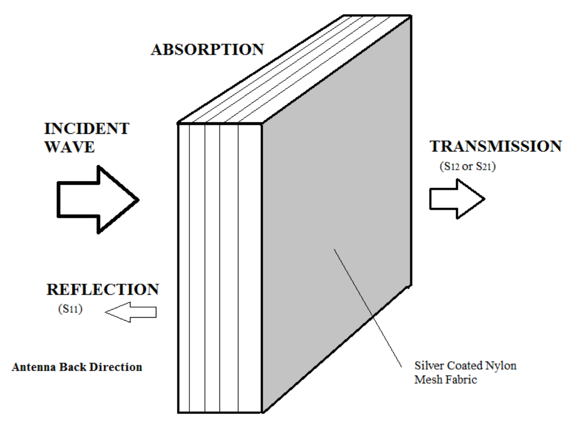

Figure 6. Illustrative absorber and its cross section with the mentioned material and their designated location.

The final absorber consisted of four layers: one flat (1% CB), two pyramidal layer (pyramids facing each other, 1%CB-1%G to 2%CB-1%G), and the final one cast with silver mesh fabric (2%CB-1%G+cenospheres+silver coated nylon threads perpendicular to wave front) (Figure 7).

Figure 7. The second layer and the fourth and final layer left-to-right.

3.3 Measurements and Field Tests

The final prototype was measured with the same set-up. The S_{11} was around 20 dB and the S_{21} was around 55 dB on the 1-10 GHz range (Figure 8, Figure 9). The shielding performance was around 20-30 dB less than expected because of the near field positioning compared to IEEE STD-299 values for the silver coated mesh fabric [25].

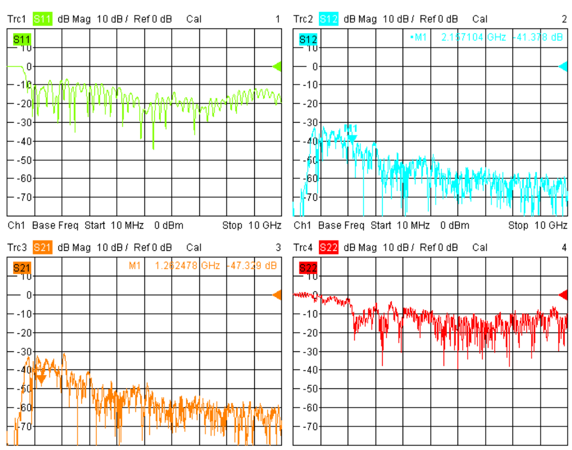

Figure 8. The S-parameter measurement of the prototype.

Then the prototype has been tested in the field with an MNO, which wanted to test the absorber in the front lobe of the antenna in order to evaluate the performance under harder conditions. The absorber was positioned on the radome itself without any space in between. The voltage standing wave ratio (VSWR) performance was used to assess the load match. The measurements were recorded with drive tests before and after the montage of the absorber to the antenna.

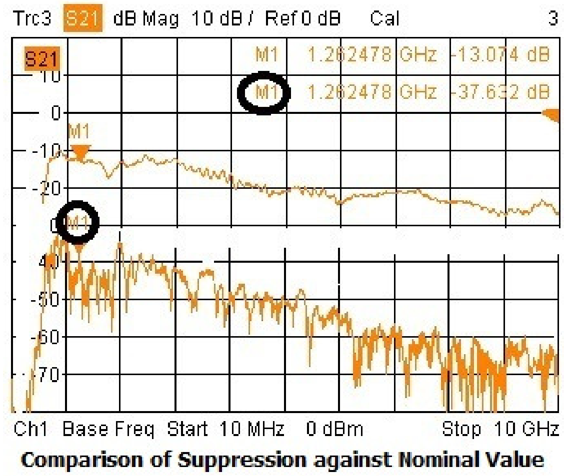

Figure 9. Measurement marker at 1.26 GHz with 24.5 dB suppression.

The initial test drive was taken without any absorber (Figure 10) to observe normal propagation of the signal. The average suppression of the front lobe of the antenna was around 18 dB (12-28 dB) in 900 MHz - 1800 MHz - 2150 MHz range.

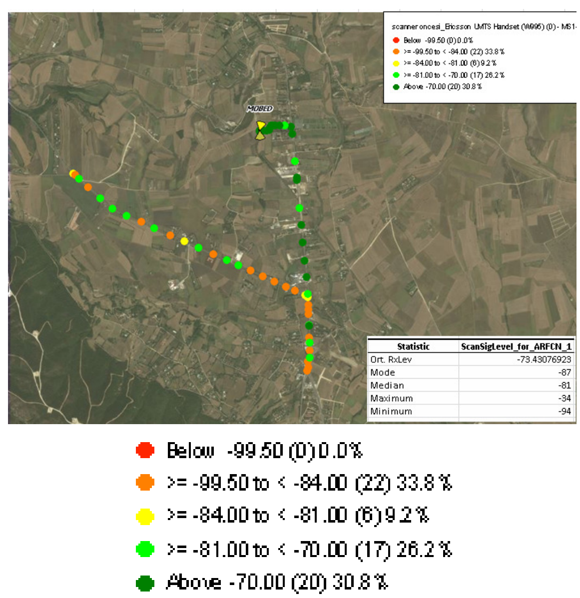

Figure 10. The first drive test to measure nominal signal strength and its related percentage in colour legend.

This performance was way over the mobile operator's 6 dB expectation (Figure 11). There was not any VSWR related alarm on the BS operation and maintenance system.

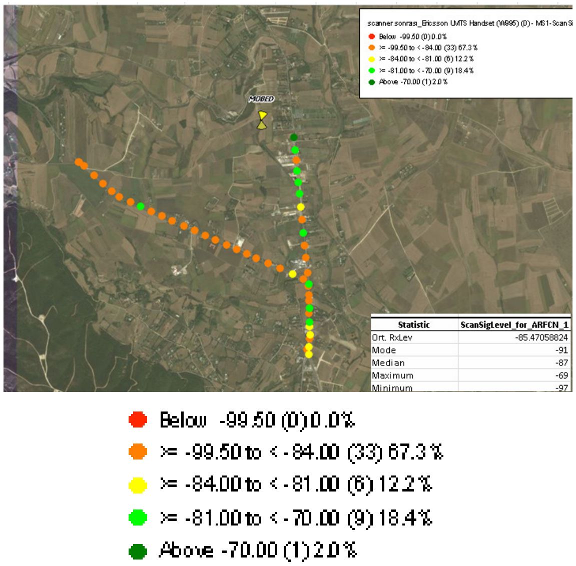

Figure 11. The second drive test results to measure the signal strength through the absorber and its related percentage in colour legend.

4. Results and Discussion

Open cell polyester matrix with CB and graphite of appropriate size was an efficient and sufficient solution for suppressing the unwanted back and side lobe signals of mobile telecommunication combo antennas. Open cell structure of polyester acoustic sponge was easily impregnatable with materials up to 100 micrometer without loss of homogeneity. Our selection of CB and graphite provided us with the availability of off-the-shelf industrial materials. Although this combination does not necessarily give the best absorption per thickness performance [7-10;15-17], it was cost-wise very successful together with the matrix selection. The disadvantage in thickness was partially related with the open cell structure of our matrix since even after loading the matrix still contained void areas. If loading ratios were increased even higher, then there would be more of the inhomogeneity related issues. Thus, we have utilized nanometric nickel and silver coated cenospheres in between layers to increase the scattering and magnetic attenuation to contain the thickness related issue.

The absorber layers were light and flexible. The final layer was supported with a silver coated nylon fabric to resemble the good conductor effect. The total multilayer structure still kept its flexibility, though. This was a great advantage over the wider area of combo antennas’ surfaces.

The field performances were slightly less than the laboratory measurements. There are two details to be mentioned. Firstly, the shielding and absorption performances degrade in very close proximity [17]. Secondly, the antenna absorber interaction was in the near field, and one could expect capacitive effects. Thus, we believe capacitive effects and frontal lobe testing could have lowered the field performance with higher power output of the antenna.

The field test also revealed three distinct advantages. Firstly, the absorber can withstand even the front radiation of telecommunication antenna without any thermal runaway. The second advantage is that a lower noise level will either improve the radio network quality or increase the frequency reuse pattern, on which mobile network planning is mainly based. The third and final one is in the uplink telecommunication channel part, where unrelated mobile terminal signals will no longer be received by the back lobe of the antenna. In 3rd and 4th generation mobile radio technologies, the absorber would also lessen the unnecessary breathing cell feature utilization. This, in turn, serves the customer masses in front of the antenna with a spectrum efficient focus providing higher data throughput by the second advantage. In the 5th generation mobile telecommunications, the absorber can handle the immense power of massive MIMO antennas and suppress the backlobe EM pollution.

5. Conclusion

As a result of this study, one may deduct that the mobile radio networks may benefit an average noise suppression of 9-18 dB by the mass utilization of such absorbers.

The prototype lessens the mobile telecom industry's one of the hardest challenges in radio network optimization. It can be used for optimum performance in urban areas between coverage and quality in all available spectrums concurrently, where 80% of the whole data and speech traffic take place.

For our future studies, we are planning to investigate different ways of utilizing nanometric cenospheres of nickel, copper and silver coatings [22]. Ferromagnetic material addition to the absorber looked promising to absorb the magnetic component of the antenna radiation and to further decrease the overall energy spread on back-lobe [26].

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