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Citation: Appl. Phys. Lett. 108, 113502 (2016); doi: 10.1063/1.4944042
View online: http://dx.doi.org/10.1063/1.4944042
View Table of Contents: http://aip.scitation.org/toc/apl/108/11
Published by the American Institute of Physics
Mantle cloaking for co-site radio-frequency antennas

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(Received 26 January 2016; accepted 2 March 2016; published online 15 March 2016)

We show that properly designed mantle cloaks, consisting of patterned metallic sheets placed around cylindrical monopoles, allow tightly packing the same antennas together in a highly dense telecommunication platform. Our experimental demonstration is applied to the relevant example of two cylindrical monopole radiators operating for 3G and 4G mobile communications. The two antennas are placed in close proximity, separated by 1/10 of the shorter operational wavelength, and, after cloaking, are shown to remarkably operate as if isolated in free-space. This result paves the way to unprecedented co-siting strategies for multiple antennas handling different services and installed in overcrowded platforms, such as communication towers, satellite payloads, aircrafts, or ship trees. More broadly, this work presents a significant application of cloaking technology to improve the efficiency of modern communication systems. © 2016 AIP Publishing LLC.

Modern communication systems are progressively handling an ever-increasing number of services, which require radiators to broadcast information across an ever broadening spectrum. Consequently, communication platforms, such as mobile communication towers, satellite payloads, aircrafts, and ship trees, host an ever-increasing number of antennas within a limited space. However, antennas cannot be packed together ad libitum in a small area, for at least two reasons: electromagnetic interference among different antennas dramatically limits their functionalities, and blockage effects significantly affect their electrical (e.g., impedance matching) and radiation properties (e.g., radiation pattern shape and realized gain).1 In this letter, we show that electromagnetic cloaking,2–5 and in particular, mantle cloaking,8–16 can be used to largely mitigate the issues related to antenna packing in overcrowded platforms. The proposed idea, which is demonstrated and validated both numerically and experimentally, allows placing different antennas in deep electrical proximity (i.e., antennas are nearly touching one another, with a separation of a small fraction of the operating wavelength), without affecting their operation. The proposed solution, which is based on the design of patterned metallic sheets surrounding the antennas, may revolutionize co-siting strategies for the design of complex radio-wave platforms, allowing more services in a reduced space.

Differently from cloaking techniques based on transformation electromagnetics,2–4 which guide the impinging electromagnetic fields around the object to hide, preventing any interaction between the field and the object, scattering cancellation6,7 is based on producing a destructive interference between the field scattered by the illuminated object and the one scattered by the cloaking cover placed around it. The latter technique, thus, is particularly appropriate to cloak objects with an electromagnetic functionality, such as antennas and sensors,8 especially wire antennas.12–16 At microwave frequencies, scattering cancellation can be realized applying the mantle cloaking technique,7 based on patterned metallic sheets that synthesize the required surface impedance to support proper currents on the metasurface, which cancel the scattering from the object we want to hide.

In the following, in order to highlight the relevant potential of these concepts for radio-communication applications, we consider two closely spaced monopole antennas mounted on the same platform—see Fig. 1(a)—and operating in the Long Term Evolution (LTE) low band (790–860 MHz) and UMTS services (1900–2200 MHz), respectively. The two antennas are placed in extreme proximity of each other, with a separation distance equal to $d = \frac{\lambda_2}{10}$, being $\lambda_2$ the central wavelength in the UMTS band. The lengths of the two antennas and their radii are $l_1 = 80$ mm, $l_2 = 35$ mm and $r_1 = 5$ s, $r_2 = 3$ mm, respectively. The two monopoles have been fabricated as brass cylinders drilled in the bottom face to allow the

![FIG. 1. Photograph of the fabricated system, consisting of two electrically close monopoles working for LTE and UMTS services, respectively, in both (a) uncloaked and (b) cloaked scenarios.](image-url)
insertion of SubMiniature version A (SMA) connectors, whereas the ground plane consists of a double-sided printed circuit board (PCB) laminate (with dimensions $307 \times 307 \text{mm}^2$). In order to mitigate edge effects due to its finite dimensions, the two metallic sides of the PCB laminate have been short-circuited through a highly conductive metallic tape alongside the laminate perimeter and some vias placed around the SMA connectors. Finally, the spacing between the LTE monopole and the ground, needed to achieve impedance matching with the source, has been ensured with a spacer made of an electromagnetically transparent foam. In the scenario depicted in Fig. 1(a), both monopoles are located in the near-field of each other. However, degradation effects caused by the presence of the UMTS antenna on the LTE are expected to be smaller, due to the electrically small dimension of the UMTS radiator at the LTE operation frequencies. Conversely, the LTE antenna represents a strong scatterer for the UMTS monopole, due to its large electrical dimensions in the UMTS band. Therefore, in the following we explore an optimal mantle cloak for the LTE monopole to significantly reduce its electrical presence within the entire UMTS band.

The cloak, shown in Fig. 1(b), consists of a hollow cylinder made of vetronite (inner and outer radius are $r_{\text{in}}^\text{shell} = r_1$ and $r_{\text{out}}^\text{shell} = 2r_1$, respectively) and a metasurface consisting of three horizontal metallic strips, whose width is $a = 26.67 \text{mm}$ and separation $w = 2.6 \text{mm}$. The metasurface design has been developed using the formulas in Refs. 9 and 10, and optimizing the scattering reduction and cloaking bandwidth. The simple pattern of the metasurface and the

**FIG. 2.** SCS of the uncloaked (continuous line) and cloaked (dashed line) LTE antenna for a plane wave excitation. In the insets, it is possible to appreciate the 3D bistatic scattering cross section of the antenna in the uncloaked (left) and cloaked (right) case. The scale used for the two scattering patterns is the same.

**FIG. 3.** (a)–(c) Magnitude of the reflection coefficient at the input ports of the monopoles shown in Fig. 1 in the isolated, uncloaked, and cloaked scenarios, respectively. (d) Mutual coupling between the two monopoles in the uncloaked and cloaked scenarios. The horizontal line represents the commonly used matching threshold at $-10 \text{dB}$.
high robustness of the design to fabrication tolerances allowed us to manually engineer the three metallic strips, using high-conductivity metallic tape. The realized cloak may retrofit existing systems that can be easily added to/removed without surface friction and without perturbing its original operation. As it can be appreciated in Fig. 2, our simulations, conducted through a full-wave electromagnetic simulator\(^{18}\) for an ideal transverse-magnetic plane wave excitation, confirm that the designed cloak allows reducing the overall LTE antenna scattering by 10 dB at 2050 MHz with a broad \(-3\) dB fractional bandwidth of 20%. This significant bandwidth performance, a necessity for practical communication scenarios, is ensured by the non-negligible thickness of the cloak, as discussed in Refs. 16 and 19. The insets of the figure show the different scattering patterns in the two cases on the same scale.

In Fig. 3, we show the magnitude of the measured scattering parameters at the antenna feeds. We mark as “isolated” the scenario in which only one antenna is present on the platform. Conversely, “uncloaked” is the scenario in Fig. 1(a), in which both antennas are present, and “cloaked” refers to the scenario in Fig. 1(b), in which both antennas are present, and the LTE radiator is covered by the cloak described above. While the antennas are well matched in the isolated case, in the unclad scenario, as expected, the interaction between the two antennas is responsible for a dramatic deterioration of the impedance matching properties at the UMTS monopole port (Fig. 3(b)—dotted and dash-dotted lines), as well as a strong coupling coefficient within the UMTS frequency band (Fig. 3(d)—continuous and dashed lines). Conversely, in the cloaked scenario, we observe a restoration of the original impedance matching features of the UMTS monopole (Fig. 3(c)—dotted and dash-dotted lines), while also the mutual coupling between the two antennas is significantly reduced within the UMTS band (Fig. 3(d)—dotted and dash-dotted lines). The second additional weak resonance around 1250 MHz in the LTE reflection coefficient, in both the unclad and cloaked scenarios, is given by the presence of the UMTS antenna, whose scattering cannot be neglected any longer at higher frequencies outside the LTE band. However, this interaction does not affect the proper operation of the LTE monopole, because it occurs outside its operational bandwidth. These results prove that the realized mantle cloak is effectively able to recover the antenna impedance matching of the UMTS antenna despite the presence of the LTE antenna in very tight proximity. The LTE monopole is still properly working within its operating band, despite the presence of the surrounding cloak. This result has been achieved by designing the cloak to operate within the UMTS band while being almost transparent in the LTE one.\(^{17}\)

To further demonstrate the improvement offered by the designed mantle cloak, we show the measured radiation properties of the two antennas. In Fig. 4, we show the far-field realized gain patterns of the UMTS antenna, measured with the Satimo StarLab system. Comparing the results to the isolated case, we observe a dramatic deterioration of the far-field patterns in the unclad scenario, impacting the symmetry and exhibiting preferred radiation directions not expected in the isolated case. In the cloaked case, instead, the UMTS patterns are almost totally restored and show a good agreement with the isolated case. This is impressive, given the moderate loss of the vetronite spacer used in this
design, which highlights the wideband non-resonant nature of the mantle cloaking technique.

Analogous considerations can be made inspecting the very near-field distribution around the antennas, as shown in Fig. 5. Here near-field maps have been obtained with a raster scanning non-resonant E-field probe with both high spatial resolution and position accuracy (more details about this instrument can be found in Ref. 11). The near-zone field plots are taken on a plane perpendicular to the axis of the monopoles, at approximately half the UMTS monopole height. The near-field distributions of the electric field in the cloaked case are almost identical to the ones of the isolated case, further proving the cloaking effect. As in the far-field measurements, the bare LTE monopole acts as a director to the UMTS antenna when they are placed in ultra-tight proximity. The upper UMTS frequencies are mostly affected, where we see almost complete radiation blockage by the LTE monopole in the uncloaked case. In contrast, the cloak allows to completely suppress these effects in the near- and far-field. It is also worth noticing that the restoration effect achieved here is within a significantly wider range of frequencies compared to earlier solutions adopted in mantle cloaking designs.13–15

Interestingly, since both antennas properly operate in both the isolated and the cloaked scenarios, the designed cloak is backwards compatible with pre-existing antenna systems. This design peculiarity has two important consequences: (a) there is no need to design the cloak and the LTE monopole together, making, thus, the cloak applicable to a pre-existing monopole with same radius; (b) the cloaked LTE antenna can be approached as much as needed to an already installed UMTS radiator without affecting its performance, i.e., the cloak functionality is totally independent of the type of excitation or distance to nearby antennas.

To conclude, we have experimentally demonstrated an extremely compact communication platform for mobile communications based on mantle cloaking, composed by two tightly packed monopole antennas operating in the low-LTE and UMTS bands, respectively. Rarely explored in typical cloaking demonstrations, we have shown here by standard near- and far-field techniques the potential of the mantle cloaking technique applied to mobile communication systems. In particular, by exploiting the peculiarities of the mantle cloaking technique, we have restored the operation of an UMTS antenna that was shown to be strongly affected by the nearby presence of an LTE radiator over a broad frequency range. This demonstration has been obtained using a simple and low-cost patterned metallic cover placed around the LTE antenna. Similar solutions can be employed for other multiple-antenna scenarios, enabling numerous degrees of freedom for the design of miniaturized satellite and terrestrial radio platforms.

J.S. and A.A. were supported by the U.S. Air Force Office of Scientific Research and the National Science Foundation.

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See supplementary material at http://dx.doi.org/10.1063/1.4944042 for a more detailed description of the cloak design.
See www.cst.com for CST Microwave Studio 2014.