WHITEPAPER

Optically transparent conductive structures for wireless communication

Created in cooperation with inotec group and Bopla Gehäuse Systeme GmbH

Dr. Conrad Clauss, Head of RFID Development

Dipl. Ing. MBA Sebastian Gepp, Head of Development Printed Electronics

INTRODUCTION

It is no secret that communication has always been a key element to life itself – from the very basic concept to the prerequisite of working societies.

In our modern world, not only humans (and animals) do communicate with each other but also do entities, devices, things. In addition, nowadays, no physical connection between the communication partners is necessary. Instead, communication is done via the air interface – devices can communicate directly over short distances or, via intermediate hubs over larger distances. Wireless communication has become an integral part of our lives – so far, that a poor cell phone reception automatically generates annoyance. On the other hand, we don't want to be reminded of our need to be connected all the time – we don't want to see cell phone towers, routers, signal booster, etc. all around us all the time. The technology should be hidden or should blend in well with the surroundings. Here, we present a technology that can be used to hide antennas for wireless communication in plain sight. These transparent antenna structures can be placed on windows or displays without obscuring the view or be applied to any item so that the communicating part remains (almost) invisible.

Within this report, we would like to address the following aspects:

- Introduction of the technology behind transparent antennas for wireless communication
- Application as active transceiver antennas for wifi, cell phone or tv/radio
- Usage as passive RFID transponder antennas
- Advantages of transparent antennas and possible use cases/market sectors

The underlying technology is not based on any newfound material with exceptional properties, but rather utilizes the human visual perception to render the conductive structure almost invisible. To be precise, the functional part consists of a metal mesh grid of extremely fine copper wires separated by distances much larger than the diameter of a single wire. The typical dimensions of the structures used for the devices presented here are wire diameters of approx. 5 µm and mutual wire distances of approx. 100 µm until 1000 µm, depending on application.

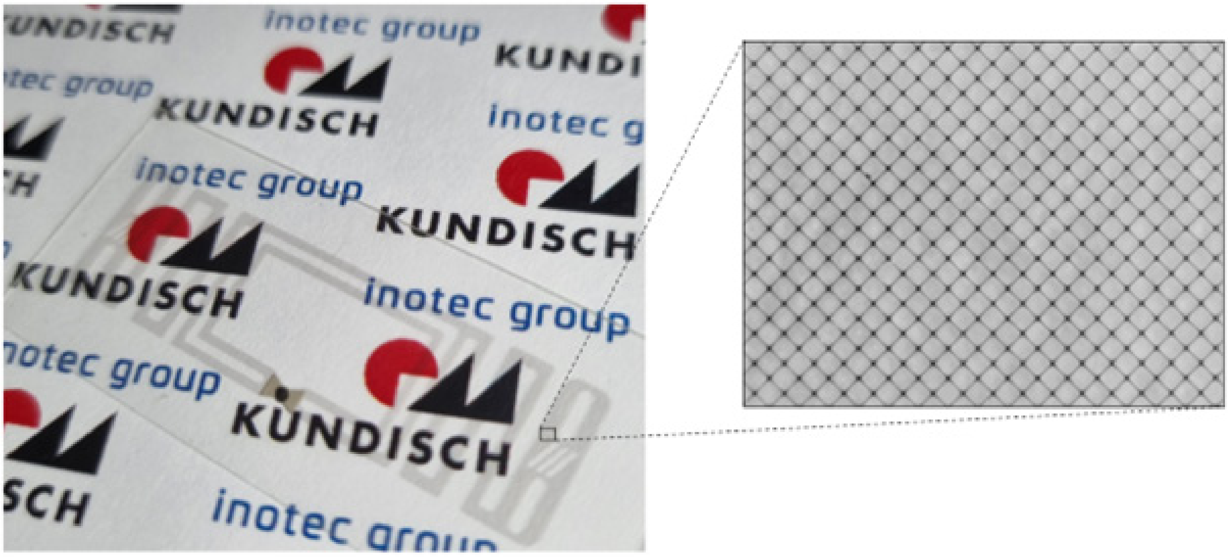

Fig. 1: Transparent conductive structure on top of a printed paper (left panel) and highly enlarged view of the metal mesh grid (right panel).

With this configuration the metal mesh grid becomes almost invisible. Against light backgrounds, the conductive layer appears slightly grayish, but in front of darker or just colored backgrounds, the mesh grid is nearly imperceptible. As a matter of fact, an optical transparency in the visible spectrum of 85% until 90% is achieved with this kind of mesh grid. The Metal Mesh is complemented with a very thin layer of Carbon Nano Tubes (CNT). These are conductive and yet invisible. The presence of the CNTs is decisive for high frequency applications. This hybrid structure of Metal Mesh and CNT in any structured form via a printing and very scalable manufacturing process enables unmet transparency and conductivity with freedom of design.

Apart from good optical transparency, the electrical properties play a crucial role when it comes to functionalization of those metal mesh grids for applications in the fields of electronics and high frequency technologies. Especially for the use of these structures as antennas, a preferably low sheet resistance will result in better performance values. Here, we achieve typical sheet resistances of 0.2 Ohm/sq. Compared with the sheet resistance of a bulk thin layer of copper (approx. 0.5 mOhm/sq) the metal mesh grid value is significantly higher, but nevertheless still within the range of typical conductive inks, which are often used for printed electronics circuitry. These values are also much lower than printed transparent conductive inks such as Pedot.

For high frequency applications other aspects also have to be considered. Depending on the frequency, the metal mesh grid can behave differently. For very low frequencies the grid can be regarded as a closed metallic thin film and for very high frequencies the optical regime is reached, and the grid gets transparent. Here, we only regard cases in the radio and microwave frequency range and therefore are allowed to consider the grid as a closed surface with an effective thickness quite lower than that of a single grid wire. The resulting effective thickness is also lower than the skin depth of copper with approx. 2 µm (at a given frequency of 1 GHz). Hence, not the complete signal strength is “caught” by the antenna. Taking this, as well as the higher surface resistance into account, it is not surprising that transparent antennas do not show the same level of performance as compared to antennas made from bulk material. Although the performance may be reduced, it is still more than enough for many applications. In the case of active antennas, the performance can also be enhanced quite a lot by utilizing stacks of structured conductive transparent layers.

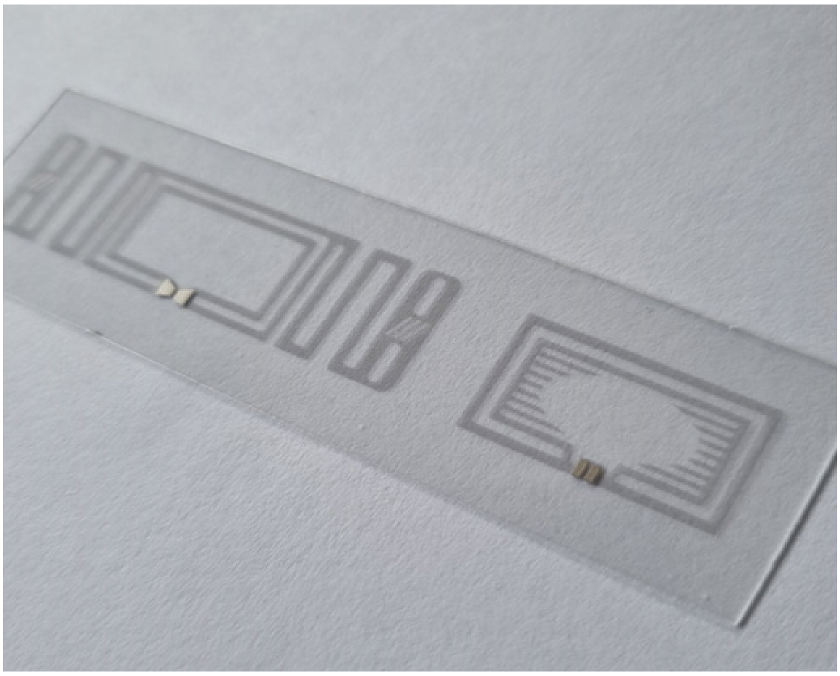

Fig. 2: Example illustration of two transparent RFID antennas.

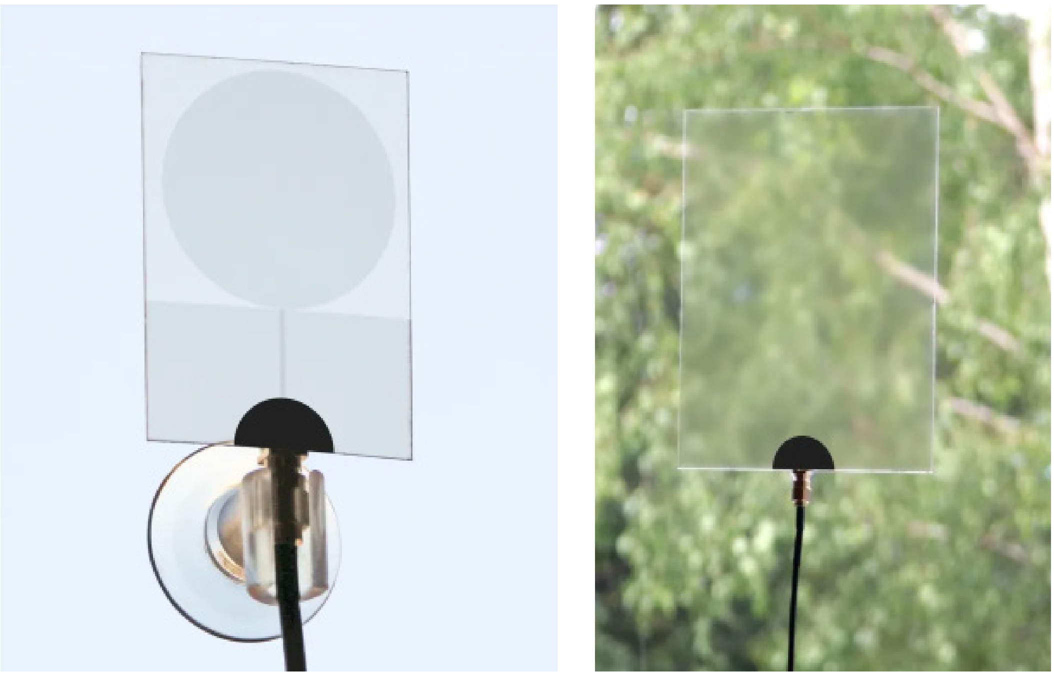

Fig. 3: Example illustration of two transparent Wifi antennas.

Active transceiver antennas

Antennas for WiFi access points, cellular network antennas, (Radio Antennas), are very present in every building. With rising demand for high bandwidth and constant data transfer these devices need to get very good, and in some cases very fast connections to the Internet. This in turn means that one needs to have many antennas in one building and best to have these antennas outside or in direct line of sight to the cellular base station. Due to the minimal invasive nature of transparent films the advantage of transparent antennas using the Metal Mesh Technology is obvious. The easiest application is to install a cellular to wifi router in your mobile home, boat or in your regular home. This can be installed as a redundant system for your home automation or office building. But in the first instance it is a gateway to the world (Internet) which is hardly seen and very performant.

Antennas made of this Technology are proven to work fine up to 8GHz, which makes them very well suited for high speed data transmission, GNSS Systems, Wifi at all frequencies and even Broadcast TV reception. These antennas are configurated to different demands as a sticky piece of plastic to a robust multilayer stack.

Passive RFID antennas

Apart from active antennas to provide a communication field, this technology can also be used for passive transceivers like RFID tags. These devices, consisting of an antenna structure and a microchip, are self-powered devices which drain the energy required from the surrounding field – effectively rendering them into passive communication devices. There exist different classes of RFID devices, which operate at different frequencies and use different communication protocols. Here, we focus on UHF RFID tags with operating frequencies around 866 MHz and 915 MHz (regionally dependent) and typical read ranges of several meters.

A direct comparison of two structurally identical RFID antennas with overall dimensions of 41 x 12 mm and outfitted with a state of the art chip (NXP UCODE 9) yield to peak read ranges of approx. 8.5 m and 4.5 m for bulk aluminum and metal mesh grid, respectively. Although this is almost a factor of two difference, a read range of 4 to 5 m

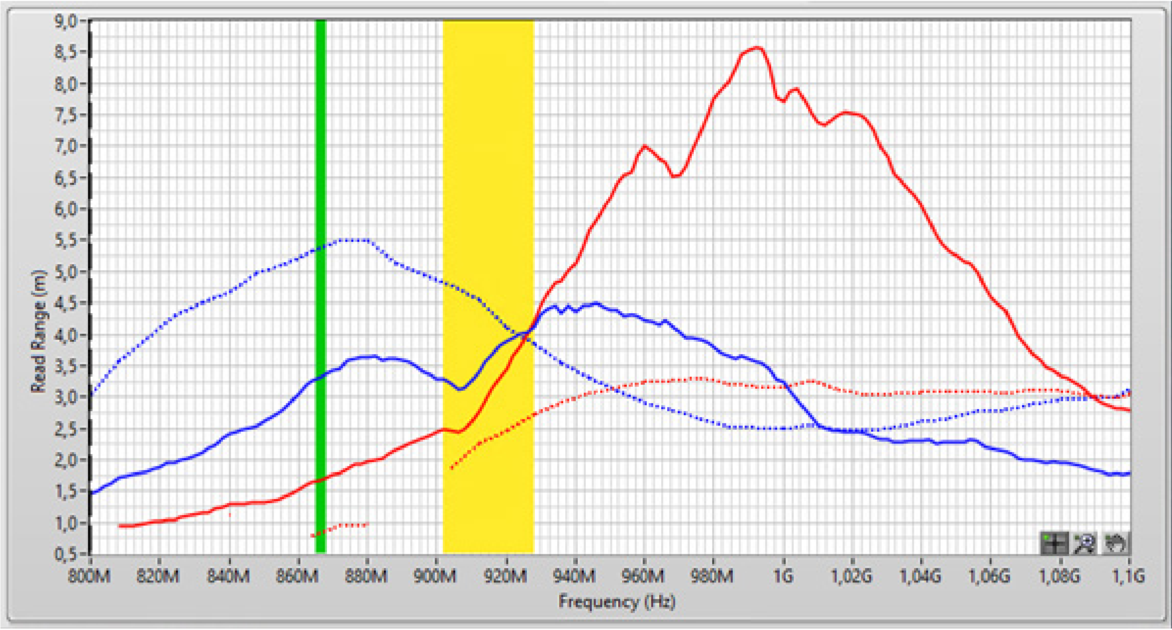

Fig. 4: Read ranges of conventional (red) and transparent (blue) RFID tags in free air (solid) and applied on a glass surface (dotted). Since this antenna was designed for the transparent material and for application on glass, the read range is optimized for that combination. The green and yellow shaded areas denote the ETSI and FCC frequency bands, respectively.

RFID devices are very often provided in the form of adhesive labels, with the functional part of antenna and chip, the so-called inlay, embedded within the label composition. Very often, the label also provides additional information about the product it is to be attached to in the form of print. For many applications, the label is composed of opaque white or colored (printed) plastic films and the inlay is therefore hidden from direct view – as is anything behind the label.

For some applications, however, it might be useful or even necessary to not obscure the view to what is behind the label or to even give the impression of no label at all whilst still being able to identify each and every device on a single item basis. For those kinds of applications, an RFID label composed of clear plastic films, optical clear adhesive (OCA) and (almost) invisible RFID antenna provides a perfect solution.

Such applications could be found in the pharmaceutical market for tagging of primary containers such like vials or syringes, in the cosmetics and beauty sector for inconspicuously labelling or for discreet tagging of wine and spirits, just to name a few examples.

Fig. 5: Transparent NFC Tags. The high conductivity and yet high transparency enables one to produce transparent NFC tags. The Frequency of 13.56MHz is met although the coil resistance is much higher than aluminium etched antennas. The transparent NFC Tags can be comparable to printed NFC Tags using silver or copper inks, if the design is taking the novel material parameters of CNT + Metal Mesh into account.

CONCLUSION

In conclusion, advancements in transparent antenna technology have a potential to revolutionize the landscape of wireless communication. By leveraging metal mesh grids combined with carbon nanotubes, these nearly invisible antennas maintain high transparency without compromising on functionality. This innovation allows for the seamless integration of antennas in environments where aesthetic preservation is crucial, like in windows, displays, and various consumer products. Whether in active transceivers for high-speed data or passive RFID applications, these antennas fulfill the growing demand for unobtrusive connectivity. The potential applications span diverse fields, from healthcare to retail, underscoring a significant step forward in merging functionality with design in modern technology.

Fig. 6: View on (and through) transparent RFID antennas.

BOPLA
A Phoenix Mecano Company

Bopla Gehäuse Systeme GmbH
Borsigstraße 17-25 I D-32257 Bünde
Tel. +49 (0) 5223-969-0 I Fax +49 (0) 5223-969-100
info@bopla.de I www.bopla.de

02/2025
English