Optimizing Performance When Integrating Multiple Antennas

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The general trend of smaller hand held devices with an increasing number of wireless functions significantly complicates the antenna selection and integration process. It is now common to have devices combining regular cellular communication capabilities with wireless LAN, GPS and Bluetooth; each system requiring its own antenna. The size reduction is a known problem for the individual performance of each antenna. Beyond the size/performance tradeoff, the interaction between the different antennas is also critical for the whole system performance. In this article we present Ethertronics' IMD (Isolated Magnetic Dipole) antenna technology. This technology enables high isolation and selectivity while reducing the antenna size and delivering higher performance. After reviewing the challenges of multiple antenna integration, the basic benefits of the IMD technology will be discussed. Then we show how the use of the IMD technology can increase the performance of multiple antenna devices while reducing development time. We will also briefly overview the next challenges facing antenna design and integration as the number of antennas increases furthermore with systems such as EVDO, MIMO, etc…

New Challenges in Mobile Devices

Over the past few years cell phones have increased their functionality beyond a basic communication device including digital cameras, sophisticated audio/video capabilities and multiple input output connections. All of these occupy prime real-estate for the antenna and impose more complicated mechanical designs. The input output ports are necessarily on the edge of the device which is the optimum location for the antenna. Cameras require an opening through the phone housing and are generally located close to the top of the phone to avoid interference with the user's fingers. Increased audio quality demands for cavity backed speakers that utilize a large volume are usually at the top of the phone. For these devices the first challenge is to develop, smaller, higher performing antennas restricted to less favorable areas of the device. The complexity is further increased by the growing number of wireless functions added to these devices which generally requires different antennas for each application. For instance a device capable of cellular communication, GPS, UMTS and Bluetooth would typically require four antennas. Integrating all these antennas into one device brings a new set of challenges. All these antennas have to cohabitate in a restricted environment and meet tough performance specifications while complying with strict regulatory ratings. Aggressive schedules also demand for antenna systems to adapt rapidly to mechanical modifications of the device that often have a significant impact on them. The high isolation, selectivity and flexibility of Ethertronics' IMD antenna technology are well suited to deal with all these challenges.

Small Antenna Limitations

The first problem that arises when limiting the size or volume of an antenna is achieving sufficient operational bandwidth. Wheeler [1] defined the following general formula that links the bandwidth of an antenna to its mode volume at a certain frequency:

$$\frac{\Delta f}{f} = K \times \frac{\text{antenna mode volume}}{(\text{radio wavelength})^3}$$

This equation shows that the bandwidth Δf over the central frequency f is linked by a dimensionless number K to the ratio of the antenna mode volume to the wavelength. The K factor is a figure of importance when, all things being equal, we want to compare one antenna to another. The K factor is related to the antenna technology and how it is designed. In Wheeler's original paper, the antennas used to demonstrate this were electric or magnetic dipoles and loops in free space. This allowed the overall antenna mode volume to be defined according to its natural boundaries. For the dipole, it was the sphere enclosing the dipole. In the case of electrically small antennas, the problem is defining the antenna mode volume since in most cases it significantly exceeds the physical volume of the antenna itself. Indeed some antennas tend to couple strongly to the ground plane making the whole device the antenna. This might lead to an apparent advantage when bandwidth alone is considered but has many drawbacks for system performance and multiple antenna integration. For this reason, the antenna alone should be designed to provide sufficient bandwidth.

Benefits of IMD Technology

The majority of internal antennas use the electric field created between the antenna element and the ground plane as the main source of radiation [2,3]. Isolated Magnetic Dipole technology, as its name suggests, relies on the magnetic field as the main source of radiation. The advantage of this is a strongly confined electric field that couples weakly to the rest of the device. Figure 1 illustrates the difference in current distributions generated on equal size ground planes for PIFA (Planar Inverted F Antenna) type structure and an IMD [4] operating at the same frequency, top and bottom respectively. Both antennas are located in the center of the ground plane with red indicating the highest level of current and blue the lowest.

In the PIFA design, high currents can be observed all the way to the edge of the ground plane. In the IMD design, the currents are strongly localized to the antenna region and do not propagate on the ground. This illustrates the different mode of operation of the two antennas and that for the PIFA the ground plane is a significant part of the antenna. An underling advantage of the IMD is its properties depend mainly on the antenna structure itself and not the surroundings. Therefore multi-band IMD structures maintain their properties of independent tuning of the bands and matching. This accelerates integration an optimization of the antenna since systematic procedures that are independent of the device are used.

Isolation

Isolation or coupling can be defined as the level of power transmitted through a two port network. In our case one port is the antenna of interest and the second port can be another antenna in the device or other components such as: speakers, cameras, etc… There are mainly two coupling mechanisms involved; conductive and radiative. Conductive coupling is caused by currents induced by the antenna on the ground plane.

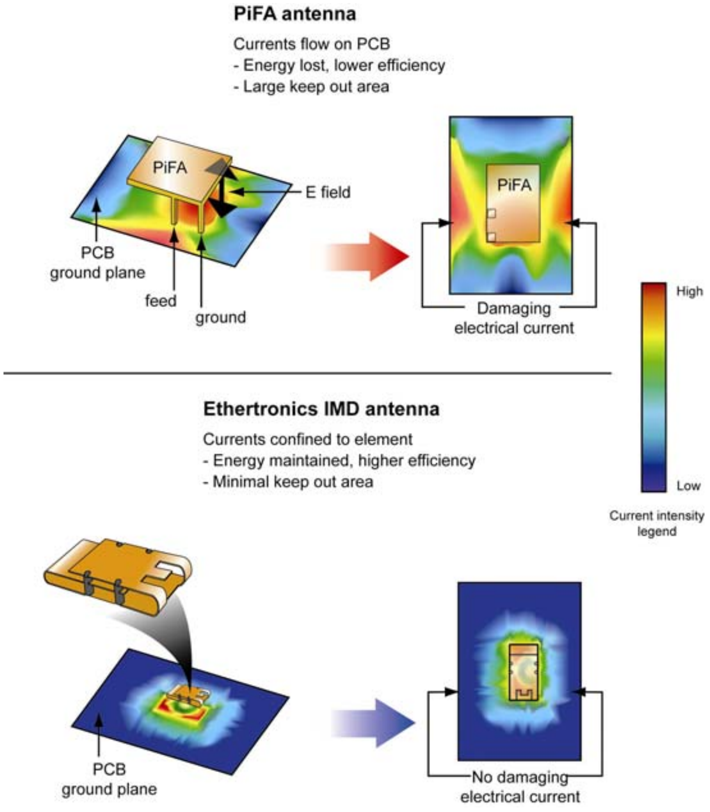

Figure 1: Current distribution. Top PIFA, bottom IMD

The difference in current distributions (Figure 1) shows that the potential for conductive coupling is much higher for the PIFA than for the IMD. Radiative coupling is due to the near fields generated by the antenna.

In the case of objects or components other than antennas, absolute isolation measurements are not possible since the second port is inaccessible. However, frequency shift as a function of the distance of that object to the antenna is a good indication of the antenna isolation properties. Figure 2 shows that the resonant frequency of a narrow band GPS IMD antenna is practically unchanged when the user holds the phone in different positions.

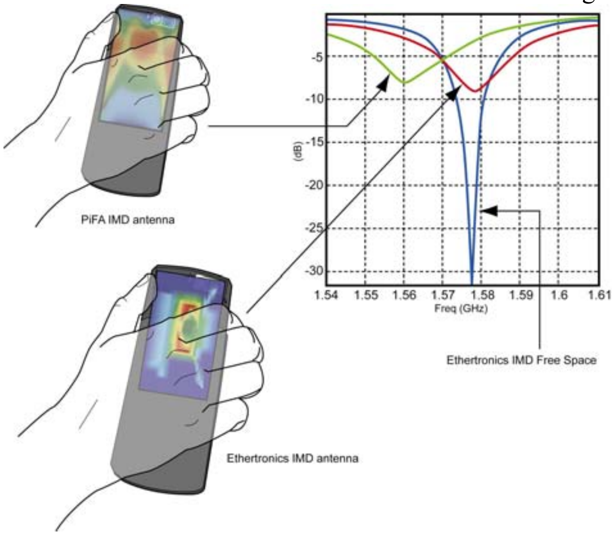

Figure 2: Difference in frequency shift when the user holds the phone.

However, for the PIFA a significant frequency shift is observed due to the different loading of the ground plane as a function of the hand position. In another experiment the frequency shift of an IMD antenna is shown to be unchanged when a large shield can is moved as close as 2 mm to the antenna.

When multiple antennas are integrated, isolation values between antennas can be obtained through S_{21} measurements with a vector network analyzer. Figure 3 shows the return loss and isolation obtained between two dual band IMD antennas for WLAN 3 cm apart. High isolation is obtained in both bands even though they are operating at different frequencies. This is possible because the low level currents on the ground plane allow further optimization of the relative position of each antenna.

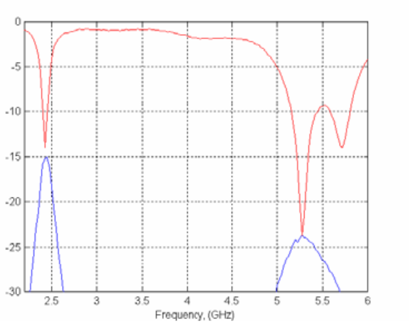

Figure 3: Return loss (red) and isolation measured with two dual band

Beyond the loss of efficiency, the implication of poor isolation varies depending on the system. In the case of a multiple antenna installation for diversity purposes, poor isolation reduces the achievable diversity gain, sometimes to the level of a single antenna. When multiple antennas are installed for different applications poor isolation can be catastrophic. Often the systems operate at significantly different power levels and the signals from the high power one can overwhelm the low power one. An example of this is WLAN and Bluetooth that operate at the same frequency with a power difference of two orders of magnitude.

Selectivity

Selectivity is defined here as the out of band rejection of the antenna. It can be evaluated through broad band efficiency measurements. Figure 4 shows such measurements for a Bluetooth antenna and a GPS antenna, left and right respectively. In these examples out of band rejection levels of the order of -20 dB are measured. High out of band rejection levels such as these ones greatly improve the isolation of antennas operating in separate bands and enables their implementation in close proximity. One reason of the high selectivity obtained with IMD technology is the ability to control the operational bandwidth of the antenna and produce sharp cutoffs. PIFA antennas tend to have a natural broad band response because of their effective large size due to their interaction with the ground plane. This makes it difficult to control the out of band response of these antennas.

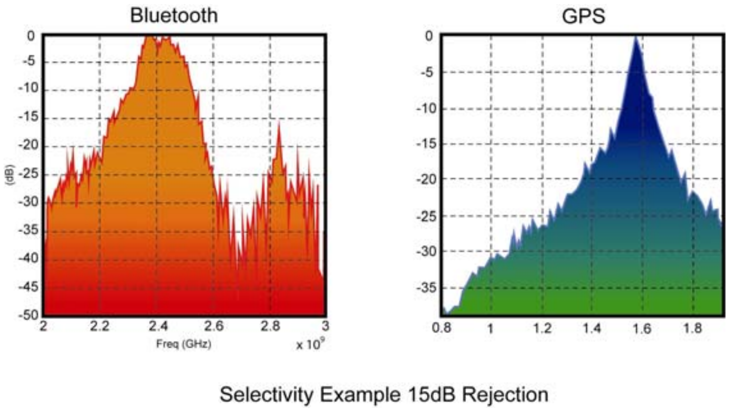

Figure 4: Broadband efficiency measurements of a Bluetooth and IMD antennas

Good selectivity not only improves isolation but can also be an effective low cost method to suppress interference between applications. Figure 5 shows an example of integration of a GPS antenna installed next to a tri band cellular antenna. In this case, the spacing between the antennas is less than 5 mm. In order for the GPS system to function correctly an isolation of 15 dB was required. The high selectivity and isolation properties of both IMD antennas enabled to achieve this.

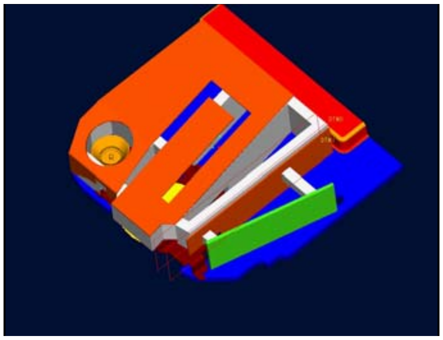

Figure 5: Tri band cell antenna and GPS antenna separated by less than 5 mm.

Other Considerations and Future Challenges

Regulations impose constraints to the device other than pure performance. For one, electromagnetic compatibility certification must be obtained for a product to reach the market. When the regulatory requirements for this are not met debugging the system can be extremely difficult and time consuming. This is also the case for SAR (Specific Absorption Rate) requirements. SAR is basically linked to the amount of energy that is transferred to the user and can be controlled through the near field of the antenna. In the case of monopole or PIFA antennas where the ground plane is a significant part of the antenna, the near field is difficult if not impossible to control. Often in these cases the regulatory SAR level is achieved by reducing the performance of the antenna either by detuning the antenna or inserting losses. A good metric to evaluate the SAR performance is therefore the ratio of the SAR over the antenna efficiency. This eliminates artificially low SAR values because of poor antenna performance. Figure 6 shows where different antenna technologies stand when using this metric.

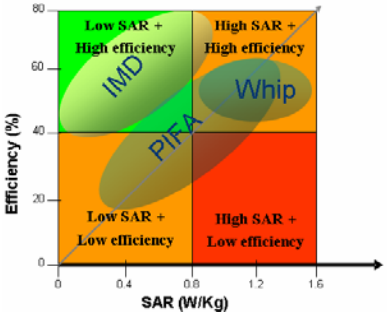

Figure 6: SAR efficiency ratio

The development of future more sophisticated communication technologies such as MIMO or 802.11.n will present even greater challenges for antenna integration. Not only will the number of antennas increase but the isolation requirements between antennas will become more stringent. In deed these systems depend on transmitting data in parallel over the same frequency bands using separate antennas. In order to achieve the significant data rate increases promised by these new technologies, antenna isolation such as that obtained with IMD technology will be a critical factor.

Conclusion

The main challenges when considering the implementation of multiple antennas into a mobile device have been covered. While the antenna size has to be reduced, the band width of operation needs to be increased. In order to maintain high system performances the interaction and coupling between the antennas themselves and other components must be minimized. The most efficient method to realize this is to employ antennas that inherently posses high isolation and selectivity properties. The Isolated Magnetic Dipole antenna technology presented here showed significant advantages in the areas of size reduction, isolation and selectivity as compared to more standard technologies. It was also indicated that these properties not only improve system performance but also facilitate antenna integration. This ultimately leads to more reliable and predictable implementations that are less sensitive to late design modifications and can accelerate qualification and time to market.

References

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Dr Sebastian Rowson joined Ethertronics in 2000 as a Senior Engineer. Since that time, he has been instrumental as part of the development team creating cost-effective, high volume antenna manufacturing. Rowson was recruited from UCLA where he worked as a research engineer developing new RF antenna technologies, enabling the creation of low profile antennas with improved control of radiation properties, ultimately contributing to the invention of the core technology for Ethertronics. In addition to Rowson’s 30 technology patents, his educational background includes a BA in Applied Mathematics and Physics, an MS in Fundamental Physics, Electronic Sensors and Integrated Circuits; and a PhD in Physics (which is supplemented with his post-doctoral studies in electrical engineering).