Advancements in Antennas
The development of dielectric antenna technology

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1. Introduction

In recent years a new type of antenna technology has emerged that is based around radiating high-permittivity dielectric ceramic materials. Dielectrics are insulators and they might therefore seem to be unlikely materials out of which to try and make antennas, but if they are excited in the right way they can be made to radiate very efficiently. Dielectric antennas can generally be made smaller than similar conducting antennas by the square root of the relative permittivity (ε_r). So for ε_r's in the range 35 - 100, typically used in this type of antenna, the antennas can be expected to be around 6 - 10 times smaller than similar conventional designs. The use of dielectrics in antennas also offers the possibility of making the antennas more efficient, by reducing some of the ohmic losses present in conducting antennas, and makes it easier to build antennas electrically close together for MIMO and diversity applications.

2. A short history of dielectric antennas

Dielectric antennas have been around a long time. A successful early type was the polyrod, designed at Bell Labs by Dr. George Mueller and his team and first used in anger during WWII, see figure 1. At the same time, in Japan, Dr. Hidetsugu Yagi also worked on dielectric antenna design, except that his project was to create an antenna that could be raised and lowered with a submarine periscope and not de-tune with different heights above the salt water. Resistance to de-tuning is a further important aspect of dielectric antenna technology.

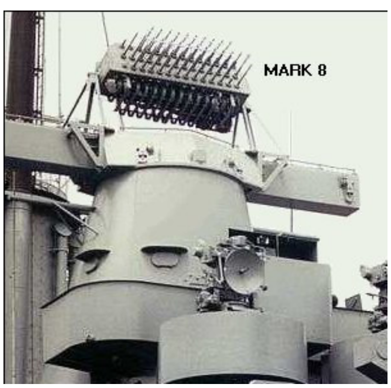


Figure 1 Bell Labs X-band "Mark 8" surface fire control radar, using an array of 42 polyrod antennas. This picture was taken from the **www.vectorsite.net** website.

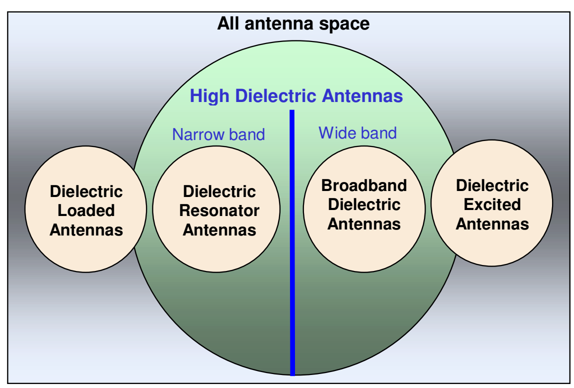


Figure 2. A Venn diagram representation of High Dielectric Antenna technology.

In fact the term 'dielectric antennas' encompasses several different types of technology and Antenova has used the term High Dielectric Antenna or HDA™ to describe the whole technology field. Figure 2 shows a Venn diagram representation of HDA technology. Perhaps the best-known type of dielectric antenna is the dielectrically loaded antenna. Here the primary radiating component is a conducting element and the dielectric just modifies the medium, so this antenna type only just intersects the HDA circle. The effect of the dielectric is often to reduce the bandwidth. However, dielectric loading of an antenna can impart important performance advantages; see the presentation by Sarantel Ltd at this conference.

In the 1980's a new type of dielectric antenna evolved known as the Dielectric Resonator Antenna or DRA[1,2]. In this antenna the radiating mechanism is a displacement current circulating in a dielectric medium, usually a ceramic pellet, so this antenna is inside the Venn diagram of dielectric antenna space.. The stored energy inside the dielectric is extremely high and it is difficult for external objects or for other antennas to disturb the resonance and de-tune the device. The use of readily-available materials allows the achievement of very low dielectric losses in this type of antenna and so the efficiency is high, the main losses being ohmic and occurring in the feed mechanism and the groundplane currents. Because DRAs tend to have classical and well-matched resonances, they are characterised by excellent return losses, but have quite restricted bandwidths.

The bandwidth of a resonant device is a function of its *loaded Q,* which is controlled by the manner in which energy is coupled into and out of the resonant device and is under the control of the designer; the *unloaded Q* is a measure of the internal losses in the device. There is no conflict between the use of a device with a high unloaded Q to create an antenna structure with a low loaded Q and wide impedance bandwidth.

DRAs have a well-resolved resonance (high loaded-Q) because of the groundplane beneath them. If this groundplane area is reduced, the bandwidth of the antenna rises dramatically at the expense of a worse return loss and a somewhat greater susceptibility to de-tuning (although still generally better than conducting antennas because the internal stored energy remains high). To distinguish these antennas from DRAs we have called them Broadband Dielectric Antennas (BDAs) and, like DRAs, the radiating mechanism is a primarily displacement current although radiation from the feed structure can be present as well. Figure 3 shows how a the same ceramic pellet can be configured to be a DRA with a bandwidth of 4.5% or a BDA with a bandwidth of greater than 33%, as measured at the –10 dB return loss level.

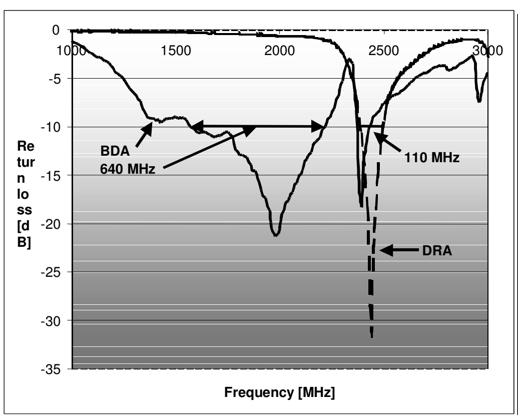


Figure 3. Comparison of a ceramic pellet used as a DRA (dotted line) or a BDA (solid line). The BDA has a bandwidth 7.5 times greater than the DRA.

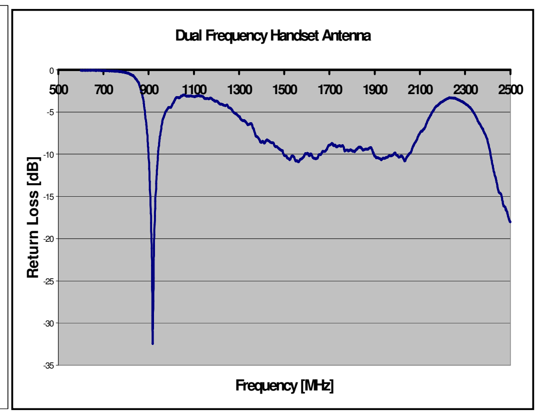


Figure 4 Return loss for a hybrid dielectric and parasitic PILA antenna combination

The last category of dielectric antennas (discovered so far!) involves parasitic dielectric solids with no feeds of their own. It has been known for many years that DRAs can excite other DRAs[3,4] but only recently have various types of dielectric antenna been used to excite parasitic copper antennas or vice versa. We have called this class of antennas as dielectrically excited antennas (DEAs) and it is often the conductor that forms the major radiating part of the antenna. There are bandwidth advantages in this dielectric-copper hybrid approach. For example, if a parasitic copper PILA is excited by the BDA used to produce the results shown in figure 3 then the return loss shown in figure 4 is obtained. The lower resonance near 900 MHz comes from the parasitic PILA and the upper wideband resonance comes from the ceramic pellet. This technology formed the basis of early Antenova triband+WCDMA antenna designs.

3. Microwave dielectric materials

Conductors are materials whose outer orbit, or valence band, is either only partially filled with electrons or the forbidden band between this and the next conduction band is so small that electrons can be easily liberated. Electrons are then free to migrate through the structure and give rise to conduction. In contrast, dielectrics are materials composed of atoms whose valence band is completely filled with electrons and the energy gap of the forbidden band is so large that free electrons do not normally exist. This means that these materials will not conduct a direct current them and they can be regarded as insulators.

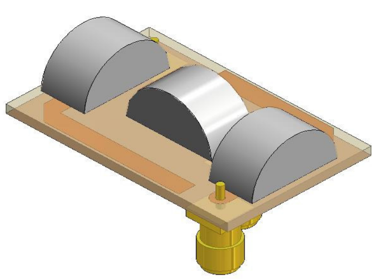
Until recently antennas were always made from conducting materials such as copper. It seems almost counter-intuitive to try and design an antenna from an insulating material, but in fact at radio frequencies these materials will support a displacement current. Obviously a displacement current cannot be a flow of free charge and it is actually caused by a displacement of the electrons about their mean position in the lattice structure. This is similar to the way another dielectric device, the capacitor, will not conduct DC but will pass radio frequencies.

The basic requirement of a dielectric for use in these novel antenna designs is to have a high relative permittivity, but two other important characteristics are required before they can be used. Firstly, they need to be a high-Q material (i.e. low dielectric loss) and secondly the temperature coefficient of the dielectric constant must be low to avoid the antenna de-tuning over wide temperature changes. Fortunately the dielectric resonator filter industry has been demanding high performance microwave dielectrics for many years and the materials developed are generally suitable for antenna applications.

4. Meeting today’s antenna needs

Whenever a problem can be solved using simple printed or stamped-metal antenna, then this probably represents the lowest cost and therefore the most desirable solution. However, when there is a need for several antennas to work in an electrically small space, for antennas that do not easily detune, or when high isolation is required between antennas for radio systems that are operating on the same frequency but with different protocols, then dielectric antennas are often the solution. Some examples are given below. The coupling between closely-spaced antennas has components produced by the radiating fields of both antennas (which is inevitable if the antennas are to radiate) and also by local fields which only represent stored energy. In HDAs this local field is largely contained within the dielectric, so as their spacing is reduced the coupling between these antennas rises less quickly than for conventional antennas.

Antenna diversity is often required in an electrically small space, such as at the end of a PCMCIA card projecting beyond the case of a laptop computer. These antennas might be used for WLAN and Bluetooth™ applications (see figure 5) or for a WCDMA connection (see figure 6).



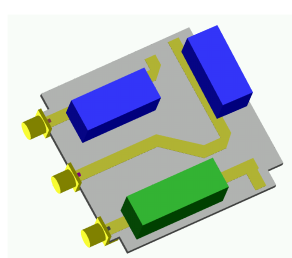


Figure 5. Two orthogonal WLAN antennas for diversity and one Bluetooth™ antenna, all operating on the 2.4 GHz band with 17 dB port isolation between them.

Figure 6. Two orthogonal WCDMA receive antennas for diversity and one WCDMA transmit antenna with 15-20 dB isolation between pellets..

By using DEA hybrid technology, dual-band WLAN antennas can be made to cover the 802.11a&b bands, and provide good isolation and wide bandwidth. Figure 7 shows a pair of WLAN antennas on the end of a PCMCIA card. In the 2.4 GHz band it is the printed copper monopole that is the radiating element, but in the 5-6 GHz band the dielectric is the primary radiator and the monopoles are acting as feeds. This design is inherently self-diplexing and so avoids the need for lossy diplexer circuitry.

Figure 7. Two-dual band WLAN antennas covering the 802.11a&b bands on a PCMCIA card

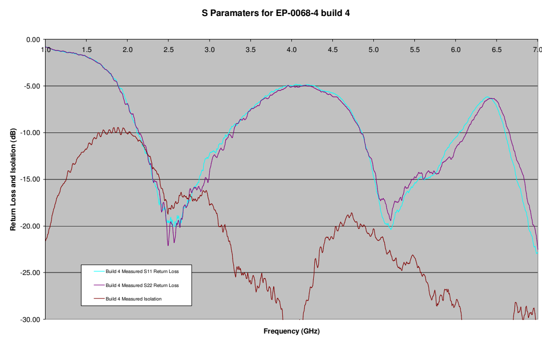


Figure 8. S11 return loss and S21 coupling for the two antenna shown in figure 7Two dual-band WLAN antennas covering the 802.11a&b

The same dual-band, self-diplexing concept can be applied to WLAN and Bluetooth™ laptop antenna combinations. Figure 9 shows a laptop computer with a pair of dual-band WLAN antennas near the top left had corner of the screen. There is about 15 dB port isolation between these antennas. However there is more than 40 dB isolation between these two antennas and the Bluetooth™ antenna half way up the right hand side of the screen. Reasonably omni-directional patterns can be obtained for these antennas, see figure 10.

Figure 9. Two dual-band WLAN antennas and a Bluetooth™ antenna on a laptop computer ~~laptop~~

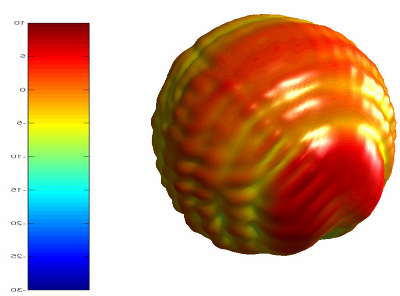


Figure 10. Gain pattern for one of the WLAN antennas measured at 5.5 GHz

Finally the DEA antenna technology discussed in section 2 has been used to make an efficient quadband handset antenna. Figure 11 shows the basic concept of a ceramic high-band antenna exciting a parasitic low-band antenna and giving the measured return loss shown in figure 12. The antenna covers the bands 824 - 960 MHz and 1710 – 1990 MHz and measured terminal efficiencies are above 50% across these bands. This technology is straightforward to manufacture and Antenova is taking it to market through a collaboration with Galtronics.

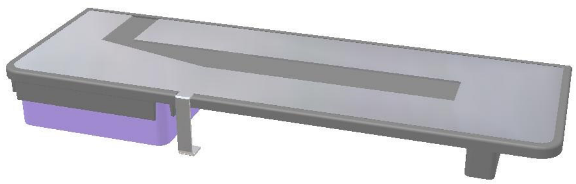


Figure 11. A dielectric quad-band handset antenna with good efficiency.

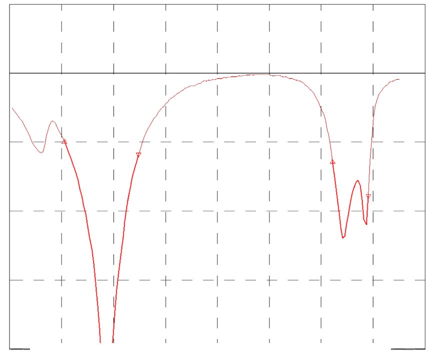


Figure 12. Return loss of the quad-band antenna.

In meeting today's antenna needs, the advantages of using dielectric antenna technology can be summarised by the following tables:

Advantages of dielectric-based WLAN antennas are:

- Multiple antennas possible in a small space
- Dual protocols possible on same frequency
- Narrow band sharp filtering possible
- Diplexers may be eliminated
- Wide band/dual band possible

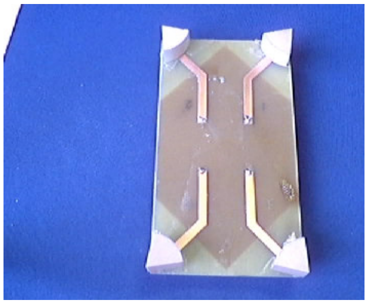
The advantages of dielectric-based handset antennas are:

- Stable performance reduces design costs
- High terminal and talk position efficiency
- Can be designed for low SAR
- Diversity has been demonstrated

Whither dielectric antenna technology

There is a continuous requirement for ever higher data rates in radio communication systems. A solution already adopted by WLAN to counter the effects of multipath is to use two diversity antennas, even in an electrically small platform such as a PCMCIA card. If more antennas can be provided at the transmitter and receiver sites then Multiple Input Multiple Output (MIMO) techniques can be used to exploit the spatial dimension and improve the performance of the wireless link. This process does not require increased power or additional bandwidth. In a similar way, the Bell Laboratories BLAST (Bell Labs Layered Space-Time) technique also uses multiple transmit and receive antennas to increase data rates. Combining MIMO techniques with adaptive coding and modulation, interference cancellation and beam-forming technologies, should lead to data rates of around 30 times greater than current 3G systems. The key to this new technology is to be able to build several (4 or more) antennas into an electrically small space.

The properties of dielectric antennas makes them well suited to MIMO applications. Figure 13 shows a 50 x 100mm PCB equipped with 4 dielectric antennas, each covering all the upper GSM and WCDMA bands. The measured isolation and cross-correlation figures for these antennas are good and the system could form the basis for a future MIMO equipped PDA or even handset. With today's technology, it does not seem likely that MIMO will ever be possible in the AMPS and GSM bands below 1 GHz, but these two bands might be catered for by a single parasitic PILA, as shown in the concept picture in figure 14.



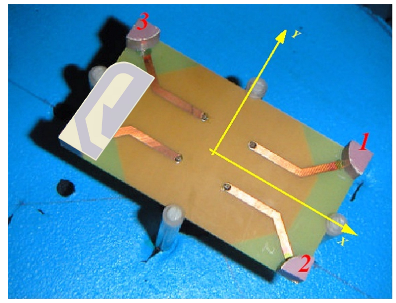


Figure 13. Four dielectric wide band antennas on a small PCB

Figure 14. Concept of a PDA or handset equipped with MIMO technology

With the possible future advent of all-dielectric handset antennas and Low-Temperature Co-Fired (LTCC) ceramic technology it is likely that the concept shown in figure 14 will soon begin to look obsolete as antenna sizes shrink further and approach the Chu-Harrington[5,6] limit, which represents the physical limit for this technology.

References

[1] LONG, S.A., McALLISTER, M.W., and SHEN, L.C.: "The Resonant Cylindrical Dielectric Cavity Antenna", IEEE Transactions on Antennas and Propagation, AP-31, 1983, pp 406-412.

[2] MONGIA, R.K. and BHARTIA, P.: "Dielectric Resonator Antennas - A Review and General Design Relations for Resonant Frequency and Bandwidth", International Journal of Microwave and Millimetre-Wave Computer-Aided Engineering, 1994, 4, (3), pp 230-247.

[3] Simons, R. Lee, R.; “Effect of parasitic dielectric resonators on CPW/aperture-coupled dielectric resonator antennas”, *IEE proceedings-H*, 140, pp. 336-338, 1993.

[4] Fan, Z. Antar, Y. Ittipiboon, A. Petosa, A.; VV “Parasitic coplanar three element dielectric resonator antenna subarray”, *Electronics Letters*, 32, pp. 789-790, 1996.

[5] Chu L.J.: “Physical Limitations of Omni-Directional Antennas”, J. Appl. Phys., 19, pp1163-1175, 1948.

[6] Harrington, R.: “Effects of Antenna Size on Gain, Bandwidth, and Efficiency", J, Nat. Bur. Stand., 64-D, pp. 1-12, 1960.