Abstract

This paper describes essential antenna design considerations as well as best practices for successful integration and co-existence of Bluetooth™ and WI-FI technologies in converged devices, Pen and key based PDA's or SMART phones.
The importance of spatial and cross polar isolation is discussed. Further, this paper discusses novel antenna layout considerations for electrically small embedded antennas to overcome practical hand-held device issues such as hand-loading effects and optimization of antenna polarization for various user modes. Consideration is given to the typical user modes, as defined by Hewlett Packard, such as portrait and landscape modes in order to ensure an optimum end-user wireless experience.
It will be shown through measured VSWR results that an electrically small embedded antenna, deployed as a classic monopole, is sensitive to hand-loading effects when the same antenna deployed as a hybrid ceramic/IFA approach results in stabilization of the antennas' resonant frequency even under typical loading conditions.
Finally - antenna technology selection considerations in terms of; cost, RF performance, size and commercial availability are presented based on various embedded antenna technologies in today's wireless markets.

Introduction

To clarify language used throughout this paper, some commonly used industry terms and acronyms are defined as follows:

Pen-Based Handheld Devices
These pocket-sized devices feature a pen-centric design and are capable of synchronizing with desktop or laptop computers. Positioned to replace paper-based address books, day planners, and even laptops themselves, these devices may also include an expanding list of features, such as multimedia, email, and wireless connectivity capabilities. These devices feature evolved operating systems or applications environments such as the Palm OS, Windows Mobile Pocket PC, Linux, or other proprietary platforms with the ability to download, run applications, and store user data beyond their required PIM capabilities.

Keypad-Based Handhelds
These pocket-sized devices feature a keypad-centric design and are capable of synchronizing with desktop or laptop computers. Positioned to replace paper-based address books, day planners, and even laptops themselves, these devices may also include an expanding list of features such as multimedia, email, and wireless connectivity capabilities. These devices feature evolved operating systems such as Windows CE .NET or Handheld PC 2000, with the ability to download, run applications, and store user data beyond their required PIM capabilities.

Converged Mobile Devices
These mobile devices combine the features of a mobile phone with the features of a handheld device. Positioned to solve the "multiple device question" and designed to replace the need to carry a mobile phone and a pen-based handheld or a mobile phone and a pager, for example, these devices must match wireless telephony capability to evolved operating systems or application environments such as Palm OS, Microsoft Pocket PC Phone Edition 2002, Microsoft Windows Smart phone, and the Symbian platform. These devices must include the ability to download data to local storage, run applications, and store user data in addition to PIM capabilities. Converged mobile devices must also offer the full extent of their application processing capability to the user, regardless of network availability.

VSWR is the Voltage Standing Wave Ratio measurement commonly used to characterize and specify the quality of the antenna's input impedance match and referenced to 50 Ohm system impedance. VSWR may also be expressed in terms of reflection co-efficient, or S-Parameter S11, sometimes referred to as return loss and measured in decibels (dB) as illustrated in fig 4.0.

Inverted F-Type (IFA) Antennas exhibit an electrical schematic or RF layout pattern that resembles an inverted letter F and are thus named. See fig 6.0 for an example of this.

Why Embedded Antennas ?

In today's converged handheld wireless devices Original Equipment Manufacturers (OEM's) are increasingly adding multi-mode and multi-band wireless capabilities to their product offering to meet increasing consumer demands for wireless connectivity and global roaming capability.
For example it is not uncommon today to see converged devices with Bluetooth™ (2.4GHz), WLAN (2.4GHz), GPS (1.575GHz), and Quad-band GSM (850/900/1800/1900MHz) with a trend to add 3G UMTS (2.1GHz) to the mix of radio technologies crammed into these devices with a requirement and expectation for flawless and simultaneous operation.
Consumers are increasingly demanding smaller, more inclusive and clean ID's for mobile devices and companion accessories.
No wonder then that the RF engineers, responsible for integrating all of these technologies into the one device, are under increasing pressure to embed the antennas inside the device as it would be clearly impractical and unsightly to have a handheld device with 4 or more antennas protruding from it.
In this paper we will focus on embedded antenna considerations for just two of the technologies commonly deployed in today's converged devices and handheld PDA's, Bluetooth™ and WLAN (WI-FI). In this scenario, both technologies are intended to operate simultaneously at 2.4GHz, with Bluetooth™ providing support for short range communications using Adaptive Frequency Hopping (AFH) radio technology and WLAN (802.11b/g) providing support for longer range and higher speed communications using Direct Sequencing radio technology.

User Mode Effects on Embedded Antenna Polarization

Having a converged device with all these technologies available is only acceptable if the end product performs well (good range, throughput and of course flawless simultaneous operation). Therefore, in addition to being under pressure to integrate many wireless technologies into the one device, RF engineers are faced with the challenge of how to accomplish this effectively without giving up the performance they know they can achieve with an externally mounted antenna. Additionally, antenna solutions must be engineered to reduce the battery consumption demand/loading by minimizing the radio amplifiers RF output power which at the same time helps to minimize co-existence interference issues and those related to Spatial Absorption Rate (SAR), the latter is mentioned briefly in the next section.

In order to ensure that in the real world the device does perform well, one must consider the end user affects on the performance and behavior of the embedded antennas under the most common user modes.
Since a gaming or Audio/Video (AV) user is likely to be viewing a web page it can be argued that the most common user viewing mode for the these functions is "landscape-mode" (Fig 1.0b). This common user mode is important to keep in mind when considering the desired vertical polarization, linear operation and installation of the embedded WLAN antenna associated with those functions, since unlike some external antennas the polarization is fixed by the orientation of the device during normal use.

Conversely, it can be argued that since a Bluetooth™ user might be listening to an MP3 file on their PDA that is either held upright in their hand, in a holster or placed in their shirt pocket that the most common user viewer mode for the PDA during Bluetooth™ operation is "portrait mode" (Fig 1.0a). This mode can also be commonly used for someone using the WLAN function in some devices. Again, one needs to keep this in mind when considering the desired vertical polarization, linear operation and installation of the embedded antenna. Other examples of potential user modes are flat table-top mounted or mounted in a device charging dock or keyboard cradle, each of which have the potential to change the orientation of the device and therefore the orientation of the antenna inside of the device.

Fig 1.0a – Common PDA User Modes
Portrait

Fig 1.0b – Common PDA User Modes
Landscape

Spatial Separation and Cross Polar Considerations for Successful Co-Existence

It is well known that when two or more radios are embedded into a single handheld device that one radio when transmitting can easily cause interference on the receive channel of the other radio. When you consider that Bluetooth^{TM} and WLAN (802.11b/g) radios are typically operating at the same carrier frequency (2.45GHz nom.) it becomes even more obvious that there is an opportunity for one radio to cause interference with the other when the two are in close proximity. Even with the Bluetooth^{TM} AFH scheme and the WLAN direct signaling schemes, that are designed to improve simultaneous operations, antenna placement issues and pattern polarization are critical to improving the simultaneous operation of these two technologies.
Leaving aside the obvious fact that poorly placed or unshielded micro-strip transmission lines can and do cause conducted emissions that introduce interference, it is apparent that the most sensitive part of the radio receivers' front-end that is prone to picking up and amplifying an interfering signal (noise) is the receiving antenna. Therefore it is clear that one should position the Bluetooth^{TM} and WLAN antennas as far apart as is practical (spatial separation) given the typical space constraints of today's small handheld converged devices and PDA's.

It is easier to prevent an interference problem early on in the product development cycle then to try and fix it later. Once the plastic tooling is committed to and the antenna locations are fixed the design engineer is limited to adding filters or other means of minimizing spurious signals and interference that might have been prevented by ensuring adequate RF isolation between the antennas in the first place. A good figure of merit for antenna to antenna RF isolation is 20-30dB. See fig 2.0
In addition to spatial separation, antenna-antenna RF isolation can be increased by using orthogonal modes of propagation. Since both Bluetooth^{TM} and WLAN technologies make use of linear vertically polarized antennas it is possible to take into consideration and plan to deliberately place the Bluetooth^{TM} embedded antenna so that the dominant vertical propagation mode is 90 degrees off-set compared to the WLAN antenna. Cross polar isolation can account for up to 20dB of RF isolation for two antennas operating at the same frequency.

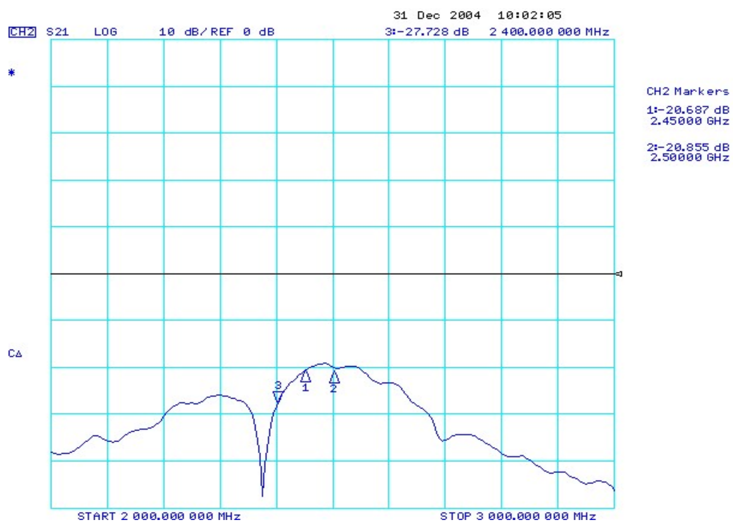

Fig 2.0 – Typical Cross Polar RF Isolation for two optimized antennas

User Hand Loading Effects

It is not within the scope of this paper to cover the subject of Specific Absorption Rate (SAR). However, it is appropriate to comment that there are world-wide regulatory guidelines (FCC in the USA, ANSI, etc.) for the amount of RF energy permitted to be radiated and absorbed by the human body. OEM's should be aware of these requirements and may be required to verify compliance with SAR regulations based on the intended point of sale for the end product.
Leaving aside SAR specific issues, the end users hands and other body parts that come into contact with the device during normal operation can and do affect the ability of the embedded antenna's to propagate into free-space efficiently. See fig's 1.0a and 1.0b. In other words, the water contained in the human body provides significant loading and radiation resistance to the transverse electromagnetic (TEM) waves propagated by the antenna.
Surface mount ceramic antennas are a low cost and effective solution to the embedded antenna challenge, however for handheld converged devices and PDA's it is critical to beware of the pitfalls of certain types of embedded antenna configurations when they encounter what is commonly referred to as "hand-effects" or more fully "hand-loading effects. Other user modes mentioned earlier in this paper that can also affect the typical embedded antenna performance includes mounting the device flat onto a table top surface that may be made up of RF reflective or absorbing materials (wood, metallic etc.).
The VSWR curves in fig 3.0 below show the typical VSWR for an embedded monopole antenna with and without the hand-loading effect. Fig 4.0 shows the typical VSWR for an embedded hybrid LTCC-IFA structure with and without the hand-loading effect. Clearly, the hybrid LTCC-IFA antenna is less sensitive to the loading effects created by the user's hands. It is desirable for the center frequency of the antenna to stay on-frequency even under hand-loading conditions so that there is a stronger likelihood of the signal being able to propagate. Meanwhile it can be seen that the monopole structure results in significant frequency drift of the antenna when loaded by the hand. Fig 5.0 and 6.0 shows the monopole and hybrid LTCC-IFA layout approach, respectively, used in these tests.

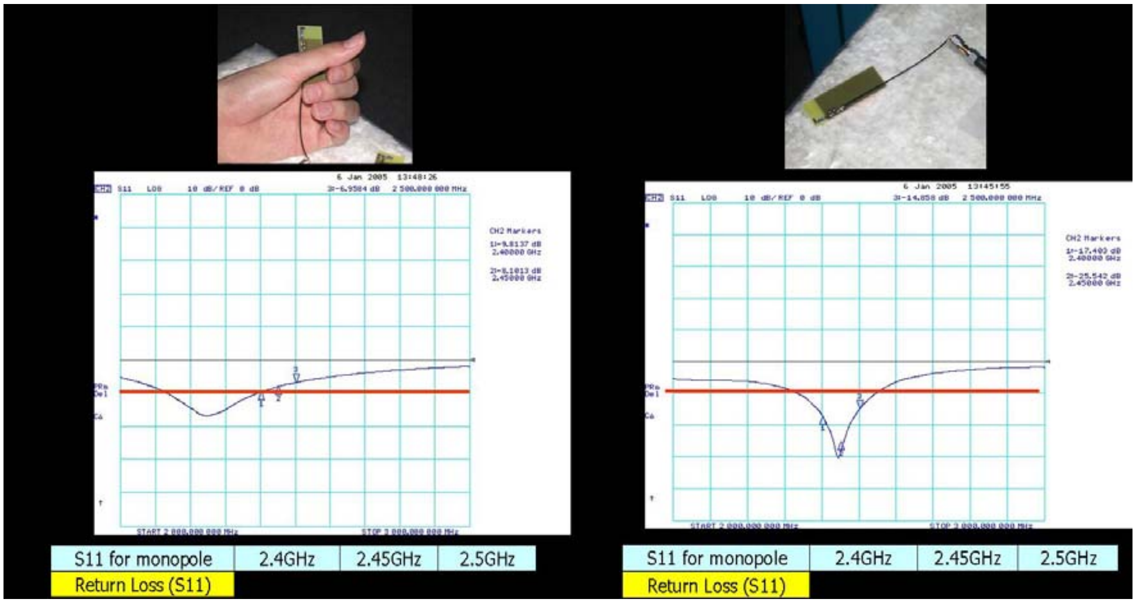

Fig 3.0 – Hand-loading Effect on Monopole structure

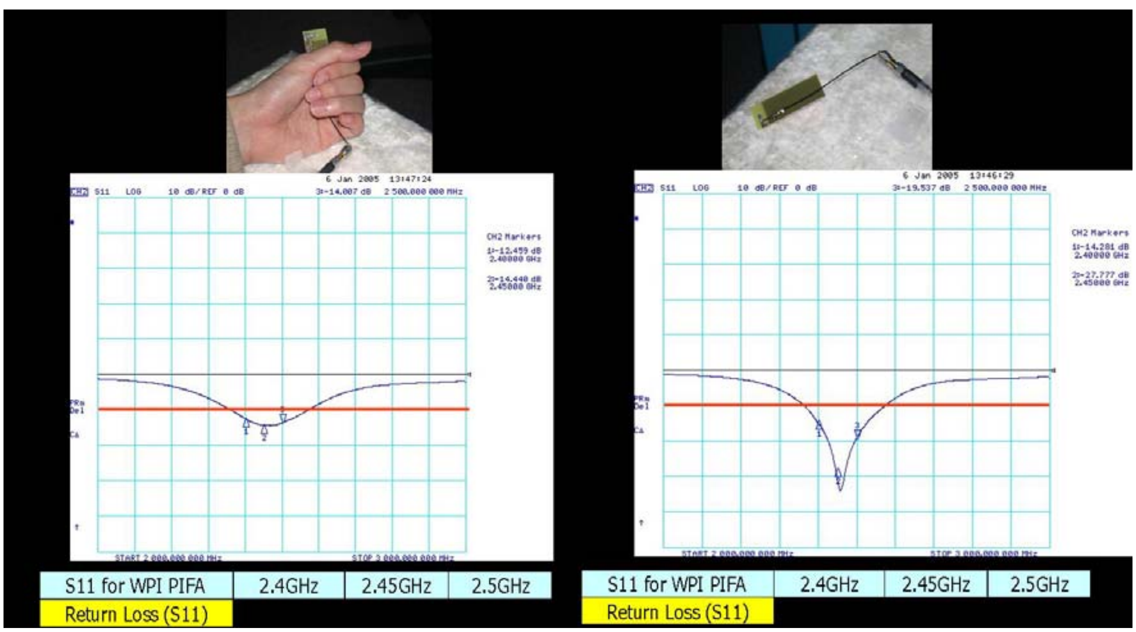

Fig 4.0 – Hand-loading Effect on Hybrid LTCC-IFA

Fig 5.0 – Monopole Layout Structure

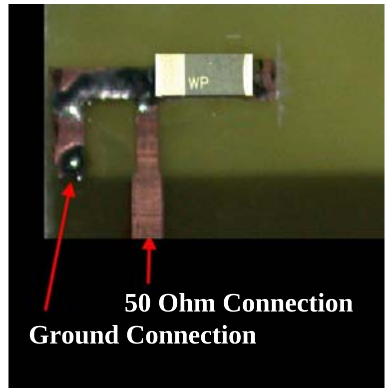

Fig 6.0 – Hybrid LTCC-IFA Layout Structure

Antenna Technology Considerations

Having understood the complexity of integrating multiple embedded antennas into one handheld device, it is appropriate to give a mention to the many types of embedded and external antenna technologies available to the wireless design engineer today. These range from embedded metal PIFA (Planar Inverted F-type Antenna) structures, LTCC (low temperature co-fired ceramic), printed dipoles and monopoles, inverted L, helical, patch antennas, dielectrically loaded variants etc.

Some antenna vendors invest heavily on specific intellectual property in order to be first-to-market with a unique product offering and often put aside the fact that each OEM's converged device or handheld PDA is unique.
Further, a specific OEM's antenna technology, selection criteria is dependant on the rank order of importance of 5 main antenna decision factors. Namely:

1. Price
2. RF Performance
3. Appearance (Size/weight)
4. Availability (lead time)
5. Commonality across multiple platforms

Antenna vendors that promote a single technology when recommending an antenna solution to the OEM are deliberately forcing the OEM down a path of one-size fit's all.
Increasingly however, educated OEM's and more recently ODM's (original device manufacturers) are becoming aware that there is another way.
RF savvy antenna vendors that really understand the nuances of proper antenna technology selection and integration to meet the OEM's antenna decision factors are able to offer antenna solutions that are tailored to the OEM's specific requirements without introducing compromise.

Conclusions

It should be noted that to successfully integrate several embedded antennas a balance needs to be made between obtaining sufficient spatial and polarization isolation when optimizing the RF performance of the radio systems through careful thought and consideration of the common end user modes.
In presenting these findings, WP Wireless, would like to recognize the support and contribution of Hewlett Packard's iPAQ Hand Held Devices Group that provided input on the common user modes for the typical Bluetooth™ and WLAN enabled PDA.
In summary, this paper has highlighted major considerations and best practices in embedded antenna placement to increase the likelihood of successful Bluetooth™ and WI-FI co-existence in converged devices, SMART phones and PDA's.

Author Biographies

Norman Smith is the Vice President of WP Wireless. He has been working with leading OEM's to successfully integrate embedded antenna technology into their hand-held wireless devices. Prior to his current position, Norman held leadership roles in sales and marketing at Agilent Technologies Wireless Network Test Division (formerly Hewlett Packard). During his former engineering years he held hands-on RF Engineering Design roles over a period of 12 years at; Nokia Telecommunications, GEC-Marconi Defence Systems and the British Governments Intelligence Communications HQ. He earned his BEng (Hons) in Electrical and Electronics Engineering at the University of Hertfordshire (England) in 1994.

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About WP Wireless

WP Wireless is a business group of World Products Inc headquartered in Sonoma, Northern California, USA, with applications and sales offices in Taipei, Taiwan, R.O.C.
World Products Inc. is a privately held company that was incorporated in Minnesota in 1969. World Products Inc's other two major business groups serve the; telecommunications, automotive and surge protection markets.
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