The Challenges of Integration

This article explores the problems encountered with integrating an internal antenna into a cellular handset. It explains ways to design handsets that avoid these problems and shows how the handset designer and the antenna designer can work together to improve integration and performance.

Dropped calls annoy everyone who uses a mobile phone and users quickly become irritated by handsets with poor reception. The antenna performance is critical to the RF performance of the handset. Network operators often measure the transmit and receive performances of handsets. If a handset does not meet their standards some will simply not sell it because it will reflect badly on their network.

A poor antenna can harm power consumption and battery life. A less efficient antenna will produce less power at the base-station and the closed-loop power control system will have to compensate for this. The base-station will order the handset to transmit more power. This means the antenna can affect the power consumption of the handset in-call.

Style and ergonomics are also important. Given the choice, users prefer handsets with internal antennas as they are more comfortable in people's pockets and they allow cases to be styled more attractively. Internal antennas are more mechanically robust and reliable. However, more features - such as cameras - make handsets more electrically complex, and leaving less room for the antenna. The challenge all handset designers today are facing is integrating internal antennas into the style of handsets that people now want to buy.

The first and most important question the handset designer must ask themselves is: Can an internal antenna with acceptable performance be integrated into their handset? In almost every case the answer is yes, if proper accommodation is made for the antenna. Specifically, a reasonable amount of space must be given over to the antenna and the handset designer must be willing to work with the antenna designer to solve any problems that might arise. Since the antenna is inside the phone problems of interference and cross-coupling with other components often occur. Integrating an internal antenna is more challenging than integrating an external antenna. But, if the right approach is taken it can be done quickly and efficiently.

For the handset designer there are three main tasks when integrating an antenna:

- Deciding where the antenna is to be placed in the handset
- Apportioning space for the antenna
- Arranging other components in the handset so they do not cause problems.

The antenna designer can advise on all of the above.

But, before going into the details it is useful to understand why integration is difficult. This requires a little antenna theory.

In general there are two types of antennas, balanced antennas and unbalanced antennas. Balanced antennas work by themselves, in isolation from their environment whereas unbalanced antennas must be connected to a ground of some sort. Unbalanced antennas produce currents on this ground and these currents contribute to the total radiation from the combination. The monopole antennas generally used on cars are a good example, the ground being provided by the car body.

The performance of an antenna is related to its size - which is best measured in fractions of a wavelength. The ground of an unbalanced antenna contributes to its effective size, so the size of the actual antenna can be made smaller.

Portable phone antennas are another type of unbalanced antenna. Their ground is the metallic structures in the handset, normally the PCB and the metallized parts around it. Antenna designers refer to these parts together as the Chassis. Unbalanced antennas are generally used because of their size. For the low frequency bands, such as GSM900 and CDMA800 the typical volume available in a handset for the antenna is small when measured in wavelengths. It is not possible to build an efficient balanced antenna in this volume, so unbalanced antennas must be used.

In the case of the higher frequencies the situation is not so limiting. The wavelength of GSM1800 for instance is half that of GSM900, so the space appears larger. Balanced antennas can be used for the higher bands. Recently this has been achieved with WCDMA internal and GPS external antennas. This has the advantage that the antenna does not cause large currents to flow on the handset. This means the antenna design does not depend so heavily on the design of the handset.

The problem though, is that most handsets must cover a low-frequency band, and a high-frequency one. This means it is simplest to incorporate the high-band antenna into the low-band antenna, making them both unbalanced.

Types of Antenna

Many types of antenna have been used in mobile handsets. They can be roughly placed in two categories.

First, there are antennas that are similar to monopoles. Externals such as normal mode helicals, meanders and retractables are of this type. Recently antennas of these types have been used as internal antennas, but they are not common. These antennas do not work when they have a ground underneath them, so they cannot work with a populated section of the PCB underneath them.

Second are antennas such as PIFAs that work on top of a ground. Because this type of antenna reuses the space over the PCB it is most often used. Antenova have recently developed the Hybrid Dielectric Antenna. This is a combination of a dielectric antenna and a PIFA and, like a PIFA it can work on top of a ground. See figure 1.

Deciding where to place the antenna

The telecoms industry has had years of experience with bar-shaped handsets showing that it is best to put the antenna at the top of the handset. The reason for this is that when the hand covers the antenna its performance will collapse and at the top of the handset it is less likely to be covered.

Today though the situation is different, new form factors for handsets demand fresh ideas. Generally there are now two types of handset: those that are a bar shape and those that are in two parts. Flip (Clamshell) handsets and bar handsets have been around for many years, more recently new types have appeared, for example, sliding handsets where two parts slide against each other. Some new handsets have two parts that swivel around a pivot, these are referred to as "rotary" handsets. All of these two part handsets introduce a complication that is not present in the bar type - they must work in both the open and closed states. Electrically speaking, these states are different, meaning that a compromise must be reached that produces reasonable performance in both states.

The compromise between these two states is difficult. If a handset is two-part, then before the handset case is designed an antenna designer should be contacted to inform on the best antenna placement for that handset type.

Surroundings

The antenna designer is always interested in the components surrounding the antenna. Modern handsets are quite crowded, so components such as the battery and camera frequently come close to the antenna. Often, nearby components determine to a great extent the performance that can be achieved. Their impact varies from one handset to another, but can be seriously degrading to antenna performance. This can lead to parts of the handset being redesigned at late stages of the development process.

Antennas induce currents in any conducting objects close to them. Generally, the conducting parts of a handset fall into two groups, firstly there is the chassis, that is the PCB and its shielding. These connected conductors act as one large conductor, forming a ground that aids the antenna performance. The second class of conductors are the smaller separate components that connect to the PCB through interconnections such as wires and Flexible PCBs (FPCBs). Exciting currents on these components should be avoided as energy is lost in the component itself or the associated circuitry. These components or circuits have not being designed with this in mind, so the losses are usually high.

If a few guidelines are followed the problems these components may cause can be avoided.

Connection Methods

Inside handsets interconnections that require many lines are normally made using FPCB. For instance, FPCBs are usually used to connect to cameras. It is important to be careful putting FPCBs near the antenna, because coupling between the two may affect the antenna performance. A small change in the FPCB or the antenna may solve this. Where the position of the FPCB is fixed the problem may not be great, but when it is not fixed the issue can become serious. An example would be the connection to a rotary camera (that is a camera that's free to rotate). If the FPCB can curl in a number of different ways then any experiment done to assess its effect will not be repeatable. It's difficult to do much about the FPCB in this case.

Connections needing only a few lines, such as those to the speaker tend to use simple methods, such as spring contacts or wires soldered at each end. In general antenna designers prefer spring contacts to wires. If a part is connected by spring contacts then the length of the circuit it forms is the same in every handset. When wires are used each one may be slightly different, even if the length is consistent in manufacture it may not be in prototype handsets. So, a problem that manifests itself at, for example, a frequency of 1600MHz in one handset may show itself at 1800MHz in a second. If the handset in question uses the GSM1800 band then the first handset will function correctly but the second will not.

The Battery

The battery is a major part of the handset and can have a big influence on the antenna performances. The presence of the battery lowers the resonant frequency of the antenna and can reduce the efficiency. It is best to try to: -

- Keep the battery as far as possible from the antenna, 5 mm is the absolute minimum recommended.
- RF-ground the battery source and controls by means of shunt capacitors of about 15 pF - 33 pF. The antenna designer can advise on this.
- Tell the antenna designer if the battery structure has changed internally. It may look the same as on an earlier prototype, but affect the antenna differently.
- Use plastic battery clips as metal spring clips can act as an antenna loss mechanism.

Speaker

In most phones the speaker is on the opposite side of the PCB to the antenna where it causes no real problems. However several recent handsets have been made that are quite thin by removing a part of the PCB where the speaker is; this moves the speaker into the antenna space. If coupling to the speaker occurs the antenna efficiency reduces significantly. In this case it is preferable to connect the speaker using very short spring contacts, avoiding floating wires. Since it is close to the antenna space it's important to give the antenna engineer a sample of the speaker as soon as possible. If floating wires can't be avoided then the speaker should be protected with series inductors on both of its connecting wires. Surface mount (SMT) inductors will normally prevent much RF coupling occurring. Leave pads for series inductor and remove them in the final PCB if they are found to be unnecessary.

Shielding

RF cans or EMI coating will generally shield the RF circuits in the handset. If EMI coating is used it is best to make sure that the coated boxes over the PCB form a closed space. If the EMI boxes have open sides then from the antennas point of view they are cavities and the antenna may couple into them. In general, the antenna designer may recommend changes to the EMI coating close to the antenna, small changes may significantly improve performance. Finally, during prototyping the EMI coating is usually painted in by hand, these hand-painted phones are not consistent enough to be used to compare antennas.

Apportioning Space for the Antenna

The volume a handset antenna occupies is an extremely important parameter. It is well known that the performance of an antenna is related to its volume, this was proved by Chu[1] and Harrington in 1948. However, much of this article is concerned with the surroundings of the antenna this is because the antenna environment must be made friendly. If this isn't done then the volume of the antenna becomes irrelevant, the performance being determined by the surrounding loss mechanisms.

It is very hard to give precise guidelines on the amount of space an antenna will require. An antenna designer will estimate the volume needed based on experience; there is no mathematical formula to do it. Estimates will vary with the experience of the antenna designer, and with the technology available to him or her.

To make an accurate estimate it is necessary to know: -

- The bands the antenna must cover
- The performances required in each band
- The form-factor of the handset
- Any objects there may be in the antenna space
- The length and width of the chassis

Rough guesses can be made without all of this information, and customers often request them, but they are generally not useful.

One simple guideline is that the more bands the antenna must cover the more volume is required. Especially, if the antenna must cover two of the low-frequency bands it should be significantly larger than if it need cover only one. This is because the volume measured in wavelengths is relatively smaller at low frequencies, and poses more difficulty at these frequencies. This makes Quad-band antennas in particular more difficult to implement. An antenna can be made in almost any volume, however the performance and efficiency will deteriorate significantly as the volume reduces.

The size of the ground influences the performance of the antenna. Given the same antenna, the dimensions of the chassis can change the bandwidth by a factor of two. An antenna designer must know the size of the ground to estimate the size of the antenna. In general terms, ~130mm is the optimum length for good low-band performance and ~40mm the optimum width, see figure 2 (also see [2]).

For PIFA antennas and Antenova's Hybrid Dielectric antennas the most important dimension is the height, the length and width being less important. Most handsets use PIFAs, but a few use Inverted-F type antennas without ground underneath them. They don't follow this rule since they're more like monopoles, the other dimensions are just as important.

Conclusions

Many of the issues mentioned here are caused by unbalanced nature of handset antennas. Antenova are currently researching using balanced antennas for the higher frequency bands, though it is unlikely to be possible to use balanced antenna for the lower frequency bands.

The key to avoiding the problems mentioned in this article is to involve the antenna designer from an early stage, preferably at the stage of case design.

References

[1] L.J.Chu, "Physical Limitations of Omnidirectional Antennas", Journal of Applied Physics, Vol. 19, Dec. 1948
[2] Jani Ollikainen "Design and Implementation Techniques of Wideband Mobile Communications Antennas" Helsinki University of Technology technical report

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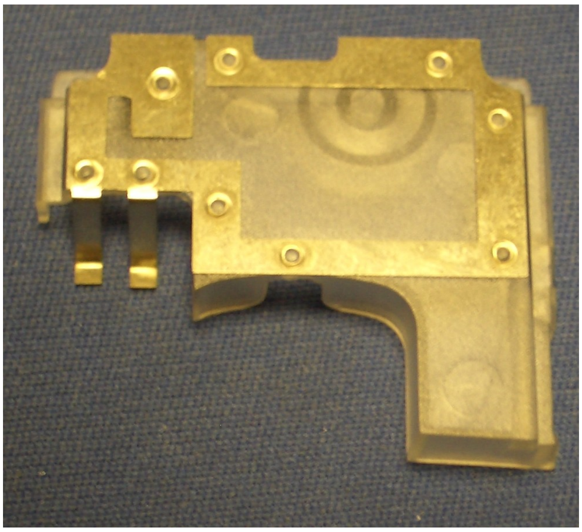
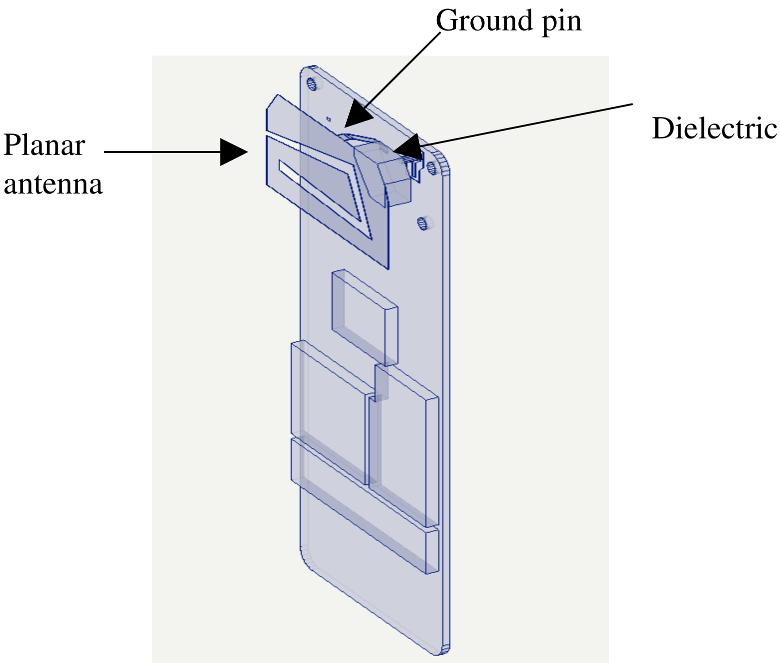
Diagrams:

Figure 1. Top a PIFA antenna, Bottom a Hybrid Dielectric Antenna on a PCB





Ground pin
Planar antenna
Dielectric

Figure 2. Bandwidth of a Hybrid Dielectric Antenna vs Length of Chassis (courtesy of Devis Iellici)