Institution: The University of Birmingham

Unit of Assessment: B13 – Electrical and Electronic Engineering, Metallurgy and Materials Electronic, Electrical and Computer Engineering submission

Title of case study: Multiple Band Antennas for Mobile Phones

1. Summary of the impact

Increasing use of mobile phones and the consequent congestion of the original bands have meant that over the last decade, additional bands have been released, and all current mobile phones need to operate at up to five different frequency bands. Professor Hall's group supported by £160k from British Telecom Labs, showed how to design a multi-band planar inverted F antenna, using slots in the antenna top plate. The published papers have since been quoted in many industrial patents and widely acknowledged to be the first publications of the antenna. Nokia, who had the largest market share in the REF period, based their antenna designs on the slot concept, and hence a large proportion of the several billion phones in the world today use this antenna, with a financial value of many millions of pounds.

2. Underpinning research

Mobile phones use radio frequency (RF) communications. An important part of an RF transmitter or receiver is the antenna. The RF circuits themselves, e.g. amplifiers or filters cannot radiate or receive radio waves efficiently on their own. The first mobile phones used antennas external to the case, the stub antenna or the pull out whip antenna. However it soon became clear that consumers did not want external antennas. Early mobile phones, with internal antennas, used the planar inverted F antenna, (PIFA), which consists of a metal top plate suspended above a ground plane, which is usually the printed circuit board of the phone. The size of a well-designed PIFA antenna has to be about a quarter of a wavelength at the frequency of operation, and would typically occupy the top quarter of the mobile phone. The pressure on performance and size is a continual challenge for antenna designers.

In 1994, as consumer demand soared, Professor Hall (Professor of Electronic and Electrical Engineering, 1994-) identified that spectral congestion was pushing the Government to release new frequency bands and that multi-band antennas would be needed. The key problem was to find a multi-band antenna small enough to fit inside the phone case. Good design of the antenna is important to the mobile phone, both in terms of maximising the battery life and keeping the power dissipated in the user, below the safe exposure limits set by Governments.

Professor Hall has been researching into antenna design for over 35 years and built an internationally renowned team at Birmingham of over fifteen researchers and three staff members. Important indicators to quality are over 350 publications, H factor of 19, total citations of 1360 (Web of Science). Hall recently gained the IEEE John Kraus Award for Contributions to Antenna Design, the European Association for Antennas and Propagation Award (EurAAP) for Contributions to Antennas in Europe and IET LAPC Lifetime Award for Work on Printed and Active Antennas, and Body Centric Wireless Communications. Hall has obtained over £5M in research support since 1994, with over £500k from industry. The group are currently involved in spinning out a company to exploit a set of patents relating to the design of 4G mobile phone antennas.

The specific research for this case study was funded by BT Labs (£161K) and took place between 1995 and 2001. Professor Hall supervised the work of two talented PhD students, Dr Z Liu and Dr P Song, who along with over 30 other PhD and MPhil students graduated by Hall, have since gone into academia and the antenna research and development industry, around the world.

The results were six seminal papers, Section 3, the first being a Letter, [3.1], followed by papers in major conferences in USA and Japan, [3.2,3.3] and then by an IEEE Transaction paper, [3.4]. These were followed by a further conference paper and letter, [3.5, 3.6], showing extensions to the method.

The papers describe how to insert one or more slots into the top plate of a PIFA, to make it operate in two or more bands. The slots create a number of different current paths in the plate, each of which has a characteristic length and thus a different resonant frequency, [5.2]. The Transaction paper also shows the effect of slot position and slot length, which have an effect of the shifting relative frequency of the two (or multiple) bands. Variants were shown that had either a single or multiple connectors. This was important, because it was clear that some handset manufacturers would use separate transmitters and receivers for the two bands, which would need two antenna connectors, whilst others would develop combined systems, requiring a single connector. The method of putting slots in the PIFA top plate, described in the papers, remains the key step in the design of many mobile phone antennas for handsets. Because all handsets have a different internal layout to provide the different set of features, the antennas have to be re-designed for each new handset. However, use of slots in the top plate is a common feature in all of them. In addition to mobile handsets, the multiband PIFA antenna is used for cellular communications in vehicles. The value for the idea, calculated in the following section, does not include the vehicle applications.

Subsequently, the method of slotting the top plate was referenced by many industrial patents from a number of companies. Corroborating Source [5.2] describes over 50 such patents, in particular 21 from Nokia, 6 from Centurion and others from RIM (Blackberry), Sony-Ericsson and FCI. The date of the first Birmingham paper, [3.1], July 1996, predates the filing of the first patent discovered in our search, by 17 months. This lead time is significant in industrial terms, for the second 2G GSM band was allocated in the UK in 1996/97.

3. References to the research

The outputs that best indicate the quality of the underpinning research are references 3.2, 3. 4 and 3.5

3.1 Liu, Z. D. and Hall, P. S., “Dual Band Antennas for Hand Held Portable Telephones”, Electronics Letters, 28th March 1996, 32, No.7, pp.609-610 DOI: 10.1049/el:19960433

3.2 Liu, Z D and Hall, P S “Novel dual-band antenna for handheld portable telephone”, IEEE AP-S International Symposium, Baltimore, 21-26 July, 1996, pp54-57

3.3 Liu, Z D and Hall, P S “Novel dual-band handheld antenna”, International Symposium on Antennas and Propagation, Chiba, Japan, 24-27 Sept, 1996, pp509-512

* 3.4 Liu, Z. D., Hall, P. S. and Wake, D., “Dual Frequency Planar Inverted F Antenna”, IEEE Trans on Antennas and propagation, vol 45, no 10, Oct. 1997, pp1451-1458 DOI: 10.1109/8.633849

3.5 Song, C T P, Hall, P S, Ghafouri-Shiraz, H and Wake, D, “Triple band planar inverted F antenna”, IEEE AP-S Symp, Orlando, July 1999, pp908-911

3.6 Song, C T P, Hall, P S, Ghafouri-Shiraz, H and Wake, D, “Triple band planar inverted F antennas for handheld devices”, Electronics Letts, vol 36, no 2, 20 Jan 2000, pp 112-114 DOI: 10.1049/el:20000131

* IEEE Transactions on Antennas and Propagation has an Impact Factor (IF) of 1.728 with the median IF for Electrical Engineering being 0.962

4. Details of the impact

Mobile phones are currently the biggest selling piece of electronic equipment and have changed the way society interacts, from the one to one level, to their use to gather large groups of people together for political purposes. Today they are much more than a phone, but communications remains at the centre of their capabilities, through mobile connection to the Internet and other data services.

This revolution was primarily enabled by the introduction of the 3G standard in 2000/2001. As part of this, governments around the world auctioned new spectrum. For example, the major operators in the UK invested over £22bn as part of this process. Like the second GSM band, this increase in bands again placed high demands on antenna design. Achieving small size for four or more bands with high efficiency was the goal and the Birmingham concept was again used in the design process. Due to the high investment for 3G, lead time was even more significant.

The initial response to the need for additional band coverage, [5.1], is to fit an extra antenna into the handset case. However the number of other components, such as the camera and accelerometers for example, mean that there is an increasing demand on internal handset volume. Having two antennas means that the size of each must be smaller. A reduction of the antenna size results in reduced antenna efficiency, with a significant reduction on battery life, which also significantly increases the environmental impact of owning a phone, due to increased charging times. The only solution is to make the antenna multi-band.

After the publication of the first Birmingham paper, [3.1], many industrial groups around the world began work on the problem, such as, Nokia, Lucent, Filtronic, Motorola and Sony-Ericsson. The nature of mobile phone design is that all phones are different in small or large ways. Whilst some differences may be software based and use the same hardware, many relate to handset size and shape, the inclusion of additional hardware and the capability to operate over the various bands available. The availability of RF front end chipsets and digital processor chipsets also changed during the period. This means that the internal layout of the phones change regularly and as a consequence the antennas need to be redesigned for each phone. In addition, companies need to protect their intellectual property, by finding variations on the basic principle. The process of antenna redesign and variation can be seen in the patents for multi-band antennas.

Patents must refer to previous publications and patents, but need not describe the subsequent exploitation of the ideas described. Many of the patents noted in [5.2] reference one of the Birmingham papers. Although other papers are quoted, they are on other aspects of antenna design, and thus the Birmingham papers are the prime source of the slot concept for mobile phone antennas. Some of the companies that have filed patents do not make handsets, and it is difficult to trace the on-going path from those patents to market. However 21 of those patents are from Nokia, who had by far the biggest share of the handset market during the REF impact period. Patents for both dual band antennas, for the two 2G GSM bands and four or more bands for 3G, are described in [5.2]. Antennas that are close in form to the drawings in these patents have been identified by Professor Hall’s group by disassembly of actual handsets.

Patents describing other methods of achieving multi-band antenna action in a small size are also given in [5.2]. In some sense, they also owe something to the Birmingham papers, but a direct relationship is hard to show, as no references are made. In addition these are from companies that have much lower market share than Nokia, and are much less influential in terms of total impact.

In Corroborating Source [5.3], the Head of Motorola Antenna Group, Florida, USA, writes, “The conception and dissemination .... of the multi-band planar inverted F antenna, by Prof Hall.... has been a key enabler for the development of ever more capable .... mobile phones” and “An even stronger indication is the frequent reference to PIFAs as prior art in patents ... clear testament of the seminal value of the original concept developed by Prof Hall...”

In Corroborating Source [5.4] the Sony Ericsson designated expert in terminal antenna technologies writes, “I knew your work very well, this paper was the first academic paper to tell how to design a dual band PIFA antenna system” and “Your work is definite the first paper to guide industry to realize it in the practical products.”

The value of the multi-band antennas in Nokia phones can be estimated from the market share and market size, [5.5]. Trefis.com, a business analysis organisation, states that “We estimate that Nokia will have 2011 market share of 30% in the 1.1 billion mobile phone market within emerging markets and 17% market share in the 500 million mobile phone market within developed markets.” Forbes, indicate an approximately linear variation of the Nokia market share over the period, from 45% in 2008 to 23% in 2012. At the time of writing data for 2013 was not available. The typical value of each antenna can be estimated from the costs as advertised in web based catalogues from Chinese companies. For example, the antenna for the Nokia N6300 costs $0.75 and for the N76 cost $1.35.

From this data the likely value of antennas in all Nokia phones over the period can be estimated. The equation below has two parts, as the total market share is the sum of the shares in the developed and emerging markets. A market share is averaged over the period. An average antenna value of around $ 1 is used.

Value = (developed market size x market share x average antenna value x period)

+ (emerging market size x market share x average antenna value x period)

= (1.1 billion x 30 % x 1 $ x 5 years)

+ (0.5 billion x 17 % x 1 $ x 5 years)

= $ 415 million

With an average market share of 30% for Nokia, it could be assumed that the total value of antennas designed using the Birmingham concept could be double this amount.

In addition, it is difficult to extend the above calculation to the impact on Nokia's turnover during the REF period, However, since Nokia was in profit during this period, it is reasonable to assume that this had a direct impact on their revenues and, assuming no margin, this equates to a revenue contribution in excess of $400M and a global contribution of twice this. Whilst this is only indicative, it does serve to illustrate the magnitude of the impact.

5. Sources to corroborate the impact

5.1 “Importance of handset antennas in the mobile phone system.” Supporting document by P.S Hall et. al

5.2 “Developments of the Birmingham dual band antenna concept for mobile phone handsets” Supporting document by P. S. Hall el. al.

5.3 Corroboration from the Head of Motorola Antenna Group, Florida, USA

5.4 Corroboration from the Sony Ericsson designated expert in terminal antenna technologies

5.5 “Value of inventions through Nokia products” Supporting document by P. S. Hall el. al.

5.6 Corroboration from independent expert of value calculations