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Antennas for next generation mobile communications

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In future mobile communications many antennas will coexist on the device. This creates a number of problems related to bandwidth, efficiency, and correlation. Remedies are discussed in the paper, and attention is called to the promising area of adaptive matching, which also can solve problems related to the user.

Keywords: antennas; mobile; millimeter

Antennen für die nächste Mobilfunk-Generation.

In der künftigen Mobilkommunikation werden mehrere Antennen auf einem Gerät vorhanden sein. Dies schafft eine Reihe von Problemen im Zusammenhang mit Bandbreite, Effizienz und Korrelation. Im vorliegenden Beitrag werden mögliche Lösungen diskutiert, wobei im Besonderen der zukunftsträchtige Bereich der adaptiven Anpassung betrachtet wird. Diese wird auch in der Lage sein, bestehende anwenderseitige Herausforderungen zu bewältigen.

Schlüsselwörter: Antennen; Mobilkommunikation; Millimeter

1. Introduction

Antennas 50 years ago were simple in principle, usually simple wire structures, which were difficult to analyze theoretically, and they were usually stationary. Designers were concerned with gain, side-lobe level and such point-to-point issues. The emerging satellite communications put high demands on the performance, but terrestrial mobile communications have changed all that. At least for the handsets the demands on the radiation pattern are minor; in fact the mean gain is unity in a completely random environment. The days of theoretical integral equation studies are over, in fact the present day numerical codes for solving complex electromagnetic structures are so efficient that they are used everywhere. The results are not questioned, which may be a problem in some cases, and physical insight is usually lost. In the present handsets multiple antennas are already there for diversity purposes and in the newest cases a moderate MIMO is introduced. The demands on antennas are shifting to system requirements on efficiency, bandwidth, MIMO related problems of coupling, user influence, and general integration of the antennas with the overall design. An integrated antenna couples to the complete device, so in fact it is more a coupler to the total device than an antenna in its own right. Measurement of the quality of the complete radio with antennas is a major test issue, and it is now realized that this must be an OTA (over the air) activity, testing the whole device with the integrated antennas. These developments will be briefly discussed in the paper together with a look at the development for very high frequencies.

New ideas continue to appear which is a healthy sign. As an example MAS (Massive Antenna Systems) is mentioned briefly, where maybe hundreds of antennas are applied on one base station. Metamaterials consist of many small components which seen as a macro material may have negative permittivity and permeability. Using metamaterials is a popular theoretical discipline; it still remains to be seen though, whether it is a fruitful way to go. Another, more questionable idea is the use of orbital angular momentum, a physics concept translated into the antenna field.

An alternative use of parasitic elements is to modulate them to create two different radiation patterns (*Alrabadi et al. 2012*), which allows a two-stream MIMO with only one RF source, Fig. 2.

The conclusion is that antennas for next generation mobile communications are a fertile and fruitful area of research and development. Developing antennas for millimeter and THz frequencies is a special challenge due to the high path loss for constant directivity antennas. Applying power modulations neglecting phase is one way forward.

2. Multiple antennas on handset

An early attempt of counteracting the influence of coupling may be found in *Andersen and Rasmussen* (*1976*) where additional coupling is introduced via a branch line. A more general approach is the so-called multiport conjugate match by *Wallace and Jensen* (*2004*). The introduction of these matching and decoupling networks have two drawbacks: they introduce additional losses and the resulting bandwidth may be quite small for closely spaced antennas. One simplification is to introduce a passive loaded parasitic element which may serve as a shield between two active antennas (*Lau and Andersen 2012*). The scattering from the passive element neutralizes the coupling; radiation patterns change, but as mentioned this is not important for the mean gain in a random environment. The narrow instantaneous bandwidth remains. The principle is shown in Fig. 1, where the tuning load on the parasitic element is chosen to be re-

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active to avoid additional losses. The dipoles are only generic, any antenna may be used.

Compact multiple antennas on a small device like a smartphone have inherently high coupling and low bandwidth. Making the system adaptive by applying tunable impedance matching may turn the disadvantage into an advantage: the narrow bandwidth reduces the coupling to the nearby frequency bands and by making the matching adaptive the system may have a wide total bandwidth, assuming
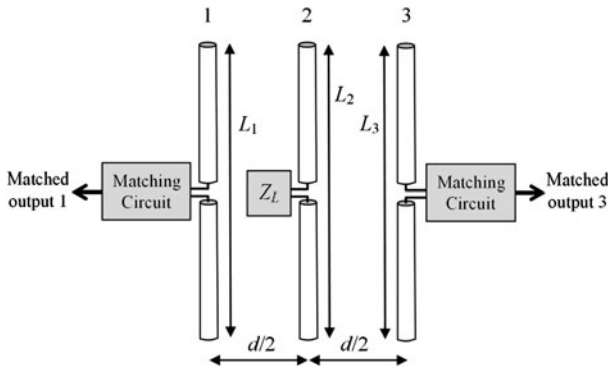
Fig. 1. Loaded parasitic center antenna neutralizes the coupling between the two edge elements
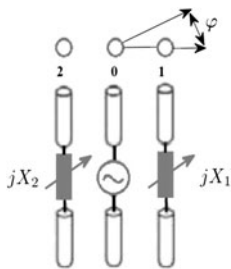
Fig. 2. Modulated parasitic scatterers allowing two data streams with one RF port (courtesy O. Alrabadi)

that the instantaneous bandwidth is sufficient, like 20 MHz (*Wispry 2012*). As seen from Fig. 3 the overall tunable range is 500 MHz.

The technology making this feat possible is MEMS (Micro Electro-Mechanical Systems) technology, a bank of capacitors is switched in to minimize insertion losses. MEMS devices have a wider field of applications, such as in ordinary phased arrays (*Haridas and Erdogan 2008*). It is noteworthy that such an adaptive system also is beneficial for the channel changes introduced by the hand and head of a user (*Pelosi et al. 2012*).

As far as test issues are concerned it is now realized that the electronics and antennas must be tested together over the air, OTA. Early days of doing this goes back to testing in an urban environment (*Andersen and Hansen 1977; Taga 1990*). Today it is more practical to test indoors in an artificial radio environment, in a reverberation chamber or an array surrounding the device in an anechoic room.

3. Unconstrained arrays

There are situations where the antenna elements are not constrained to the small volume of a mobile phone, and more 3D solutions may be pertinent. One such case is the MIMO cube (*Getu and Andersen 2005*) where all twelve edges of a cube are occupied by a dipole antenna. This arrangement gives in a completely random environment twelve orthogonal MIMO channels utilising all combinations of pattern diversity and space diversity. An 18-port compact antenna cube is realised by *Zheng et al.* (*2012*) with good results.

How many antennas can there be at a base station? The question has been addressed recently by a number of people under the heading MAS (Massive Antenna System), for an overview see *Rusek et al.* (*2013*). The number of antennas may be very large, maybe several hundreds, with the intention to accommodate multiple users with broadband data. This creates challenges in information theory, coding, signal processing and system design. According to the authors '*very large MIMO offers the unique prospect within wireless communication of saving an order of magnitude, or more, in transmit power. As an extra bonus, the effect of small scale fading averages out so that only the much more slowly changing large scale fading remains. Hence, very large MIMO has the potential to bring radical changes to the field*'.
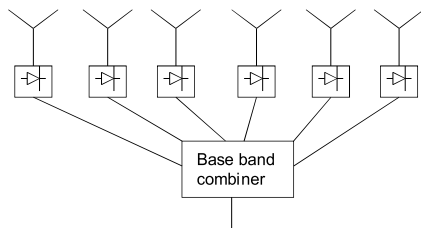
The physics community has launched the idea of a novel technique, different but similar to MIMO, and thus creating hopes for
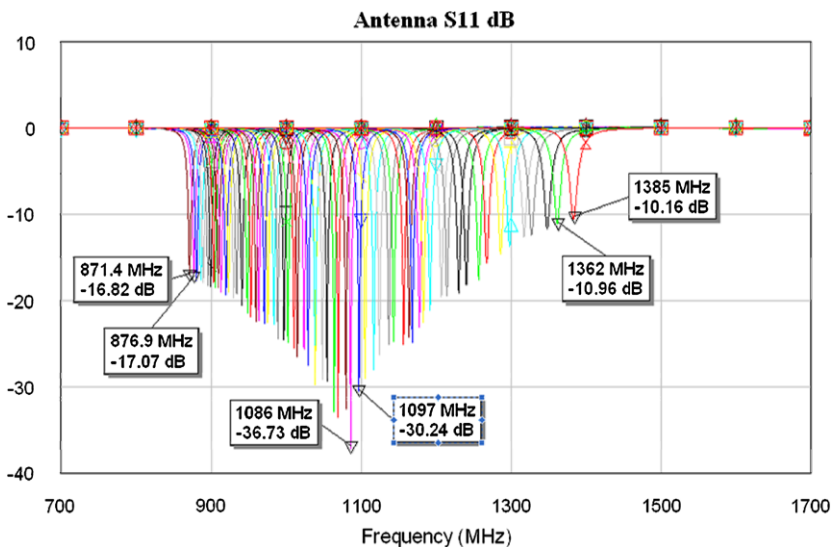
Fig. 3. Tunable impedance matching (Wispry) by tunable capacitors and MEMS technology
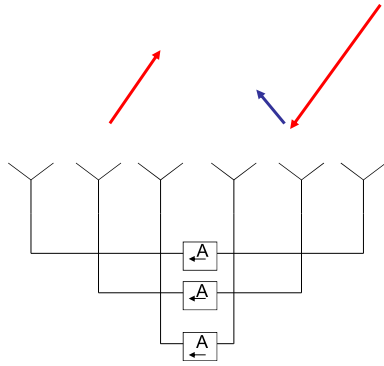
Fig. 4. Van Atta array with possibility of amplification and modulation

Fig. 5. An array of rectennas combined at baseband

even higher spectral efficiencies. Cross-fertilizations between different fields may be very productive, in this case between physics and engineering, which are very close, but still different mindsets. In the optical field Laguerre-Gaussian mode laser beams have an orbital angular momentum (OAM), where the different modes have phase variation, an integer number of 2π around the beam. This has been turned into Radio OAM by *Mohammadi et al.* (*2010*) and *Tamburini et al.* (*2012*). Whether this is different from ordinary MIMO has been questioned by *Edfors and Johansson* (*2012*).

4. Millimeter and Terahertz challenges

It is often mentioned that very high frequencies have a pathloss problem, following Friis' law for constant directivity, due to the small absorption area. Consider a reformulated version

$$\frac{P_r}{P_t} = \frac{A_1 A_2}{(\lambda R)^2} \tag{1}$$

where A is the antenna absorption area. For a given area the received power increases with frequency, so if large areas can be established, there is no pathloss problem.

The solution is simple if it is a question of LOS, two parabolic dishes facing each other would do. The problem is that we are interested in the case of non-stationary antennas, possible in a random environment. One solution would be the MAS mentioned above, where the area is divided into many small units which may be controlled in amplitude and phase. This is probably not economical. In order to establish a focused beam, it is necessary to phase conjugate the incoming signals and this can be done automatically by means of retrodirective arrays. An example is shown in Fig. 4 (*Andersen and Pedersen 2009*).

The three elements to the left are placed in the opposite order of those to the right, such that phase conjugation is achieved by

geometry alone. If used only as a retrodirective scattering array, it is called a van Atta array. The connecting lines must have the same electrical length.

At optical and infrared communications it is power communications which is possible, since phase is difficult to handle and highly variable. At millimeter and THz frequencies the same could very well be true and also acceptable since the bandwidths are so high that simple power modulation schemes will be sufficient, compared with more efficient phase modulations. The simplest power receiving antenna is the so called rectenna, a combination of a *recti*fier and an ant*enna*. The modulated signals are then combined after the rectifier. Work on rectennas goes back to the ideas of power transmission from solar panels in space, but recently there has been renewed interest in connection with powering sensors through the air. Conversion efficiencies from RF to DC (or baseband) of the order 50 % is possible. The sketch in Fig. 5 shows the idea (*Andersen and Pedersen 2009*).

5. Conclusion

A brief overview of some trends for antennas in mobile communications is presented. Multiple antennas in a small volume call for special aspects of decorrelation in order to make MIMO work. Relieved from the volume or area constraint there are new possibilities in having a massive number of elements, serving many users at the same time. Finally, the goal of multi-Gb/s systems will require increasing the carrier frequency considerably into the millimeter and THz region. Antennas that compensate for large pathloss are discussed.

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Authors

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received the M.Sc. and Dr. techn. degrees from the Technical University of Denmark (DTU), Lyngby, Denmark, in 1961 and 1971, respectively. In 2003 he was awarded an honorary degree from Lund University, Sweden. From 1961 to 1973, he was with the Electromagnetics Institute, DTU and since 1973 he has been with Aalborg University, Aalborg, Denmark, where he is now a Professor Emeritus and a consultant.
He has been a Visiting Professor in Tucson, Arizona, Christchurch, New Zealand, Vienna, Austria, and Lund, Sweden. From 1993 to 2003, he was Head of the Center for Personkommunikation (CPK), dealing with modern wireless communications. He has published widely on antennas, radio wave propagation, and communications, and has also worked on biological effects of electromagnetic systems. He was on the management committee for COST 231 and 259, a collaborative European program on mobile communications. Professor Andersen is a Life Fellow of IEEE and a former Vice President of the International Union of Radio Science (URSI) from which he was awarded the John Howard Dellinger Gold Medal in 2005.

Gert Frølund Pedersen
was born in 1965 and is married to Henriette and have 7 children. He received the B.Sc. E. E. degree, with honour, in electrical engineering from the College of Technology in Dublin, Ireland, and the M.Sc. E. E. degree and Ph.D. from Aalborg University, Denmark, in 1993 and 2003, respectively. He has been with Aalborg University since 1993 where he is now Full Professor heading the Antenna, Propagation and Networking LAB with 36 researchers. Further he is also the head of the doctoral school on wireless communication with some 100 Ph.D. students enrolled. His research has focused on radio communication for mobile terminals especially small Antennas, Diversity systems, Propagation and Biological effects and he has published more than 175 peer reviewed papers and holds 28 patents. He has also worked as consultant for developments of more than 100 antennas for mobile terminals including the first internal antenna for mobile phones in 1994 with lowest SAR, first internal triple-band antenna in 1998 with low SAR and high TRP and TIS, and lately various multi antenna systems rated as the most efficient on the market.
He has worked most of the time with joint university and industry projects and have received more than 12 M $ in direct research funding. Latest he is the project leader of the SAFE project with a total budget of 8 M $ investigating tunable front end including tunable antennas for the future multiband mobile phones.
He has been one of the pioneers in establishing Over-The-Air (OTA) measurement systems. The measurement technique is now well-established for mobile terminals with single antennas and he was chairing the various COST groups (swg2.2 of COST 259, 273, 2100 and now ICT1004) with liaison to 3GPP for over-the-air test of MIMO terminals.