Application

Vetenskapsrådet

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Information about applicant

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Information about application

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Funds applied for

Year:	2016	2017	2018	2019
Amount:	900,700	910,100	950,400	976,600

Descriptive data

Project info

Project title (Swedish)*

Tidsdomänen Antenn Karakterisering för Applicering på UWB och Små Antenner

Project title (English)*

Time Domain Antenna Characterization for Application to UWB and Small Antennas

Abstract (English)*

Antennas are a very important component of communication systems for transmitting and receiving signals. Traditionally, antennas are mostly evaluated with frequency domain parameters such as return loss, radiation patterns, gain and efficiency. However, the knowledge on antenna characterization in the time domain is quite limited, though it is of significance for both wireless communication and radar. Time-domain distortions in the received signals of the system can lead to more errors and reduce the data rate of wireless communication. For radar systems, dispersion and ringing effects can deteriorate the resolution of detection and accuracy of localization. Moreover, the time constant for the antennas to reach the steady state is important to reconfigurable antennas. In this project, we will characterize antennas in the time domain based on characteristic mode (CM) expansion, and apply the technique to optimise the design of UWB and electrically small antennas.

The time plan and method for the 4-year project are given as follows:

Year1-2: We will build the time domain model of antennas based on CM expansion. We use the theory of CM because the modes are excitation independent, so that we can separate the time domain response inherent to the antenna structure from the influence of the external excitation. We will describe antenna as a linear system, whose time response is the superposition of the response of each mode. With the extension of our in-house method of moment (MoM) code in Matlab, we will computationally calculate the transfer function of each mode, and get the impulse response using Fourier transform.

Year 3: We will optimise UWB antennas in the time domain using the results from the previous task. Since UWB antennas normally excite many modes across the bands, we will first identify the contribution of each mode to the final response and select the ones with higher modal significant to optimise. Then we will synthesis the antennas by designing the feed to excite the modes with high fidelity factor. For band-reject UWB antennas, we will modify the notch structure to manipulate the modes and reduce the influence of the notches.

Year 4: We will analyse and reduce the time constant of electrically small antennas, which store energy in the near field due to the strong resonance of the structure. We will first calculate the impulse response of the main radiating mode for lossless antennas, and find the optimal feed to achieve the smallest time constant. Then, we will generalise the transient mode study to lossy antennas, and analyse the relationship between material loss, Q factor and the transient effect of modes. A circuit model will be developed according to CM analysis, based on which excitation can be determined to achieve the smallest possible time constant.

For all the above mentioned antennas, we will perform simulation, fabricate the prototypes for representative cases, and do experiments to validate our methods. We will also put our designed antennas in radar application to test the resolution improvement. We have commercial electromagnetic simulation software CST Microwave Studio, COMSOL and FEKO, as well as in-house facilities for antenna fabrication (e.g., mechanical workshop and chemical laboratory) and antenna pattern measurements.

We believe that support for such a project will contribute greatly to the scientific progress in this field of growing importance. In the long run, it is also expected to have a significant impact on the development of Swedish wireless communication and radar technologies.

Popular scientific description (Swedish)*

Antennen är en av de viktigaste delarna i system för trådlös kommunikation och radar, som sänder och tar emot elektromagnetiska vågor. Traditionellt utvärderas antenner med frekvensdomänparametrar som reflektionsförlust, strålningsmönster, förstärkning och effektivitet. Dock är kunskap om antenners beteende i tidsdomänen också viktigt inom en stor spännvidd av områden som trådlös kommunikation, radar och internet of things (IoT). Antenner med liten signaldistorsion kan leda till lägre felfrekvens och således en utökad datahastighet. Placering av objekt och lokaliseringsnoggrannhet inom industrin förlitar sig också på beteendet hos antenner i tidsdomänen. IOT kräver enhet till enhet kommunikation med låg latens, där tidskonstanten av antenner är viktig.
Det förekommer lite forskning om att karakterisera antenner i tidsdomänen. Speciellt har ingen ansträngning gjorts att använda teorin om karakteristiska moder i tidsdomänen för att analysera EM spridning och strålning. I detta projekt kommer vi karaktärisera och optimera antenner i tidsdomänen baserat på karakteristiska moder expansion, och tillämpa teknik för att optimera utformningen av UWB och elektriskt små antenner.
Vi kommer vara de första att bygga en linjär tidsdomänmodell baserat på teorin om karakteristiska moder för att särskilja bidrag av extern excitation från en antennstruktur. Vi kommer att beskriva antennen som ett linjärt system, vars tid är en överlagring av svaret av varje läge. Genom utbyggnad av en egen befintlig momentmetodskod (MoM) i Matlab kommer vi att beräkna överföringsfunktionen för varje steg, och extrahera systemets impulssvar med hjälp en Fouriertransform av signalen. Baserat på detta kommer riktlinjer att ges till antenningenjörer så att de kan utforma antenner på ett systematiskt tillvägagångssätt.
Vi kommer att tillämpa vår metod för att optimera ultra-bredbandiga antenners fidelity factor i tidsdomänen. Eftersom ultra-bredbandiga antenner normalt exciterar många moder över frekvensbanden, kommer vi först identifiera bidraget från varje mod för att sedan välja ut de mest betydande moderna för slutoptimering. Då kommer vi att syntetisera antenner genom att utforma matningen och excitera moder med fidelity faktor. För bandstopp ultra-bredbandiga antenner, kommer vi att ändra notchstrukturen genom att ändra moden och minska påverkan av notcherna.
Slutligen kommer vi analysera och reducera tidskonstanten för elektriskt små antenner, som lagrar energi i närfältet på grund av strukturens starka resonans. Vi kommer först att beräkna pulssvaret hos huvudloben för en förlustfri antenn, och att hitta den optimala matningen för att uppnå en minimal tidskonstant. Vi kommer att generalisera vår transienta modstudie till antenner med förluster, och analysera förhållandet mellan materialförluster, Q-faktorn och övergående effektlägen. En kretsmodell kommer att utvecklas genom analys av karakteristiska moder, baserad på vilken excitation som ger minsta möjliga tidskonstant.
För alla de ovan nämnda antennerna kommer vi att utföra simuleringar, tillverka prototyper för representativa fall och göra experiment för att validera våra metoder. Vi kommer också att sätta våra utformade antenner i radarsystem för att testa om systemupplösningen förbättras. Vi har tillgång till kommersiella elektromagnetiska simuleringsprogram som CST Microwave Studio, COMSOL och FEKO, samt in-house möjligheter för antenntillverkning (t.ex. mekanisk verkstad och kemisk laboratorium) och antennmönstermätningar.

Project period

Number of project years*

4

Calculated project time*

2016-01-01 - 2019-12-31

Deductible time

Deductible time

	Cause	Months
1	Parental leave	6
	Total	6

Career age: 27

Career age is a description of the time from your first doctoral degree until the last day of the call. Your career age change if you have deductible time. Your career age is shown in months. For some calls there are restrictions in the career age.

Classifications

Select a minimum of one and a maximum of three SCB-codes in order of priority.

Select the SCB-code in three levels and then click the lower plus-button to save your selection.

SCB-codes* 2. Teknik > 202. Elektroteknik och elektronik > 20203. Kommunikationssystem

Enter a minimum of three, and up to five, short keywords that describe your project.

Keyword 1*

antenna characterization

Keyword 2*

time domain analysis

Keyword 3*

theory of characteristic mode

Keyword 4

UWB antenna

Keyword 5

electrically small antenna

Ethical considerations

Specify any ethical issues that the project (or equivalent) raises, and describe how they will be addressed in your research. Also indicate the specific considerations that might be relevant to your application.

Reporting of ethical considerations*

The research does not raise any ethical issues.

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

Time Domain Antenna Characterization for Application to UWB and Small Antennas

1. Purpose and Aims

Antennas are a very important component of communication systems for transmitting and receiving signals. As a traditional topic in the field of electromagnetic (EM), antennas are normally studied and analysed in the frequency domain and characterized by parameters such as return loss, gain, directivity and polarization etc. However, the knowledge on antenna characterization in time domain is quite limited, though it is of significance for both wireless communication and radar applications. The data rate of wireless system will be reduced if the original signal is widened by the receiving antennas or when the ringing effect is severe. Similarly, those factors will also affect the resolution of radar and accuracy of localization.

State-of-the-art analyses on antennas in the time domain mostly focus on calculating the fidelity factor of small UWB antennas [1], [2]. Yet, it is always a post processing after the antenna is designed, i.e., it is a trial and error procedure to obtain high fidelity factors. For small antennas, stored and radiated energies in the time domain have been characterized [3]-[5]. However, a similar lack of design guideline exists, and more figures of merit concerning different scenarios are needed.

The project requests a 4-year grant for research on time domain antenna characterization and optimization based on characteristic mode (CM) expansion, and its novel applications in UWB and electrically small antennas. The specific aims are

1. Characterizing antennas in the time domain with CM expansions. The advantage of CM expansion is that the modes compose a complete set to describe the antenna, with each mode excitation independent. Thus, we can separate the time domain response inherent to the antenna structure from the influence of the external excitation.
2. Increasing the fidelity factor of UWB antennas by synthesizing the feed structure. Increase the fidelity factor of band-reject antennas by co-designing the notch structures with original antenna element and the excitation method. Those are based on the selection of modes and the near field properties of modes.
3. Optimizing the time constant of small antennas for antenna switching, taking into account the dielectric loss of the antennas. This will be achieved first by analyzing the main mode and calculating the lower bound of the time constant, and then building circuit model of the main mode for matching purposes.

We are well positioned to take on this exciting and challenging project, with 7 years of experience in the theory of characteristic mode and antenna designs.

2. Survey of the Field

Antenna behavior in the time domain is quite important for wireless communication and radar applications. The distortion between transmit and receive signals can lead to high error rate and reduce the data rate of communication. For UWB antennas which are used as part of radar to detect hidden objects (e.g., landmines or concealed weapons) or diagnose cancers, well-behaved time domain performance is required for achieving high resolution. Even for electrical small antennas with narrow band operation, the transient response of the antenna is of significance in a fast time-varying scenario [6]. For example, when a reconfigurable antenna is switched between frequency bands or beam directions, a comprehensive knowledge of antenna behaviour in the time domain is required, especially when the switch period is on the order of the time constant of the system. CM, as a powerful tool for designing antennas, is a good candidate for antenna analysis in the time domain, but it has not been extended to time domain before.

(1) Theory of characteristic mode

The theory of characteristic mode (TCM) was first introduced by Robert Garbacz et al. [7] and later refined by Roger Harrington et al. [8]. It is an attractive framework for analysis and design of antennas due to two important properties. First, the modes are excitation independent, meaning that they are inherent to geometry and material properties. This provides a systematic approach for designers to first analyse the modes and then design feedings to excite the desired modes and suppress the undesired mode. Due to this property, TCM has been used for antenna pattern synthesis [9] and shape synthesis [10].

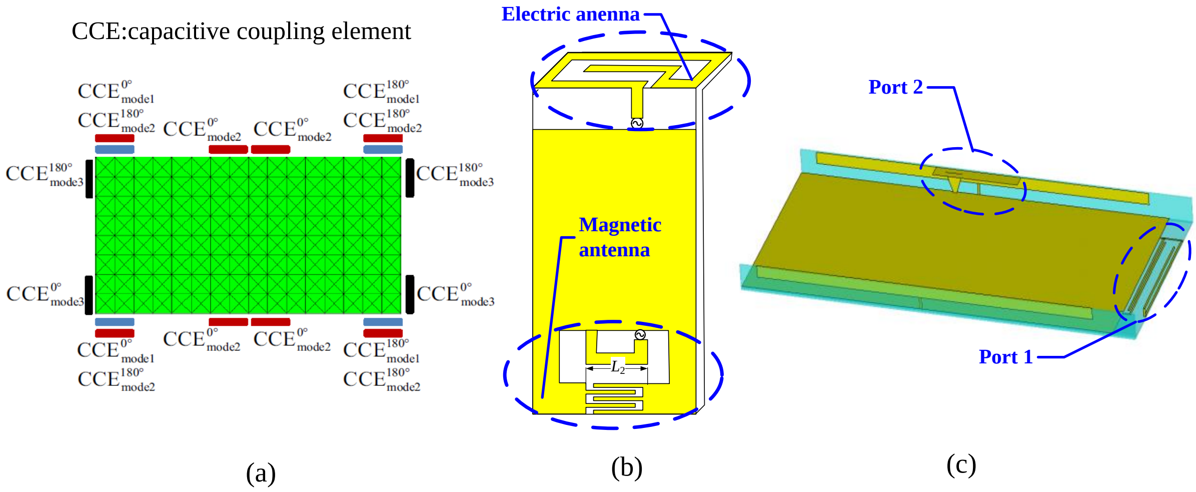


Fig. 1 (a) Non-resonant capacitive feeding for orthogonal mode excitation; (b) Electric and magnetic antennas on the chassis for mode excitation and suppression; (c) Optimized ports for excitation of mutual orthogonal dipole modes.

The second property is the orthogonality of the eigencurrent and eigen farfield between modes for lossless structures. Based on this property, quite a few MIMO antennas have been designed [11]-[16] with low correlation, low mutual coupling and high efficiency. During the design, it is critical to determine the feeding method, which by itself is a research topic. A non-resonant coupling element is a good candidate for feed realization due to its compactness. In [12], four orthogonal modes have been excited at 2.5 GHz by four compact non-resonant capacitive couplers located at four vertices of the chassis. In [12], inductive and capacitive coupling approaches were compared, and their design of capacitive feeding is shown in Fig. 1 (a). It is seen that an extra feeding network is required to excite the modes, which is a common drawback of using non-resonant elements, leading to high loss and low efficiencies. To avoid this, real antennas were used in mode realization [14] as in Fig. 1 (b). The monopole is used as an electric antenna to excite the fundamental CM, while the loop as a magnetic antenna suppresses the mode excitation. In [16], proper structure modification and feed optimization even generated new modes, with port 1 and port 2 exciting the mutual orthogonal dipole modes along the length and width of the chassis, respectively (see Fig. 1(c)). The orthogonality property has also been applied to reconfigurable antennas [16], [17] and multiband applications [19].

However, to the applicant's knowledge, only frequency response of the modes has been analyzed in the literature, and no attention is paid on its behaviors in the time domain. The proposed research will build antenna systems with CM expansion in the time domain, analyze transient modal behaviors and establish new feeding guidelines.

(2) Antenna characterization in the time domain

Traditionally, most of the antennas are evaluated with frequency domain parameters such as return loss, radiation patterns, gain and efficiency. According to the Maxwell equations, radiated EM fields are derived from the differentiation of the current/charge distribution of antennas. For UWB antennas, due to the broad frequency band, its current distribution and thus the radiated field changes over the operating bands. This results in distortion of the received signal from the transmitted signal, described by the term of *fidelity factor*, which has been widely studied in the literatures, e.g., in [1] and [2]. Other than this, signal dispersion and ringing effects are also quite important. However, there is no systematical study or guideline on how to increase the fidelity factor by optimizing antennas or feeding structures.

Band-reject UWB antennas have attracted significant attention in recent years [21]-[23], which are alternative choices to mitigate the potential interference but also to remove the requirement of extra filters in the UWB system. Reduction of the antenna fidelity factor has been reported [23] due to the notched structure of the antennas, which disturbs the current distribution. There is still lack of insight on how energy flows in the notches and how negative effects can be mitigated by rigorous co-design of notch structure, antenna structure and feeding.

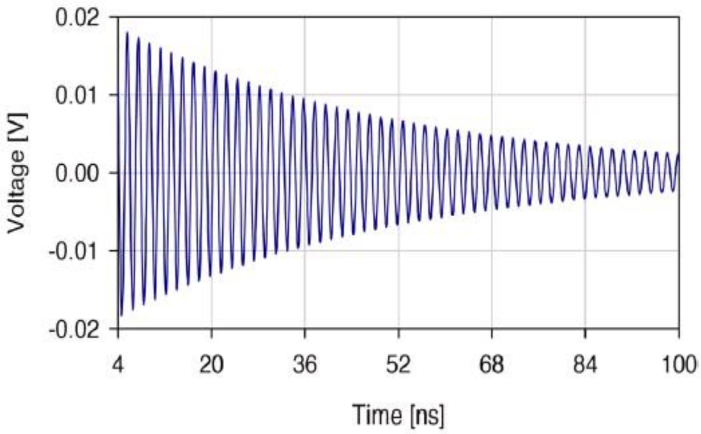


Fig.2 Reflected voltage at port for PIFA with Q factor of 78

For electrically small antennas, the transient effect is important for antenna switching. As the size of the antenna decreases, its Q factor increases. Energy is stored either as magnetic energy or electric energy in the near field. The radiating procedure of antenna is such that, when the signal is input into the antenna, a certain amount of energy is first accumulated in the near field before it reaches to far field. The higher the Q factor is, the longer it takes for the far field pattern to build up. The time it takes for the far field to get its maximum value is called the time constant. The time constant can also be represented by decay of reflected voltage at the antenna port. As shown in Fig. 2, for a planar inverted-F antenna (PIFA) with Q factor of 78, it takes 100 ns for the reflected voltage at the port to decay to 10%. Though a lot of researches have been carried out on reactive energies and Q factors in the frequency domain, only a few papers deal with stored energy in the time domain [3]-[5], [24]. A combination of the Poynting theorem in frequency and time domain has been used to separate electric and magnetic energy and derive the Q factor in [24]. In [5], reactive energy is studied fully in the time domain by decomposing the field into spherical modes. In order to obtain deeper understanding of time domain character and reduce oscillation, more studies, e.g., the relationship between time constant and antenna loss, are needed.

3. Project Description

The response of antennas in the time domain is quite significant for 1) UWB antennas for communication, radar or positioning application; 2) antennas operating in time varying environments even for narrow band antennas. The proposed project aims at characterizing antenna behaviors in the time domain based on CM expansion, and further applying the analytical results to optimize the transient effect and improve the system performance in the time domain. The project includes the tasks as follows.

(1) Build characteristic mode based antenna models in the time domain

CM theory is a powerful tool in electromagnetics. According to the theory, any current on a structure can be decomposed to an orthogonal set of weighted mode currents over the surface. Attractively, those mode currents are inherent to the structure's shape and material and independent of external excitations. This gives insight into the electromagnetic characteristic of the structure itself. *However, to the applicant's knowledge, CM analysis has only been carried out in frequency domain. This task aims at transforming mode analysis into the time domain.*

The mode current of a conducting body can be solved from the following eigenvalue equation

$$X(\vec{J}_n) = \lambda_n R(\vec{J}_n), \tag{1}$$

where R and X are the real and imaginary part of the impedance operator Z. λ_n and $\vec{J}_n$ are the eigenvalues and eigenfunctions (eigencurrents), respectively. Each eigenvalue represents the ratio of the stored reactive power (P_{stored}) to the radiated power (P_{rad}) of each mode

$$\lambda_n = \frac{P_{stored}}{P_{rad}} = \frac{\left\langle \vec{J}_n^*, X\vec{J}_n \right\rangle}{\left\langle \vec{J}_n^*, R\vec{J}_n \right\rangle} \tag{2}$$

where $\left\langle \vec{B},\vec{C} \right\rangle = \oiint_S \vec{B}\bullet\vec{C}\, ds$. The stored energy is related to the Q factor in the frequency domain, which determines the early response of the antenna in the time domain when excited. As mentioned before, any current distribution on the surface can be expanded with mode current:

$$\vec{J} = \sum_n \alpha_n \vec{J}_n = \frac{\left\langle \vec{J}_n, \vec{E}^i \right\rangle}{1 + j\lambda_n} \vec{J}_n . \tag{3}$$

In this equation, α_n is modal excitation coefficient, determined by the external fields or voltage. Due to the linearity between current and field, the total field can also be expressed in a similar modal form.

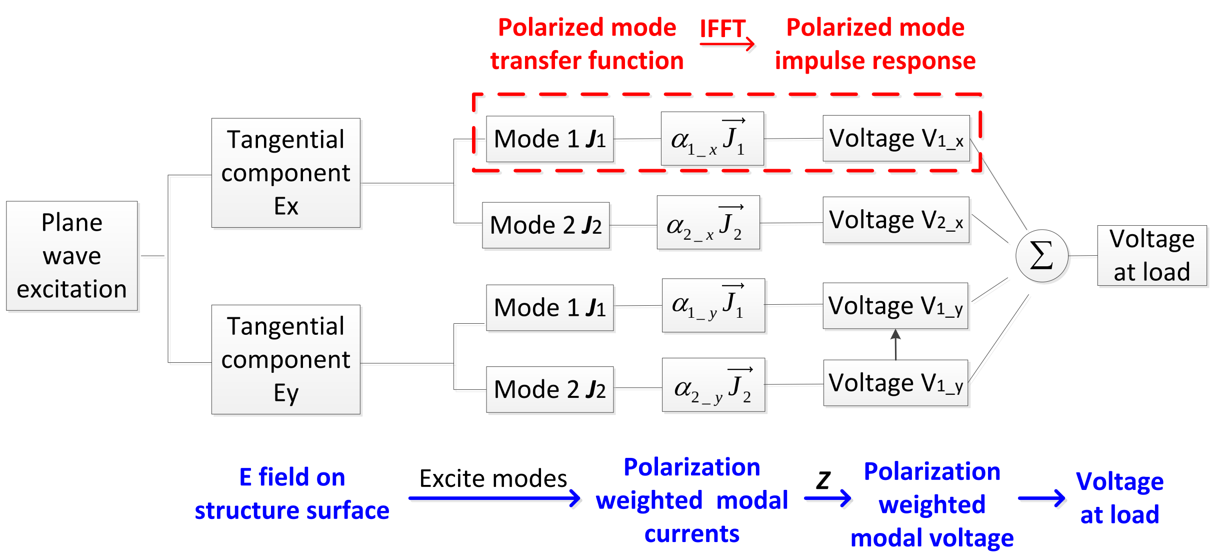


Fig.3 Sketch description of the procedure to obtain mode impulse response.

In order to analyze different modes in the time domain, i.e., finding the impulse response of each mode, we will first describe the antenna system as a linear system in terms of modes, and then focus on key technologies in each component. A sketch description on how we will obtain the impulse response of CMs is shown in Fig. 3. For simplicity without loss of generality, it is assumed that there are two main CMs at the bands of interest and the excitation is plane wave in the far field region of the antenna. Since the antenna is a reciprocal system, the internal voltage excitation should work in a similar manner.

According to the flow in Fig. 3, we will try to accomplish this task in the following steps:

1) Finding the tangential component of the incident *E* field on the antenna surface. This is the prerequisite for calculating modal coefficients according to Eq. (3); Decomposing the *E* field into orthogonal polarizations (e.g., *x* and *y* polarization), which ensures the linearity of the system;
2) Calculating the modal excitation coefficient weighted by polarizations according to Eq. (3). We will first track the mode over frequency, and an extension of the existing method of moment (MOM) code will be developed.
3) Calculating the response, i.e., the voltage at the predefined antenna port, of each mode due to the polarized *E* field. This voltage will be calculated from impedance matrix *Z* and weighted modal current from step 2), including both the amplitude and phase information.
4) Obtaining the transfer function of each polarized mode. With plane wave excitation and voltage response information, the transfer function of each polarized mode will be calculated, which is excitation independent. Afterwards, an inverse Fourier transform will be performed to get the impulse response of the mode. The linearity of the antenna system will be re-checked by summing up the impulse response and comparing it with the total response.

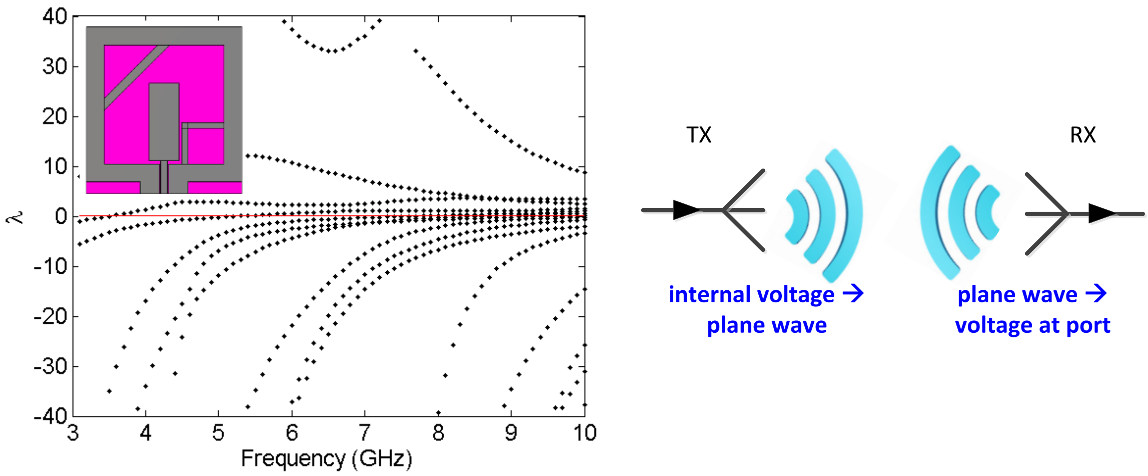
In the abovementioned steps, steps 2) and 3), which are in the red dashed frame in Fig. 3, are important and challenging parts. The modes need to be tracked correctly, which is especially difficult for UWB antennas with lots of modes. Also port impedance needs to be taken into the impedance matrix Z of the meshed structure, and voltage is polarization dependent. Other than this, the reciprocal procedure with voltage as the excitation needs to be considered and evaluated.

(2) Design UWB antennas with optimized behaviour in time domain

All the distortions of signal over time, i.e., pulse fidelity factor, dispersion and ringing effect, will reduce the communication data rate and deteriorate the resolution of UWB radar and localization accuracy. *This task aims at 1) analyzing the behavior of each decomposed mode in time domain 2) selectively exciting the modes with higher quality by optimizing the feeding method or antenna resonating structure.* The steps will be as follows:

Identify modes of importance. With TCM analysis, a lot of modes are available to resonate in an UWB antenna. As presented in Fig. 2 (a), more than ten modes are observed for a circularly polarized UWB antenna shown in the inset of the figure. Hence, it is important to identify the modes with more contributions. We will calculate the modal significance in the time domain and analyze how each mode is related with the total impulse response. The modes with more energy on the ringing effect, rather than the main signals, will be removed from the importance list.

Optimize modal excitations. Based on the results of the mode impulse response in task (1) and mode significance in the time domain, excitations of antennas will be optimized for better time domain behavior. Fig. 4 (b) gives a schematic diagram on the fidelity factor measurement carried out on the boresight of the antenna, where the voltage of Tx and Rx antennas are correlated in time domain. For the Rx end, the procedure is the same as described in Fig. 3, whereas it is the reciprocal procedure for the Tx end. Thus, we will carry out mapping between plane wave and voltage at ports. Also the fidelity factor of each mode will be evaluated using the impulse response of modes obtained from task (1). Afterwards, the feeding of the UWB antenna will be designed to selectively excite the modes with higher fidelity factor and mode significance. However, mode selection might affect the achievable bandwidth of UWB antennas. Hence, trade-off performance is expected, and iterative assessment will be needed.



(a) (b)

Fig. 4 (a) Eigenvalues of circularly polarized UWB antenna over frequency (b) Schematic diagram of fidelity factor measurement of UWB antenna.

Design notches for band-reject antennas. Notches in band-reject antennas always store energy in themselves and change the current distributions over the antenna surface. This will result in ringing effects and reduction of the fidelity factor [23]. However, there exists no guideline on how to reduce the influence of notches. In our research work, we will firstly evaluate how the original modes of UWB antennas are disturbed and re-shaped by the notch. Different notch structures will also be analyzed independently and compared to retain insight into their characteristics in the time domain. Notches will be modified and co-designed with UWB structure to manipulate the modes of antennas for higher fidelity factor.

(3) Analyse and improve transient behaviour of small antennas

Unlike UWB antennas, electrically small antennas normally rely on only one or two CMs to radiate, and the time constant of the modes is an important figure of merit in the time domain.

Study the transient behavior of modes. Following the procedure in Fig. 3, the impulse response of the main mode will be calculated. The time constant of the mode will be defined and described.

Generalize transient mode study to lossy materials. Most small antennas, especially the ones based on LC resonances, are printed on dielectrics, which are lossy in practice. We will analyse the relationship between material loss, Q factor and the transient effect of modes. Since modes are excitation independent, we will establish the relationship quantitatively. According to Eq. (2), eigenvalue defines the ratio between the net stored energy and the dissipated energy. It is different from, but related to the Q factor of the mode. We will evaluate how the eigenvalues are changed by different levels of material loss and how those eigenvalue curves affect the time constant of the modes. Those analyses will rely on the further development of our in-house Matlab code for CMs in lossy materials, and part of them will be carried out in EM simulation software FEKO.

Reduce time constant of lossy antennas. Just as with the excitation independent property of the Q factor, the time constant we obtained from CMs is also excitation independent, meaning that it provides the shortest time constant ever achievable. Thus, we will work on feeding methods to approach this limit. We will first describe the mode transient behavior in a circuit modal as accurately as possible, and obtain the optimal port impedance analytically. Afterwards, a feeding network will be applied to realize the impedance matching.

As a final step, for all the above mentioned antennas, we will perform simulation, fabricate the prototypes for representative cases, and do experiments to validate our methods. We will also apply our designed antennas to radar to test the resolution improvement. We have commercial electromagnetic simulation software CST Microwave Studio, COMSOL and FEKO, as well as in-house facilities for antenna fabrication (e.g., mechanical workshop and chemical laboratory) and antenna pattern measurement.

Time Plan

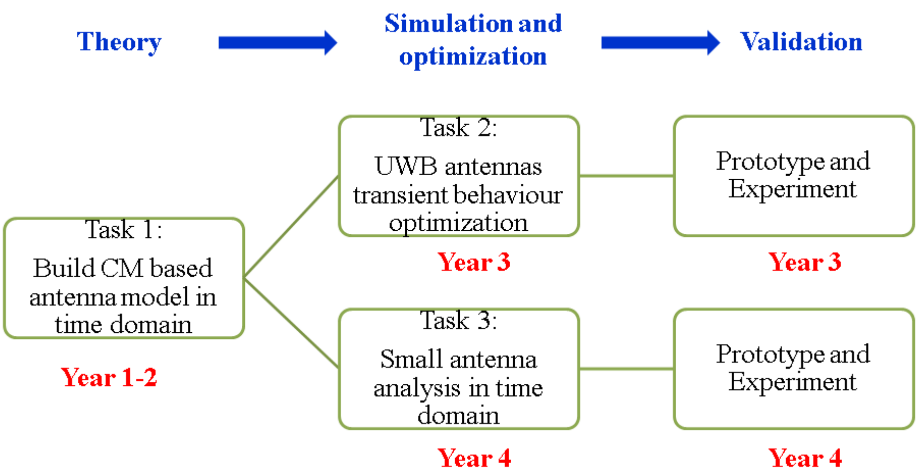


Fig. 5. Summary of the project components and time plan as a flowchart.

The summary of the project and the time plan is shown in Fig. 5. The project will mainly involve the applicant and a PhD student in the group. In each year, the applicant and the PhD student will spend 20% and 80%, respectively, in the research project.

4. Significance

The long-term impact of this project is far-reaching, both from the scientific aspect and application aspect. According to our knowledge, no effort has been made in using TCM in time domain to analyze EM scattering and radiations. It opens an opportunity for us to make solid contribution to the basic science in electromagnetics. We will be the first to build a linear time domain model based on CM theory so that we can separate contribution of external excitation from antenna structure. Based on this, guidelines will be provided for antenna engineers and designers so that they can design antennas in a systematic approach.

Apart from this, the time domain analysis and its antenna applications have a very large span of applications in fields such as wireless communications, radar and internet of things (IOT). Antennas with good time domain behavior can lead to lower error rate and thus increase the data rata. In industry, positioning of objects and localization accuracy also rely on the behavior of antennas in the time domain. The IOT requires device to device communication with low latency, where the time constant of antennas is important. Medical applications, especially when using antennas to diagnose diseases, will also benefit.

We believe that support for such a project will contribute much to our progress in this field of research, and provide new ideas and technical breakthroughs in this important technology. It will have a lasting impact on the level of competence in Sweden in a field with many applications.

5. Preliminary Results

The applicant has deep knowledge in TCM and has developed the program code to calculate the modes in Matlab based on the method of moments (MOM). With the in-house code, we have analyzed antenna structures and designed several CM based MIMO terminals for mobile handsets. Our focus has been in low frequency bands below 1 GHz, which is challenging due to the small size of mobile chassis. The study on low frequency MIMO antennas was first carried out in detail by us in [11], and some tradeoff has been investigated. We have also investigated the impact of antenna current localization on CM. Regarding CM excitations, electric and magnetic antennas have been employed to effectively explore or suppress certain CMs [14]. Furthermore, recently we made successful attempts to manipulate and create modes by changing the antenna structure at certain locations [16], [25]. Fig. 6 (a) shows one example of a T-shape loaded chassis, which increased the number of resonating modes from one to three at frequency below 1 GHz by adding two T strips along the length of the chassis. Effective methodologies have also been developed by us to design pattern reconfigurable antennas at low frequency [17] and multi-band antennas [20].

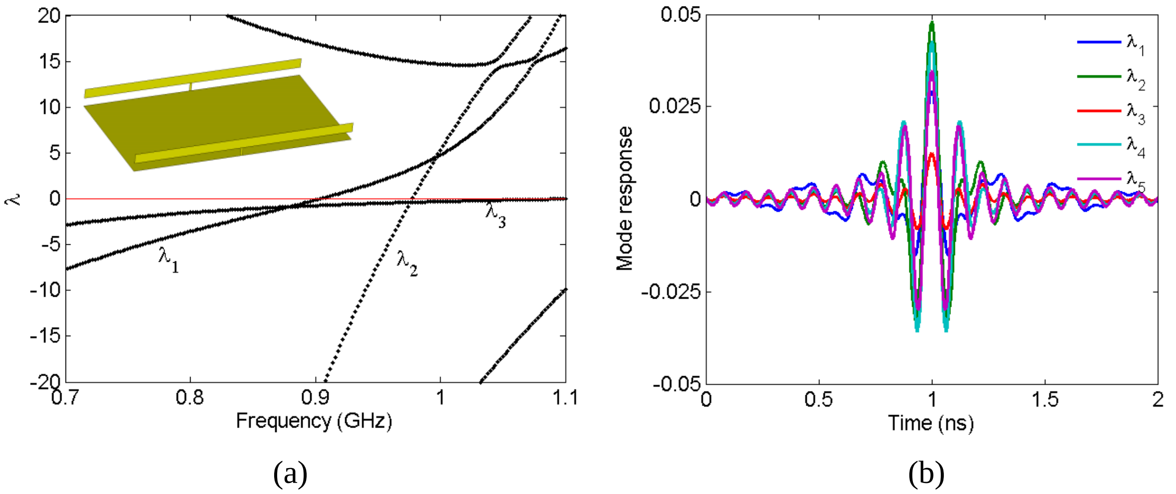


Fig. 6. (a) Example of chassis modifications with 3 resonant modes available below 1 GHz; (b) Modal significance of UWB antennas in the time domain.

We have also obtained some preliminary results for electrically small antennas, which will be directly applied to, or be a good candidate for, transient analysis of high Q antennas. An extremely compact capacitively loaded PIFA for dual band operation has been designed in [26], where strong resonance has already been observed. In [27], by utilizing metamaterials (a double-positive (DNG) and epsilon negative (ENG) metamaterial), we have proposed an extremely small patch antenna with high efficiency. The resonance principles are different for those two sub-wavelength antennas, providing good reference for transient analysis for comparison.

Recently, we have performed extensive simulation studies on UWB antennas for chipless RFID application, where different levels of signal distortion and ringing effects have been observed for different UWB antennas. To analyse the contribution of each mode in the received signal, Fourier transforms were performed on model significant of first five modes. The result is shown in Fig. 6 (b). It is observed that modes contribute to the signal on different levels, and some modes follow the shape of the final received signal more closely than the others. This confirms that CMs in the time domain can provide useful information on optimizing the behaviour of the system in the time domain.

6. Independent line of research

Although being part of and cooperating within a research group, I have a well-defined project of my own. The present project is based on similar techniques and tools, which I used during my PhD project, yet here the project has switched focus from frequency domain analysis to time domain behaviors, which is a quite different topic by itself. My former supervisor, Prof. Sailing He, is continuing his work on MIMO antennas and metamaterial antennas. My present group leader, Prof. Buon Kiong Lau, has a VR grant “Novel Antenna System Design Paradigm for High Performance Mobile Communications”, which works on the interaction between antennas and channels in frequency domain. My project is focusing on time domain characterization of antennas, and thus complements the existing project without overlapping.

Furthermore, I am currently co-supervising a PhD-student in the field of antennas, and have supervised 3 master students. Additionally, I teach the compulsory master course ‘Multiple antenna systems’, and have gained industrial experience from cooperating with Sony Mobile in Lund.

7. Form of employment

I presently have a 2-year employment as post-doc, which is supported by our eLLIIT grant that is based on my scientific and pedagogic merits. If the present application succeeds, there will be at least a 4-year contract from 2016-01-01 to 2019-12-31, supported together with eLLIIT grant. The applicant will then be 100% employed by Lund University.

8. International and National Collaborations

The applicant mainly belongs to the Communications Engineering Group in the department, in which Prof. Buon Kiong Lau works on both antennas and channels. We also have strong link to the Electromagnetic Theory Group, represented by Prof. Mats Gustafsson, which can be used as a resource as the technologies advance. We have close collaboration with Sony Mobile Communications AB, Lund on various aspects of terminal antenna-related research. Good collaborations are also maintained with Prof. Sailing He in KTH.

Internationally, we have strong collaboration with the company of ART-Fi in Paris, France, represented by Benoit Derat, who is a specialist in electromagnetics, small antennas and near-field interactions. We also have good collaboration with Prof. Xianqi Lin and Prof. Jiangxiong, who are experts in circuit modeling and electrically small antennas, respectively, in University of Electronic Science and Technology of China.

9. References

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[22] M.-C. Tang, S. Xiao, T. Deng, D. Wang, J. Guan, B. Wang, and G.-D. Ge, “Compact UWB antenna with multiple band-notches for WiMAX and WLAN,” *IEEE Trans. Antennas Propag.*, vol. 59, no. 4, pp. 1372–1376, Apr. 2011.

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Interdisciplinarity

My application is interdisciplinary

☐

An interdisciplinary research project is defined in this call for proposals as a project that can not be completed without knowledge, methods, terminology, data and researchers from more than one of the Swedish Research Councils subject areas; Medicine and health, Natural and engineering sciences, Humanities and social sciences and Educational sciences. If your research project is interdisciplinary according to this definition, you indicate and explain this here.

Click here for more information

Scientific report

Scientific report/Account for scientific activities of previous project

Budget and research resources

Project staff

Describe the staff that will be working in the project and the salary that is applied for in the project budget. Enter the full amount, not in thousands SEK.

Participating researchers that accept an invitation to participate in the application will be displayed automatically under Dedicated time for this project. Note that it will take a few minutes before the information is updated, and that it might be necessary for the project leader to close and reopen the form.

Dedicated time for this project*

	Role in the project	Name	Percent of full time
1	Applicant	Hui Li	100

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	2019	Total
1	Applicant	Hui Li	20	209,200	215,300	221,700	228,400	874,600
2	PhD Student	to be employed	80	611,500	629,800	648,700	668,200	2,558,200
	Total			820,700	845,100	870,400	896,600	3,432,800

Other costs

Describe the other project costs for which you apply from the Swedish Research Council. Enter the full amount, not in thousands SEK.

Premises

Type of premises	2016	2017	2018	2019

Running Costs

	Running Cost	Description	2016	2017	2018	2019	Total
1	Travelling	participate conference	40,000	40,000	40,000	40,000	160,000
2	Computer and software	New computer and software license	30,000	15,000	15,000	15,000	75,000
3	Publication costs	Journal paper publicaitons	10,000	10,000	10,000	10,000	40,000
4	Lab	Antenna fabrication and measurement	0	0	15,000	15,000	30,000
	Total		80,000	65,000	80,000	80,000	305,000

Depreciation costs

Depreciation cost	Description	2016	2017	2018	2019

Total project cost

Below you can see a summary of the costs in your budget, which are the costs that you apply for from the Swedish Research Council. Indirect costs are entered separately into the table.

Under Other costs you can enter which costs, aside from the ones you apply for from the Swedish Research Council, that the project includes. Add the full amounts, not in thousands of SEK.

The subtotal plus indirect costs are the total per year that you apply for.

Total budget

Specified costs	2016	2017	2018	2019	Total, applied	Other costs	Total cost
Salaries including social fees	820,700	845,100	870,400	896,600	3,432,800		3,432,800
Running costs	80,000	65,000	80,000	80,000	305,000		305,000
Depreciation costs					0		0
Premises					0		0
Subtotal	900,700	910,100	950,400	976,600	3,737,800	0	3,737,800
Indirect costs					0		0
Total project cost	900,700	910,100	950,400	976,600	3,737,800	0	3,737,800

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

Salaries

From 2016-01-01 to 2019-12-31, the applicant and the PhD student will spend 20% and 80% respectively, in the research project. Yearly salary increases of 3% and overhead cost of 46% have been accounted for.

Antenna fabrication and measurement

Antennas will be fabricated and measured in years 2018-2019. Antenna fabrication involves some material costs, for example printed circuit boards, copper tape, feed cables. Also some complicated antennas will be sent to company to fabricate. Measurement mainly involves new reader to measure UWB performance, and replacement of worn out cables and standard antennas in anechoic chamber. Estimated cost: 15kkr/year for year 2018-2019, including overhead.

Travelling

Active participation in two international conferences per year. Estimated cost is 40kkr including overhead.

Computer

The required computer equipment for the PhD student is budgeted to 15kkr for year 2016, including overhead. Antenna simulation software CST will cost 15kkr /year.

Publication costs

Publication cost involves charge for pages in IEEE journals. It will increase initially due to more results being generated over time.

Other funding

Describe your other project funding for the project period (applied for or granted) aside from that which you apply for from the Swedish Research Council. Write the whole sum, not thousands of SEK.

Other funding for this project

Funder	Applicant/project leader	Type of grant	Reg no or equiv.	2016	2017	2018	2019

CV and publications

CV

Curriculum Vitae for Hui Li

1. Higher education qualifications (discipline/subject area)
B. Sc. in optical engineering, Tianjin University (China), 2007

2. Doctorial degree (year, discipline/subject area, title of thesis, supervisor)
June 2012, Electrical Engineering
Royal Institute of Technology (KTH), Sweden.
Thesis title: "Decoupling and Evaluation of Multiple Antenna Systems in Compact MIMO Terminals"
Supervisor: Prof. Sailing He

3. Postdoctoral work (year and position)
2012.09-now Department of Electrical and Information Technology, Sweden

4. Qualification required for appointments as a docent:

5. Current position, period of appointment, time for research in the position
Post doc (since September 2012)
90% in research portion (the rest 10% for teaching).

6. Previous positions and periods of appointment

7. Interruption in research
Parental leave: 2013.11.01-2014.3.31 100% parental leave
2015.03.01-2015.04.30 50% parental leave

8. Supervision
PhD supervision as co-supervisor

- 2012- Zachary Miers. Thesis topic: "Optimal Multi-antenna Design based on Fundamental Properties of Radiating Structure and Feeding Technique"

9. Other merits of relevance to the application.

Master supervision

- 2013 Apostolos Tsiaras. Thesis topic: "SAR Evaluation in Multi-Antenna Mobile Handsets"
- 2014 John Chountalas and Rui Ma, Thesis topic: "Pattern reconfigurable MIMO antennas for Multiband LTE Operation"

Teaching

- Compulsory course: Multiple antenna systems 2013-2015

Involvement in conference organization

- Lecturer in training school of SAR & EM exposure in wireless networks, Paris, 2014
- Oral session chair in European Conference on Antennas and Propagation, 2013

- Short course lecturer in European Conference on Antennas and Propagation, 2013;
- TPC (Technical Program Committee) member: PIMRC'13-Funfamentals & PHY Track; Loughborough Antenna & Propagation Conference (LAPC) 2014; European Conference on Antennas and Propagation 2015; IEEE Vehicular Technology Conference 2015
- Evaluator of the 2013 Antenna and Propagation Society Student Design Contest
- Reviewer of international conferences: European Conference on Antennas and Propagation 2013, International Conference on Communications (ICC) 2013
- Organizer of the International Conference of Asia-Pacific Optical Communications, 2008

Other information that is relevant

- Reviewer: IEEE Transactions on Antennas and Propagation; IEEE Magazine on Antennas and Propagation; IEEE Transactions on Wireless Communications; IEEE Antennas and Wireless Propagation Letters; IET Microwaves, Antennas and Propagation; International Journal of Antenna and Propagation; Progress in Electromagnetic Research; Journal of Communications and Networks

Publication list

Publications

1. Peer-reviewed original articles:

[1] ***H. Li,*** Z. Miers, B. K. Lau, “Design of Orthogonal MIMO Handset antennas based on characteristic mode manipulation at frequency bands below 1 GHz,” *IEEE Trans. Antennas Propag.,*vol. 62, no. 5, pp. 2756-2766, May 2014. *Cited: 8*

[2] ***H. Li,*** B. K. Lau, Z. Ying and S. He, “Decoupling of multiple antennas in terminals with chassis excitation using polarization diversity, angle diversity and current control,” *IEEE Trans. Antennas Propag.,* vol. 60, no. 12, pp. 490-502, Dec. 2012. *Cited: 19*

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[5] *Z. Miers, **H. Li,** B. K. Lau, “Design of bandwidth enhanced and multiband MIMO antennas using characteristic modes,” *IEEE Antennas Wireless Propag. Lett.,* Vol. 12, pp. 1696-1699, 2013. *Cited: 8*

[6] **H. Li,** J. Xiong and S. He, “A compact planar MIMO antenna system of four elements with similar radiation characteristics and isolation structure,” *IEEE Antennas Wireless Propag. Lett.,* vol. 8, pp. 1107-1110, 2009. *Cited: 58*

[7] **H. Li,** J. Xiong, Y. Yu, and S. He, “A simple compact reconfigurable slot antenna with a very wide tuning range,” *IEEE Trans. Antennas Propag.* vol. 58, no. 11, 2010. *Cited: 39*

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[14] J. Xiong, **H. Li**, Y. Jin, and S. He, “Modified TM020 mode of a rectangular patch antenna partially loaded with metamaterial for dual band applications,” *IEEE Antennas Wireless Propag. Lett.*, vol. 8, pp. 1006-1009, 2009. *Cited: 26*

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2. Peer-reviewed conference papers:

[1] **H. Li,** R. Ma, J. Chountalas, and B. K. Lau, “Characteristic Mode Based Pattern Reconfigurable Antenna for Mobile Handset” *to be in Proc. 9th Europ. Conf. Antennas Propag., Lisbon, Portugal*, Apr. 2015.

[2] **H. Li,** Apostolos Tsiaras, Benoît Derat, Buon Kiong Lau, “Analysis of SAR on Flat Phantom for Different Multi-antenna Mobile Terminals,” *in Proc. 5th Europ. Conf. Antennas Propag., The Hague, Netherlands*, Apr. 2014.

[3] Z. Miers, **H. Li** and B. K. Lau, “Design of Bezel Antennas for Multiband MIMO Terminals Using Characteristic Modes,” *in Proc. 5th Europ. Conf. Antennas Propag., The Hague, Netherlands,* Apr. 2014.

[4] **H. Li,** X. Lin, B. K. Lau, S. He, “Calculating signal correlation in lossy dipole arrays using scattering parameters and efficiencies,” in *Proc. 4th Europ. Conf. Antennas Propag.*, Gothenburg, Sweden, Apr. 2013.

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[6] Z. Miers, **H. Li,** B. K. Lau, “Design of multi-antenna feeding for MIMO terminals based on characteristic modes,” in *Proc. IEEE Int. Symp. Antennas Propag.*, Lake Buena Vista, FL, Jul. 2013.

[7] **H. Li** and S. He, ‘‘A compact reconfigurable antenna with pattern diversity, ’’ in *Proc. IEEE Int. Symp. Antennas Propag.*, Chicago, IL, Jul. 2012.

[8] X. Lin, **H. Li** and S. He, “A decoupling technique for increasing the port isolation between two closely packed antennas,” in *Proc. IEEE Int. Symp. Antennas Propag.*, Chicago, IL, Jul. 2012.

[9] **H. Li,** B. K. Lau, and S. He, ‘‘Angle and polarization diversity in compact dual-antenna terminals with chassis excitation,’’ in *Proc. URSI General Assembly and Scientific Symposium,* Istanbul, Turkey, Aug. 2011.

[10] **H. Li,** B. K. Lau, and Z. Ying, ‘‘Optimal multiple antenna design for compact MIMO terminals with ground plane excitation,’’ in *Proc. Int. Workshop Antenna Technol.*, Hong Kong SAR, P. R. China, Mar. 2011.

[11] S. He, J. Xiong, **H. Li**, and Y. Jin, ‘‘Patch antennas based on a pair of DPS and SNG metamaterial,” in *Proc. 4th Europ. Conf. Antennas Propag.*, Barcelona, Spain, Apr. 2010.

[12] **H. Li,** J. Xiong, Z. Ying, and S. He, “High isolation compact four-port MIMO antenna systems with built-in filters as isolation structure,” in *Proc. 4th Europ. Conf. Antennas Propag.*, Barcelona, Spain, Apr. 2010.

[13] **H. Li,** B. K. Lau, Y. Tan and Z. Ying, ‘‘Impact of current localization on the performance of compact MIMO antennas,’’ in *Proc. 5th Europ. Conf. Antennas Propag.*, Rome, Italy, Apr. 2011.

3. Patents:

[1] **H. Li,** B. K. Lau, and Z. Ying, “Polarization diversity enabled co-located MIMO antennas for compact mobile terminals at low frequency bands,” PCT filed, No. PCT/IB2011/001532, Jun., 2011.

[2] **H. Li,** Z. Miers, and B. K. Lau, “Orthogonal multi-antennas for mobile handsets based on characteristic mode manipulation,” US Provisional Patent Application No. 61/843,172, Jul. 5, 2013.

[3] **H. Li,** J. Xiong and S. He, “Planar MIMO antennas for wireless communication terminals；Chinese Patent, ZL201010104617.X, Dec. 26th, 2012.

CV

Name: Hui Li	**Doctorial degree:** 2012-06-15
Birthdate: 19860615	**Academic title:** Doktor
Gender: Female	**Employer:** Lunds universitet

Research education

Dissertation title (swe)

Frikoppling och utvärdering av flera Antenna Systems Kompakta MIMO Terminaler

Dissertation title (en)

Decoupling and Evaluation of Multiple Antenna Systems in Compact MIMO Terminals

Organisation	Unit	Supervisor
Kungliga Tekniska Högskolan, Sweden Sweden - Higher education Institutes	Skolan för elektro- och systemteknik	Sailing He

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
20203. Kommunikationssystem	1653-5146	2012-06-15

Publications

Name: Hui Li	**Doctorial degree:** 2012-06-15
Birthdate: 19860615	**Academic title:** Doktor
Gender: Female	**Employer:** Lunds universitet

Li, Hui has not added any publications to the application.

Register

Terms and conditions

The application must be signed by the applicant as well as the authorised representative of the administrating organisation. The representative is normally the department head of the institution where the research is to be conducted, but may in some instances be e.g. the vice-chancellor. This is specified in the call for proposals.

The signature*from the applicant*confirms that:

- the information in the application is correct and according to the instructions form the Swedish Research Council
- any additional professional activities or commercial ties have been reported to the administrating organisation, and that no conflicts have arisen that would conflict with good research practice
- that the necessary permits and approvals are in place at the start of the project e.g. regarding ethical review.

The signature *from the administrating organisation* confirms that:

- the research, employment and equipment indicated will be accommodated in the institution during the time, and to the extent, described in the application
- the institution approves the cost-estimate in the application
- the research is conducted according to Swedish legislation.

The above-mentioned points must have been discussed between the parties before the representative of the administrating organisation approves and signs the application.

Project out lines are not signed by the administrating organisation. The administrating organisation only sign the application if the project outline is accepted for step two.

Applications with an organisation as applicant is automatically signed when the application is registered.