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学位論文題目	**A Study on Integrated Active Magnetic Probes for Near-field Measurement** （近傍磁界計測のための集積化アクティブプローブに関する研究）	
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論文内容の要旨

Since the increasing occurrence of digital system interference with wire and radio communication, electromagnetic compatibility (EMC) becomes a major design issue. Recent unavoidable trends, such as the high digital clock frequencies, high density integration of electronic circuits, and wireless communication devices on the chip, boost the integrated circuits (ICs) up the most candidate of the source of emissions.

As a result, the subject of interest and investigation of the EMC moves from Printed Circuit Boards (PCBs) into IC chips in these days. In evaluation and troubleshooting of the electromagnetic interference, identifying the noise source is usually the primary approach. One of the most popular method for searching the source is to measure the near-field in/over the ICs with a near-field probe. However, due to the decreasing size of objects, and the increasing complexity of the electromagnetic environment, an identification of the radiated emissions in ICs becomes more difficult to achieve. With that background, a miniature size near-field probe has been greatly expected. Unfortunately, downsizing the probe leads to the degradation of its sensitivity, and worsening the evaluation efficiency because mechanical scanning with a small-sized probe requires much time for the measurement.

To solve the problems, it is sensible to apply a CMOS technology to develop the desired probe. An advanced CMOS process enables us to make submicron devices, integrate active components, and easily configure an array. In this thesis, our work concentrates in developing a magnetic probe and probe array based on Silicon-on-Insulator CMOS technology, featuring high sensitivity, high spatial resolution and wide bandwidth. Since the CMOS circuits actively contribute to its performance, the proposed probes are described as "active probes", compared with the conventional passive ones.

In chapter 2, preliminary knowledge on EMC is presented giving stress to the IC radiated emissions. For the IC emissions test, five different methods are proposed by the International Electrotechnical Commission (IEC) standard, and two of them require a small magnetic and/or electric probe as a sensor device. The popular probes used for these tests, particularly shielded loop coil and optic probes, are studied here. Furthermore, crucial problems inherited in these passive probes and their practical solutions are discussed.

Chapter 3 demonstrates the fundamentals of an active magnetic probe. The architecture and technology to achieve the high sensitivity and high spatial resolution are proposed. Differential detecting coil and wideband differential amplifiers having the high common-mode rejection (CMR) characteristics enable the probe to amplify the magnetic field, and remove the electric field at the same time.

The experimental results from the fabricated prototype verify, for the first time, that the active probe can discriminate the magnetic field from the electromagnetic emissions. Since the CMR ratio of the on-chip amplifiers directly affects the e-field suppression of the probe, it is analyzed by the small-signal analysis, considering the effect of the mismatch. The result indicates that even though there is 1% mismatch in the circuits, the e-field suppression ratio of the active probe can attain over 40dB, although the measured result does not reach the value because of the large stray loop in the system.

Chapter 4 presents a fully integrated active probe and probe array, which are aimed for a pragmatic tool. In response to the evaluation results of the prototype, the amplifiers are modified in bandwidth and the CMR ratio. All the peripheral circuits are integrated in a same chip, in order to make the probe more practical. As a result, measurement results show that the modified probe gains the e-field suppression ratio of 38.0dB at 50MHz, which is by far superior compared with that of the conventional shielded loop coil as well as the prototype.

Active probe array can offer not only a high-speed and precise measurement but also multiple-point concurrent measurement. Using the modified amplifiers, an active probe array is configured with three aligned detecting coils, which are scanned fast and exactly by electrical switching. The fabricated array demonstrates that the three different points are determined simultaneously with an excellent isolation. It should be emphasized that this is the first result obtained by multiple-point concurrent measurement using micron-sized probe array. Furthermore, a 2-dimensional magnetic field distribution map is successfully drawn by the probe array. It is clearly found that the obtained image is finer than that of the shielded loop coil.

Although the above-mentioned probe is proven as an utility tool at the low frequency, the effect of off-chip parasitics becomes critical at the high frequency. It degrades the probe performance by mismatched impedance and limited bandwidth. Therefore, expanding the probe bandwidth towards the gigahertz range will be a next challenge. As a matter of fact, this can be achieved with another circuit technique introduced in chapter 5. The alternative active probe is called a down-conversion magnetic probe. The idea applying for the probe is based on a frequency translation technique in RF front-end. With an on-chip mixer and a voltage controlled oscillator (VCO), noise spectrum is down converted to the far lower frequency, which can be arbitrarily chosen by an off-chip band- pass filter. Although a measurable frequency range is limited due to the operation range of the VCO, simulation results verify that the spectrum is successfully identified at the translated frequency. The architecture and the components design are also discussed.

The developed active probes in the thesis are well applicable for the modern chip level EMI measurement, the one with on-chip amplification technique is at low frequency up to 1GHz and the other down-conversion probe is at several gigahertz range, respectively.

論文審査結果の要旨

LSIの高速、高密度集積化に伴い、半導体チップレベルでのEMI測定の必要性から、高性能な近傍磁界計測用プローブが求められている。従来のパッシブ型プローブでは、高感度化と高分解能化の両立が困難であった。また、近傍磁界分布計測の解像度を高めると多大な計測時間が必要とされ、計測を高速化する新しい手段の開発が必要とされていた。本論文は、CMOS SOI技術を用いて高感度、高空間分解能の両立を可能とし、高速近傍磁界分布計測を実現する新しいアクティブ型プローブに関する研究を取りまとめたものであり、全6章よりなる。

第1章は緒言であり、本研究の背景と目的を述べている。第2章は、EMI測定に関する基礎的考察として、EMI測定に関する先行研究について述べ、本研究の課題と到達目標について述べている。第3章では、電界成分を除去し、高感度に磁界成分を検出することができる、差動プローブコイルと高同相成分除去比をもつ差動増幅回路に基づく新しいアクティブ型プローブを提案し、CMOS SOI技術に基づく試作により近傍増幅による高い空間分解能と高感度化の両立と、回路的手法により電界成分除去が可能であることを、初めて実証している。第4章では、CMOS技術によるアクティブ型磁界プローブの利点を最大限活用し、必要な機能をすべて集積化するとともに、多点同時測定を可能にする初めてのアクティブ型磁界プローブアレイの試作に結果について述べている。全機能の集積化によって、電界除去性能が高められ、50MHzにおいて38dBの電界除去比を得ている。これは従来のシールデッドループ型磁界プローブに比べて20dB以上高い値である。また、アレイ型プローブにより2次元高周波磁界分布を得ており、これはミクロンレベルの空間分解能をもつプローブとして、初めて多点同時測定が可能であることを示したものである。第5章では、GHz帯の高周波磁界の計測を高感度なアクティブ型プローブとして実現するため、周波数変換技術を導入した新概念の高周波磁界プローブを提案し、その有用性をシミュレーションによって明らかにしている。第6章は、結言であり本研究により得られた成果をまとめている。

以上のように本論文は、高周波磁界計測にアクティブプローブという新しい概念を導入し、従来困難であった高分解能化と高感度化の両立と、高速2次元磁界分布計測への道を開いたものであり、計測の分野に寄与するところが大きい。よって、本論文は、博士（工学）の学位を授与するに十分な内容を有するものと認める。