論文の内容の要旨

A Fully Integrated CMOS Pulse Transmitter with On-Chip Antenna Array for Millimeter-Wave Imaging

(ミリ波イメージングに向けたオンチップアレイアンテナ付
集積化 CMOS パルス送信回路)

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This dissertation focuses on the implementation of integrating pulse transmitter with wide-band antenna array into a chip by CMOS process for beam-forming in millimeter-wave (mm-wave) active imaging applications. Integrated antenna arrays in this research electrically control and steer radiated-pulse beams towards objects to be imaged.

Among imaging approaches, active imaging method provides more sensitivity compared with passive one since mm-wave transmitted beams of active method can illuminate on relevant imaged portions belonging to the objects. For active imaging purposes such as medical-image diagnosis support applications, an integrated antenna array transmitter with beam-formability enhances radiation signals from imaged objects (cancer cells, teeth, etc.), achieves high resolution, and acquires electrical controllability over scanning angles. Our approach of antenna array integration for active imaging utilizes timed array to achieve pulse beam-formability and controllability of the mm-wave pulse transmitter. It means that radiated beam directions or angles can be controlled by changing inter-element pulse delays of timed-antenna array without rotating the physical antenna array system.

First, we designed and integrated a 100 – 120-GHz shock wave transmitter with a 54×24 loop antenna array into a 0.25-μm Silicon Germanium BiCMOS chip. The 30-μm×30-μm loop antenna located on the top-metal layer operates as a coil in an integrated mm-wave pulse generator or shock wave generator (SWG). Each of the on-chip SWGs employing under-damped/over-damped conditions to produce mm-wave pulses includes an R-L-C circuit, a bipolar junction transistor (BJT) operated as a switch, and a CMOS inverter chain circuit for shaping the rising edge of the input clock. From the measurement result, we demonstrated the possibility of on-chip loop antenna array integrated together with mm-wave shock wave transmitter towards the purpose of beam-forming by changing power supplies of inverter chains.

Second, we performed a 0.18-μm CMOS fully integrated X-band SWG with an on-chip dipole antenna and a digitally programmable delay circuit for pulse beam-formability. A 9–11-GHz resistorless SWG circuit was designed, fabricated and measured with on-chip meandering antenna and digitally programmable delay circuit (DPDC). The SWG operates

based on damping conditions to produce a 0.4-V peak-to-peak (p-p) pulse amplitude at the antenna input terminals in HSPICE simulation. The DPDC was designed to adjust delays of shock-wave outputs for the purpose of steering beams in antenna array systems. The wide-band dipole antenna element designed in the meandering shape is located in the top metal of a 5-metal-layer 0.18-μm CMOS chip. By simulating in Momentum of ADS 2009, the minimum value of antenna's return loss, S11, and antenna's bandwidth (BW) are −19.37 dB and 25.3 GHz, respectively. The measured return loss of a stand-alone integrated meandering dipole is from −26 dB to −10 dB with frequency range of 7.5–12 GHz. In measurements of the SWG with the integrated antenna, a 1.1-mV_{p-p} shock wave with a 9–11-GHz frequency response is received and a 3-ps pulse delay resolution was also obtained. These results prove that our proposed resistorless shock wave generator and the digitally programmable delay circuit are suitable for the purpose of fully integrated pulse beam-forming system.

Finally, from the previous results of the 0.18-μm CMOS chip, we proposed and implemented an on-chip antenna array with 8-dipole elements operating with 117 – 130-GHz frequency bandwidth. The key improvement of this fabrication is the integration of programmable timed delay monitoring and controlling system with on-chip jitter measuring circuit for the whole array system into the same chip. Also, we proposed a new on-chip dipole antenna whose special geometry is a meandering one working in a wide-band mm-wave regime. This design is the combination of patch antenna and dipole antenna in order to exploit both advantages of two antenna types and also to satisfy the layout design rules. An 8-element dipole array with programmable delay monitor/control circuit, a single meandering dipole antenna, a single SWG with this antenna and an on-chip jitter measuring circuit are integrated in this chip for mm-wave shock wave transmitter system. A peak-to-peak shock wave voltage is about 1.66-V with 9.13-ps shock wave duration in HSPICE simulation at the antenna input terminals. In each of pulse antenna element, a CMOS DPDC is operated with digital input codes to adjust delays of transmitting shock waves. Due to the small propagation delay of 65-nm CMOS process, we performed a less-than-1ps programmable delay circuit and an integrated jitter measuring circuit. This circuit is used to adjust delay differences of generated pulses in order to control the angle of the transmitter's beam form toward corresponding imaging objects. The random jitter distribution and the relative setup time measurements were done by using Advantest T2000 logic test system in VDEC. Measurement for fully integrated mm-wave shock wave transmitter with the meandering dipole antenna array was performed by using a 90 – 140-GHz standard gain horn antenna, an mm-wave Schottky diode, and the customized set-up for automatically measuring mm-wave radiation patterns. Our measurement results prove that the 65-nm CMOS proposed antenna array can be employed for beam-formability of mm-wave active imaging transmitter.