

Development of High Q Circuit Components in CMOS Technology for Millimeter Wave and Sub-THz Band Applications

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(ミリ波及びサブテラヘルツ波帯高 Q 値 CMOS 回路の開発)

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論 文 内 容 の 要 旨

Nowadays, the implementation of Complementary Metal-Oxide Semiconductor (CMOS) for millimeter and sub-terahertz bands has attracted many researchers due to its low cost and easy integration into next-generation wireless communication systems, which are expected to achieve wireless communication links of more than 100 Gbps. However, the conventional on-chip designs of passive elements such as resonators, filters, interconnects, and transmission lines, which are typically made of microstrip and coplanar waveguide (CPW) structures, suffer from higher radiation, conductor, and dielectric losses at frequencies above the millimeter wave range. Alternatively, Substrate Integrated Waveguide (SIW) and Defected Ground Structure (DGS) structures have gained attention for high-frequency applications due to their low profile and high quality (Q) factors. Although these structures perform well in high-frequency applications, their size remains a challenge for implementation in circuit designs. Consequently, a considerable amount of work has been done to improve circuit size and reduce losses in SIW-based designs using PCB technologies, but few studies have focused on CMOS technology. Therefore, this thesis aims to design and fabricate low-loss, high- Q resonators, filters, and transmission lines using SIW and DGS topology in $0.18\ \mu\text{m}$ CMOS technology.

In this dissertation, firstly, two transmission poles (TPs) DGS-based band-stop filters for the millimeter wave band are proposed. These filters utilize a capacitively loaded T-shaped resonator embedded in the original DGS resonator, resulting in two high- Q factor small loop resonators. By combining this structure with the feedline and series capacitor, the position of two TPs can be independently controlled, one on each side of the parallel resonance, without increasing the layout size while achieving a sharp scattering (S -) parameter response. As a result, the loaded Q -factor and negative group delay of the band-stop filters are significantly improved, making them suitable for oscillator and filter designs. Two prototypes of the proposed band-stop filters with symmetric and asymmetric structures are designed and fabricated. The measurement results for these designs exhibit a return loss of 1.78 dB and 2.2 dB at a center stopband frequency of 53 GHz, with negative group delays of 161 pS

and 118 pS, respectively. Moreover, the respective chip areas are only 0.024 mm² and 0.0129 mm².

Secondly, on-chip SIW cavity resonators for the millimeter wave band at 60 GHz resonance frequency are designed and fabricated. When implementing SIW-based cavities in CMOS technology, besides the bulky size, issues related to transition loss and matching circuits also arise. To address these challenges, sub-modes SIW structures with folded ridge structures inside the proposed cavities are utilized, resulting in a significant reduction in size. Experimental work on the effects of microstrip and blind via transitions is also conducted in this design. Additionally, Complementary Split Ring Resonators (CSRRs) are incorporated into the design to achieve internal matching within the SIW cavities, eliminating the need for external matching circuits. The designed ultraminiaturized cavities have a compact size of 0.019 mm² (only 0.446% of a standard SIW design at the same resonance), a good return loss of 33.42 dB at 60 GHz, and an external Q-factor of 112 and to the author's knowledge, this is the first realization in CMOS technology.

Finally, sub-terahertz band SIW cavities and transmission lines are proposed and designed at 200 GHz. The SIW structures proposed in the literature have design equations that are valid for PCB CMOS technology in low-frequency bands. However, these design equations need to be redefined for frequencies above the millimeter wave range. In this work, a new set of design equations for SIW in sub-terahertz designs is first proposed and verified through simulation. Various designs of compact and miniaturized SIW cavities, ranging from standard to sub-modes, are then fabricated using half mode and quarter mode designs based on the updated equations. Six prototypes of sub-terahertz band SIW cavity resonators are fabricated: standard SIW, half mode SIW, half mode with folded ridge SIW, half mode with folded ridge and CSRR loading, quarter mode with folded ridge, and quarter mode with folded ridge and CSRR loadings. All of these designs exhibit lower return loss, high Q-factor, and small chip area overhead. The measurement results are obtained by performing multi-line thru-reflect-line (m-TRL) de-embedding to remove the effect of the pads in such high-frequency designs. Additionally, using the same design equations, a 200 GHz band half mode SIW transmission line is designed and fabricated. Moreover, bandpass response using the CSRR resonators were also studied. The simulation results of this design demonstrate a promising insertion loss of 1.1 dB in the frequency band ranging from 150 GHz to 280 GHz, making it suitable for various sub-terahertz band applications.