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（博士課程）
Doctoral Program

論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary (approx.800 English Words)

The dissertation presents a study of millimeter-wave satellite communication systems targeting low power consumption and high link speed by improving the performances of ground base station transceivers and LEO satellite terminal receivers. The satellite communication system is one of the main candidates for the next generation of wireless communication systems (6G) due to the ultra-wide network access coverage, which is capable of providing low-cost, high-speed network access all over the world. The satellite communication system is the paving stone of many communicable electronic devices, such as desktop computers, mobile phones, movable tablets, smart watches, automobiles, and the internet of things. The power consumption and operation cost are the key issues in the satellite communication system. Designed for future 6G networks with extreme coverage extension, a high link speed transmitter utilizing a high linearity power amplifier is introduced in this work. This work also utilized mutually coupled inductors to decrease the system power consumption for the high link-speed receiver in the LEO satellite terminal.

First of all, this work conducted cutting-edge research on integrating a Ka-band satellite communication transceiver in a standard CMOS topology with an enhanced dual-channel low-NF wide-dynamic-range receiver and high-linearity transmitter for the ground base station. This work reported and demonstrated the world-first integrated CMOS satellite ground base-station transceiver, which attracted a lot of academic and industry attention. In terms of the high-linearity ground station transmitter, this work reported a single-turn high-quality-factor transformer as the matching network at the output port of the power amplifier, which boosts the transmitter modulated signal adjacent channel power ratio by about 12dBc compared with the conventional solutions. This work also proposed and implemented the first integrated adjacent channel interference cancellation block at the receiver side of the satellite transceiver. Combined with the cancellation block, the transceiver can successfully mitigate the cross-talk interference from another in-band satellite signal, which is crucial for the satellite communication system.

Secondly, low-cost, low-latency and high-resolution radio frequency integrated circuits with beamforming functions are the key blocks to support high-accuracy beam steering and high-data access. The phased array techniques are becoming promising solutions to overcome the high free-space-path-loss (FSPL) for the Ka-band frequency (mm-wave) allocation. In phased-array systems, the phase shifter is the key block that directly influences the beamforming accuracy and quality. A high-resolution and low-insertion-loss phase shifter is necessary to support accurate beam steering with low side lobe level and low noise figure (NF) for the satellite communication system. This work proposes a magnetic-tuning phase shifter for lower insertion loss and high beam steering accuracy. In terms of the coarse-tuning core, the proposed part is served as a conventional reflective-type phase shifter, which not only reduces the chain

insertion loss but also helps to relieve the coverage of the fine-tuning phase shifter range. The fine-tuning range is implemented by the three-coil tank and can tune the output phase by adjusting the variable resistor value. Thus, the phase shifter can realize high resolution with low insertion loss for the satellite communication phased-array system.

Thirdly, this work has conducted deep research in RF/millimeter-wave phased-array receiver IC design in the LEO satellite terminal. Dr. Xi Fu developed a new theory and topology of a novel mutually coupled inductor based LNA and reported a novel radiation-hardened magnetic-tuning phase shifter for the first time. Noted that the small LEO satellite constellation has been demonstrated as a promising technology for providing global internet access, the available solar panel area limits the system power consumption for the phased-array transceiver. To solve the power issue, a new mutually coupled LNA with the current-reuse topology is proposed. The mutually coupled LNA utilizes three coupling inductors to reduce the input matching impedance with smaller input N-type transistors. After implementing the mutually coupled LNA, the proposed RF circuit realized 5.5% of the typical power consumption compared with the conventional front-end. The radiation-hardened magnetic-tuning phase shifter mitigates the channel leakage-current impact at the variable resistor region and achieves 0.06dB/Mrad gain and 0.4degree/Mrad phase degradations, which are ten times better compared with conventional vector-summing phase shifter based millimeter-wave receiver.

In conclusion, these introduced systems are implemented in standard 65nm CMOS technology and the effectiveness of the proposed techniques was verified in clean-room and over-the-air measurements. This thesis presented novel building block circuits and transceiver diagrams for the future 6G network with extensive coverage. The phased-array millimeter-wave receivers can increase the link speed between the small cube satellite and the ground station terminals. Thus, the network coverage for the global network can be realized by the significant number of small cube satellites with the phased-array transceiver. The future research directions and the possible improvements to the high-speed satellite communication system are briefly presented in the last chapter of the thesis.