MAJOR RESEARCH ACHIEVEMENTS

Developing innovative microwave and millimeter-wave components, integrated circuits, and systems for wireless broadband communication, biomedicine, and environmental protection is our research roadmap (Fig. 1). These include compact filters, transceiver MMICs, Butler-matrix beamforming phased arrays (Fig. 2), vital radars, wireless indoor positioning systems (Fig. 3), and wireless ecological monitoring systems, based on printed-circuit low temperature co-fired ceramic (LTCC), integrated passive device (IPD), and Si-based and III-V compound MMIC technologies.

For millimeter-wave wireless broadband communication, a new beamforming technique has been demonstrated, where the adaptive antenna beam pattern is synthesized in beam space instead of element space of the conventional approach. This beamformer consumes only 30 mW and the chip size is only 1.4 mm2(Fig. 2). An emergency E-Nurse system was also developed (Fig. 3), where the vital radar and wireless positioning techniques are integrated into a name-card size tag to simultaneously detect the heart-beat, breath rates, and indoor/outdoor positions.

MMIC / RFIC

ARRAY BEAMFORMING TECHNIQUES

The array beamforming techniques based on Bulter matrix have been developed in 2-70 GHz range. The phased antenna array is commonly employed to provide advantageous beamforming and steering, where the phase shifter is crucial to control the radiation beam. The reflection-type phase shifter(RTPS) aiming for constant insertion loss over a wide relative phase-shift range has been presented [1]. The impedance-transforming quadrature coupler is used to increase the maximal relative phase shift. The typical large insertion-loss variation during the phase tuning is minimized by shunting the series-resonated varactor with a resistor. The measured results from three implemented phase shifters show that insertion-loss variation is < 0.1 dB within a 237° phase tuning range at 2 GHz.

The RTPSs were also implemented in CMOS technology. In this study, a phase-compensated inductively coupled hybrid [2] is designed with to minimize the phase/amplitude imbalance, while the impedance-transformed-resonated varactor network is presented to provide a full 360 phase range. Two 2.4 GHz monolithic RTPSs in a standard 0.18-μm CMOS technology have been presented in [3]. One has a measured phase-shift range of 120° with the insertion loss of 5.6±1.2 dB and the other has a phase range larger than 340° with the insertion loss of 10.6±2 dB, which are competitive to RTPS MMICs in GaAs MESFET technology. Both chips are extremely compact and consume zero dc power.

Butler matrix is the most popular beamforming network for switch-beam array architecture. By combining both techniques, a compact enhanced switching/steering 8-way Butler matrix has been also proposed and demonstrated [4]. The radiation beam is initially switched to a certain direction through the Butler matrix, and then slightly adjusted by the tunable phase shifters. The phase shifters are only responsible for a small steering range between two adjacent beams. By using this approach, the beam resolution is dramatically improved, while the Butler matrix still remains low order and only a small amount of phase tuning is needed. It not only helps in the size compactness, but also alleviates the design difficulty of the beamforming circuitry.

To achieve a full integration of smart antenna system monolithically, the first demonstration of a single-chip Butler matrix in CMOS technology has been presented [5]. The designed 2.5-GHz 0.18-mum CMOS 4-way Butler matrix, which consists of the phase-compensated transformer-based quadrature couplers, consumes no dc power with chip area of 1.99 mm2. Further study proposed a continuously steering phased array receiver MMIC based on the subsector beam steering technique [6]. The entire beam steering range is divided into five subsectors from four characteristic beams of the Butler matrix. In each subsector the receive beam is steered by weighted combination of the received signals from array antennas. The proposed architecture has lower circuit complexity and less power consumption because no challenging CMOS 360° variable phase shifters and multi-phase voltage-controlled oscillators are required. The phased array MMIC is implemented in 0.13-μm CMOS technology, and the measurement results show that continuous beam steering within a spatial range of ±90°is achieved with very low power consumption of 30 mW and compact chip size of 1.43 mm2.

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MICROWAVE/MILLIMETER WAVE SYSTEMS

MICROWAVE WIRELESS SENSING RADARS FOR BIOMEDICAL APPLICATIONS

Numerous wireless sensing radars have been developed for biomedical applications. A glottal radar system has been successfully built for extracting human speech information from the vocal vibration signal of a human subject [1]. Due to the tiny glottis motion of several millimeters, a coherent homodyne demodulator with high sensitivity is developed to detect reflected radio signal, phase modulated by the vibrating vocal cords. Measurements of vowels and words, both with the speech radar system and the conventional acoustic microphone system, were conducted and compared. The results show that the essential speech information can be reliably obtained from the proposed speech radar. With great immunity to acoustic interference, it enables numerous speech related applications. Two potential uses were proposed and demonstrated in [2]. First, for the communication quality enhancement of mobile handsets in a noisy environment, the background acoustic noise can be effectively detected and eliminated based on the glottal radar detection of the unvoiced segments. Second, for the use in speaker recognition, the identification rate of the microphone detection system drops to 82% even though the system is in a 15-dB SNR condition. In contrast, the glottal signal radar still remains 95% identification accuracy.

A quadrature Doppler radar using the same theoretical concept has been developed for vital signal detection [3]. Since the dc offset at baseband varies with the change of test environment, dramatically reducing the accuracy of vital signal detection, a fast clutter cancellation technique has been proposed and demonstrated in this work to robustly detect the vital signals when clutters enter the test environment. Based on the detected dc offset values in I and Q channels, the generator produces an output signal, anti-phase to the received clutter signal, such that the clutter signal is cancelled at RF frontend. Therefore the time-varying dc offset at baseband is eliminated. By combining the switched-beam phased array techniques with angle-of-arrival (AOA) algorism, a 2.28-GHz tag-free 2-D wireless positioning system for human subject tracking has been proposed and demonstrated in [4]. Without carrying a tag, this system can sense the target's presence simply from the respiration of the subject. The potential application is aimed for healthcare purpose, such as elderly living or nursing home facilities.

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A HIGH RANGE RESOLUTION 9.4/18.8 GHZ HARMONIC RADAR FOR BEES SEARCHING

This research demonstrates a 9.4/18.8 GHz harmonic radar for bee searching to investigate the phenomenon of colony collapse disorder (CCD). The radar system transmits a pulsed coarse/acquisition code (C/A code) signal with 0o and 90o shift key modulation and then receives the C/A code signal from transponders attached on the bees in BPSK modulation. Using the technique of C/A code positioning, a distance resolution of 0.15 m is achieved. The transponders are designed to minimize the effect from the bodies of bees. The outdoor experiments indicate the sensitivity of the radar system to be -95 dBm and with the distance of 65 m with 6-W peak power. With 3-kW peak power, the distance at which the bees can be located is expected to be 450 m.

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RF/MICROWAVE/MILLIMETER WAVE PASSIVE CIRCUITS

MICROWAVE/MILLIMETER-WAVE FILTERS

To achieve wide stopband range, a pseudo-combline bandpass, which is composed of the step-impedance resonator with transformer-tapped I/O coupling networks, has been designed with two features [1]. First, the transmission-zero can be generated near the passband and also in the stopband. Second, the spurious passband can be removed to higher frequency by the step-impedance resonator. Therefore, the transition-band roll-off rate is dramatically increased and the stopband range is significantly increased. In this work, the second- and fourth-order bandpass filters of pseudo-combline SIR structures was demonstrated. The measurement results show that the return losses are > 16 dB, the insertion losses < 2.7 dB at 2.45 GHz and two transmission zeros exist on each side of passband. All filters have 35 dB stopband suppression levels up to 10 GHz.

The reconfigurable bandpass and bandstop filter based on a dual-mode ring resonator, have been also studied in [2]. The reconfigurability is achieved by tuning the series-resonated perturbation extent to control the splitting frequency between the even and odd mode. Two issues have been addressed, including the alignment of central frequencies and the impedance match at both bandpass and bandstop modes. The measured bandpass response has an insertion loss of 1.6 dB, return loss > 20 dB at 2.4 GHz, while the bandstop response has > 20 dB rejection from 2.38 GHz to 2.8 GHz. This work also won the first price in 2008 IMS student design competition.

The compact monolithic millimeter-wave bandpass filters have been successfully implemented using CMOS technologies [3-4]. To further reduce the circuit size, a new stepped-impedance technique is proposed by incorporating a grounded pedestal into the microstrip line. The characteristic impedance of a microstrip line can be effectively changed by varying both the height of pedestal and the width of line. The experimental results show that the millimeter-wave bandpass filters designed by using the new stepped-impedance resonators and stubs can significantly reduce the chip sizes to 0.37 x 0.2 mm2, equivalently 0.012 λg2.

The planar bandpass filters with wide passband/stopband have been studied in [5-8]. In order to miniaturize circuit size, a series compact microwave bandpass filters have been successfully developed with LTCC technologies [9-16]. Moreover, compact or multiband branch-line couplers have been developed in [17-19].

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