

# 采用 CMOS 工艺的 C 波段 5 bit 数字移相器设计

张 杰<sup>1,2</sup>, 吴 蓉<sup>1</sup>, 徐 进<sup>2</sup>, 梁竞贤<sup>2</sup>, 来龙坤<sup>2,3</sup>, 罗卫军<sup>2,3</sup> Symbol'@@

(1 兰州交通大学 电子与信息工程学院, 甘肃 兰州 730070;

2 中国科学院 微电子研究所, 北京 100029; 3 中国科学院大学, 北京 100049)

摘 要: 基于 SMIC 0.13  $\mu\text{m}$  CMOS 工艺, 采用片上巴伦、正交全通滤波器和吉尔伯特单元的设计方案, 设计了一款 C 波段 5 bit 数字移相器. 巴伦将单端输入信号分成两路反相的差分信号, 并通过吉尔伯特单元将正交全通滤波器产生的正交信号进行矢量运算. 在满足移相精度  $11.25^\circ$  的条件下, 实现 4.5~7.5 GHz 的工作带宽. 电磁场仿真结果显示: 在 4.5~7.5 GHz 频段, 数字移相器插入损耗的典型值是 -10 dB; 输入回波损耗和输出回波损耗分别优于 -10.6 dB 和 -9.9 dB; RMS 移相精度小于  $3.5^\circ$ ; 芯片面积  $1.66\text{ mm} \times 0.74\text{ mm}$ ; 该 5 bit MMIC 数字移相器相对带宽为 50%, 适用于 5G 低频段的通信系统中.

关键词: 相控阵; 数字移相器; 片上巴伦; 正交全通滤波器; 吉尔伯特单元; 矢量合成

## Design of C-band 5 bit digital phase shifter

### based on CMOS technology

ZHANG Jie<sup>1, 2</sup>, WU Rong<sup>1</sup>, XU Jin<sup>2</sup>, LIANG Jing-xian<sup>2</sup>,

LAI Long-kun<sup>2, 3</sup>, LUO Wei-jun<sup>2, 3</sup>

(1 School of Electronic and Information Engineering, Lanzhou Jiaotong University, Lanzhou 730070, China;

2 Institute of Microelectronics, Chinese Academy of Sciences, Beijing 100029, China;

3 University of Chinese Academy of Sciences, Beijing 100049, China )

Abstract: Based on SMIC 0.13  $\mu\text{m}$  CMOS technology, a C-band 5 bit digital phase shifter was designed by using on-chip Balun, orthogonal all-pass filter and Gilbert cell. The balun divided the input signal at one end into two inverse differential signals, and then carried out vector operation on the quadrature signals generated by the quadrature all-pass filter through Gilbert cell. The bandwidth of 4.5~7.5 GHz was achieved when the phase-shifting accuracy was  $11.25^\circ$  degrees. The simulation results of electromagnetic field showed that the typical insertion loss of digital phase shifter was -10 dB at 4.5-7.5 GHz; the input and output return losses were better than -10.6 dB and -9.9 dB, respectively; the phase shifting accuracy of RMS was less than  $3.5^\circ$  degrees, the size of the layout was  $1.66\text{ mm} \times 0.74\text{ mm}$ ; and the relative bandwidth of the 5 bit MMIC digital phase shifter was 50%, which was suitable for 5G low frequency communication system.

Key words: phased array; digital phase shifter; on-chip balun; quadrature all-pass filter; Gilbert cell; vector sum

作者简介:

张 杰 男, (1993-), 硕士研究生. 研究方向为射频电路及集成电路技术.

吴 蓉 女, (1968-), 硕士生导师, 教授. 研究方向为电路与系统和微电子技术.

徐 进 男, (1993-), 硕士研究生. 研究方向为微波集成电路的设计.

梁竞贤 男, (1994-), 硕士研究生. 研究方向为微波开关电路和器件.

来龙坤 男, (1995-), 硕士研究生. 研究方向微波集成电路和氮化镓电平控制电路.

罗卫军 (通讯作者) 男 (1981-), 博士, 副研究员. 研究方向为 GaN 微波器件与集成电路.

E-mail: luoweijun@ime.ac.cn.