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A Compact Broadband Phase Shifting Network for a Four-feed Multi-mode Global Navigation Satellite System Antenna

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Abstract. A compact feeding network for a wideband circularly polarized multi-mode Global Navigation Satellite System (GNSS) antenna is presented. Four feed method for the antenna is adopted to suppress the higher modes and increase the 3dB axial ratio (AR) bandwidth. A broadband phase shifter with 0°, 90°, 180°, 270° phase differences using composite right/left-handed transmission line structure combined with novel schiffman phase shifter is analyzed, designed, simulated, implemented and measured in this article.

Introduction

Global Navigation Satellite System (GNSS) can provide high quality global positioning, navigation, timing service and velocity measurement. So far, GNSS mainly includes four systems: GPS (America), GLONASS (Russia), Galileo (Europe) and Compass (China). Multi-mode navigation system which can receive the signals coming from two or more systems will improve the accuracy and reliability of positioning and navigation.

Multi-mode receiving antenna is required to cover the operating frequency of the four systems, ranging from 1163.72MHz to 1278.75MHz and from 1561.098MHz to 1605.375MHz. As we know, navigation satellite signals are right-hand circularly polarized (CP).CP antenna can be excited by single feed or multi-feed. Compared with single feed, the impedance bandwidth and axial ratio bandwidth of multi-feed are enhanced [1,2]. But the multi-feed network is complicated. For dual feed, quadrature power splitters are used for circularly polarized microstrip antenna [2].A broadband power divider and phase shifter with 90° and 180° are introduced in [3].

In this paper, a four-feed feeding network of a patch antenna for wideband GNSS applications is designed. By combining three Wilkinson power dividers, two 90° phase shifters using composite right/left-handed (CRLH) transmission line and one 180° novel schiffman phase shifter, a broadband phase shifter feeding network with phase difference 0°,90°,180°,270° is investigated. Details of the design and performance are addressed below.

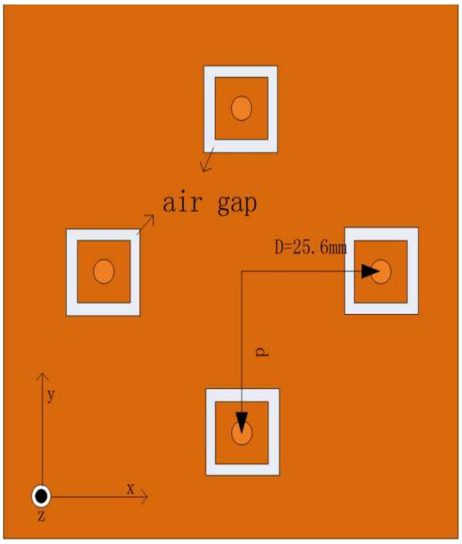

Fig.1. Structure of antenna's radiation patch and feed points

Antenna Description

The antenna is excited by four metallic probes mounted symmetrically around +z direction. The distance between the feeding point and the center of the ground plane is D=25.6mm. The structure and geometry of the proposed antenna's radiation patch is shown in Fig.1.

Feeding Network Design

The purpose of the feeding network is to drive the radiation patch with equal amplitude and 90° phase shift to obtain the right-hand polarization while maintaining good impedance matching over wideband.

90° Phase Shifter Using CRLH. The composite right/left-handed (CRLH) transmission line has the ability to synthesize an arbitrary phase response, it provide an approach to realize the phase-adjusting circuit[4].The slope of the phase-response curve of a CRLH TL can be the same as that of a conventional TL along with a stable phase increment, such as 90° , over a wideband frequencies. Based on the phase synthesis capability of the CRLH, it finds applications in the realization of couplers [5], filters [6], phase shifters [7], baluns [8], and transitions [9].

In this paper, we use CRLH approach to realize the 90° broadband phase shifter part. It consists of a Wilkinson power divider and two phase adjusting TLs, namely a CRLH TL and a conventional TL. The conventional TLs and CRLH TLs are connected to two output ports of the divider as a phase adjusting circuit to achieve broadband phase shift. The center frequency of Wilkinson power divider is at 1385MHz. Frequency range is between 1.16-1.61GHz. As the name describes, CRLH consist of left-handed (LH) transmission line and right-handed (RH) transmission line. In this design, the LH TL part is cascaded by two T-type network with the value of L=15nH and C=6pF, which are obtained by the design procedures in [10]. Then, the power divider, the TLs and the lumped elements for the CRLH TLs are co-simulated together in ADS software. The schematic of 90° phase shifter using CRLH developed in this paper is shown in Fig.2.

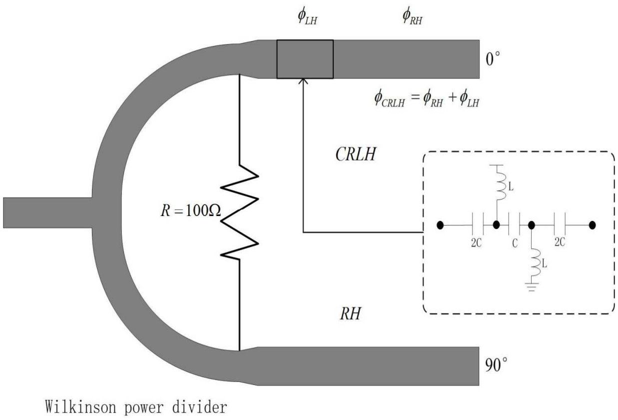

Fig.2. Schematic of the CRLH phase shifter used for the proposed design

Compared with conventional RH transmission line phase shifter, the CRLH phase shifter is compact with a much wider bandwidth. When the phase shift is more than 90°, the phase shift error of CRLH approach become bad. That will seriously affect the 3dB axial ratio (AR) bandwidth of the antenna. So it is necessary to adopt other kinds of phase shift methods to overcome this limitation. A new switched-network phase shifter with broadband characteristic has been proposed in [11]. In this letter, we use this approach to design the part of 180°phase shifter.

180° Phase Shifter. Fig.3 shows the broadband phase shifter scheme for 180° phase difference. The phase shift can reach to 180° by using λ/8 parallel open and short stubs. Path 1 is a standard transmission line whose characteristic impedance is Z_0=50Ω and electrical length is 2π. Path 2 consists of a fixed main line with a length of λ/2 and two double stubs, which are shunted at the edge points of the main line. The stub length is λ/8. Even-odd mode method and the principle of superposition can be used to analyze the structure. For 180° broadband phase shifter, using the values in [11], Z_0=50Ω, Z_s= 62.8 Ω, Z_m = 80.8Ω.

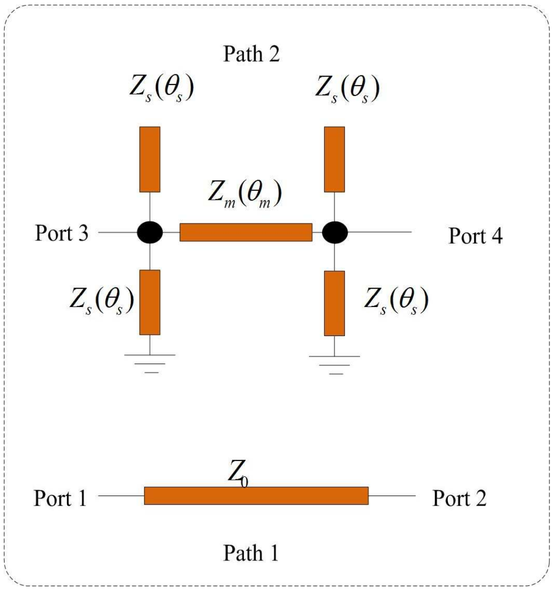

Fig.3. Schematic of the 180°phase shifter used for the proposed design

Whole Feeding Network. We can still use the method introduced in section"180 ° Phase Shifter" to realize 90° phase shifter in fact. However, the transmission line, with the maximum length of λ/2, is too long to place on the limited space. Combining the CRLH phase shifter and the suggested structure in section "180° Phase Shifter" is a feasible method to achieve acceptable phase error and relative compact size in the mean time.

The whole configuration of the proposed feeding network is shown in Fig.4.

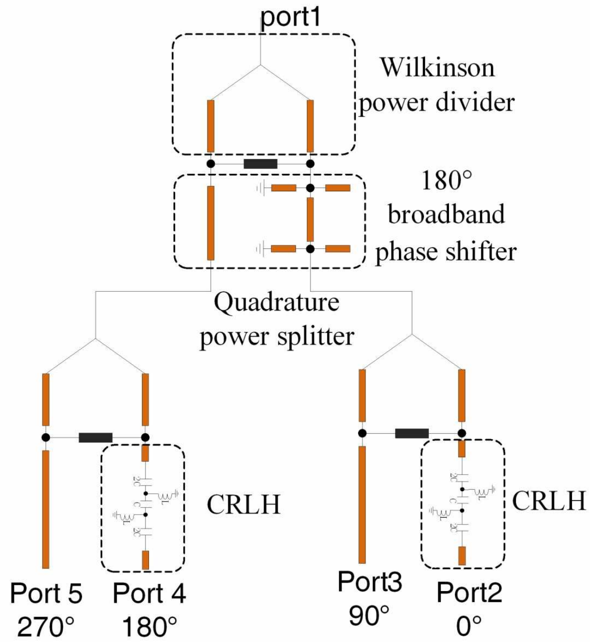

Fig.4. Whole configuration of the proposed feeding network

Implementation

The FR4 substrate with a thickness of 1.6mm and the dielectric constant of 4.4 is employed to fabricate the developed feeding network circuit. All RH TLs with 50Ω characteristic impedance are implemented with microstrip lines with a width of 3mm on this substrate.

Based on the design, the feeding network circuit is implemented as shown in Fig.5. Its dimension parameter is 21cm × 16cm. The artificial LH part in the CRLH TL is realized by 0603(1.6mm×0.8mm) surface-mount-technology (SMT) chip inductors and capacitors. However, there are limited discrete available values of inductance/capacitance of SMT chip components. Therefore, the values of inductance or capacitance in the fabricated circuit are slightly different from the design values.
In practice, the parasitic effects of soldering and vias have to be taken into account in the CRLH case. It will significantly affect the phase shift performance.Fig.6 shows the photograph the CRLH phase shifter part. Fig.6. photograph of the fabricated CRLH phase shifter

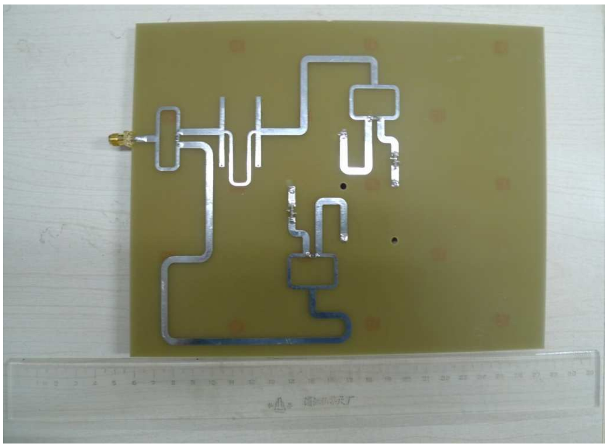
Fig.5 Photograph of the whole fabricated feeding network


Fig.6. Photograph of CRLH phase shifter

Simulation and Measurement Results

The effectiveness of the whole feeding network is demonstrated by the experimental results.

Fig.7 shows the simulated and measured results of the reflection coefficients S_{11}. The S_{11} are better than 10dB from 1.16GHz to 1.61GHz.

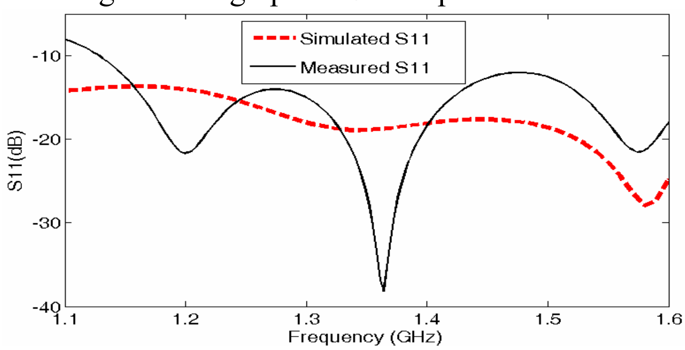

Fig.7. Simulated and measured results of S_{11}

The performance of 0°, 90°, 180°, 270°broadband phase shifter is shown in Fig.8, Fig.9 and Fig.10 .Over the working frequencies of the multi-mode GNSS antenna, the measured phase difference between port 4 and port 5 fluctuates between 89.6°and 92.1°, port 3 and port 5 fluctuates between 175.6 °and 183.1°, port 2 and port 4 fluctuates between 268.6°and 278.5°. The phase tolerance is acceptable.

Summary

A feeding network for a four feed wideband circularly polarized antenna for multi-mode Global Navigation Satellite System (GNSS) is proposed. By combining two 90° CRLH phase shifters and one 180° novel schiffman phase shifter , a broadband phase shifter with the phase shift of 0°, 90°, 180 °,270° is designed, implemented and experimentally verified. Results show that the phase error of the proposed design is acceptable. It is an effective approach to realize the feeding network.

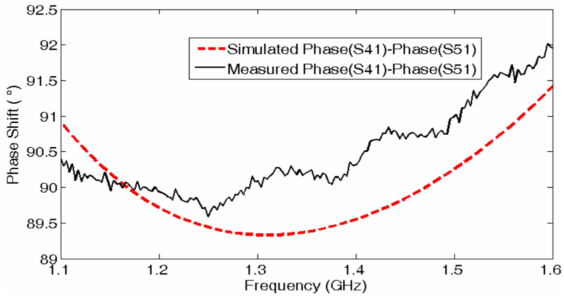

Fig.8. Simulated and measured results of the phase difference between port 4 and port 5

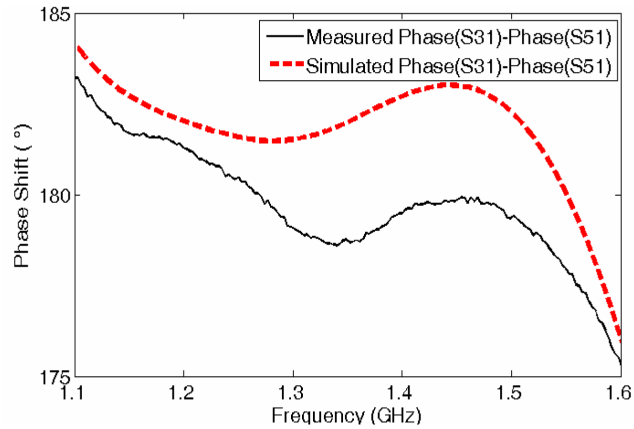

Fig.9. Simulated and measured results of the phase difference between port 3 and port 5

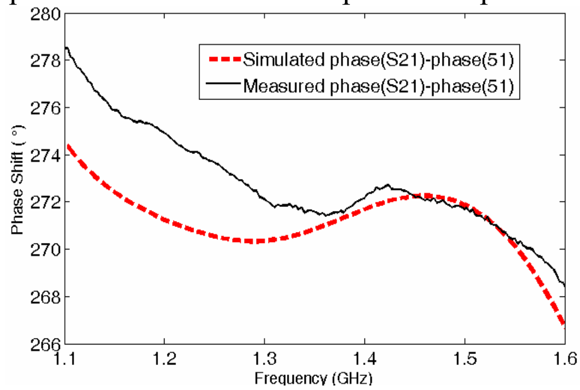

Fig.10. Simulated and measured results of the phase difference between port 2 and port 5

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