

# 一种基于 CRLH 传输线的圆极化微带天线

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**摘要** 提出了一种利用复合左右手传输线(CRLH TL)来设计小型圆极化贴片天线的方法。采用在天线地板刻蚀逆开口谐振环(CSRR)实现并联电感以及在贴片中央开槽实现串联电容。由于 CSRR 能够有效降低+1阶模式谐振频率,因此,可以缩小天线电尺寸。同时,由于 CSRR 的不对称性产生的寄生模式与+1阶模式相互正交,通过调整贴片中央的圆形宽缝可以使二者幅度相等,故而形成圆极化辐射。实验结果表明:该圆极化天线电尺寸为  $0.389\lambda_g \times 0.389\lambda_g$ ,阻抗带宽和轴比带宽分别为 16.08%和 1.52%,该天线用  $50\ \Omega$  微带线直接馈电,不需要阻抗变换线和接地过孔,易于设计加工。

**关键词** 圆极化天线;小型化;轴比;复合左右手传输线

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## A Design of A Compact Circularly Polarized Patch Antenna Based on Composite Right/Left-Handed Transmission Line

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**Abstract:** A method of designing a compact circularly polarized (CP) patch antenna is proposed based on a composite right/left-handed (CRLH) transmission line (TL) unit-cell. The CRLH TL unit-cell includes a complementary split ring resonator (CSRR) nicked at antenna floor for realizing inductance in parallel and a gap slotted at the center of a stickered plate for realizing serial capacitance. The CSRR can decrease the TM<sub>10</sub> mode resonance frequency, thus reducing the size of the proposed antenna. Simultaneously, the asymmetry of the CSRR brings about a parasitical mode which crosses the +1st-order mode orthogonally by changing the slot radius. The combination of these two orthogonal modes with 90° phase shift makes the proposed antenna form a CP property. The experimental results show that the size of the proposed antenna is  $0.389\lambda_g \times 0.389\lambda_g$ , and the impedance bandwidth and the axial ratio bandwidth are of 16.08% and 1.52% respectively. Moreover, the proposed antenna is designed without impedance transformer, 90° phase shift and ground via, and is easy to design and process.

**Key words:** circularly polarization antenna; miniaturize; axial ratio; composite right/left CRLH TL

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近年来,伴随着左手材料(Left-Handed Materials, LHM)的人工实现,人们对复合左右手传输线(Composite Right/Left Handed Transmission Line, CRLH TL)的研究产生了极大热情。由于CRLH TL的非线性色散关系,将其应用于微波器件和天线的设计之中可以表现出很多优异的性质<sup>[1-3]</sup>。例如,利用CRLH TL设计漏波天线具有在全空域内进行波速扫描的特性<sup>[1]</sup>,加载CRLH TL的谐振天线具有很强的尺寸缩减能力<sup>[5]</sup>,等等。但是由于这类天线往往只能辐射线极化波,使得它在现代通信系统中的应用大大受限。

在现代卫星通信系统中,圆极化天线具有重量轻、剖面低、抗雨雾干扰等诸多性能。很多学者已经提出多种方法来设计小型圆极化天线。其中包括使用高介电常数介质板并且刻蚀臂长不等的十字缝隙<sup>[6]</sup>,或者加载4条不对称的缝隙<sup>[7]</sup>来获得小型圆极化性能。文献[6]设计的天线相比于传统的切角圆极化贴片天线具有10%的尺寸缩减,但是其轴比带宽只有0.7%;而文献[8]中设计的圆极化天线的电尺寸为 $0.454\lambda_g \times 0.454\lambda_g$ ,但是其轴比带宽只有0.5%。

本文设计了一种基于CRLH传输线的小型圆极化微带贴片天线。在天线地板上刻蚀逆开口谐振环提供并联电感,以及在贴片中央开槽提供串联电容。通过调整逆开口谐振环和圆形缝隙的尺寸,可以有效降低天线尺寸<sup>[8]</sup>。

### 1 天线结构及其等效电路

天线结构和CRLH TL单元的等效电路模型分别见图1和图2。天线印制在介电常数 $\epsilon_r=2.2$ ,厚度为 $h=1.5\text{ mm}$ 的聚四氟乙烯玻璃布板上。逆开口谐振环刻蚀在天线的地板上,等效为并联谐振回路( $L_c, C_c$ )。贴片中央开槽,并在中心处加载圆形宽缝,整个槽相当于串联电容( $L, C_g$ )。此外, $C$ 表示贴片和地板之间的固有电容。天线参数具体尺寸为: $W_1=35\text{ mm}$ ,  $W_2=18.4\text{ mm}$ ,  $W_3=22\text{ mm}$ ,  $W_4=4.6\text{ mm}$ ,  $L=40\text{ mm}$ ,  $g_1=0.2\text{ mm}$ ,  $g_2=2\text{ mm}$ ,  $r=5.1\text{ mm}$ 。根据等效电路模型,CRLH TL单元的色散曲线通过下式计算:

$$\cos(\beta d) = 1 + \frac{\left[ \frac{\omega^2}{\omega_c^2 - 1} \right] \left[ \frac{\omega^2}{\omega_R^2 - C} \right]}{2 \left[ 1 - \frac{\omega^2}{\omega_z^2} \right]} \quad (1)$$

式中:  $\omega_R = 1/\sqrt{LC}$ ;  $\omega_c = 1/\sqrt{L_c C_c}$ ;  $\omega_z = 1/$

$$\sqrt{L_c(C + C_c)}。$$

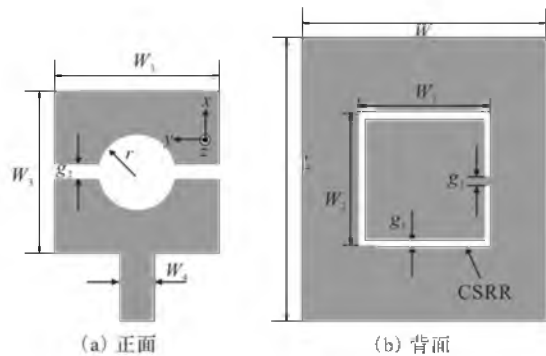


图1 天线结构示意图

Fig.1 Diagram of antenna structure

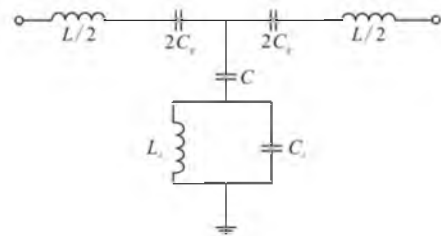


图2 CRLH TL单元等效电路模型

Fig.2 Equivalent circuit model of the CRLH TL

### 2 天线性能分析

天线回波损耗仿真结果( $r=3\text{ mm}$ )见图3。从图中可以看出,天线除了在1.6 GHz和3.34 GHz处分别激励了0阶模式和+1阶模式外,在3.8 GHz处还激励出了一个寄生模式。这是因为CSRR的不对称性导致天线激励了沿y轴的感应电流引起的。

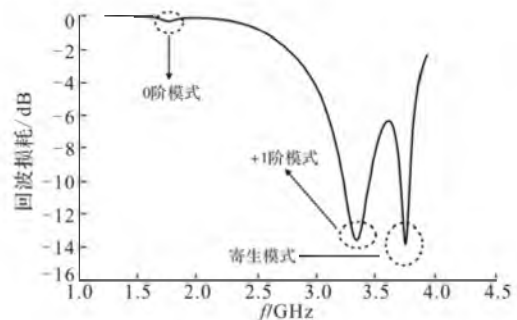


图3 天线回波损耗仿真结果

Fig.3 Simulated return loss of the antenna

图4为当圆形缝隙 $r$ 变化(0~5.1 mm)时天线回波损耗仿真结果。从图中可以看出,随着 $r$ 的增大,  $TM_{10}$ 模式谐振频率升高,这是由于 $r$ 的增大会导致串联电容的减小。同时,由于 $r$ 的增大会使贴片表面电流路径延长,因而导致  $TM_{01}$ 模式谐振频率降低。仿真发现,当 $r=5.1\text{ mm}$ 时,  $TM_{10}$ 模式

和  $TM_{01}$  模式谐振频率相互靠近,此时天线辐射圆极化波。图5为3.677 GHz时贴片表面电场分布( $r=5.1$  mm)。从图中可看出,当输入信号为 $0^\circ$ 时,天线主要辐射  $TM_{01}$  模式,当输入信号为 $-90^\circ$ 时,天线主要辐射  $TM_{10}$  模式。因此,当  $r=5.1$  mm时,天线在3.677 GHz可以辐射圆极化波。

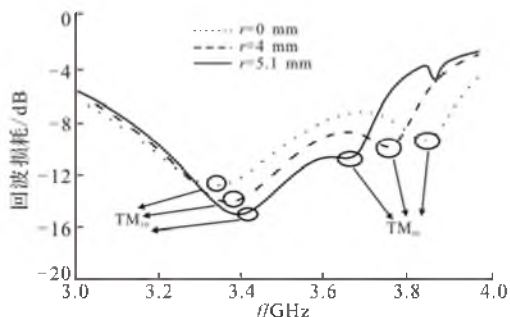


图4  $r$ 变化时天线回波损耗仿真结果  
Fig.4 Simulated return loss of the antenna for various slot radiuses

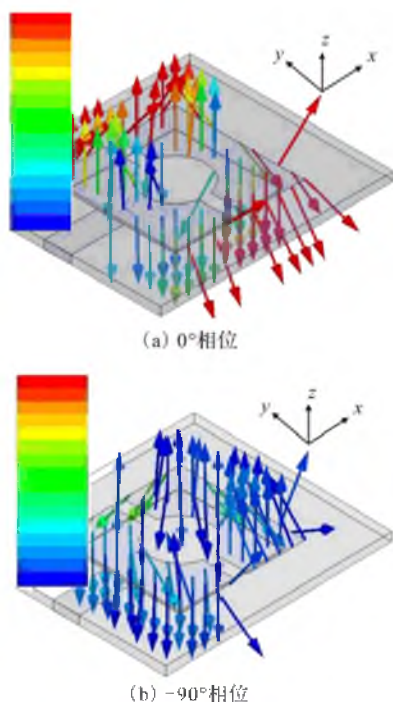


图5 3.677 GHz时不同相位下贴片电场分布仿真  
Fig.5 Simulated electric field distributions on the patch at 3.677 GHz when the input phase are  $0^\circ$  and  $-90^\circ$

### 3 实验结果

图6和图7分别是圆极化天线的实物加工图和天线回波损耗仿真与实验结果对比。从图中可以看出,实测阻抗带宽为16.08%(3.156~3.708 GHz),测试带宽比仿真值略宽的原因是介质板介电常数不均匀导致。天线仿真和实测轴比对比结果见图8。从图8可以看出,天线实测轴比为1.52%(3.649~

3.705 GHz)。贴片尺寸为22 mm×22 mm,相当于 $0.389\lambda_g \times 0.389\lambda_g$  ( $f=3.677$  GHz)。表1列举了文献[6~7,9~11]中所设计的圆极化天线性能与本文天线性能对比。可以看出,本文设计的小型圆极化贴片天线不仅具有更高的尺寸缩减性能,而且轴比带宽也比其他的宽。

天线实测归一化方向图见图9。前向辐射为左旋圆极化,后向辐射为右旋圆极化。天线在3.667 GHz时的峰值增益达到了4.43 dBi。

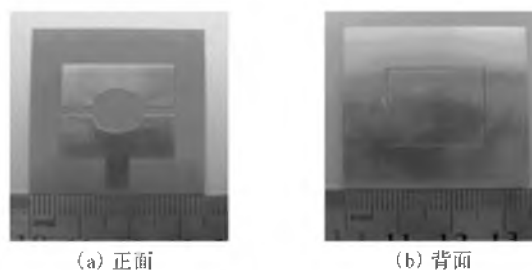


图6 圆极化天线实物照片

Fig.6 The prototype of the antenna

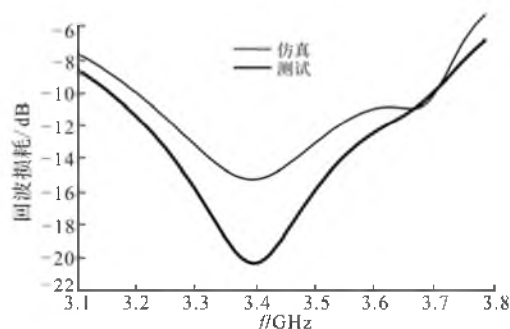


图7 天线回波损耗仿真与测试结果对比  
Fig.7 Simulated and experimental return losses of the proposed antenna

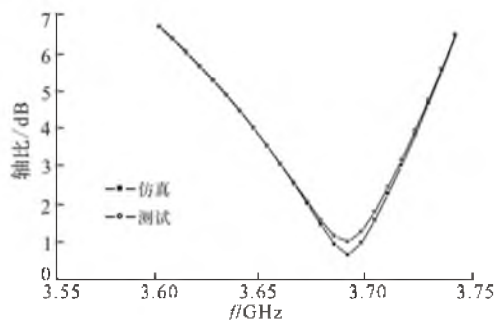


图8 天线轴比仿真与测试结果对比

Fig.8 Simulated and experimental AR

表1 本文天线与其他文献天线性能比较

Tab.1 Comparison of antenna performances

| 各类文献   | $\lambda_g$          | 轴比带宽/% |
|--------|----------------------|--------|
| 本文     | $0.389 \times 0.389$ | 1.52   |
| 文献[6]  | $0.428 \times 0.428$ | 0.70   |
| 文献[7]  | $0.454 \times 0.454$ | 0.50   |
| 文献[9]  | $0.429 \times 0.429$ | 0.84   |
| 文献[10] | $0.408 \times 0.408$ | 0.86   |
| 文献[11] | $0.414 \times 0.414$ | 0.80   |

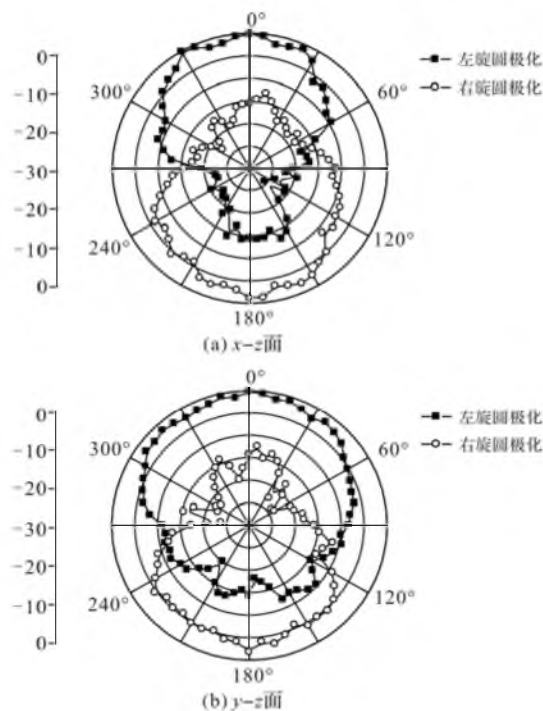


图9 3.677 GHz时天线实测归一化方向图

Fig.9 Experimental normalized radiation patterns of the proposed antenna at 3.677 GHz

## 4 结语

本文提出了一种加载复合左右手传输线的小型圆极化微带天线。通过调整贴片中央圆形缝隙的大小,使得由于CSRR的不对称性激励出来的寄生模式( $TM_{01}$ 模)与天线本身的 $TM_{10}$ 模相结合产生了圆极化波。实测结果表明,本文设计的天线电尺寸为 $0.389\lambda_g \times 0.389\lambda_g$ ,阻抗带宽和轴比带宽分别为16.08%和1.52%。

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