Research and Experimental of MRI RF High Power Bridge

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Abstract. A micro-scale 3dB high power RF (Radio Frequency) balance 4 Ports Bridge of MRI (Magnet Resonator Imaging) is realized with 3D PCB manufacturing and integrated capacity and theoretical calculation in this paper. At first a analysis method is proposed based on transmission line theory of the 1/4-wavelength and the lump and transmission parameters, and the transmission line length and lump components of capacitors value are gotted for this micro-scale bridge. Then this Micro-Balance Bridge (MBB) manufacturing with FR4 and overall size is 100mm×60 mm × 1mm, and it size reduce 1/3 compared with plane bridge. MBB could be achieved 2 ways amplitude balance is about ±0.1dB, phase balance is ±1°, insert loss is about 0.3dB, flatness is not more than 0.01dB on the operate frequency of 64MHZ±5MHZ. This bridge could be supported input pulse power more than 1000W by temperature experiment result. Use MBB integrate into the MRI systems and make imaging experiment and could reduce 20% imaging time from 1.2ms to 900us, and it has good efficiency and homogeneity.

1 Introduction

The magnetic resonance RF power bridge is splitted one way high power signal to two ways balance signals to polarize the body coil with its phase’s difference of 90 degrees. The performance of the device will affect the polarization efficiency of the coil. In order to improve the polarization efficiency of the coil, it is necessary to realize the phase difference of the two ways signal to be accurate to 90 degrees, and the two signals amplitudes are balanced. The isolation port need to ensure that the reflected signal of the coil is completely absorbed, when the condition of load variation, the phase and amplitudes of two ports are kept the balance. Furthermore, the RF coil could achieve the very high transmitter efficiency in the conditions of VSWR (Voltage Standing Wave Ratio) variation (1:1 ~1:5). A new 4 ports mixed balance bridge is studied to get the phase and amplitude balance in this paper. In general, balance bridge is a splitter with the isolation ports[1]. For MRI balance bridge, and it has more special requirements:

(1)All components can not contain magnetic materials, and also need meet very high voltage capability.Because the peak power of the RF power amplifier is very large, it can reach the kilowatt level, the bridge need meet the large voltage capability.

(2) General bridges are usually implemented using microwave integrated circuits.But it is in the lower frequency band of MRI operator band, if use this method will lead to large size, high loss, low power bearing capacity etc. If only use the lump parameter components could lead to more parasitic parameters, poor device consistency, and complicated debugging processing.

According to the basic requirements of the magnetic resonance system for balanced bridges, this paper use parts of MMIC to replace the original lumped components of inductors, and also use the capacitors. The bridge has the advantages of simple manufacturing process, wide bandwidth, strong power capacity and small size. After theoretical simulation and experimental research, the device has better performance. Compared with the domestic and international magnetic resonance system transmitting power bridge, the balance bridge has better isolation and balancer. It could be easy integrated with the RF transmitting coil to achieve the entire miniaturized magnetic resonance RF front-end system if further studied. At last, this BB are taken he imaging experiment in MRI system and the image uniformity and polarity are improved compared with the international products of the same type.

2 Fundamental principles of RF power bridge for MRI experimental verification

The magnetic resonance RF power bridge is shown in Figure 1. The BB divides RF power amplifier (PA) output signal into two equal amplitudes and their phase difference of 90. These two signals polarizes the RF coil to achieve uniform RF B1 field. Since the magnetic resonance system has a large load variation which could be varied from a very low load to a full load (VSWR:1:1~1:5), so BB need has very strong isolation more than 20dB. According to the requirements of the MRI system, P1 is input port, P2 and P3 are output port with the same amplitude and phase difference is 90 degrees, and the P4 is the isolated. A standard bridge
consists of 4 transmission lines. The characteristic impedance of \( L_2 \) and \( L_1 \) is \( Z_0, Z_0/\sqrt{2} \), and the length is \( \lambda/4 \) lines show as fig2. It can be seen that its size is very large when the operating frequency is 64 MHz, the length of a single bridge is greater than 1.17 m. It can be seen that the length is very long and then these lengths of microwave lines are realized on a PCB board, considering their power capacity and loss characteristics, if use FR4 material and the thickness is 1mm, the line width of 50Ohm is about 3.8mm, and the area occupied by the 1/4 wavelength line will be 2435mm\(^2\), considering the distance between the lines and the line, the size is will be more than 300\( \times \)100mm.

According to the above calculation, the value of \( L_1 \) can be obtained as 127 mm.

Set the working frequency to 64MH and load impedance \( Z_0=50\,\text{Ohm} \) observe the S parameters of the 3dB bridge like as fig.4(b), and the simulation model like as fig.4(c).This bridge include a PCB board with 8 capacitors, total has four runners of microstrip with some \( Z_0 \) by Fig4.(c),(b), and the four segment microstrip lines lay up on both sides top and bottom layer.

Like as fig.2, P1 is the input port, P4 is the isolated terminal, P2 and P3 are the output terminals, and P3 and P2 are 90 degrees difference phase. The simulation result is shown in Figure 4(d). It can be seen that the design has better performance, the S11 < -35dB, the S41 < -35dB, and the amplitude and phase of the output are close to the ideal result. The bridge is layout and it is fabricated by FR4 material and with ATC 100C capacitor integrated like as fig.5 (a,b,c,d).

Test above MBB with E5071C and the result is following fig.6 (a, b).

When the operating frequency is 64MHz, the simulation and measured data are compared as shown in Table 1.

Since the micro-strip width of the bridge is greater than 3mm, the thickness of the copper skin is 1 ounce, and the current that can be passed is greater than 3.5A [4]. When the power is 500W, the voltage of the microstrip line is 158V, considering the load is 50Ohm, The current is calculated to be 500/158 = 3.16A [4], so the continuous wave withstand power can be greater than 500W. The peak power can withstand a power of more than 5000W with a 10% duty cycle.
Fig. 4. (a) Equivalent circuit; (b) Simulation model; (c) Schematic circuit; (d) Simulation data.

Fig. 5. (a) PCB layout Top layer; (b) PCB layout bottom layer; (c) PCB top layer; (d) PCB bottom layer.

Fig. 6. (a) VSWR and S(11) (b) Phase gap.

Table 1. Comparison of S-parameter simulation and actual test.

<table>
<thead>
<tr>
<th>Unit</th>
<th>S11 (dB)</th>
<th>S21 (dB)</th>
<th>S31 (dB)</th>
<th>S41 (dB)</th>
<th>S(11) (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simulation</td>
<td>Test</td>
<td>Simulation</td>
<td>Test</td>
<td>Simulation</td>
</tr>
<tr>
<td>dB</td>
<td>-35</td>
<td>-29</td>
<td>3.3</td>
<td>3.33</td>
<td>3.29</td>
</tr>
<tr>
<td>Phase(°)</td>
<td>-91</td>
<td>-89</td>
<td>179</td>
<td>180</td>
<td></td>
</tr>
</tbody>
</table>

3 Balance bridge experimental magnetic resonance system study

According to the above analysis, in order to verify the imaging characteristics and efficiency characteristics of the bridge, the bridge was placed in a 1.5T superconducting magnetic resonance system, and the magnetic resonance system was used by Xingaoyi Medical Equipment Co., Ltd. Super SCAN 1.5T device. Figure 7 shows the test environment. According to the requirements of Xingaoyi equipment system, first, the spectrometer system generates -12dBm signal to the RF power amplifier. The output signal of the RF power amplifier can be obtained as 60dBm (≈1kW). The signal enters the MBB through the cable, and the MBB divides the 2 signals into the RF coil polarization. The specific experimental data is as shown in table 2.

Fig. 7. MBB image test bench of XGY system.
Table 2. Image test result.

<table>
<thead>
<tr>
<th>Electric Bridge</th>
<th>90° flip angle time</th>
<th>Polarization efficiency</th>
<th>Isolation (S14)</th>
<th>SNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>MBB</td>
<td>1.2ms</td>
<td>99.00%</td>
<td>-25dB</td>
<td>100081</td>
</tr>
<tr>
<td>XGYBB</td>
<td>0.9ms</td>
<td>95%</td>
<td>-20dB</td>
<td>90065</td>
</tr>
</tbody>
</table>

Fig. 8. (a) MBB SE Imaging; (b) XGYBB SE Imaging; (c) MBB Pixel-XGYBB Pixel.

Since the input signal has reached the peak power of 3KW, in the case of an air conditioning environment temperature of 25 degrees, the power is continuously scanned for 1 hour, and the surface temperature of the MBB is detected by a multi-meter and test result as following table4:

Table 4. Temperature of surface comparison.

<table>
<thead>
<tr>
<th>Option (1kW input)</th>
<th>Surface°C (10 minutes)</th>
<th>Surface°C (30 minutes)</th>
<th>Surface°C (40 minutes)</th>
<th>Surface°C (60 minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MBB</td>
<td>24.3</td>
<td>25.4</td>
<td>25.5</td>
<td>23.2</td>
</tr>
<tr>
<td>XGYBB</td>
<td>25.6</td>
<td>26.4</td>
<td>24.5</td>
<td>24.1</td>
</tr>
</tbody>
</table>

It can be seen that MBB has almost no heat temperature rise when it is working continuously 1 hours, and it can completely dissipate heat through natural cooling, which is enough to prove that its power capability can reach 1000 watts of peak power, which fully meets the design requirements.

Above two table results could find, for these polarization effective, isolation, SNR hot effective of key performance, MBB is better than XGYBB.

4 Conclusion
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