On-coil Power Monitor with a High Directivity Coupler

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Target audience

RF engineers and MR scientists with a basic knowledge of MR hardware circuits and systems.

Purpose

RF power monitoring is an indispensible process to prevent device damage and safety problems in MR systems. Current RF power measurements are performed in remote, and thus it is not accurate and needs calibration due to a long cable loss. An RF coupler is necessary to sample a specific portion of power travelling in the main signal line and is a key device in RF power measurement. Among characteristics of a coupler, the directivity plays a critical role to separate the coupled forward and reflected signals. In general, forward power is much larger than reflected power, and the influence of the reflected power is insignificant when forward power measurement is performed. However, high forward power can impact on a reflected power measurement, and it is difficult to accurately measure a reflected power without high directivity.[1] To achieve accurate and stable power measurements in MR systems, a high directivity coupler is proposed and compared to a conventional coupler, and a compact MR-compatible on-coil power monitor with the high directivity coupler was built and tested both on the test bench and 7T MRI (Siemens Magnetom, Erlangen, DE).

Methods

Figure 1 presents a schematic of a general RF power measurement with a coupler to monitor the power reflection in RF coil design. The RF power detector connected to port 3 should receive only a coupled reflection power (solid red line). However, a portion of RF input power in port 1 appears at port 3 (dotted blue line) due to the finite isolation. In that case, a coupled forward power is added to a coupled reflection power in the coupled line, and thus the uncertainty of the output signal at port 3 is increased as the directivity decrease. As a result, the output of an RF power monitor becomes inaccurate.[2] The high directivity coupler was designed, manufactured, tested, and compared to the conventional coupler. Dimensions of couplers are first defined to make approximate 25 dB coupling factor, and then values of a circuit to build the high directivity between port 3 and port 4 are decided after checking rough values by ADS simulation (eyesight Technology). The on-coil power monitor with the high directivity coupler in figure 4 (left) was adjacent to an RF coil, and MR-compatibility, high power capability, and functions were validated at 7T MRI.

Results

Figure 3 (bottom) shows the results of simulations (dotted line) and experiments (solid line) as well as schematics and photos of prototypes. The coupling factor (S_{32}) and isolation (S_{31}) were measured using a network analyzer and then the directivities were calculated with the conventional and proposed coupler, respectively. In figure 3 (a), the directivity of the conventional coupler is 18 dB in measurement, whereas the high directivity coupler has 43 dB at 297.2 MHz for 7T systems as shown in figure 3 (b). For example, power variation at the coupled output (port 3) is only 0.4 dBm (from 18.8 dBm to 19.2 dBm) when the coupler has a directivity of 40 dB, coupling factor of 25 dB, forward power of 50 dBm, and VSWR of 3. However, power variation is sharply increased to 3.6 dBm (from 17 dBm to 20.6 dBm) when the coupler directivity is 20 dB and other characteristics are same. Capacitors, C_{L1} and C_{R1}, control the frequency and resistors, R_L and R_R, control the phase of the coupled signal to achieve the high directivity. Thus, properly selected values create dip isolation at desired frequency band. Figure 4 shows a photo of the home-built on-coil RF power monitor (left) and a sample uncorrected MR image (right) associated with the on-coil power monitor. Since any significant defect or distortion is not observed in the MR image obtained with a gridded head shape phantom and functions are appropriately working up to 1kW RF power, MR-compatibility and functions of the on-coil power monitor are validated.

Conclusion

The proposed high directivity coupler has been accomplished more than 25 dB improvement of directivity than a conventional coupler. The coupler is applied to the on-coil reflected power monitor that provides the accurate and stable power monitoring output. The on-coil power monitor can be used to build a RF safety device or an automatic control system to reduce the RF power reflection.

Acknowledge

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References

[1] J. Madic, P, et al. RFIC Symposium. p. 715-718, 2003 [2] Sung-Min Sohn, et al. Microwave symposium (IMS). June 2014

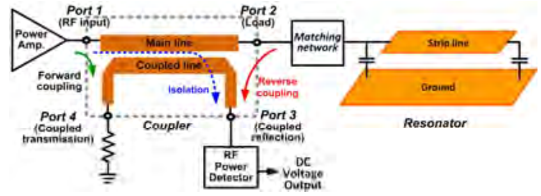


Figure 1. A general RF power monitoring system in RF coils.

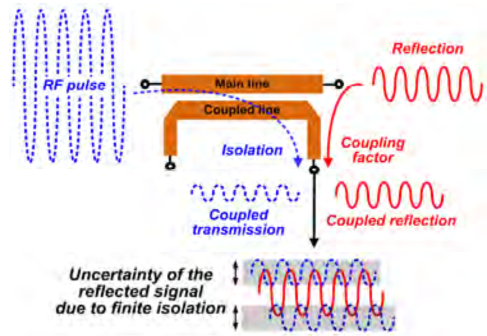
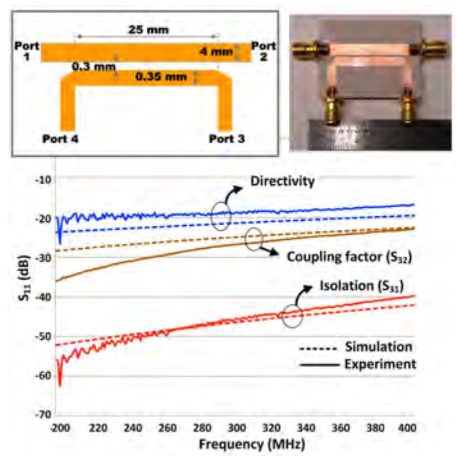
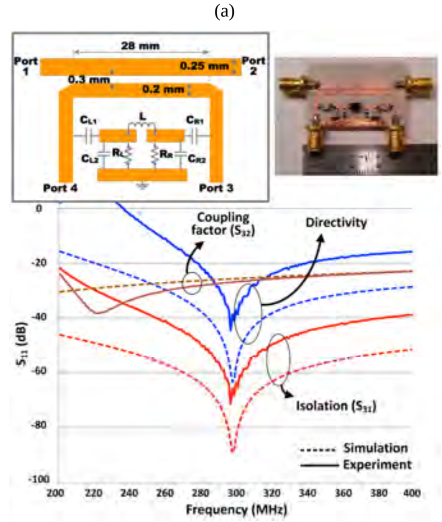


Figure 2. Uncertainty in RF power measurement by the finite isolation.



(a)



(b)

Figure 3. Comparisons of (a) the conventional vs. (b) high directivity coupler.

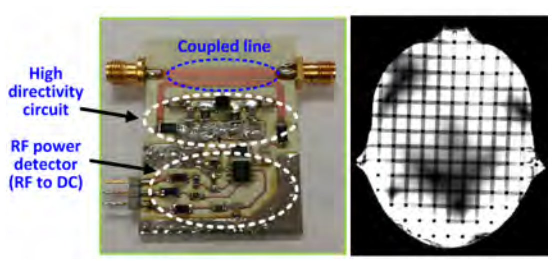


Figure 4. Photo of the on-coil power monitor (left) and a sample MR image (right) associated with the on-coil power monitor operation.