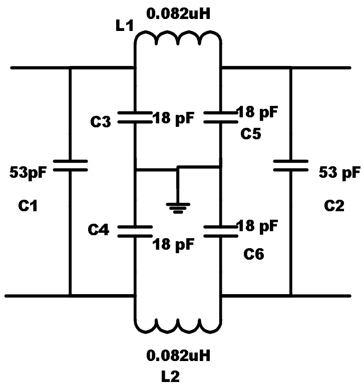
Hardware Combiner Testing and Simulation

J. H. Akao[1], D. D. Spencer[1], C. A. Saylor[1]
[1]MRI Devices Corporation, Gainesville, Florida, United States

Introduction

The performance of multi-element RF coils can be improved by using phased splitter-combiner circuitry between the elements and the MR system channel receivers. At a single frequency, each circuit output is a phased linear combination of the inputs. For example, in a bird-cage coil with a two-point pickup, a quadrature combiner extracts a strong mode on one output and an orthogonal weak mode on the second output. The 2 ch. to 2 ch. combiner can be implemented with an LC quad-hybrid circuit, shown in Figure 1. The outputs sum the two inputs with a +90º and a -90º phase shift.

Figure 1



More general N ch. to N ch. combiner circuits preserve the full information of the N input elements, while ranking the outputs in strength. Discarding weak outputs allows a reduction in channels when receivers are scarce [1]. Selecting noise correlation eigenmodes whitens the noise on the output channels for improved array SNR [2].

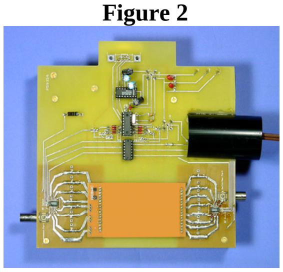
An 8 ch. to 8 ch. combiner circuit consists of hundreds of LC components. An ideal circuit implementation of the 8 x 8 forward scattering matrix should have good power and phase stability in the presence of frequency shifts and component variation. Effective scattering simulation tools and hardware test equipment shorten the circuit design cycle and assure quality during production.

Methods

RF tableau equations are implemented for circuit schematics of linear components [3]. SPICE simulation computes 16 x 16 complex scattering for each frequency. The equations are analytically differentiated to compute the sensitivity of the scattering with respect to variation in the R, L, and C values of every component.

The combiner test fixture uses a computer controlled RF switching network to obtain a 16 x 16 forward, reverse, and reflection scattering matrix. GPIB communication synchronizes acquisition from 2 RF network analyzer ports. The scattering measurement is fully automated and is used for production quality testing as well as validation of the simulations. A picture of the combiner test fixture is shown below in Figure 2. A calibration board with opens, loads, shorts, and throughs is used with the network analyzer's calibration to remove losses and phase shifts in the test fixture itself.

Figure 2



Results

An 8 input to 8 output Fourier mode combiner was created for 8 element radially symmetric coils. Power should be split equally among the 8 outputs at -9 dB with lossless components. Output channels should have input phase increments of 0, 45, 90, ..., 315 degrees. A hardware combiner board design was simulated, built and tested. Table 1 shows the transmission power and channel to channel phase difference of the board. Phase differences match the ideal up to ±15º. Simulations match the measured results to the tolerance of the components.

Used for production circuit boards, the system tests each unit in approximately 30 seconds. Without automated RF port switching and data acquisition, each unit required 10 minutes to record the scattering.

Table 1 – Hardware Combiner Measurements

Power Transmission

		Inputs							
		1	2	3	4	5	6	7	8
Outputs	1	-10.2	-10.3	-10.07	-10.3	-10.2	-10.5	-10.2	-10.5
	2	-10.5	-10.2	-10.49	-10.2	-10.6	-10.3	-10.6	-10.5
Power	3	-9.97	-10.8	-10.17	-10.9	-9.99	-10.9	-10.2	-11.1
(dB)	4	-10.3	-10.8	-10.42	-11.2	-10.3	-10.7	-10.5	-11.1
	5	-9.97	-10.5	-9.9	-10.5	-9.76	-10.1	-9.51	-10.1
	6	-10.5	-10.2	-10.44	-10.2	-10.2	-9.93	-10	-9.87
	7	-10.2	-10.4	-9.9	-10.1	-9.84	-10.1	-9.86	-9.89
	8	-10.5	-10.3	-10.14	-10	-10.1	-9.88	-10	-9.7

Transmission Phase Angle Difference Input-Input

		Inputs							
		1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-1
Outputs	1	147	138	139	120	143	139	138	116
	2	-32	-43	-39	-62	-36	-42	-41	-65
Phase	3	47	56	41	40	44	57	39	36
(deg.)	4	-132	-126	-137	-140	-138	-123	-139	-145
	5	104	80	97	81	100	83	95	80
	6	-76	-100	-82	-101	-78	-99	-84	-100
	7	-173	179	180	176	-176	-180	179	175
	8	8	-2	1	-6	6	-2	0	-5

Discussion

SPICE simulation is combined with automated testing to design complex LC splitter-combiner circuits. The hardware combiner testing and simulations provide a way to rapidly check the combiner circuit's performance. In production, failing components can be identified and replaced.

References

[1] King, S. et. al. Proc. ISMRM 11:712 (2003).
[2] Roemer, P.B., et. al, Magn Reson Med 16:192-225, 1990.
[3] Rodrigues, P. "Computer Aided Analysis of Nonlinear Microwave Circuits", Artech House, 1997.