Design of MOSFET Matching Networks without Inductors

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Introduction:

Parallel transmission has been recently suggested as a method for improved B1 field homogeneity in MRI[1,2]. Expensive high power single channel RF amplifiers have been successfully replaced with MOSFET based amplifiers by several groups for reduced cost[3,4]. Usually, a MOSFET based amplifier requires both capacitors and inductors for matching. While capacitors are readily available in most values needed for such matching networks, this is not the case for inductors. Inductors are often wound in house to produce the values necessary. This is not a problem for small quantity production, but this becomes time consuming when a large number of channels is required. Inductors can also produce an alternating B field, resulting in coupling between adjacent channels when amplifier boards are not shielded separately. We have developed a MOSFET (Freescale MRF6V2150NR1) based 100W class-AB amplifier with only microstrip transmission lines and fixed capacitors for matching networks. By completely eliminating inductors from the matching networks, the design shows improved isolation between adjacent channels. Furthermore, in building a 64 channel amplifier system, no tuning of individual boards is required, which makes this solution attractive for high-channel-number parallel transmission for MRI.

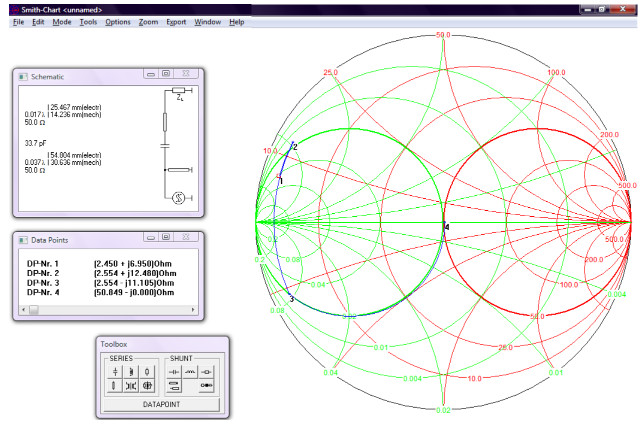

Figure 1. Smith chart program used for matching network design. Point 1 is the input impedance of the MOSFET given by manufacturer's specifications. Using a transmission line in series, the impedance is brought to point 2. Then a capacitor in series brought the impedance to point 3 on the constant conductance bold green circle. A 50Ω shunt stub brings the impedance to the desired impedance. Values of all components are conveniently shown the top left window.

Methods:

The input and output impedances of the MOSFET at 200MHz was first obtained from the MOSFET data sheet. The matching networks were then designed using a Smith Chart application (Figure 1) by F. Dellsperger from Berne University of Applied Sciences, Switzerland. Since microstrips can become unacceptably long at 200MHz, about 80cm for a full wavelength of 50Ω line on FR-4 board, microstrips with capacitors were mixed together for matching networks. Two microstrip transmission lines and a capacitor are used for the input and output matching networks, except with different lengths and values. Based on Brian C. Wadell's[5] microstrip characteristic impedance and effective dielectric constant calculation formula, we decided to use 50Ω microstrip transmission lines. This is because the calculations indicate a width of 110mil on standard FR-4 board, and the lengths required for input and output matching fit well inside the chosen enclosure. Higher impedance microstrips are narrower in width and resulting in lossy matching networks, while lower impedance microstrips make the matching network more bulky.

A short 50Ω microstrip transmission line is used immediately after the MOSFET input so that the capacitor value would be smaller than 100pF, since capacitors below 100pF are more readily available. A capacitor is then used in series to bring the impedance to the constant conductance circle, from where we used another 50Ω shunt microstrip transmission line to bring the impedance to 50Ω. A picture of the finished amplifier is shown in Figure 2. A large inductor was wound in house for biasing the drain of the MOSFET, however its value is not critical because it simply works as an RF choke. "Pigtail" style cables are used to reduce the cost. Gate bias voltage is controlled to turn on and off the amplifier and the output also includes a PIN diode based noise blanking circuit and a PIN diode driver. A picture of 16 amplifiers inside a rack mountable enclosure is shown in Figure 3.

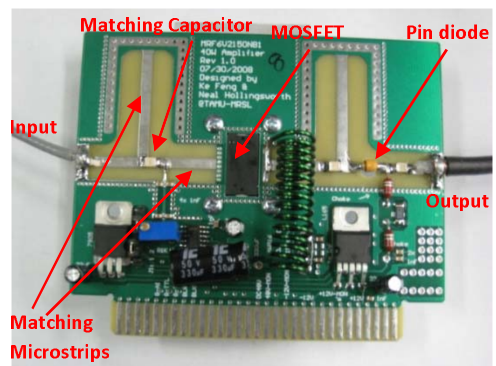

Figure 2. One of our finished amplifiers. The tin-lead plated straight traces are the microstrips for the matching network. The card edge connector brings the module its DC power, digital signals (gate on/off switch, and blanking on/off switch), and brings the status back to motherboard which hosts this module.

Results and Discussion:

Although the Smith Chart software gives reasonable estimations (within 20% error) of the lengths of the microstrips and the capacitor values, it was still necessary to fine tune the lengths and the capacitors. Since the length of the shunt stub is critical, we first built a prototype with extra length. Then by moving the shunt to ground, we fine tuned the length. We also changed the capacitor values until we achieved optimum performance. Once this was done, the same values served for the construction of more amplifiers without additional concern for matching. Isolation was also improved. With a previous MOSFET amplifier design, even though amplifiers were individually shielded and spaced 1.85 inches apart, the isolation was -30dB between adjacent channels[6]. In this new design, the worst case isolation between neighboring channels of the whole transmitter chain was measured to be -31dB even though amplifiers are not individually shielded and are placed 1.5 inches apart (Figure 3). Furthermore, by putting fixed capacitors at the matching networks without any tuning, the amplifiers give gains of 22.9dB ±1.1dB for 64 amplifiers. Since the modulators used to feed the amplifiers have dynamic ranges of 60dB, this variation in gain is not a problem for us[7]. We expect that if the FR-4 boards were replaced with other boards with better electrical characteristics, like Roger R4003, better performance and less variation in the gain could be achieved.

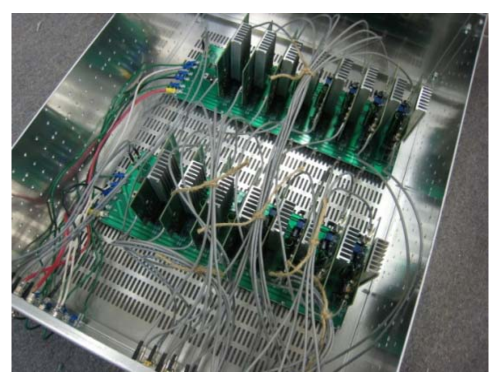

Figure 3. Amplifiers on motherboards inside a rack mountable enclosure.

Acknowledgment:

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References:

1. Katscher U, et al, NMR Biomed. 2006; 19: 393-400. 2. Zhu Y, MRM 2004; 51: 775 - 784 3. Kurpad KN, et al, Proc. Intl. Soc. Mag. Reson. Med. 11 (2004) p.1585 4. Hoult DI et al, Proc. Intl. Soc. Mag. Reson. Med. 16 (2008) 5. Wadell BC, Transmission Line Design Handbook, Artech House, 1991. 6. Chen X, et al, Proc. Intl. Soc. Mag. Reson. Med. 15 (2008) 7. Feng K, et al, Proc. Intl. Soc. Mag. Reson. Med. 16 (2008)