MRI Transmitter Amplifier Systems

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Highlights

- MRI RF power amplifiers have linearity requirements of broadcast Television.
- Modern 1000W LDMOSFETs simplify whole body and transmit array architectures.
- RF pulses suffer a variety of subtle distortions that are not corrected by lookup tables.

Target Audience: MRI RF coil designers and pulse sequence designers.

Objectives: Understand the physical limitations and architecture compromises of power amplifiers that constrain MRI wave-shapes and power transmission.

Purpose:
RF power amplifier systems design is an exceedingly broad and complex engineering discipline. The goal of this tutorial is to identify the important architecture and design limitations relevant to MRI. All MRI pulse sequences assume that the RF power amplifier has high linearity, and maintains phase and amplitude stability over the entire pulse sequence duration. In typical pulse sequences, the time average power needs may be as little as 1-5% of the peak power requirements. Real RF power amplifiers have distortion, generate heat, and can suffer from various drift or memory effects. By the end of this presentation, the MRI pulse sequence or RF coil designer will have developed a more realistic understanding of RFPA operation.

RFPA Basics RF power amplifier operation falls under a veritable alphabet soup of classes A, B, AB, C, D, E, F of which the A-B range refer primarily to linear but inefficient designs, and C-F are nonlinear but very efficient classes. It is one of the least appreciated mysteries of RFPA technology that simultaneously linear AND efficient power amplifier design goals are contradictory. Class AB, which leaves transistors always partly biased on, is the most common choice to maintain good linearity without huge penalties in heating. With solid state amplifiers, the maximum power a single LDMOSFET transistor pair can now control is about 1KW through to 500 MHz. Given peak power needs reach 35 KW at 3T, multiple modules must be combined. This is achieved through quadrature combiners, or in phase combiners. Interestingly, transmit arrays represent a third form: spatial power combining.

Nonlinearities: RF amplifiers exhibit some nonlinearity that can be modeled by a static nonlinearity model as well as time dependent (memory) effects. Thermal heating of the transistor over the duration of an RF pulse occurs on the 100 us to ms time scale, creating a detectable temporal dependence. Indeed, certain RF pulses such as a rectangular “hard” pulse, demand infinite rise times in power supply currents, and are invariably distorted by the voltage rail linear systems dynamics. Advanced architectures are needed to mitigate these effects.

Conclusions MRI systems occupy similar frequency ranges to that of the broadcast bands, and can directly leverage the new high power transistors developed for FM radio and digital broadcast. The topic of RFPA design is vast, with almost a century of research publications. For a basic introduction and further references [1,2] are very readable and offer excellent breadth into this fascinating discipline.

References: [1] RF and Microwave Power Amplifier and Transmitter Technologies, Frederick H. Raab, Peter Asbeck, Steve Cripps, Peter B. Kenington,Zoya B. Popovic, Nick Pothecary, John F. Sevic and Nathan O. Sokal, High Frequency Electronics, Parts 1, 2, May 2003, Part 3 Sept 2003, Part 4 Nov 2003, Part 5 Jan 2004. [2] RF Power Amplifiers for Wireless Communications, 2nd Ed Steve C. Cripps, Artech house, 2006.