High-Efficiency RF Power-Amplifier Module for Magnetic-Resonance Imaging

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Introduction

The Kahn EER technique (polar modulation) achieves high-efficiency linear RF amplification by combining high-efficiency RF-power amplifiers with high-efficiency amplitude modulators [1]. This implementation (Fig. 1) also incorporates a digital signal processor (DSP) and modulation of the drive signal [2].

Hardware

The final RF power amplifier (PA) is a push-pull class-E design that uses a 50-V RF-power MOSFET. The PA is broadband except for the output tuning, hence operation at different frequencies requires only substitution of the appropriate output network. An output of 200 W with an efficiency of 80 is obtained through lower VHF. The efficiency drops to 71 percent at 128 MHz. The class-S modulators are based upon a quasi-complementary topolgy. The combination of a 2-MHz switching frequency and a six-pole output filter allows a 500-kHz envelope bandwidth and a 1-μs rise/fall time. Partial modulation of the driver [2] is used to provide good linearity and efficiency at all amplitudes. The signal inputs to the RF driver and class-S modulators are produced by the digital signal processor (DSP). The DSP includes the capability to generate a stored signal upon receipt of a trigger as well as the capability to digitize an analog-RF input signal. The sampling period is 1 μs and the *I*/*Q* bandwidths are 250 kHz. The DSP predistorts the signals that it produces.

Performance

The efficiency of the final amplifier and modulator is shown in Fig. 2 for operation at 42.6 MHz. The efficiency ranges from 50 to 70 percent over the top 10 dB of the amplitude range. For a typical MRI sinc pulse, the power consumption is cut in half and the dissipation cut to one fourth those of a conventional linear amplifier. The linearity is shown in Fig. 3. The amplitude-transfer function fits a straight line within 0.13 percent rms. AM-PM conversion is about 0.5º over most of the 80-dB amplitude range. The transmitter accurately reproduces the envelopes of a variety of signals (Fig. 4). The third-order IMD for a two-tone signal is typically -36 dBc (Fig. 5). The images produced (Fig. 6) are comparable to those of a conventional amplifier. Multiple modules can be combined for higher power. The capability to produce a variety of signals with high efficiency makes this transmitter attractive for MRI as well as a variety of communication applications.

References

[1] Raab, F. *et al.* *IEEE Trans. Microwave Theory Tech.*, vol. 50, no. 3, pp. 814 - 826, March 2002.
[2] Raab, F. *IMS. Digest*, vol. 2, pp. 811 - 814, Anaheim, CA, June 14 - 17, 1999. (U.S. Patent 6,256,482).

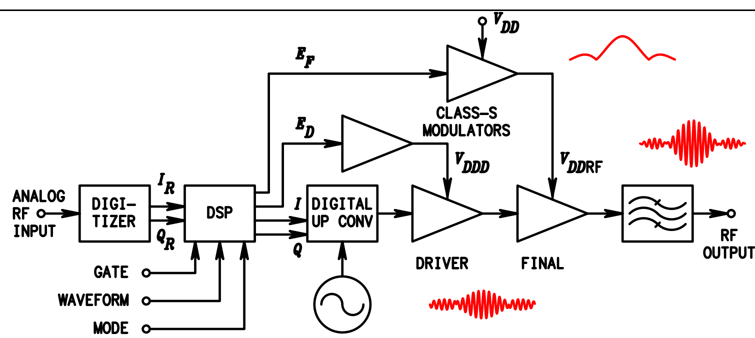

Fig. 1. Block diagram.

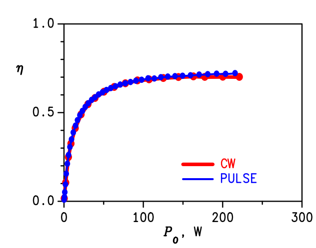

Fig. 2. Efficiency.

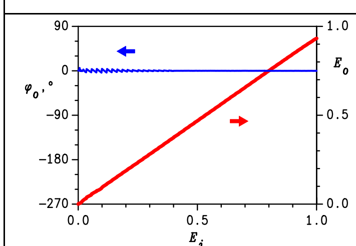

Fig. 3. Linearity.

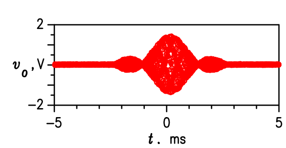

Fig. 4. Sinc envelope.

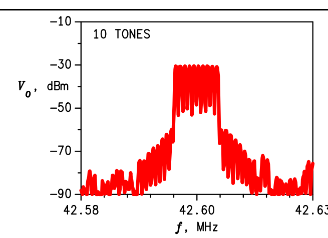

Fig. 5. Ten-tone spectrum.

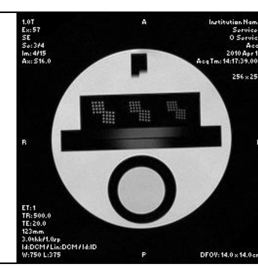

Fig. 6. Test image.