

16-Bit Vector Modulator for B₁ Shimming in 7T MRI

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Introduction:

The concept of B₁-shimming is important for improving SNR and uniformity in MRI at high field. B₁-shimming can be performed using multiple transmitters [1,2] connected to a coil array. A homogeneous slice can be achieved by adjusting the magnitude and phase on each transmitter channel until a uniform composite excitation is obtained. In this paper a high resolution vector modulator has been designed to control the phase and amplitude of eight channels for B₁ shimming in MRI at 7T. The IQ modulator replaces more expensive components like digitally controlled phase shifters and attenuators.

Method:

An 8+8 bit 300 MHz vector modulator with 8-bit digital potentiometers for I and Q control as shown in Fig 1 was designed. Eight silicon RFIC quadrature modulators AD8345 and eight quad-channel digital potentiometers AD8403 were employed in the design. Surface-mount high-frequency relays were used as safety overrides and to switch the vector modulator in and out of the RF path. Relays and potentiometers are controlled by a PIC18F4550 Microcontroller. This I-Q type vector modulator yields 256x256 possible signal combinations, with each symbol representing 16 bits. Fig 2, a constellation diagram, represents all states of a QAM (for reasons of resolution, only states for a 5+5 bit constellation are shown). Circuit boards used in the vector modulator are shown in Fig 3. A PC program (MATLAB) was written to control the phase and amplitude of each channel. Using the GUI, shown in Fig 4, the PIC18F4550 Microcontroller receives control data via a USB port, and the appropriate signals are sent to the potentiometers. Finally, the potentiometers produce controlling voltages for I and Q of the vector modulator. All of the circuits for eight channels have been fabricated and integrated into one 19" chassis (Fig 5).

Results:

The vector modulator internally uses a 90° phase shifter for the creation of an in-phase (I) signal and a quadrature (Q) signal. The quadrature phase error was found to be just above 1° at 300 MHz. Both I- and Q-signals are controlled in amplitude by the differential d.c. voltages applied.

The level range that can be controlled was found to be more than 30 dB at 300 MHz without extra zero-adjustment. Using the 8-bit potentiometers for the generation of the control voltages, the vector modulator produces 128 equal amplitude steps between the maximum and the minimum output signal for positive and 128 steps for negative sign. The size of these steps was verified in measurements for high to medium levels which means that the amplitude accuracy of the vector modulator is a about 0.01; however, at the low levels around -30 dB, a residual signal (feed-through) degrades the level control. The recombination of level controlled I- and Q-signals produces the ultimate output signals of the vector modulator, such that the resolution is of the order 0.01 in amplitude and from 0.5° to 5° in angle for amplitudes in the 0 to -20 dB range. Note that the vector modulator electronic IC exhibits nonlinear characteristics when the input signal exceeds the compression point; therefore, an attenuator was placed at the input, see Fig 1. Using this vector modulator in the system shown in Fig.1, T₁-weighted FLASH images were produced as in Fig 6. Results show that the system is capable of full modulation.

Discussion:

The vector modulator is based on a very inexpensive and well repeatable circuit design with minimum interfacing. All printed circuits were designed in house and were easily fabricated with inexpensive tools. In the current implementation, B₁-shimming is readily achievable, but the interface circuitry is not fast enough to support Transmit SENSE. As can be seen from Fig 1, a long chain of power splitter, vector modulator, power amplifiers, switches, Transmit Antenna Level Sensors (TALES, power monitoring devices), long coaxial cables and the RF coils all affect the ultimate coil current that we want to control in our RF shimming approach. We therefore need to measure the overall tracking errors between the eight channels in order to utilize the high-resolution vector modulator for error correction and B₁-shimming at the same time. Experience with this "calibration" concept will be reported later.

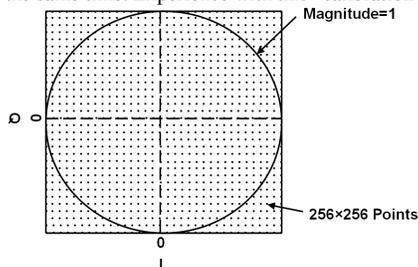


Fig. 2 Constellation diagram for QAM (quadrature amplitude modulation)

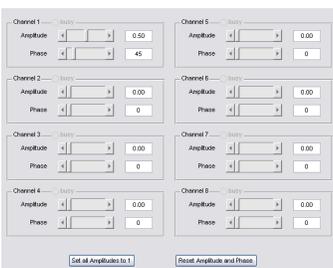


Fig. 4 Matlab GUI program to control amplitude and phase

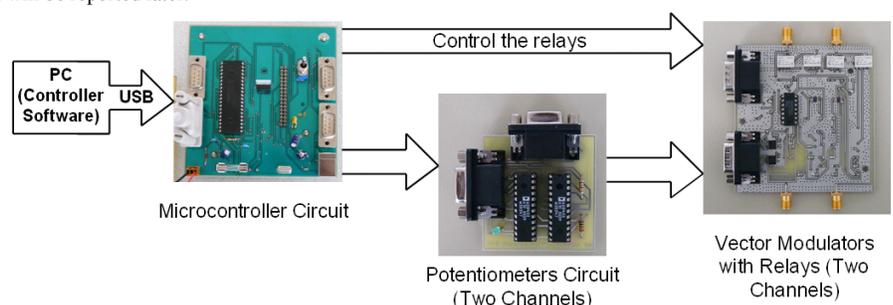


Fig. 3 Circuit boards and system schematic to control the amplitude and phase in B₁ shimming

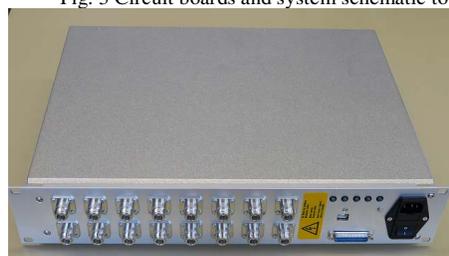


Fig. 5 Fabricated vector modulator

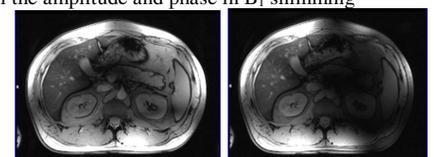


Fig. 6 T₁-weighted FLASH image obtained with flexible 8-ch body array. (a) phase shifts of channels adjusted to yield good image quality throughout the whole image (left); amplitude and phase shift adjusted for optimized B₁+ homogeneity in right body region (right)

References:

[1] Collins CM et al, Magn Reson Med 2005; 54:1327-1332. [2] Adriany G et al, Reson Med 2005; 53:343-445.