Cartesian Feedback Configuration with Direct RF Signal Injection for Power Amplifier Linearization at 1.5T MRI

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Introduction We implement a simplified Cartesian feedback configuration for power amplifier linearization for use in MRI transmit, that injects the incoming MRI signal into the feedback path without the need for an initial demodulator, providing greater simplicity and cost reduction. This form of Cartesian feedback, or RF feedback, creates the error signal at RF using a power splitter, rather than at baseband [1, 2], allowing direct use of the MRI RF transmit source signal. Such a linearity technique is useful in MRI multi-channel transmit where coupling between multiple coils can change the load conditions and generate unpredictable changes in coil current distributions which can compromise the fidelity of the transmitted waveform.

In the original Cartesian feedback setup [3-5], the MRI signal input must be down-converted to baseband or IF before it enters the Cartesian feedback loop through the error amplifiers. An error difference amplifier links the forward and feedback path by comparing the down-converted MRI signal input and sampled feedback signal. When given enough loop gain, it forces the difference between the two signals to zero, and outputs a pre-distorted waveform into the forward path. The forward path includes an up-converter and the RF power amplifier. The feedback path includes another down-converter that demodulates the RF signal back down to baseband or IF as our sampled feedback signal into the error amplifier.

The modified Cartesian feedback architecture precludes the need for the first down-converter that demodulates the signal from RF down to baseband/IF, by injecting the error RF signal prior to the down-converter (Fig 1) [1-2]. We perform this form of Cartesian feedback for a 63.88 MHz RF signal for use at 1.5 T MRI, though applicable at other field strengths.

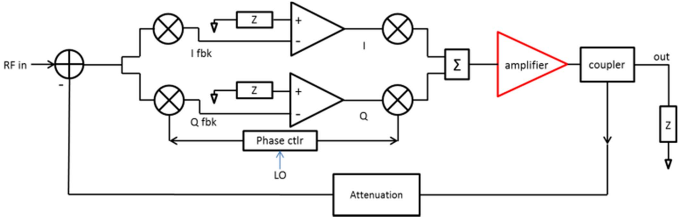

Figure 1. Modified Cartesian feedback configuration. RF input is injected before the down-converter in the feedback path

Materials and Methods To carry out the amplifier linearization experiment, we used a Medusa console [6], and a frequency-offset Cartesian feedback system with poly-phase difference amplifiers [7-8]. The CMX998 chip (CML Microcircuits) implements quadrature Cartesian feedback and includes a down-converter, up-converter, and built-in attenuators in the forward and feedback loop. Band-pass filters were added to screen out upper harmonic frequencies and intermodulation products. We used a PE0001 serial port interface card (CML Microcircuits) and GUI to allow our pc to communicate with the CMX chip to adjust both the phase alignment between the up-converter and down-converter in the feedback and the forward/reverse path attenuation, which sets the magnitude and phase of the open loop gain function of the feedback loop. We used this feedback setup to linearize a 60 dB gain 200 W power amplifier. Before the loop is closed, we measured the open loop gain of the feedback loop using an HP network analyzer E5071C to ensure the necessary conditions are met that will linearize our signal output once our loop is closed. We used the Medusa console to generate linearly ramping voltage level inputs and measured the resulting output voltage of the closed loop system.

Results and Discussion We ensured that a loop gain response with a peak gain of approximately 20 dB at approximately 63.88 MHz across input power levels (-40 dBm to -10 dBm) was provided to linearize the power amplifier. Since the CMX998 chip has maximum input power constraints in its mixers, care was taken in adding attenuation to prevent clipping. In addition, the phase alignment between the up-converter and down-converter was adjusted to ensure a comfortable phase margin for system stability. The 3dB bandwidth of our open loop gain was approximately 200 kHz. After achieving the correct loop gain, we closed the loop and would expect the final gain of the linearized system to be dictated by attenuation in the feedback loop. The gain is $|G(\omega)| = |(A(\omega)/(1+A(\omega)f))|$ where f is the feedback attenuation and $A(\omega)$ is the forward gain of our system. The gain of the error amplifier, CMX chip path, and power amplifier comprise the forward path for a total magnitude peak gain at center frequency 63.88 MHz of approximately 83 dB. The total feedback path attenuation is approximately -63 dB. The attenuation within our feedback loop sets the gain of our closed loop system as long as our loop gain is large enough to sustain linearization. We can see in Fig 3 that the magnitude gain with respect to input voltage has been linearized and the phase variation is 6° (as opposed to 27° without feedback).

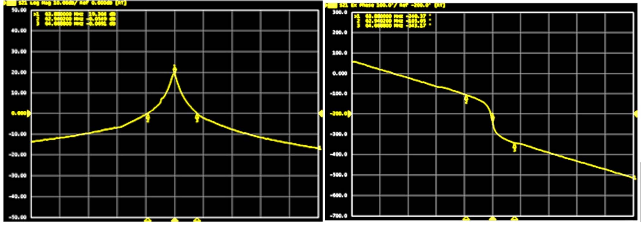

Figure 2. Loop gain magnitude & phase plot. Peak gain is 20 dB and phase set to ensure stability. Plot Center: 63.88 MHz, Span: 10 MHz

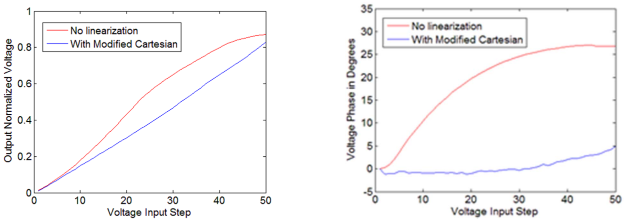

Figure 3. Magnitude (left) and Phase (right) of power amplifier output without feedback (red line) and with feedback (blue line).

Conclusion We demonstrated a modified RF Cartesian feedback configuration for use at 63.88 MHz (1.5 T). We see improvement in linearization both in the phase and magnitude in a 60 dB, 200 W power amplifier. The savings of the extra down-converter simplifies hardware and can be helpful in scenarios including multiple coil transmit. Future works include automating the down and up-converter phase alignment once the loop is closed, since further phase adjustment is usually required to keep the loop stable. Such instabilities may be alleviated by improving the cable shielding and reducing the number of components and cable lengths that contributes to undesired group delay, thereby improving the robustness of the system.

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