Current versus Timing Control in Active Anodic Feedback of Biphasic Stimulation

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***Abstract*— Artificial electrical stimulation that uses biphasic current pulses requires that the cathodic and anodic phases have zero biphasic mismatch. While biphasic mismatch should be minimized, a residual voltage appears due to charge leakage even for perfectly matched signals. Active anodic feedback methods control the charge in the anodic phase such that the tissue environment is electrochemically neutral. In this work, we designed and taped-out a 7-bit current DAC and measured biphasic current mismatch data from 9 chips to suggest that active anodic feedback be performed with timing control rather than amplitude control of current.**

I. Introduction & Background

Artificial electrical stimulation is used in prosthetic devices to evoke responses in neural tissue. Biphasic current stimulation has evolved as the *de facto* standard for artificial electrical stimulation due to its controllability.

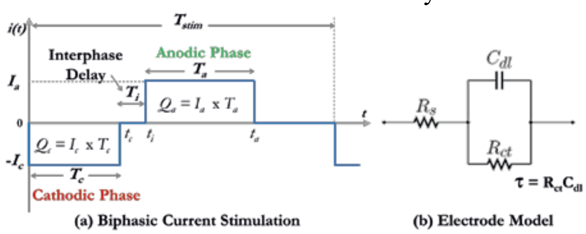

Fig. 1: (a) Biphasic current stimulation signal (b) First order electrode-tissue interface model. R_s is the solution resistance, C_{dl} is the double layer capacitance and R_{ct} is the charge transfer resistance.

We define two terms related to biphasic current stimulation (Fig. 1a) delivered to an electrode-tissue interface model (Fig. 1b): biphasic mismatch and residual voltage. Biphasic mismatch (β_Q) is the difference in charge between the cathodic (Q_c) and anodic (Q_a) phases of a biphasic stimulus pulse, measured with respect to Q_c, shown in (1).

$$\beta_Q = (Q_c - Q_a)/Q_c \; ; \; \beta_I = (I_c - I_a)/I_c \; ; \; \beta_T = (T_c - T_a)/T_c \quad (1)$$

$$\beta_Q = \beta_I + \beta_T - \beta_I \beta_T \quad (2)$$

A biphasic stimulator is designed to have zero biphasic mismatch [1]. However, even if the biphasic mismatch is zero, for a first order electrode-tissue interface model, it can be shown that there exists a non-zero residual voltage (RV) at the end of the anodic pulse [2]. A general expression for residual voltage is given by,

$$RV = -I_c R_{ct}[e^{-(T_i+T_a)/\tau} - e^{-(T_c+T_i+T_a)/\tau}] + I_a R_{ct}[1 - e^{-(T_a)/\tau}] \quad (3)$$

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In recent years, the most prevalent method to prevent residual voltage growth has been active anodic feedback [2-4]. Active anodic feedback involves the correction of the anodic charge to counter the measured residual voltage for each stimulation pulse. Anodic charge can theoretically be corrected either by changing the magnitude of the anodic current (I_a) or the pulse width duration (T_a), or both, fundamentally based on (2).

II. Methods & Results

We designed a 7-bit programmable current source integrated circuit using a 0.35µm AMS process. We measured the biphasic current mismatch (β_I) for 9 chip samples at each quantization level (0-127). The variability in biphasic current mismatch at each quantization level is shown in Fig. 2.

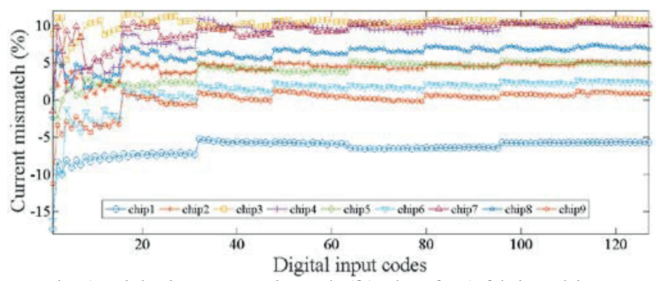

Fig. 2: Biphasic current mismatch (β_I) plots for 9 fabricated integrated circuits plotted against digital input codes. Higher variability exists at lower bit values, which implies that small changes in charge should be done by changes in pulse width. A single LSB in amplitude (1µA) for 1ms pulse is 1nC of charge. For 100µA of current, 10ns pulse-width change is 1pC.

III. Discussion

Clock systems can be designed to be more precise than DAC current circuits and offer a higher resolution to control charge delivery. Typically, the same clock system is used for both anodic and cathodic phases, so the mismatch error is the same. The high variability of biphasic mismatch (Fig. 2) at lower bit values of current, indicates that pulse-width (timing) correction be used for active anodic feedback in biphasic stimulation over anodic current amplitude to ensure safer control of residual voltage growth.

References

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