Correction

Correction to "Feedback Analysis and Design of RF Power Links for Low-Power Bionic Systems"

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We report on corrections to two equations in a paper [1] authored by two of us (M. W. Baker and R. Sarpeshkar). These corrections were discovered and graciously pointed out by two authors of this manuscript (M. Gasulla and J. Albesa). These corrections generate a more accurate set of equations that do not make approximations made in the original paper [1]. The approximations to the equations do not impact fits to experimental data presented in [1], which continue to remain excellent: The experimental data in [1] were obtained for typical near-field RF power links used in bionic implants where the accurate and approximate equations yield nearly identical results. However, in other experimental systems, the more accurate expressions derived by M. Gasulla and J. Albesa should be used.

In Section II.D.3 of [1], *Optimal Loading Condition*, we listed the quality factor of the secondary that will maximize the efficiency of energy transfer to the load. The paper [1] reported the optimal quality factor expression as

$$Q_{\mathrm{L,opt}} = \frac{1}{k}\sqrt{\frac{Q_2}{Q_1}}. \tag{14}$$

As we show below, (14) is approximate and a more accurate expression can be found.

The overall efficiency is calculated with

$$\eta = \eta_2 \eta_k = \left(\frac{k^2 Q_1 Q_2'}{1 + k^2 Q_1 Q_2'}\right)\left(\frac{Q_2}{Q_2 + Q_{\mathrm{L}}}\right), \tag{A}$$

where

$$Q_2' = \left(\frac{Q_2 Q_{\mathrm{L}}}{Q_2 + Q_{\mathrm{L}}}\right). \tag{B}$$

Substituting (B) in (A), we get, after some algebra that

$$\eta = k^2 Q_1 Q_2^2 \frac{Q_{\mathrm{L}}}{(Q_2 + Q_{\mathrm{L}})[Q_2 + Q_{\mathrm{L}}(1 + k^2 Q_1 Q_2)]}. \tag{C}$$

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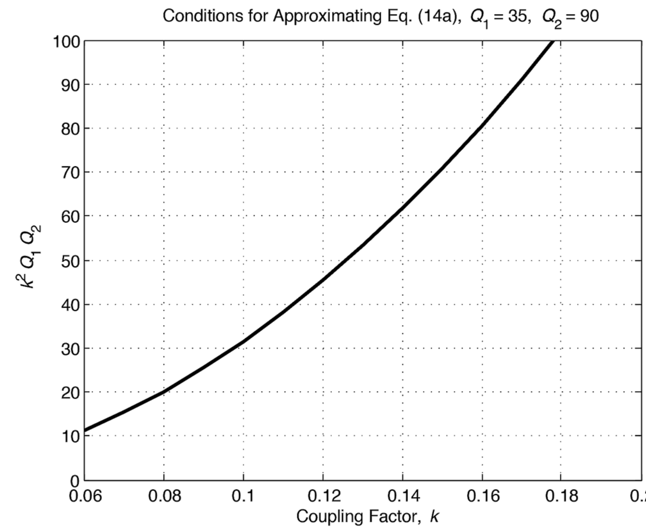

Fig. 1. The variation of the magnitude of $k^2 Q_1 Q_2$ in [1] as a function of k.

We can then find the loading quality factor that maximizes efficiency at any point by differentiating with respect to Q_{L} and simplifying

$$\frac{\partial \eta}{\partial Q_L} = k^2 Q_1 Q_2^2 \frac{Q_2^2 - Q_L^2(1 + k^2 Q_1 Q_2)}{\{(Q_2 + Q_{\mathrm{L}})[Q_2 + Q_{\mathrm{L}}(1 + k^2 Q_1 Q_2)]\}^2}. \tag{D}$$

Therefore, by equating (D) to zero, we find the correct expression for the optimal loading

$$Q_{\mathrm{L,opt}} = \frac{Q_2}{\sqrt{1 + k^2 Q_1 Q_2}}. \tag{14a}$$

Expression (14) is a valid approximation for the coupling factors and quality factors explored in the bionic implant application described in [1]. However, the text did not indicate that an approximation had been made: (14) is a good approximation of the more accurate (14a) only if $k^2 Q_1 Q_2 \gg 1$, which was true for the experimental measurements reported in [1]. Fig. 1 shows that the smallest measured value of $k^2 Q_1 Q_2$ in [1] was 10.

While the approximation of (14) is valid for a good practical range of bionic implant coupling factors ($k = 0.06 - 0.18$), the full expression may be of more general interest to readers who are exploring applications with lower coupling factors ranges, or building systems with lower quality factors.

Fig. 2 shows a comparison of the optimal quality factor, $Q_{\mathrm{L,opt}}$, calculated from both (14) and (14a). Coupling factors at very small values (below the experimental range where data was collected in the original paper) do not show as good an agreement with the approximation in (14) as larger values do.

A second equation in the paper is also approximate: Computing the maximum efficiency that can be achieved for the transcutaneous link, in [1], it was reported that

$$\eta_{\mathrm{MAX}} = \frac{k^2 Q_1 Q_2}{(kQ_1 + 1)(kQ_2 + 1)}. \tag{15}$$

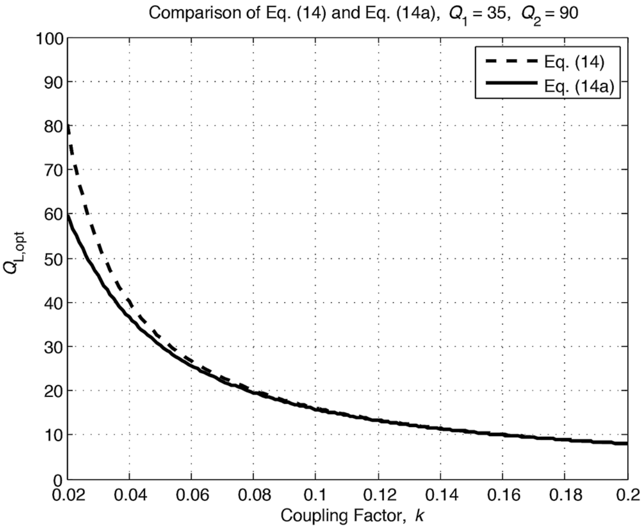

Fig. 2. Both (14) and (14a) are plotted for a $k = 0.02$ to 0.2. There is good agreement for the range of coupling factors (above 0.06) that were experimentally measured in [1] and less agreement as the coupling factor is lowered.

Solving for the full expression, that is, substituting (14a) into (C), yields

$$\eta_{\mathrm{MAX}} = \frac{k^2 Q_1 Q_2}{(1 + \sqrt{1 + k^2 Q_1 Q_2})^2}. \tag{15a}$$

The complete expression, (15a), was approximated to (15) in [1] for the application of interest and the text did not alert the reader of this approximation. The approximation in (15) is valid for the coupling factor and quality factor range in [1] as shown in Fig. 3. In general, the approximation in (15) is a good approximation whenever $k^2 Q_1 Q_2 \gg 1$ and when the quality factors, Q_1 and Q_2, are not significantly mismatched, i.e., when $kQ_1 \ll 1 \ll kQ_2$ does not hold. Both conditions are typically accomplished in implant designs.

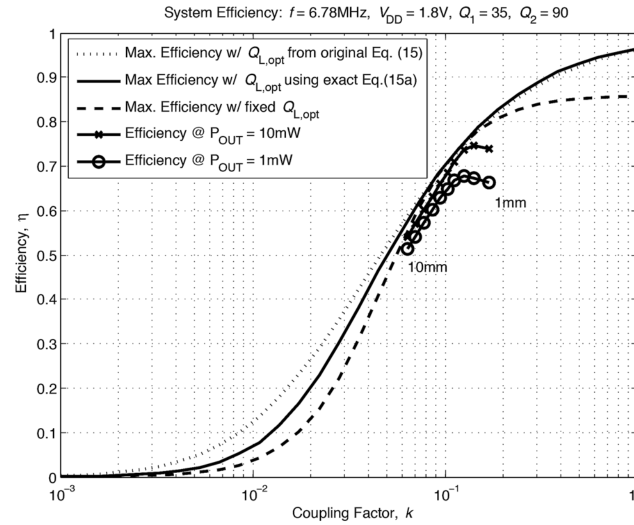

Fig. 3. Approximate and exact fits to the experimental data of [1].

Fig. 3, based on the calculated traces from Figure 15 in [1] shows a trace for the original approximation of (15). Down to $k = 0.06$, the approximation shows good agreement with the full solution of (15a) as well as with the experimental data. At lower coupling factors, however, the approximate form progressively overestimates the maximal efficiency with more error.

Readers who are working with low-Q resonators, mismatched coil quality factors, and/or low coupling factors, should use (14a) and (15a) rather than (14) and (15) for their designs. These changes do not, however, alter the design guidance or conclusions of the paper [1].

References

[1] M. W. Baker and R. Sarpeshkar, "Feedback analysis and design of RF power links for low-power bionic systems," *IEEE Trans. Biomed. Circuits Syst.*, vol. 1, no. 1, pp. 28–38, Mar. 2007.