

# Microsystem Design

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Kluwer Academic Publishers

## Errata

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The following errors occur in the First Printing

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This list compiled on March 9, 2002

- Page 36** In Table 3.3, the value of  $A_{DG}$  at 920 °C should be 0.5  $\mu\text{m}$  instead of 0.05  $\mu\text{m}$ .
- Page 40** In the first line after Eq. 3.5, the quantity  $N_p$  should be  $N_{I,p}$ .
- Page 159** In the first equation of Example 7.1, the exponent of the second term inside parentheses should be  $-j\omega_o t$  instead of  $-j\omega t$ .
- Page 168** In the second paragraph of text, the word “undamped” should be replaced with “damped”. There are two such occurrences in the paragraph.
- Page 179** A comma is missing after the author name Nayfeh, under Related Reading.
- Page 180** Problem 7.7 lacks a mass. Assume that the armature is made of NiFe alloy with a density of 8000 kg/m<sup>3</sup> and has dimensions to exactly fill the gap.
- Page 185** In the first paragraph, 69,000 should be replaced by 6,900.
- Page 195** The biaxial modulus expression in parentheses in Eq. 8.38 should have a subscript  $f$ , reflecting the fact that it is the biaxial modulus of the film that is indicated.
- Page 205** The angle indicated as  $\theta$  in Fig. 9.3 should be the complement of what is shown, such that  $F_N$  approaches  $F$  as  $\theta$  goes to zero, consistent with Eqs. 9.12 and 9.13.

- Page 224** In the previously posted erratum (March 10, 2001) for this page, the correction for the thickness  $t$  in the left-hand portion of for the thickness in Figure 9.14 should be  $h$  rather than  $H$ .
- Page 226** Equations 9.93 and 9.94 should both have a factor of  $W$  on the right-hand side.
- Page 226** The  $H$  outside the parentheses in the denominator of Eq. 9.97 should be removed.
- Page 233** In Eq. 9.133, the argument of the *cos* function should be  $k_n L/2$ .
- Page 234** In Eq. 9.140, the term  $-(-1)^n$  should be removed.
- Page 257** In Eq. 10.81, the last term should be  $-z(d^2\hat{w}/dx^2)$ .
- Page 258** In Eq. 10.82, the last term should be  $-z(d^2\hat{w}/dy^2)$ .
- Page 608** In the bottom line of text, just above Fig. 22.5, the word “they” should be struck out.

This list added on May 27, 2001

- Page 34** In the eight line of Section 3.2.2, insert the word “to” so that the text reads “...dilute hydrofluoric acid etch to remove this oxide when cleaning a bare silicon wafer.”
- Page 313** The previously reported error with respect to Eq. 12.50 requires further correction. The equation lacks a factor of  $n^2$  in the denominator. The correct equation is

$$\frac{I_Q(2j\omega)}{(I_o^2 \mathbf{R}_e \mathcal{V}/2)} = \frac{8}{\pi^2} \sum_{n \text{ odd}} \left( \frac{1}{n^2(1 + 2j\omega \mathbf{R}_n \mathbf{C}_n)} \right)$$

The origin of the confusion was that the  $\mathbf{R}_n \mathbf{C}_n$  product goes as  $1/n^2$ . Hence an equally correct way of writing the equation is

$$\frac{I_Q(2j\omega)}{(I_o^2 \mathbf{R}_e \mathcal{V}/2)} = \frac{8}{\pi^2} \sum_{n \text{ odd}} \left( \frac{1}{n^2 + 2j\omega \mathbf{R}_1 \mathbf{C}_1} \right)$$

**Page 140** Because it is not trivially obvious that the sign of Eq. 6.67 should be a +, a new Problem 6.6 has been added to the Third Printing which asks the reader to verify that when using the displacement rather than the total unfilled gap as the position variable in the magnetic co-energy, the force is obtained from the positive gradient with respect to that displacement.

**Page 587** In the caption to Fig. 21.10, the word “mechanical” should be replaced with “electromechanical” and the quantity  $C_u$  by  $C_e$ .

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This list added on May 26, 2001

**Page 14** The year for the K. S. Wise reference should be 1998.

**Page 480** There is a factor of  $H$  missing from the right hand side of Eq. 18.29.

**Page 480** The units for  $\pi_l$  in the last line should be Pa<sup>-1</sup>.

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This list added on May 19, 2001

**Page 26** In the eight line, “constructe” should be “constructed.”

**Page 27** The word “which” appears twice in the fourth line of the final paragraph.

**Page 34** In the eighth line of Section 3.2.2, the word “wafer” should be added at the end of the sentence so that it reads “when cleaning a bare silicon wafer.”

**Page 45** There is a space missing between “PECVD” and “is” in the third line of the second paragraph.

**Page 54** In the third line, an additional right parenthesis is needed after “(page 58).”

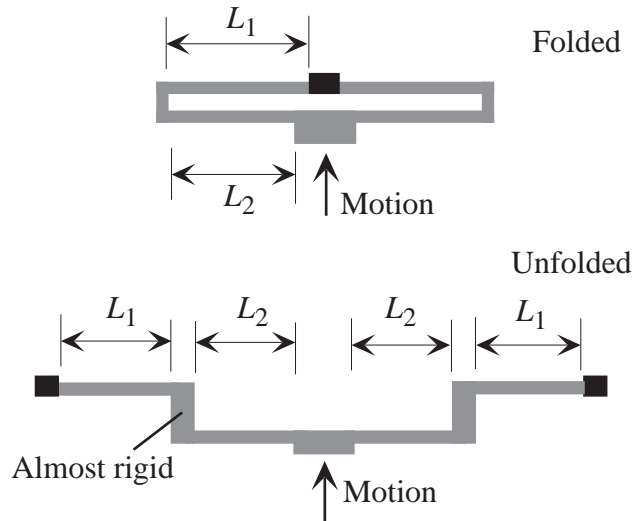
**Page 61** Ten lines from the bottom, replace “bond” with “bonds.”

**Page 64** In the caption to Fig. 3.24, replace “beneath a rectangular” with “beneath a rectangle.”

**Page 69** In the first line of the first full paragraph of text, replace “feature” with “features.”

- Page 86** In footnote 3 at the bottom of the page, Microcosm Technologies has changed its name to Coventor, and the MEMCAD product referred to is now called CoventorWare.
- Page 96** In the third line from the bottom, insert “is” after “This.”
- Page 318** Throughout page 318, the term “shear force” should be replaced with “shear stress.” There are six instances of this error on the page.
- Page 409** There are two errors in Eq. 15.27. In the expression for  $\varepsilon$ , the sign of the term containing  $D$  should be negative. In the expression for  $F$ , the numerator of the term containing  $D$  should be 1.
- Page 419** In the fifth line, the expressions  $I_L > 9.764$  should read  $i_L > 9.674$ .
- Page 446** There is an arithmetic error in Eq. 16.44. The value of the numerator should be  $9.6 \times 10^{-4}$ . The text below Eq. 16.44 should then read:  
 “ or about 1 mK for a 1-Volt excitation signal. This looks very attractive. However, to detect a temperature change this small, it is necessary to detect a resistance change of 3 parts in  $10^6$ . When we examined resistor self-heating in Section 11.6.4, we were interested in a maximum allowed temperature rise of 40 mK, which is 40 times as large as this calculated minimum, and even for that example, it was necessary to use currents of less than 300  $\mu\text{A}$ . . . .”
- Page 446** Immediately after Eq. 16.45, the RMS noise estimate of 2.7  $\mu\text{V}$  should be 27  $\mu\text{V}$ . The following sentence should then read:  
 “Therefore, it is possible to reduce  $V_S$  by a factor of 10, thereby reducing the self-heating driving force by a factor of about 100, and still maintain the same signal-to-noise ratio.”
- Page 476** In Eq. 18.13, the right-hand side should read  $(\pi_l + \nu\pi_t)\sigma_l$ .
- Page 477** The right-hand side of Eq. 18.18 should be
- $$\frac{\alpha_1 + \alpha_2}{2(1 + \alpha_1 - \alpha_2)}$$
- Page 507** In Fig. 19.10, the labels on  $\mathbf{C}_2$  and  $\mathbf{R}_2$  are reversed.

**Page 518** There is a serious error in Fig. 19.22 and the associated analysis. The unfolding of the beam as shown neglects the fact that the short folds behave as almost rigid structures. Therefore, a more accurate picture is as shown below:



**Page 519** Because of the error in Fig. 19.22, the corresponding analysis leading up to Eq. 19.20 is incorrect. The unfolded spring is, if we assume that the short folds are perfectly rigid, equivalent to two doubly supported fixed-fixed beams, one of length  $2L_1$ , the other of length  $2L_2$ . Because the two springs share a common force (effort), their equivalent circuit is in parallel. Hence, the two capacitances corresponding to the springs add. The net result is that the spring stiffness calculated in Eq. 19.20 should be

$$k = \frac{F}{c} = \left( \frac{\pi^4}{6} \right) \left[ \frac{EWH^3}{(2L_1)^3 + (2L_2)^3} \right]$$

The text that follows refers to  $2L$ , whereas it should identify both  $2L_1$  and  $2L_2$  as the lengths of the unfolded springs. Further, the lengths of  $L_1$  and  $L_2$  are estimated incorrectly from the photograph in Fig. 19.18. The stated values of  $75 \mu\text{m}$  are, more accurately, in the range  $110 - 120 \mu\text{m}$ . Interestingly enough, if  $120 \mu\text{m}$  is used, the resulting stiffness is within a few percent of the originally printed value of  $2.8 \text{ N/m}$  which resulted from the incorrect figure in combination with the incorrect lengths. Therefore, the remaining conclusions are unaffected, even though this intermediate calculation, as originally printed, was incorrect.

- Page 558** In Fig. 20.22, the notation for nitrogen should be  $N_2$  instead of  $N^2$ .
- Page 564** In the left-hand side of Eq. 21.12, there is a factor of  $y$  missing after  $\omega_y^2$ .
- Page 565** In Eqs. 21.14 and 21.15, the factor of  $m$  should be replaced with a factor  $x_o$ .
- Page 587** In Fig. 21.20, there is a + sign missing from the upper left terminal.
- Page 597** In Fig. 21.27, the two lower capacitors labeled  $R_F$  should be drawn as resistors.
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This list added on April 14, 2001

- Page 258** In Equation 10.88, the factor of  $L^2$  in the denominator should be removed.
- Page 356** In Equation 14.11, the final term on the right-hand side should be  $n'/\tau_m$  instead of  $n/\tau_m$ .
- Page 356** In the fourth line after Equation 14.12, the factor  $10^{-16}$  should be  $10^{16}$ .
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This list added on April 2, 2001

- Page 139** There is a space missing after “space,” in the second line after Eq. 6.63.
- Page 139** In Eq. 6.64  $\mathcal{M}$  should be replaced by  $F_{MM}$ .
- Page 218** The text immediately beneath Eq. 9.60 should read “The maximum stress is the maximum strain multiplied by Young’s modulus; hence”
- Page 237** The term  $n_x n_y$  in the denominator of Eq. 9.157 should be carried through and appear in the denominators of Eq. 9.158, 9.159, and 9.160. This also modifies the sum of the first few terms expressed in E. 9.161. The coefficient .47 should be replaced with .45.
- Page 243** In Eq. 10.24, the sign before the third term, the volume integral over the body forces, should be negative.

- Page 252** The order of the differentials in Eq. 10.59 should be  $dx dz$ .
- Page 262** There is a factor of  $H$  missing in the denominators of both Eq. 10.105 and 10.106.
- Page 291** In the first line of Section 11.8, the word “and” should be replaced with “as.”
- Page 292** In the final paragraph, the sentence that begins “Even for neutral species...” should read “Even for neutral species, for which there is no electric current, there can be a particle current.”
- Page 297** In Problem 11.3, sixth line, the word “affected” should be replaced by “affect.”
- Page 300** In the line immediately after Eq. 12.4, the diffusivity should be written  $\kappa/\tilde{C}$ .
- Page 303** The  $S$  on the right-hand-side of Eq. 12.12 should be removed and the second  $h$ -factor should be  $h_y$  instead of  $h_z$ .
- Page 304** There are two errors in Fig. 12.2. The term  $\mathbf{G}$  in position (2,3) in the conductance matrix should be  $-\mathbf{G}$  and the minus sign on the right-hand-side of the equation should be a plus sign.
- Page 306** The exponent of  $n$  in the denominator of Eq. 12.24 should be 3 instead of 2.
- Page 307** In Eq. 12.27, the trial solution should be of the form  $\hat{T}(\mathbf{r})e^{-\alpha t}$ .
- Page 311** In Eq. 12.41, the  $C$  on the right-hand-side should be  $\tilde{C}$ .
- Page 311** Two lines above Eq. 12.45,  $X_n$  should be replaced by  $T_n$  to correspond to Fig. 12.4.
- Page 313** In Eq. 12.50, the denominator of each term should be of the form  $(n^2 + 2j\omega\mathbf{R}_n\mathbf{C}_n)$ . That is, the 1 should be replaced with  $n^2$ . Figure 12.6 was calculated with this correct formula.
- Page 326** The  $c$  in Eq. 13.30 should be  $c^2$ .
- Page 403** In the line below Eq. 15.17, the three cube roots of -1 are -1,  $e^{j\pi/3}$ , and  $e^{-j\pi/3}$ .

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This list added on March 19, 2001

- Page 36** For notational consistency, Example 2.1 should be numbered as Example 3.1.
- Page 43** For notational consistency, Example 2.2 should be numbered as Example 3.2.
- Page 140** The sign of Eq. 6.67 is incorrect. The reason, by analogy with the capacitive actuator, is that the variable that leads to positive work being done on the actuator by the external force is the armature-filled portion of the gap  $x_o - x$  instead of the displacement  $x$ . This changes the signs of the partial derivatives of both the energy and co-energy needed to obtain the correct sign of the force.
- Page 167** In Table 7.1, the symbol for Permittivity should be  $\varepsilon$  instead of  $e$ .
- Page 167** Equation 7.60 is missing the terms  $-0.5x_3$ .
- Page 168** At the start of the final paragraph, the text should read “The damped resonance frequency...”
- Page 169** The graph on the right actually plots the damped resonance frequency *vs.* voltage rather than the undamped resonance frequency. Both the axis label and the figure caption are incorrect.
- Page 171** In Equation 7.67, the first term should contain  $Q^2$  instead of  $Q_2$ .
- Page 178** The fourth line contains an extra “an.”
- Page 180** For notational consistency, the turns ratio in Problem 7.7 should be denoted with  $n$  instead of  $N$ .
- Page 180** The notation  $g\mu$  in Problem 7.7 should be  $g_\mu$ .
- Page 197** In the second line of Section 8.5.1, the word order should read “the various types...”
- Page 297** In Problem 11.4, there are spaces missing after the two  $\mu\text{m}$  units.
- Page 307** In Equation 12.28, both the  $\alpha\hat{T}$  and the  $D\nabla^2\hat{T}$  terms should carry a minus sign.



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This list added on March 10, 2001

- Page 154** Equation 7.16 assumes that the  $\mathbf{D}$  matrix is zero.
- Page 180** Problem 7.3 incorrectly states that the circuit of Problem 5.3 is the equivalent circuit for the structure of Problem 5.2 It is a different circuit, but of a similar level of complexity.
- Page 195** The calculated thermal mismatch strain in the example below Equation 8.38 should be 0.0151 instead of  $2.6 \times 10^{-3}$ . The thermal mismatch stress of 60 MPa is correct.
- Page 224** In Figure 9.14, the thickness label  $t$  in the left-hand graph should be  $H$ .
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This list compiled on February 5, 2001

- Page 14** The US Navy changed the web site for the Walker and Nagel report on "Optics and MEMS". The new website is: <http://mstd.nrl.navy.mil/6330/6336/moemsdownload.html> This web site also appears under "Related Reading" on page 559 and in Reference 114 on page 673. (This is why you should be cautious about publishing web sites in books.)
- Page 35** The left-hand square bracket in Equation 3.1 should be to the right of  $A_{DG}$ . The corrected equation is
- $$x_f = 0.5A_{DG} \left[ \sqrt{1 + \frac{4B_{DG}}{A_{DG}^2}(t + \tau_{DG})} - 1 \right]$$
- Page 35** The units for  $B_{DG}$  in Table 3.2 should be  $\mu\text{m}^2/\text{hr}$ .
- Page 36** The units for  $B_{DG}$  in Table 3.3 should be  $\mu\text{m}^2/\text{hr}$ .
- Page 36** The numerical answers in Example 2.1 should be 3.48 hours for wet oxidation and 85.5 hours for dry oxidation.
- Page 666** The authors in Reference 21 are incorrect. The correct authors are "M. A. Schmidt, R. T. Howe, S. D. Senturia, and J. H. Haritonidis."