Errata and Comments: *Radio Frequency Integrated Circuit Design*, by Rogers and Plett

Last updated Nov. 30, 2008, latest corrections in blue. Corrections in black were done up to May 7, 2004.

Chapter 2:

Page 12. Units for noise in (2.8) should be W.

Page 15, 16. We have been using *F* for noise factor and NF for noise figure where $NF=10\log_{10}F$. This is probably unnecessary and *F* could have been used throughout since it should be clear which one is intended from context – however, we started with this convention, so we should stick with it. Well, we messed up a few times on these two pages – Equations (2.22), (2.27) and (2.27) and the accompanying text are for noise factor *F* rather than noise figure NF. (cp)

Page 15. Between (2.22) and (2.23) replace the word "admittance" with "conductance" to result in "…in terms of equivalent resistance and conductance" (vk)

Page 16. Equation (2.31) replace G_i with G_1. (vk)

Page 18, in Example 2.1, the equation $P_0 = \frac{v_0^2}{4R}$ should be $P_0 = \frac{v_s^2}{4R}$ (cf,fs)

Page 20, in Example 2.2, the equation for total output noise has v_{RS} appearing twice. The second occurrence should be v_{R3}. (cf,fs).

Additional note about this example: In the calculation of v_{RS}, it is being determined from the result of the previous example in which the total noise was found from two equal noise sources – thus the noise due to each component is lower by $\sqrt{2}$. (cf,fs)

Page 27, in Table 2.2, for the second order term, f_2-f_1 is listed as 2, it should be 1. (cf,fs)

Page 31 For gain compression, k_3 is negative. However, for negative k_3 one needs to take the absolute value of k_3 to solve equations (2.66) and (2.69). (cp)

Page 32, Last line before Section 2.3.6, "signal tone" should be "single tone". (sg)

Page 34, Between (2.73) and (2.74), references to IP3 tones should be IM3 tones.

Page 36, the 1-dB compression point was listed as 15.6 dBm. It should have been –18.6 dBm, (to agree with Example 2.7). As a result, the corrected dynamic range should be –18.6+80 = 61.4 dB. The corrected degradation over the 200 kHz system is 26 dB (we note this is also the difference between the two dynamic ranges). (cf,fs)

Page 39, In Figure 2.12, part of Example 2.9, the arrow labeled as f_c does not refer to the center frequency but to the worst case input frequency, so should perhaps be labeled as f_{RF} instead to avoid confusion. (cf,fs). Comment on this example – on page 38, channel bandwidth and spacing is specified as 200 kHz, yet IF1 in Figure 2.12 has a bandwidth of 2 MHz. This was intended to be a double conversion system, where the bandwidth of IF2 (not shown) would determine the system bandwidth. (sg)

Chapter 3:

Page 45 Since output resistance $r_o = V_A/I_C$, (defined on Page 48) in order for the sign to work out, in Figure 3.3, V_A should really be $-V_A$. (sg)

Page47, in Figure 3.7 the current source is labeled $g_\mu v_\pi$. It should be $g_m v_\pi$. (cg)

Page 50, in Equation 3.18, the first part of the equation referring to Miller multiplication of C_μ is missing a negative sign – so the part which currently reads $\left(1+\frac{v_c}{v_\pi}\right)$ should read $\left(1-\frac{v_c}{v_\pi}\right)$.We believe the rest of the equation is correct. (cf,fs)

Page 55, Figure 3.11 the noise source should be $v_{bn} = \sqrt{2kTr_\pi}$ to agree with (3.25). (cp)

Page 58 In Example 3.1, the real part of the output impedance using (3.16) should be 98.6Ω. Recalculation of f_{max} results in 104.7 GHz.

Chapter 4

Page 66, After (4.4) "axis of the plot" should be changed to "center of the Smith Chart" the full correct sentence is "This means that the center of the Smith Chart is the point where the load is equal to the characteristic impedance (in other words perfect matching)."

Page 69, Table 4.2 series capacitor moves the impedance along a constant resistance circle, not conductance. (jc)

Page 71, Example 4.2 "we need a capacitor admittance of 0.348j" should be "we need a capacitor admittance of 0.358j" (sg)

Page 73, Figure 4.11 In the high pass matching network the parallel inductor should be 18.37 nH, not 18.37 pH (cp).

Page 74. Figure 4.14 the impedance seen by the base shot noise to the left when matched reads 55 + j220 - it should be 50 + j220. It is correct in the accompanying text. (cp)

Page 76. Equation (4.10) is not correct, it should be

$$L_p = L_s\left(\frac{1+Q^2}{Q^2}\right) = L_s\left(1+\frac{1}{Q^2}\right).$$

For high Q, $L_p \approx L_s$. Note that for both LR and CR circuits, the following equations hold: $X_p = X_s\left(\frac{1+Q^2}{Q^2}\right) = X_s\left(1+\frac{1}{Q^2}\right) \approx X_s$, and $R_p = R_s\left(1+Q^2\right)$

where X_p is reactance of L or C, and with the approximation that $L_p \approx L_s$ if Q is high.

Page 77. Equation (4.15) negative signs should not be there. In the first part, the L_1+L_2 term in the denominator should not be squared. The correct equation is shown below. (am2)

$$L_{eq} = \frac{R^2(L_1+L_2)^2 + \omega^2 L_1^2 L_2^2}{R^2(L_1+L_2) + \omega^2 L_1 L_2^2} = \frac{(L_1+L_2)^2 + \frac{L_1^2}{Q_2^2}}{L_1 + L_2 + \frac{L_1}{Q_2^2}}.$$

Chapter 5

Page 99, In the skin depth example, final equation for resistance affected by skin depth, one occurrence of 3µm was replaced by 2µm. The final calculation and commentary should be:

$$R = \frac{\rho L}{Wt - (W-2\delta)(t-2\delta)} = \frac{3\,\mu\Omega\text{cm} \cdot 100\,\mu\text{m}}{20\,\mu\text{m} \cdot 3\,\mu\text{m} - 17.5\,\mu\text{m} \cdot 0.54\,\mu\text{m}} = 59.3\,\text{m}\Omega$$

This is almost a 20% increase. Thus, while we may be able to count on process engineers to give us thicker metal, this may not solve all our problems.

Page 105, Figure 5.8, base and emitter inductors should be labeled L_b and L_e (sg)

Page 113 Bottom of page the formula for R_{ac}(f) the H in the second bracket should be replaced with t, the thickness of the line.

Page 115 First sentence, second paragraph in Section 5.15 "… and ω_L is equal to the imaginary part of the impedance". ω_L should be ωL.

Page 116 middle of the page, just after (5.18) "… this effectively grounds out both C_1 and R_1, or C_2 and R_2." This should read "… this effectively grounds out C_{oxide}, R_{sub}, and C_{sub} on one side of the inductor." (hp)

Page 131 just after Section 5.32.2, a coplanar waveguide should be abbreviated to CPW while the abbreviation CPWG refers to a coplanar waveguide with ground (cp).

Page 138 in Figure 5.38, the bond pad is labeled as Pond pad – some have told us that it should be left this way!

Chapter 6

Page 142, equation (6.1) last part should have a negative sign, to read $\approx -\frac{Z_L}{r_e}$ (sg)

Page 145, Top, expression for f_T should have g_m in the numerator, in the numerical solution this should have had a value of 0.2 in the numerator, correct equation is below. (sg)

$$f_T = \frac{g_m}{2\pi(C_\pi + C_\mu)} = \frac{0.2}{2\pi \cdot (700\ \text{fF} + 23.2\ \text{fF})} = 44\ \text{GHz}.$$

Page 145, In the solution to Example 6.4, the exact calculation of the zero should have been 1,372 GHz, instead of 1,384 GHz. This is the difference between Cμ of 23.2 fF versus 23 fF.

Page 149, 150, Equation (6.17) should not have had negative signs: the equation should be:

$A_v(s) = A_{vo}\left(\frac{1 + s/z_1}{1 + s/p_1}\right)$ Solutions were given for f_{z1} and f_{p1} in (619), (6.20) and (6.23). First of all, these should have been in radians per second, not in hertz, and to simplify, they should really have been expressions for z_1 and p_1 and as such they would all be positive numbers. Then, one could set the numerator or denominator of (6.17) to zero to solve for s and this solution for s would have been negative, that is for the numerator, s = -z_1, and for the denominator, s = -p_1. Thus (6.19), (6.20) and 6.23) should be: $z_1 \approx \frac{g_m}{C_\pi} = \omega_T$, $p_1 \approx \frac{1}{C_\pi R_A}$, and $p_1 \approx \frac{R_E}{R_E + R_B}\omega_T$ respectively.

Page 155, equations (6.36) and (6.37) all occurrences of R_F should be replaced with R_f (hp)

Page 156, equation (6.40) the first simplification assumes that R_E is much less than $1/g_m$ and that R_F is significantly bigger than $|z_\pi|$. If these approximations do not hold, then Z_{in} would still depend on R_E. (am2)

Page 162, equation (6.57) similar to comment for page 15, 16 - since we started out using *F* for noise factor, and *NF* for noise figure, this equation should be about *F*, not *NF*. (jc)

Page 173, Equation (6.76), the third term should be 1/3 instead of 1/2. (am2)

Page 174, top line should say "The following can be found from Math Tables:" (hp)

Page 174, Equation (6.82) third order coefficient should be: $b_3 = \frac{1}{a_1^5}\left(2a_2^2 - a_1 a_3\right)$ (cp)

Page 176, Table 6.1, second row, last entry is $0.4A + 24A^3$, should be $0.04A + 24A^3$ (cp)

Page 177, Fig 6.27, the vertical axis is current, so numbers should read 16.91mA, 1mA, and 59µA. (the "A" was missing and the last number was 59µm) (cp)

Page 184, just after (6.98) it says "Note there will only be even-order harmonics" this should say, "Note there will only be odd-order harmonics…". The sentence goes on to say, "…and hence no dc shifts or even harmonics…" which would probably be clearer if it said, "…and hence no dc shifts or even-order harmonics…" (jc)

Page 189, the calculation for current range over temperature for constant voltage biasing was done for variation in V_{BE} only. A mistake was made for the positive range in that it was calculated using a 13 mV change of V_{BE} instead of the actual 130 mV change. As a result, the calculated current should have been (about 181 mA!). If the change of v_{T} is also taken into account the change of current is less severe (0.18 mA and 71 mA), but this clearly indicates that the calculation is much too simplistic. (am2)

Chapter 7

Page 199, Figure 7.2, the current source should be controlled by v_1, not v_2 as is currently shown. (fs)

Page 200, Comment under (7.4) is missing three words "from v_1 will", thus the sentence should read "Note that feedthrough from v_1 will appear equally in the output voltages above (common mode), and so does not appear in the differential output voltage." (cp)

Page 216, Figure 7.15 top plot, x axis should have f_1 on it – it had lost its subscript. (jc)

Page 221, The text below (7.25) should be corrected to say that the HPF has phase of 45° and the LPF has phase of -45°. Phase is shown correctly in Figure 7.24. (sk)

Page 224 The analysis of the image reject mixer has the correct final result (7.39) on page 226, in spite of a few errors in the derivation. First of all, note that the original diagram for the image reject mixer shown in Figure 7.22 on page 220, had cosine input signals while Figure 7.27 on page 224, has sine input signals. The phase of the input signal should not change the operation of the circuit and the same result (7.39) can be obtained for both. However, with the original cosine inputs, the phase shifter in the bottom branch converts cosine signals into sine signals as shown in Figure 7.22. To be consistent, with sine inputs, as in Figure 7.27, the phase shifter should convert cosine signals into *negative* sine signals, however, in the derivation the conversion was incorrectly shown as converting cosine signals into *positive* sine signals. This is offset by other sign errors in the derivation and in (7.28) the two sine terms should both be multiplied by $(1+\Delta A)$. Note also that with (7.39) showing $(\phi_{e2} - \phi_{e1})$ it is possible to have phase errors that cancel out and produce infinite image rejection. The plots in Figure 7.28 have been made without such cancellation, for example by assigning the full phase error to one of ϕ_{e1} or ϕ_{e2}.

Page 235, Comments: close to the bottom of the page, we are determining R_E for linearity. We refer to (6.85) from the previous chapter (page 174), which was valid for a single-ended LNA. We note that we should have referred to (7.24) on page 215, which is the same equation except linearity is better by a factor of two because it is for a differential circuit. The calculation is correct if it is valid to extend the single ended case to the differential case – it turns out that this isn't quite correct as the differential case does not have even order nonlinearity. A better way to calculate nonlinearity is to use the current-voltage equations for a differential pair directly. But assuming (7.24) is valid, there are a few other things to note about this example. In the equation in this example, v_{IP3} is rms single ended voltage while in (7.24) it is peak differential voltage, thus the equations differ by $2\sqrt{2}$. As well, (7.24) is derived with two resistors of value R_E in series, and in the example, only a single resistor of value R_E is used. So, to arrive at this equation, you need to replace R_E in (7.24) with $R_E/2$. (cp)

Page 236, Middle of the page, in calculating the voltage allowed across the load resistors, we used 0.7V across the current source and 1.5V across the RF transistors. The statement is then made that this leaves about 0.8V for the resistor. This is roughly correct but not immediately obvious. With the base of the RF transistors at 2.2V, if we allow the collector to swing down about 0.4V lower than the base, to about 1.8V, this leaves about 1.5V to the 3.3V rail. If we bias the collector about half way, this allows about 0.8V across the resistor. (jc)

Page 237, First equation for $v_{\mathrm{on(source)}}$ should be for $v_{\mathrm{no(source)}}$ to be consistent with other equations. Mid page expression for $v_{\mathrm{no}(RE)}$ should replace R_L with R_C. (vk)

Page 237, comment - note in the calculation of noise due to the emitter resistor, $i_{n(\mathrm{RE})}$, no current divider has been used, unlike a similar calculation for the noise due to emitter degeneration in an LNA (see page 192). For a mixer, using a current divider would be correct, however, it has been assumed that R_E in a mixer is significantly bigger than r_e, thus most current flows into r_e, and if this assumption is correct, the current divider may be ignored. In an LNA, typically R_E would not be much bigger than r_e, in fact R_E might be smaller than r_e, hence a current divider is necessary. (Actually, an easier technique is to use a series noise voltage, then gain from the degeneration series noise source is approximately the same as the gain from the input source resistance, both related to $R_L/(r_e+R_E)$. where R_L is equivalent collector resistance).

Page 238, IIP3 calculated from the fft shown in Figure 7.35, is correct but requires that you convert from dBV to dBm with the input matched to 100 Ω.(cg)

Page 242, Second paragraph mentions SSB mixer, but it should have said image reject mixer. (jc)

Chapter 8

Page 247 Equation (8.2) the magnitude $\frac{\sqrt{2}I_{Pulse}}{C}$ isn't quite correct. The full equation has both a cosine term and a sine term. However, if $4Q^2 >> 1$, where $Q=R/\omega L$, then the cosine term is much bigger than the sine term. This is usually the case, so the equation should be modified to read:

$$v_{\mathrm{out}}(t) \approx \frac{I_{\mathrm{pulse}} e^{\frac{-t}{2RC}}}{C} \cos\left(\sqrt{\left(\frac{1}{LC} - \frac{1}{4R^2C^2}\right)} \cdot t\right) .\text{(pp, jr)}$$

Page 254, Equation (8.16) should be $\omega = \sqrt{\left(\frac{C_1+C_2}{C_1C_2}\right)\frac{1}{L} + \frac{1}{r_eR_pC_1C_2}}$ (previously, the second term also contained L – it should not be there. (am)

Page 255, Figure 8.12 has two capacitors labeled C_1. The bottom one should be C_2. (jc)

Page 264, In example 8.3, the calculation for series negative resistance should have been for R_{neg} instead of r_s. As well, in the problem statement, g_m should have units of A/V. (hp)

In the calculation of Q, the equation should not have a negative sign, the negative answer comes from the negative value of R_{neg}. (vk)

Page 265, First equation, replace C_S with C_T. (vk)

Page 265, Example 8.3 Why is there a 10% error when a previous calculation showed a 5% error? The short answer is that the equation for frequency offset was derived for the marginal condition for oscillation. This would have a smaller value for g_m hence a smaller value for series negative resistance (in the marginal case it should exactly match the positive resistance). With a smaller negative resistance, the parallel capacitance will be larger, hence the frequency will be lower. In fact the original frequency offset calculation should also be adjusted with the new larger value for r_e (assuming r_e is equal to the $1/g_m$). As a result, the actual frequency is 7.27607 Grad/sec for both approaches, which is about 3%.

Page 278, Second last paragraph, second last word should be "than", not "then".

Page 281, Equation (8.68) The middle part and the end part of this equation don't agree. The corrected form should be: $V_{\text{tank}} = 2 \cdot i_{\text{fund}} \frac{R_p}{2} = 2 \cdot \left(\frac{2}{\pi} I_{\text{tank}} \right) \cdot \frac{R_p}{2} = \frac{2}{\pi} I_{\text{tank}} R_p$. (jc)

Page 286, middle of page, between (8.89) and (8.90) should say, "If noise from the bias i_{nt} is filtered …" (cp)

Page 288, 289, Remove the term A from the calculation of phase noise, in a later section, the term A is introduced to accounts for the increase in noise due to folding from nonlinear effects. Since it has not been discussed yet, it can be removed, the answer then changes from 1.79 to 1.43. On the top of page 289, this results in –98.5 dBc/Hz which is now 6.5 dB higher than the spec, but the conclusions are still the same. (vk)

Page 297-299, example 8.10 requires some comments and corrections. For example, on page 298, C_{total} is calculated to be 1.05 pF. Note that C_{total} is not a constant but will change by up to about 0.04 pF, depending on which frequency we are trying to generate. While generating this example, simulations were carried out and it was discovered that our output frequency was about 120 MHz lower than expected. This can be explained by an additional parasitic capacitance, estimated at about 0.1 pF. On page 300, in the calculation of Q, C_{total} of 1.18 pF was used which uses the above estimates. Thus, the comment should be added that the value of C_{total} is being increased to account for parasitics. As well, on page 300 we calculate I_{bias} to be 1.71 mA and a few lines down a value of I_C of 1.69 mA is used – this is a typo, and it changes the resulting resistance to 14.6Ω. As a result in the next equation 19.8 should be replaced with 19.6Ω , but the final answer is still approximately equal to 200Ω.(cf)

Page 298, 2/3 of the way down the page, in the phrase, "we can make C_{var} with", replace "make" with "replace".

Page 299, Example 8.10, the component name C_{var} is reused. Previously, on page 298 it was set equal to 3.78 pF, then it is split into a fixed capacitor of 2.98 pF and variable part with C_{max} of 1.14 pf. On page 299, in the calculation for r_s this maximum value is called C_{var} instead it should have been called C_{max}. Note in this calculation, the varactor Q is 30 at C_{max}

which corresponds to f_{min}. Thus the equivalent series resistance should have been calculated at 2.4 GHz rather than 2.5 GHz. The correct answer is 1.94 Ω. Then this value is used to calculate the parallel resistance at the nominal capacitance. Using 1.94 Ω, the correct parallel resistance is 2.98kΩ (ja).

Page 300 Note noise voltage is calculated with small signal resistance values while output voltage is calculated using large signal resistance. For noise, this is justified since the dominant noise occurs during the zero crossings during which time the transistor nonlinearity is typically not being exercised. A more general approach would consider the noise sensitivity function to quantify the amount of noise being contributed during each part of the output waveform. Note also that in the calculation of phase noise, small signal resistance is used in calculating carrier power – but he amplitude of the carrier was calculated using equivalent large signal resistance. This can be justified by noting that, in reality, on the tank, we are typically concerned with a voltage ratio, rather than a power ratio. Then, later, we convert the tank voltages (both carrier and noise) to an output power using a buffer. Thus, using the small signal resistance can be seen as turning the noise power back into a noise voltage to allow a direct comparison. (mh)

Page 305, Figure 8.48 Caption should mention AAC, not AGC. (jc)

Page 309, the calculation for A_2 is really a calculation for A_3. thus, 4 occurrences of A_2 should be replace with A_3. The result turns out to be equal to 25.1 mA/V. In the middle of the page, a value of 2.51 mA/V is used, this should have been 25.1 mA/V (although the final calculated value is correct) (ja).

Page 309, In the final calculation at the bottom of the page, g_{m5} was incorrectly copied from page 308 as 10.34 mS instead of the correct value of 17.04 mS. As a result, the capacitance calculated and used was also incorrect. The intended capacitor would have been 27.12 pF. Thus, with a capacitor that is too small, this pole will not actually be at 100 MHz as intended, but instead will be at about 159 MHz. (am)

Page 313, Figure 8.53 Caption should mention AAC, not ACC. (jc)

Chapter 10

Page 360 comments regarding Figure 10.13. The peak value should be about 1.07 (instead of 1.15). (tf)

Page 364 in Example 10.1 we assumed peak voltage was 2.5V (from a 3V supply) to get a better approximation of required load resistor. However, later we use 3V for other calculations, for example in calculating peak current.

Page 372 in (10.22) top of page, the equation for X is incorrect. It should be $X = 1.152R$. In practice, this equation is not often used, as (10.27), which includes Q, is usually used.

Page 372 in (10.22) top of page, the equation for B should have a constant of 0.1836. In practice, for finite Q, (10.28) is used, but with infinite Q, it should simplify to (10.22). (am2)

Page 374 in Example 10.3 in solving for B, the contents of the second bracket did not match the first. As well, this example was initially done with a Q of 5, later with a Q of 3. In the numerator, 5 was used, in the denominator, 3 was used. The correct equation and the correct answer is shown below. This also changes C to 0.556 pF.

$$B = \frac{0.1836}{R}\left(1 + \frac{0.81Q}{Q^2 + 4}\right) = \frac{0.1836}{26}\left(1 + \frac{0.81 \cdot 3}{3^2 + 4}\right) = 0.00838 \qquad \text{(jd)}$$

Page 374 In solving for X, a value of 1.110 incorrectly became 1.10. The equation should be:

$$X = \frac{1.110Q}{Q - 0.67}R = \frac{1.110 \cdot 3}{3 - 0.67}26 = 37.2\ \Omega \qquad \text{(jd)}$$

Page 381, Example 10.4, The peak output current uses R = 22Ω. it should have been 28.3Ω as calculated in the previous part. $i_{o,\text{peak}}$ =118.4 mA, and $I_{\max}$ =237 mA.

Also, the multiplication sign between the $I_{\max}$ calculation and the I_{dc} calculation should not be there. These are simply two distinct calculations. (hp)

Page 381, Example 10.4. The peak transistor current labeled as $I_{\max}$ was previously labeled as i_{cm}, for example on page 377 to page 380. (am2)

Page 388, Figure 10.41 – the label R_L has been misplaced in the middle of the diagram. It should refer to the output load resistor. (jc)

Page 392, Figure 10.45. The top and bottom branches for the branch line coupler should each have an impedance of $z_0/\sqrt{2}$. That is, if z_0 is 50Ω, they should be 35.4Ω (ac).

Page 398, Figure 10.55 In the output matching circuit, the series inductor, parallel capacitor and series capacitor are missing a connecting line – they should be connected. (cp)

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