Solutions to Assignment 3

Question 1

(a) The specifications extracted from the datasheets are given in Table 1 below.

(b) For the cascade of all three devices:

(i) the total current would be the sum of the currents: $12 + 22.7 + 155 = 189.7$ mA

(ii) the gain is the sum of the gains in dB: $15 + 33.5 + 15.5 = 64$ dB.

(iii) to compute the noise figure we use linear units in the formula in the lecture notes:

$$NF = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2}$$

$$= 1.29 + \frac{2.45 - 1}{31.6} + \frac{2.24 - 1}{31.6 \cdot 2239} = 1.34 \approx 1.3 \text{ dB}$$

(iv) to compute the IIP3 we use linear units in the formula in the lecture notes:

$$IIP3 = \frac{1}{\frac{1}{I_1} + \frac{G_1}{I_2} + \frac{G_1 G_2}{I_3}}$$

$$= \frac{1}{\frac{1}{7.9} + \frac{31.6}{0.026} + \frac{31.6 \cdot 2239}{447}}$$

$$= 0.73\,\mu\text{W} = -31.4\,\text{dBm}$$

Note that the LNA has an input disable mode that reduces the gain of the first stage to −14 dB (0.04) and when the LNA is disabled the cascade IIP3 increases to:

$$= \frac{1}{\frac{1}{7.9} + \frac{0.04}{0.026} + \frac{0.04 \cdot 2239}{447}}$$

$$= 0.536\,\text{mW} = -2.7\,\text{dBm}$$

	Device	Symbol	SKY 65405	ON SMA 3117	MAAM-009286	Units
(i)	current consumption		12	22.7	155	mA
(ii)	impedance		50	50	50	Ω
(iii)	gain		15	33.5	15.5	dB
	gain (linear)	G	31.6	2239	35.5	
(iv)	noise figure		1.1	3.9	3.5	dB
	noise figure (linear)	F	1.29	2.45	2.24	
(v)	IIP3		9	-15.8[a]	26.5[b]	dBm
	IIP3		7.9	0.026	447	mW
(vi)	OP1dB		15[c]	5.7	27	dBm

Table 1: RF amplifier specifications.

[a] estimated as OP1dB+12dB-gain=5.7+12-33.5=-15.8
[b] estimated as OIP3-gain=42-15.5=26.5
[c] estimated as IP1dB+gain=0+15=15

Question 2

The fundamental tones are at −10 dBm and the third-order products are 25 db below that at −35 dBm. If the power of the fundamental tones increase by x dB the third-order products will increase by $3x$ dB. They will be equal when $-35+3x = -10+x$. Solving for x: $x = 12.5$ dB. Thus the OIP3 is $-10+12.5 = 2.5$ dBm.

Question 3

Solution 1: The noise source output power is given by kTB and is proportional to the source noise temperature. When the noise source is off, $T_{\text{off}} = T_0 = 290$ K. When the noise source is turned on the power output and thus the noise temperature increases by 12 dB and $T_{\text{on}} = 290 \times 10^{\frac{12}{10}} = 4596$ K.

The amplifier output noise power is given by $P = k(T+T_e)BG$ where T is the noise temperature of the input noise, T_e is the amplifier equivalent noise temperature and G is the amplifier gain. The ratio of the amplifier output powers with these two input temperatures is measured to be $-80 - -89 = 9$ dB:

$$\frac{k(4596+T_e)GB}{k(290+T_e)GB} = 10^{9/10} \approx 8$$

from which we can solve for T_e:

$$(4596+T_e) = 8(290+T_e)$$

$$4596 - 8 \cdot 290 = (8-1)T_e$$

$$T_e = \frac{4596 - 8 \cdot 290}{8-1} = 325$$

from which we can compute the noise figure:

$$F = \frac{T_0+T_e}{T_0} = \frac{290+325}{290} = 2.12 \approx 3.3 \text{ dB}$$

Solution 2: The noise factor can also be calculated from the equation[1]:

$$NF = \frac{ENR}{Y-1}.$$

[1] See, for example, this application note from Keysight (an updated version of HP's AN 57-1).

where Y is the increase in output noise. ENR is state in the question to be 12 dB = 15.85 and $Y = 10^{(-80--89)/10} = 7.94$ so the noise figure is $\frac{15.85}{7.94-1} = 2.28 \approx 3.6$ dB.

Solution 3: The two solutions above give different results because the question erroneously stated that the 12 dB increase in noise source output power was equal to the ENR. However, ENR is defined as $\frac{T_h - Tc}{T_0} = \frac{T_h}{T_c} - 1$ when $T_c = T_0$ as in this question. Thus a noise source power output ratio of 12 dB actually corresponds to an ENR of $10^{12/10} - 1 = 14.85$. If we use the correct definition of ENR the noise figure is $\frac{14.85}{7.94-1} = 2.13 \approx 3.3$ dB as before.

Either of the above results was considered correct because the ENR was incorrectly stated to be 12 dB when it was in fact 11.7 dB.

Many answers assumed that the noise factor was equal to the ratio of the SNRs with the noise turned on and with the noise turned off. This is not equal to the noise figure because the amplifier output power when the noise source is turned off also includes the noise generated by the amplifier itself ($N_a = kT_eB$).