Different methods of evaluating noise figure improvement

Problem definition

Consider three situations shown in Figure 1, Figure 2, and Figure 3.

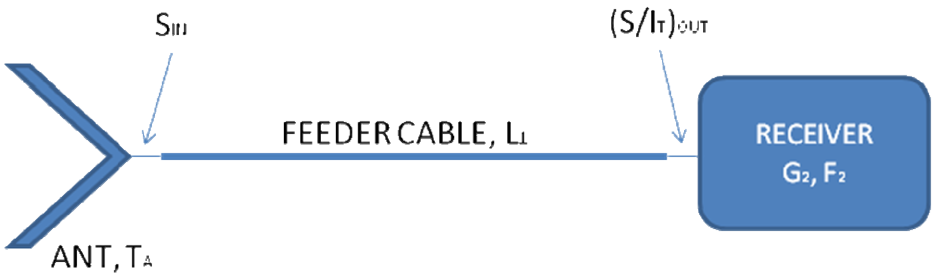

Figure 1 – end lineup without a Tower Mounted Amplifier (CONFIGURATION 1)

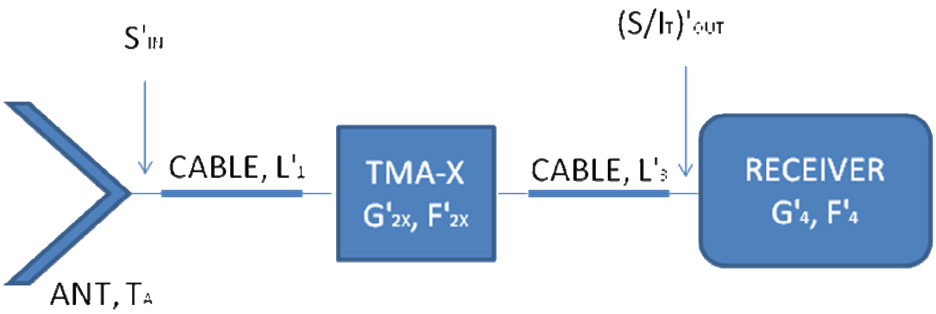

Figure 2 – end lineup with a Tower Mounted Amplifier X (CONFIGURATION 2)

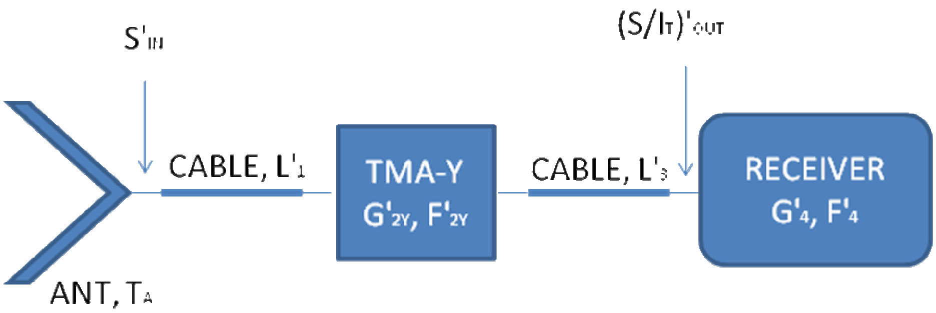

Figure 3 – end lineup with a Tower Mounted Amplifier Y (CONFIGURATION 3)

Parameters:

- $T_A = T_{ANT}$ = effective antenna noise temperature [K]
- L1 = feeder cable (section 1) insertion loss [a positive number indicating loss, dB]
  - This will also be taken to be the noise figure, i.e. $NF_1 = L_1$

- L3 = feeder cable (section 3) insertion loss [a positive number indicating loss, dB]
    - This will also be taken to be the noise figure, i.e. $NF_3 = L_3$
- G2, F2 = Receiver gain and the noise figure in Configuration 1.
- G'_{2X}, F'_{2X} = TMA gain and noise figure in Configuration 2 (TMA-X).
- G'_{2Y}, F'_{2Y} = TMA gain and noise figure in Configuration 3 (TMA-Y).
- G'_4, F'_4 = TMA gain and noise figure in Configurations 2 and 3 (TMA-X and TMA-Y).
- S_{IN} = Input signal (at antenna output) in Configuration 1.
- $(S/I_T)_{OUT}$ = Output signal-to-noise (at antenna output) in Configuration 1.
- S'_{IN} = Input signal (at antenna output) in Configurations 2 and 3.
- $(S/I_T)'_{OUT}$ = Output signal-to-noise (at antenna output) in Configurations 2 and 3.

Aim:

- Calculate the overall front-end improvement in the noise figure when going from Configuration 1 to Configuration2 to Configuration 3.
    - Perform calculations at different antenna temperatures.

Typical values:

- We have used the following parameters in performance estimates:
    - UE emitted power = 23 dBm, BS antenna gain = 18 dB
    - Feeder cable loss without TMA, L_1 = 4 dB
    - Feeder cable loss before TMA, L'_1 = 1.0 dB
    - Feeder cable loss after TMA, L'_3 = 3.0 dB
    - Effective antenna temperature range: 50 K to 300 K
    - Reference (measurement) temperature T_0 = 290 K
    - Processing gains, margins and losses, UE and BS heights, propagation models etc, as in a typical 3G system.

Calculation methods

There are several ways in which the benefit of reduced TMA noise figure can be calculated. Here we consider two methods: signal-to-interference-and-noise ratio improvement (SINR method), and cascaded noise figure improvement (Cascaded NF method). The difference in the results produced by these two methods is identified and discussed.

Signal-to-interference-and noise ratio [1]

The signal-to-interference-and-noise ratio (SINR) before the receiver (at the output of the TMA/feeder combination) is given as

$$SINR = \frac{S_{IN}}{R \cdot F \cdot N}$$

Equation 1

where S_{IN} is the input signal power and $R{\cdot}F{\cdot}N = I + F{\cdot}N$ is the total power received. Quantity I is the co-channel interference power due to transmissions of mobiles in the same cell and in the other cells, $N = k{\cdot}B{\cdot}T$ is the thermal noise, F is the noise figure of the base station, and B is the spread-spectrum bandwidth. The reverse-link noise rise, R, is defined as the rise of the interference level above the thermal noise level due to the traffic load.

In CDMA, power control adjusts the mobile transmit power so that a constant SINR is maintained, i.e. the mobile transmit power is adjusted so that $SINR_X = SINR_Y$. The reverse-link sensitivity improvement by going from $SINR_X$ to $SINR_Y$, Q, is defined as:

$$Q = \frac{SINR_X}{SINR_Y}$$

Equation 2

If we assume that, in two situations ($SINR_X$ and $SINR_Y$), $S_{IN,X} = S_{IN,Y}$ (same input signal power), and $N_X = N_Y$ (same ambient noise), the sensitivity improvement becomes

$$Q = \frac{R_X}{R_Y} \cdot \frac{F_X}{F_Y}$$

Equation 3

Furthermore, if we assume that $R_X = R_Y = 1$ (no loading), we see that the reverse-link sensitivity improvement in a CDMA system is directly related to the improvement in the noise figure of the receiver.

For Configuration 1 shown in **Error! Reference source not found.**, the noise figure (without the antenna is found to be):

$$F_{\mathrm{CONFIGURATION1}} = F_1 + \frac{F_2 - 1}{G_1} = L_1 + L_1\left(F_2 - 1\right) = L_1 F_2$$

Equation 4

For Configurations 2 and 3 shown in **Error! Reference source not found.** and Figure 3 the noise figure (without the antenna) is found to be:

$$F'_{\text{CONFIGUTRATION 2 AND 3}} = L_1' + L_1'\left(F_2' - 1\right) + \frac{L_1'\left(L_3' - 1\right)}{G_2'} + \frac{L_1' L_3'\left(F_4' - 1\right)}{G_2'} =$$
$$= L_1' F_2' + \frac{L_1'\left(L_3' F_4' - 1\right)}{G_2'}$$

Equation 5

By using Equation 3 above, the sensitivity improvement of Configuration 2 over Configuration 1 is

$$Q = \frac{F'_{\text{CONFIGURATION1}}}{F'_{\text{CONFIGURATION2}}} = \frac{L_1 F_2}{L_1' F_2' + \dfrac{L_1'\left(L_3' F_4' - 1\right)}{G_2'}}$$

Equation 6

Configuration 2 shown in **Error! Reference source not found.** can be used with a different TMA, as shown in **Error! Reference source not found.**. In that case, the sensitivity improvement of Configuration 3 over Configuration 2 is given as

$$Q = \frac{F'_{\text{CONFIGURATION2}}}{F'_{\text{CONFIGURATION3}}} = \frac{F_X'}{F_Y'} = \frac{L_1' F_{2X}' + \dfrac{L_1'\left(L_3' F_4' - 1\right)}{G_{2X}'}}{L_1' F_{2Y}' + \dfrac{L_1'\left(L_3' F_4' - 1\right)}{G_{2Y}'}}$$

Equation 7

The effect of the antenna on the sensitivity improvement can be evaluated by introducing the effective antenna noise temperature, T_{ANT}:

$$Q = \left(\frac{R}{R'}\right) \frac{1 + \left(F - 1\right)\left(\dfrac{T_0}{T_{\text{ANT}}}\right)}{1 + \left(F' - 1\right)\left(\dfrac{T_0}{T_{\text{ANT}}}\right)}$$

Equation 8

where T_0 is the temperature at which measurements are made (reference temperature). In Equation 8, F is the baseline noise figure, while F' is the noise figure of the new configuration.

Cascaded noise figure method

When N components are cascaded, the resulting noise factor is given as

$$F_{\mathrm{CAS}} = F_1 + \sum_{i=2}^{N} \frac{F_i - 1}{\prod_{j=1}^{i-1} G_j}$$

Equation 9

For Configuration 2, with TMA “X”, shown in **Error! Reference source not found.**, Equation 5 gives the cascaded noise factor as:

$$F_{\mathrm{X}}{}' = L_1' + L_1'\left(F_{2\mathrm{X}}' - 1\right) + \frac{L_1'\left(L_3' - 1\right)}{G_{2\mathrm{X}}'} + \frac{L_1' L_3'\left(F_4' - 1\right)}{G_{2\mathrm{X}}'} =$$
$$= L_1' F_{2\mathrm{X}}' + \frac{L_1'\left(L_3' F_4' - 1\right)}{G_{2\mathrm{X}}'}$$

Equation 10

For Configuration 3, with TMA “Y”, the cascaded noise factor is given as simply

$$F_{\mathrm{Y}}' = L_1' F_{2\mathrm{Y}}' + \frac{L_1'\left(L_3' F_4' - 1\right)}{G_{2\mathrm{Y}}'}$$

Equation 11

With antenna noise temperature included, Equation 10 and Equation 11 become

$$T_{\mathrm{X,TOT}} = T_{\mathrm{ANT}} + T_0\left(F_{\mathrm{X}}' - 1\right)$$

Equation 12

$$T_{\mathrm{Y,TOT}} = T_{\mathrm{ANT}} + T_0\left(F_{\mathrm{Y}}' - 1\right)$$

Equation 13

Converting back to noise factors, we obtain:

$$F'_{\mathrm{X,TOT}} = \frac{T_{\mathrm{X,TOT}}}{T_0} + 1$$

Equation 14

$$F'_{\mathrm{Y,TOT}} = \frac{T_{\mathrm{Y,TOT}}}{T_0} + 1$$

Equation 15

The noise factor improvement can then be calculated as:

$$F'_{\text{IMPROVEMENT}} = \frac{F'_{\text{X,TOT}}}{F'_{\text{Y,TOT}}} = \frac{1+\left(F'_{\text{X}}-1\right)\dfrac{T_0}{T_{\text{ANT}}}+\dfrac{T_0}{T_{\text{ANT}}}}{1+\left(F'_{\text{Y}}-1\right)\dfrac{T_0}{T_{\text{ANT}}}+\dfrac{T_0}{T_{\text{ANT}}}}$$

Equation 16

Note that the same result is obtained by cascading antenna and remainder noise factors, where the antenna noise factor is obtained from its effective noise temperature:

$$F'_{TOT} = \left(\frac{T_{\text{ANT}}}{T_0}+1\right)+\frac{F'_{\text{X/Y}}-1}{1} = \frac{T_{\text{ANT}}}{T_0}+F_{\text{X/Y}}$$

Equation 17

It is implicitly assumed above that the antenna has neither gain nor loss.

Model difference

If the effect of the antenna is neglected, there is no difference between the two methods. The difference between the two models occurs due to the way in which effective antenna temperature is taken into account.

Sensitivity improvement, for going from Configuration 2 to Configuration 3, according to the SINR method is:

$$Q = \frac{1+\left(F'_{\text{X}}-1\right)\left(\dfrac{T_0}{T_{\text{ANT}}}\right)}{1+\left(F'_{\text{Y}}-1\right)\left(\dfrac{T_0}{T_{\text{ANT}}}\right)}$$

Equation 18

Sensitivity improvement, for going from Configuration 2 to Configuration 3, according to the cascaded noise figure method is:

$$F_{\text{improvement}} = \frac{1+\left(F'_{\text{X}}-1\right)\dfrac{T_0}{T_{\text{ANT}}}+\dfrac{T_0}{T_{\text{ANT}}}}{1+\left(F'_{\text{Y}}-1\right)\dfrac{T_0}{T_{\text{ANT}}}+\dfrac{T_0}{T_{\text{ANT}}}}$$

Equation 19

The difference is that Equation 19 contains additional T_0/T_{ANT} in numerator and denominator. If in the cascaded noise figure method we consider the improvement in the effective noise temperature rather than the effective noise factor, we obtain:

$$T_{\text{improvement}} = \frac{T_{\text{X,TOT}}}{T_{\text{Y,TOT}}} = \frac{T_{\text{ANT}} + T_0\left(F_X^{/} - 1\right)}{T_{\text{ANT}} + T_0\left(F_Y^{/} - 1\right)} = \frac{1 + \left(F_{\text{X}}^{/} - 1\right)\left(\frac{T_0}{T_{\text{ANT}}}\right)}{1 + \left(F_Y^{/} - 1\right)\left(\frac{T_0}{T_{\text{ANT}}}\right)}$$

Equation 20

which is effectively the same as Equation 18.

If the antenna effect is included in calculation, the SINR method shows that a larger sensitivity improvement is obtained as the effective antenna noise temperature is lowered. The sensitivity improvement with a low T_{ANT} is larger than the straight difference of the TMA noise figures.

On the other hand, the cascaded noise figure method also shows that sensitivity improvement is increased as T_{ANT} is lowered. However, the main difference is that the maximum improvement that can be obtained is the difference of the noise figures of the two TMAs. This maximal improvement can be obtained when antenna is noiseless (i.e. with T_A = 0 K).

The author of this document believes that the cascaded noise figure method is the accurate one. The primary reason why the SINR method is not considered accurate is the fact that it interprets the ratio of effective noise temperatures as the sensitivity improvement. It seems to be more accurate to first convert the noise temperatures to noise factors, and then calculate the sensitivity improvement. Furthermore, it does not seem physically sustainable to have an overall sensitivity improvement larger than the improvement in the sum of its parts.

Results & Notes

- Calculate the improvement by going from Configuration 1 to Configuration 2. Denote this as Improvement A.
- Calculate the improvement by going from Configuration 2 to Configuration 3. Denote this as Improvement B.
- The improvement by going from Configuration 1 to Configuration 3 is equal to the difference of Improvement B and Improvement A.

Improvement by going from TMA "X" to TMA "Y"

Consider TMA-X and TMA-Y with $G_X = G_Y$ = 14 dB, NF_X = 2.2 dB and NF_Y = 0.75 dB, the overall improvement in the uplink sensitivity is:

	SINR method	Cascaded NF method
T_{ANT} = 50 K	ΔNF_{TOT} = 2.00 dB	ΔNF_{TOT} = 1.12 dB
T_{ANT} = 100 K	ΔNF_{TOT} = 1.76 dB	ΔNF_{TOT} = 1.04 dB
T_{ANT} = 150 K	ΔNF_{TOT} = 1.57 dB	ΔNF_{TOT} = 0.97 dB

T_{ANT} = 250 K ΔNF_{TOT} = 1.30 dB ΔNF_{TOT} = 0.86 dB

T_{ANT} = 300 K ΔNF_{TOT} = 1.19 dB ΔNF_{TOT} = 0.81 dB

If NF_X = 2.5 dB is assumed, the sensitivity improvement is:

- Between 1.45 dB [with T_{ANT} = 300 K] and 2.38 dB [with T_{ANT} = 300 K] (SINR method)
- Between 1.00 dB [with T_{ANT} = 300 K] and 1.36 dB [with T_{ANT} = 300 K] (Cascaded NF method).

If NF_Y = 0.5 dB is assumed (still with NF_X = 2.5 dB), the improvement is:

- Between 1.64 dB [with T_{ANT} = 300 K] and 2.75 dB [with T_{ANT} = 50 K] (SINR method)
- Between 1.12 dB [with T_{ANT} = 300 K] and 1.54 dB [with T_{ANT} = 50 K] (Cascaded NF method)

References

[1] S. C. Yang, J. Payne, and M. I. Salkola, “The Effect of Higher Receiver Sensitivity on the Coverage of a Spread Spectrum CDMA System,” *IEEE Microwave and Wireless Components Letters* vol. 15, no. 5, pp. 372 – 374, May 2005.

Version history

Version 1 (23 OCT 2008): First release.