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## Introduction

Noise from the bias circuit at frequency, $w_{\text{noise}}$, can mix with a jammer at frequency, $\omega_{\text{RF}} + w_{\text{noise}}$, to generate a noisy signal at a desired frequency, $\omega_{\text{RF}}$, in a low noise amplifier or in the driver of a mixer. In the switching pair of a mixer, noise mixes from the RF=LO+IF to IF frequency and from Image=LO-IF to IF frequency.

### Inputs

- $\omega_{\text{off}} := 900\text{kHz}$
- $\omega_{\text{RF}} := 869\text{MHz}$
- $P_{\text{jamdBm}} := -46\text{dBm}$
- $\Delta f := 30\text{kHz}$
- $\Delta f_{\text{des}} := 1.23\text{MHz}$
- $\omega_{\text{corner}} := 100\text{kHz}$
- $R_{\text{bias}} := 1\text{kohm}$
- $\text{Temp} := 300\text{K}$
- $I_{\text{c}} := 6\text{mA}$
- $I_{\text{C}} := 3\text{mA}$
- $r_{b} := 8\text{ohm}$

- Frequency offset of the jammer
- Frequency of desired signal
- Power of Jammer
- Bandwidth of Jammer
- Bandwidth of Desired Signal
- $1/f$ noise corner frequency
- Thermal noise resistance of bias circuitry and transistor
- Operating Temperature in Kelvin
- Inductive Degeneration
- Bias Current
- Base Resistance
**Calculations**

\[ \omega_{\text{jammer}} := \omega_{\text{RF}} + \omega_{\text{off}} \]
\[ S_{\text{jammer}} = \sqrt{2} \cdot \frac{P_{\text{jamdBm}}}{10^{10} \cdot \text{mW} \cdot \text{50ohm}} \]
\[ V_T := \frac{k \cdot \text{Temp}}{q} \]
\[ g_m := \frac{I_C}{V_T} \]
\[ R_{\text{eff}} := R_{\text{bias}} \cdot \left( \frac{50\text{ohm}}{2} + \frac{50\text{ohm}}{\frac{2}{R_{\text{bias}}}} \right) + \frac{1}{2} g_m + r_b \]
\[ V_n(f) := 4 \cdot k \cdot \text{Temp} \cdot R_{\text{eff}} \cdot \left( 1 + \frac{\omega_{\text{corner}}}{f} \right) \]
\[ S_{\text{noise}} := \int_{\omega_{\text{off}} - \frac{\Delta f}{2}}^{\omega_{\text{off}} + \frac{\Delta f}{2}} V_n(f) \, df \]
\[ Z_e(\omega) := 2 \pi j \cdot \omega \cdot L_e \]
\[ A_1(\omega) := \frac{g_m}{1 + g_m Z_e(\omega)} \]
\[ A_2(\omega_1, \omega_2) := \frac{g_m}{2 \cdot V_T \cdot (1 + g_m Z_e(\omega_1)) \cdot (1 + g_m Z_e(\omega_2))} \]
\[ I_{\text{outnoise}} := \left| A_2(\omega_{\text{jammer}} - \omega_{\text{off}}) \right| \cdot \sqrt{S_{\text{noise}}^2 \cdot S_{\text{jammer}}} \]
\[ S_{\text{innoise}} := \left( \frac{I_{\text{outnoise}}}{A_1(\omega_{\text{RF}})} \right)^2 - \frac{1}{\Delta f_{\text{des}}} \]
\[ NF := 10 \log \left[ 1 + \frac{S_{\text{innoise}}}{4 \cdot k \cdot \text{Temp} \cdot \text{50ohm}} \right] \]
\[ NF := 10 \log \left[ 1 + \frac{R_{\text{eff}}}{\text{50ohm}} \right] \]

\[ \omega_{\text{jammer}} = 869.9 \text{ MHz} \]
\[ S_{\text{jammer}} = 1.585 \text{ mV} \]
\[ V_T = 25.899 \text{ mV} \]
\[ g_m = 115.835 \text{ mA/V} \]
\[ R_{\text{eff}} = 14.696 \text{ ohm} \]
\[ S_{\text{noise}} = 8.13 \times 10^{-3} \mu \text{V}^2 \]

Integration Thermal Noise (rms)

Emitter Impedance

Approximate High Frequency with inductive degeneration.

Approximate High Frequency with inductive degeneration.

Noise at the output of the amplifier

Input Noise Spectrum

Noise Figure due to mixed noise

Noise Figure without jammer

**Frequency of jammer**

**Jammer Voltage 0-pk**

**Thermal Voltage**

**Device Transconductance**

**Effective Input Noise Resistance**
Hand Calculation Simplifications

\[
NF = 10 \log \left( 1 + \frac{\left( \frac{A_2(\omega_{RF} + \omega_{off}, -\omega_{off})}{\omega_{RF}} \right)^2 \cdot R_{eff}}{50 \cdot \left( \Delta f + \omega_{corner} \cdot \ln \left( \frac{\omega_{off} + \frac{\Delta f}{2}}{\omega_{off} - \frac{\Delta f}{2}} \right) \right) S_{jammer} \cdot \omega_{corner}} \right)
\]

\[
NF = 10 \log \left( 1 + \left( \frac{S_{jammer}}{1C \cdot \omega_{RF} \cdot L_e} \right)^2 \cdot R_{eff} \cdot \frac{\Delta f}{50 \text{ohm}} + \frac{\omega_{corner}}{\Delta f_{des}} \cdot \ln \left( \frac{\omega_{off} + \frac{\Delta f}{2}}{\omega_{off} - \frac{\Delta f}{2}} \right) \right)
\]

dB Increase from Noise Doubling

Here is an interesting side calculation. If you double the noise in a circuit how much does the noise figure increase? For large noise figures it is 3dB. For small noise figure the dB's double. This is useful for comparing the noise of a differential circuit to a single-ended circuit, such as a differential LNA to a single-ended LNA.

\[
N := 100
i := 1..N
NF_i := \frac{i - 1}{N} \cdot 10
\Delta NF_i = 10 \log \left( 1 + \left( \frac{NF_0}{10^i - 1} \right)^2 \right) - NF_0_i
\]

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