

MODELING AND SIMULATION OF NOISE ON RADIO FREQUENCY (RF) AMPLIFIERS

BY

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Abstract

In Radio frequency (RF) communication receivers, one of the major limiting factors for their performance is noise. Increased noise in these systems is bringing serious resource constraints to today's high-density wireless communication channels. Therefore, this problem must be carefully considered when designing RF receivers. This paper demonstrates the modelling and simulation to explore the characteristics of the RF receiver under additive noise models using MATLAB/SIMULINK software. Simulation results indicate good agreement with the theoretical results.

Keywords: Radio Frequency, Phase Noise, SNR, Decibel MATLAB

Introduction

Modern RF communication systems such as mobile phones, satellite receivers, navigation equipment, etc in low coverage areas, are increasingly required to capture and process very weak signals. One limiting factor for these systems is noise. Controlling the noise figure of a receiver is paramount because it is usually more cost-effective to do than increasing the broadcast signal power or optimising the receiving antenna to achieve a better signal-to-noise (SNR) ratio. RF receivers amplify signals and shift them to lower frequencies. The receiver itself introduces noise that degrades the received signal. The SNR at the receiver output ultimately determines the usability of the receiver.

The output SNR ratio of a communication RF receiver depends on the input SNR ratio and the noise figure (Joe, 2017). In terrestrial systems, the input S/N ratio is a function of the transmitted power, transmitting antenna gain, atmospheric transmission coefficient, atmospheric temperature, receiving antenna gain and the noise figure (Mitchell, 2021).

Noise in an RF system is generated internally by active components in the system or introduced externally as channel interference or antenna. Different types of noise exist in RF communication receivers.

These are phase noise, white and coloured noise and thermal noise (Bergeron, 2017). Factors that influence these noises are the output power of the amplifier, carrier frequency, offset frequency, the technology used internal to the device, biasing voltage, noise from the DC source and the number of cascaded amplifier stages (Liu, 2019).

Phase noise is defined as the noise arising from the rapid, short-term, random phase fluctuations that occur in a signal. It is measured as a power spectral density (PSD) in decibels relative to the carrier power per hertz of bandwidth dB/Hz (Acar, 2021). The lower the phase noise, the better the performance of the RF systems (Delos, 2017). This noise introduces uncertainty in the detection of digitally modulated signals. White noise has a flat frequency spectrum and equal power across all frequencies of the system bandwidth, whereas *coloured noise* has power that varies according to frequencies in an RF system bandwidth. Thermal noise is the most common noise introduced in an RF system. This noise is generated internally by active components in the system or externally due to channel interference or antenna. Thermal noise is also known as Johnson or Nyquist noise (Mustafa and Samarah, 2017).

Several research works have been proposed in the literature on the study of

noise on amplifiers for the last three decades. A simulation of phase noise distortion and its analysis in RF transceiver of IEEE 802.11a WLAN bridge system has been proposed by Shairi, (2013). The RF behavioural models and Agilent Ptolemy simulator are used to perform constellation error and receiver sensitivity simulation based on IEEE 802.11a standard. Frederick, (2023) has carried out the simulation and Analysis of Phase Noise Distortion in RF Transceiver of IEEE 802.11a WLAN Bridge System. Phase noise analysis procedure has been performed to develop the RF component phase-noise models as well as calculating its propagation dynamics that contribute to output phase-noise and simulate them. A lowest phase noise at the 10-GHz mid-band has been achieved. An Investigation into the effect of phase noise of OFDM system and realization LO (local oscillator) with and without phase locked loop (PLL) has been conducted by Pandey et al. (2017). A comparative analysis has been carried out to show the effectiveness of the simulation results.

In this study, an RF amplifier is chosen to demonstrate the effect of noise on the proposed communication system. The MATLAB/Simulink package is used to model and simulate this scheme over an Additive external noise and the receiver noise to assess the interference signals effect under these conditions.

Methodology

The goal of the research methodology is to find the combination of various steps that simplifies system implementation. The Methodology begins with a description of the workflow used and pitfalls that occurred when designing the RF noise model and ends with a description of work carried out to prove the modelling work based on the concept of the system. This form the basis for

$$N_{out,sys} = 10 \log_{10}(K(T_s + T_e)G_1 + 30) = -667.97 \text{ dBm/Hz} \quad (2)$$

The available noise power is the power that can be supplied by a resistive source when it is feeding a noiseless resistive load

the design, analysis and development of the simulation models involved. For each development, assumptions are stated, and mathematical expressions are provided as the primary technical descriptor of the analysis followed by computer simulations to prove the assumed theory and finally evaluation mechanism to assess the performance of the proposed system.

Materials

The modelling and simulation of the RF noise model consist of the following key materials and components:

- 1) High-capacity PC
- 2) MATLAB® R2021b software

Method

The methodology covers the entire content and process for setting up the RF noise model. There are three main work functions required to implement the simulation work. It follows the sequence outlined below:

1. The Noise Modeling
2. System Implementation
3. Experimental set-up

The Noise Modeling

In this paper, for a specified low noise amplifier (LNA) gain of 4 dB ($G_1 = 2.5119$) and noise figure of 3 dB ($F_1 = 1.9953$), the output noise is calculated using the following equations (MathWorks, 2019):

$$T_e = (F - 1) \times T = 288.63 \quad (1)$$

It converts the noise factor to an equivalent noise temperature. T is the temperature parameter of the RF Blockset Configuration block.

The final equation calculates the output noise power. T_s is the temperature of the SimRF™ External Noise block and the Communications Toolbox External Noise Floor block.

equal to the source resistance. The green external noise floor block generates an available power referenced to 50 ohms

(Nahla, 2020).

The front-end gain block models the voltage divider due to the source resistance and the input impedance of the amplifier, while the green reference amplifier noise and amplifier gain blocks model the noise added by the amplifier and the amplifier gain, respectively. The output of the Communications Toolbox Amplifier gain block is equal to the voltage across the RF Blockset R_load block.

Noise Figure

The noise figure value determines the degradation of the signal-to-noise ratio of a signal as it goes through the network. The noise figure is defined by the equation:

$$N_f = \frac{\frac{\text{signal}}{\text{noise}} \text{ at the input}}{\frac{\text{signal}}{\text{noise}} \text{ at the output}} \quad (3)$$

Excessive noise figure in the system causes the noise to overwhelm the signal, making the signal unrecoverable. The noise figure is a function of frequency but it is independent of the bandwidth of the system. The noise figure is expressed in dB (Amaal et al 2019).

Thermal Noise

Thermal noise is the most common noise introduced in an RF system. This noise is generated internally by active components in the system or externally due to channel interference or antenna. Thermal noise is also known as Johnson or Nyquist noise. The equation for thermal noise is:

$$P_N = k_B T B \quad (4)$$

k_B is Boltzmann's constant, equal to 1.38065×10^{-23} J/K.

T is the noise temperature, specified as 293.15 K in this example.

R_s is the noise source impedance, specified as 50Ω in this example to agree with the resistance value of the Resistor block labelled R1.

B is the bandwidth.

At room temperature, the thermal noise generated by the system with a bandwidth of 1 Hz is -174 dBm.

The thermal noise floor in RF Blockset is defined by the equation (Shivani and Vikash, 2020):

$$P_{noise} = 4k_B T R_s \Delta f \quad (5)$$

where:

k_B is Boltzmann's constant, equal to 1.38065×10^{-23} J/K.

T is the noise temperature, specified as 293.15 K in this example.

R_s is the noise source impedance, specified as 50Ω in this example to agree with the resistance value of the Resistor block labelled R1.

Δf is the noise bandwidth.

System Implementation

The following stages detail each specific part of the system as well as how each section is developed and interacts with other blocks to result in the production of the RF signals and subsequent application of the noise.

A Configuration block, which sets global simulation parameters for the RF Blockset system. With the Simulate Noise option checked, noise is included in the simulation.

An External Noise source with a power spectral density of $4k_B T_s R$ is applied at the input. In this equation, k is the Boltzmann constant, T_s is the temperature of the source, and R is the noise reference impedance. The calculated noise level of -174 dBm/Hz is used in this example. The External Noise source is an explicit signal.

An Amplifier block with a specified power gain and noise figure.

A Voltage Sensor (i.e., Output) block, with the Source type parameter set to Voltage. Source and load resistors.

Gain blocks that model amplifier gain and loading effects.

Two Receiver Thermal Noise blocks model the external noise and the amplifier noise, respectively.

The Calculate Power block computes RMS noise power. Note that the Communications Toolbox signal is referenced to 1 ohm, while RF Blockset power is computed for the actual load.

Computing Rf System Noise

To enable noise in the RF Blockset circuit envelope environment, the following parameter settings were made:

In the Configuration block dialogue, simulation noise was selected.

The temperature was specified in the RF Blockset and this value was used to calculate the equivalent noise temperature inside the amplifier.

The Noise figure (dB) was specified in the parameter of all the amplifiers and mixers in the system.

Experimental Set-Up

The simulation model can be complex when the thought of as a whole but when broken up into smaller stages and divisions it becomes much easier to approach the work. Representation of the proposed system is completed first using Simulink blocks showing the bonds between components. This simulation also employs blocks from the Simulink RF Communications Blockset. The RF amplifier block was obtained from the RF communications toolbox (Comm. Sources / RF blockset), External and thermal noise blocks were obtained from the communication blockset, the gain block was obtained from the commonly used blocks, the load resistors were obtained from the Simscapeblockset and the power block was obtained from the sink blockset. The simulation block diagram can be seen in Figure 1.1.

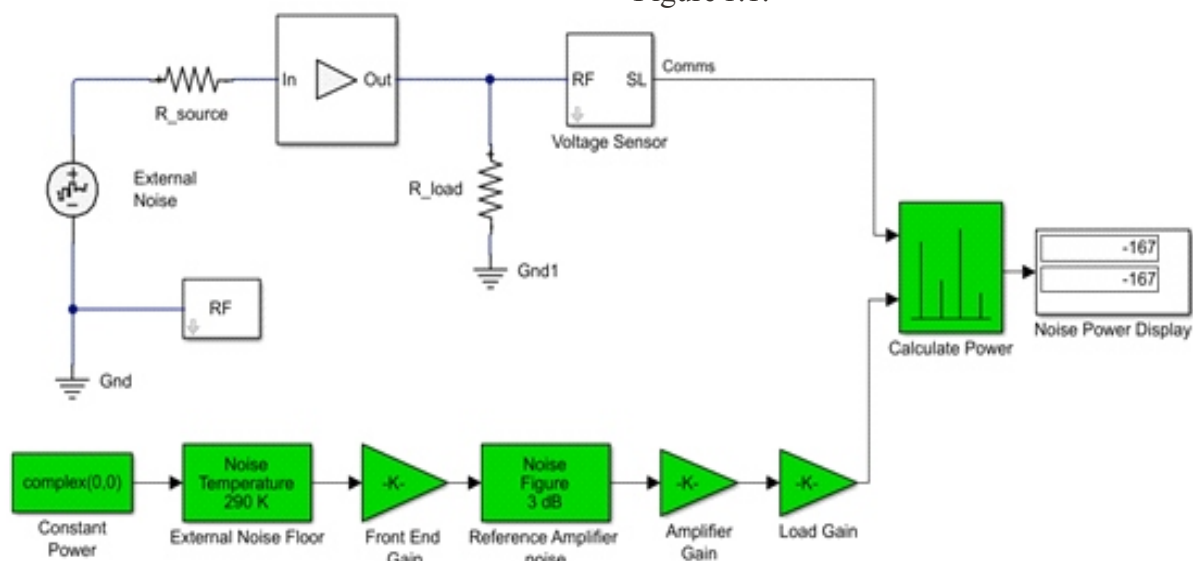


Figure 1.1: Complete System Simulation block diagram

Results and Discussion

The physical result of the work presented is embodied in a proof of concept first envisioned previously. This section presents the compilation of simulation results as well as the results of the measurements and final test conducted on the RF noise model

implemented above.

Figure 1.2 shows the output waveform of the amplifier signal in the presence of thermal noise. It shows the received signal with the noise generated by the internal components of the amplifier.

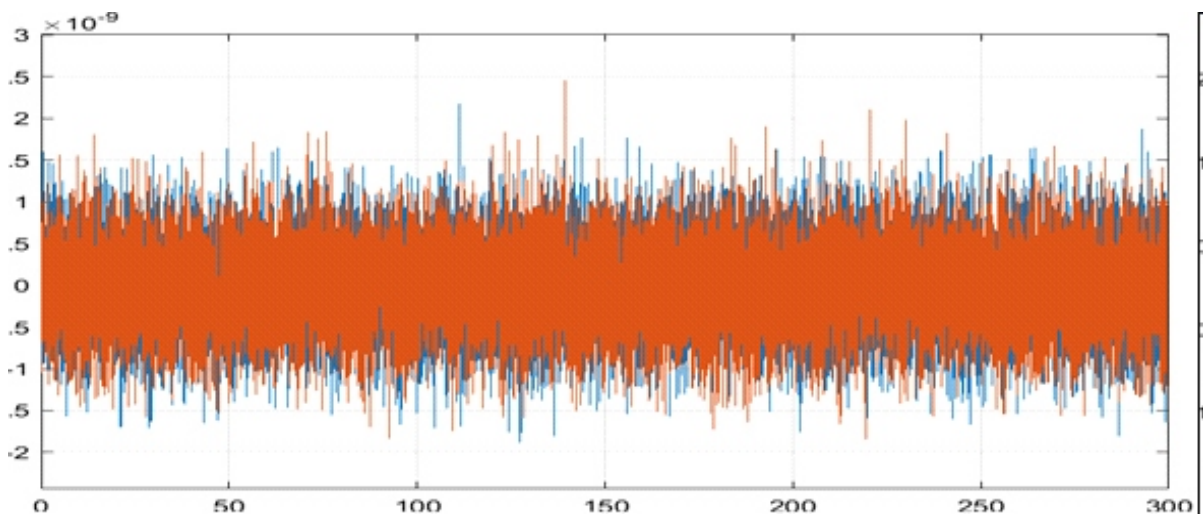


Figure 1.2: Waveform of a noisy signal

Figure 1.3 shows the waveform of the external noise introduced in an RF system. This noise is generated externally due to channel interference or antenna. As can be seen in the figure, this type of noise consists of spurious radio signals with components spread over a wide frequency range. These

spurious radio waves constituting the noise get propagated over the earth in the same fashion as the desired radio waves of the same frequency. Consequently, the receiving antenna intercepts not only the signal but the noises.

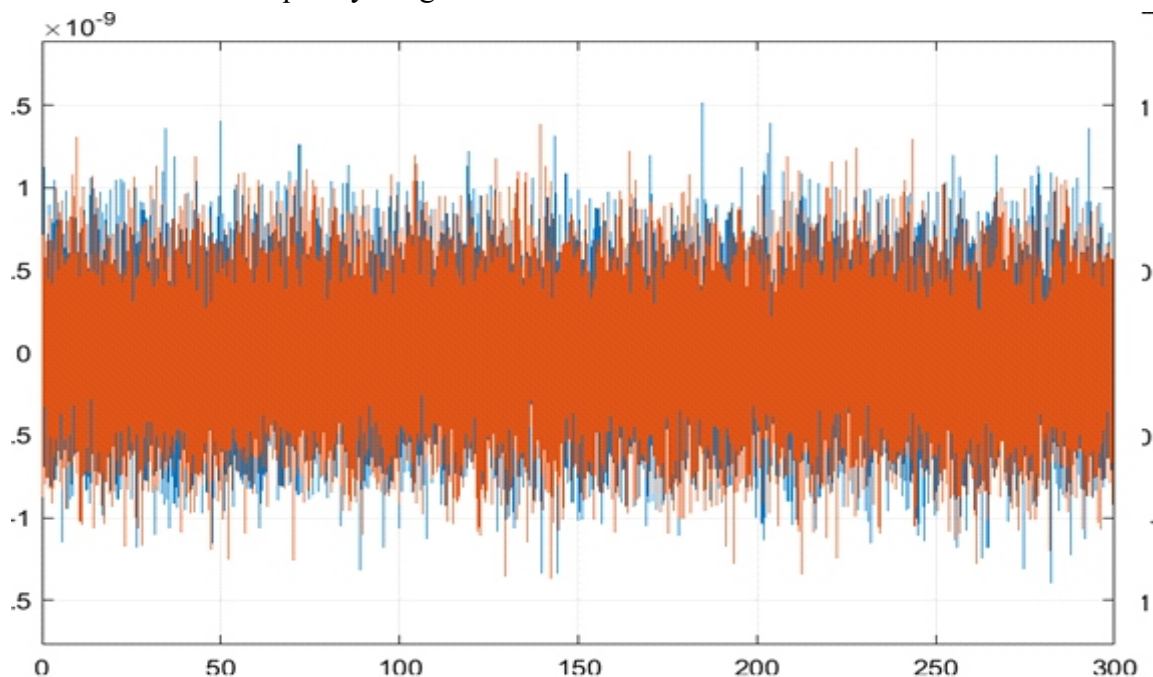


Figure 1.3: Waveform of the externally generated noise

Figure 1.4 shows the calculated power block displaying the RMS noise power being computed during the simulation phase. As can be seen, noise is usually expressed in

terms of power. By knowing the signal-to-noise powers, the signal-to-noise ratio can be easily computed. Rather than expressing the SNR as simply a number, it is usually expressed in decibels (dBm/Hz).

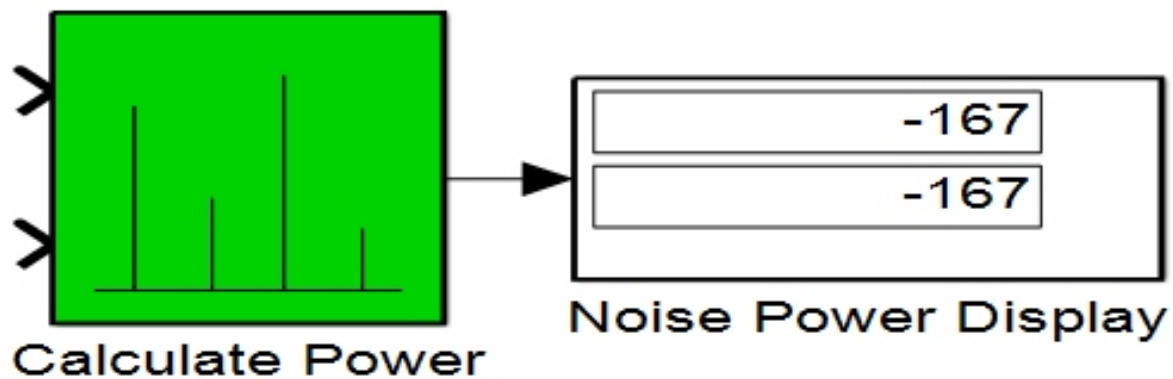


Figure 1.4: Computation of the Noise Power

Conclusion

When designing RF amplifiers, it is a common practice to consider the effect of noise in order to improve system performance. This paper has demonstrated the modelling and simulation to explore the characteristics of the RF amplifier and analyze the effect of thermal and external noises over an additive external noise and the amplifier's noise. The MATLAB/Simulink® package is used to simulate this scheme to assess the interference signals effect under

these conditions. Finally, the waveform of the corrupted signals and the RMS noise power were obtained.

As can be seen in the foregoing presentation, the theoretical calculation of the RMS noise power is closely related to the result obtained in the simulation experiment. A good benchmark value for the amplifier noise is -165dBc at a 10 kHz offset. It has been proven that this method has good features and is effective for analysis of noise on RF-based communication systems.

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