SNR improvement by Stochastic Resonance Receiver for subthreshold signal in Radio Frequency

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Abstract—Stochastic Resonance (SR) is well known as a phenomenon in which the weak signal in a nonlinear system can be detected by added noise. We consider the application of SR phenomenon to a wireless communication system. The receiver using SR phenomenon can detect the subthreshold signal which is not detectable by the conventional receiver. The effect of SR receiver has been verified, but it has never been verified in radio frequency which is used by a wireless system. In this paper, we consider the implementation of SR System for Radio Frequency and evaluate its performance of Signal to Noise Ratio (SNR).

1. Introduction

In wireless communication, a received signal may become very weak by channel attenuation. Let us consider an extremely weak signal with the amplitude below receiver sensitivity. The receiver cannot detect such signal. However, Stochastic Resonance Receiver(SR Receiver) can detect the extremely weak signal.

Stochastic Resonance(SR) is a nonlinear phenomenon which enhances the response by adding noise. The response is usually evaluated by Signal to Noise Ratio(SNR). In SR system, its output SNR increases with increasing noise, passes through a peak and deteriorates gradually. By the additon of suitable noise, SR system can detect an extremely weak signal[1].

Some applications of SR phenomenon in a communication system have been discussed. In the bistable system which is one of SR system, the enhancement of the bi-polar pulse and the BPSK signal were reported by simulation[2]. Using SPICE simulator, the bistable system designed by the simple Schmitt Trigger circuit was discussed[3]. In bipolar pulse signal, enhancement of SNR and Bit Error Rate had been reported by experiments[4].

In this paper, we consider the application of SR for a wireless communication system. We implement SR Receiver and evaluate its performance. First, the received signal at the receiver passes through the Stochastic Resonance circuit(SR Circuit) which causes SR phenomenon. Then, output of SR Circuit is fed to the demodulator. As a result, the extremely weak signal is converted to the detectable signal with SR circuit. We consider the implementation of SR Circuit for radio frequency and evaluate its SNR performance.

This paper is organized as follows. First, SR system for radio frequency is presented in section 2. An overview of SR Circuit and SR Receiver is introduced in Section 3. In section 4, we evaluate the performance of the implemented circiuit in output SNR. Conclusions are given in section 5.

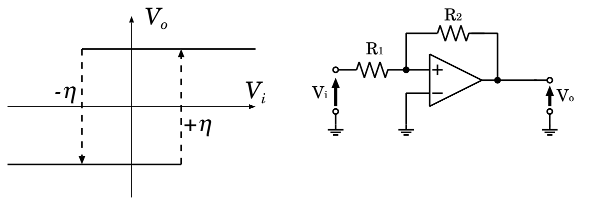
2. SR System for radio frequency

Using SR phenomenon for wireless communication, the receiver can detect an extremely weak signal with amplitude below its receiver sensitivity. We can consider two architectures of SR Receiver. One is the detection of the radio signal from an antenna. The other is the detection of the baseband signal from the demodulator. Using simulation, it was reported that the former can achieve better performance than the latter[2]. Therefore, we consider the detection of the radio signal from an antenna. However, the signal frequency assuemd by the conventional Stochastic Resonance System is very low. In order to apply SR phenomenon to the radio communication system, it is necessary to consider whether SR phenomenon can be used in the radio frequency. Moreover, the implementation of SR Circuit which can function in radio frequency is required.

3. System Overview

3.1. Schmitt Trigger

For the implementation of the SR Receiver, we build a SR circuit using Schmitt Trigger. Schmitt Trigger is one of the circuit models of SR system. Figure 1 shows its input-output characteristic and the circuit schematic using an operational amplifier. In Fig 1, V_i and V_o are its input and output voltage, respectively. Schmitt Trigger is known as a comparator which has hysteresis. It is the circuit model



(a) (b)

Figure 1: The characteristic of Schmitt Trigger (a) and its circuit schematic (b).

of the bistable system. In ideal conditions, the output of Schmitt Trigger $r_s(t)$ is represented as

$$r_s(t) = V_m \mathrm{sgn}\left(r(t) - \frac{R_1}{R_2} r_s\right), \quad (1)$$

where V_m is the maximum voltage of its output and $s(t)$ is the input of the Schmitt Trigger[5]. In more practical Op-amp model, the output is given by

$$\dot{r}_s(t) = -\beta \left\{ r_s - \tanh\left[B\left(r(t) - \frac{R_1}{R_2} r_s \right)\right]\right\}, \quad (2)$$

where β and B are constants which decide its transition characteristics. If $\beta, B \to \infty$, circuit characteristics become ideal. Then, the threshold of Schmitt Trigger is given by

$$\eta = \frac{R_1}{R_2} V_m. \quad (3)$$

3.2. SR Receiver

In this section, we introduce our proposed SR receiver using Schmitt Trigger. Figure 2 shows the block diagram of our system. The receiver consists of the SR system and the conventional receiver. The received signal is detected by the SR system composed of the internal noise source and Schmitt Trigger. The internal noise source can control its intensity to improve the received signal.

At the channel, the channel noise $n_c(t)$ assumed to be zero-mean white Gaussian noise with variance σ^2 is added to the transmitted signal $s(t)$ and the composed signal is fed to the receiver. Then the received signal $r(t)$ can be represented as

$$r(t) = s(t) + n_c(t). \quad (4)$$

The model of the sensitivity of the conventional receiver is shown in Fig 3. The conventional receiver cannot detect the signal level whose is not whithin its sensitivity $\pm\eta$. The output of the receiver $y(t)$ can be modeled as follows.

$$y(t) = \begin{cases} r(t) & (|r(t)| \geq \eta) \\ 0 & \text{(otherwise)}. \end{cases} \quad (5)$$

We assume that the received signal $r(t)$ is extremely weak and the conventional receiver can not detect it. Here, we consider the detection of the weak received signal by SR. Our SR Receiver is composed of Schmitt Trigger and the conventional receiver.

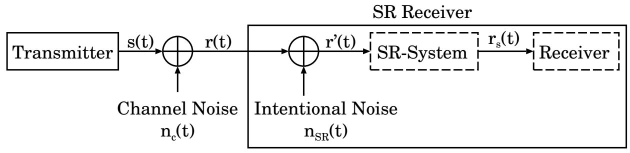


Figure 2: Block diagram of the proposed system.

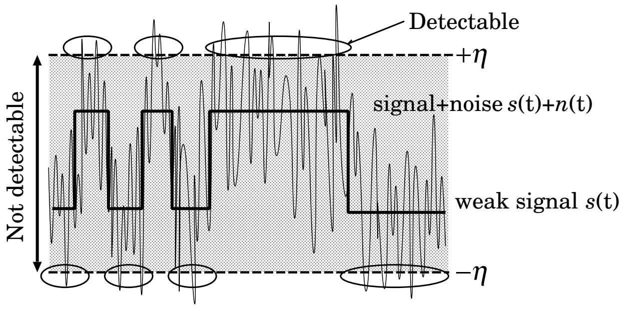


Figure 3: Model of the sensitivity of the receiver.

The input of Schmitt Trigger $r_{ST}(t)$ is composed of the received signal $r(t)$ and the intentional noise $n_{SR}(t)$ and represented as

$$r_{ST}(t) = r(t) + n_{SR}(t), \quad (6)$$

where the intentional noise $n_{SR}(t)$ is zero-mean Gaussian noise with variance σ^2_{SR}. The output of Schmitt Trigger $r_s(t)$ is demodulated and decided at the subsequent stage.

The proposed system can detect the subthreshold signal using noise. In this paper, we implement and evaluate the performance of this receiver.

3.3. Implementation of Schmitt Trigger for radio frequency

We implemented the Schmitt Trigger for radio signal. Figure 4 shows its schematic. In the conventional Schmitt Trigger, its input bandwidth is narrow. However, wide input bandwidth is required in order to detect the radio signal. Therefore, we designed the circuit with wide input bandwidth of 750MHz. ADCMP607 has the wide bandwidth and can operate at the radio frequency.

When the input signal has the extreme weak amplitude, the fluctuation of the threshold which is caused by the temperature affects its performance. We design the Schmitt Trigger so that it has the programmable threshold in order to stabilize its threshold.

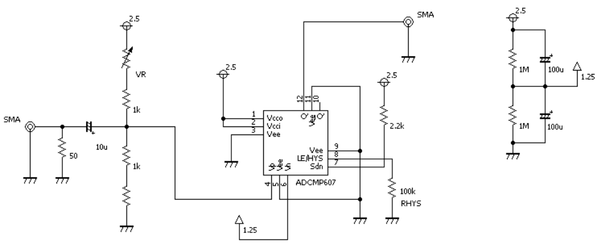


Figure 4: Circuit of Schmitt Trigger for radio frequency.

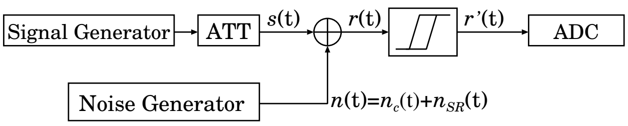


Figure 5: The system diagram for output SNR measurement.

4. SNR measurement

In this section, we experimentally evaluate the output SNR of the implemented Schmitt Trigger. The purpose of the output SNR evaluation is evaluation of SR effect of the implemented circuit.

The system diagram for the output SNR measurement is shown in Figure 5. Here, we consider that the channel noise $n_c(t)$ and the internal noise $n_{SR}(t)$ are the equivalent noise $n(t) = n_c(t) + n_{SR}(t)$. The noise $n(t)$ is zero-mean Gaussian noise with bandwidth 100MHz generated by the vector signal generator(Agilent Technologies N5182A). The attenuated signal $s(t)$ and the noise $n(t)$ are fed to the implemented circuit. The signal amplitude is 80mV and the threshold of Schmitt Trigger is ±100mV. Therefore, the output without input noise has no signal component. In SNR measurement, $s(t)$ is generated the signal generator(Agilent Technologies 33250A) and the signal is the sinusoidal with its frequency 14MHz. The output SNR γ is given by

$$\gamma = 10 \log \frac{S(\omega_s)}{S_N} \ \text{[dB]}, \tag{7}$$

where $S(\omega_s)$ is Power Spectrum Density(PSD) at the signal frequency and S_N is the noise PSD around the signal frequency.

4.1. Experimental Results

The results for the SNR measurement are shown in Figure 6. It is clear from this figure that the output SNR has the peak at PSD=10^{-3}V^2/Hz. Hence, the implemented Schmitt Trigger has SR characteristic at radio frequency. The SR receiver can implement by the Schmitt Trigger with its wide bandwidth.

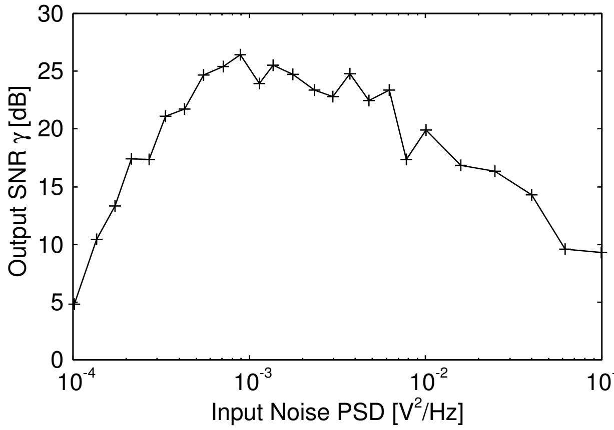


Figure 6: Output SNR of the SR receiver using Schmitt Trigger, where the signal amplitude is 80mV and the threshold is ±100mV.

5. Conclusions

In this paper, we have implemented Stochastic Resonance circuit for the radio signal and have evaluated the performance. For the radio signal, we have shown that the SR can improve the output SNR performance by experimental evaluation. By the addition of the noise with appropriate power, SR receiver can detect a weak signal. The experimental result shows that Schmitt Trigger for radio frequency can use SR phenomenon and detect the weak signal.

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