

## A Novel Noise Measurement Technique Using Bit Error Rate in Receiver of Wireless Communication

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**Abstract:** Modern receiving systems must often process very weak signals, but the noise added by the system components tends to obscure those very weak signals. In this study, a novel noise measurement technique using the Agilent ESG-D series RF signal generators provide an optional internal BER analyzer (Option UN7) is proposed. This technique offers generic BER analysis capabilities for demodulated PN9 and PN15 data sequences that meet ITU-T standards. Also, the study presents the techniques which relate the BER to the noise figure of the system and BER with Minimum Detectable Radiated Power Density (MDRPD).

**Key words:** Noise, bit error rate, noise figure, FSK, PSK, MDS, MDRPD

### INTRODUCTION

Bit Error Rate (BER) is a key specification that characterizes the performance of wireless communication receiver. Noise is a part of all electronic circuits and systems, it is a limiting factor in performance, but it is also a valuable tool for measuring performance. The reason for measuring noise properties of networks is to minimize the problem of noise generated in receiving systems. New receiving systems must often process very weak signals, but the noise added by the system components tends to obscure those very weak signals. Sensitivity, BER and noise figure are system parameters that characterize the ability to process low-level signals. One of the basic measures of the performances of any digital communication system is its BER characteristic that shows the dependence of the BER on the bit-energy-to-noise density ratio ( $E_b/N_0$ ). Another these parameters, noise figure is unique in that it is suitable not only for characterizing the entire system but also the system components such as the pre-amplifier, mixer and IF amplifier that make up the system (Gary, 2004; Stevan, 2004; Peyton, 1987).

In this study, a novel noise measurement technique for wireless receiver which uses Bit Error Rate is proposed. The test response waveforms captured in the receiver baseband are analyzed and the BER value for the receiver is predicted using the alternate test framework (Widad, 2005). Moreover, using the proposed approach, the test instrumentation complexity is also reduced.

### NOISE IN RECEIVER WIRELESS COMMUNICATION SYSTEMS

One of the basic measures of the performances of any digital radio communication system is its Bit Error Rate (BER) characteristic that shows the dependence of the BER on the bit-energy-to-noise density ratio ( $E_b/N_0$ ). To obtain this characteristic a sufficient number of BER values should be measured for various ratios  $E_b/N_0$ . One standard of demodulator performance is bit error rate, or BER, which is defined as:

$$BER = NE/NT$$

Where:

NE = The number of detected bits which are in error

NT = The total number of bits in the measurement gating period.

Under the common assumption of an Additive White Gaussian-Noise channel (AWGN), very definitive statements can be made concerning theoretical error rates for PSK and FSK systems are given by:

$$BER = P(e)_1 = \frac{1}{2} \operatorname{erfc} \sqrt{\frac{E_b}{N_0}} \quad (1)$$

$$BER = P(e)_2 = \frac{1}{2} \operatorname{erfc} \sqrt{\frac{E_b}{2N_0}} \quad (2)$$

Where:

$P(e)_1$  = The system probability of error (BPSK-QPSK).

$P(e)_2$  = The system probability of error (FSK).

$b, o, E, n$  = The bit energy to noise power spectral density.

$$\operatorname{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_0^x \exp(-y^2) dy$$

BER is related to  $E_b/n_o$ , signal to noise ratio (SNR) and bandwidth, B of the receiver as shown:

$$\frac{E_b}{n_o} = \text{SNR} \times \frac{B}{R_b} \quad (3)$$

The noise in receiver wireless communication systems as follow (Schwartz, 1980; Wozencraft and Jacobs, 1965; Widad, 2005; Rajarajan and Soumendu, 2007; Xiang, 2005).

**Sources of noise:** There are several sources of noise; poor circuit design, heat, over-amplification, external influences, automatic gain control, transmission systems such as microwave, infrared, Radiated noise (picked up by antenna or receiver circuitry), Conducted noise (picked up by power and/or other cables) and Internally-generated noise (thermal, shot and flicker). Usually only internally-generated noise can be controlled by designer.

**Signal-to-Noise Ratio (SNR):** Signal-to-noise ratio (often abbreviated SNR or S/N) is an electrical engineering concept, also used in other fields (such as scientific measurements, biological cell signaling and oral lore), defined as the ratio of a signal power to the noise power corrupting the signal. In less technical terms, signal-to-noise ratio compares the level of a desired signal (such as music) to the level of background noise. Output SNR is less than (worse than) input,

$$\text{SNR}_o = \frac{P_{s_o}}{P_{n_o}} = \frac{GP_{s_i}}{GP_{n_i} + P_{NG}} = \frac{P_{s_i}}{P_{n_i} + P_{NG}/G} < \text{SNR}_i \quad (4)$$

Where:

$P_{s_o}$  = Output signal power.

$P_{s_i}$  = Input signal power.

$P_{n_o}$  = Output noise power.

$P_{n_i}$  = Input noise power.

$P_{NG}$  = Internally-generated noise power.

G = Gain of the stage (linear, not dB, form).

**Standard noise factor:** The noise performance of the receiver is measured with noise Factor (F), defined at specified frequency as the ratio of the output noise power per unit bandwidth to the output noise power engendered

by the source (Widad, 2005). In most wireless receiving systems, the source impedance is 50Ω and F is defined at the standard noise temperature  $T_o$  of 290 K. The noise factor expressed in decibel form is called the Noise Figure (NF).

Standard input noise power:

$$P_{n_i} = kT_o B$$

Where:

k = Boltzmann's constant ( $1.38 \times 10^{-23}$  J/K).

$T_o$  = Standard room temperature (290 K).

B = Bandwidth of stage or system (narrowest).

$$F = 1 + \frac{P_{NG}}{GkT_o B}$$

or

$$P_{NG} = (F - 1) GkT_o B \quad (5)$$

Noise factor is always  $>1$ , standard noise figure (NF):  $\text{NF} = 10 \log(F)$ , noise floor of amplifier output:  $P_{\text{noise}} = P_{NO} = kT_o BGF$ . Output noise power referred to input:  $\bar{P}_{N_o} = kT_o BGF$  (equivalent to input noise of ideal noiseless amplifier that produces same output noise as real amplifier) overall standard noise factor,

$$F_{\text{out}} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \dots + \frac{F_N - 1}{G_1 G_2 \dots G_{N-1}} \quad (6)$$

each noise factor in the equation is a standard noise factor, the first one or 2 stages in a receiver are the most critical determiners of the overall system noise figure for passive (no transistors or diodes), lossy, impedance-matched stages:  $G = 1/L$  and  $F = L$ .

We can write the equations for BER related to noise figure:

$$\text{NF} = \text{SNR}_i / \text{SNR}_o$$

$$\text{SNR}_o = \text{SNR}_i / \text{NF}$$

$$E_b/N_o = \text{SNR} \times B/R_b$$

$$E_b/n_o = \text{SNR}_i / \text{NF} \times B/R_b$$

**Minimum Detectable Signal (MDS):** The minimum detectable signal (MDS) is a measure of responsiveness to a weak signal in the presence of noise. It is a measure of sensitivity within a limited bandwidth, defined as the input noise floor, given by  $\bar{P}_{N_o}$  plus min. SNR (in dB) min acceptable SNR is often specified as 0 dB but could be any value, depending on modulation, signal integrity requirements, etc., related to noise factor by  $\text{MDS (Watts)} = kT_o BF \times \text{SNR}$  related to noise figure by:

$$\text{MDS(dBW)} = 10 \log(kT_o) + 10 \log(B) + \text{NF} + \text{SNR(dB)} \quad (7)$$

However, in a digital receiver the BER is function of the digital signal-to-noise ratio ( $E_b/N_o$ ). The theoretical probability of bit error in additive white Gaussian noise (AWGN) can be expressed as  $\text{BER} = 1/2[1 - \text{erf} \sqrt{(E_b/N_o)}]$ .

We can relate the  $E_b/N_o$  to the S/N by the following equation:

$$S/N = E_b/N_o + 10 \log R_b/B_w$$

where,  $R_b$  = the data rate,  $B_w$  = channel bandwidth. If we know the BER requirements we can calculate the  $E_b/N_o$  to S/N and using the above equations.

**Effective Isotropic Radiated Power (EIRP):** Effective isotropic radiated power (EIRP) is the equivalent power of a transmitted signal in terms of an isotropic (omni directional) radiator. Normally the effective isotropic radiated power equals the product of the transmitter power and the antenna gain (reduced by any coupling losses between the transmitter and antenna).

$$\text{EIRP} = \text{MDP}_t \times G_t \quad (8)$$

Where:

$\text{MDP}_t$  = The minimum detectable antenna transmit power.

$G_t$  = The transmit antenna gain.

In addition, another parameter that can be defined using EIRP is the minimum detectable radiated power density, MDRPD that can be defined as:

$$\text{MDRPD} = \text{EIRP (db)} - 10 \log 10(4\pi R^2) \quad (9)$$

Where:

$R$  = The path length of the link system.

## PROPOSED MEASUREMENT TECHNIQUE

In this study, we propose a new measurement technique for determining the noise figure of different receivers (e.g., FSK, BPSK) by using BER to relate to noise figure. The block diagram of the BER proposed experimental setup is shown in Fig. 1. BER is the fundamental measurement used when testing receiver performance parameters such as sensitivity and selectivity. It is the percentage of erroneous bits received compared to the total number of bits received during an observation period. Virtually all BER test instruments use a Pseudo-Random Binary Sequence (PRBS) as the test signal. PRBS signals are usually labeled PN<sub>x</sub>, where x is (for example, PN9 = 29-1 or 511 bits). Since an entire PN<sub>x</sub> sequence can be reconstructed from any sequence of "x" bits, using a PRBS signal eliminates the need to synchronize the received and transmitted bits. Alternatively, the entire PRBS is reconstructed in the BER tester (BERT) receiver from the first correct "x" bits received. The received signal is then compared to the reconstructed correct bit sequence. For the base band BER test, the demodulated PRBS signal at the receiver remains at base band and is compared to the reconstructed PRBS by the BERT (Stevan, 2004) (Fig. 1).

## RESULTS

The simulation results for BER testing using sinusoid stimulus for a 70 MHz wireless are presented by matlab.

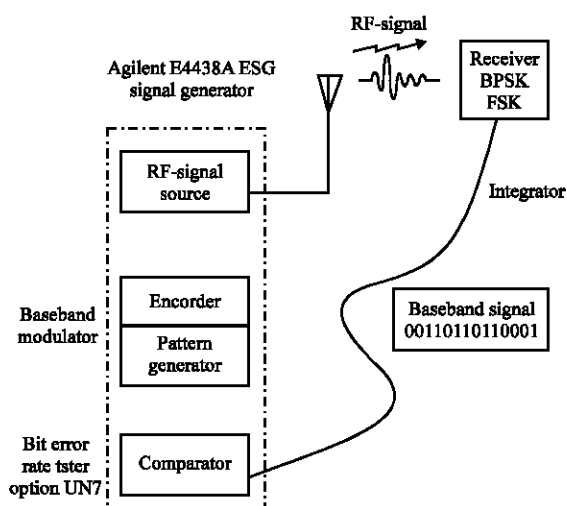


Fig. 1: Experimental BER setup

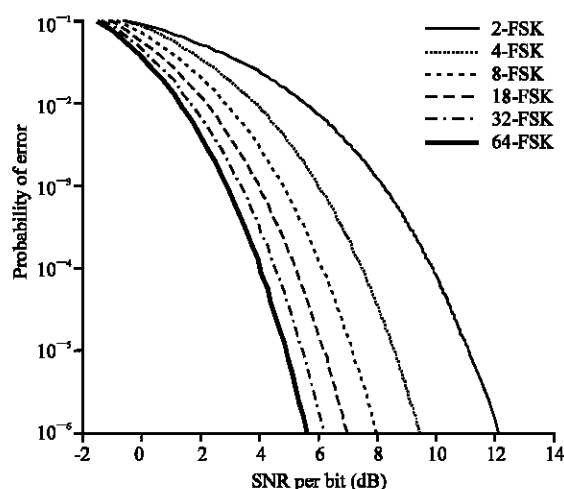


Fig. 2: Probability of error,  $p(e)$  as function of signal to noise ratio of M-FSK signal

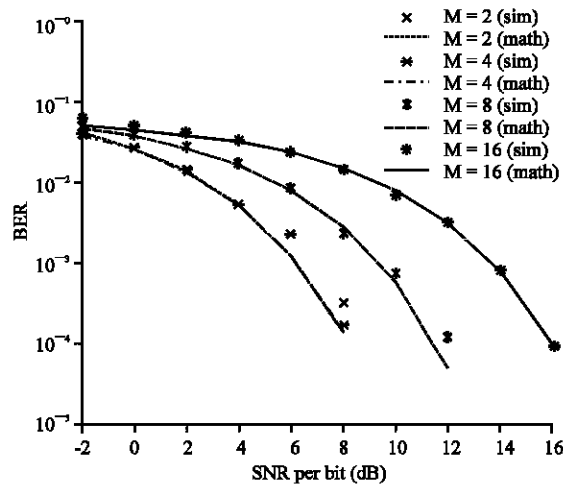


Fig. 3: Probability of error,  $p(e)$  as a function of signal to noise ratio of M-PSK signal

The simulation is done frame by frame, each frame consisting of 600 data bits, generated using a pseudorandom bit sequence of period 127 in Fig. 2 and 3 show the simulation of probability of errors vs. signal to noise ratio of M-FSK, M-PSK signal.

### CONCLUSION

A novel noise measurement technique Using the Agilent ESG-D series RF signal generators provide an optional internal BER analyzer (Option UN7) to measure

the BER of wireless communication. Also, we are presented BER and noise amylases to relate the BER to the noise figure of the system and BER with Minimum detectable radiated power density (MDRPD).

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