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Impact of Gaussian And Impulsive Multiplicative Noise on Instantaneous Frequency Estimators of FM Signals: Comparative Study

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Abstract: Performance of time-frequency distribution (TFD) based instantaneous frequency estimators for one-component, linear and quadratic FM signals is investigated under two models of multiplicative noise: Gaussian and impulsive. The periodogram (which is a specific time-frequency distribution (TFD)) of linear and non-linear FM signals has been considered. Two statistical models of multiplicative noise (Gaussian, impulsive) are handled. Simulation results show that impulsive noise has less impairment effect than Gaussian noise with the same power for instantaneous frequency estimation based on periodogram with multiplicative noise power less than 3 dB; however, the periodogram fails at multiplicative noise power more than 3 dB for both models of multiplicative noise (Gaussian, impulsive).

Keywords: frequency estimation; multiplicative noise; time-frequency distribution; periodogram; impulsive noise

1. Introduction

Estimating the instantaneous frequency of FM signals to extract significant information has many Beneficiaries: Communication (especially Networks) engineers and biomedical engineers [1]. Practically, there is no noise free signal therefore, the instantaneous frequency estimation was major important signal processing problem [2, 3]. Nonstationary signal which their frequency content is time-varying found in important application and its important parameter defined by IF, therefore due to this importance these signals should be analysis by powerful time-frequency analysis tool and IF estimated by robust and effective accurate method [4, 5]. Since the multiplicative noise power is affecting both the amplitude and phase of the signal according to its structural properties, it can be considered as most severe degradation noise that affects signal and system [6]. There are many type of multiplicative noise, impulsive noise is one of these types that severely causes damage and weakness performance of most important applications such as: image, processing and communication system [6, 7]. According to its very high amplitude and short duration characteristic, impulsive noise causes great impairments and high error rate during transmission data in power line communication system (PLC) [8]. To reduce impulse noise effect in PLC system, powerful, robust and simple implement Orthogonal frequency division multiplexing (OFDM) technique was used, because the noise effect is spread over multiple subcarriers due to the discrete Fourier transform at the receiver [9]. In network there are two classes of noise: background noise which is modelled as Gaussian noise and impulsive noise that is modelled as Poisson-Gaussian noise [9].

New algorithm was proposed in [10] to alleviate impulsive noise that degrade the power line communication system performance using sparse Bayesian learning. Due to important advantage of relay network in wireless communication such as self-heading, self- configuration and reliability against failures, simulation of relay wireless channel under impulsive noise was produced in [8] to help designer for choosing robust channel and optimum design. In [11] new effective robust method for estimating the signal frequency of sampled sinusoidal signals in present of impulsive noise was proposed using Hampel estimator in order to obtain exact frequency of sampled signal, where the error of estimated frequency was close to the Cramer Rao Bound. Gaussian noise process based frequency estimation method of sinusoidal signals under impulse noise was unsuccessful, therefore fractional lower order statistics (FLOS) based estimation approach was presented in [12] where noise was modelled as alpha-stable process, this method was robust performance especially with high levels of impulsive noise. In order to overtop degeneration performance of DFT estimation method in presence of impulsive noise, signal selective carrier frequency estimation algorithm for AM, BPSK, and QPSK signals was proposed in [13], as a result this new algorithm was high resistant against noise. In important application such as power quality monitoring, online fault detection and speech analysis, new VFF-QRRLM algorithm was proposed in [14] using new variable forgetting factor (VFF) schemes to improve QR-decomposition-based recursive least M-estimate (QRRLM) algorithm for recursive frequency/spectrum estimation and feature detection of nonstationary signals in impulse noise environment, this algorithm characterized by efficient computationally and high accuracy and robustness unlike conventional recursive least squares-based methods.

Few literature focus on multiplicative noise especially when it modelled as impulse process. This paper analyses the effects of impulsive multiplicative noise on frequency estimation methods of FM signals. A comparative study on the performance of the TFD under impulsive and Gaussian multiplicative noise with different values of power is presented.

The paper is organized as follows: The FM signal model is defined in section 2. In section 3, multiplicative noise models are presented. while Section 4 handles IF estimation based on time-frequency distribution. Finally, in section 5 simulation details and results are explained.

2. The FM Signal Model

In this paper the noisy signal is modelled as:

$$y(t) = n(t)\sin\big(\phi(t)\big) + \epsilon(t) \qquad (1)$$

where $n(t)$ is multiplicative noise, $\phi(t)$ is the initial phase and $\epsilon(t)$ is an additive white Gaussian noise with zero mean and variance $\sigma_a{}^2$; with $n(t)$ and $\epsilon(t)$ considered as independent processes.

First, consider $n(t)$ as white Gaussian noise with zero mean and variance $\sigma_m{}^2$. And then $n(t)$ consider as impulsive noise with Poisson-Gaussian model.

Linear frequency modulation (LFM) law of signal model in equation (1) has been modelled as [15]:

$$s(t) = e^{\left\{j2\pi\left(f_o t + \frac{\alpha}{2}t^2\right)\right\}} \qquad (2)$$

where α is the linear modulation index, and f_o is the initial frequency (in Hertz).

Quadratic frequency modulation (QFM) signal has also been modelled as follows:

$$s(t) = e^{\left\{j2\pi\left(f_o t + \frac{\alpha}{2}t^2 + \frac{\beta}{3}t^3\right)\right\}} \qquad (3)$$

where β is the quadratic modulation index of the QFM signal.

important characteristic of the FM signal was represented by instantaneous frequency [2, 3].

In order to deal with IF estimation, the analytic associated signal should be considered to avoid aliasing. for a given real signal, $s(t)$, the analytic associated signal is [16, 17]:

$$z(t) = a(t)e^{j\theta(t)} = s(t) + j\mathcal{H}[s(t)] \tag{4}$$

where $a(t)$ is instantaneous amplitude, and $\mathcal{H}$ is Hilbert transform of $s(t)$ defined as follows [16]:

$$\mathcal{H}(f) = \begin{Bmatrix} -j & f \geq 0 \\ j & f < 0 \end{Bmatrix} = -j \cdot \mathrm{sgn}(f) \tag{5}$$

The IF was defined for a given real signal, $s(t)$, as follows [18]:

$$f_i(t) = \frac{1}{2\pi}\frac{d\theta(t)}{dt} \tag{6}$$

where $\theta(t)$ is instantaneous phase of real signal $s(t)$, which is modelled in the case of LFM as:

$$\phi(t) = 2\pi\left(f_o t + \frac{\alpha}{2}t^2\right) \tag{7}$$

And in the case of QFM is:

$$\phi(t) = 2\pi\left(f_o t + \frac{\alpha}{2}t^2 + \frac{G}{3}t^3\right) \tag{8}$$

According to above equations and using equations (6) and (7), the IF of LFM signal in equation (2) will be:

$$f_i(t) = f_o + \alpha t \tag{9}$$

Using equations (6) and (8) the IF of QFM signal in equation (3) will be:

$$f_i(t) = f_o + \alpha t + \beta t^2 \tag{10}$$

3. Multiplicative Noise Models

There are different statistical models of multiplicative noise such as: Gaussian, Poisson, Impulsive, non-Gaussian, Rice model, Rayleigh model, Hoyt model, and Nakagami model [6]. In this paper Gaussian and impulsive models have been considered.

Source of noise may be natural source (such as thermal noise) or human-made (physical or industrial) source such as: underwater acoustic channels, indoor radio channels, car ignitions, fluorescent light, mechanical switches, breakers, even light switches or breakers, power lines [8, 11].

Noise in physical source environment cannot be modelled as Gaussian noise because of human -man interference, so it can be modelled as impulsive noise [11]. Below a brief description of each model is given.

Gaussian model

Multiplicative noise that is mostly generated in electrical systems by natural source is Gaussian process which has probability density function (pdf) with zero mean and variance (power) σ^2 as follows [16]:

$$p(n) = \frac{1}{\sigma\sqrt{2\pi}}e^{-n^2/2\sigma^2}$$

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Impulsive model

Impulsive noise is mostly encountered power line communication (PLC) system [7].

Impulsive noise can be modelled as [7]:

$$i_k = b_k \cdot g_k \tag{11}$$

Where b_k is Poisson process that is modeling the arrival time of impulsive noise at instant k with parameter λ which denote the rate of unit per second.

A random variable X is said to be Poisson if its pdf is given by [19]:

$$P(X = x) = e^{-\lambda}\frac{\lambda^x}{x!}\ ; \quad x = 0,1,2,\ldots..$$

$$\mathcal{E}\{X\} = \lambda\ ;\ \mathrm{var}(X) = \lambda.$$

Where $P(X = x)$ is the probability of event of x arrivals in unit time, thereby when X represents the time count of arrival of impulsive noise, then it distributed with above Poisson PDF.

And g_k is Gaussian process that is used to model the amplitude of impulsive noise with zero mean and variance (power) σ^2, so the total power of impulsive noise is [7]:

$$n_p = \frac{\sigma^2}{\lambda} \tag{12}$$

4. IF Estimation Based On Time-Frequency Distribution

Although the Fourier transform is most useful adaptive tool for analysis stationary situations, but it no longer a well-adapted for nonstationary signal because there is no time information after frequency transformation [20, 21].

Frequency modulated (FM) signals are nonstationary signals which their frequency contents are time-varying, so such signals are analysed by time-frequency analysis

only because the FT and correlation methods fails in IF estimation that is represent the important parameters of nonstationary signals [18].

Fourier transform of the instantaneous autocorrelation of the analytic associate of the signal represents a time-frequency distributions (TFD) that is representing the double transform from the time-domain into the time-frequency domain. The short-time Fourier transform (STFT) is the simplest formula of time-frequency distribution (TFD) it is well-known as windowed frequency distribution [16]:

$$\rho_s(t,f) = \int_{-\infty}^{\infty} s(\lambda)h(\lambda - t)e^{-j2\pi f\lambda}d\lambda$$

$$= \underset{\lambda\to f}{\mathrm{FT}}\{s(\lambda)h(\lambda - t)\} \tag{13}$$

where $s(\lambda)$ is the analytic signal, $h(\lambda - t)$ is a time window.

As in [1], [18], [22] and [23] the instantaneous frequency (IF) can be estimated by solving the problem below:

$$\widehat{f_i}\,(t) = \arg[\max_f \rho_z(t\,,f)];\ 0 \le f \le f_s/2 \tag{14}$$

where $z(t)$ is analytic signal as in equation (4). So the TDF uses for nonstationary signals to identify their variation of time, where in the time-frequency distribution denoted by $\rho(t,f)$, the variables t and f are not alternately, but are exist together. The TFD representation is centralized in t and f, so the TFD constant-t cross-section should show the frequency or frequencies exists at time t, and its constant-f cross-section should show the time or times at which frequency f is existing [18].

In this paper, the periodogram is used to estimate the IF of linear and quadratic FM signals.

Periodogram is the square magnitude of STFT ($|STFT|^2$), denoted by $S_s^w(t,f)$ [24]:

$$S_s^w(t,f) = |F_s^w(t,f)|^2$$

$$= |F_{\tau\to f}\{s(\tau)w(\tau-t)\}|^2$$

$$= \left|\int_{-\infty}^{\infty} s(\tau)w(\tau-t)e^{-j2\pi f\tau}d\tau\right|^2 \qquad (15)$$

5. Simulation Results

Simulation results of TFD IF estimation of LFM signals

Linear frequency modulation (LFM) signal is simulated as follows:

$$y(t) = n(t)\sin\left\{j2\pi\left(f_o t + \frac{\alpha}{2}t^2\right)\right\} + \epsilon(t)$$

where $n(t)$ is multiplicative zero-mean noise and $\epsilon(t)$ is additive white Gaussian noise (AWGN) with zero mean, $\alpha = 0.5$ is slope of IF low of the signal.

the simulated signal has total time length $L = 10$s, the sampling interval is $T_s = 0 \cdot 001$s, and the number of samples is given by $N = [L/T_s]$. The signal amplitude is $A = 1$ volt, ω_o is angler frequency $\omega_o = 2\pi f_o$, where $f_o = 23$Hz. First, MN has been modelled as zero-mean Gaussian, then it has been modelled as impulsive processes as per equation (11) and (12) with Poisson parameter $\lambda = 20$. Monte Carlo simulations were performed with $M = 20$ realizations.

Because the multiplicative noise power is affecting both the amplitude and phase of the signal, the signal-to-noise ratio (SNR) in the presence of both AWGN and MN is defined as follows:

$p_{nm} = (p_n + p_m)$, then

$$SNR = \frac{p_x}{p_{nm}} \qquad (16)$$

where p_x being the signal power, p_m being the MN power, and p_n is the additive noise power.

The relative squared-error under each SNR and MN power is calculated as follows:

$$e = |\,((F_O - f_o)/f_o)|^2 \qquad (17)$$

Figures (1)-(3) show IF estimation at mid-time of the LFM signal versus different SNRs for two multiplicative noise models (Gaussian, Impulsive) with MN power $p_m = -3$ dB, 0 dB, and 3 dB, respectively.

Figures (4)-(6) show relative mean-squared error (MSE) of IF estimation at mid-time of the LFM signal versus different SNRs for two multiplicative noise models (Gaussian, Impulsive) with MN power $p_m = -3$ dB, 0 dB, and 3dB, respectively.

Simulation results of TFD IF estimation of QFM signals

Quadratic frequency modulation (QFM) signal has also been simulated as follows:

$$y(t) = n(t)\sin\left\{j2\pi\left(f_o t + \frac{\alpha}{2}t^2 + \frac{\beta}{3}t^3\right)\right\} + \epsilon(t)$$

where $n(t)$ is multiplicative zero-mean noise (MN), and $\epsilon(t)$ is additive white Gaussian zero-mean noise; with QFM parameters α=3 and $\beta = -0.5$. Monte Carlo simulations were performed with $M = 20$ realizations.

Figures (7)-(9) show IF estimation at mid-time of QFM signal versus different SNRs for two multiplicative noise models (Gaussian, Impulsive) with MN power $p_m = -3$ dB , 0 dB, and 3 dB, respectively.

Figures (10)-(12) show MSE of IF estimation at mid-time of QFM signal versus different SNRs for two multiplicative noise models (Gaussian, Impulsive) with MN power $p_m = -3$ dB , 0 dB, and 3 dB, respectively

From these figures it can be seen that IF estimation for LFM and QFM signals based on TFD for the case of Impulsive MN model gives reasonable results under MN up to MN power of 0 dB more than for the case of Gaussian MN model. For MN power less than 0 dB there is little difference between effect of two models, while at high MN power more than 0 dB especially at 3 dB the estimation algorithm holds in case of impulsive noise.

Figures (13)-(14) show IF estimation at mid-time of QFM signal versus different SNRs for two multiplicative noise models (Gaussian, Impulsive) with MN power $p_m = 3$ dB and $\lambda = 30,10$ respectively.

Figures (15)-(16) show MSE of IF estimation at mid-time of QFM signal versus different SNRs for two multiplicative noise models (Gaussian, Impulsive) with MN power $p_m = 3$ dB and $\lambda = 30,10$ respectively.

Figures (13)-(16) show the effect of Poisson parameter (λ) on IF estimation method based on TFDs, where the IF estimation method produced more accurate results at high value of λ (low arrival rate).

6. Conclusions

This paper presented a study on the performance of instantaneous frequency (IF) estimation of linear frequency-modulated (LFM) and quadratic FM (QFM) signals using time-frequency analysis (specifically periodogram) by considering two models for multiplicative noise (MN): Gaussian, and Impulsive. Although the two considered MN models are not correlated, the MSE of estimated instantaneous frequency in case of impulsive noise (at high value of average impulse rate) is lower than the MSE in case of Gaussian noise at multiplicative noise power = 3 dB.

الخلاصة

تم تحليل أداء تخمين التردد الاني للموجات المضمنة ترددديا تحت تاثير نوعين من الضوضاء الضربي (الكوسي والنبضي) باستخدام توزيع الزمن-التردد. بينت نتائج المحاكاة بان للضوضاء النبضي اقل تاثير مدمر للإشارة مقارنة بالضوضاء الكوسي عند قدرة اقل من 3 ديسي بيل ولكن بصورة عامة فان طريقة التخمين المستخدمة في هذا العمل (periodogram) تفشل عندما تكون قيمة الضوضاء الضربي اعلى من 3 ديسي بيل لكلا النوعين من الضوضاء (الكوسي والنبضي).

References

[1] Z. M. Hussain and B. Boashash, “Adaptive Instantaneous Frequency Estimation of Multicomponent FM Signals Using Quadratic Time–Frequency Distributions,” IEEE Transactions on Signal Processing, vol. 50, no. 8, 2002.

[2] B. Boashash, “Estimating and Interpreting the Instantaneous Frequency of A Signal. I. Fundamentals,” Proceedings of the IEEE, vol. 80, no. 4, pp. 520–538, 1992.

[3] B. Boashash, “Estimating and Interpreting the Instantaneous Frequency of a signal. II. Algorithms and applications,” Proceedings of the IEEE, vol. 80, no. 4, pp. 540–568, 1992.

[4] D. König and J. F. Böhme, “Wigner-Ville Spectral Analysis of Automotive Signals Captured at Knock,” Applied Signal Processing, 1996.

[5] L. Cohen, Time-frequency analysis, Prentice-Hall, 1995.

[6] V. P. Tuzlukov, Signal Processing Noise, CRC Press LLC, 2002.

[7] K. S. Al-Mawali, F. S. Al-Qahtani, and Z. M. Hussain, “Adaptive Power Loading for OFDM-Based Power Line Communications Impaired by Impulsive Noise,” Proceedings of the IEEE International Symposium on Power Line Communications and Its Applications (ISPLC’ 10), 2010.

[8] S. Ghadimi, J. Hussian, T. S. Sidhu, Serguei Primak, “Effect of Impulse Noise on Wireless Relay Channel,” Scientific Research, 2012.

[9] K. S. Al-Mawali, Techniques for Broadband Power Line Communications: Impulsive Noise Mitigation and Adaptive Modulation, PhD. Thesis, RMIT University, 2011.

[10] J. Lin, “Impulsive Noise Mitigation in Powerline Communications Using Sparse Bayesian Learning,” IEEE, 2013.

[11] Y. R. Gurubelli, S. Koneti, U. Bollampalli, S. Kolloju, “Robust Frequency Estimation of Sampled Sinusoidal Signals With Impulsive Noise,” Fifth International Conference on Intelligent Systems, Modelling and Simulation, IEEE, 2014.

[12] M. A. Altinkaya, H. Deliç, B. Sankur, E. Anarim, “Subspace-Based Frequency Estimation of Sinusoid Signals in Alpha-Stable Noise,” Elsevier Science, 2002.

[13] Y. Liu, Y. Tie, S. Na and S. Tan, “Carrier Frequency Estimation with Cyclostationary Signals in Impulsive Noise,” International Journal of Signal Processing, Image Processing and Pattern Recognition, vol. 9, no. 6, pp. 89-102, 2016.

[14] Z. G. Zhang, “Recursive Parametric Frequency/Spectrum Estimation for Nonstationary Signals with Impulsive Components Using Variable Forgetting Factor,” IEEE Transactions on Instrumentation and Measurement, vol. 62, no. 12, December 2013.

[15] B. Boashash, P. O'Shea and M. J. Arnold, “Algorithms for instantaneous frequency estimation: a comparative study,” Proc. SPIE, 1990.

[16] Z. M. Hussain, A. Z. Sadik, and P. O’Shea, Digital Signal Processing: An Introduction with MATLAB and Applications, Springer, 2011.

[17] N. Linh-Trung, Estimation and Separation of Linear Frequency-Modulated Signals in Wireless Communications using Time-Frequency Signal Processing, PhD. Thesis, Queensland University of technology, Australia, 2004.

[18] B. Boashash, Ed., Time Frequency Signal Analysis and Processing: A comprehensive Reference, Elsevier, 2016.

[19] R. V. Hogg and A. T. Craig, Introduction to Mathmatical Statistics, Macmillan Publishing Co., Inc.,1978.

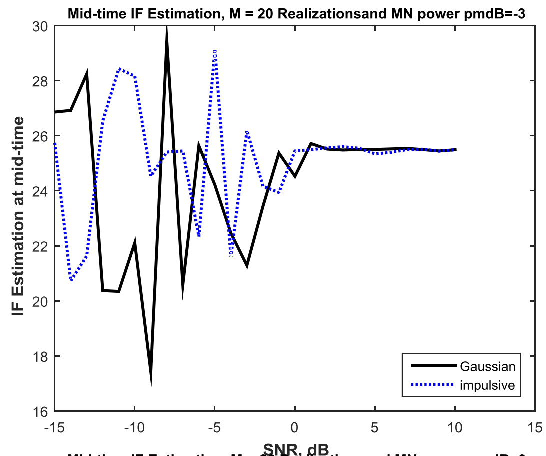
[20] B. Torresani, “Time-Frequency and Time-Scale Analysis,” Signal Processing for Multimedia, IOS Press, 1999.

[21] P. Flandrin, Time-Frequency/Time-Scale Analysis, San Diego: Academic Press, 1999.

[22] Z. M. Hussain and B. Boashash, “Adaptive Instantaneous Frequency Estimation of Multi-Component FM Signals” IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP' 2000), 2000.

[23] Z. M. Hussain and B. Boashash, “Design of Time-Frequency Distributions for Amplitude and IF Estimation of Multicomponent Signals,” invited paper, International Symposium on Signal Processing and Its Applications (ISSPA'2001), vol. 1, pp. 339-342, Aug. 2001.

[24] F. Hlawatsch and G.F. Boudreaux-Bartels, “Linear and Quadratic Time-frequency Signal Representations,” IEEE Signal Processing Magazine, vol. 9, no. 2, pp. 21-67, April 1992.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IF Estimation at mid-time
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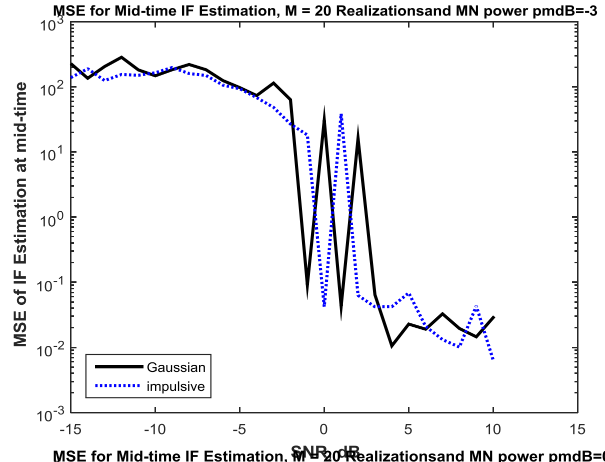
Gaussian
impulsive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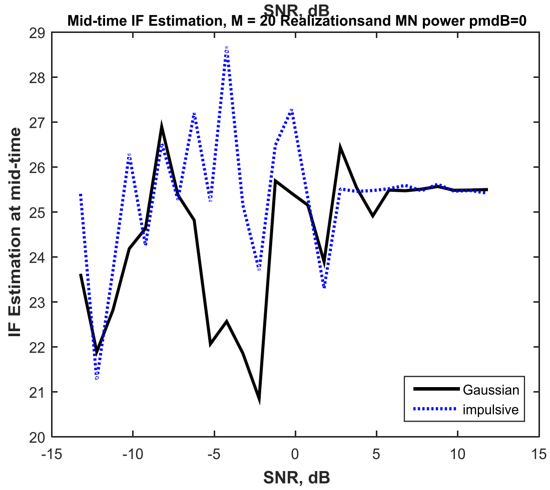
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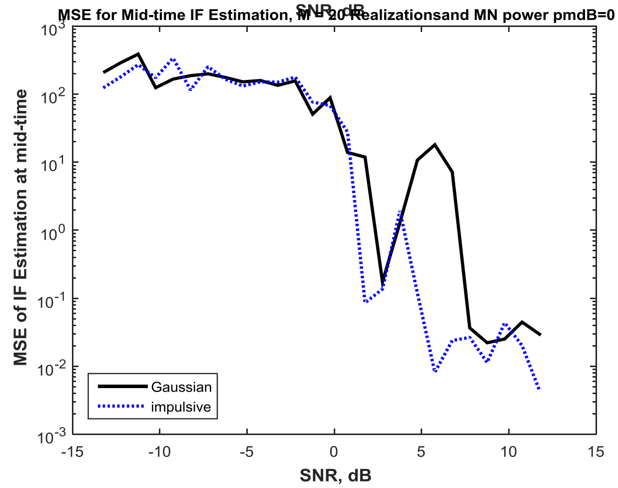
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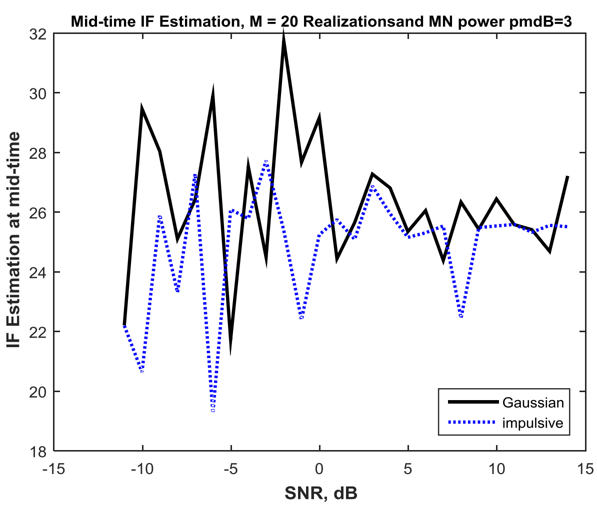
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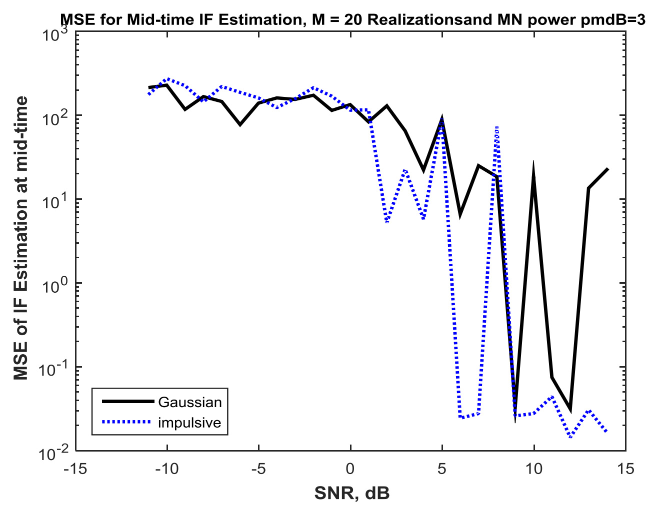
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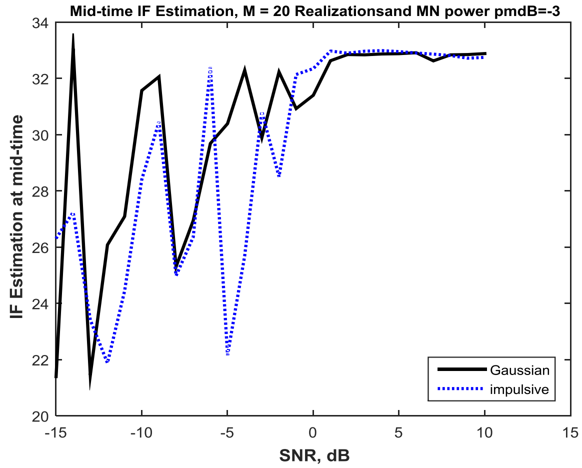
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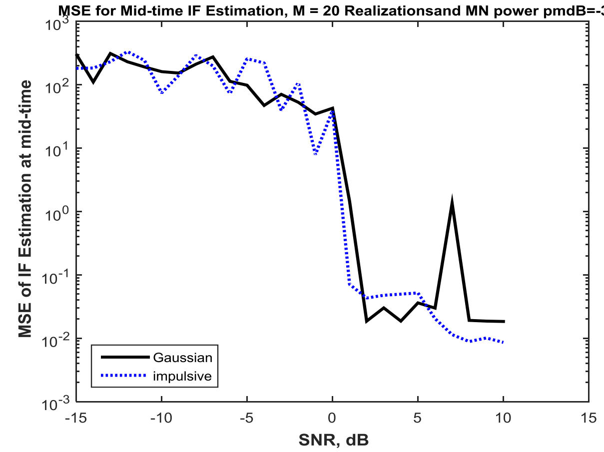
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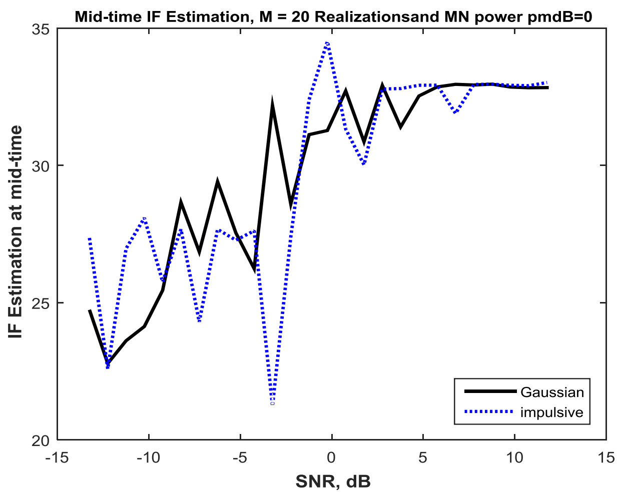
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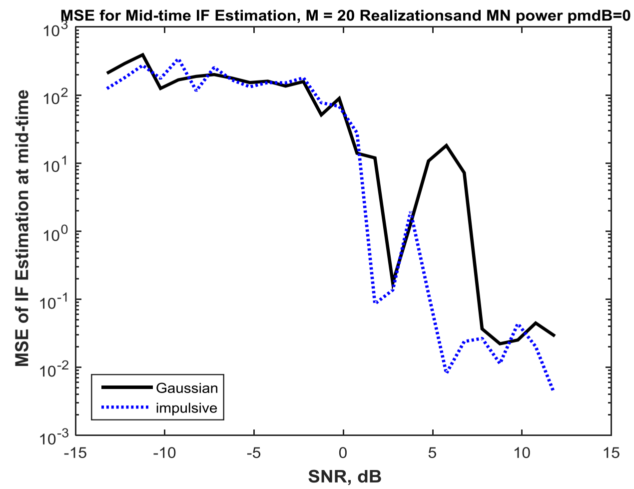
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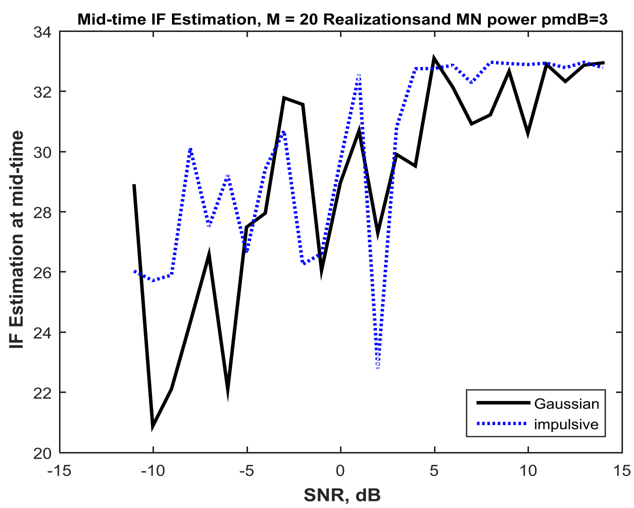
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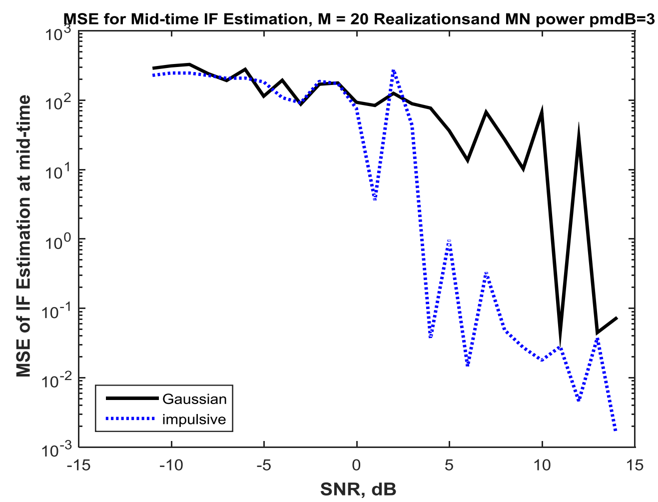
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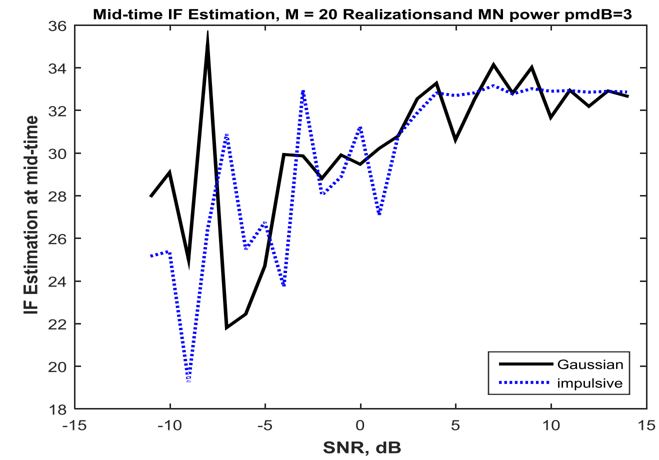
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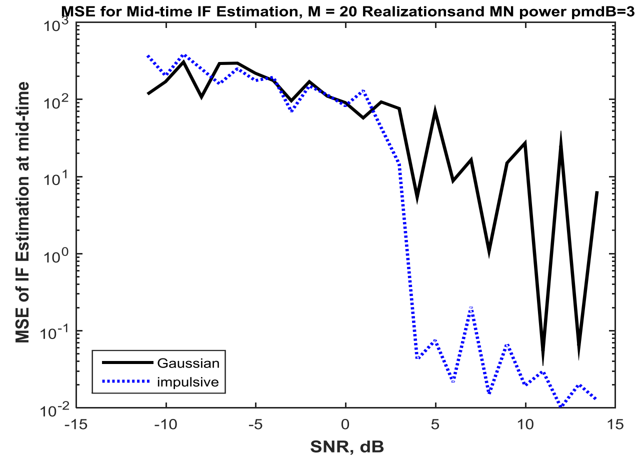
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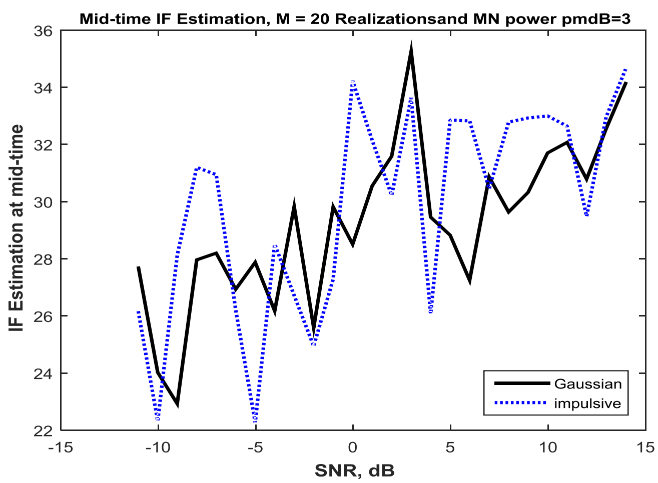
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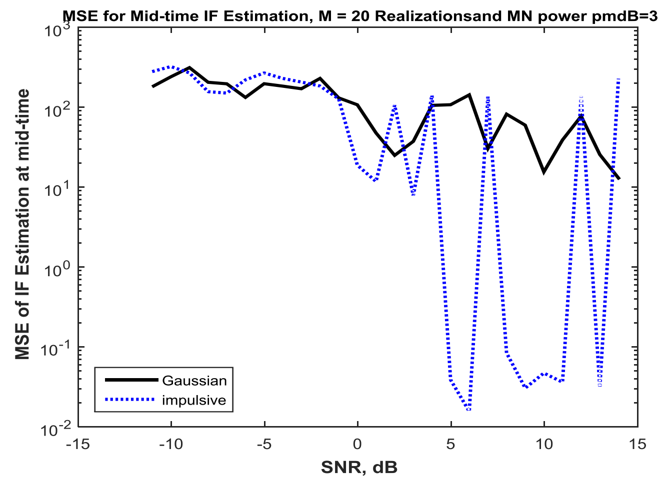
MSE for Mid-time IF Estimation, M = 20 Realizationsand MN power pmdB=3
MSE of IF Estimation at mid-time
SNR, dB
Gaussian
impulsive