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Performance Analysis of MF Receiver: Review

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ABSTRACT: The paper concentrates on the review of performance analysis of Matched Filter based receiver (MF Receiver). MF receivers are designed to achieve reliability at physical layer of TCP/IP model. The matched filter is the optimal linear filter commonly used in RADAR, in which a signal is sent out, and we measure the reflected signals, looking for something similar to what was sent out. Matched filters are for maximizing the signal to noise ratio (SNR) in the presence of additive stochastic noise. Two-dimensional matched filters are commonly used in image processing, e.g., to improve SNR for X-ray pictures. The literature review is carried from some of the journals.

KEYWORDS: MF Receiver, TCP/IP, RADAR, SNR

I. INTRODUCTION

In digital signal processing, a matched filter is obtained by correlating a known signal with an unknown signal to detect the presence of the pattern in the unknown signal. This is equivalent to convolving the unknown signal with a conjugated time-reversed version of the pattern of known signal. The matched filter is the optimal linear filter for maximizing the signal-to-noise ratio (SNR) in the presence of additive noise [23].

Matched filters are commonly used in radar, in which a known signal is sent out, and the reflected signal is examined for common elements of the out-going signal. Pulse compression is an example of matched filtering. It is so called because impulse response is matched to input pulse signals. Matched filtering is a demodulation technique with LTI (linear time invariant) filters to maximize SNR [23]. A general representation for a matched filter is illustrated in Fig. 1

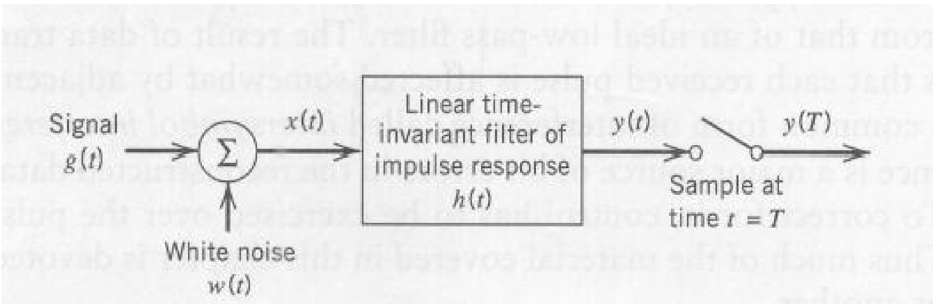

Fig. 1 Matched filter [24]

The filter input x(t) consists of a pulse signal g(t) corrupted by additive channel noise w(t), as shown by

$$x(t) = g(t) + w(t) \qquad 0 \le t \le T \qquad \text{eq.(1)}$$

where T is an arbitrary observation interval. The pulse signal g(t) may represent a binary symbol 1 or 0 in a digital communication system.

The w(t) is the sample function of a white noise process of zero mean and power spectral density No/2. The source of uncertainty lies in the noise w(t). The function of the receiver is to detect the pulse signal g(t) in an optimum manner, given the received signal x(t). To satisfy this requirement, we have to optimize the design of the filter so as to minimize the effects of noise at the filter output in some statistical sense, and thereby enhance the detection of the pulse signal g(t). Since the filter is linear, the resulting output y(t) may be expressed as

$$y(t) = g_o(t) + n(t) \qquad \text{eq.(2)}$$

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where $g_o(t)$ and n(t) are produced by the signal and noise components of the input x(t), respectively.

A simple way of describing the requirement that the output signal component $g_o(t)$ be considerably greater than the output noise component n(t) is to have the filter make the instantaneous power in the output signal $g_o(t)$, measured at time t = T, as large as possible compared with the average power of the output noise n(t). This is equivalent to maximizing the peak pulse signal-to-noise ratio, defined as

$$\eta = \frac{|g_o(T)|^2}{E[n^2(t)]} \quad \text{eq. (3)}$$

The impulse response of the matched filter (white-noise case) is simply the known signal wave shape that is "played backward" and translated by an amount to. Thus, the filter is said to be "matched" to the signal [23].

Consider a binary PCM system based on polar non return-to-zero (NRZ) signalling. Symbols 1 and 0 are represented by positive and negative rectangular pulses of equal amplitude and equal duration. The channel noise is modelled as additive white Gaussian noise w(t) of zero mean and power spectral density $N_O/2$; the Gaussian assumption is needed for later calculations. In the signalling interval $0 < t < T_b$ the received signal written as:

$$x(t) = \begin{cases} +A + w(t) & \text{symbol 1 was sent} \\ -A + w(t) & \text{symbol 0 was sent} \end{cases} \quad \text{eq. (4)}$$

where, Tb is the bit duration, and A is the transmitted pulse amplitude. The receiver has acquired knowledge of the starting and ending times of each transmitted pulse; Given the noisy signal x(t), the receiver is required to make a decision in each signalling interval as to whether the transmitted symbol is a 1 or a 0. The structure of the receiver used to perform this decision-making process is shown in Fig. 2.

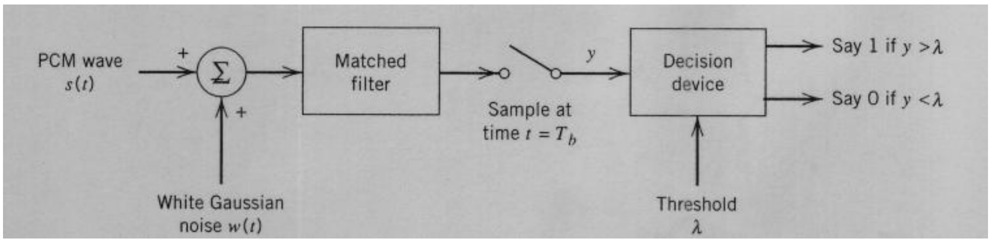

Fig. 2 Receiver for baseband transmission of binary-encoded PCM wave using polar NRZ signalling [24].

It consists of a matched filter followed by a sampler, and then finally a decision device. The filter is matched to a rectangular pulse of amplitude A and duration Tb, exploiting the bit-timing information available to the receiver. The resulting matched filter output is sampled at the end of each signalling interval. The presence of channel noise w(t) adds randomness to the matched filter output. The sample value y is compared to a preset threshold A in the decision device. If the threshold is exceeded, the receiver makes a decision in favour of symbol 1; if not, a decision is made in favour of symbol 0 [23].

There are two possible kinds of error to be considered:

1. Symbol 1 is chosen when a 0 was actually transmitted; we refer to this error as an error of the first kind.
2. Symbol 0 is chosen when a 1 was actually transmitted; we refer to this error as an error of the second kind.

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Overcome the practical difficulties encountered with the ideal Nyquist channel by extending the bandwidth from the minimum value $W = R_b/2$ to an adjustable value between W and 2W. A particular form of P(f) that embodies many desirable features is provided by a raised cosine spectrum. This frequency response consists of a flat portion and a roll off portion that has a sinusoidal form. The frequency response P(f), normalized by multiplying it by 2W, is plotted in Fig. 3 for three values of a, namely, 0, 0.5, and 1.

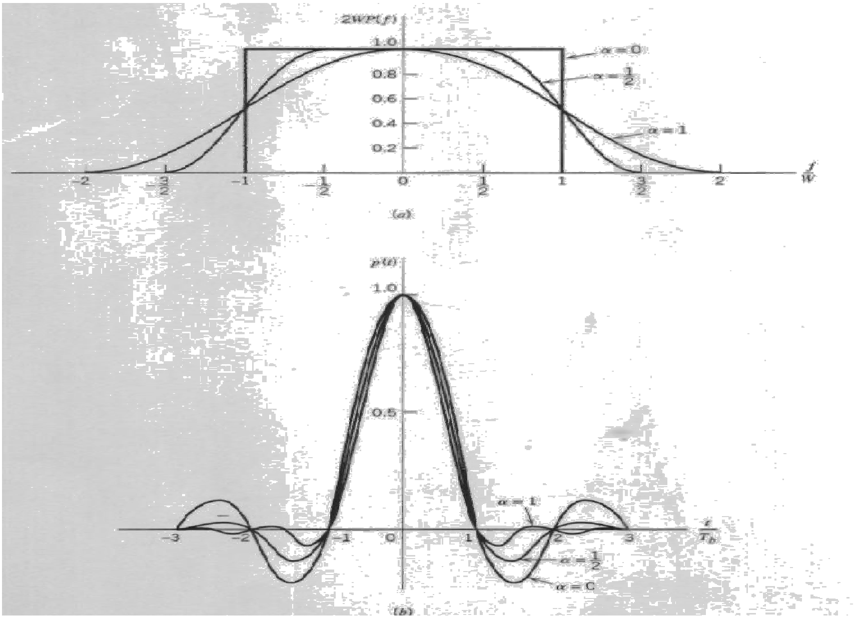

Fig. 3 Responses for different roll-off factors. (a) Frequency response. (b) Time response [24].

II. LITERATURE REVIEW

The need and necessities of communication systems are expanding day by day. System reliability is an important user requirement, and, *BER* is one of the important QoS measure at the physical layer of TCP/IP model [1][2][3]. Matched filter based receiver (MF receiver) are designed to achieve reliability at physical layer of TCP/IP model. Signal detection in this receiver is based on the use of threshold which is logarithmic function of input signal parameters, r_0 and r_1 [4].

$$\lambda_{opt} = \frac{N_o}{4AT_b} \ln \frac{r_0}{r_1} \quad \text{eq. (5)}$$

The subscript *opt* in Eq. (5) indicates that this threshold is optimal provided parameters N_o, A, T_b, r_0, r_1 are known at the receiver. Usually, at the receiver, N_o, A, T_b are known and r_0 and r_1 are assumed as 0.5. This leads to $\lambda = 0$. But, in many practical situations, such as transmission of sound and image signals through AWGN channel, $r_0 \neq r_1$, resulting in $\lambda \neq 0$. If that is the case, there would be performance deviation of MF receiver under these two cases. (i) When $\lambda^{0.5,0.5} = 0$ is used for evaluating *BER* at the receiver output, and, (ii) when λ^{r_0,r_1} is used for evaluating *BER* at the receiver output. Here $\lambda^{0.5,0.5}$ is the threshold derived by assuming $r_0 = r_1 = 0.5$ and λ^{r_0,r_1} is the practically derived threshold by calculating r_0, r_1 from within binary stream of given length. Further the corresponding *BER* are labelled as $BER^{0.5,0.5}$ and BER^{r_0,r_1}. The simulation analysis study is carried out using MATLAB 7.6.0.324 (R2008a). For different considered signals, various results are plotted in the form of percentage *BER* deviation vs. *SNR* curves.

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The detailed literature review can be explained with the help of following papers:-

Harjot Kaur, Bindiya Jain & Amit Verma [4], In digital communication system design, the main objective is to receive data as similar as the data sent from the transmitter. It is important to analyse the system in term of probability of error to view the system's performance. Each modulation technique has different performance while dealing with signals, which normally are affected with noise. General explanation for probability of error is explained and simulated in this paper. They focused on comparative performance analysis of basic M-ary PSK modulation schemes like BPSK, QPSK and 8-PSK. To better understand the M-ary PSK system, a Simulink-based simulation system is designed for M-ary PSK for M=2, 4 and 8 using communication toolbox in Simulink. This paper indicates that increasing of M results in increase of BER. Error rates of M-ary PSK system versus the signal-to-noise ratio (SNR) are used to evaluate the performance of M-ary PSK system. The BER curves for MPSK obtained after simulation are compared with theoretical curves [4].

G Tharakanatha, Mahaboob Kamal Basha, Vijay Bhaskar Chanda & I Hemalatha [5], presents the theoretical background of digital modulation and evaluate the performance of BPSK system with respect to Bit error Rate and finally implement Binary Phase shift Keying modulation technique in MATLAB. The main objective of any communication system is to receive the transmitted data accurately. There are lot digital modulation techniques that are well flourished in the communications field, selection of a suitable modulation technique for an application depends on many factors like Bit error rate, data rate, design complexity etc., one of the modulation techniques that is used in many areas of applications is the BPSK modulation. It is widely used due to its low BER and simplicity in design when compared to other modulation techniques [5].

Vikas Chauhan, Manoj Arora and R S Chauhan [6], deals with PSK based modulation under various channel & fading environment. Subsequently, a comparison study is carried out to obtain BER performance for each modulation. They found BER for QPSK & BPSK is similar and they give lowest BER under multipath fading environment. Nonetheless, GMSK's BER is just slightly higher than BPSK & QPSK [6].

K Pahlavan & J. W. Matthews [7], have published a paper on Performance of adaptive matched filter receivers over fading multipath channels. The objective of their paper is to present a unified discrete channel model from the information source up to the sampler was developed for fading multipath channels. Different methods for adaptive channel measurement were studied. The performance of a discrete matched filter using different adaptation techniques and working over a troposcatter channel is predicted. They showed that the effects of channel measurement noise are less damaging for the decision-directed adaptation technique as compared to any kind of reference-directed adaptation [7].

V.P Kaasila and A. Mammela [8], presented a paper on Bit error probability of a matched filter in a Rayleigh fading multipath channel in the presence of interpath and intersymbol interference. The objective of their paper is to presents the exact bit error probability of a matched filter receiver in a known discrete Rayleigh fading multipath channel is determined for a binary antipodal system. The matched filter receiver or the RAKE is one form of a diversity receiver. Traditionally, both the interpath interference (IPI) and the intersymbol interference (ISI) caused by the non-ideal autocorrelation function of the bit waveform are neglected in the analysis of the RAKE. Previously, the exact matched filter bounds; which include IPI, were derived. This bound gives the performance of the matched filter if only one symbol is transmitted. In our analysis, a symbol sequence is transmitted instead of only one symbol. Thus, our analysis includes both IPI and ISI as well as the correlation between the paths, the analysis permits direct comparisons between different kinds of bit waveforms [8].

V.P. Kaasila and A. Mammela [9], published a paper on Bit error probability of a matched filter in a Rayleigh fading multipath channel. The objective of paper is to presents the exact matched filter bound for an L-path Rayleigh fading channel is determined. The result is used to study the effect of interpath interference. The numerical analysis shows that the loss in the signal-to-noise ratio due to the interpath interference depends on the selected waveform [9].

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T. Matsumoto, S. Matsufuji [10], focused on BER performance of M-ary/ASK-SS system using compact matched filter bank for optical ZCZ code. The objective of paper is to presents the optical ZCZ code, which is a set of pairs of binary and bi-phase sequences with zero correlation zone, can provide code division multiple access (CDMA) communication system without co-channel interference. And M-ary amplitude shift keying spread spectrum (M-ary/ASK-SS) system using this code can detect a desired sequence without interference of undesired sequences. We proposed the compact construction of a bank of matched filters for this code, which is called tree-type bank of matched filters. However, M-ary/ASK-SS system using this filters might go down the bit error rate (BER) performance because input-output characteristics of this filters for zero correlation zone 4n - 2 is nonlinear characteristics. In this paper, we clarify that BER performance in ASK-SS and M-ary/ASK-SS system under the additive white Gaussian noise (AWGN) and the frequency nonselective fading environments are not influenced by nonlinear characteristics of these filters by the computer simulation. The BER performance of ASK-SS system using tree-type bank of matched filters under the AWGN and frequency nonselective fading environments go down compared to BER performance of parallel-type filters as expected. But the BER performance of M-ary/ASK-SS system using this compact filters under the AWGN and frequency nonselective fading environment are almost equal compared to BER performance of parallel-type filters. In fact, the BER performances in M-ary/ ASK-SS are not influenced by nonlinear characteristics of tree-type bank of matched filters [10].

Tan Peng and N.C.Beaulieu [11], presents Accurate BER Performance Comparison of Frequency Domain and Time Domain π/4-DQPSK OFDM Systems. The objective of paper is to presents an exact closed-form bit error rate (BER) expression is derived for an orthogonal frequency-division multiplexing system with π/4-shifted differentially encoded quadrature phase shift keying (π/4-DQPSK) in the presence of carrier frequency offset over frequency-selective fast Rayleigh fading channels. Different system configurations, including time domain differential modulation, frequency domain differential modulation, single channel reception, and multi-channel reception with maximal ratio combining, are considered in the exact BER analysis. For a small number of subcarriers, the BER expression can be calculated directly. A Monte Carlo method is designed to evaluate the BER for a large number of subcarriers. The analytical expression can be used to investigate the effect of several channel parameters, including mean delay spread and maximum Doppler spread, on the system BER performance. Particularly, the effect of carrier frequency offset on the system performance, and the differences and opportunities to use frequency domain differential modulation or time domain differential modulation, can be studied in a quantitative way for a more realistic wireless channel environment model [11].

L. E. Miller and J. S. Lee [12], presented BER expressions for differentially detected π/4 DQPSK modulation. The objective of paper is to presents closed form bit-error rate (BER) expressions for differentially detected π/4-shifted differentially encoded quadrature phase-shift keying (QPSK) modulation (π/4 DQPSK) are derived for both additive white Gaussian noise (AWGN) and Rayleigh-fading channels. The derivations are carried out in an exact and most general manner in that in-phase (I) and quadrature (Q) channel bit-error probabilities P_{cl} and P_{co} are separately obtained in terms of the same-quadrature and cross-quadrature noise Correlation functions, including a measure of noise nonstationarity. We then specialize the general expressions for uncorrelated noise and equal noise powers in successive symbol periods to obtain a useful bit-error probability expression for the AWGN channel in the form $P_e \approx Q(\sqrt{(1.1716 \cdot E_b/N_0)})$ where $Q(\cdot)$ is the Gaussian distribution Q-function and E_b/N_0 is the bit energy-to-noise density ratio. Exact BER expressions for the Rayleigh-fading channel that involve the noise parameters are also given and are extended to the case of L-fold diversity combining [12].

J. Proakis [13], presents a paper on the probability of error for multichannel reception of binary signals. In this paper a derivation of the probability of error which arises in
1) adaptive multichannel reception of binary signals and
2) multichannel communication with binary signaling over channels that are characterized by both a specular (nonfading or constant) component and a Rayleigh fading component is presented [13].

T. Matsumoto, S. Matsufuji [14], explained Theoretical analysis of BER performance in ASK-SS and M-ary/ASK-SS systems using compact matched filter bank for an optical ZCZ code over AWGN channels. The objective of paper is to

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presents the optical ZCZ code, which is a set of pairs of binary and diphase sequences with zero correlation zone, can provide code division multiple access (CDMA) communication system without co-channel interference. The M-ary amplitude shift keying spread spectrum (M-ary/ASK-SS) system using this code can detect a desired sequence without interference of undesired sequences. We have proposed the compact construction of a matched filter bank for this code, which is called the compact-type matched filter bank. However, M-ary/ASK-SS system using this filter bank might go down the bit error rate (BER) performance because input-output characteristics of this filter bank for this code with zero correlation zone 4n - 2 are nonlinear characteristics. In this paper, we clarify that BER performance in the M-ary/ASK-SS system over the additive white Gaussian noise (AWGN) channels is not influenced by nonlinear characteristics of this filter bank by the theoretical formula of BER characteristics and the computer simulation. The BER performance in the ASK-SS system using compact-type matched filter under the AWGN environment go down compared to that using direct-type matched filter as expected. But the BER performance in the M-ary/ASK-SS system using this compact-type matched filter bank under the AWGN environment is almost equal compared to that using parallel-type matched filter bank. In fact, this compact-type matched filter bank is effective in the M-ary/ASK-SS system [14].

R. Price [15], published paper on Error probabilities for adaptive multichannel reception of binary signals. In this paper a description and performance are given for two slightly different forms of an adaptive receiver that is used with binary signaling in a multichannel communication system. Each channel has a non-dispersive, nonfading propagation path and additive white Gaussian noise that is independent of, and equal in intensity to, the other channel noises. Either phase-independent orthogonal signaling (such as FSK) or phase-reversal-comparison signaling is employed to convey to the receiver both the message and information about the path strengths and phases. The receiver measures the path parameters and applies the results to the detection processing as though they were perfectly accurate; it is shown that this procedure is a natural extension of non-adaptive reception. Results are given without derivation for the probability of binary decision error, which depends on the type of signaling, the ratio of the total noise-exclusive signaling energy received to the noise intensity, the number of channels, and the ratio of the effective measurement time to the binary signal duration. The distribution of the received signaling energy among the channels is immaterial. Graphs of error probability are presented for selected system parameters. A novel by-product of the study is an error-probability expression for non-adaptive multichannel reception of quite general binary signaling. Optimal adjustment of the adaptive receiver for fading-path situations is also considered, but corresponding error probabilities have not yet been derived [15].

C. W. Helstrom [16], presented paper on The resolution of signals in white, Gaussian noise. The objective of paper is to presents the resolution of two signals of known shapes F1(t) and F2(t) in white Gaussian noise is treated as a problem in statistical decision theory. The observer must decide which of the signals is present with a minimum probability of error. The optimum system for this decision is specified in terms of filters matched to the two signals, the outputs of which are compared. The error probability is exhibited as a function of the cross-correlation of the two signals and of the signal-to-noise ratio. If the phases of the two signals are unknown, as in radar, and if the signals are of equal strength and equal a priori probability, the optimum system consists of filters matched to each of the signals, each followed by a detector. The observer then bases his decision upon which of the detectors has the larger output. The probability of error is computed for this case also [16].

R. VanBlerkom, R. E. Sears and D. G. Freeman [17], presented paper on Analysis and Simulation of a Digital Matched Filter Receiver of Pseudo-Noise Signals. This paper discusses the performance of a digital matched filter receiver matched to a diphase-modulated signal in a clutter environment consisting of other diphase-modulated signals. Analytic results for a white-Gaussian model and for a non-linear capture model are compared with simulation results obtained from an IBM 7094 computer. The white-Gaussian model is in general agreement with the simulation results for equal power clutter signals; the capture model and the simulator yield similar results when a dominant clutter source is present [17].

Md. Emdadul Haque, Md. Golam Rashed & M. Hasnat Kabir [18], gives A Comprehensive study and performance comparison of M-ary modulation schemes for an efficient wireless mobile communication system. The objective of

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paper is to presents Wireless communications has become one of the fastest growing areas in our modern life and creates enormous impact on nearly every feature of our daily life. In this paper, the performance of M-ary modulations schemes (MPSK, MQAM, MFSK) based wireless communication system on audio signal transmission over Additive Gaussian Noise (AWGN) channel are analysed in terms of bit error probability as a function of SNR. Based on the results obtained in the present study, MPSK and MQAM are showing better performance for lower modulation order whereas these are inferior with higher M. The BER value is smaller in MFSK for higher M, but it is worse due to the distortion in the reproduce signal at the receiver end. The lossless reproduction of recorded voice signal can be achieved at the receiver end with a lower modulation order [18].

Deepali, Y Kirange and Kalyani N Neve [19], explained Wireless communication: the comparative study between broadcasting, satellite communication and cellular service. The objective of paper is to presents Wireless communication is essentially the transmission of information between two points without using wires. Wireless data services and systems represent a rapidly growing and increasingly important segment of the communications industry. Wireless communications are ubiquitous in the modern society. In this paper we will discuss the importance of the types of wireless communication. And our discussion will focused on three popular types: 1) broadcasting 2) satellite 3) cellular service. We are going to highlight the advantages of each individual system and factors that affect to these types of wireless communication and application of each system [19].

A.Z. Sha'ameri [20], presented paper on Bit-error rate performance analysis of spectrum based detector for FSK digital modulation. This paper discusses FSK is widely used digital modulation technique due to its simplicity in implementation using non coherent detection. Further availability of digital signal processing algorithms such as the FFT (fast Fourier transform) and necessary supporting technology makes it possible to implement spectrum based detector for FSK. This paper formulates the BER (bit-error rate) performance of the spectrum based detector. Generally, the performance lies between the optimum that is the coherent detector and the suboptimum that is the non coherent detector. Verification was performed by computer simulation to confirm the results [20].

K. Pahlavan and J.W Matthews [21], showed Performance of adaptive matched filter receivers over fading multipath channels. This paper discusses a unified discrete channel model from the information source up to the sampler was developed for fading multipath channels. Different methods for adaptive channel measurement were studied. The performance of a discrete matched filter using different adaptation techniques and working over a troposcatter channel is predicted. It is shown that the effects of channel measurement noise are less damaging for the decision-directed adaptation technique as compared to any kind of reference-directed adaptation [21].

III. CONCLUSION AND FUTURE WORK

This research paper is a literature survey carried out in the performance analysis of Matched Filter receiver under different modulation scheme and inputs. Also we have discussed MF receiver applications in RADAR, X-Ray pictures, mobile and wireless communication systems. Matched filter based receivers (MF receivers) are widely used in communication systems for the purpose of efficient signal recovery. The conventional MF receiver is based on the use of single threshold whose selection is crucial for the efficient detection of bits, at the receiver. It was shown that threshold (λ_{opt}), as given by expression eq. (5), is optimal for the case when bits are modulated by polar NRZ signalling, and, transmitted through AWGN channel. We can consider different types of input signals under different modulation scheme and compare their MF receiver performance.

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BIOGRAPHY

Bimla Pandey is an Assistant Professor in the Electronics and Communication Department, IIMT College of Engineering, Abdul Kalam Techincal University. She received Master of Technology (M.Tech) in Digital Communication degree in 2015 from MIET, Meerut (U.P), and India. Her specialised branch and research interests is Digital Communication.