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FAST DISCRIMINATION OF UPPER AND LOWER SIDEBAND SIGNALS

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Abstract

Some recognition algorithms for analogue modulation types - AM, FM, DSB, and SSB - have been recently developed. In such algorithms, the LSB and USB are considered as one type (SSB). In this paper two fast algorithms for the discrimination between LSB and USB signals are presented. The first algorithm is based on the spectrum symmetry of the complex envelope of the signal. In the second algorithm, two new signal parameters used to derived the key features are presented. The developed algorithms require less computer storage, and they can be implemented at extremely low cost. Furthermore, they require short segment duration and hence they can be used for on line analysis. The performance evaluation of the developed algorithms were derived from 400 realizations for each of LSB and USB signals. It is found that the discrimination with 100% success rate is achieved at 0 dB SNR.

Key Words

Modulation recognition, Single sideband discrimination, Upper sideband, Lower sideband, Complex envelope.

1. Introduction

Modulation recognition [1-5] brings together many aspects of communication theory such as signal detection, parameter estimation, channel identification and tracking. Modulation recognition environments may vary from no significant noise in the best circumstance to very noisy with interference, and fading. However, any surveillance system in communication intelligence application consists of three main blocks: receiver front-end (frequency down converter and energy detector), modulation recogniser (demodulation, feature extraction and

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modulation classification) and output stage (information extraction, recording and exploitations). Once the modulation type is determined by the modulation recognizer all the functions at the output stage are straightforward classical functions. The key functional block in the surveillance system is the modulation recogniser, since any recognition errors cause partial or complete loss of information.

The following is an overview of the more recently published modulation recognizers those concerned with the analogue modulations. In some recognisers [1-3], LSB and USB signals are recognized as SSB signals and no further discrimination is provided. **Fabrizi et al.** [1] suggested a modulation recogniser for analogue modulations. This recogniser is used to discriminate between some types of analogue modulation - CW, AM, FM, and SSB. In this recogniser it is claimed that the discrimination between the aforementioned modulation types could be achieved at SNR > 35 dB. **Chan and Gadbois** [2] proposed a modulation recogniser based on the envelope characteristics of the intercepted signal. The modulation types that can be classified by this recogniser are AM, DSB, SSB, FM, and CW. In [2], it is claimed that at SNR of 7 dB, the probability of correct modulation recognition is 100% for FM signals, 90.5% for AM signals, 80.0% for SSB signals and 94.0% for DSB signals. **Nagy** [3] proposed a modulation recogniser for analogue radio signals only. The modulation types that can be classified by this recognizer are AM, DSB, SSB, FM and CW. In [3], it is claimed that the different modulation types have been classified with success rate 90.0% at SNR = 15 dB. However, in [1-3] nothing is mentioned about the recognition of the LSB and USB signals.

The discrimination between the LSB and USB signals is discussed in [4] and [5]. **Nandi and Azzouz** [4] proposed a modulation recogniser for analogue modulated signals. This recogniser utilises four key features, extracted by using conventional signal processing methods, and is able in real time to discriminate among AM, DSB, VSB, LSB, USB, FM, and Combined modulated signals with success rate >90% at 10 dB SNR. The simulation results were derived from 400 short realizations (1.707 msec.) for each of the considered modulation types. **Al-Jalili** [5] proposed a discriminator between USB and LSB signals. This discriminator is based on the fact that the instantaneous frequency of USB signal has more -ve frequency spikes than +ve ones, and vise versa for LSB signal. The key feature used is the ratio, G, of the number of -ve spikes to the number of the +ve ones of the instantaneous frequency. So, G is > 1 for USB and it is < 1 for LSB. Based on 10 realizations, each of 128 msec. length for each modulation type it is claimed in [5] that the discriminator described there performs well at 0 dB SNR. Thus the discriminator in [5] requires much longer signal duration than that required in [4] and even than the algorithm presented in this paper. Also, the required processing time and the computation complexity required in [5] - since it uses the instantaneous frequency - is larger than that required in [4] and the algorithms developed in this paper.

2. Developed modulation recognition algorithms

In this paper, two novel algorithms for the discrimination between the LSB and USB are proposed and analysed. In these algorithms all the key features used are derived from the complex envelope; i.e., no need to evaluate the instantaneous frequency of a signal. For that reason, the proposed algorithms should be faster than that utilises the instantaneous frequency [5]. Furthermore, they require short signal duration ($\approx$ 1.707 msec.). In the first algorithm, a measure of the symmetry of spectral power density of the complex envelope is used to discriminate to discriminate between the LSB and USB signals. In the second algorithm the power contained in two new signal parameters (see Appendix A) are used to distinguish between USB and LSB signals.

The developed algorithms adopt a decision-theoretic approach and both of them start by dividing the intercepted signal frame of length L seconds into successive segments, each of length N_s = 2048 samples (equivalent to 1.707 msec.), resulting in $M_s = L\, f_s / N_s$ segments, where f_s is the sampling rate. In practice, the segment length should be enough to avoid the fading modulation effect and to allow good feature extraction. From each available segment, the proposed key feature is extracted and compared with a suitable threshold to decide about the modulation type.

Algorithm I

In this algorithm, the key feature used to discriminate LSB and USB signals is the spectrum symmetry measure of the complex envelope, which is defined as follows

$$P = \frac{P_L - P_U}{P_L + P_U}, \qquad (1)$$

where, $P_L = \sum_{f=1}^{N_s} |\gamma_a(f)|$, and $P_U = \sum_{f=N_s+1}^{2N_s} |\gamma_a(f)|$,

where $\gamma_a(f)$ is the power spectral density of the complex envelope and it is defined by the Fourier transform of correlation function, $\Gamma_a(\tau)$, of the complex envelope as

$$\gamma_a(f) = FT\{\Gamma_a(\tau)\}, \qquad (2)$$

where $\Gamma_a(\tau) = E\{\alpha(t)\,\alpha^*(t+\tau)\}$, and $\alpha(t)$ is the complex envelope of a signal and for a noise free SSB signal, the complex envelope, $\alpha(t)$, can be expressed as

$$\alpha(t) = x(t) \mp j\,y(t) \qquad (3)$$

The -ve sign is for LSB signal and the +ve sign is for USB signal. Examples of the real and imaginary parts of complex envelope for only one and the same realization of LSB and USB signals (using the same modulating signal) are shown in Figs. 1 and 2. respectively. The autocorrelation function, $\Gamma_{\alpha}(\tau)$, for SSB signals can be expressed as

$$\Gamma_{\alpha}(\tau) = 2\,\Gamma_{x}(\tau) \pm j\,2\,\Gamma_{xy}(\tau) \qquad (4)$$

The +ve sign is for LSB signal and the -ve sign is for USB signal. By straight forward analysis, the power spectral density, $\gamma_{\alpha}(f)$, is expressed by

$$\gamma_{\alpha}(f) = 4\,u(-f)\,\gamma_{x}(f) \qquad \textit{for LSB} \qquad (5.a)$$

$$\gamma_{\alpha}(f) = 4\,u(f)\,\gamma_{x}(f) \qquad \textit{for USB} \qquad (5.b)$$

From (5.a) and (5.b), it is clear that the ratio P is always negative for LSB signal, and positive for LSB signal Based on this fact, comparing the ratio P with 0, LSB and USB signals can be distinguished. Furthermore, the dependence of the ratio P on the SNR values for only one and the same realization of LSB and USB signals (using the same modulating signal) is as shown in Fig. 3. From the simulation results, it is found that the ratio P is close to + 1 for LSB and -1 for USB at noise-free signals.

Algorithm II

In this algorithm, the key features used to discriminate between the LSB and USB signals is derived from new signal parameters which are noise resistant and they are defined by

$$C_1(t) = r(t) + \hat{Q}(t) \qquad (6)$$

$$C_2(t) = \hat{r}(t) + Q(t) \qquad (7)$$

where $r(t)$ and $Q(t)$ are the in-phase and the quadrature components of the complex envelope respectively, and $\hat{r}(t)$ and $\hat{Q}(t)$ are the Hilbert transform of $r(t)$ and $Q(t)$ respectively. The mathematical expressions of $C_1(t)$ and $C_2(t)$ for LSB and USB signal are presented in Appendix A. From (A.6) - (A.9) it is found that the power contained in the signal parameter, $C_2(t)$ should be greater than that in $C_1(t)$ for USB and vise versa for LSB. Based on this fact, LSB and USB signals can be distinguished at poor SNR. Furthermore, the dependence of the power contained in $C_1(t)$ and in $C_2(t)$ on the SNR values for only one and the same realization of LSB and USB signal (using the same modulating signal) is as shown in Figs. 4 and 5.

3. Computer Simulations

In our simulations, the carrier frequency, f_c, and the sampling rate, f_s, were respectively chosen to be 150 kHz and 1200 kHz. The procedure used for generating a non-intelligible speech signal of length 1.707 msec. which is used as a modulating signal for SSB signals, was presented in [4]. SSB (i.e. LSB or USB) signals were generated according to the expression in [6].

$$s(t)= x(t) \cos(2 \pi f_c t_t) \pm y(t) \sin(2 \pi f_c t) \qquad (8)$$

where x(t) is a simulated speech signal and y (t) is its Hilbert transform. The -ve sign in (8) is used for USB signal whereas the +ve sign is used for LSB signal.

4. Performance Evaluation

Two signal parameters, C_1 (t) and C_2 (t) have been introduced. Extensive simulations of 400 realizations of each of the LSB and USB signals have been carried out. The simulation results prove that these parameters are noise resistant parameters. It is found that both developed algorithms allow correct discrimination (100% success rate) between the LSB and USB signals at 0 dB SNR.

5. Conclusions

The aim of this paper has been to develop fast and reliable algorithms for the discrimination between LSB and USB signals. Extensive simulations of 400 realizations of each of LSB and USB signals have been carried out. It is found that correct discrimination can be achieved at SNR of 0 dB. These results are strongly competitive with those recently published in [4] and [5]. On the other hand, the algorithms developed in this paper computationally are less complex than those presented in [4 and 5], as the used key features are derived from the complex envelope of a signal only and using conventional signal processing tools. Now, a current research interest of the author discriminating analogue and digitally modulated signals based on complex envelope only is.

References

[1] Fabrizi, P. M., Lopes, L. B. and Lockhart, G. B., " Receiver recognition of analogue modulation types," IERE Conference on Radio Receiver and Associated Systems, Bangor, Wales, pp. 135-140, (1986).

[2] Chan, Y. T. and Gadbois, L. G., "Identification of the modulation type of a signal," Signal Process, Vol. 16, No. 2, pp. 149-154, (1989).

[3] Nagy, P. A. J. " Analysis of a method for classification of analogue modulated radio signals," European Association for Signal Processing VII Conference 94, Edinburgh, Scotland, pp. 1015-1018, (1994).
[4] Al-jalili, Y. O. " Identification algorithm for upper sideband and lower sideband SSB signals," Signal Processing, Vol. 42, No. 2, pp. 207-213, (1995).
[5] Nandi, A. K. and Azzouz, E. E., " Recognition of analogue modulations," Signal Processing, Vol. 46, No. 2, October 1995, pp. 211-222.
[6] Shanmugam, K. S., Digital and analogue communication systems, John Wiley and Sons, Inc, (1985).

Appendix A: Mathematical expressions of C_1 (t) and C_2 (t) for SSB signals

A noisy SSB signal can be expressed as

$$x_{SSB}(t) = s(t) + n(t) \qquad (A.1)$$

where s(t) is defined by (8) and n (t) is a narrow-band Gaussian noise, as

$$n(t) = n_c(t)\cos(2\pi f_c t) - n_s(t)\sin(2\pi f_c t) \qquad (A.2)$$

From (A.1) and (A.2), the real, r (t), and the imaginary, Q (t), parts of the complex envelope are expressed as

$$r(t) = x(t) + n_c(t), \quad \textit{for both LSB and USB} \qquad (A.3)$$

while,

$$Q(t) = -y(t) + n_s(t) \quad \textit{for LSB} \qquad (A.4)$$

$$Q(t) = y(t) - n_s(t) \quad \textit{for USB} \qquad (A.5)$$

Thus, from (6) and (7) the signal parameter, C_1 (t) for LSB and USB is given by

$$C_1(t) = 2x(t) + n_c(t) + n\hat{}_s(t) \quad \textit{for LSB} \qquad (A.6)$$

$$C_1(t) = n_c(t) - n\hat{}_s(t) \quad \textit{for USB} \qquad (A.7)$$

Also, the signal parameter C_2 (t) for LSB and USB is given by

$$C_2(t) = n\hat{}_c(t) + n_s(t) \quad \textit{for LSB} \qquad (A.8)$$

$$C_2(t) = 2y(t) + n\hat{}_c(t) - n_s(t) \quad \textit{for USB} \qquad (A.9)$$

where $\hat{n}_c(t)$ and $\hat{n}_s(t)$ are the Hilbert transforms of $n_c(t)$ and $n_s(t)$ respectively.

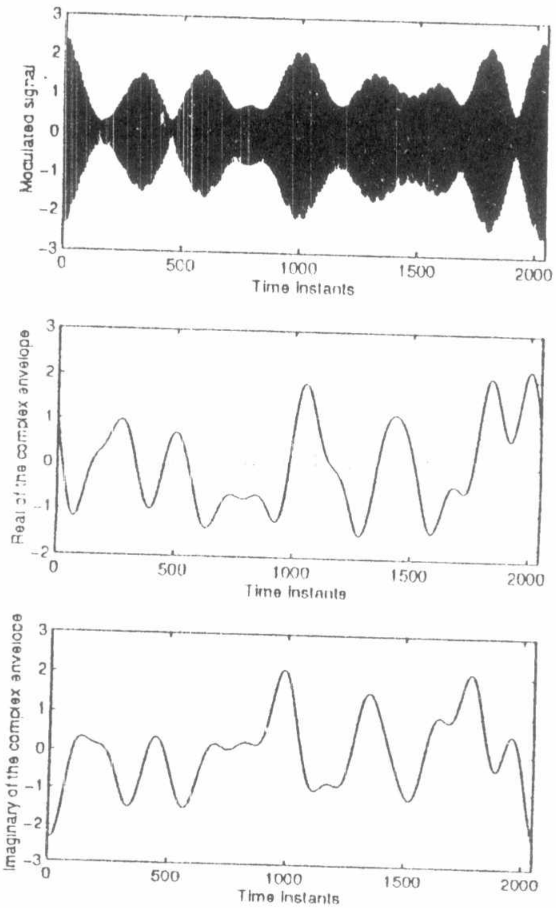

Fig. 1. LSB Signal

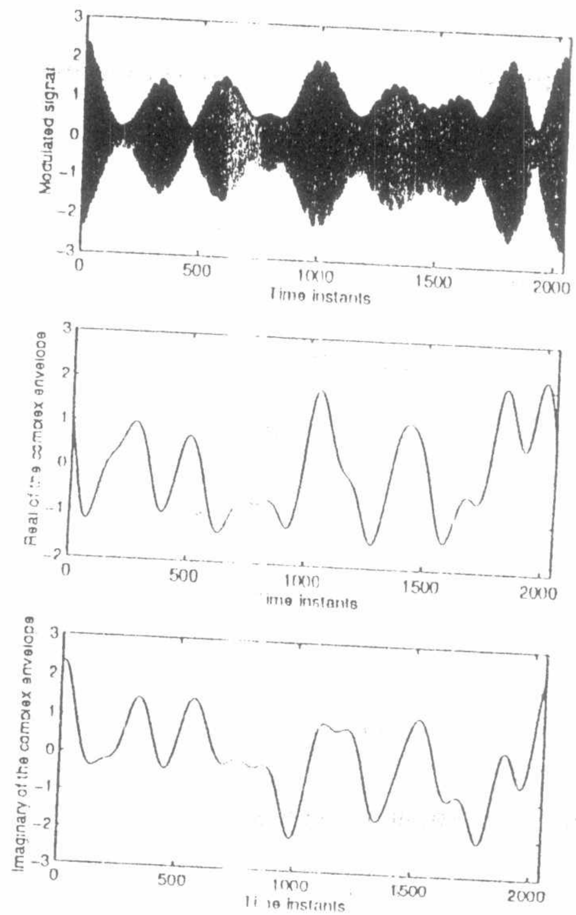

Fig.2. USB Signal

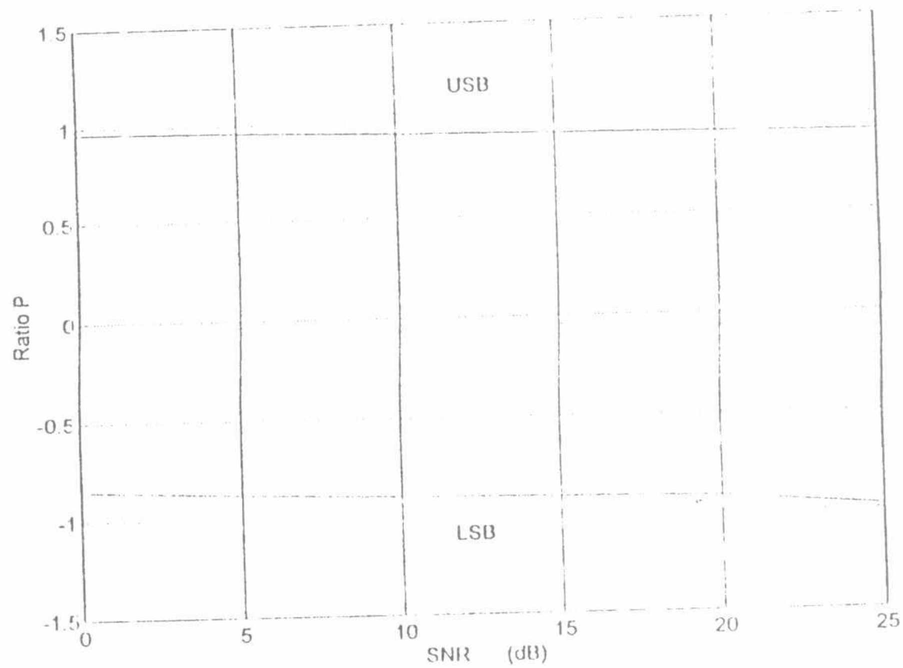

Fig.3. Dependence of P on SNR

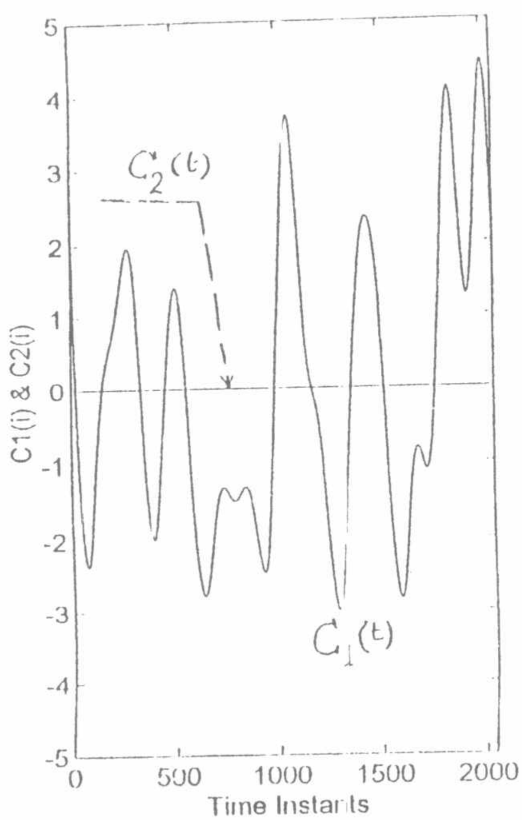

Fig. 4. LSB Signal

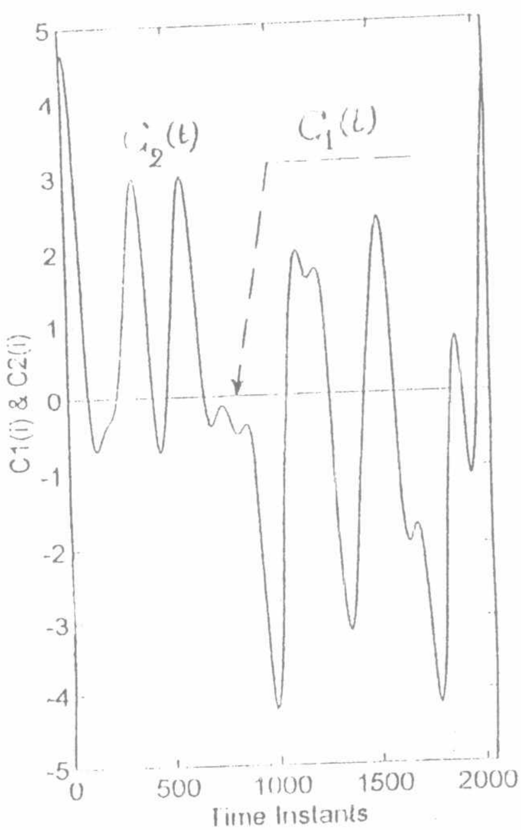

Fig. 5. USB Signal