*Sensors & Transducers, Vol. 170, Issue 5, May 2014, pp. 153-159*

**Sensors & Transducers**



# A Specific Combination Scheme for Modulation Identification of Mixed Modulation Signal

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*Received: 11 March 2014 /Accepted: 30 April 2014 /Published: 31 May 2014*

**Abstract:** In this paper, we propose a specific combination scheme for modulation identification of mixed modulation signal based on decision theory and the tree classifier. In order to reduce the noise interference and improve the accuracy of modulation identification, we adopt the joint modulation signal characteristics with eigenvector made up of the number of subcarrier signal, envelope variance of mean normalization and the statistical value of subcarrier signal instantaneous amplitude distribution in identification of external modulation and internal modulation. Simulation results show that modulation identification ratio is close to 90 % when the SNR is 6 dB. And the proposed scheme outperforms the existing mixed modulation scheme. *Copyright © 2014 IFSA Publishing, S. L.*

**Keywords:** Tree classifier algorithm, Mixed modulation signal, Combination eigenvalue, Modulation identification.

## 1. Introduction

Modulation identification has been widely used in the military and civil communication such as signal monitoring, signal confirming, interference discrimination, electronic countermeasure, electronic rescue and the analysis of military threat etc. It is foundation of software defined radio, cognitive radio and spectrum sensing. With new modulation modes emerge, signal processing becomes increasingly complicated which affect the effectiveness of modulation identification. To achieve the automatic identification technology is still a challenge research topic [1, 2]. The analog communication system (e.g. civil broadcasting system of AM and FM, bus company, sea fisheries, maritime search and rescue, property management of residence, institution security, police work, etc) is still used in many fields at home and abroad. All these analog communication systems can not be replaced immediately, it is only to be reformed and upgraded. At first, the digital information was modulated in digital. Then the carrier of the original analog system was modulated in analog by the modulated signals. Thereby, it will become hybrid communication system of the analog and digital after modulating twice. For the subcarrier communication system [3] now, subcarrier broadcast-ting system and automatic vehicle location system [4] have been widely used in military and civil communication system. Because these hybrid modulation signals can be regarded as multi-carrier signal launched by using analog system, it is not easy to distinguish these signals from other signals. Meantime, their frequency is very close, so the electromagnetic environment is complicated and the mutual interference is serious. It brings the larger challenge to the spectrum monitoring and modulation identification. However, there is less research in modulation identification of these multi-carrier hybrid modulated signal. A new hybrid modulation scheme was proposed to improve spectrum efficiency and lower bit error rate in [5] that using hybrid modulation method little improved. The initial analysis and simulation on the spectrum characteristics of the satellite line signal measured were made respectively in [6-8], the conventional method was used in identifying the external modulation firstly, then the signal of internal modulation was deal with so as to realize classification and identification of hybrid modulating signal after demodulation. Nevertheless, the accuracy of the identification needs to be improved further. In this paper, We propose a specific combination scheme of hybrid modulation signal for modulation identification by the tree classification based on the analysis of instantaneous amplitude, instantaneous frequency, the number of subcarrier, characteristic vector, envelope variance of subcarrier of the mean normalized, the distribution area statistic of subcarrier instantaneous amplitude, the histogram related to the order of signal modulation and the characteristic parameters of wave number [9, 10]. Simulation results show the proposed scheme is outperforms the existing mixed modulation scheme.

## 2. Combination Eigenvalue of Mixed Modulation Signal Identification

### 2.1. Instantaneous Amplitude and Frequency of Mixed Modulation Signal

The hybrid modulating signal is made up of the internal modulation and external modulation. Internal modulation is the baseband signal modulated by the regulated digital modulation, including ASK, FSK, PSK and DPSK et al. All these carriers are called subcarrier. External modulation is the carriers in the original analog system (named the main carrier or the common carrier) modulated by the subcarrier in subsequent times with the signal. Denoting the modulated signal modulated by subcarrier as $u(t)$ and modulation degree as $k$, the launching signal of hybrid AM modulated is given by:

$$S_{AMh}(t) = [1 + ku(t)]\cos\omega_0 t\,, \quad (1)$$

Let the receiving signal is $r(t)$ and noise is $n(t) = N(t)\cos\omega_0(t)$, then the receiving signal is:

$$r(t) = A(t)\cos[\omega_0 t + \theta(t)] + N(t)\cos\omega_0(t)$$

Transformation by Hilbert, the conclusion is:

$$\hat{r}(t) = A(t)\sin[\omega_0 t + \theta(t)] + N(t)\sin\omega_0 t\,,$$

Let $\theta(t) = 0$, then the instantaneous amplitude of receiving hybrid AM modulating signal is:

$$a_{AMh}(t) = \sqrt{r^2(t) + \hat{r}^2(t)} = A(t) + N(t)$$

Comparing with (1), it can be obtained that

$$a_{AMh}(t) = 1 + ku(t) + N(t)\,, \quad (2)$$

Similarly, signal of hybrid FM modulated can be expressed by:

$$S_{FMh}(t) = A_C\cos[\omega_0 t + k_f \int u(t)\mathrm{d}t]$$

Then instantaneous frequency of hybrid FM modulating signal on the receiver as:

$$f_h(t) = \frac{1}{2\pi}\frac{\mathrm{d}\varphi(t)}{\mathrm{d}t} = \frac{1}{2\pi}\frac{\mathrm{d}[tg^{-1}\frac{\hat{r}(t)}{r(t)}]}{\mathrm{d}t} \approx f_0 + \frac{1}{2\pi}k_f u(t)\,, \quad (3)$$

### 2.2. The Numbers of Signal Subcarrier and Eigenvector

Subcarrier signals are obtained by calculating the instantaneous amplitude and instantaneous frequency respectively of hybrid AM and FM modulating. The hybrid signals of the subcarrier and noise can be obtained with (2) and (3), and the corresponding power spectrum can be obtained by FFT. Take AM-2FSK hybrid modulation as an example, the comparison of instantaneous power spectrum between hybrid modulating and conventional AM, 2FSK is shown in Fig. 1.

As seen from Fig. 1, the power spectrum of hybrid modulating signal contains the envelope of subcarrier signal, while the power spectrum of non-hybrid modulating signal has no envelope of subcarrier signal. With this, the number $Z_a$, $Z_f$ of subcarrier signal can be extracted and they form a character vector $Z_{af} = [Z_a, Z_f]$. If $N_{af} = [0,0]$, it can be considered as a signal of non-hybrid modulating.

The number of the subcarrier signal extracted is critical in the algorithm of the eigenvector extracted, the algorithm is described in the following [11, 12]:

- The power spectrum $P(n\Delta f)$ is calculated by the instantaneous frequency or amplitude;
- The threshold is determined:

$$\alpha = \frac{1}{\lfloor \lambda M \rfloor} \sum_{i=0}^{\lfloor \lambda M \rfloor} P(i\Delta f) \quad 0 \prec \lambda \prec \frac{1}{4}, \qquad (4)$$

where $\lfloor \ \rfloor$ is the floor.

- Counting the number of points continuously larger than the threshold value and record the corresponding starting point H, finishing point L and continuous segments r

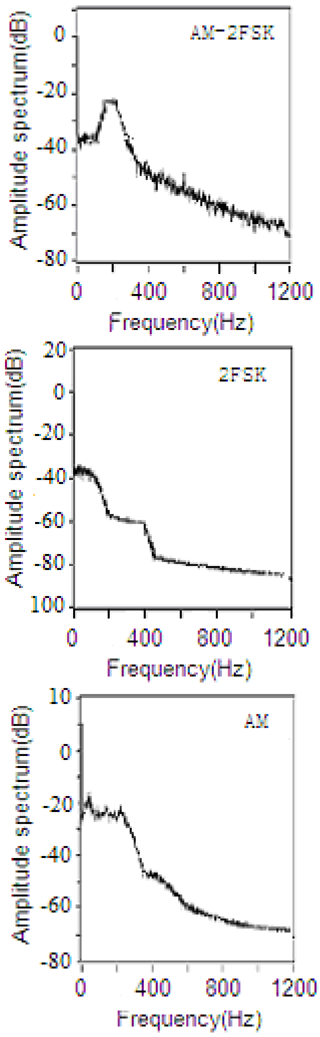



**Fig. 1.** Instantaneous power spectrum of AM-2FSK of hybrid modulation and conventional AM, 2FSK.

$$N_L^H(r) = Stat\{P(n\Delta f) \succ \alpha\}, \qquad (5)$$

where $Stat$ is to record the number of sequence under certain condition

- Estimating the bandwidth of each segment:

$$\hat{\alpha}_r = \Delta f \cdot N_L^H(r), \qquad (6)$$

Calculating the numbers $n_1$ larger than the setting threshold value among $\hat{\alpha}_r$, that is to say, the number parameter of the subcarrier.

## 2.3. The Envelope Variance of the Normalized Mean

The envelope variance of the normalized mean is defined as:

$$c = \frac{\sigma^2}{\mu^2}, \qquad (7)$$

where $\mu$, $\sigma^2$ are the mean value and variance of the signal envelope respectively, This parameter reflects the change of the signal envelope to classify better on the signal of constant and non constant envelope of the hybrid modulating.

According to the principle of the modulation, the range of the hybrid AM signal changes with the modulating signal, and the frequency of the hybrid FM signal changes with the modulating signal for the external modulation which contains AM, FM hybrid modulation respectively. The calculating result indicates that corresponding *C* of the modulation of the hybrid AM is far larger than that of the modulation of the hybrid FM. It can be shown in Table 1.

According to Table 1, the modulation identification of the hybrid AM modulation and FM modulation signal can be achieved by choosing the threshold properly, which is known as external modulation identification.

**Table 1.** The numerical result C of hybrid modulation when external modulation is AM, FM in different SNR respectively.

| C | 5 dB | 6 dB | 7 dB | 8 dB | 9 dB | 10 dB | 11 dB | 12 dB | 13 dB | 14 dB | 15 dB |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AM-4FSK | 0.343 | 0.294 | 0.283 | 0.250 | 0.243 | 0.213 | 0.205 | 0.185 | 0.180 | 0.178 | 0.175 |
| AM-MSK | 0.318 | 0.285 | 0.283 | 0.241 | 0.239 | 0.225 | 0.193 | 0.182 | 0.175 | 0.173 | 0.172 |
| AM-BPSK | 0.293 | 0.251 | 0.242 | 0.235 | 0.190 | 0.185 | 0.183 | 0.178 | 0.179 | 0.166 | 0.162 |
| AM-QPSK | 0.285 | 0.265 | 0.250 | 0.240 | 0.230 | 0.190 | 0.180 | 0.175 | 0.160 | 0.150 | 0.148 |
| FM-4FSK | 0.155 | 0.164 | 0.106 | 0.081 | 0.088 | 0.053 | 0.06 | 0.042 | 0.035 | 0.028 | 0.025 |
| FM-MSK | 0.161 | 0.132 | 0.119 | 0.102 | 0.075 | 0.063 | 0.055 | 0.045 | 0.028 | 0.026 | 0.021 |
| FM-BPSK | 0.148 | 0.135 | 0.120 | 0.108 | 0.063 | 0.051 | 0.052 | 0.042 | 0.031 | 0.026 | 0.021 |
| FM-QPSK | 0.181 | 0.130 | 0.122 | 0.080 | 0.061 | 0.073 | 0.060 | 0.053 | 0.032 | 0.026 | 0.020 |

### 2.4. The Statistic Parameters of Subcarrier Instantaneous Amplitude Distribution

For the hybrid modulating signal, it is necessary to extract the instantaneous amplitude twice so as to extract the instantaneous amplitude of the subcarrier signal. The first is the hybrid signal of the subcarrier and the noise. After filtering this signal, the instantaneous amplitude is extracted in the second so that the hybrid signal combining the noise and the base band can be obtained for the modulating signal of the subcarrier. Then, the subcarrier distribution is the second instantaneous amplitude. Hence, the distribution of subcarrier amplitude is

$$Q = \frac{M\{a(t) \le 0.3b\}}{M},$$
$$b = \frac{\sum_{i=1}^{\lfloor M\lambda \rfloor} \overline{sort\{a(t)\}}}{\lfloor M\lambda \rfloor}, \lambda \in (0,1), \quad (8)$$

where $sort\{a(t)\}$ is the ascending for $a(t)$ of instantaneous amplitude, $\overline{sort\{a(t)\}}$ is the descending for $a(t)$, and $M\{a(t) \le 0.3b\}$ is the sampler among the envelope of the signal [13]. Take AM hybrid modulation as an example, for the internal modulation of 2FSK, 4FSK, BPSK, QPSK, the distribution of subcarrier amplitude Q under different SNR (Signal Noise Ratio) are shown in Table 2.

As seen from Table 2, the Q of internal modulation MPSK is considerably larger than that of the MFSK. Therefore, the hybrid signal of FSM and PSM can be separated by choosing the size of the threshold Q properly in the internal modulation.

### 2.5. The Number of the Crest in the Histogram of the Hybrid Signal

For the FSK signal, the number of crest reflects modulation order of the FSK signal, which is denoted as *N*.

To extract the instantaneous frequency of subcarrier from the histogram for FM-2FSK, FM-4FSK signal of hybrid modulating, the results are shown in Fig 2 when the number of segment will be 100 in the x-axis.

**Table 2.** Q simulation value of hybrid modulation which internal modulation contains MPSK, MFSK in different SNR respectively.

| Q | 5 dB | 6 dB | 7 dB | 8 dB | 9 dB | 10 dB | 11 dB | 12 dB | 13 dB | 14 dB | 15 dB |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AM-BPSK | 0.151 | 0.132 | 0.128 | 0.127 | 0.126 | 0.125 | 0.125 | 0.125 | 0.125 | 0.126 | 0.125 |
| AM-QPSK | 0.105 | 0.091 | 0.085 | 0.081 | 0.078 | 0.075 | 0.070 | 0.068 | 0.065 | 0.064 | 0.063 |
| AM-4FSK | 0.065 | 0.043 | 0.038 | 0.020 | 0.012 | 0.001 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 |
| AM-2FSK | 0.035 | 0.025 | 0.012 | 0.011 | 0.002 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

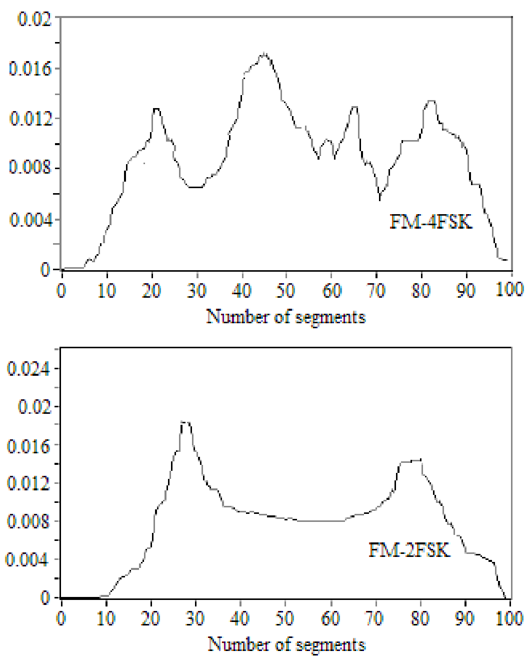



**Fig. 2.** Histogram of instantaneous subcarrier frequency with hybrid FM-MFSK, FM-2FSK modulation.

Fig. 2 shows the number of crests in the statistical histogram corresponding to the modulation order of FSK signal. By detecting the number of crests in the histogram, the modulation order of the FSK signal can be evaluated and the hybrid FM-MFSK and AM-MFSK signal can be distinguished. Similarly, for the distinction a signal of the classes within the MPSK, it is necessary to detect the statistical histogram of the instantaneous phase extracted. The number of the crest in the histogram is related to modulation order of PSK signal so that the distinction of the MPSK signal can be achieved based on the *N* [14, 15].

## 3. Algorithm of Modulation Classification with Hybrid Modulation Signal

According to the various characteristic parameters above, the hybrid modulation classifier based on the tree decision is adopted to achieve the flow of the classification algorithm with AM-2FSK, AM-4FSK, AM-QPSK, AM-BPSK, FM-2FSK, FM-4FSK, FM-BPSK and FM-QPSK. It can be shown Fig. 3:

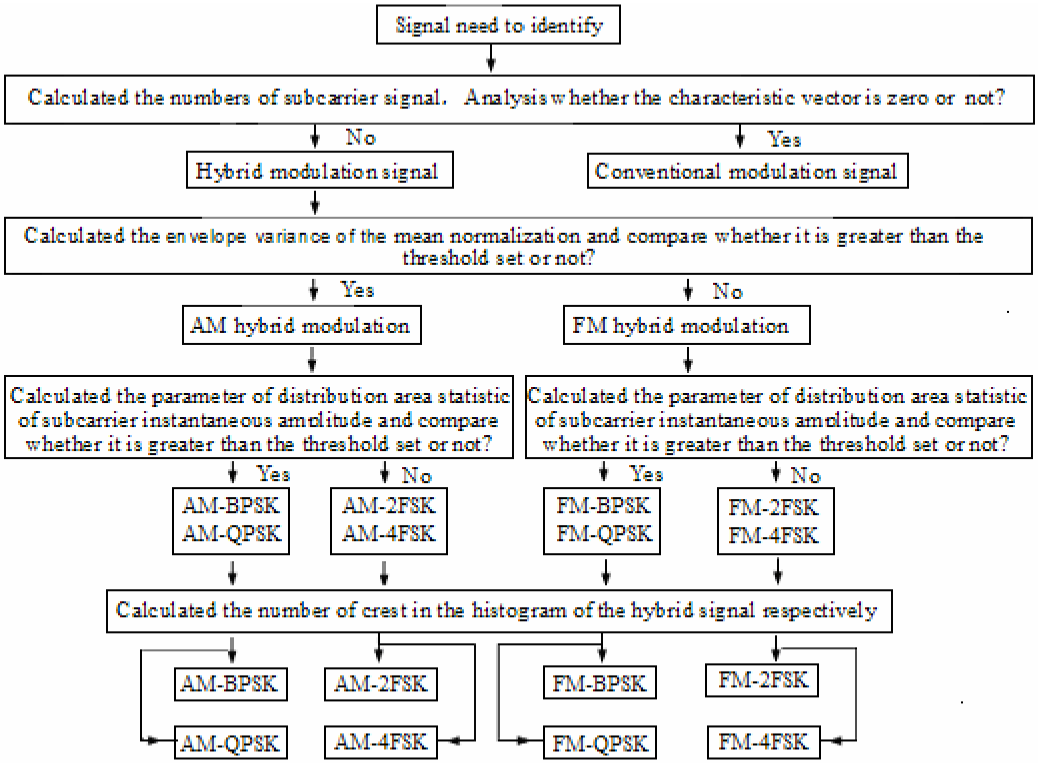



**Fig. 3.** Flow chart of modulation classification identification algorithm with hybrid modulation signal.

In the classifier of the tree decision, it is important to choose the discriminating characteristic threshold for the accuracy of the modulation identification with hybrid modulating signal such as the regulate modulating signal, hybrid AM and FM modulating signal, internal modulation the MPSK and MFSK modulation et al. The threshold is determined by the search method. For each the characteristic parameter, it is available for modulating signal characteristic to distinguish as the experimental signal. For each experimental signal, the distribution of the parameter choice under a certain SNR should be calculated and its mean is considered as the typical value of this signal. With the variation of SNR, the above procedure is carried out. Finally, the threshold of the parameter is determined by making the curve.

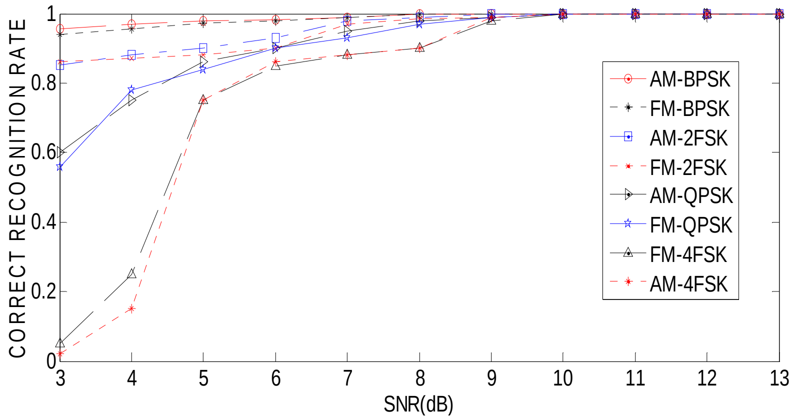
## 4. Performance Evaluation

According to the classification algorithm mentioned in section 3, MATLAB2012 is used to evaluate the modulation identification of hybrid modulating signal (e.g. AM-2FSK, AM-4FSK, AM-QPSK, AM-BPSK, FM-2FSK, FM-4FSK, FM-BPSK, FM-QPSK et al) The simulation parameters is given as follow: the frequency of main carrier is 15000 Hz, subcarrier frequency is 1500 Hz, the symbol rate is 1200 baud, the modulation index of FSK is 0.35, frequency offset of FM is 1000 Hz, modulation degree of AM is 0.8. We assume that the noise of channel is additive white Gaussian, the multipath propagation gain is 4, maximum delay of multipath transmission is 2 ms, and the phase distribution is uniform with $0 \sim 2\pi$. The SNR changes from 3 dB to 13 dB. The results obtained by each SNR is averaged over 200 independent trials, which are shown in Fig. 4.

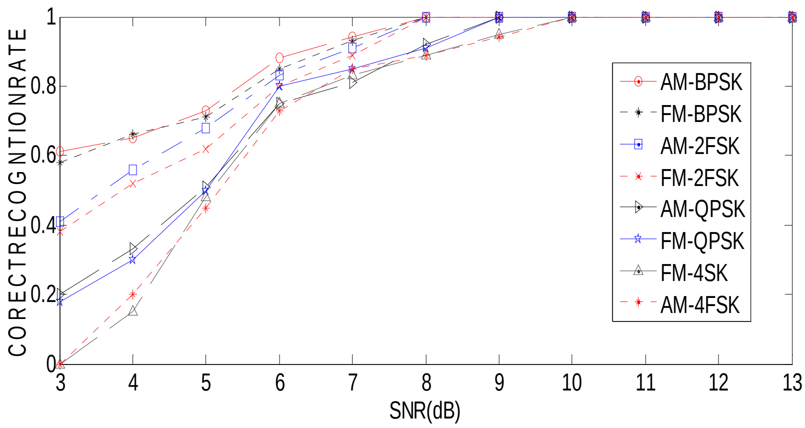
Under the condition of additive white Gaussian noise channel, the result in Fig. 4(a) shows that when SNR is larger than 6 dB, the rate of classifier recognized all kinds of hybrid modulating signal is closed to over 90 %, and with the increasing of SNR, the identification rate is improving as well. When SNR is over 9 dB, the identification rate can be 100 %. With regard to the hybrid modulation of AM-BPSK, FM-2FSK, FM-BPSK, FM-BPSK et al, the classifier still have high recognize rate when SNR is lower comparatively. Even on the conditions of multipath transmission modeling channel in Fig. 4(b), due to the influence of multipath fading, the system identification rate has reduced. However, the system average identification rate is still above 80 % when SNR is greater than 7 dB.

## 5. Conclusion

A specific combination scheme for signal identification of hybrid modulation and conventional modulation was proposed by extracting joint statistics characteristic with hybrid modulation signal instantaneous amplitude, instantaneous frequency, and number of subcarrier signal. The identification of external modulation classification was realized by extracting the mean normalized envelope variance; the identification of internal modulation classification for MFSK and MPSK was carried out with subcarrier signal instantaneous amplitude distribution statistics and identification of internal modulation classification for MFSK and MPSK is recognized with the numbers of histogram peaks. Finally, modulating identification on various hybrids modulating signal can be achieved. These simulations indicate the scheme proposed in this paper has a better effect of the identification on the hybrid modulating signal.




(a)




(b)

**Fig. 4.** Identification rate of modulation identification with hybrid modulating signal.

## Acknowledgements

This work has been performed in the National science and technology major project (2010ZX03006-002-04), the National natural Science foundation of China (61072070), the doctorial programs foundation of the Ministry of education (20110203110011), the fundamental research funds of the Ministry of education (72124338).

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