Sub-Peaks Suppression for DTMB Signal Based Passive Detection Systems

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Abstract. Passive detection is an effective way to monitor the security of the low-altitude airspace. Tsinghua University’s independently developed Digital Television Terrestrial Multimedia Broadcasting (DTMB) signal enjoys a high coverage in China, whereas few studies have addressed the passive detection based on this kind of signal in detail. Ambiguity function is utilized to detect the targets, however there exists sub-peaks caused by the frame format of the DTMB signal. In this paper, we propose a sub-peaks suppression scheme based on DTMB. The influence of the repeated PN sequence and the power difference on sub-peaks generation are analyzed. To tackle the sub-peaks problem, sampled Linear Frequency Modulation signal with the same power of the frame body is adopted to replace the original PN sequence in DTMB reconstruction. The experimental results show that our proposed method can effectively mitigate the sub-peaks problem.

1. Introduction

With the gradual opening of the low-altitude airspace, the traffic situation becomes more and more complex. In order to maintain the flight order and ensure the safety of the aircraft, the implementation of airspace surveillance has become an inevitable trend of development. At present, the shortage of means to monitor the low-altitude airspace not only seriously affects the flight safety, but also restricts the development of general aviation.

Passive detection is a kind of probing method that can be used to monitor the security of the low-altitude. The system itself does not emit energy, but passively receives the reflected electromagnetic signals from non-cooperative radiation source to locate and track the targets [1]. This system definitely brings up many advantages of low cost, excellent concealment and strong anti-interference ability, etc. The study of passive detection began in 1922, Taylor detected a sailing wooden ship in a river using a bi-static continuous-wave radar in USA [2]. By 1988, the Lockheed Martin developed the "silent sentry", which was the representative of the detection system [3].

In the past twenty years, the digital television terrestrial broadcasting (DTTB) system has been developed rapidly, passive detection based on DTTB standard signal has absorbed substantial attention from academic research [4]. Nowadays, China’s independently developed Digital Television Terrestrial...
Multimedia Broadcasting (DTMB) has become a technical standard and entered the period of commercial application. In view of the high coverage of DTMB signal in China nowadays, the study of passive detection based on DTMB signal is undoubtedly a powerful way to monitor and control the low-altitude airspace. Unfortunately, there are relatively few researches about passive detection based on DTMB signal by now.

Correlation peaks are generated by ambiguity function calculation between the received reference signal and the target signal, by which we can acquire the distance and velocity information about the target. However, there are repeated signal segments (e.g. PN etc.) in DTMB signal frames, which will cause sub-peaks after ambiguity function computation, and increase the probability of false alarm at the same time. [5] Just recognize the position of the sub-peaks, but did not take steps on how to suppress them. [6] Set the PN sequence to zero, but there still existed sub-peaks generated by the power difference. Therefore, how to mitigate the sub-peaks of DTMB signal based passive detection is worthy of research.

In this paper, we propose a sub-peaks suppression scheme based on DTMB signal. The expression of the ambiguity function is presented. The influence of repeated PN sequence and the power difference on sub-peaks generation are analyzed. To tackle the sub-peaks problem, sampled Linear Frequency Modulation (LFM) signal with the same power of the frame body is adopted to replace the original PN sequence in DTMB signal reconstruction. The experimental results show that our proposed method can effectively mitigate the sub-peaks problem.

2. Frame Format of the DTMB Signal

In 2006, Tsinghua University issued the standard of ‘channel coding and modulation for frame structure of digital television terrestrial transmission system’ [7]. The fundamental block of DTMB is the signal frame, which is composed of two parts: the frame head (FH) and the frame body (FB), and both of them share the same baseband symbol rate of 7.56Mbps.

2.1. Frame Header

The FH uses pseudo-noise (PN) sequences modulated by 4QAM with the same I and Q components in three different lengths: 420, 595 and 945, which are correspondingly abbreviated to PN420, PN595 and PN945. Details about three FH types are summarized in Table 1.

| Mode | Length of FH | Number of PN | Carrier mode | Average power: FH/FB |
|------|--------------|--------------|--------------|----------------------|
| 1    | 55.6us       | 420          | multi-carrier| 2 times              |
| 2    | 76.7us       | 595          | single-carrier| 1 times              |
| 3    | 125us        | 945          | multi-carrier| 2 times              |

In the rest of the paper, we take PN420 as an example to give a detailed illustration of the DTMB signal. PN420 consists of a preamble, a PN255 sequence, and a postamble, where the preamble and postamble are defined as the cyclic extension of the PN255 sequence, respectively [7]. Specifically, the length of the preamble is 82 symbols, and the length of the postamble is 83 symbols, as shown in Figure 1. There are 225 signal frames in a super frame, which are distinguished with each other by PN sequences with different phase.
2.2. Frame Body

The FB consists of 36 system information symbols and 3744 data symbols. System symbols provide the necessary information about demodulation and decoding for each signal frame. When 3744 data symbols are connected to the system information, frame data processing is performed to form a complete frame body. The frame body of PN420 is modulated by 3780 sub-carriers, occupying bandwidth of 7.56MHz in frequency domain and 500us in time domain. After interleaving the frame body symbols in frequency domain we get $X(n)$, and the time domain symbols are:

$$
X(n) = \sum_{k=1}^{3780} e(kn) e^{j2\pi \frac{k}{3780}}, k = 0, ..., 3779
$$

3. Analysis of the Ambiguity Function Based on DTMB Signals

3.1. Expression of the Ambiguity Function Based on DTMB Signal

The ambiguity function can be expressed as:

$$
A(\tau, f_d) = \int_0^T e(t)e(t+\tau) e^{-j2\pi f_d t} dt
$$

Where $e(t)$ is DTMB signal, $\tau$ is time delay, $f_d$ is Doppler shift, $T$ is the accumulation time signal. Ideal ambiguity function of DTMB signal is like a thumbtack, but in fact there exists obvious sub-peaks. The presence of sub-peaks can cause false alarm and misjudgment of the targets. In order to obtain a clean ambiguity graph, it is necessary to analyze and deal with the sub-peaks.

3.2. Sub-peaks Generated by Repeated PN Sequence

From the model of DTMB signal we can see that there are repeated fragment in the frame. It is obviously that these repeated signal contribute to the sub-peaks. To be concrete, there will present a sub-peak when the repeated segments in two signals are aligned. In PN420 mode, things will get worse because the FH itself has repeated parts, i.e. preamble and postamble as shown in Figure. 1. In summary, there are two kind of sub-peaks, which is called intra-symbol sub-peak and inter-symbol sub-peak, respectively. Intra-symbol sub-peaks happen when the FHs are not aligned but the preambles or postambles are aligned. Inter-symbol sub-peaks happen when the FHs are approximately aligned except for the cycle shift. The location of the sub-peaks generated by repeated FH is:
Where $T_s = 555.6\,\text{us}$ denotes the length of a signal frame, $T_b = 0.13\,\text{us}$ denotes the length of a symbol.

### 3.3. Sub-peaks Generated by Power Difference

In PN420 mode, the average power of the FH is 2 times of the FB, which can be written as:

$$h(t) = \begin{cases} \sqrt{2}, & t \in \text{frame header} \\ 1, & t \in \text{frame body} \end{cases}$$

(4)

Where $h(t)$ is a periodic rectangular wave signal. When $\tau = 0$, (4) can be written as

$$A(0, f_d) = \left[ \int_0^T |d(t)|^2 |h(t)|^2 \exp(-j2\pi f_d t) dt \right]$$

(5)

In fact, (5) can be seen as computing a Fourier transform. Instead we can compute $D(f) \otimes H(f)$, where $\otimes$ denotes convolution operation, $D(f)$ and $H(f)$ denote Fourier transform of $d^2(t)$ and $h^2(t)$, respectively. According to the properties of Fourier transform, $H(f)$ is a discrete signal. Therefore, $A(0, f_d)$ is the result of $D(f)$ convolving discrete signals with period $1/T_s$. The normalized amplitude of the highest sub-peak is also -20dB around. The location of the sub-peaks generated by power difference is

$$P_{pd} = \left\{ (0, \frac{i}{T_s}) | i \neq 0, i \in Z \right\}$$

(6)

When $\tau \neq 0, f_d \neq 0$, there are no strong relativity between the signals, so no more sub-peaks will occur. Moreover, the sub-peaks generated by TPS are neglected in this paper because they are too weak.

### 4. Sub-peaks Suppression of the DTMB Signals

In this section, we consider sub-peaks suppression when computing the ambiguity function. From the above analysis, the repeated PN sequence and the power difference in DTMB frame structure cause sub-peaks. Therefore, it is not difficult to infer that in order to eliminate the periodic sub-peak interference, we just remove the correlation of the FH and the power difference between the FH and the FB. Accordingly, the idea of sub-peaks suppression is: sampled LFM signal with the same power of the frame body is adopted to replace the original PN sequence in DTMB signal reconstruction.

The ambiguity function calculation is essentially a processing of two dimensional cross-correlation between the target signal which added the target's delay and the Doppler information and the original signal without the target's information. Therefore, to ensure no duplicate segment between the two signals, we can just replace the repeated FH. Consider the reconstruction processing of the DTMB signal shown in Figure 2. The conventional reconstruction is the steps of synchronization, channel estimation, equalization, de-multiplexing and multiplexing, decoding and error correction [7]. When the correct bit stream is obtained, we generate the desired signal according to the signal forming steps at the transmitter. But note that in our scheme, the step of 'Insert PN frame header' is replaced by 'Insert sampled LFM signal' to mitigate the sub-peaks problem.
The replacement steps are as follows: first, sample the LFM signal; second, store the data; third, read the data out when reconstruction, and set their normalized power equal to the received reference signal; at last, insert them instead of PN sequence to form a complete signal.

5. Simulation Results
In this section, we present the sub-peaks suppression results of computing the ambiguity function. Simulation parameters are set as follows: the length of the LFM signal is 12.5ms, the sampling frequency of LFM is 7.56MHz, the amplitude is 1 and initial phase is 0, the accumulation time of DTMB signal T is 125ms.

Figure 3 shows the simulation results of adopting the original DTMB signal. As we can see, there are periodic sub-peaks in the figure which are not expected, so some solutions should be taken out to remove them. Figure 4 shows the result of setting PN sequence to zero which is proposed in [6]. As we can see, sub-peaks are mitigated mostly except for those caused by power difference. Accordingly, this method has limitations in real application. In comparison, the simulation result of adopting the sampled LFM signal instead of PN sequence is shown in Figure 5. From Figure 5, first, we can see that most of the sub-peaks are mitigated clearly by removing the repeated segments. Then, by setting the same power between the sampled signal and the FB, we mitigate the sub-peaks caused by power difference. Therefore, our method can drastically suppress the sub-peaks and outperform the method in [6] with better result.

6. Conclusion
In this paper, we proposed a sub-peaks suppression scheme based on DTMB signal. The expression of the ambiguity function is presented. The reason and the position of the sub-peaks generation are analysed in the paper. To tackle the sub-peaks problem, sampled Linear Frequency Modulation signal with the same power of the frame body is adopted to replace the original PN sequence in DTMB signal. The experimental results show that our proposed method can effectively mitigate the sub-peaks problem in passive detection. More kinds of signals used in passive detection will be studied in the future research.
Figure 3. Result of adopting the original signal.  Figure 4. Result of setting PN sequence to zero.

Figure 5. Result of adopting the sampled LFM signal.

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