1. Introduction

High data rate radio communication techniques are required for multimedia systems. Users can transmit and receive large volume of data in a short time without wires by using the radio communication systems. In general, the higher data rate systems occupy wider frequency bandwidth. However, the frequency bands for radio systems are limited and it is lacking. Therefore, the spectrum sharing techniques are attractive.

The cognitive radio is one of the spectrum sharing techniques that several radio systems use the frequency band dynamically\(^1\)\(^-\)\(^3\). In this system, communication terminals of the secondary system detect the usage of the primary systems and the resulting detected vacant frequency bands can then be used by the secondary system.

In the Ultra Wideband (UWB), it is also possible to share the spectrum with narrow band systems\(^4\)\(^-\)\(^6\). However, the Detect and Avoid (DAA) technique on the frequency band around 4GHz is required by the regulations in some countries to prevent interference by UWB systems affecting existing frequency allocation systems\(^7\)\(^-\)\(^8\).

The TV white space that is a vacant frequency band for terrestrial television broadcasting depending on the region is used as one of the cognitive radio systems\(^9\). In this system, kinds of the primary systems and the secondary systems are limited as the primary signal is the digital TV broadcasting, and the secondary systems are radio microphones and fixed wireless access systems. In this paper, it is assumed that the various kinds of primary and secondary systems share in the same frequency bands, considering frequency utilization for future.

To realize these spectrum sharing techniques, the primary systems detection technique is an important facility. It is necessary to detect the emissions from primary systems and their frequency bands to prevent interference with them. It is assumed that the detector is installed in the transmitter-receiver of the secondary systems, thus the detector structure should be simpler. Moreover, the technique should be able to detect various types of modulated signals, and the time for this detection must be kept short because of the rapid changes in radio conditions.

Energy detection is a conventional detection technique\(^10\). However, many band pass filters are needed to detect the frequency bands of the primary systems. Consequently, a filter band bank technique has been proposed\(^11\). The detection technique using Fast Fourier Transform (FFT) is often used\(^7\)\(^12\)\(^13\). In this technique,
the output of the FFT is compared with a threshold.

The future detection like matched filter based sensing, signature based sensing, waveform based sensing and cyclostationary based sensing have been proposed. By using those techniques, better detection performances can be obtained. However, the technique specialized for the particular kind of primary signal, and they cannot be applied for the various types of radio signals.

We have proposed detection techniques where correlation detection is applied. The wideband chirp signal and the multi-band pulse consisting of several sub-band pulses are prepared for the template signals and the received signal is correlated with the template waveform. Those techniques can detect various kinds of signals. For Orthogonal Frequency Division Multiplexing (OFDM) systems, the guard interval correlation was effective as the detection technique.

In this paper, a coexisting primary systems detection technique is proposed. The received primary signals are assumed to be the sum of the sinusoidal waves. The sinusoidal wave is detected in the received signal and successively subtracted from it. The frequency, phase and amplitude are estimated by minimizing the evaluation function using the Newton method. The detected amplitude is compared with a threshold to detect the emission of the primary system. By using the proposed technique, the frequency band of the primary signals is also detected. The Detection Error Rate (DER) and False Alarm Rate (FAR) are evaluated to show the effectiveness of the proposed detection technique.

As advantages of the proposed detection technique, the both the emission and frequency band of the primary signals can be detected. And, it can be applied for the various kinds of modulated signals without prior information of the primary signals. Thus, band pass filters are not needed for the proposed technique unlike the energy detection. Moreover, the DER and FAR performance are improved compared to the conventional technique using FFT.

This paper is organized as follows. In Section 2, we explain our proposed primary systems detection technique and coefficients of the detected sinusoidal signal estimation technique. The performance is evaluated and the effectiveness of the proposed scheme is discussed in Section 3. In Section 4, conclusions are given.

2. Coexisting Primary Systems Detection Technique

In this chapter, the primary systems detection technique is explained. In Fig.1, a model of frequency band is illustrated. Several primary systems consisting of several primary signals are allocated in the detection target band. The terminals of the secondary systems detect emitted primary signals and the secondary systems utilize the vacant frequency band. The detection target bandwidth is set as wider than the bandwidth of primary signals and vacant bandwidth.

2.1 Proposed Detection Scheme

The proposed detector structure is shown in Fig.2. In this paper, it is assumed that the coexisting primary signals are detected in the receiver of the secondary systems, and the primary signals are detected before beginning communication between the secondary systems. The received signal is then down-converted and sampled by t = nts as follows:

\[ r(n) = \sum_{m=1}^{M_i} h_m(n) * i_m(n) + z(n), \]  

where \( r(n) \) denotes the received signal, \( i_m(n) \) denotes the signals of the primary system, \( h_m(n) \) denotes the channel for the primary systems, \( z(n) \) denotes noise, \( M_i \) denotes the total number of primary signals in the detection target band and \( * \) denotes convolution.

In this study, an ideal received signal without noise is
assumed to be the sum of the sinusoidal waves as follows:
\[ i(n) = \sum_{k=1}^{K} \left( A_k \cos(2\pi f_k n + \phi_k) + j B_k \sin(2\pi f_k n + \phi_k) \right), \]  
(2)
where \( A_k \) and \( B_k \) are amplitude coefficients, \( f_k \) is a frequency coefficient, \( \phi_k \) and \( \phi_a \) are phase coefficients and \( K \) is the number of sinusoidal waves.

If the all sinusoidal signals are completely detected from the received signal in an ideal environment without noise, the following error function becomes zero:
\[ e = \sum_{n=0}^{N_t-1} |r(n) - \tilde{i}_k(n)|^2 = 0, \]  
(3)
where \( N_t \) is the number of sampling points for the detection. Therefore, Equation (3) should be set to zero to estimate the signal of the primary systems. However, it is difficult to derive \( K \) sets of \( A_k, B_k, \phi_k, \phi_a \) and \( \phi_a \) coefficients simultaneously, because there are too many coefficients.

First, the most powerful sinusoidal signal is found from the received signal and is expressed as follows:
\[ \tilde{i}_k(n) = A_k \cos(2\pi f_k n + \phi_k) + j B_k \sin(2\pi f_k n + \phi_k). \]  
(4)
The proposed scheme for detecting the highest power of the sinusoidal wave and the estimation scheme of the coefficients is described in Sections 2.2 and 2.3. The error is then given by:
\[ e_0 = \sum_{n=0}^{N_t-1} |r(n) - \tilde{i}_k(n)|^2. \]  
(5)
The most powerful sinusoidal signal is subtracted from the received signal as follows:
\[ r_1(n) = r(n) - \tilde{i}_k(n). \]  
(6)
Next, the second most powerful sinusoidal signal is found from \( r_1(n) \) as follows:
\[ \tilde{i}_k(n) = A_k \cos(2\pi f_k n + \phi_k) + j B_k \sin(2\pi f_k n + \phi_k). \]  
(7)
The error function and subtracted received signal then become:
\[ e_1 = \sum_{n=0}^{N_t-1} |r_1(n) - \tilde{i}_k(n)|^2, \]  
(8)
\[ r_2(n) = r_1(n) - \tilde{i}_k(n). \]  
(9)
The detection and subtraction processes are iterated. From these procedures, the sinusoidal signals are detected in the order of their power. The error can be derived as follows:
\[ e_i = \sum_{n=0}^{N_t-1} |r_i(n) - \tilde{i}_k(n)|^2. \]  
(10)
This equation is used as an evaluation function.

The detection of the sinusoidal waves is terminated when the error function becomes smaller than the criterion value \( c_i \). The \( c_i \) is set a sufficiently small value comparing to the power of the received signal.

After detection, the \( K_{di} \) sets of coefficients are obtained, where \( K_{di} \) denotes the number of iterations. The amplitude coefficients are then compared with the threshold values to detect the emission of the primary signals.
\[ \sqrt{A_k^2 + B_k^2} > \text{threshold}. \]  
(11)

The frequency of the primary signals is determined by the frequency coefficient corresponding to the amplitude coefficients. In the proposed primary systems detection scheme, it is necessary to estimate the coefficients precisely to minimize the evaluation function.

### 2.2 Frequency Estimation

In this section, the scheme to detect the most powerful sinusoidal signal from the received signal, and its frequency estimation technique, are explained. The coefficients of the sinusoidal signal are estimated from the frequency, followed by the estimation of the amplitude and phase coefficients.

When the frequency of the coexisting primary signal is detected, energy detection using the Discrete Fourier Transform (DFT) or FFT process is often used. The equation for the DFT is expressed as follows:
\[ |H_k|^2 = \frac{1}{N} \sum_{n=0}^{N_t-1} |r(n) \exp(-j2\pi f_k n)|^2. \]  
(12)
However, \( f_k \) becomes multiple numbers of \( 1/t_s \), where \( t_s \) denotes the signal duration for the detection and \( t_s = t_s (N_t-1). \) Thus, the signal length should be longer to detect the frequency precisely.

In this study, a frequency estimation scheme to obtain better performance in a shorter detection time is proposed. \( |H_k|^2 \) is differentiated partially by \( f_k \):
\[ \frac{\partial |H_k|^2}{\partial f_k} = \frac{j2\pi}{N} \sum_{n=0}^{N_t-1} r(n) \exp(-j2\pi f_k n) \sum_{n=0}^{N_t-1} \overline{r(n)} \exp(-j2\pi f_k n) \]  
\[-\sum_{n=0}^{N_t-1} r(n) \exp(-j2\pi f_k n) \sum_{n=0}^{N_t-1} \overline{r(n)} \exp(j2\pi f_k n) \right] = 0. \]  
(13)
When Equation (13) is equated to zero, the signal power reaches its extreme value. \( f_k \) is derived using the Newton method as follows:
\[ f_k \leftarrow f_k - \frac{\partial |H_k|^2}{\partial f_k} \cdot \frac{\partial |H_k|^2}{\partial f_k^2}. \]  
(14)

An initial value of \( f_k \) is set as the maximum value of \( |H_k|^2 \) in Equation (12). Thus, the number of iterations in Equation (14) reduces. Moreover, in an ideal environment without noise, \( f_k \) does not converge to the local minimum. In the proposed scheme, the frequency can be
better estimated in a shorter observation time.

In Ref. (23), the interpolation technique is used to decrease the number of iterations for the Newton method. The technique assumes that the analyzed signal is only made up of sinusoidal waves. Moreover, the objective of the referenced paper is to estimate the frequency of the signal. In this study, the emission of the primary signals detection technique is proposed to obtain better DER and FAR performances with lower complexity. And, the primary signals that are various types of modulated signals must be detected to employ the spectrum sharing technique. Therefore, the interpolation is not adopted.

### 2.3 Amplitude and Phase Estimation

In this section, the amplitude and phase estimation scheme is explained. It is performed after frequency estimation.

First, the real part of the evaluation function is considered as follows:

\[
\text{Re}[e_i] = \sum_{n=0}^{N-1} \text{Re}[r(n)] - A_k \cos(2\pi f_i n t_s + \phi_{ak}) \]

To minimize Equation (15), it is differentiated partially by \(A_k\) and the result is zeroed as follows:

\[
\frac{\partial \text{Re}[e_i]}{\partial A_k} = 2 \sum_{n=0}^{N-1} \{A_k \cos^2(2\pi f_i n t_s + \phi_{ak}) - \text{Re}[r(n)] \cos(2\pi f_i n t_s + \phi_{ak})\} = 0.
\]

Thus, \(A_k\) becomes:

\[
A_k = \frac{\sum_{n=0}^{N-1} \text{Re}[r(n)] \cos(2\pi f_i n t_s + \phi_{ak})}{\sum_{n=0}^{N-1} \cos^2(2\pi f_i n t_s + \phi_{ak})}.
\]  
(17)

The evaluation function is also differentiated partially by \(\phi_{ak}\) and is zeroed as follows:

\[
\frac{\partial \text{Re}[e_i]}{\partial \phi_{ak}} = 2 \sum_{n=0}^{N-1} \{A_k \sin(2\pi f_i n t_s + \phi_{ak}) - \text{Re}[r(n)] \sin(2\pi f_i n t_s + \phi_{ak})\} = 0.
\]

Equation (17) is substituted into Equation (18). \(\phi_{ak}\) is derived by the Newton method as follows:

\[
\phi_{ak} \leftarrow \phi_{ak} - \frac{\frac{\partial \text{Re}[e_i]}{\partial \phi_{ak}}}{\frac{\partial^2 \text{Re}[e_i]}{\partial \phi_{ak}^2}}.
\]  
(19)

The calculated \(\phi_{ak}\) is substituted into Equation (16) and \(A_k\) is derived.

\(B_k\) and \(\phi_{ak}\) can be derived from the imaginary part of the evaluation function as well as the real part. The imaginary part of the evaluation function is expressed as follows:

\[
\text{Im}[e_i] = \sum_{n=0}^{N-1} \text{Im}[r(n)] - B_k \sin(2\pi f_i n t_s + \phi_{bk})\]

(20)

The equation is differentiated partially by \(B_k\) and the result is zeroed as follows:

\[
\frac{\partial \text{Im}[e_i]}{\partial B_k} = 2 \sum_{n=0}^{N-1} \{B_k \sin^2(2\pi f_i n t_s + \phi_{ak}) - \text{Im}[r(n)] \sin(2\pi f_i n t_s + \phi_{ak})\} = 0.
\]

\(B_k\) becomes:

\[
B_k = \frac{\sum_{n=0}^{N-1} \{\text{Im}[r(n)] \sin(2\pi f_i n t_s + \phi_{ak})\}}{\sum_{n=0}^{N-1} \sin^2(2\pi f_i n t_s + \phi_{bk})}.
\]  
(22)

The evaluation function is also differentiated partially by \(\phi_{bk}\) as follows:

\[
\frac{\partial \text{Im}[e_i]}{\partial \phi_{bk}} = -2B_k \sum_{n=0}^{N-1} \cos(2\pi f_i n t_s + \phi_{ak})\]

\[
\{\text{Im}[r(n)] - B_k \sin(2\pi f_i n t_s + \phi_{ak})\} = 0.
\]

\(B_k\) is substituted into Equation (23) and \(\phi_{bk}\) is derived by the Newton method as follows:

\[
\phi_{bk} \leftarrow \phi_{bk} - \frac{\frac{\partial \text{Im}[e_i]}{\partial \phi_{bk}}}{\frac{\partial^2 \text{Im}[e_i]}{\partial \phi_{bk}^2}}.
\]  
(24)

\(\phi_{bk}\) is substituted into Equation (22) and \(B_k\) is derived.

From these procedures, the amplitude and phase can be derived. The detected primary signals can be re-constructed as Equation (2) using the estimated coefficients.

The processes of the coefficient estimation and subtraction from the received signal are iterated until all signals of the primary systems are detected.

### 2.4 Ordinary Technique using FFT

In this section, the ordinary technique is described to compare its performance with that of the proposed technique\(^{12}\). As the ordinary technique, the detection scheme using the FFT is considered, because the technique can detect various types of modulated signals and their frequency band.

The received signal is down-converted and sampled similarly to the proposed scheme. The signal is processed using the DFT (or FFT) as expressed in Equation (12). To detect the emission of the coexisting primary signals, the amplitude of the FFT output is compared with the threshold as follows:

\[|H_k| > \text{threshold}.
\]  
(25)

The frequency of the primary signal is decided on the
basis of the corresponding $|H_k|$. Therefore, the performance of frequency estimation is dependent on the bandwidth of the FFT bin.

$A_k$ and $B_k$ define the real and imaginary parts of $H_k$. The phase coefficients are derived from when the evaluation function becomes a minimum using $A_k$, $B_k$, and $f_k$.

3. Performance Evaluation

In this chapter, the performances of the frequency, phase and amplitude coefficients are evaluated by computer simulation to discuss the effectiveness of the proposed primary systems detection technique. First, the simpler model that the primary signal is a CW (Continuous Wave) is considered to verify the proposed detection technique and the coefficients estimation technique. After that, the proposed technique is used for when the primary signal is a modulated signal for radio systems.

3.1 Coefficient Estimation for Continuous Wave

The performance for the estimation of the frequency, phase and amplitude coefficients was evaluated. This was performed for a Continuous Wave (CW) emitted in the detection target band.

The performances were evaluated using the Root Mean Square Error (RMSE), determined by:

\[
RMSE = \sqrt{\frac{1}{M} \sum_{n=0}^{M-1} (x_n - x_m)^2},
\]

where $x_n$ is the true value, $x_m$ is the detected value. Thus, the RMSE has the same meaning as the standard deviation of the error when the mean error is the same as the true value. The primary signal to noise ratio (PSNR) is defined as the averaged power ratio over a sufficiently long period until the measured power of both the primary signal and noise converge.

The setting values for primary systems detection are shown in Table 1. The detection target bandwidth ($B_d$) was set wider because it was assumed that the technique was applied to the DAA technique in the UWB system. The received signal was double precision sampled to avoid aliasing, thus $t_s = 1/2B_d$. The signal duration for the detection was set at 100 ns and 1000 ns, corresponding to bandwidths for the FFT bin of 10MHz and 1MHz. The loop termination condition for the Newton method was set to a sufficiently low value not to affect the performance against the PSNR. In this simulation, the condition value was set at $10^{-6}$ times the interval in which the initial value of the Newton method was decided.

In Fig.3, the performances of the frequency, phase

\begin{table}[h]
\centering
\caption{Setting Values for the Primary Systems Detector.}
\begin{tabular}{|c|c|}
\hline
Detection Bandwidth: $B_d$ & 2GHz \\
Sampling Interval: $t_s$ & 0.25ns \\
Signal Duration for Detection: $(N-1)/\nu$ & 100ns 1000ns \\
FFT bin: $B=1$ & 10MHz 1MHz \\
Sampling Points: $N=1/2B_d+1$ & 401 4001 \\
\hline
\end{tabular}
\end{table}

\begin{figure}[h]
\centering
\includegraphics{fig3.png}
\caption{Estimation Results for the Coefficients of the Sinusoidal Signal.}
\end{figure}
and amplitude coefficient estimations are shown. The setting value used was $t_i = 100$ ns in Table 1. The frequency band of the CW was random in the detection target band. The ordinary scheme that is explained in Section 2.4 was also evaluated to compare the performance of the proposed system. The settings of the ordinary scheme were also set to the same as the proposed scheme. In Fig.3(a), the estimation performance of the frequency is shown. In the ordinary scheme, the absolute error converged from 0 to $\frac{B_{fft}}{2}$ in uniform distribution. The standard deviation of the uniform distribution from 0 to $x_a$ is expressed as follows:

$$D(x) = \sqrt{\int_0^1 f(x) \left( x - E(x) \right)^2 \, dx}$$

where $f(x)$ denotes the probability distribution function and $E(x)$ denotes expectation value. In this case, $f(x) = \frac{1}{x_a}$, $E(x) = \frac{x_a}{2}$ and $x_a = \frac{B_{fft}}{2}$. The RMSE is now expressed as follows because it is the same as the standard deviation:

$$\text{RMSE} = \frac{B_{fft}}{\sqrt{48}}.$$  \hspace{1cm} (28)

From the figure, the converged value corresponds to Equation (28). On the other hand, the performance of the proposed system did not reach the error floor until the PSNR = 10dB. The RMSE of the frequency became smaller by about an order around a PSNR = 0dB. Therefore, the performance improved when using the proposed system.

The results of phase estimation are shown in Fig.3(b). In the ordinary system, it was difficult to estimate the phase because the error in frequency estimation was too large. The RMSE corresponded to Equation (27) with $x_a = \frac{\pi}{2}$. In the proposed system, the RMSE became smaller, increasing the PSNR. Therefore, the performance of proposed system was also better than the ordinary system.

The performance of amplitude estimation is shown in Fig.3(c). The average power of the detected CW was normalized to one in this simulation. As a result, the performance was also better when using the proposed system.

The performance of the coexisting primary systems detection technique depended on the amplitude estimation. Thus, the Probability Density Function (PDF) of the estimated amplitude of the CW and noise were examined and shown in Fig.4. The durations for the detection signals were set at 100 ns and 1000 ns as shown in Figs.4(a) and (b). The average powers of both the signal and noise were normalized to one. There were 10,000 trials and the interval for the amplitude was set at 0.01.

First, the PDF for detecting the CW is discussed. The ordinary system had the potential to detect smaller amplitudes than the CW which was limited by the rectangular window function before the FFT and the spectrum after the FFT became a sinc function. The detected amplitude depended on the center frequency of the CW. The best and worst cases are shown in Fig.5. The best case was obtained when $f_{sc} = B_{fft} n_a$, whereas the worst case was obtained when $f_{sc} = B_{fft} (n_a + 1/2)$, where $f_{sc}$ is the center frequency of the CW and $n_a$ denotes an integer when $|f_{sc} - B_{fft} n_a|$ reached a minimum. Thus, the amplitude detected by the ordinary technique is expressed as follows:

$$\sqrt{A_{sk} + B_{sk}} = \sqrt{A_{sk} + B_{sk}} \text{sinc}(r),$$

$$r = \frac{f_{sc} - B_{fft} n_a}{B_{fft}},$$

where, $A_{sk}$ and $B_{sk}$ denote the actual amplitude of the CW, and $r$ changes from $-1/2$ to $1/2$. Therefore, the maximum amplitude was 2 and minimum amplitude was $2\text{sinc}(\pm 1/2)$.
as illustrated by the PDF in Fig.4. When using the proposed system, the amplitude could be detected precisely in the ideal environment without noise. Therefore, the detection error became much smaller.

Next, the PDF of detecting the noise is discussed. The PDFs detected by both schemes were almost the same as shown in Fig.4. Therefore, the detection performance was improved when using the proposed system. The variation became smaller when the signal duration for detection was longer. Thus, the performance for \( t_l = 1000 \) ns was better than for \( t_l = 100 \) ns.

### 3.2 Continuous Wave Detection

In this section, the primary system detection performance is evaluated using the simulation when the signal of the primary system is a CW.

In Fig.6, the FAR and DER are evaluated by changing threshold. The setting values in Table 1 are also used. The center frequency of the primary signal is emitted at random in the detection target band. The DER is determined so that a primary signal cannot be detected when the signal has already been emitted. Whereas, the FAR indicates the miss-judgment that a primary signal is detected when it has not actually been emitted. In general, when the threshold is set lower, the DER improves, however the FAR becomes worse. Thus, in actual detection system, the threshold is decided first to satisfy with the criteria of the DER performance not to interfere with the primary signals. Then, the FAR is automatically decided. If the FAR is higher, the secondary system cannot be utilized. Thus, both the DER and FAR performance needs to be improved for the detection technique.

When using the proposed primary systems detection scheme, both the DER and FAR are improved for signal durations \( t_l \) of 100 ns and 1000 ns. Therefore, the proposed technique is effective when the primary system is a CW because its amplitude can be detected precisely using the proposed technique, and the primary signal to noise power ratio after detection can increase, as described in the previous section. When \( t_l \) equals 1000 ns, the DER and FAR performances improve against the PSNR since the bandwidth of the FFT bin is narrower and the variation of the amplitude of noise becomes smaller.

### 3.3 OFDM Modulated Signal Detection

In the previous section, the detection performance is improved by using the proposed technique. In this section, the technique is applied to the Orthogonal Frequency Division Multiplexing (OFDM) modulated signal that is used for high data rate mobile systems such as the Worldwide Interoperability for Microwave Access (WiMAX) and Long Term Evolution (LTE) systems. The parameters of the OFDM signal are shown in Table 2. The parameters used are from the WiMAX parameters\(^{25} \). The primary modulation is the QPSK.

The estimation and detection of the coefficients of the sinusoidal signal for the modulated signal are iterated until the error between the received signal and the

### Table 2 Parameters of the OFDM signal.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth: ( BW )</td>
<td>1.25MHz / 5MHz / 10MHz / 20MHz</td>
</tr>
<tr>
<td>Number of Sub-Carriers: ( N_c )</td>
<td>128 / 512 / 1024 / 2048</td>
</tr>
<tr>
<td>IFFT/FFT Duration: ( T_{FFT} )</td>
<td>91.4 ns</td>
</tr>
<tr>
<td>Guard Interval Duration: ( T_{GI} )</td>
<td>11.4 us</td>
</tr>
<tr>
<td>Symbol Duration: ( T_{SYM} = T_{FFT} + T_{GI} )</td>
<td>102.8 us</td>
</tr>
</tbody>
</table>

---

Fig.5 The Case for Detecting the Maximum and Minimum Amplitudes in the Ordinary System.

Fig.6 Coexisting Primary Systems Detection Performance. (Primary system is a CW).
reconstructed signal becomes sufficiently small in Equation (10). In this simulation, the condition is set at $c_v = 0.1$ when the total powers of the received and reconstructed signals are normalized to one.

In Fig. 7, the FAR and DER performances are shown. The signal duration is 100 ns and 1000 ns with PSNRs of –6 dB and –15 dB in Fig. 7 (a) and (b). When $t_l$ equals 100 ns, the performance depends on the bandwidth of the OFDM signal. The FFT bin ($B_{fft}$) becomes 10 MHz, thus the bandwidth of the OFDM signal is less than three times of the FFT bin even if the signal bandwidth is 20MHz. The performances improve in both the proposed and ordinary detection schemes when the primary signal has a wider bandwidth. Notice that the performance is improved when using the proposed scheme compared with the performance of the ordinary detection scheme using FFT.

When $t_l$ is 1000 ns and $B_{fft}$ is 1 MHz, the curve of the performance for the bandwidth of the OFDM signal is 1.25 MHz different from other bandwidth OFDM signals. When the FAR is higher, the lower threshold is utilized for detection. Then, the DER of $BW=1.25$ MHz becomes higher than other OFDM signals as well as Fig. 7 (a). When the FAR is lower, the higher threshold is used. When the bandwidth of the OFDM signal is much wider than the bandwidth of the FFT bin, the power of the OFDM signal is divided to many FFT bins in the ordinary system. In the proposed system, the number of sinusoidal signals becomes more from the OFDM signal. Thus, the detected amplitude becomes lower and the detection performance is deteriorated when the bandwidth of the OFDM signal is wider and the FAR is lower. The detection performance improves when the bandwidth of the FFT bin is narrower, since average noise variation is smaller as shown in Fig. 4. In this context, the detection performance has also improved when using the proposed scheme.

With regard to the simulation results of the OFDM signal, the DER and FAR performances are also improved since the primary signal is a CW. Consequently the proposed technique is effective for detecting the primary systems.

4. Conclusion

In this study, a coexisting primary systems detection technique in the same frequency band is proposed for the spectrum sharing technique in radio systems. In the proposed system, the primary signals are assumed to be the sum of the sinusoidal signals. The sinusoidal signals are detected in the order of the larger power signals and the detected signals are successively subtracted from the received signal. The frequency, phase and amplitude coefficients are then estimated by minimizing the evaluation function using the Newton method. The amplitude coefficient is compared with a threshold to detect the emission of the primary signals. The frequency band of the primary signals can also be detected. From the simulation results, the detection performances are improved compared with the ordinary scheme using the FFT, because the amplitude of the signal is estimated precisely. The proposed technique can be applied for the various kinds of modulated signals without prior information of the primary systems. Therefore, the proposed technique is effective for the coexisting primary systems detection technique and is expected to help the spectrum sharing techniques.

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