Multimode Receiver | Cognitive Radio | Image-band Interference Canceler

Collaboration Projects

Multimode Receiver with an RF Receiver Chain

With the aim of making more efficient use of the radio spectrum through the future technology of cognitive radio, we have researched the development of a multimode receiver that can support any frequency band and radio transmission system on a single mobile terminal. This research was conducted jointly with the Graduate School of Informatics (Associate Professor Satoshi Denno) , Kyoto University.

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1. Introduction

Mobile terminals need to support multiple frequency bands and radio systems on a single terminal. For example, Third-Generation mobile communication systems were initially limited to the 2 GHz band, but they have come to include the 800 MHz band and 1.7 GHz band to accommodate a dramatic increase in users. Furthermore, to accommodate users who wish to use their terminals overseas, mobile terminals must be able to support even more frequency bands (multiband terminals).

Likewise, as the conventional W-CDMA system comes to be supplemented by the High Speed Packet Access (HSPA) system to provide higher transmission speeds and GSM for overseas markets, mobile terminals also need to support multiple radio transmission systems (multimode terminals).

New radio systems like Super3G (Long Term Evolution (LTE)*1) and IMT-Advanced and new frequency bands are also being studied for future use, which means even more systems and bands that mobile terminals will be expected to support. In addition, mobile terminals are coming to be equipped with a variety of add-on radio functions such as One Seg broadcast reception, wireless LAN, and Bluetooth®*2. In short, terminals are being required to incorporate an especially large number of radio functions relative to the allowable circuit scale.

At the same time, if we consider such multiband/multimode receivers (hereinafter referred to as "multimode receivers") from the viewpoint of frequency usage, they play an important role in leveling frequency-usage conditions so that traffic does not concentrate in one frequency band. Since there is a limited amount of spectrum that can be used by mobile communications, there is growing concern that frequency resources will eventually dry up, and efficient use of the radio spectrum has become an important issue as a result. Cognitive radio [1], which has recently gathered much attention as a means of enabling efficient use of the radio spectrum, is a technology that enables a radio device to become aware of the surrounding radio environment and to use those radio resources (frequency, time, space) that are currently available in an autonomous manner. Achieving cognitive radio will require receivers that can operate under any frequency,

*1 **LTE**: An evolutional standard of the Third-Generation mobile communication system specified at 3GPP; LTE is synonymous with Super3G proposed by NTT DOCOMO.

*2 **Bluetooth®**: A short-range wireless communication specification for wireless connection of mobile terminals, notebook computers, PDAs, and other portable terminals.

bandwidth, or radio system. These receivers will have to have a more flexible configuration than existing multimode receivers that can receive only a previously determined set of frequency bands or radio systems exceeding no more than two or three bands. One hurdle to cognitive radio is the configuration of the Radio Frequency (RF) analog radio section that cannot, at this point in time, be digitized.

Against the above background, we have studied a receiver configuration that removes the RF filter (for converting to broadband) and makes the RF analog radio section available for common use by multiple frequency bands. This configuration can make for a more flexible receiver overall since the RF analog radio section requires no complex functions or processing. Here, however, a new issue arises as the interference that up until now had been suppressed by the RF filter must now be removed.

In this article, we propose a receiver configuration that can cancel interference without the use of an RF filter. We also propose an algorithm for achieving ideal interference-cancelation characteristics by estimating and compensating for error in the analog devices making up the receiver and describe its effect. This research was conducted jointly with Associate Professor Satoshi Denno of Kyoto University.

2. Conventional Technology

Various technologies for giving a single receiver multimode capabilities have been proposed [2][3]. In principle, the receiver's RF filter must be removed (the receiver must be converted to broadband) to achieve a multimode receiver that can receive signals in any frequency band. A frequency conversion system must also be studied so that signals in any frequency band can be received.

Frequency conversion systems include the heterodyne system, which converts the received RF signal to a baseband signal only after the former has been converted to an Intermediate Frequency (IF) band, and the direct conversion system, which, as the name implies, converts the RF signal directly to a baseband signal.

The direct conversion system uses no IF circuits and is therefore conducive to a compact circuit configuration. This system has come to be applied to mobile terminals in recent years. In principle, the direct conversion system can be achieved without the use of an RF filter, and as such, it is expected to be used for constructing highly flexible circuits. On the other hand, the direct conversion system suffers from DC offset[*3], and various studies [4] have been performed to mitigate this issue. In the end, however, the application of the DC-offset-reduction technologies resulting from those studies requires the use of an RF filter. In contrast, the heterodyne system performs frequency conversion in two stages and, as a result, circuit scale is relatively large. However, as amplification and filtering are repeated in multiple steps, high gain and frequency selectivity can be obtained without falling into an unstable operating state such as oscillation, which facilitates stable amplification in the mobile environment. If, however, the RF filter is removed from the receiver, image-band interference[*4] that cannot be removed by the IF filter can occur and create an issue. A configuration that uses a Hilbert Transformer (HT) in the frequency-conversion step from RF to IF has been proposed as a technique for canceling this image-band interference [5].

Achieving a multimode receiver using this HT requires that the HT operates ideally across a wide reception band. However, as the HT must be able to operate in the RF band, it must be configured by analog devices under existing technology, but since errors can occur in the HT due to imperfections in analog devices, image-band interference can remain.

To cancel this residual interference, a method has been proposed to compensate converter error adaptively based on the Constant Modulus (CM) criterion, but this approach requires tens

*3 **DC offset**: For a signal component originally centered about a voltage of 0 V, this is the offset of this center voltage due to the application of a DC component. It causes a decode error of digital signals.

*4 **Image-band interference**: In a heterodyne system, interference due to a signal having a frequency (image frequency) superimposed on the desired signal after frequency conversion. If the frequency of the desired signal (f_R) is related to the local oscillator frequency (f_L) and the intermediate frequency (f_{IF}) by $f_R = f_L + f_{IF}$, then $f_L - f_{IF}$ is the image frequency.

of thousands of symbols for convergence in the compensator. Also proposed for the baseband section is a method for canceling this interference using a linear adaptive filter based on the Minimum Mean Square Error (MMSE) criterion. In this method, pilot signals are required, but if they cannot be detected because of strong interference, the system will not be able to compensate for the image-band interference.

3. Proposed System and Operating Principle

Although image-band interference is a receive signal having a frequency different than that of the desired signal, it becomes superimposed on the receive band in the IF step as a result of frequency conversion. We can therefore consider cases in which image-band interference has a somewhat larger receive power than that of the desired signal. Such intense image-band interference will make it even more difficult to receive the pilot signals of the desired receive signal.

The proposed system makes use of the fact that the desired receive signal and the image-band interference signal are uncorrelated and estimates error in the HT from the results of calculating the correlation matrix. This is called the deterministic cancelation matrix estimation method. Compensating for HT error in this way and having the HT operate in an ideal manner enables image-band interference to be canceled.

The configuration of the proposed receiver is shown in **Figure 1** and that of the HT used in the receiver is shown in **Figure 2**.

The HT is used to make a frequency conversion from RF to IF. It enables the RF signal to be handled as a complex signal consisting of an in-phase component and a quadrature-phase component.

The proposed receiver converts RF signals to IF signals by the HT after which interference signals that include image-band interference will be removed by the Band Pass Filter (BPF). However, if the HT includes error at this time, image-band interference will remain. Thus, the signal passing through the BPF is now passed through a compensation-matrix weight multiplier (W) to compensate for this error, and the IF signal passed through W is now converted to a baseband signal by two complex frequency converters. Next, deterministic cancelation matrix estimation is performed by an algorithm that we have proposed based on these two converted baseband signals and the compensation matrix is determined. This matrix is applied to W in order to cancel the residual components of image-band interference due to error in the HT.

The compensation-matrix estimation algorithm defines the receive-signal vector u(k) by equation (1) whose elements are the signals obtained by subjecting the outputs from the two complex-frequency converters to Analog/Digital (A/D) conversion.

$$u(k)=\begin{pmatrix} Z_1(k) \\ Z_2(k) \end{pmatrix} = G_{BB}\begin{pmatrix} \sum_{m=0}^{M_1-1} h_{1,m}S_1(k-m)+n_1(k) \\ \sum_{m=0}^{M_2-1} h^*_{2,m}S^*_2(k-m)+n^*_2(k) \end{pmatrix} \quad (1)$$

Here, $h_{i,m}$ is the channel impulse response of the receive signal, $S_i(k)$ is the transmission signal, $n_i(k)$ is Addi-

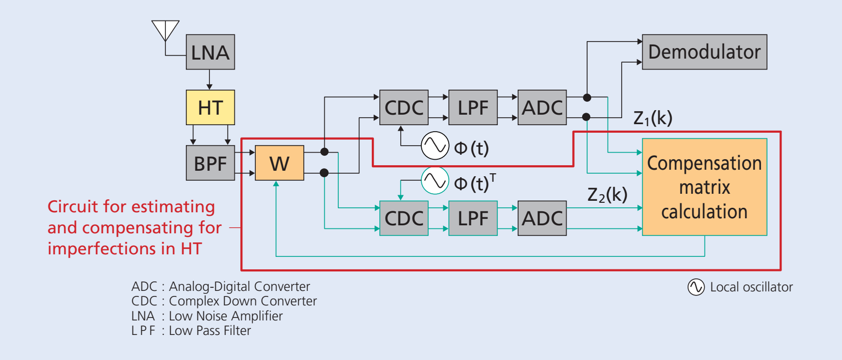

Figure 1 Configuration of proposed receiver

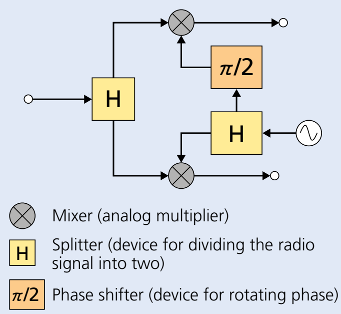

Figure 2 Configuration of HT based on analog devices

tive White Gaussian Noise (AWGN), i = 1 denotes desired frequency band, and i = 2 denotes the image frequency band. In addition, G_{BB} is the baseband error matrix defined by equation (2), and α, β are error coefficients determined from amplitude error and phase error.

$$G_{BB}=\begin{pmatrix}\beta & \alpha \\ \alpha^* & \beta^*\end{pmatrix} \quad (2)$$

Correlation matrix R is given by equation (3) in terms of u(k).

$$R=E\left[u(k)u(k)^H\right] \quad (3)$$

Here, E [·] represents expected value. Using the fact that the desired signal and image-band interference signal are uncorrelated, R can also be given by equation (4).

$$R=\begin{pmatrix}\beta & \alpha \\ \alpha^* & \beta^*\end{pmatrix}\begin{pmatrix}\sigma_1^2 & 0 \\ 0 & \sigma_2^2\end{pmatrix}\begin{pmatrix}\beta^* & \alpha \\ \alpha^* & \beta\end{pmatrix} \quad (4)$$

Here, σ_i^2 ; i = 1, 2 is the receive power of the desired frequency band and the image frequency band as given by equation (5).

$$\sigma_i^2=E\left[\left|\sum_{m=0}^{M_i-1} h_{i,m}S_i(k-m)+n_i(k)\right|^2\right] \quad (5)$$
$$i=1, 2$$

The proposed algorithm determines a relational expression involving error coefficients α, β from the observed correlation matrix R and sequentially determines those elements of the compensation matrix that need to be updated. The mathematical expression is omitted here, but we refer the reader to [6] for details.

An advantage of the proposed receiver is that signal demodulation or synchronization is not needed since correlation calculations are used for estimating the compensation matrix. The receiver operates stably and converges quickly even for a particularly strong image-band interference signal. Moreover, as the receiver makes use of the property that no correlation exists between the desired signal to be demodulated and the image-band interference signal, the receiver operates whether either one of these two signals constitutes noise or if they both do.

4. Performance Evaluation

The proposed receiver is independent, in principal, of the radio system, but to evaluate performance, we performed a computer simulation assuming dual-mode reception of Orthogonal Frequency Division Multiplexing (OFDM)*5 and Code Division Multiplexing (CDM). The transmission path was assumed to follow the multi-path Rayleigh fading*6 model. Simulation parameters are shown in **Table 1**.

Bit Error Rate (BER) characteristics versus Carrier to Interference Ratio (CIR) are shown in **Figure 3** and BER characteristics versus E_b/N_0 (signal to noise power ratio per bit) are shown in **Figure 4**. Here, CIR is the power ratio of the desired signal (C) to image-band interference (I). A CIR of -80 dB denotes that the power of image-band interference is 80 dB higher than that of the desired signal. These results show that, without the proposed compensation, BER increases as CIR becomes smaller, but that, with the proposed receiver, image-band interference can be completely canceled even in a poor environment of CIR = –80 dB. They also show that an interference cancelation effect can be obtained with the proposed system regardless of using

Table 1 Simulation parameters

	OFDM	CDM
Modulation	BPSK	BPSK
Transmission path model	Quasi-static multi-path Rayleigh fading channel	
Number of paths	10	2
Spread code length	1	128
Multiplicity	1	5
Number of carriers	256	1

BPSK : Binary Phase Shift Keying

*5 **OFDM**: A digital modulation system developed to improve resistance to multi-path interference. It converts a signal with a high data rate to multiple low-speed narrow-band signals and transmits those signals in parallel along the frequency axis. OFDM enables signal transmission with high spectrum efficiency.

*6 **Multi-path Rayleigh fading**: A phenomenon by which radio signals emitted from a transmit point traverse multiple transmission paths (multi-path transmission) and combine at a moving receive point resulting in severely fluctuating receive levels. It is known that this statistical fluctuation distribution approximates a Rayleigh distribution especially in a non-line of sight propagation environment.

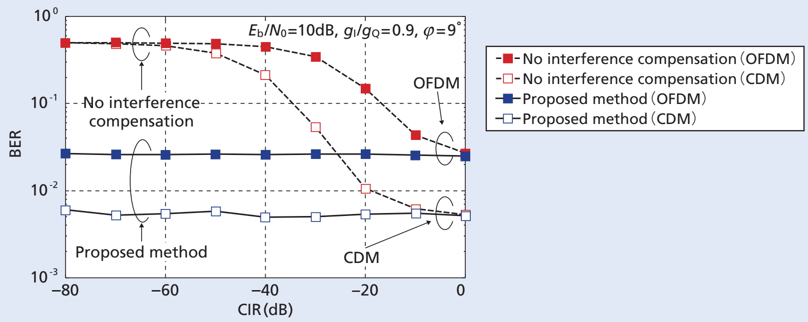

Figure 3 BER versus CIR

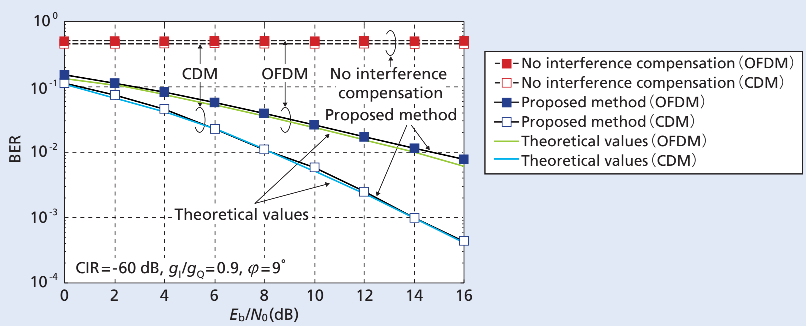

Figure 4 BER versus E_b/N_0

OFDM, CDM, or other radio systems.

5. Conclusion

Image-band interference can be a major issue to achieving a heterodyne multimode receiver capable of receiving any frequency. In this article, we have proposed a method for estimating error in an HT and compensating for that error at high speed without the use of pilot signals or other known signals, and achieving ideal interference cancelation characteristics in the process. The proposed method performs two complex frequency conversions and uses the autocorrelation matrix of those output vectors to deterministically estimate the cancelation matrix. Computer simulations have shown that the proposed method operates at high speed regardless of the radio system used such as OFDM or CDM, and that it can achieve the theoretical values corresponding to no interference even under strong image-band interference of 70 – 80 dB. In future research, we plan to study a method that can cancel both image-band interference and co-channel interference at the same time.

References

[1] J. Mitola III and G. Q. Maguire Jr.: "Cognitive radio: making software radios more personal," IEEE Personal Commun., Vol. 6, No. 4, pp. 13-18, Aug.1999.

[2] J. Ryynanen, S. Lindfors, K. Stadius and K. A. I. Halonen: "Integrated circuits for multi-band multi-mode receivers," IEEE Circuits Syst. Mag., Vol. 6, No. 2, pp. 5-16, Jul. 2006.

[3] M. Gustafsson, A. Parssinen, P. Bjorksten, M. Makitalo, A. Uusitalo, S. Kallioinen, J. Hallivuori, P. Korpi, S. Rintamaki, I. Urvas, T. Saarela and T. Suhonen: "A Low Noise Figure 1.2-V CMOS GPS Receiver Integrated as a Part of a Multimode Receiver," IEEE J. Solid-State Circuits, Vol. 42, No. 7, pp. 1492-1500, Jul. 2007.

[4] J. J. Liu, M. A. Do, X. P. Yu, K. S. Yeo, S. Jiang and J. G. Ma: "CMOS even harmonic switching mixer for direct conversion receivers," J. Circuits Syst. Comput., Vol. 15, No. 2, pp. 183-196, Apr. 2006.

[5] J. R. Long: "A low voltage 5.1-5.8-GHz image-reject downconverter RF IC," IEEE J. Solid-State Circuits, Vol. 35, No. 9, pp. 1320-1328, Sep. 2000.

[6] D. Hayashi, S. Denno, T. Furuno and M. Morikura: "A Deterministic Cancellation Matrix Estimation Scheme in Heterodyne Multimode Receivers," IEICE Trans. on Commun. B. Vol. J91-B No. 11 pp. 1440-1449, Nov. 2008.