Multimode Reception Technology Using a Common RF Circuit – Heterodyne Reception with Image-band Interference Canceller –

With an increasing demand for mobile terminals equipped with a variety of radio functions, we investigated the issues involved in developing common hardware for the radio section to achieve multimode receivers that can receive signals from multiple radio systems. This research was conducted jointly with the Morihiro Lab (Associate Professor Satoshi Denno), Graduate School of Informatics, Kyoto University.

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1. Introduction

There is an increasing demand to downsize mobile terminals while also equipping them with multiple radio functions. FOMA terminals, for example, are to be equipped with communication functions supporting High Speed Downlink Packet Access (HSDPA)[*1], a high-speed data communications system commenced in August 2006, in addition to basic W-CDMA communication functions. Other high-speed communication systems such as Super 3G are also being studied for future use, which means that new radio functions will have to be provided every time a new communication system is developed. Furthermore, mobile terminals will have to be equipped with supplementary radio functions to support such diverse services as “One-Seg” (one segment) digital terrestrial TV broadcasts, Global Positioning System (GPS), and wireless LAN. There will therefore be a need for functions that can receive radio signals of various frequencies corresponding to each of these radio functions.

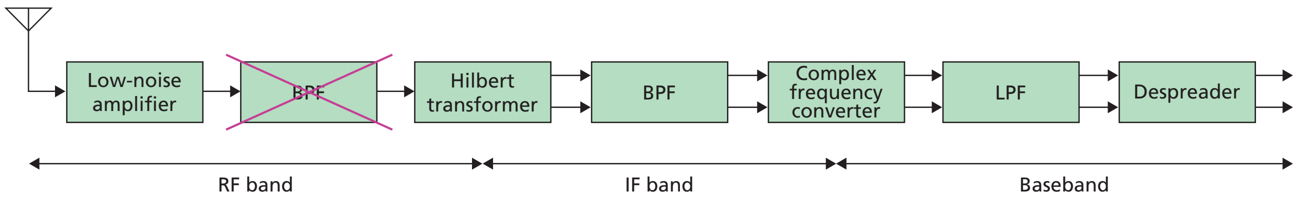
Radio functions supporting multiple radio systems, i.e., multimode radio functions, have so far been achieved by downsizing and combining the radio circuits developed for each of those systems. This approach, however, limits the number of radio systems that can be supported and takes long period for developing downsized radio receivers. It has consequently been difficult to get multimode terminals that support new systems to the market in a timely manner.

The greatest economic advantage of incorporating multimode radio functions is thought to occur during periods of system migration, such as from the Third-Generation mobile communications system (FOMA) to the Fourth-Generation system. When introducing a new system, it is difficult for that system to spread until its area coverage rate is equivalent to that of the existing system. But if multimode terminals that can support both the existing and new systems from the time of new-system launch were to be sold, the spread of the new system should accelerate.

A method for achieving radio communication functions by exchanging software as in software radio [1] technology has been considered as a means of realizing multimode terminals that can quickly support new systems. At present, though, it is proving difficult to digitize (to convert to software processing) all processes including those of the radio section. In particular, the high-frequency radio section composed of analog circuits is a technical wall for engineers.

In this article, we present the results of a basic study that we performed on a common configuration for the analog high-frequency radio section with the aim of receiving signals of multiple systems in a multimode terminal. We propose a new receiver configuration based on a method for canceling image-band

*1 HSDPA: A high-speed downlink packet transmission system based on W-CDMA. Maximum downlink transmission speed under the 3GPP standard is about 14 Mbit/s. Optimizes the modulation method and coding rate according to the radio reception status of the mobile terminal.



LPF: Low Pass Filter
Complex frequency converter: A device that treats the two components making up the received signal (in-phase component and quadrature component) as the real part and imaginary part of a complex number and performs a frequency conversion on each.

Figure 1 Configuration of a conventional heterodyne multimode receiver

interference that is generated when designing multimode receivers using a heterodyne system and examine the effectiveness of that system.

This research involves hardware configurations including those of the analog Radio Frequency (RF) section, and realizing that a theoretical study based on fundamental principles is essential for obtaining a technological breakthrough, we conducted this research jointly with Associate Professor Satoshi Denno of Kyoto University, who has exceptional technical experience in this field.

2. Multimode Receiver Configurations

Conventional configurations of multimode receivers can be broadly divided into a "direct conversion system" and "heterodyne system." As the name implies, the direct conversion system directly converts the received signal to a baseband[*2] signal, while the heterodyne system first converts the received signal to an Intermediate Frequency (IF) band and then performs frequency conversion to a baseband signal.

Compared to the direct conversion system, the heterodyne system has a more complicated configuration due to the need for IF-band processing, but it has the advantage of being robust against degradation in receive characteristics caused by problems like Direct-Current (DC) offset[*3] and 1/f noise[*4] that plague the direct conversion system.

In the following, we discuss the issues involved in designing multimode receivers with a heterodyne system for which stable and favorable performance can be expected even when receiving radio signals of various modulation systems and bandwidths.

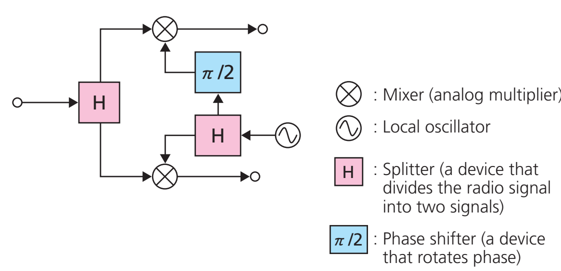


Figure 2 Typical configuration of Hilbert transformer

3. Issues in Heterodyne Multimode Receivers

3.1 Configuration of Heterodyne Multimode Receivers

Figure 1 shows the configuration of a conventional heterodyne multimode receiver and **Figure 2** shows a typical configuration of a Hilbert transformer[*5] used in that receiver. We note here that, for multimode reception, the use of a Band Pass Filter (BPF) in the RF section would limit the frequency bands that could be received, and for this reason, we consider a configuration with that BPF removed. In this case, however, an image signal may superpose the desired signal as interference as shown below resulting in significant degradation of receive characteristics.

3.2 Image Signal

Figure 3 shows the relationship between image signal and desired signal. In a heterodyne configuration in which the BPF in the RF section is removed, the system also performs an RF-to-IF signal conversion on a signal having a frequency component (image frequency) opposite that of the desired frequency

*2 Baseband: The band of the information signal before modulation and after demodulation (i.e., the most basic information signal before modulation or the last signal to be demodulated and extracted on the receiver side). It is normally a low-frequency band.

*3 DC offset: In the direct conversion system, the local oscillation frequency (see *6) and receive-signal center frequency are the same so that the difference frequency component is zero (DC). A large DC component is generated, however, when the local oscillation signal leaks into the receive signal. DC offset means that DC deviates from its average value due to this addition of a DC component.

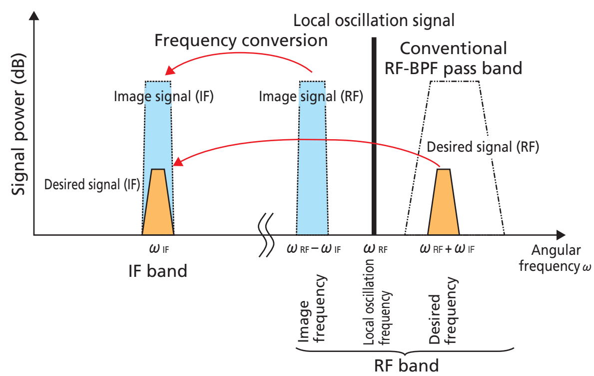


Figure 3 Relationship between image signal and desired signal

relative to the local oscillation frequency[*6] on the frequency axis (Fig. 3). This signal, which is called an "image signal," acts as interference degrading the performance of the receiver. An image signal may be received from a different radio system, and because the transmission point of the image signal may be closer to the receiver than that of the desired signal, the image signal could very well be several tens of dBs larger than the desired signal. A technique must therefore be developed to remove this relatively large interference.

3.3 Removal of Image Interference

The conventional heterodyne multimode receiver configuration shown in Fig. 1 applies a Hilbert transformer composed of analog circuits to convert an RF signal to an IF signal. Under ideal operation, a Hilbert transformer will convert the signal received in the RF band to an analytic signal (that is, a signal that can be expressed in terms of complex numbers), which means that the image signal should be able to be removed completely theoretically speaking [2]. But since the Hilbert transformer is achieved with analog devices, individual differences among those devices will cause actual amplitude and phase values to deviate from theoretical values (imperfection). This prevents the image signal, which can be completely removed in theory, from being completely removed in actuality.

4. Proposed Image Canceller Method

4.1 Constant Modulus Image-band Canceller

Image-signal interference can be cancelled out if the imperfection inherent in the Hilbert transformer in the receiver configuration of Fig. 1 can be compensated for. This can be done by multiplying the real part and imaginary part of the complex signal after transformation by a coefficient that is manipulated in a way that the deviation in amplitude and phase from an ideal transform can be compensated for. This coefficient is called a "compensation coefficient." Here, the method chosen for determining the compensation coefficient will effect image-interference removal characteristics. One reported method for inferring the compensation coefficient uses an adaptive algorithm [3]. However, it must be kept in mind that the image signal can be several tens of dBs larger than the desired signal depending on radio propagation path conditions. In such a situation, a training signal[*7] required by general adaptive algorithms cannot be applied. We therefore propose an image-interference cancellation method that applies an envelope[*8] constant modulus as an algorithm that enables operation without the need for a training signal. This method is called a Constant Modulus Imageband Canceller (CMIC). Based on a modulus that minimizes envelope variation, CMIC determines the coefficient to compensate for the imperfection of the Hilbert transform.

4.2 Synchronization Acquisition in the Presence of Image Interference

When applying multimode receivers to spread-spectrum communications, failure to synchronize the spread code sequence included in the received signal with the spread code sequence used in despreading[*9] will prevent correct despreading results from being obtained. Some means is therefore needed to acquire synchronization using the received signal. When using CMIC, which applies an envelope constant modulus, it will be possible to achieve characteristics corresponding to the theoretical upper limit if synchronization can be acquired correctly before applying CMIC. **Figure 4**(a) shows a receiver configuration (proposed configuration 1) that performs synchronization acquisition before canceling image interference. In actuality,

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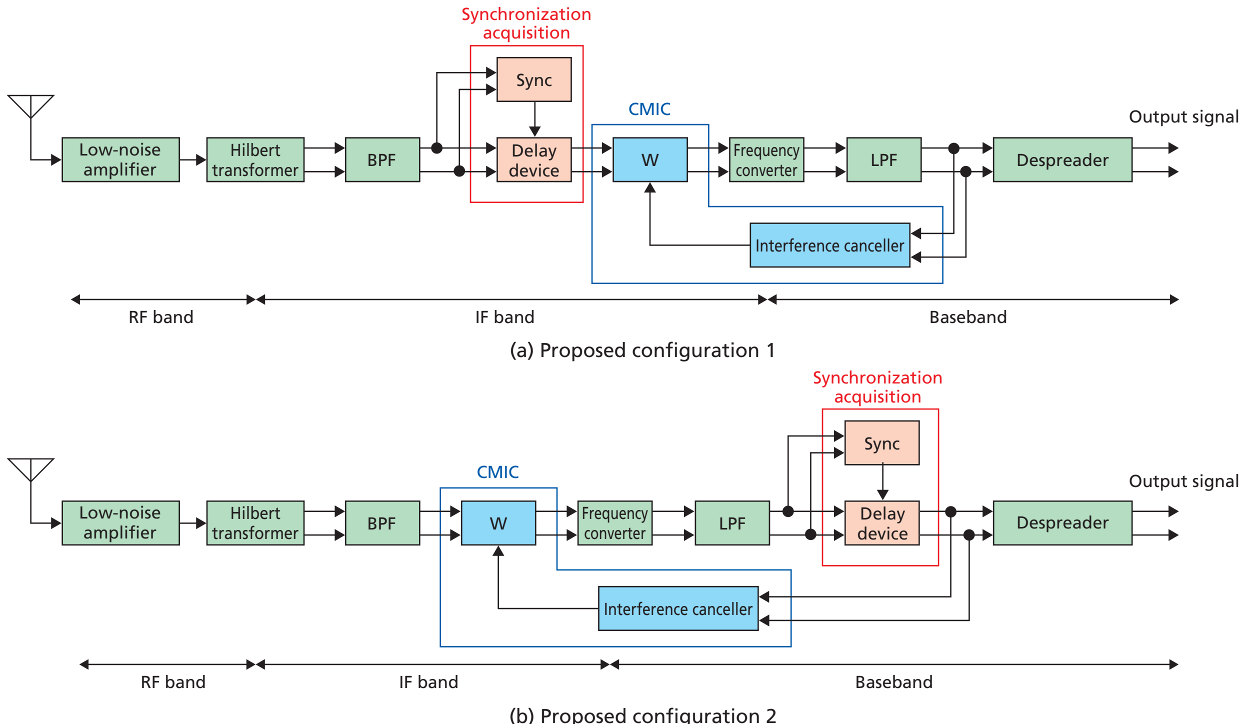
*4 1/f noise: A distortion component inversely proportional to frequency generated when amplifying a broadband signal on the baseband.

*5 Hilbert transformer: A device that performs a transformation equivalent to rotating the phase of the signal by 90°.

*6 Local oscillation frequency: Frequency conversion is performed by multiplying the received signal and the local oscillator's sinusoidal signal in an analog manner to create sum and difference frequency components of those two signals and then extracting only the difference component. The local oscillation frequency is the frequency generated by the local oscillator at this time.

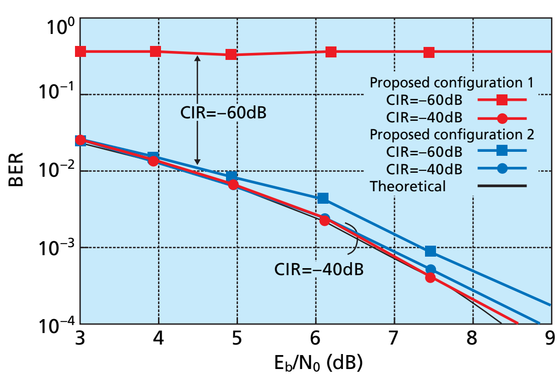


W: compensation coefficient multiplier
Sync: synchronization acquisition device

Figure 4 Configuration of proposed multimode receivers

however, there will still be cases in which image interference is large compared to the desired signal making for conditions in which even synchronization acquisition cannot be accomplished. It has consequently become clear that interference cancellation can be effectively performed by combining synchronization acquisition with image-interference cancellation by CMIC [4]. Fig. 4(b) shows the proposed receiver configuration for this scheme (proposed configuration 2).

Figure 5 shows receive Bit Error Rate (BER) characteristics. While the conventional system (Fig. 1) is nearly incapable of reception in the presence of an image-interference signal, proposed configuration 1 can perform reception for small image interference. Proposed configuration 2, moreover, can obtain favorable reception characteristics even under severe conditions in which the image signal is more powerful than the desired signal by more than 60 dB [5].



CIR (Carrier to Interference Ratio): Desired-signal-to-image-signal power ratio.
E_b/N_0: Signal-to-noise power ratio per bit.

Figure 5 BER characteristics of proposed systems

5. Conclusion

With the aim of performing basic research toward the realization of multimode receivers, we presented a study on a method for canceling image-signal interference generated by a heterodyne system when using a common analog radio section. We proposed a CMIC that enhances the interference-cancellation effect when canceling interference using a Hilbert transformer by compensating for the imperfection in that conversion. We then showed that combining CMIC with synchroniza-

*7 Training signal: A signal to which a known pattern has been added to enable the receive side to detect changes applied to a signal on the transmission path.

*8 Envelope: A curve representing the variation in amplitude of a high-frequency radio signal.

*9 Despreading: In spread-spectrum communication systems, the operation of extracting the information signal from the received signal using the same code as the spread code used on the transmit side.

tion acquisition produces effective cancellation of interference. In future research, we plan to investigate the applicability of these findings to characteristics recognition in a fading environment and to multicarrier transmission.

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