Multi-Service Receiver for Automobiles

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Abstract

As various new communication services are introduced in automobiles, integration of receivers for the various services is desired. Thus, we propose a new method by which to receive multiple services simultaneously using one piece of hardware. This method is referred to herein as Simultaneous Reception with Time-sharing Filter. In the proposed method, received signals of multiple communication services are down-converted to appropriate intermediate frequency signals, multiplexed on a cable, and then received simultaneously in an integrated receiver. The proposed method can reduce the number of cables and receivers. In this paper, we first explain the proposed method of Simultaneous Reception with Time-sharing Filter. We then introduce the prototype system developed to confirm the validity of the proposed method. Finally, we show the experimental results of simultaneous reception of DSRC, FM broadcasting and DTV using the prototype system.

1. Introduction

In the future ubiquitous network society, communication facilities for automobiles are expected to become much more advanced. Safety, convenience and comfort will be improved drastically by utilizing the information obtained through various telecommunication infrastructures and sensors installed in automobiles.

At present, various communication services are available for automobiles, such as the AM/FM radio, the terrestrial analog television and the Electronic Toll Collection (ETC) system. The introduction of new communication services, including Dedicated Short Range Communications (DSRC), Automated Highway System (AHS) and terrestrial digital television (DTV), will be considered in the near future, as shown in **Fig. 1**.

A conventional receiver is usually prepared for only one specific service; that is, the number of receivers must be the same as the number of communication services. As the number of communication services and receivers increases in an automobile, the space available for installation of new antennas, new cables, and new receivers becomes limited. Moreover, advanced controls, such as information sharing and cooperation between communication services, cannot be realized easily since the receivers are specific to one service.

Therefore, development of an integrated receiver for multiple services is desired.

In order to develop the multi-service receiver, the following technologies are required:
• Integrated wide band or multiple band antenna
• A Radio Frequency to Intermediate Frequency (RF/IF) circuit for various frequencies
• Integration of cables between antennas and receivers
• Signal processing which can treat various communication services

Moreover, the integrated receiver for automobiles has to receive multiple communication services simultaneously.[1]

We propose a new method by which to receive multiple services simultaneously using one piece of hardware. This method is referred to herein as Simultaneous Reception with Time-sharing Filter. In the proposed method, the received signals of multiple communication services are down-converted to an appropriate intermediate frequency (IF) signal, multiplexed on a cable, and then received simultaneously in an integrated receiver. The proposed method reduces the number of cables and receivers.

In this paper, we first explain the proposed method, Simultaneous Reception with Time-sharing Filter. Next, we introduce the prototype system developed to confirm the validity of the proposed method. Finally, we show the experimental results of simultaneous reception of DSRC, FM broadcasting and DTV using the prototype system.

2. New method on multi-service reception

Figure 2 shows the conventional method by which to receive multiple communication services simultaneously multiplexed on a cable in the IF band. First, the IF signal multiplexed on a cable is sampled and then converted to a digital signal by an Analog-to-Digital (A/D) converter. In each quadrature detection circuit, the signal is multiplied by a sine wave that is equivalent to the center frequency of
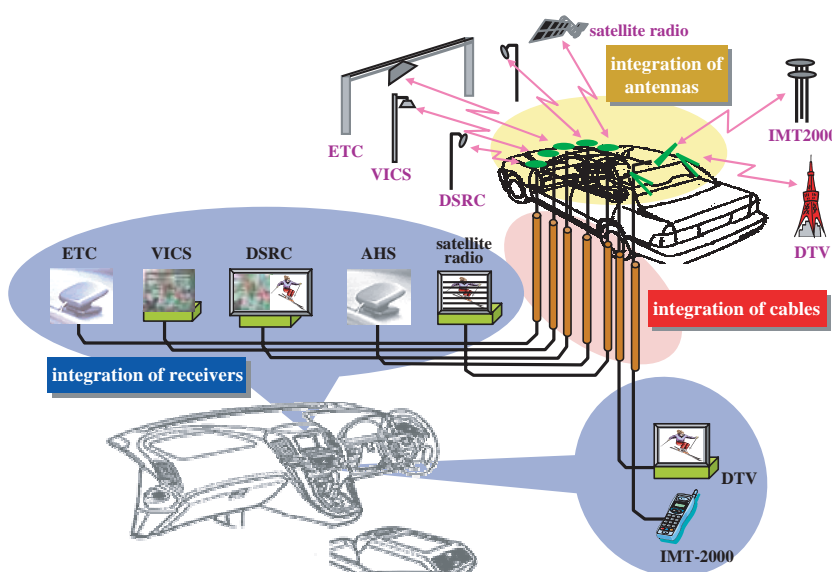

Fig. 1 Various communication services in an automobile.

each service. As a result, the IF signal is down-converted to the base-band corresponding to the services. Finally, the base-band signal desired for each service is extracted using a low pass filter (LPF).

In the conventional method, the number of quadrature detection circuits and LPFs must be equal to the number of communication services. So, the hardware cost increases in proportion to the number of services received simultaneously. Thus, the conventional method has few merits for simultaneous reception of multi-service.
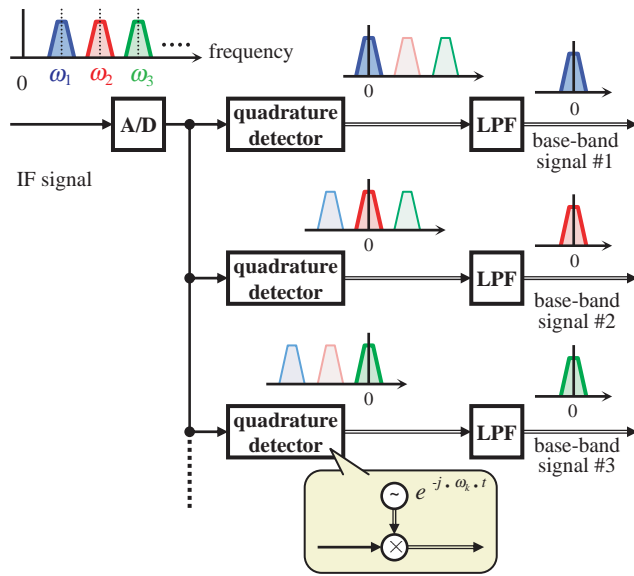
Another conventional method has been also investigated to receive multiple communication services simultaneously, in which discrete Fourier transform (DFT) is used, as shown in **Fig. 3**. This method has the advantage that quadrature detectors are unnecessary and the computational complexity is not dependent on the number of communication services. However, there is a problem in that the sampling period of the base-band signal often becomes too long compared with its frequency bandwidth.

We propose herein a new simultaneous reception method based on DFT, which we refer to as Simultaneous Reception with Time-sharing Filter. In the proposed method, the IF signal multiplexed of
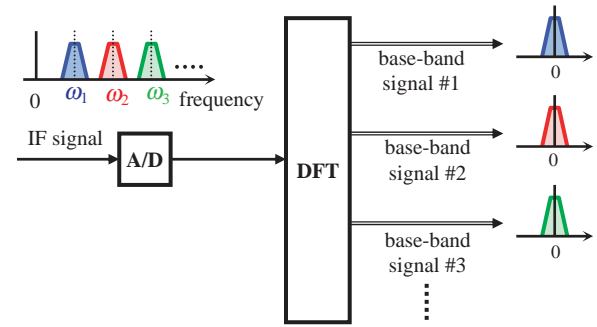

Fig. 2 Conventional method of multi-service reception.
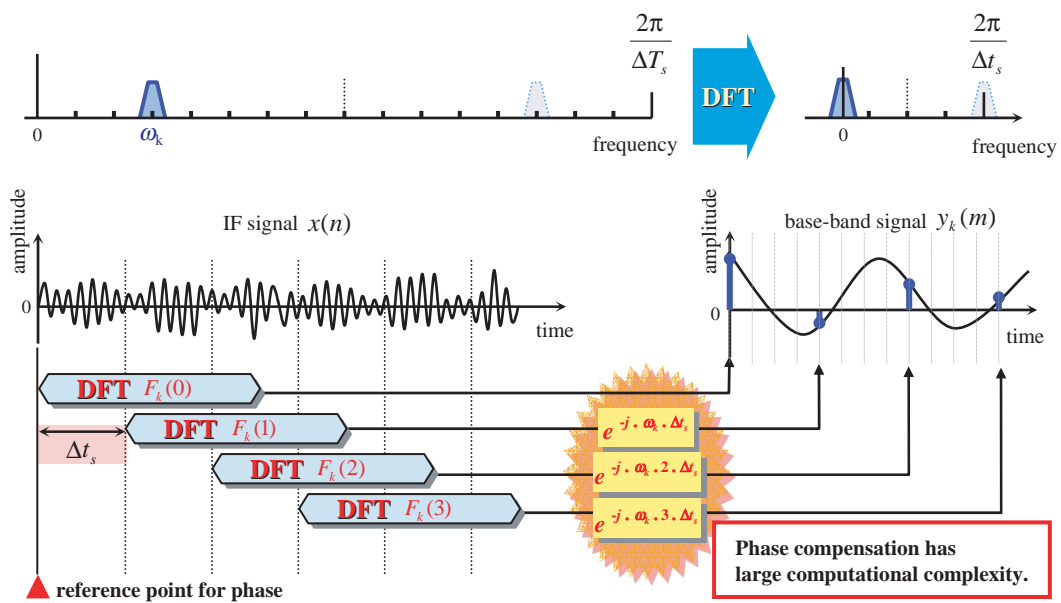
Fig. 3 Conventional method based on DFT.

Fig. 4 Principle of our method using DFT.

various communication services is down-converted to respective base-band signals of the services simultaneously using the following two methods.

• Extraction and down-conversion of signal within a specific frequency band from IF signal with sampling period appropriate for its frequency bandwidth based on DFT

• Time-sharing operation of the extraction process in order to receive various communication services simultaneously

In addition, the proposed method is applicable to various communication services by designing a window function of DFT that is appropriate for the bandwidth of each communication service.

Figure 4 shows the principle of the proposed method to down-convert the multiplexed IF signal to the base-band signal and to extract the base-band signal of a specific service by shifting the DFT window in time. IF signal multiplexed communication services are represented by $x(n)$, the sampling period of which is ΔT_s. A center radian frequency of the k-th communication service multiplexed in the IF signal is represented by ω_k. Using N-point DFT, a frequency component F_k of $x(n)$ at ω_k is given by

$$F_k = \sum_{n=0}^{N-1} x(n) \cdot e^{-j \cdot \omega_k \cdot n \cdot \Delta T_s} \quad \text{...(1)}$$

where ω_k is assumed to be $\frac{i}{N} \cdot \frac{2\pi}{\Delta T_s} (i \in \mathbf{Z})$. In the proposed method, the base-band signal of the k-th communication service is obtained by shifting the DFT window and calculating Eq. (1) every Δt_s. Thus, the base-band signal $F_k(m)$, the sampling period, Δt_s, of which is obtained by

$$F_k(m) = \sum_{n=0}^{N-1} x\left(n + \frac{m \cdot \Delta t_s}{\Delta T_S}\right) \cdot e^{-j \cdot \omega_k \cdot n \cdot \Delta T_s} \quad \text{.......................(2)}$$

Here, the shifting DFT window causes phase lag in the base-band signal according to the time $m \cdot \Delta t_s$, when $m \cdot \Delta t_s$ is not an integral multiple of $\frac{2\pi}{\omega_k}$, and the phase lag is equal to $e^{j \cdot \omega_k \cdot m \cdot \Delta t_s}$. Therefore, phase compensation is necessary in order to obtain a
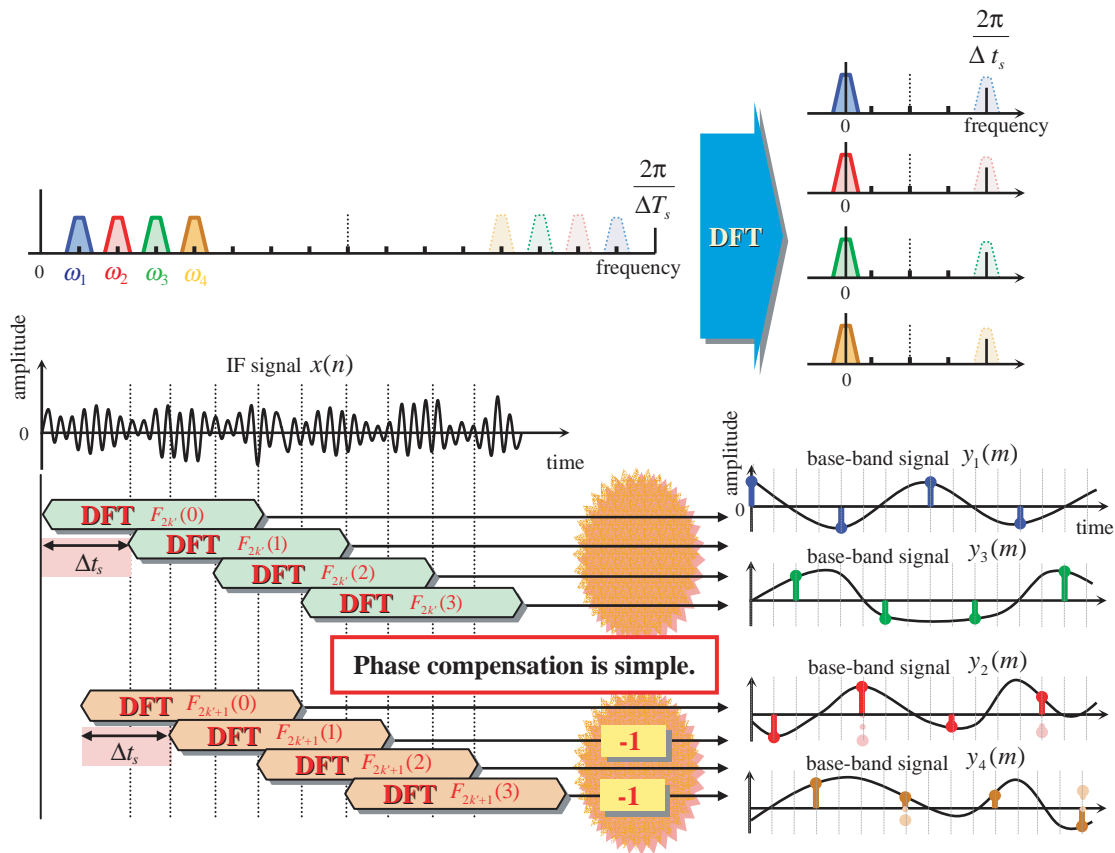

Fig. 5 Our method of multi-service reception.

correct base-band signal. The base-band signal after phase compensation is given by

$$y_k(m) = F_k(m) \cdot e^{-j \cdot \omega_k \cdot m \cdot \Delta t_s} \quad\text{.....................................(3)}$$

From Eq. (3), phase compensation might have large computational complexity. The computational complexity of phase compensation is dependent on ω_k and Δt_s. We thus choose the values of ω_k and Δt_s so as to satisfy the relation

$$\omega_k = \frac{l}{2} \cdot \frac{2\pi}{\Delta t_S} \quad (l \in \mathbf{Z}) \quad\text{...................................(4)}$$

in order to simplify the phase compensation. When satisfying Eq. (4), Eq. (3) can be rewritten as

$$\begin{aligned} y_k(m) &= F_k(m) \cdot e^{-j \cdot \frac{l}{2} \cdot \frac{2\pi}{\Delta t_S} \cdot m \cdot \Delta t_S} \\ &= F_k(m) \cdot e^{-j \cdot m \cdot l \cdot \pi} \\ &= F_k(m) \cdot (-1)^{m \cdot l} \quad\text{.......................................(5)} \end{aligned}$$

From Eq. (5), the term of phase compensation becomes simple. Namely, phase compensation is unnecessary when l is even, and phase compensation

is performed simply in order to reverse the sign of the base-band signal of every other sample when l is odd.

Figure 5 shows the operation of simultaneous down-conversion from the IF signal multiplexed communication services to base-band signals using the proposed method by time-sharing. While the DFT window shifts in time, the target frequency ω_k that corresponds to each service extracted by DFT operation is switched repeatedly. The speed of the time-sharing processing is determined by the sampling period Δt_s that is necessary for each service after down-conversion and the number of services received simultaneously.

Figure 6 shows the hardware configuration of the receiver system using the proposed method. In RF/IF circuits, the signals received by the antennas are down-converted to different intermediate frequencies, which satisfy Eq. (4), respectively, and are then multiplexed on one cable. The multiplexed
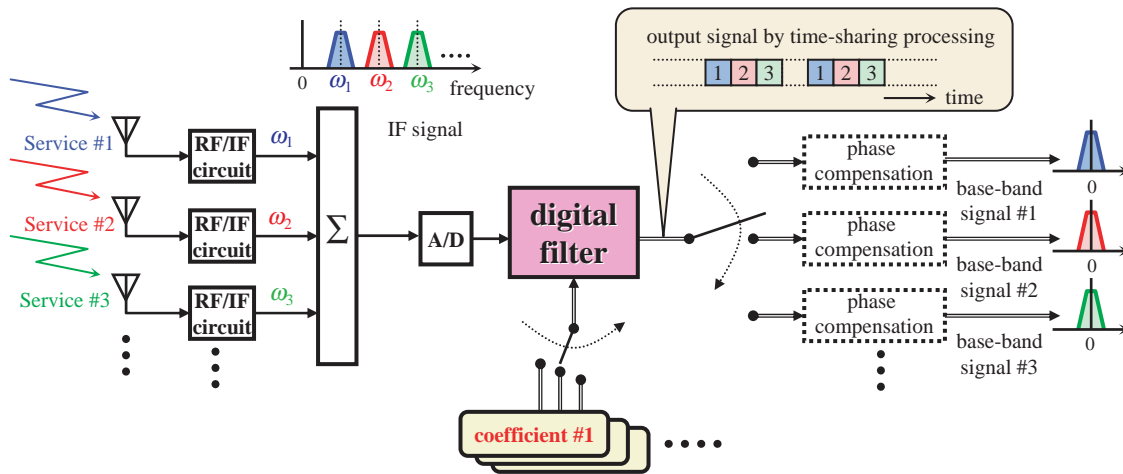

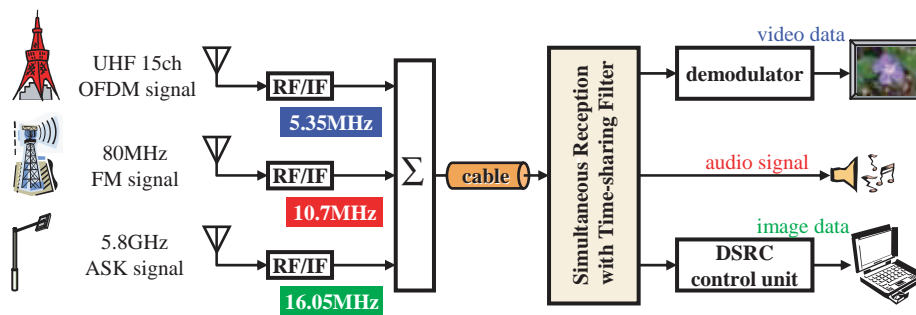**Fig. 6** Hardware configuration for our method.

Fig. 7 Block diagram of prototype system.

IF signal is sampled and quantized by an A/D converter. The IF signal is down-converted to base-band signals of respective services by a digital filter with the DFT coefficients. The simultaneous down-conversion is realized by switching the filter coefficient sets repeatedly, which are prepared for respective communication services to extract respective IF frequencies ω_k. Moreover, the pass-band width required for various communication services can be realized by multiplying the appropriate window function to the filter coefficients beforehand. After down-conversion, the sign of the base-band signal is reversed for every other sample in phase compensation, if necessary.

As mentioned above, the proposed time-sharing

filter can realize simultaneous reception of various services using a simple circuit configuration.

3. Prototype system of multi-service receiver

3. 1 System configuration

We have developed a prototype system of an integrated receiver with a time-sharing filter in order to confirm the validity of the proposed method stated in the previous section. **Figure 7** shows the block diagram of our prototype system. This prototype system receives three radio signals simultaneously, which are the radio wave (485 MHz, OFDM signal) for DTV, the radio wave (80 MHz, FM signal) transmitted from an FM broadcasting station, and the radio wave (5.8 GHz, ASK signal) from a DSRC experimental base station. The three antennas receive these services respectively. RF/IF circuits down-convert the center frequency of the OFDM signal, the FM signal, and the ASK signal to 5.35 MHz, 10.7 MHz, and 16.05 MHz, respectively. After the down-conversion, these signals are multiplexed as an IF signal, and are input into a simultaneous reception block. The spectrum of the IF signal is shown in **Fig. 8**.

Figure 9 shows the circuit configuration of the integrated signal processing with the time-sharing filter. It consists of an A/D converter, two digital filters and an FPGA. The sampling rate of the A/D converter is 42.8 MHz. One digital filter deals with the in-phase component of the IF signal, and the other filter deals with the quadrature component of
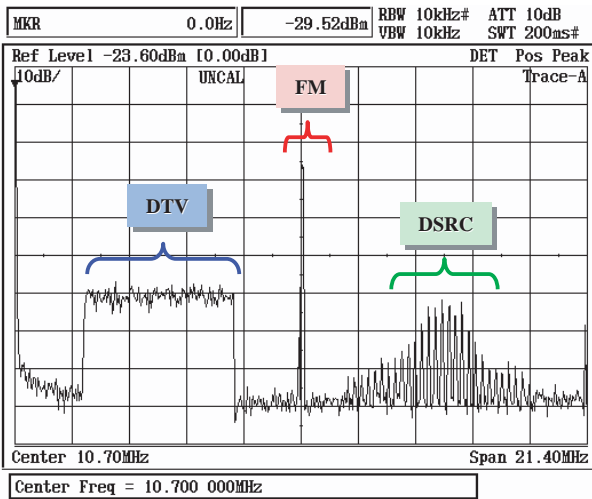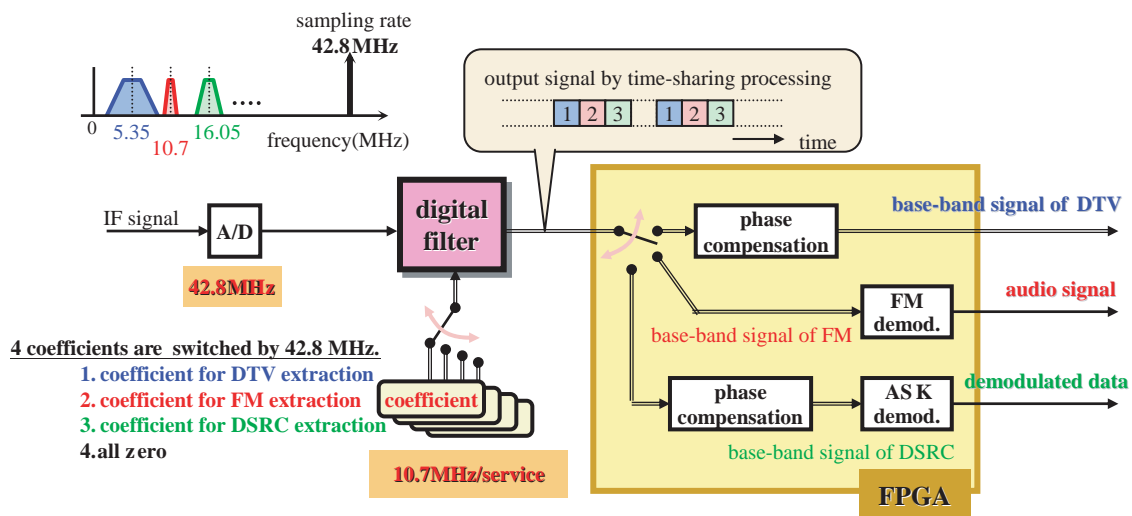

Fig. 8 Spectrum of the IF signal.

Fig. 9 Circuit configuration of integrated signal processing unit.

the IF signal. The filter for the quadrature component is the Hilbert transform of the filter for the in-phase component. Coefficients of these filters are switched by four coefficient sets to extract each service at the switching rate of 42.8 MHz. As a result, base-band signals of respective services are output from these filters by time-sharing processing with simple phase compensation, and the sampling frequency of each service becomes 10.7 MHz.

After down-conversion to base-band signals, each signal is demodulated independently. The FM signal is demodulated in the FPGA, and the resultant audio signal is output from a speaker. The ASK signal is demodulated in the FPGA, and then image data is extracted from the demodulated signal in a DSRC control unit and displayed on a personal computer. The OFDM signal is demodulated by an OFDM

demodulator and then reproduced as video data by an MPEG decoder.

3. 2 Filter design

In this section, we explain the design of the digital filters to extract the signal of DTV, FM, and DSRC from the IF signal which multiplexed them. The filter must be designed to have a pass-band width sufficiently wide to extract a target communication service. The filter must also suppress interference from other communication services multiplexed on a cable.

Interference between communication services is caused by the time-sharing filter in the proposed method, because time-sharing among the extraction processes can be regarded as a down-sampling operation. The down-sampling causes folding of the frequency spectrum of the IF signal at odd integral multiples of half of the sampling frequency, causing aliasing components to appear when the IF signal is not band-limited. As a result, inter-service interference occurs when the frequency band of the target communication service overlaps with that of another communication service after down-sampling. Therefore, it is important that the frequency response of the filter designed for a certain communication service has null points at the center frequencies of the other communication services in order to suppress the inter-service interference.

Figures 10, **11** and **12** show the frequency responses of the filters designed to extract the DTV
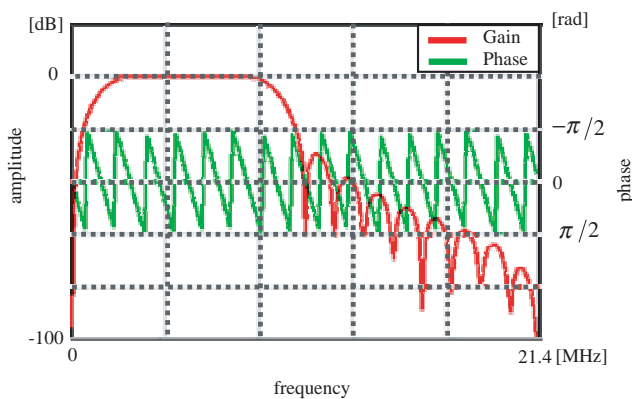

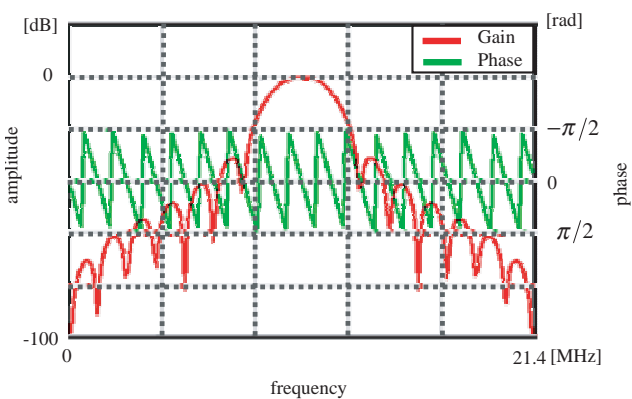**Fig. 10** Frequency response of filter for extraction of DTV.

Fig. 11 Frequency response of filter for extraction of FM.
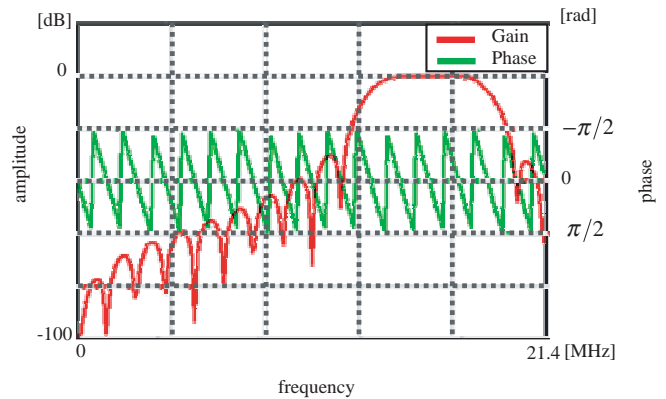

Fig. 12 Frequency response of filter for extraction of DSRC.

signal, FM signal and DSRC signal based on 32-point DFT. The red line and green line represent amplitude and phase responses, respectively. The figures show that the frequency response of each filter has zero gain at the center frequencies of other services in the stop band.

3. 3 Experimental results

We carried out experiments to investigate simultaneous reception of DSRC, FM, and DTV with the developed prototype system. As a result, the contents of the three services were found to be reproduced normally and simultaneously. Thus, the validity of the proposed time-sharing filter and the effectiveness of the developed prototype system were confirmed.

4. Conclusion

We have been developing a multi-service receiver for automobiles, which integrates the parts of receivers for multiple communication services, such as antennas, RF/IF circuits, cables, and base-band signal processing.

In this paper, we proposed Simultaneous Reception with Time-sharing Filter to integrate coaxial cables and down-conversion circuits. In the proposed method, a set of service specific cables was integrated into a single cable by multiplexing the signals of multiple communication services, and then simultaneous reception was realized by the proposed time-sharing filter. The time-sharing filter consists only of a pair of digital filters with the function of switching the filter coefficients to change the target frequency and its pass-band width.

We developed a prototype system with the time-sharing filter and confirmed the validity of the proposed method by achieving simultaneous reception of three communication services: FM, DSRC and DTV.

As the next step of our study, we plan to evaluate the inter-service interference inherent in the proposed method in more detail. Furthermore, we will further develop the method to realize an integrated multi-service communication system for automobiles, by which various communication services will be made available more flexibly and more conveniently for the user.

References

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