Implementation of Filter Bank–Based RF Transceiver for TV White Space

Kyu-Min Kang, Jae Cheol Park, and Seungkeun Park

This paper presents a general-purpose design scheme of a filter bank (FB)–based radio frequency (RF) transceiver that operates across the entire ultra-high frequency (UHF) TV band from 470 MHz to 698 MHz and complies with the TV white space (TVWS) regulatory requirements. To this end, an intermediate frequency (IF) band-pass filter (BPF) with a sharp skirt characteristic is considered as a solution for handling the incoming signals from a baseband modem. Specifically, an FB-based BPF structure with four ceramic resonator filters that effectively rejects unwanted signals is proposed to extract a desired signal in the TV band. Achievable data rates of a cognitive radio system (CRS) employing the proposed FB-based RF transceiver at the application layer are investigated in both wired and wireless environments. The service coverage of the CRS network is measured according to several modulation and coding schemes (MCSs) of the CRS. The results show that the coverage of a wireless network in a nearly open area can be extended by more than 9.3 km in the TVWS. Experimental results also confirm that the proposed FB-based RF transceiver is adequate for utilization in TVWS applications.

Keywords: Filter bank, RF transceiver, TV white space, cognitive radio system, service coverage, regulation.

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I. Introduction

As the demand for mobile and wireless data capacity is rapidly growing, spectrum sharing is expected to play an important role in increasing spectrum utilization [1]–[5]. Attention is now increasingly focused on LTE in unlicensed spectrum (LTE-U) technologies using 5 GHz Wi-Fi spectrum, to explore the possibilities of achieving better coverage and higher spectral efficiency [6]. Additional allocation of the unlicensed 5 GHz band is viewed as a way of improving Wi-Fi services [4], [7]. A licensed shared access concept is also proposed for use with a spectrum in accordance with sharing rules included in authorized users' rights of use, thereby allowing authorized users to provide a certain quality of service [8]. Most of all, the use of TV white space (TVWS), the first sharing band between incumbent services and secondary services, is now expected in a wide range of applications, thereby enabling users to install and use their own networking solutions at nearly zero incremental cost [9]–[12].

TVWS refers to TV bands that, at a particular time and in a particular geographic area, are not being used by licensed services [9]. Many efforts are underway in various areas to make good use of TVWS. In the IEEE, several task groups, such as IEEE 802.11af, 802.15.4m, 802.19.1, and 802.22b, have completed or are advancing a TV band device (TVBD) or TVBD network standardization. To protect incumbent services within a protected contour, the Federal Communications Commission (FCC) has strictly limited both the maximum transmit power and the out-of-band emissions of TVBDs [13]; that is, fixed TVBDs are permitted to operate with up to 4 W (36 dBm) equivalent isotropically radiated power (EIRP) per 6 MHz bandwidth, personal/portable TVBDs are permitted to operate with up to 100 mW (20 dBm) EIRP per 6 MHz bandwidth, and the out-of-band emissions (measured with a 100 kHz bandwidth) from the TVBD should be at least 72.8 dB below the highest average power (measured with a 6 MHz bandwidth) in the operating TV channel. The out-of-band emissions should be roughly limited to a level 55 dB below the highest power level in the band, as measured with a 6 MHz bandwidth. The European Telecommunications Standards Institute also announced a newly harmonized European standard for TVBDs [14]. Operation on the TVWS has been studied in the literature for some TVBD transceiver structures [15]–[19]. Kang and Park [20] recently proposed a cognitive radio system (CRS) design scheme that uses Wi-Fi modules and complies with TVWS regulations. In this case, a digital signal processing (DSP) module with a relatively high complexity is included to meet the out-of-band emission regulation. Moreover, the CRS radio frequency (RF) transceiver of [20] operates only within a limited frequency range, not the entire TV band. This motivated the consideration of a design scheme of a CRS RF transceiver that covers the entire ultra-high frequency (UHF) TV band from 470 MHz to 698 MHz in this study.

The aim of this paper is to provide a general-purpose design scheme for a CRS RF transceiver that complies with the TVWS regulatory requirements and also covers the entire UHF TV band using only analog filters.

A superheterodyne receiver offers superior sensitivity, frequency stability, and selectivity to a direct-conversion receiver, and intermediate frequency (IF) filters can provide narrower passbands at the same Q factor than an equivalent RF filter. Therefore, a superheterodyne receiver is considered in this paper. First, a 160 MHz IF surface acoustic wave (SAW) filter with a sharp skirt characteristic is considered for proper handling of the incoming signals from a digital-to-analog converter (DAC). Second, a filter bank (FB)–based band-pass filter (BPF) structure with four ceramic resonator filters is proposed for effective rejection of unwanted signals and to extract a desired signal from the entire UHF TV band.

The remainder of this paper is organized as follows. In Section II, the overall architecture of a CRS RF transceiver is described. In Section III, the motivation for the employment of an FB structure in the RF transceiver is briefly discussed. In Section IV, the design scheme of the RF module is proposed. Section V presents experimental results. Finally, conclusions are drawn in Section VI.

II. RF Module Architecture

Here, an RF transceiver module is proposed that operates across the entire UHF TV band (470 MHz to 698 MHz) according to the TVWS regulations. Figure 1 shows a block diagram of the TVBD RF module operating in the UHF TV band. The proposed RF module consists of an IF BPF operating at 160 MHz, RF BPFs, FB-based BPFs operating in the TV band, double sideband (DSB) mixers, amplifiers, and so on. A SAW BPF with a sharp skirt characteristic in 160 MHz IF is employed for proper handling of the incoming signals from the baseband modem. A phase-locked loop (PLL)–based frequency synthesizer is designed to generate 38 local oscillator (LO) signals from 633 MHz to 855 MHz with a frequency step of 6 MHz. At the transmitter, an up-conversion mixer converts an IF signal into an RF signal with a 6 MHz bandwidth. The output signal is then passed to a wideband BPF with a 228 MHz bandwidth, where the BPF first suppresses unwanted emissions at frequencies outside the range of the TV band. The two-stage FB-based BPF also rejects the LO leakage, image signal, and unwanted interferers in the TV band and passes only a desired signal to the high power amplifier (HPA). At the receiver, one FB-based BPF and an IF BPF are employed; three attenuators are also used for proper handling of the received input signals ranging from –90 dBm to

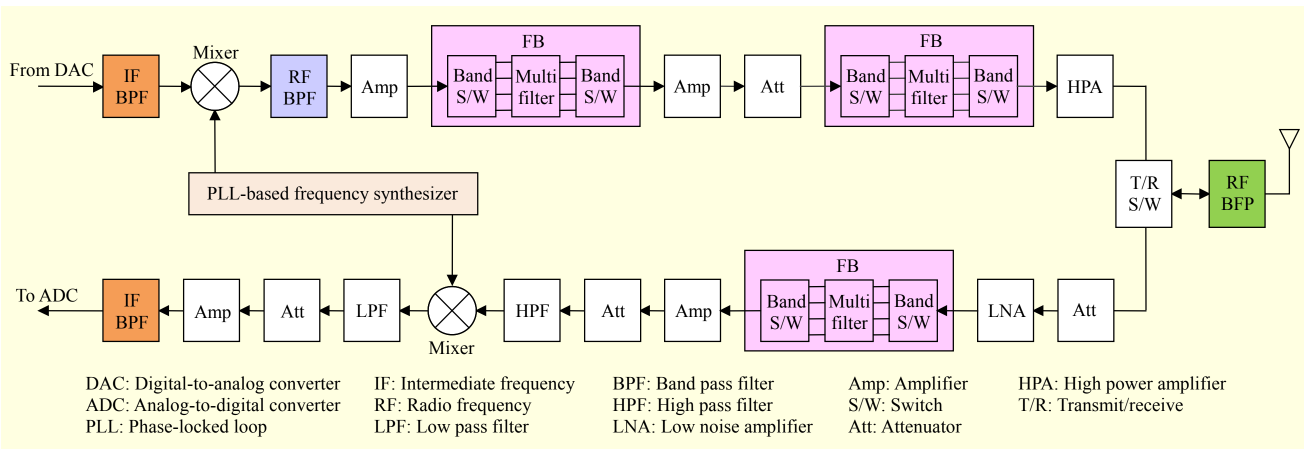

Fig. 1. Block diagram of proposed RF module operating in UHF TV band.

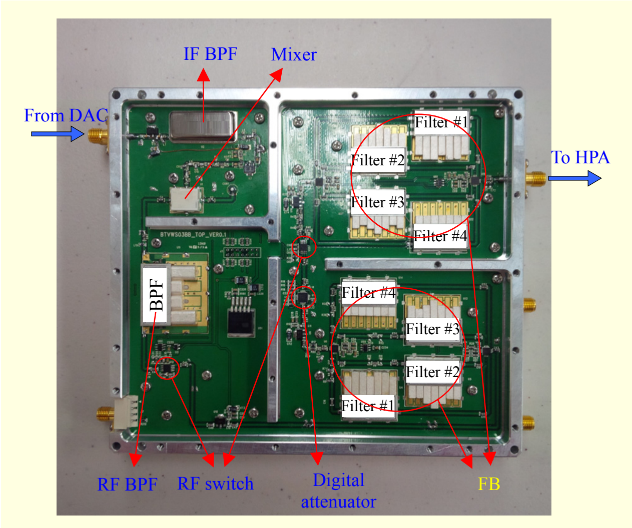

Fig. 2. RF transmitter module.

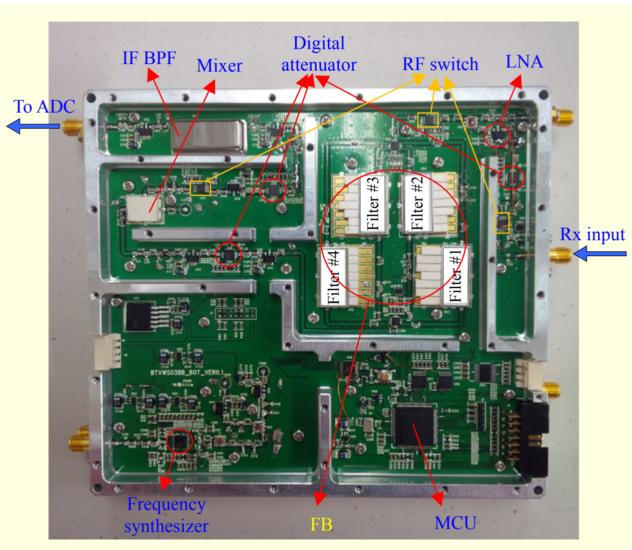

Fig. 3. RF receiver module.

–20 dBm for 6 MHz channel spacing.

Figure 2 shows the implemented RF transmitter module. The transmitter module employs two-stage FBs. Each FB consists of four ceramic resonator BPFs. Note that the HPA is separately implemented with the RF transmitter module to support a transmit signal power level of up to 28 dBm (assuming 10 dBi antenna gain and 2 dB cable loss) in the fixed TVBD mode. Figure 3 shows the implemented RF receiver module. The receiver module consists of one FB-based BPF, a mixer, a 160 MHz IF BPF, and so on. The filters in the RF transceiver are custom-made. The micro controller unit (MCU) module is implemented on the same board as the RF receiver module (see Fig. 3). The RF transmitter module is placed on the upper side of the RF transceiver case, and the receiver module is placed on the lower side. The transmitter and receiver modules utilize 0.6 mm thickness (0.6T) flame retardant (FR)-4 printed circuit boards of size 16.5 cm × 14.3 cm. The direct current power supply unit (PSU) provides +6 V for the operation of the RF transceiver. Current consumption of the RF transceiver module is 1.12 A. Accordingly, the total power consumption of the RF transceiver is about 6.7 W.

III. Motivation for FB Structure in RF Transceiver

Here, we present why an FB-based BPF structure is needed to operate an RF transceiver on the entire UHF TV band. Figure 4 shows a conceptual block diagram of an RF transmit frequency mixer. The IF signal is given by

$$s_{\mathrm{IF}}(t) = s(t)\cos(2\pi f_{\mathrm{IF}} t), \tag{1}$$

where $s(t)$ denotes the modulated signal at the baseband modem. The LO signal is given by

$$s_{\mathrm{LO}(i)}(t) = \cos(2\pi f_{\mathrm{LO}(i)} t), \tag{2}$$

where $f_{\mathrm{LO}(i)} = f_{\mathrm{RF}(i)} + f_{\mathrm{IF}}$, f_{IF} = 160 MHz, and $f_{\mathrm{RF}(i)}$ = 473 + 6i for i = 0, 1, … , 37. The RF frequency denotes a carrier frequency ($f_{\mathrm{RF}(i)}$) of the operating TV channel. Note that the frequency synthesizer generates 38 LO signals from 633 MHz to 855 MHz, with a frequency step of 6 MHz, to enable the RF transceiver to operate across the entire TV band. The RF transceiver is implemented by selecting a lower sideband (LSB) signal among the output $\tilde{s}_{\mathrm{RF}(i)}(t)$ of the DSB mixer. Since many unwanted signals are actually generated at the output of the mixer due to the LO leakage as well as the nonlinearity of the mixer, appropriate filtering should be performed to extract only the desired signal term. The desired signal is then given by

$$s_{\mathrm{RF}(i)}(t) = A_t s(t)\cos(2\pi f_{\mathrm{RF}(i)} t), \tag{3}$$

where A_t denotes the overall gain of the RF transmitter. Note that the conversion loss of the RF transmit mixer is about 7 dB and the input IF is –15 dBm. The up-converted RF output is then about –22 dBm, which is measured with a 6 MHz bandwidth. Since the L-R isolation between the LO and RF

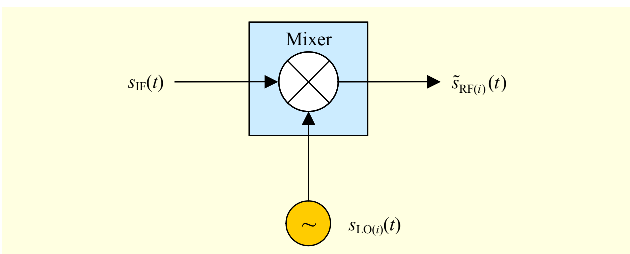

Fig. 4. Block diagram of RF transmit mixer.

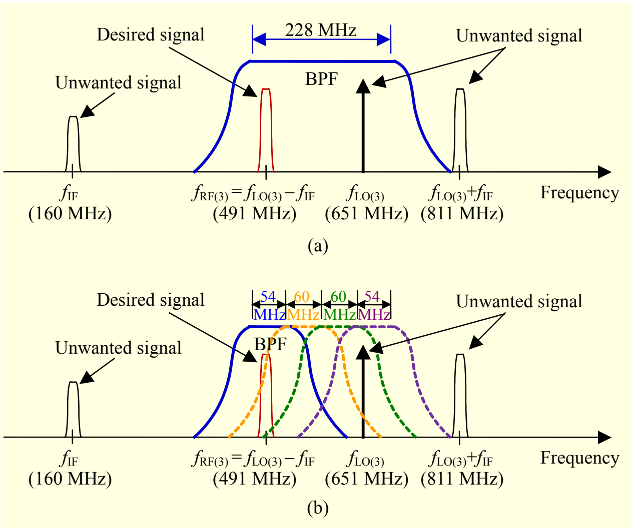

Fig. 5. (a) BPF with relatively wide bandwidth (228 MHz) that includes both desired signal and unwanted local signal (LO leakage) and (b) BPF with relatively narrow bandwidth (54 MHz) that includes only desired signal and rejects unwanted signal.

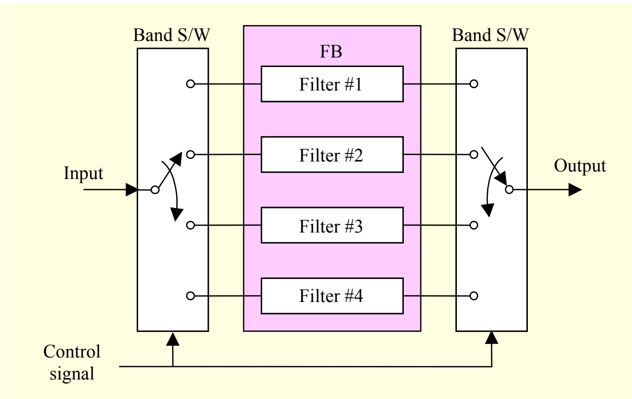

Fig. 6. Block diagram of proposed FB structure.

ports is about 40 dB and the input LO is 15 dBm, the LO leakage power is about –25 dBm, which is measured with a 100 kHz bandwidth at the mixer output.

Figure 5(a) shows a BPF with a wide bandwidth of 228 MHz. Although this BPF can operate across the entire 38 TV channels, it includes the unwanted LO leakage whose power level is similar to that of the desired signal. Therefore, the conventional BPF structure is not feasible to meet the TVWS regulatory requirements of the out-of-band emissions. On the other hand, Fig. 5(b) shows a BPF employing a relatively narrow bandwidth of 54 MHz. The narrow bandwidth filter includes the desired signal and effectively rejects any unwanted LO leakage. However, it can operate on only 9 TV channels instead of the entire 38 TV channels. Motivated by this, we consider an FB-based BPF structure consisting of four filters with a relatively small bandwidth each (54 MHz or 60 MHz) for the TVWS operation. A block diagram of the proposed FB structure is given in Fig. 6, where one of the four filters is selected by band switches (S/Ws). The main features of the proposed FB-based BPF structure are as follows:

1) Four filters of the FB are designed to attenuate at least 45 dB below the in-band average power at the second adjacent channels.
2) Two consecutive FBs are employed at the RF transmitter to meet the TVWS regulation of the out-of-band emissions.
3) Only one FB is employed at the RF receiver.

IV. RF Module Design

In the earlier CRS of [20], two types of RF modules are separately implemented to operate on two different frequency bands by considering the operation frequency range of the HPA, IF frequency, LO leakage, image rejection, and so on; the first RF module covers only the frequency range from 488 MHz to 542 MHz, and the second one covers from 566 MHz to 620 MHz. Although one of the two RF modules can be selectively employed, it cannot be utilized for a general-purpose TVWS RF transceiver covering the entire UHF TV band. Accordingly, a general-purpose design scheme of an RF transceiver should be considered to operate across the entire UHF TV band.

Here, the overall IF and RF functions of the proposed FB-based RF transceiver are designed and implemented on three RF modules — an RF transmitter module, an HPA module, and an RF receiver module. The proposed RF transceiver can be operated in fixed mode or personal/portable mode via transmit power control on the entire UHF TV band without violating the out-of-band emission requirement.

1. IF BPF

Recently, Kang and Park presented a CRS design scheme for compliance with TVWS regulations using a DSP module with a finite impulse response digital filter block [20]. However, the hardware complexity of their design scheme is somewhat high because their scheme requires a field-programmable gate array, additional PLLs, and control circuits. Here, an analog SAW filter with a sharp skirt characteristic at a frequency from 157 MHz to 163 MHz is employed for proper handling of the incoming signal from the DAC. Figure 7 shows the spectrum of a 160 MHz IF signal at the output of the IF SAW filter. The bandwidth of the IF BPF at 3 dB cutoff frequencies is 5.1 MHz, and the bandwidth at the level of –40 dB is 6.45 MHz. Note that the IF BPF at the RF receiver suppresses out-of-channel

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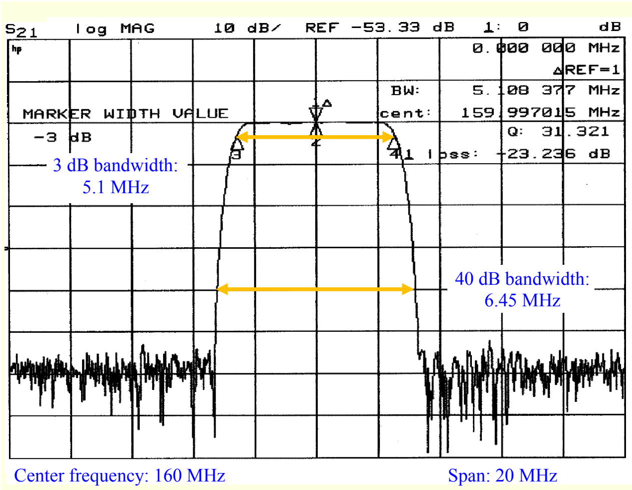

Fig. 7. Spectrum of 160 MHz IF signal at output of SAW filter.

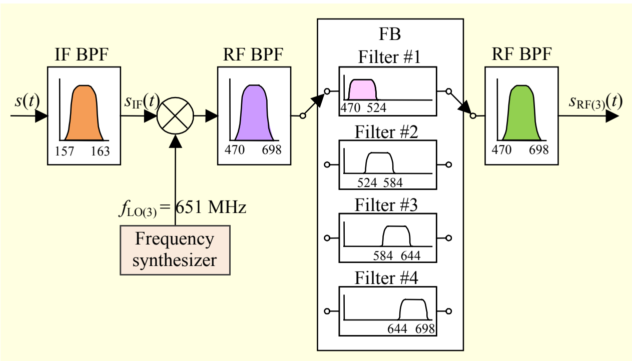

Fig. 8. Conceptual block diagram of conversion from baseband signal to desired RF signal.

interferers at the receiving path.

2. RF BPF

Figure 8 shows a conceptual block diagram of the conversion from a baseband signal to the desired RF signal with a carrier frequency of 491 MHz in the transmit path of the proposed FB-based RF module. The output signal of a 160 MHz IF BPF is mixed with an LO signal at the up-conversion mixer to generate a desired signal at the TV band. To this end, a PLL-based frequency synthesizer is designed that selectively generates one of 38 LO signals from 633 MHz to 855 MHz with a frequency step of 6 MHz. The mixed output signal is passed to an RF BPF with a 228 MHz bandwidth to first suppress unwanted emissions at frequencies outside the range of the TV band. Figure 9 shows the characteristics of the RF BPF operating at frequencies ranging from 470 MHz to 698 MHz. The residual LO leakage, image signal, unwanted interferers, and so on in the TV band are further handled by the subsequent FB-based BPF. The output of the FB-based BPF is

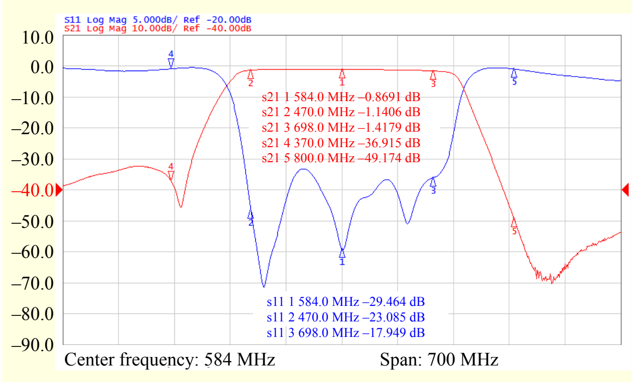

Fig. 9. Characteristics of RF BPF operating from 470 MHz to 698 MHz.

passed to an HPA and a wideband BPF with a 228 MHz bandwidth.

3. FB-Based BPF

In this subsection, an FB-based BPF structure is proposed not only to effectively reject unwanted interferers in the TV band but also to extract only a desired signal. Each FB consists of four ceramic resonator BPFs; filter #1 operates in the 470 MHz to 524 MHz band; filter #2 operates in the 524 MHz to 584 MHz band; filter #3 operates in the 584 MHz to 644 MHz band; and filter #4 operates in the 644 MHz to 698 MHz band. The operating frequency ranges of the IF BPF, the RF BPF, and the four filter types in the FB-based BPF are summarized in Table 1. Figure 10 shows the characteristics of the filters, #1, #2, #3, and #4, in the FB-based BPF. The electrical specifications of the four filters are given in Table 2. Filter #1 is designed to provide a bandwidth equal to or wider than 54 MHz at 1 dB cutoff frequencies while supporting greater than 45 dB attenuation levels at 410 MHz and 584 MHz. As shown in Table 2 and Fig. 10, the electrical specifications of filters #2, #3, and #4 are designed similarly to

Table 1. Comparison of operating frequency ranges of several filters used in TVBD RF mlodule.

Filter type	Operating frequency range (MHz)	Bandwidth (MHz)
IF BPF	157–163	6
RF BPF	470–698	228
Filter #1	470–524	54
Filter #2	524–584	60
Filter #3	584–644	60
Filter #4	644–698	54

Table 2. Electrical specifications of filters #1, #2, #3, and #4.

Parameters	Specifications			
	Filter #1	Filter #2	Filter #3	Filter #4
Center frequency	497 MHz	554 MHz	614 MHz	671 MHz
Bandwidth (BW) [†]	≥ 54 MHz	≥ 60 MHz	≥ 60 MHz	≥ 54 MHz
Insertion loss @ BW	≤ 3 dB			
Ripple @ BW	≤ 1 dB			
Return loss @ BW	≥ 15 dB			
Impedance	50 Ω			
Power handling	Up to 2 W continuous wave			
Operating temperature	–30°C to +80°C			
Attenuation	> 45 dB @ 410 MHz > 45 dB @ 584 MHz	> 45 dB @ 470 MHz > 45 dB @ 644 MHz	> 45 dB @ 584 MHz > 45 dB @ 684 MHz	> 45 dB @ 644 MHz > 45 dB @ 758 MHz

[†] Note that bandwidth is calculated with 1 dB cutoff frequencies instead of nominal 3 dB cutoff frequencies.

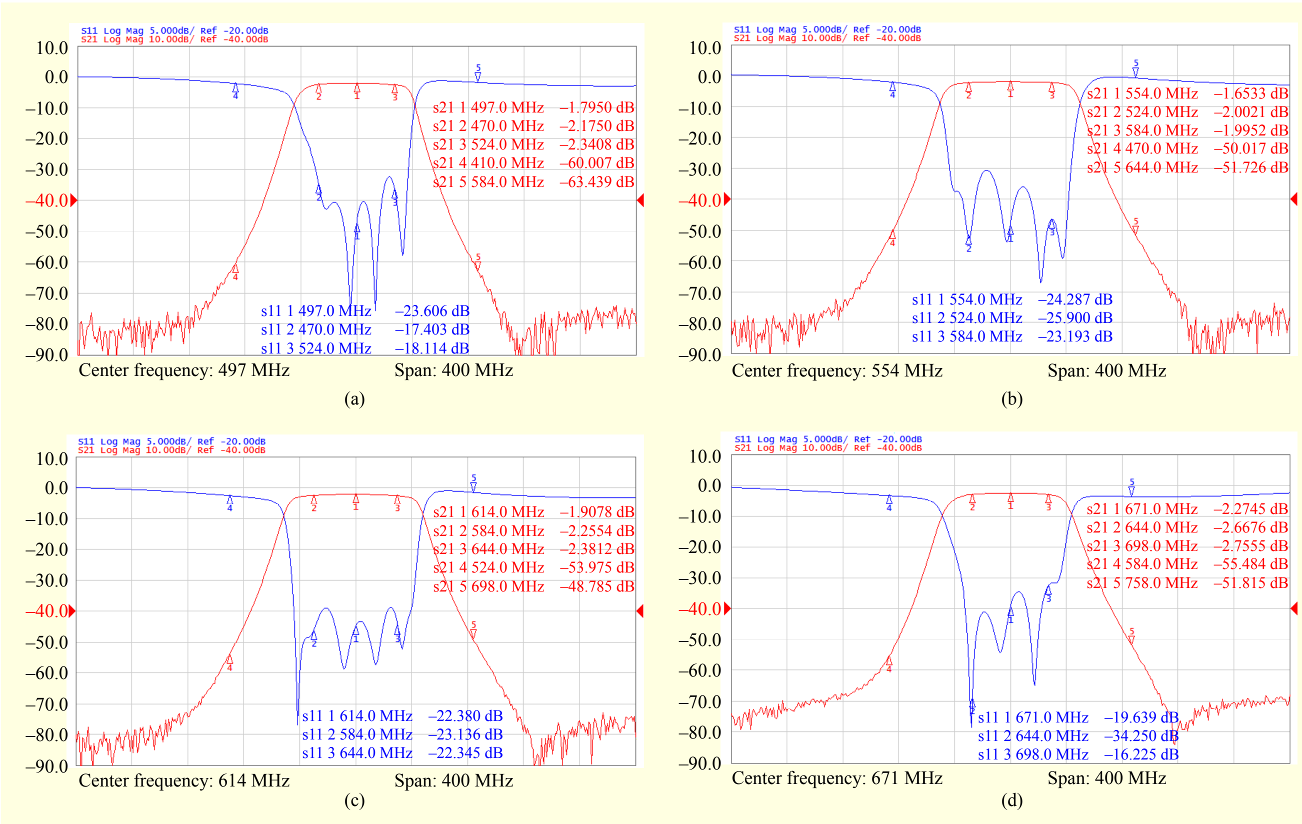

Fig. 10. Characteristics of four filters in FB: (a) filter #1 operating from 470 MHz to 524 MHz, (b) filter #2 operating from 524 MHz to 584 MHz, (c) filter #3 operating from 584 MHz to 644 MHz, and (d) filter #4 operating from 644 MHz to 698 MHz.

those of filter #1. As depicted in Fig. 10, although the four filters of the FB are designed to attenuate at least 45 dB below the in-band average power at the second adjacent channels, these are insufficient to suppress the LO leakage so as to meet the TVWS regulatory requirements of the out-of-band emissions. Two consecutive FBs are therefore employed at the RF transmitter. On the other hand, since the IF SAW filter sufficiently suppresses out-of-channel interferers at the RF receiver, only one FB is employed at the receiver. To construct an FB-based BPF with a total bandwidth of 228 MHz, filters #1 and #4 are implemented with a bandwidth of 54 MHz, and filters #2 and #3 are implemented with a bandwidth of 60 MHz.

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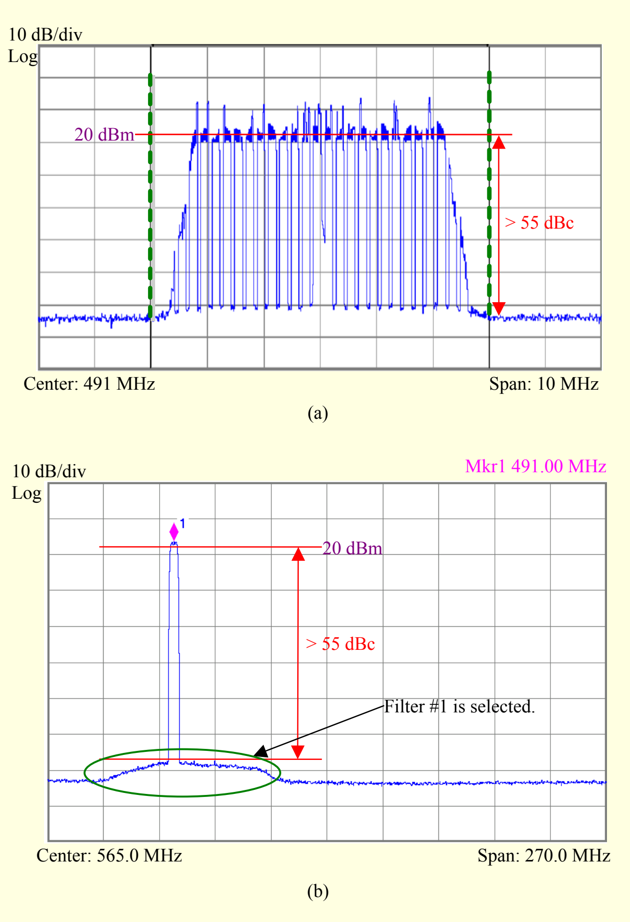

Fig. 11. Transmit spectrum of TVBD that complies with FCC regulations for unlicensed TVBDs: (a) transmit spectrum of TVBD over 10 MHz span and (b) transmit spectrum of TVBD expanding span to entire UHF TV band.

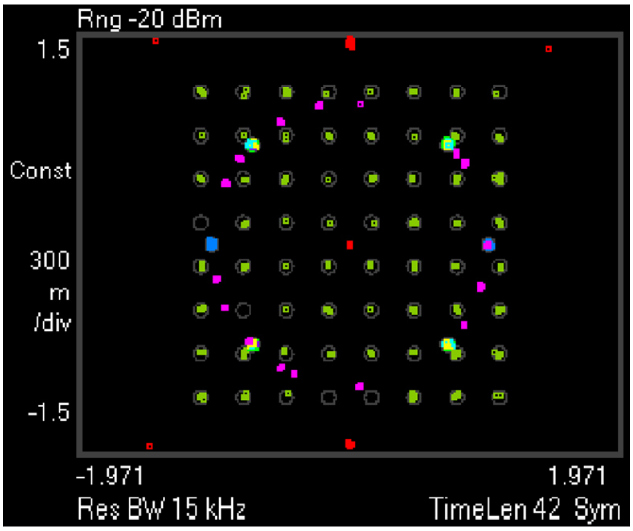

Fig. 12. EVM measurement of RF transmitter with LTE TDD physical layer signals where PDSCH uses 64-QAM format.

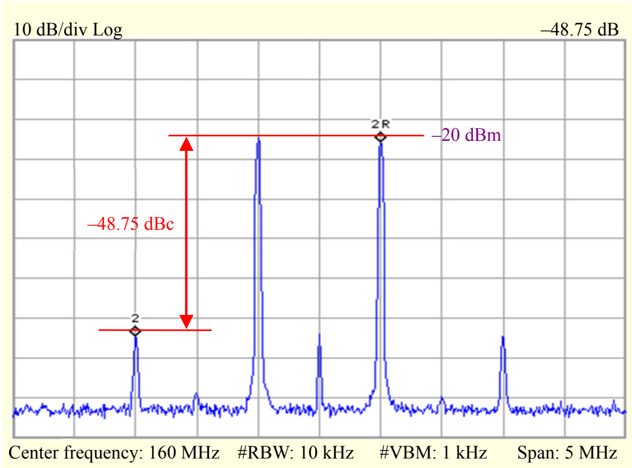

Fig. 13. Multi-tone IMD caused by two input RF signals in which input power is –20 dBm.

The transmit spectrum of the TVBD at the output of the RF transmitter is given in Figs. 11(a) and 11(b); this spectrum indicates that the implemented RF module complies with the FCC regulations for unlicensed TVBDs. The measurements of the transmit spectrum show that the out-of-band emissions are at least 55 dB less than the highest average power (20 dBm for personal/portable TVBDs) in the operating channel when measured with a 6 MHz bandwidth.

V. Experimental Results

The performance of the RF transceiver was measured using the LTE time division duplex (TDD) signal; the physical downlink shared channel (PDSCH) uses a 64-QAM format [21]–[22]. The RF module was operated at the center frequency of 491 MHz (TV channel 17). An error vector magnitude (EVM) test was conducted to quantify the performance of the RF transceiver. Figure 12 shows the EVM measurement result of the RF transmitter with LTE TDD physical layer signals. The measured EVM of the RF transmitter was less than 1.5%. The EVM of the RF receiver was measured to be about 1.9%. The performance of the RF receiver was also tested with the main metric being the noise figure (NF). The single sideband (SSB) NF of the RF receiver was around 6.0 dB. For the overall RF receiving chain, a 1 dB compression point was measured to be –10 dBm. Figure 13 shows multi-tone intermodulation distortion (IMD) caused by two input RF signals in which the input signal power is –20 dBm. Since the IMD is –48.75 dBc, the input third-order intercept point (IIP3) is about 4.4 dBm. Note that the received input signals ranging from –90 dBm to –20 dBm can be adjusted in 1 dB steps over the 70 dB range.

Table 3. Theoretical achievable data rates at physical layer and measured data rates at application layer in both wired and wireless environments.

MCS index	Modulation type	Coding rate	Data rate (Mb/s) using one TV channel			Data rate (Mb/s) using two TV channels		
			Theoretical	Measured (wired)	Measured (wireless)	Theoretical	Measured (wired)	Measured wireless
0	BPSK	1/2	1.63	1.13	1.10	3.25	2.10	2.07
1	QPSK	1/2	3.25	2.15	2.12	6.50	4.31	4.11
2	QPSK	3/4	4.88	3.24	3.20	9.75	6.40	6.13
3	16-QAM	1/2	6.50	4.22	4.15	13.00	8.56	8.15
4	16-QAM	3/4	9.75	6.35	6.24	19.50	12.66	12.40
5	64-QAM	2/3	13.00	8.32	8.19	26.00	16.57	16.02
6	64-QAM	3/4	14.63	9.41	9.28	29.25	18.10	17.55
7	64-QAM	5/6	16.25	10.47	10.27	32.25	19.87	19.41

BPSK: Binary Phase Shift Keying, QPSK: Quadrature Phase Shift Keying, QAM: Quadrature Amplitude Modulation.

Data rate performance of the implemented CRS employing the proposed FB-based RF transceiver was also measured. Table 3 compares the theoretical achievable data rates of the existing Wi-Fi system at the physical layer and the measured data rates of the CRS at the application layer in both wired and wireless environments [7]. The wireless data rates were measured in a quasi-open area where there were a few buildings and trees on the measurement path between the CRS base station (BS) and customer premise equipment (CPE). The distance between the BS and CPE is 220 m. The conducted power of the CRS BS transmitter is 22 dBm with 10 dBi antenna gain and 2 dB cable loss (producing an EIRP of 30 dBm). In this wireless experiment, the BS antenna was installed 3 m above the rooftop of a five-story building and the CRS CPE antenna was installed 3 m above the ground. Similarly to [20], the implemented CRS utilizes existing Wi-Fi modules based on the "quarter-clocked" mode using 5 MHz channel spacing for baseband signal processing [7]; that is, the CRS generates a Wi-Fi signal using only 5 MHz channel spacing per a 6 MHz TV channel. Since the CRS is composed of the proposed RF transceiver, an HPA, Wi-Fi modules, PSU, a power over Ethernet switch, a router, and so on, its size is 68 cm × 46 cm × 21 cm. The PSU provides +28 V and +6 V. The current consumption is 1.2 A for +28 V operation, and 4.1 A for +6 V operation. Data rate measurements were performed using one TV channel and two TV channels, respectively. In the single-channel measurement case, TV channel 29 is used at the center frequency of 563 MHz. In the two-channel measurement case, TV channel 31 is additionally used at the center frequency of 575 MHz. The measured data rates of the implemented CRS at the application layer in the wired experiments were approximately 65% of the theoretical data rates at the physical layer in the existing Wi-Fi system [7] (see Table 3). The data rates of the CRS, according to the modulation and coding schemes (MCSs) at the application layer in outdoor wireless environments, were measured using

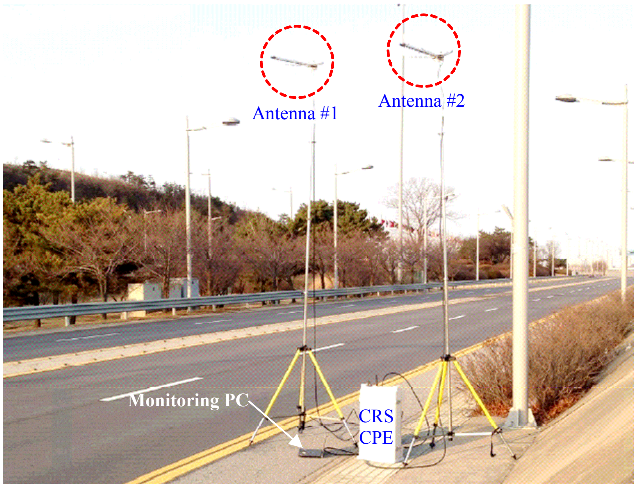

Fig. 14. CRS field trial held in Incheon, Rep. of Korea; measurement configuration of CRS CPE to estimate service coverage of CRS network.

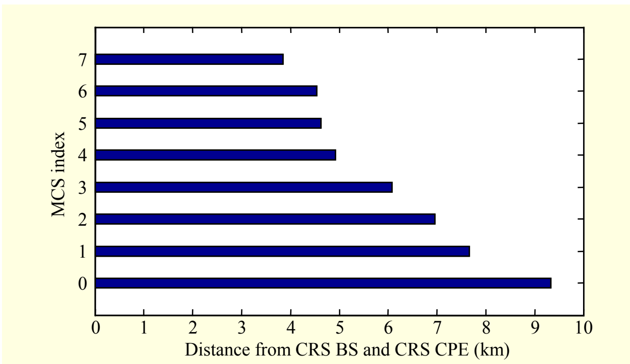

Fig. 15. Service coverage measurement of CRS network employing proposed RF module according to several MCSs in nearly open area in Incheon, Rep. of Korea.

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the received signal with a nominal power level of about –52 dBm/6 MHz. The outdoor measurement results were similar to the laboratory test results. The implemented CRS supports a data rate of up to 19.87 Mb/s at the application layer in the 64-QAM and 5/6 code-rate mode (MCS 7) using two 6 MHz carriers.

Figure 14 shows the CRS field trial held in a nearly open area in Incheon, Rep. of Korea. In this field test, a CRS BS with an antenna height of 5 m was located at a fixed point, whereas the measurement locations of the CRS CPE with an antenna height of 5 m were changed to estimate the service coverage of the CRS network according to several MCSs. The two-carrier CRS BS and CPE were operated using TV channels 29 and 31 in the fixed TVBD mode. Figure 15 depicts the coverage measurement results of a CRS network employing the proposed FB-based RF transceiver according to several MCSs. The measurement results show that the service coverage of a wireless network in the nearly open area can be extended by more than 9.3 km in the TVWS.

VI. Conclusion

This paper proposes an FB-based RF transceiver that operates across the entire UHF TV band from 470 MHz to 698 MHz and meets the TVWS regulatory requirements of transmit power levels and the out-of-band emissions for the fixed mode and personal/portable mode operations. Design methods of an IF BPF, an FB-based BPF structure, and a PLL-based frequency synthesizer were introduced for the implementation of a TVWS RF transceiver covering the entire TV band. The measured EVM of the RF transmitting chain was less than 1.5%. The NF of the RF receiving chain was measured to be around 6.0 dB. Data rates of the implemented CRS using the proposed RF module in both wired and wireless environments were compared with the theoretical achievable data rates of an 802.11-based system. The service coverage of a CRS network employing the proposed RF transceiver was also measured according to several MCSs in a nearly open area. The results indicate that the proposed RF module is sufficiently applicable to wireless solutions in the TVWS. CRS networks employing the proposed FB-based RF transceiver enable users to experience their own networking solutions in wider areas when compared to existing Wi-Fi solutions at 2.4 GHz or 5 GHz.

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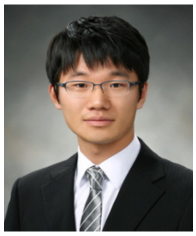

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