Prototype of Smart Phone Supporting TV White-Spaces LTE System

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Abstract. Recently, secondary use of white-spaces has been expected as one of the technologies to mitigate spectrum resource shortage problem. In particular, secondary utilization of white-spaces in the TV band (TVWS) has attracted attention and some standardizing activities such as IEEE802.11af and IEEE802.22 have been promoted. For the mobile communication systems, it is possible to secure more channels for traffic balancing by utilizing the TVWS, while there are still some difficulties in miniaturization and low power consumption for TVWS utilization. In this study, the authors prototyped a smart phone type TV band device, which supports a TVWS LTE system, by applying frequency conversion technology. This prototyped smart phone is fully operated by an internal battery and can connect to the TVWS eNB previously developed by the authors. Commercial LTE Band 1 is also supported and the phone can select and smoothly switch between two bands. This is the world's first prototyped smart phone supporting the TVWS that demonstrates not only the feasibility of miniaturization and low power consumption, but also the possibility of spectrum expansion in mobile communication system towards next generation.

Keywords: LTE · Spectrum sharing · TV white-spaces · Frequency conversion · Smart phone

1 Introduction

Recently, a variety of attractive applications for mobile terminals such as smart phones and tablet terminals have been widely used and demand of communication traffic has been burgeoning rapidly. This trend will continue over the next decade and International Telecommunications Union (ITU) estimates that a required frequency band for mobile communication will become 1,280–1,720 MHz by 2020 [1]. On the other hand, since spectrum resource is limited, it is urgently required to achieve the

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practical use of spectrum sharing technology for improving efficiency of spectrum usage. In such a situation, communication system utilizing white-spaces (WS), which is allocated to existing communication systems but not used "temporally" or "specially," has been expected as one of spectrum sharing technologies. In particular, exploitation of WS in the TV band (TVWS, TV White-spaces) has been studied worldwide due to its attractive propagation property and penetrability, and some communication systems such as IEEE802.11af for WiFi system [2] and IEEE802.22 for WRAN (Wireless Regional Area Network) system [3] have been standardized as TVWS communication systems.

For the mobile communication systems, it is possible to secure more channels for traffic balancing by utilizing the TVWS. However, the realization of miniaturization and low power consumption is a major challenge for TVWS utilization by mobile communication systems. Since the allocated frequency to TV broadcasting is lower and considerably wider than that of existing mobile communication systems and further downsizing of conventional RF (Radio Frequency) circuit and component are difficult, especially in development of small-size and wide-band antenna and filter. Furthermore, adjacent channel leakage power of secondary systems in the TV bands is severely limited in comparison with conventional standards, to protect primary users, i.e. TV broadcasters [4],[5]. On the other hand, demand of portable-size TVWS devices has been increased for further investigation of interference with/from primary users under mobile environment and also the vertical-handover based on spectrum sharing technology towards next generation of 5G.

To develop communication devices supporting heterogeneous network access including the TVWS, the frequency conversion system is one of the feasible technologies due to its versatility that enables the deployment of any communication systems to desired frequency bands. In the mobile communication system, some prototypes in the TVWS by utilizing the frequency conversion technology have been reported [6]-[8]. However, further miniaturization is still necessary for development of actual mobile communication environment in the TVWS. In this study, we prototyped a smart phone type TV band device which supports a TVWS LTE (Long Term Evolution) system, by applying the frequency conversion technology. This prototyped smart phone is fully operated by an internal battery and can connect to the TVWS eNB (enhanced Node B) developed by the authors in the previous work [8]. In addition, commercial LTE Band 1 is also supported and the phone can select and smoothly switch between bands according to an available channel list in the TVWS provided by a TV white-space database (WSDB) which is also developed by NICT [9],[10]. This is the world's first prototyped smart phone supporting the TVWS LTE system that demonstrates feasibility of miniaturization and low power consumption.

The rest of this paper is organized as follows. In Section 2, physical features and hardware design of the prototyped smart phone are described. Measured RF performance and spurious response are described in Section 3. Finally, we conclude this paper with Section 4.

2 Smart Phone Prototype

2.1 Physical Features

Fig. 1 shows a prototyped smart phone supporting the TVWS LTE system. This prototype is based on the off-the-shelf smart phone and its physical features are substantially the same as commercial ones, as summarized in Table 1. Frequency conversion circuits are additionally incorporated to support the TVWS LTE system instead of the existing TDD-LTE system which the original smart phone accommodates. Two microSIM card slots are incorporated in the phone; one is for the developed TVWS LTE system and the other one is for commercial LTE networks. The LTE system for both bands is based on the 3GPP standard release 8. Using original application, the prototyped smart phone selects and smoothly switches communication bands between the TVWS and commercial LTE Band 1.

Fig. 2 shows channel assignment of the TVWS LTE system with a signal bandwidth (BW) of 5 MHz, 10 MHz and 20 MHz to TV channels with a channel BW of 6 MHz. A center frequency of the TVWS LTE with a BW of 5 MHz is assigned to a center frequency of a single TV channel with a BW of 6 MHz. Correspondingly, center frequencies of the TVWS LTE with a BW of 10 MHz and 20 MHz are assigned to center frequencies of two and four consecutive TV channels, respectively.

Size and weight are also virtually the same as original ones, since only the RF circuits are replaced from existing TDD-LTE system to TVWS LTE system. This prototype is fully operated by an internal battery with a current capacity of 2,600 mAh. Since additional circuits for frequency conversion consume extra current, the standby time for the TVWS LTE system is shortened to 290 hours in comparison with 440 hours for commercial LTE network in Band 1.

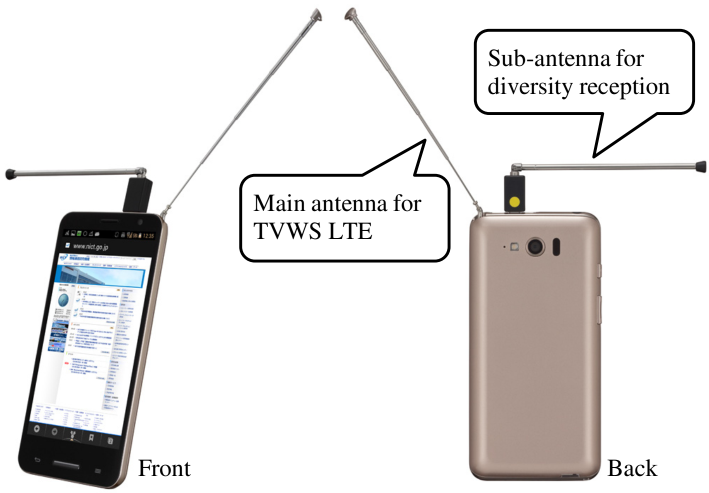
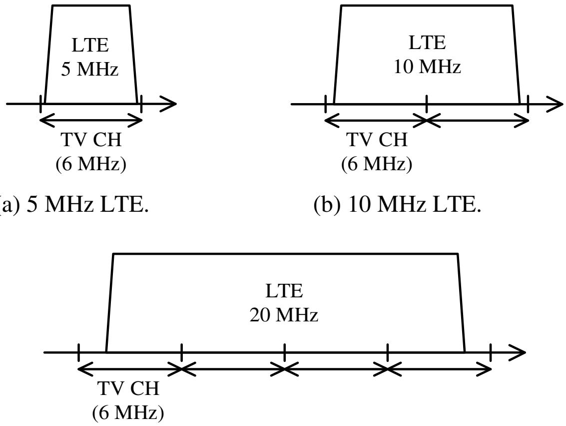


Fig. 1. Prototyped smart phone supporting TVWS LTE system.

Table 1. Physical Features.

Item	Description
LTE/3G	3GPP release 8
Wi-Fi	IEEE802.11a/b/g/n (2.4GHz/5GHz)
Bluetooth	Version 4.0
GPS	Bulit-in
CPU	APQ8064T 1.7GHz (Quad core)
Platform	Android 4.2 (JellyBean)
Internal Memory	RAM : 2GB, ROM : 32GB
SIM card slot	microSIM × 2
External Memory	microSD/microSDHC/microSDXC
Display	4.7 inch TFT panel, 1,920 x 1,080 full-HD Touch panel : electrostatic
Camera	1,340 MegaPixel
Battery	2,600 mAh
Battery Life (Standby time)	Up to 490 hours for 3G Up to 440 hours for LTE Band 1 Up to 290 hours for TVWS LTE
Battery Life (Talk time)	Up to 10 hours for 3G
Battery charge time	190 min with rapid charge adapter 270 min with wireless charger
External Antenna Port	SMA-P (for sub-antenna in UHF band)
Size	132 mm x 65 mm x 10.9 mm
Weight	146 g



(a) 5 MHz LTE. (b) 10 MHz LTE.

(c) 20 MHz LTE.

Fig. 2. LTE channel allocation to TV channels (based on 6 MHz BW).

2.2 Access to the White-Space Database

In the rule established by the FCC, a TV band device without any sensing function for TV broadcasting must access to the WSDB and acquire an available channel list according to its geo-location, before starting wireless communication in the TV band [4]. Therefore, this prototyped smart phone accesses to the WSDB and receives an available channel list via commercial network or internet access with a built-in WiFi system or the existing LTE system first, by sending its geo-location acquired by the built-in GPS (Global Positioning System) module. Here, by enhancing capabilities of the WSDB in accordance with the standard of the LTE communication system, the available channel list returned from the WSDB takes into account the operational status of neighbor TVWS eNBs [10]. Users can confirm the list of available channels on the display and switch the communication band arbitrarily by using original application.

2.3 Hardware Design

Fig. 3 shows a brief block diagram of implemented RF circuit and its control system allowing the TVWS communication in the prototyped smart phone. A customized RF IC, which supports LTE Band 1 and Band 38, is mounted on the RF board and connected to the modem IC. Here, Band 1 is a commercial band in Japan and its frequency ranges are 1,920–1,980 MHz. and 2,110–2,170 MHz for an uplink and a downlink, respectively. Band 38 with a frequency range of 2,570–2,620 MHz is not used in Japan so far. Duplex modes of Band 1 and Band 38 are FDD (Frequency Division Duplex) and TDD (Time Division Duplex), respectively. For communication in the TV band, communication frequency of Band 38 is converted to the UHF (Ultra High Frequency) band by using the frequency conversion technology. In this prototype, frequency conversion circuits are implemented instead of the RF circuits for Band 38, and thus, FDD-LTE system in the commercial band and TDD-LTE system in the TVWS are supported. Table 2 summarizes supported LTE communication systems in the phone.

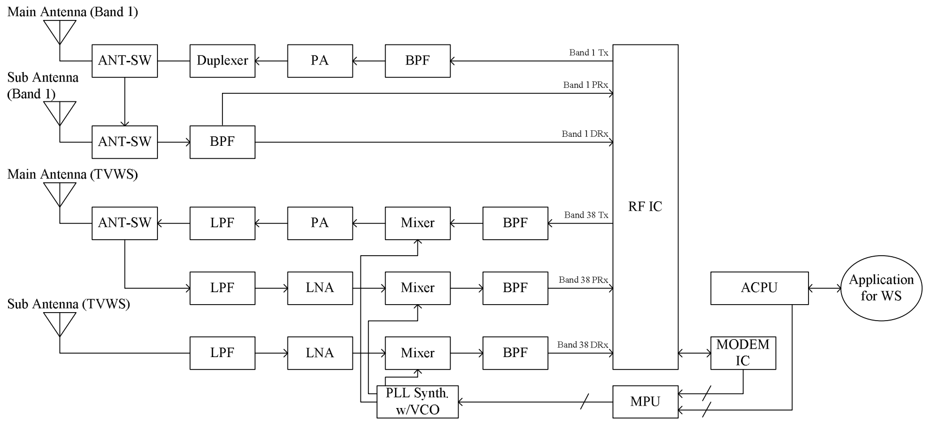


Fig. 3. Block diagram of implemented RF circuit and its control system for TVWS communication on prototyped smart phone.

Table 2. Supported LTE Communication Systems.

Item	Description
Supporting Frequency	UHF : 470-710 MHz (TVWS) Band 1 : 1,920-1,980 MHz (uplink) / 2,110-2,170 MHz (downlink)
Bandwidth	5, 10, 20 MHz
Transmission Power	Up to 20 dBm
Modulation	BPSK / QPSK / 16QAM / 64QAM BPSK : Control channel 64QAM : Downlink data channel
Duplex system	UHF : TDD Band 1 : FDD
Multiple Access	OFDMA (downlink) SC-FDMA (uplink)

For the frequency conversion, an RF signal of 2.6 GHz is converted to the UHF band with an upper local signal. Supporting frequency range in the UHF band is 470–710 MHz, which is the TV band in Japan. Since the same architecture is applied in our previously prototyped TVWS eNB [8], this prototyped smart phone enables connection to this eNB. To alleviate deterioration of frequency accuracy caused by the frequency conversion system, a high accurate TCXO (Temperature Compensated Crystal Oscillator) is used as a reference clock for the PLL (Phase Locked Loop) synthesizer with a VCO (Voltage Controlled Oscillator), which generates the upper local signal.

Additional MPU (Micro-Processing Unit) is implemented to control the communication frequency in the TVWS. The MPU is informed use channel information from the ACPU (CPU for Application) and generates control signals for the PLL synthesizer IC.

2.4 Antenna for TVWS

The prototyped smart phone supports diversity reception, as shown in Fig. 3. A built-in rod antenna originally for one-segment broadcasting reception is diverted to a main antenna for the TVWS LTE system and internally connected to an antenna port on the RF board. This antenna is retractable and used for both transmission and reception. A radiation efficiency of more than –2.7 dB is obtained in free space by measurement. For diversity reception, an additional antenna can be connected via an SMA connector, which is optionally attached to the phone. For the existing LTE system in Band 1, main and sub antennas are implemented internally.

3 RF Performance

3.1 Measured RF Characteristics

RF performance of the TVWS LTE system is measured based on the standard of the LTE communication system by using a radio communication tester (MT8820C, Anritsu). Fig. 4 shows a measurement system for TVWS LTE. Since the upper local is used to convert a communication frequency of 2.6 GHz in the prototyped smart phone, IQ (Inphase and Quadrature) polarity in the TV band is reversed. MT8820C does not support reversed IQ polarity, and thus, a mixer is inserted between MT8820C and the prototyped smart phone to reverse IQ polarity in the TV band. After the frequency of the RF signal is converted back to 2.6 GHz by an upper local with a frequency range of 3.0–3.3 GHz, IQ polarity is reversed once again to original polarity. To suppress unwanted signals generated by the mixer, LPF (Low Pass Filter) with a cut-off frequency of 780 MHz and BPF (Band Pass Filter) with a pass-band of 2,570–2,620 MHz are inserted in UHF and 2.6 GHz parts, respectively. In addition, attenuator is inserted between the LPF and the phone to avoid saturation of the mixer during transmission measurement. Note that all losses generated from the additional circuits in Fig. 4 are taken into account to measurement results described below.

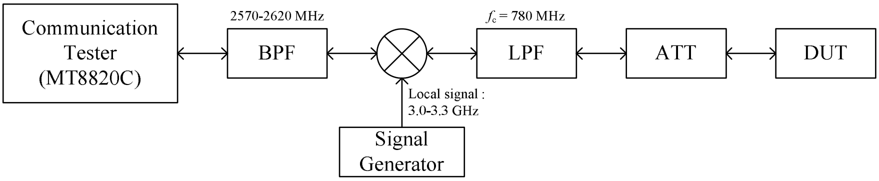


Fig. 4. Measurement system for RF performance of TVWS LTE.

Table 3. Measured RF Characteristics for TVWS LTE.

ITEM	Unit	RF Characteristics		
		Lch 473 MHz	Mch 593 MHz	Hch 707 MHz
Tx power	dBm	20.27	19.36	19.34
Frequency error	ppm	−0.041	-0062	−0.021
EVM (Data)	% rms	7.35	5.95	8.15
EVM (RS)	% rms	6.59	6.00	7.19
OBW	MHz	4.4775	4.455	4.4775
ACLR (Lower)	dBc	−28.27	−39.16	−27.07
ACLR (Upper)	dBc	−27.53	−39.70	−27.45
Rx Sensitivity	dBm	−92.6	−90.2	−87.0

Table 3 summarizes measured RF characteristics. Transmission power and signal BW are set to +20 dBm and 5 MHz, respectively, for measurement of all transmission characteristics. All the measurement was performed at a low channel (Lch) of 473 MHz, a middle channel (Mch) of 593 MHz and a high channel (Hch) of 707 MHz. Although the output power at Hch is slightly lower than that at Lch, frequency characteristics of the output power is sufficiently flat within 1 dB. Frequency error with a high accuracy of less than ±0.1 ppm is achieved in all channels and without deterioration due to the frequency conversion. An occupied BW (OBW) of about 4.5 MHz and an error vector magnitude (EVM) of less than 12.5 % in all channels are adequate in comparison with the requirement in the 3GPP standard.

A sufficient result of an adjacent channel leakage ratio (ACLR) at the Mch is obtained, while ACLR at both Lch and Hch is about –27 dBc and does not satisfy with the 3GPP standard. Fig. 5 shows typical frequency characteristics of ACLR and transmission power of the phone. Both ACLR in upper and lower sides indicates almost same frequency characteristics. ACLR is sufficiently low in a frequency range of 520–690 MHz but remarkably deteriorated in the edge of the TV band, i.e. 470 and 710 MHz. On the other hand, the transmission power is almost flat in the entire TV band. In addition, ACLR of a power amplifier (PA) device is not remarkably deteriorated even in the edge of the TV band in comparison with that in Fig. 5. Therefore, deterioration of ACLR is mainly caused by impedance mismatch of the PA with the mixer and LPF, due to wide frequency range of the TVWS. This is one of challenges in component development and circuit design for further prototype of portable size TV band devices.

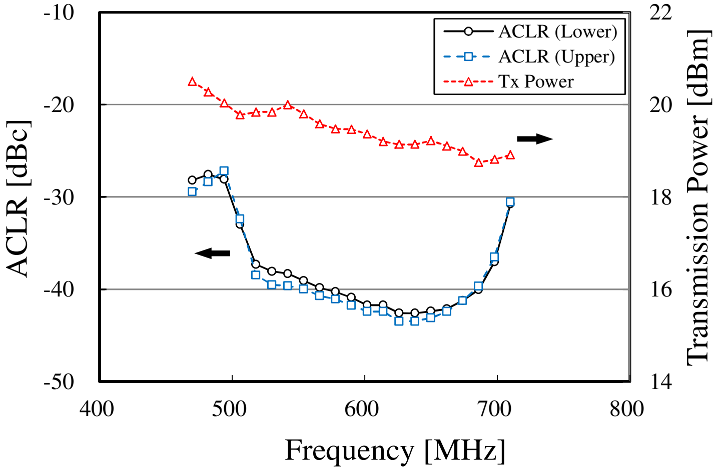


Fig. 5. Frequency characteristics of ACLR and transmission power.

Receiver sensitivity is defined as minimum received power with a throughput of more than 95 % in QPSK modulation, as following the 3GPP standard. As indicated in Table 3, a receiver sensitivity of –92.6 dBm, –90.2 dBm, –87.0 dBm is obtained at the Lch, the Mch and the Hch, respectively. This result is inadequate in comparison with a requirement in the 3GPP standard but sufficient in comparison with other TV white-space communication standards such as IEEE802.11af [2]. Fig. 6 shows frequency characteristics of RSSI (Received Signal Strength Indicator) floor level that indicates received power at which RSSI does not change due to lower received signal level than receiver noise level. This RSSI floor level almost agrees with receiver sensitivity. From this result, higher RSSI floor level is observed in higher frequency range, resulting in deterioration of the receiver sensitivity. This deterioration might be caused by insufficient frequency characteristics of gain and NF (Noise Figure) of the mixer, and also noise or spurious in a local signal. For further improvement of RF performance, it is important to flatten frequency characteristics of components constituting the RF circuit and to implement design techniques for noise reduction in wide frequency range of the TV band.

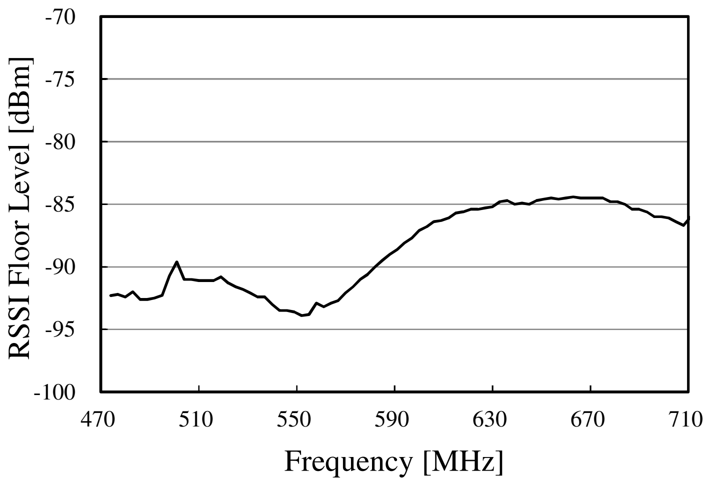
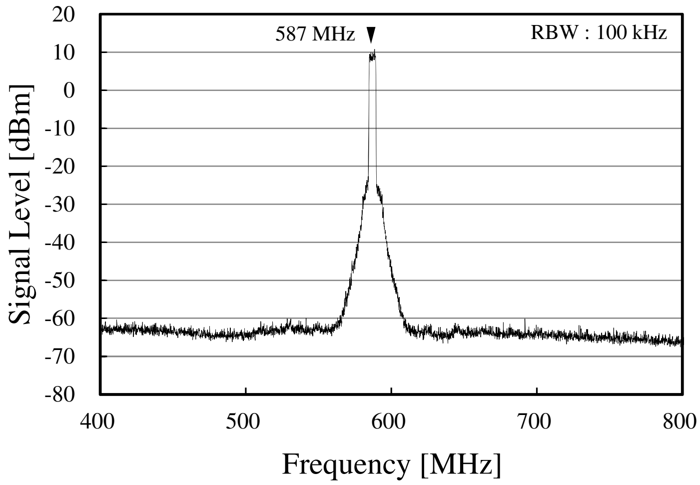


Fig. 6. Frequency characteristics of RSSI floor level.

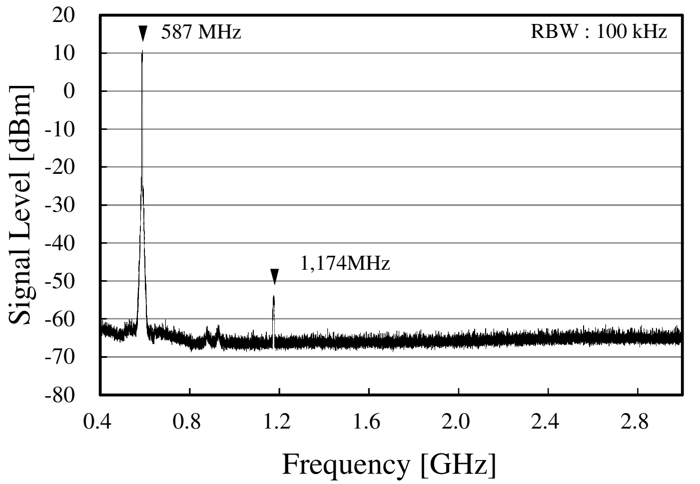
3.2 Spurious Response

Spurious response of the prototyped smart phone is measured with using a signal analyzer (FSQ8, Rohde& Shwartz). Fig. 7 shows typical spurious response in the TV band and wider frequency range up to 3 GHz. A carrier frequency of 587 MHz is generated by mixing an LTE signal at 2,595 MHz and an upper local signal at 3,182 MHz. In this measurement, a 5 MHz BW single carrier with 16QAM (Quadrature Amplitude Modulation) for the up-link is used and mean output power in the TV band is set to +20 dBm. In addition, spurious response is measured by using a max hold function with a resolution BW (RBW) of 100 kHz.

No remarkable spurious is observed and floor noise level is sufficiently low about less than –60 dBm over the entire TV band, as shown in Fig. 7(a). This unwanted signal level outside using channel complies with criteria in rules regulated by the FCC and the Ofcom, except for slopes of spectrum mask. On the other hand, 2nd harmonics with a signal level of –53.8 dBm is observed at 1,174 MHz, as shown in Fig. 7(b). This spurious level is sufficiently low and no other remarkable spurious is observed in the wide frequency range.



(a) In wide frequency range.



(b) In wide frequency range.

Fig. 7. Prototyped smart phone supporting TVWS LTE system.

4 Conclusion

In this study, the prototyped smart phone enabling TVWS communication with the LTE system is described and its physical features are summarized. In this prototyped smart phone, communication frequency of the existing LTE Band 38 is converted to the UHF band by utilizing frequency conversion technology. Existing LTE Band 1 is also supported as a commercial band and this smart phone can switch the band from Band 1 to the TVWS, after receiving the available channel list from the WSDB.

Measured RF performance for TVWS LTE systems achieves the 3GPP standard except for the ACLR at Lch and Hch. Furthermore, no remarkable spurious and unwanted emission is observed over the entire TV band. This means the possibility to deploy the existing LTE system in the TVWS without crucial alterations. In addition, this prototype is the world's first smart phone supporting TVWS LTE system, capable of fully operating in the internal battery. This indicates not only the feasibility of portable size and low power consumption TVWS device, but also the possibility of spectrum expansion in mobile communication system towards next generation. By using this prototyped smart phone, it is possible to evaluate interference with/from the primary users and also to investigate the vertical-handover based on the spectrum sharing technology under actual mobile environment.

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