

Reconfigurable anti-interference RF transceiver for cognitive radio application

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Abstract: An RF transceiver composed of a zero-IF receiver and a direct up-conversion transmitter for cognitive radio applications is presented. The adjustable channel filter array in the receiver is used to suppress adjacent channel interference in televisions signal coexistence environments. The low noise amplifier (LNA) with wide dynamic range and high linearity is employed to enhance the anti-interference competence of the zero-IF receiver. Meanwhile, the high linearity power amplifier (PA) is used to promote the adjacent channel power ratio (ACPR) characteristic of the direct up-conversion transmitter. The measured error vector magnitude (EVM) results show that the anti-interference competence of the zero-IF receiver is dramatically enhanced by employing a channel filter array. The measured ACPR of the direct up-conversion transmitter is -47.98 dBc on the channel centered at 714 MHz when the output power is 27 dBm.

Key words: zero-IF; direct up-conversion; anti-interference; cognitive radio; white space spectrum

doi: 10.3969/j.issn.1003-7985.2011.02.001

Cognitive radio (CR)^[1-3] is a new technique to raise the utilization ratio of the frequency spectrum on the system side. CR can develop the secondary market, bring more available bandwidth and guarantee individual business more steadily. The white space spectrum, which exists in a fixed distribution mode, can be effectively reused by utilizing CR, so a better overall utilization ratio of the frequency spectrum resource can be achieved^[4]. CR is an effective method to resolve the conflict between frequency spectrum shortage and waste. It is one of the strategic development directions in wireless communications and possesses broad prospects for application. Till now, several experimental networks using cognitive radio technology have been explored^[5-6].

In CR working environments, the frequency spectrum holders and CR system users coexist with each other. The frequency spectrum holders are also called primary users and these CR system users are correspondingly termed as secondary users. Because primary users and CR system users work in the same operational band, the interferences between them should be considered. The primary users are protected^[7], so these interferences need to be handled on the

CR system side. Due to the fact that the interference mainly occurs in the RF band, the RF transceivers used in the CR system should be designed with anti-interference competence to ensure that the two classes of users coexist without interferences. Many RF modules with anti-interference competence are designed for many sorts of applications^[8-12], but few of them are used in CR networks.

In this paper, a reconfigurable RF transceiver with anti-interference competence used in a special CR testing network is presented. The transceiver is composed of a zero-IF receiver and a direct up-conversion transmitter. The CR testing network, the structure of the RF transceiver and its anti-interference characteristics are described and analyzed in the following sections.

1 CR Testing Network

A CR testing network is designed to utilize a white space spectrum in a TV band (see Fig. 1). The operational band is 694 to 806 MHz, which is fixedly allocated to the television system in China. There are 14 television channels in operational bands with an 8 MHz bandwidth for each channel. Generally speaking, not all the 14 channels are used at the same time, so there are always some available channels which are free channels. The CR system will find the available channel and reuse it. Fig. 1 shows the application scene of this CR testing network, which works in the TDD mode. In this network, the frequency spectrum utilization state of the television system is first sensed by spectrum cognition modules included in both the CR network node and the CR terminal node, and all the cognition results are transferred to the spectrum decision module located in the CR network node. Then, the spectrum decision module determines the proper available channel for the CR system according to the cognition results of all the nodes and the *a priori* knowledge. Finally, system reconfiguration is carried out for working on the selected operational channel and then the CR system can accomplish data communication on the selected operational channel.

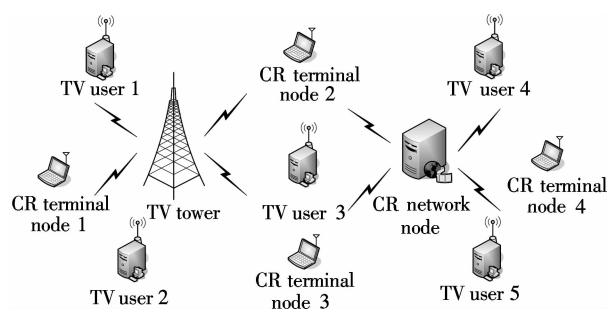


Fig. 1 Application sense of cognitive radio testing system in TV band

Received 2011-02-21.

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Foundation items: The National Natural Science Foundation of China (No. 60621002), the National High Technology Research and Development Program of China (863 Program) (No. 2009AA011801).

Citation: You Changjiang, Liu Jing, Zhang Xiaodong, et al. Reconfigurable anti-interference RF transceiver for cognitive radio application [J]. Journal of Southeast University (English Edition), 2011, 27(2): 123 – 127. [doi: 10.3969/j.issn.1003-7985.2011.02.001]

2 Reconfigurable RF Transceiver

The reconfigurable RF transceiver is composed of a zero-IF receiver and a direct up-conversion transmitter. The scheme of the reconfigurable RF transceiver is shown in Fig. 2. Because the CR system works in the TDD mode, there is a T-R switch in the transceiver to change the working state.

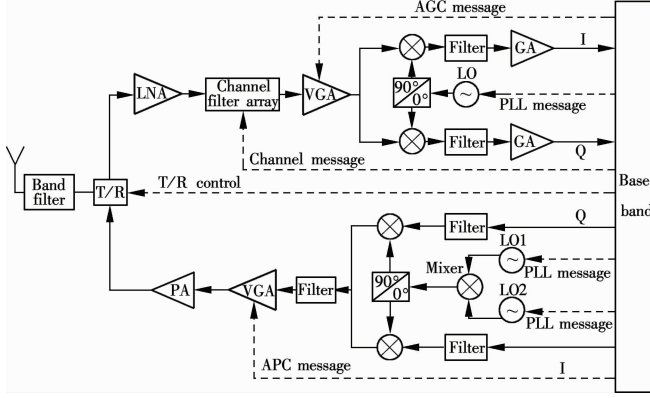


Fig. 2 Schematic diagram of reconfigurable RF transceiver

2.1 Channel filter array

The reconfiguration receiver is implemented by employing a reconfigurable channel filter array, and the structure is illustrated in Fig. 3. There are 14 filters for 14 different channels, and the center frequency of each filter is designed the same as the center frequency of the corresponding channel. The insert loss in the pass-band of each filter is 4.0 dB, and the 3 dB bandwidth of each filter is designed as 8 MHz.

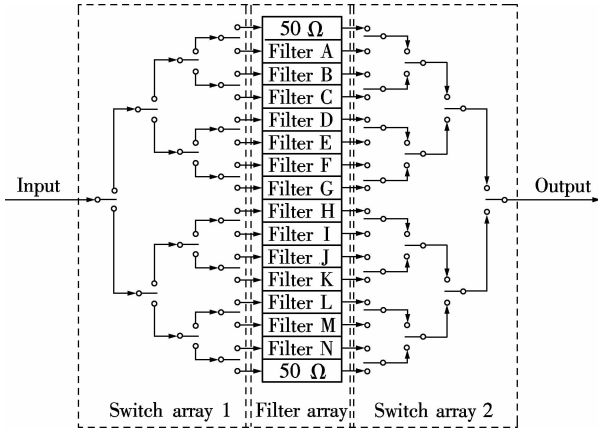


Fig. 3 Structure of channel filter array used in reconfigurable RF receiver

2.2 Zero-IF receiver

As shown in Fig. 2, the zero-IF receiver includes a reconfigurable front-end, which consists of a band filter, a low noise amplifier (LNA), a channel filter array and a variable gain amplifier (VGA). The two switch arrays in the channel filter array are controlled by the base-band system.

A received signal is first filtered by the band filter with a 0.5 dB insert loss. A LNA with high gain and low noise figures is located next to the T-R switch to amplify the signal. Moreover, to improve the anti-interference characteris-

tics, high linearity and high output power competence of LNA are required. After flowing through the channel filter array, the received signal is transferred into the VGA for amplifying. Three digital attenuators and three amplifiers are employed to make the VGA have a gain dynamic range of more than 90 dB, which contains some minus gain when the receiving signal is too strong. The gain value of VGA is controlled by an auto gain control (AGC) message which is sent by the base-band system, as shown in Fig. 2. Then, the RF signal flows into the demodulator to generate base-band I/Q signals. After being filtered and amplified, the output signals of the demodulator are transferred to the base-band system.

2.3 Direct up-conversion transmitter

The scheme of the direct up-conversion transmitter is shown in Fig. 2. The base-band I/Q signals are fed into the low-pass filter to remove other signals before up-conversion. The up-conversion is done by an I/Q modulator. The LO signal is combined by means of mixing two signals generated by two frequency synthesizers to avoid LO pulling, and the two frequency synthesizers are controlled by the base band. The following RF band-pass filter suppresses other products generated in the modulating process. Then, the RF signal flows into a VGA which has a maximum gain dynamic range of 31.5 dB, and the gain value is controlled by an auto power control (APC) message. The output signal of the VGA is transferred into the power amplifier to boost the power to 27 dBm. Finally, the signal is filtered by the band filter, and transmitted through the antenna.

3 Interference Characteristic Analysis

In CR networks, the CR system users should have the competence to coexist with primary users in the same frequency band and to avoid affecting the primary users. Thus, in the design of the RF transceiver used in the CR system, the interference between primary users and CR system users must be considered.

3.1 Interference to CR system users

It is supposed that the launched power from the television tower is 70 dBm (10 kW), and the distance from the cognitive radio RF receiver to the launching tower is 500 m. The height of the television tower and the cognitive radio terminal are assumed to be 200 and 1.5 m, respectively. According to the Okumura model, path loss L is formally expressed as ^[13]

$$L = L_s + A_M - H_M - H_B - K_C \quad (1)$$

where L_s , A_M , H_M and H_B denote the free space loss, the median attenuation, the mobile station antenna height gain factor, and the base station antenna height gain factor, respectively; and K_C is the terrain modifying factor. Therefore, in urban areas, these parameters can be calculated or obtained by the table-look-up method as

$$L_s = 32.44 \text{ dB} + 20 \lg f(\text{MHz}) + 20 \lg d(\text{km}) = 32.44 + 20 \lg 694 + 20 \lg 0.5 \approx 83.25 \text{ dB} \quad (2)$$

$$A_M = 16.7 \text{ dB}, H_M = -3 \text{ dB}, H_B = 0 \text{ dB}, K_C = 0 \text{ dB} \quad (3)$$

where the frequency is chosen as the lowest frequency in the operational band. Then, the path loss L is calculated as

$$L = L_S + A_M - H_M - H_B - K_C = 102.95 \text{ dB} \quad (4)$$

The maximum gain of antennae used in the RF system is designed as 6 dB in CR system planning. Since antennae used in the television tower vary to cover different areas, the gains of these antennae are also different from each other. Therefore, to simplify the analysis, it is assumed that the gain of the television tower antenna is also 6 dB. On this occasion, the strongest imaginable received signal power is

$$P_{in} = 70 \text{ dBm} - 102.86 \text{ dB} + 12 \text{ dB} = -20.95 \text{ dBm} \quad (5)$$

An RF signal with a power of -20.95 dBm is a strong receiving signal for wireless communications. One of the possible power distributions of the television signals on 14 channels is shown in Fig. 4. To guarantee the communication on these available channels, on whose adjacent channel there is a strong television signal with power up to -20.95 dBm , the RF receivers of CR system users must have a certain anti-interference competence.

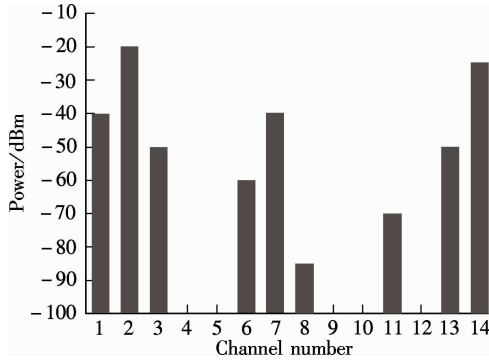


Fig. 4 One of the possible power distributions of television signals on 14 channels

In this design, in order to avoid the strong nonlinearity happening in the LNA when the interference signal and the CR system signal flow into it at the same time, the basic requirement of the LNA used in the CR system is high power and high linearity. Therefore, an LNA with a 0.6 dB noise figure, a 30 dB gain and a -4 dBm input 1dB compression point (P_{1dB}) is employed in the zero-IF receiver to enhance the anti-interference competence. Both the interference signal and the CR system signal are amplified by the LNA. Then, the output signal of the LNA is filtered by a reconfigurable channel filter array which is located next to the LNA and the interference signal is suppressed deeply. Finally, the interference signal in the output of the channel filter array will not affect the following process and the receiving quality is guaranteed.

3.2 Interference to primary users

In the CR network, to keep the primary users working without interference is a very important criterion. The receiving sensitivity of a television set is less than -60.9 dBm ^[14-15]. If the television set receives interference signals stronger than -60.9 dBm , the working quality of the tele-

vision set may deteriorate greatly on this channel. Thus, to avoid causing interference to primary users, the adjacent channel power ratio (ACPR) of the RF transmitter used in the CR system must be strictly designed.

It is supposed that the minimum distance between a CR transmitter and a television set is 20 m and the gain of a receiving and transmitting antenna is 6 dB. When the signal frequency is 694 MHz^[16], the space propagation attenuation is approximately calculated as

$$L_1 = 101 \lg \left(\frac{4\pi d}{\lambda} \right)^2 = 201 \lg \frac{4\pi d}{\lambda} \approx 55.29 \text{ dB} \quad (6)$$

Meanwhile, the receiving sensitivity of the television set is supposed to be -60.9 dBm , so the maximum transmitted adjacent channel power of the CR system transmitter is calculated as

$$P_{ac} = -60.9 \text{ dBm} + 55.29 \text{ dB} - 12 \text{ dB} = -17.61 \text{ dBm} \quad (7)$$

The maximum transmitting power of the CR transmitter is 27 dBm in this testing network, so the ACPR needs to be more than 44.61 dBc.

To meet the ACPR requirements, a power amplifier with high power and high linearity is employed in the direct up-conversion transmitter. The output 1 dB compression point (P_{1dB}) of the power amplifier (PA) is 40 dBm while the required maximum output power of the PA is 27.5 dBm, and extra 0.5 dB is used to compensate the insert loss of the band filter.

4 Measurement

A reconfigurable anti-interference RF transceiver for cognitive radio applications is designed. Fig. 5 shows the photograph of the fabricated transceiver. To validate the anti-interference competence of the designed zero-IF receiver, the EVM is measured on two occasions for comparison when there is a channel filter array or not. Fig. 6 shows the EVM testing platform when there is an interference signal. Fig. 7 illustrates the measured EVM comparison when the interference signal is on different channels. The CR system signal, which is an OFDM signal with 2 048 subcarriers, a -50 dBm power and a 7.0 MHz bandwidth, occupies the channel with a 698 MHz center frequency that is the first channel of 14 channels. The interference signal with a 7.0 MHz bandwidth and a -20.95 dBm power is added on different channels from channel 2 to channel 14, which is a modulation signal and is used to imitate a TV signal. When the interference signal is on the adjacent channel, the EVM improvement is limited. However, when the interference signal is on other channels, the measured EVM is less than 3%. It means that the interference signal will hardly influence the

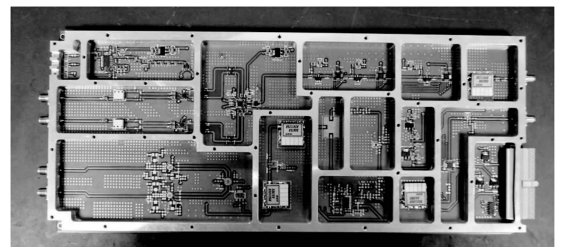


Fig. 5 Photograph of reconfigurable anti-interference RF transceiver

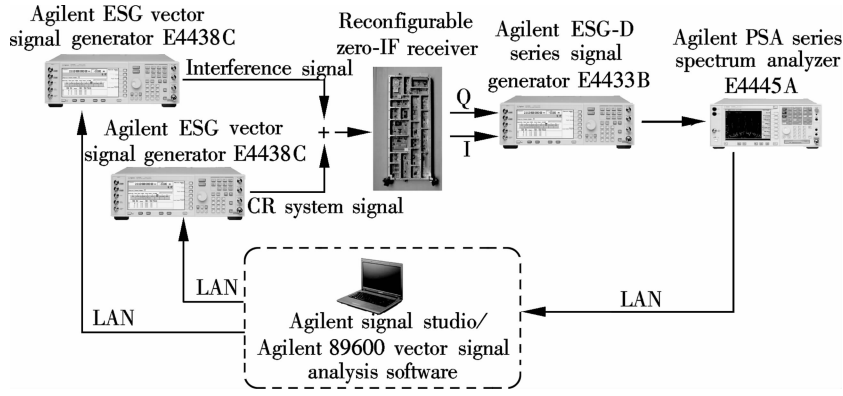


Fig. 6 EVM testing platform of reconfigurable zero-IF receiver when there is an interference signal

receiver. Moreover, it is found that the EVM is improved greatly by employing the channel filter array compared to that of the receiver without a channel filter array.

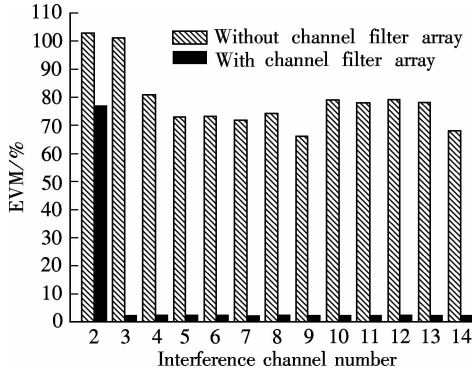


Fig. 7 Measured EVM comparison when an interference signal is on different channels

Fig. 8 demonstrates the measured EVM comparison when an interference signal has different power levels. The CR system signal is OFDM signal with 2 048 subcarriers, a -50 dBm power, a 7.0 MHz bandwidth and a 698 MHz center frequency. Meanwhile, the modulated interference signal is of a 7.0 MHz bandwidth, a 706 MHz center frequency and different power levels. Without a channel filter array, the EVM begins to deteriorate when the power of the interference signal is -35 dBm, while the value is -25 dBm when a channel filter array is used. Both Fig. 7 and Fig. 8 explain that the anti-interference competence of the zero-IF receiver is dramatically enhanced by employing a reconfigurable

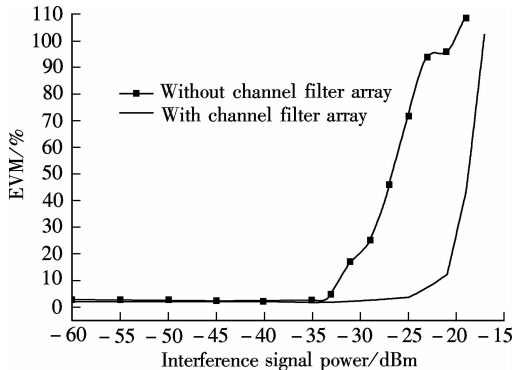


Fig. 8 Measured EVM comparison when interference signal has different power levels

channel filter array.

The ACPR of the direct up-conversion transmitter is measured when the output power is 27 dBm. The signal used in testing is an OFDM signal with 2 048 subcarriers and a 7.0 MHz bandwidth. Fig. 9 shows the output signal spectrum of the direct up-conversion transmitter when the center frequency of the working channel is 714 MHz and there is a 30 dB attenuator located at the input port of the spectrum analyzer. On this occasion, the measured ACPR is -47.98 dBc, which can meet the requirements of causing no interference to the primary users.

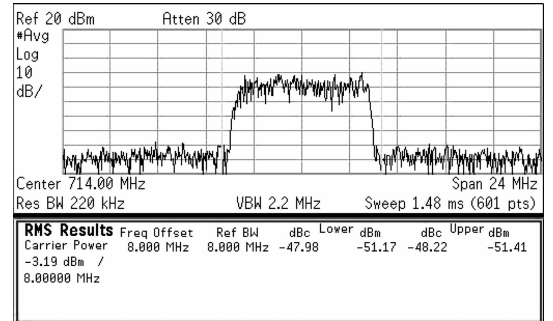


Fig. 9 Measured ACPR of direct up-conversion transmitter

5 Conclusion

A reconfigurable RF transceiver used in the UHF band cognitive radio testing system is presented. The transceiver is composed of a zero-IF receiver and a direct up-conversion transmitter. The zero-IF receiver has considerable anti-interference characteristics by employing a reconfigurable channel filter array, and the design will meet the special anti-interference requirements for cognitive radio applications.

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应用于感知无线电的可重构抗干扰射频收发机

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摘要:介绍了一种应用于感知无线电的射频收发机,该射频收发机包含一个零中频接收机和一个直接上变频发射机.在与电视信号共存的环境中,射频接收机采用可调信道滤波器组来抑制邻近信道干扰.采用了具有宽动态范围、高线性度的低噪声放大器来提升零中频接收机的抗干扰性能.同时,采用高线性功率放大器来提高直接上变频发射机的邻近信道功率比特性.测试得到的误差矢量幅度结果显示,通过采用信道滤波器组使零中频接收机的抗干扰性能得到了很大提高.当直接上变频发射机发射输出功率达 27 dBm 时,在中心频率为 714 MHz 的信道上,测得直接上变频射频发射机的邻近信道功率比为 -47.98 dBc.

关键词:零中频;直接上变频;抗干扰;感知无线电;白频谱

中图分类号:TN92