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EVALUATION OF DCS1800/CDMA-EVDO DUAL-MODE AND DUAL-LINK UE SYSTEM PERFORMANCE BASED ON THE HIGH ISOLATION HANDSET ANTENNA

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Abstract—This paper investigates the performance of DCS1800/CDMA-EVDO dual-mode dual-link (DM-DL) UE and presents an effective solution which is based on our designed high isolation antenna for the UE local electromagnetic interference (EMI). To this end, a DCS1800/CDMA-EVDO DM-DL UE model is firstly brought out, together with its system model, interference analysis and performance evaluation. Simulated results show that the DCS1800 (CDMA-EVDO) local interference will cause a sharp deterioration of the CDMA-EVDO (DCS1800) receiving sensitivity. To solve this problem, then, a compact and high isolation double-band handset antenna is given with its structure designed and performance validated by measurement. On the basis of this antenna and existing UE bandpass filter, we introduce a solution called "passive isolation" to eliminate the local interference. Finally, the performance of DCS1800/CDMA-EVDO DM-DL UE is researched again by our solution, simulated results indicate that the isolation effect is quite good and the DM-DL UE can work normally.

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1. INTRODUCTION

Multi-mode and multi-link UE (M3L-UE) receives ever-increasing attention due to its very wide communication and entertainment applications, for example, in the new version of 3GPP, type A and type B UE have been defined as M3L-UE [1]. In a M3L-UE, several wireless links are working at the same time, so there will be lots of hardware, software and product realization problems. Among the various problems, local EMI is one of the most urgent problems that need researching and solving.

During the past several years, many efforts have been paid to the multi-mode communication system. For example, many researches are placed on UE antenna designs and realizations which lead to multi-band antennas [2–11], miniaturized antennas with low return loss [12–16] are successful developed, yet these antennas are all designed without considering the isolation between them. Papers [17–20] analyze the dual-mode interference between UWB and cellular systems, and the multi-mode co-existence between cellular systems is also included in [21–25], but problems exist that the interference scenarios they researched are all single-mode single-link for each UE. These existing researches have provided a strong and well-understood basis for multi-mode communication performance evaluation necessarily for its development. As we know, however, less work has been done concerning DM-DL UE, in which case the two modes working at the same time belong to one UE and the transmitted signal of one mode is a strong local interference signal to the received signal of the other mode. Therefore, problems arise that how to evaluate the performance of a DM-DL UE under the local interference existence and how to alleviate the interference. These are the main motivations behind this paper.

The organization of this paper is as follows. In Section 2, a DCS1800/CDMA-EVDO DM-DL UE system model with interference analysis and its simulation performance are introduced. In Section 3, a high isolation double-band handset antenna designed for our DCS1800/CDMA-EVDO DM-DL UE is presented with its performance validated by measurement. In Section 4, based on our antenna, the performance of the DCS1800/CDMA-EVDO DM-DL UE is researched again. Some conclusions are finally drawn in Section 5.

2. MODEL, INTERFERENCE AND PERFORMANCE

2.1. System Model

Without loss of generality, only the CDMA-EVDO receiving mode and DCS1800 transmitting mode are considered here (or we can

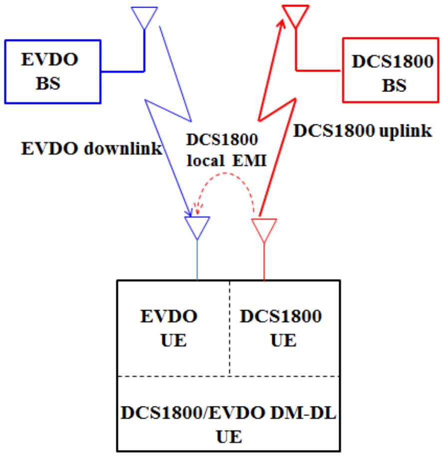


Figure 1. DCS1800/CDMA-EVDO DM-DL UE system model.

also choose DCS1800 receiving mode and CDMA-EVDO transmitting mode). As shown in Figure 1, the DCS1800/CDMA-EVDO DM-DL UE is composed of a receiver and a transmitter, and operated in dual-mode at the same time. In a DM-DL UE, the receiver and the transmitter are integrated in a small volume which leads to the interference generated from the transmitter easily to affecting the receiving system performance.

2.2. Interference Analysis

When the DCS1800/CDMA-EVDO DM-DL UE is working at the verge of a cell, the CDMA-EVDO received signal level is very low; therefore, the DCS1800 uplink spurious signal level in CDMA-EVDO frequency band is quite strong relative to the CDMA-EVDO received signal, just as shown in Figure 2.

As a result, the DCS1800 uplink spurious signal can raise the background noise of CDMA-EVDO receiver and make the quality of CDMA-EVDO downlink poor, and then the CDMA-EVDO receiver needs greater signal to noise ratio (SNR) in order to modulate the received signal correctively. The SNR demanding will lead to the deterioration of CDMA-EVDO receiving sensitivity. The background noise of the CDMA-EVDO receiver can be expressed as

$$N_{\text{floor}} = N_0 + BW + NF \tag{1}$$

Among them, $N_0 = -174\,\text{dBm/Hz}$, BW stands for the bandwidth of the CDMA-EVDO, and NF is the noise figure of CDMA-EVDO receiver. Then, the CDMA-EVDO receiving sensitivity R_s can be written by

$$R_s = -174 + 10\lg(BW) + NF + SNR \tag{2}$$

According to (2), we know that a greater SNR demanding will result in a deterioration of the R_s. In order to guarantee the CDMA-EVDO receiving sensitivity in a normal level (usually the receiving sensitivity reduction can not exceed 3 dB), the antenna isolation (AI) between DCS1800 transmitting port and CDMA-EVDO receiving port must meet the following relation

$$P_{tx}(f_c) - AI(f_c) \leq I_{\max}(f_c) = R_s(f_c) \tag{3}$$

where f_c, $P_{tx}\,(f_c)$, $I_{\max}\,(f_c)$ are the CDMA-EVDO operating frequency, the DCS1800 local interference power in the CDMA-EVDO frequency band and the maximum local interference power level that the CDMA-EVDO receiver can accept, respectively.

2.3. Performance

The performance evaluation of CDMA-EVDO under the DCS1800 local interference is a system level simulation problem. In order to simplify the analysis, the DCS1800 local interference source is equivalent with a single transmitter and its power is added directly into the receiving channel of the CDMA-EVDO UE. Considering the most serious interference, the nearest working frequencies of DCS1800 uplink and CDMA-EVDO downlink are chosen in the simulation. Namely, DCS1800 uplink operating frequency is 1710.2 MHz and CDMA-EVDO downlink is 893.985 MHz. Simulation parameters for DCS1800 uplink and CDMA-EVDO downlink are listed in Tables 1 and 2, respectively.

Based on the S-parameters obtained from the existing antennas, the antenna isolation AI between DCS1800 antenna port and

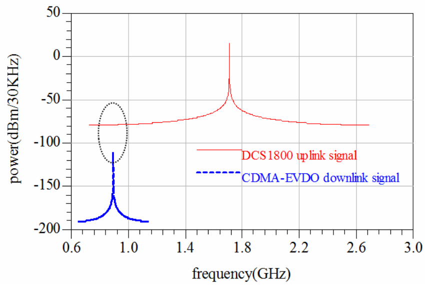


Figure 2. DCS1800 and CDMA-EVDO spectrums.

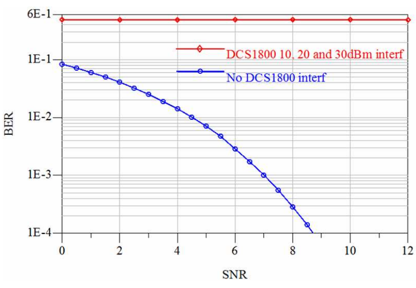


Figure 3. BER performance of CDMA-EVDO under the DCS1800 local interference.

Table 1. Parameters for DCS1800 uplink.

Parameter	Value
Operating frequency/MHz	1710.2
Signal bandwidth/KHz	200
Modulation mode	GMSK
Transmitting power/dBm	10, 20 and 30
Antenna isolation (AI)/dB	10

Table 2. Parameters for CDMA-EVDO downlink.

Parameter	Value
Operating frequency/MHz	893.985
Signal bandwidth/MHz	1.5
Modulation mode	QPSK
Transmitting power/dBm	46
Path loss/dB	151.5
Channel	AWGN

CDMA-EVDO antenna port is 10 dB. Under different DCS1800 local interference power levels, the interference effect is characterized by the variation of CDMA-EVDO BER performance for different SNR.

As shown in Figure 3, with the SNR of CDMA-EVDO downlink received signal increasing, there is a downward trend of the BER performance. We set the threshold of BER at 10^{-3}, a value above which the CDMA-EVDO system will not work properly. When the DCS1800 transmitting power is 10, 20, and 30 dBm, the BER of CDMA-EVDO system is so large that the CDMA-EVDO communication can not be established totally!

In order to alleviate the DCS1800 strong local interference, some methods which can improve the isolation between the DCS1800 channel and CDMA-EVDO channel should be carried out. A double-band antenna with high isolation is designed and measured in the following section.

3. ANTENNA DESIGN AND PERFORMANCE

3.1. Antenna Structure

As shown in Figure 4(a), the proposed high isolation antenna consists of two separated elements which are two layered chip A and two layered

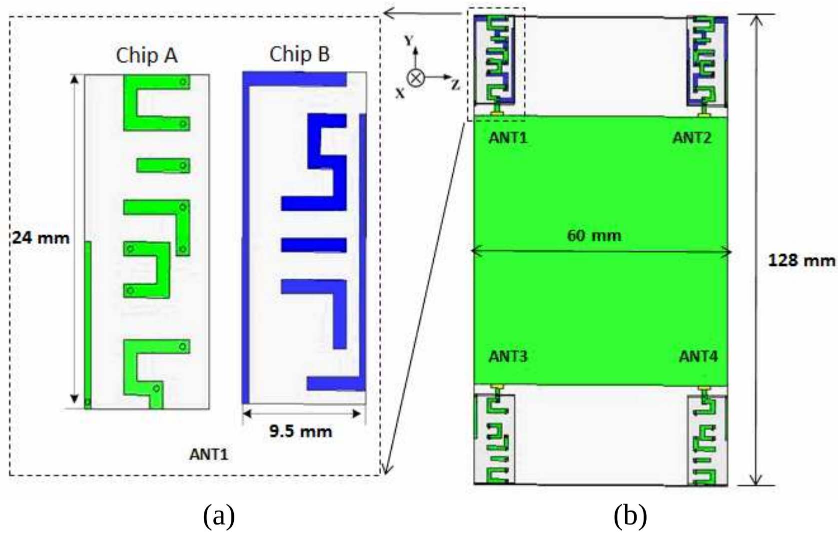


Figure 4. Geometry of the antenna: (a) single-fed antenna, (b) main PCB with antennas.

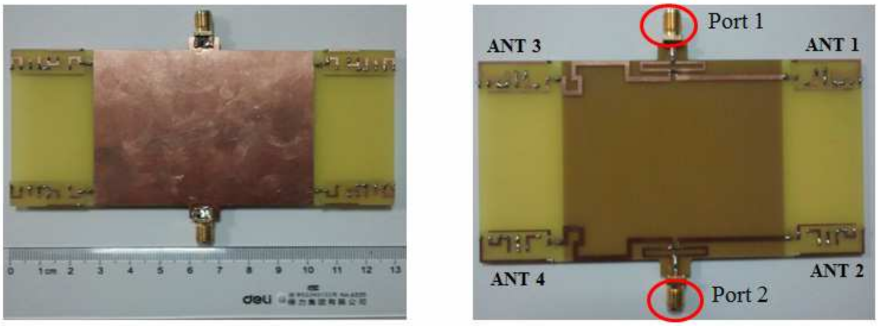
chip B. Chip A with dimension of $24.0 \times 9.5 \times 1.8\,\text{mm}^3$ is a FR4 printed circuit board (PCB) ($\varepsilon_r = 4.5$, $\tan\delta = 0.02$), which is completely integrated within handset main PCB. With the same size and material as Chip A, Chip B is designed as a part of the antenna. The main PCB shown in Figure 4(b) has a double layered structure with size of $128 \times 60 \times 1.8\,\text{mm}^3$.

There are four same dual-band antennas (ANT1, ANT2, ANT3, and ANT4) on the main PCB. Between them, ANT1 and ANT2 are used for DCS1800 and CDMA-EVDO communications, ANT3 and ANT4 which pass through additional microstrip circuits are added to improve the isolation between ANT1 and ANT2.

The fabricated prototype of the antennas is shown in Figure 5. It consists of two feeding ports, port 1 and port 2. The PCB with the antennas is used to assess the RF local interference effect of the proposed DM-DL UE.

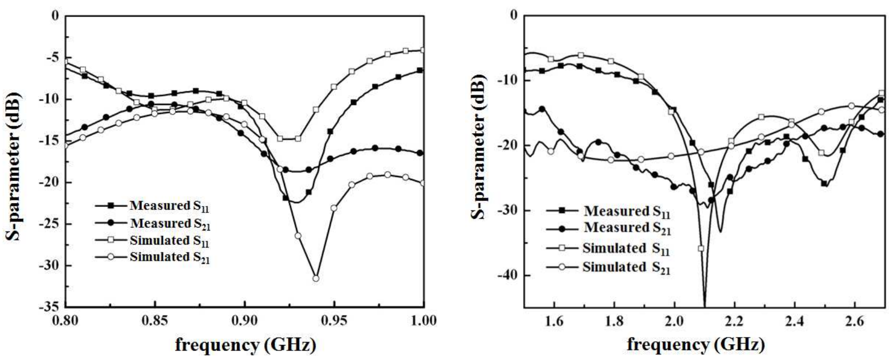
3.2. Antenna Performance

The antennas are modeled and simulated in HFSS software, and measured in a microwave anechoic chamber. The simulated and measured S-parameters of the antennas are presented in Figure 6, with good agreement between the simulated and the measured results. From Figures 6(a) and (b), we know that each antenna can effectively operate on CDMA-EVDO frequency band and DCS1800 frequency



(a) (b)

Figure 5. Photograph of the fabricated antennas: (a) top view, (b) back view.



(a) (b)

Figure 6. (a) Simulated and measured S-parameters for the CDMA-EVDO frequency band. (b) Simulated and measured S-parameters for the DCS1800 frequency band.

band. Due to the dip in all S-parameters curves which they come after the DCS1800/CDMA bands, we try to increase the antenna dimensions so as to shift the dip of both DCS1800/CDMA systems. However, because of the paradox of the two S-parameters (S_{11} and S_{21}) and the complexity of the antenna, we can hardly obtain the ideal S_{11} and S_{21} at the same time, that is to say, the S_{11} improvement results in S_{21} deterioration while the S_{21} improvement leads to S_{11} deterioration. Considering the high isolation is what we need, S_{21} plays a more important part than S_{11}, so we design the antenna with high isolation (S_{21}) and normal S_{11} (about -10 dB) finally. The isolation of the two antennas equals to 22 dB in the DCS1800 frequency band, as shown in Figure 6(b).

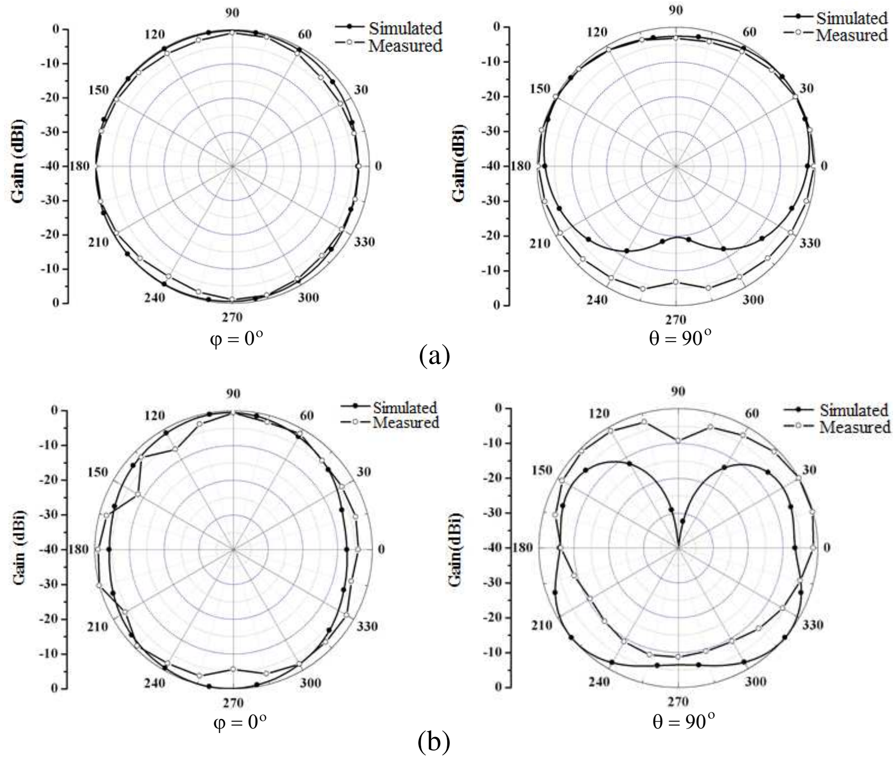


Figure 7. Simulated and measured gain patterns for the antenna: (a) 894 MHz, (b) 1.71 GHz.

The simulated and measured normalized radiation gain patterns of the antennas at 894 MHz and 1.71 GHz are presented in Figure 7. The measurement of radiation patterns is operated with one port excited, and the other terminated with a 50 Ω load. The peak Gain is 0.3 dBi at 894 MHz and 1.4 dBi at 1.71 GHz.

It demonstrates that the designed antenna can be effectively used in DCS1800/CDMA-EVDO DM-DL UE with high isolation and good performance.

4. SOLUTION

4.1. Solution Performance for CDMA-EVDO under DCS1800 Local Interference

The components used in our solution are our designed high isolation antenna and existing DCS1800 UE transmitting bandpass filter which

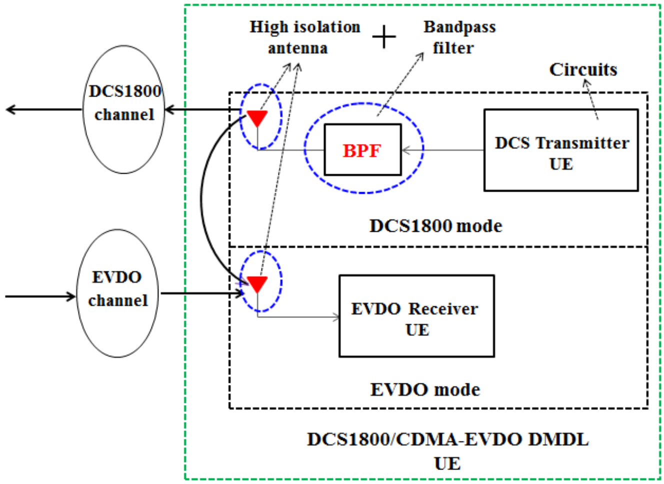


Figure 8. Passive isolation for CDMA-EVDO.

Table 3. Parameters for existing DCS1800 UE transmitting bandpass filter.

Parameter	Value
Frequency range/MHz	1710–1785
Insert loss/dB	1.2
VSWR	1.7
Isolation/dB	30 at EVDO frequency band

are all passive components, so we call this solution "passive isolation". The schematic diagram is described in Figure 8. The high isolation antenna presented in Section 3 can achieve 22 dB isolation, and the existing bandpass filter [26] whose performance is shown in Table 3 can provide 30 dB isolation in the CDMA-EVDO frequency band, thus we achieve a totally $22 + 30 = 52$ dB isolation. Figure 9 shows the results of our passive isolation. From Figure 9, it is known that there is a quite small deterioration (about 0.1 dB) for the SNR of CDMA-EVDO system after our passive isolation, that is to say, the DCS1800 local interference almost does not influence the receiving sensitivity of CDMA-EVDO.

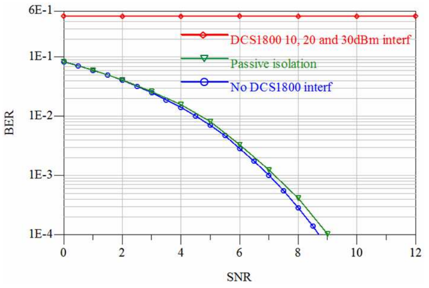


Figure 9. Performance evaluation of passive isolation for CDMA-EVDO.

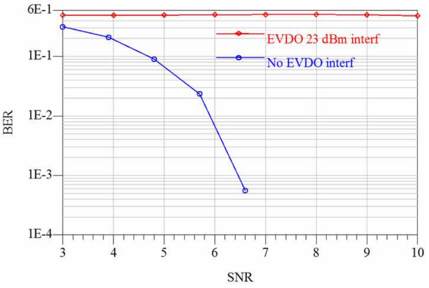


Figure 10. BER performance of DCS1800 under the CDMA-EVDO local interference.

Table 4. Parameters for CDMA-EVDO uplink.

Parameter	Value
Operating frequency/MHz	848.985
Signal bandwidth/MHz	1.5
Modulation mode	QPSK
Transmitting power/dBm	23
Antenna isolation (AI)/dB	10

4.2. Solution Performance for DCS1800 under CDMA-EVDO Local Interference

Just as the DCS1800 local interference influences the CDMA-EVDO greatly, the CDMA-EVDO local interference also has a great impact on DCS1800. Due to the similar system model and interference analysis of DCS1800 local interference to CDMA-EVDO, and for simplicity, we just give some important process and results when considering CDMA-EVDO local interference to DCS1800. Simulation conditions for CDMA-EVDO uplink and DCS1800 downlink are listed in Tables 4 and 5, respectively. The performance of DCS1800 under the CDMA-EVDO local interference is shown in Figure 10, obviously, the DCS1800 mode cannot work properly!

To solve the CDMA-EVDO local interference, the "passive isolation" is also introduced, as shown in Figure 11. Our antenna and existing CDMA-EVDO UE transmitting bandpass filter [26] whose performance is described in Table 6 can provide 12 dB and 33 dB isolation, respectively. Thus, we achieve $12 + 33 = 45$ dB isolation. Figure 12 gives the effect of the passive isolation for DCS1800, and tells us that the CDMA-EVDO local interference can be diminished at a negligible level.

Table 5. Parameters for DCS1800 downlink.

Parameter	Value
Operating frequency/MHz	1805.2
Signal bandwidth/KHz	200
Modulation mode	GMSK
Transmitting power/dBm	30
Path loss/dB	126
Channel	AWGN

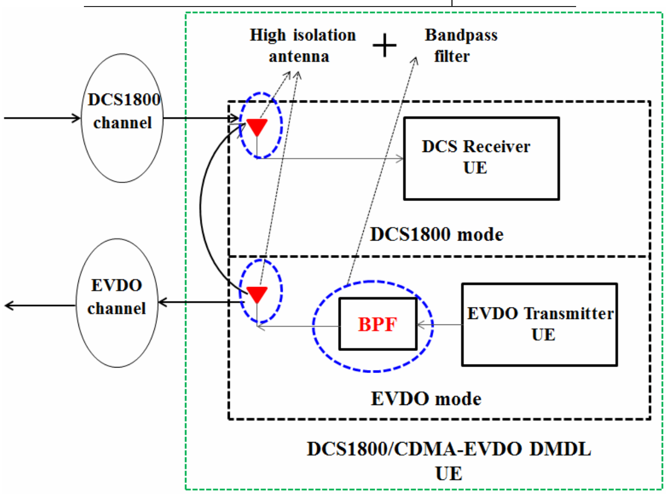


Figure 11. Passive isolation for DCS1800.

Table 6. Parameters for existing CDMA-EVDO UE transmitting bandpass filter.

Parameter	Value
Frequency range/MHz	824–849
Insert loss/dB	1.6
VSWR	1.7
Isolation/dB	33 at DCS1800 frequency band

4.3. Solution for DCS1800/CDMA-EVDO Co-existence

When considering the DCS1800/CDMA-EVDO co-existence, the DM-DL UE is either working on DCS1800 TX/CDMA-EVDO RX state or CDMA-EVDO TX/DCS1800 RX state. For the former state,

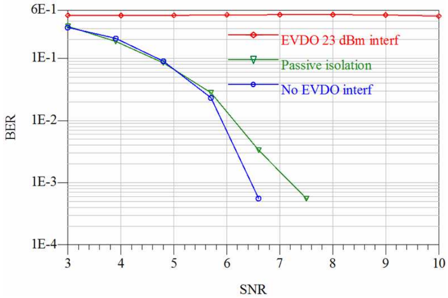


Figure 12. Performance evaluation of passive isolation for DCS1800.

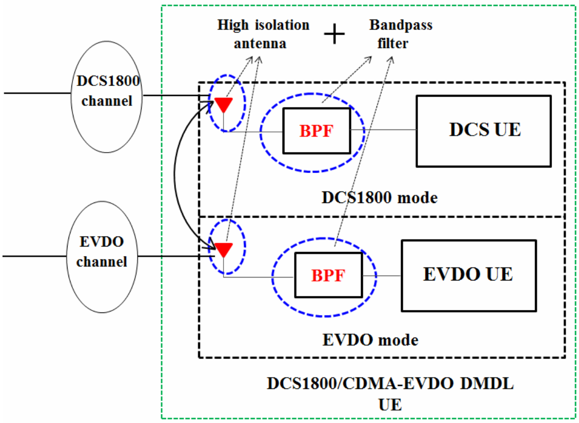


Figure 13. Solution for the DCS1800/CDMA-EVDO co-existence.

the DCS1800 local interference influences the performance of CDMA-EVDO; for the latter, the CDMA-EVDO local interference influences the performance of DCS1800. In order to solve these two interferences, a solution generalized from Sections 4.1 and 4.2 is shown in Figure 13. As shown in Figure 13, the DCS1800 local interference can be eliminated by the designed antenna and existing DCS1800 bandpass filer (This is confirmed in Section 4.1), the CDMA-EVDO local interference can be eliminated by the designed antenna and existing CDMA-EVDO bandpass filter (This is confirmed in Section 4.2). Therefore, no matter what state the DM-DL UE is working on, the DCS1800 or CDMA-EVDO local interference would be eliminated, then the DM-DL UE could work normally and achieve two modes co-existence. It should be pointed out that the antenna is our designed high isolation antenna described in Section 3, and the DCS1800 bandpass filter and CDMA-EVDO bandpass filter are all existing filters which can be easily obtained.

5. CONCLUSION

We have firstly brought out a DCS1800/CDMA-EVDO DM-DL UE system model and evaluated its performance based on the interference analysis. Simulated results show that a method which can improve the isolation between the two modes is needed. On the basis of this conclusion, four compact and high isolation dual-band handset antennas are presented in a dual-mode UE, in which we designed the antenna and UE PCB structure, measured the parameters and validated their performance. The antenna has a size of $24.0 \times 9.5 \times 1.8\,\text{mm}^3$, and is capable of operating over the frequency range of DCS1800 and CDMA-EVDO, both with the return loss equaling to 10 dB. The single antenna has gain of -0.3 Bi at 894 MHz and 1.4 dBi at 1.71 GHz respectively. It is found that considerable isolation among antenna ports can be obtained. Good agreements between the simulated and measured results are achieved. This is the base for our system level simulations. Secondly, a system level simulation model based on the antenna is developed for the system BER evaluation purpose. Using the system simulation model, the effect of DCS1800 (CDMA-EVDO) local interference on the CDMA-EVDO (DCS1800) BER of the DM-DL UE is explored. It is shown that CDMA-EVDO (DCS1800) receiving sensitivity is affected greatly by the DCS1800 (CDMA-EVDO) local interference. Therefore, a solution called passive isolation is given to alleviate the interference. Simulated results indicate that the solution can work very well. Finally, the co-existence mutual interference between DCS1800 and CDMA-EVDO is settled by two passive isolations. The researches and conclusions in this paper have major significance in the applications of spectrum planning, antenna and filter designing and dual-mode co-existence.

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