3rd URSI AT-AP-RASC, Gran Canaria, 29 May – 3 June 2022

Measurement scheme for millimeter-wave electric field based on IQ-mixing technique

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Abstract

Millimeter-wave is one of core technologies in 5G communications system. And the effects of its electromagnetic exposure on people have received a lot of attention. The Specific Absorption Rate (SAR) of electromagnetic wave and Power Density (PD) are important indicators for antenna transmission features in the mobile terminal. These two indicators are closely connected with product safety and necessary testing indexes for wireless communication terminals to enter into the markets. As for the issues mentioned, the article proposed the measurement scheme plan for millimeter-wave electric field based on IQ frequency mixing technique. The superiority of the proposed scheme had been verified in the between 24 GHz and 40 GHz band.

Keywords: 5G; millimeter-wave; electromagnetic radiation measurement; power density

1. Introduction

The critical technologies of 5th Generation Mobile Communication Technology (5G) terminals are utilizing multiple-input-output (MIMO) antennas to achieve space-time multiplexing and millimeter-wave high frequency band to provide large bandwidth spectrum resources and other technologies, which effectively enhanced the performance of wireless communication [1]. However, combined with better user experience provided by 5G, the effects of electromagnetic radiation on human health are of great concern. In terms of millimeter-wave RF band in 5G, the biological effects caused by electric field refers mainly to heat effect [2]. Temperature rise in biological tissues caused by the absorption of electromagnetic field energy. When the thermoregulation ability is not sufficient to regulate the local temperature caused by the thermal effect, the body may suffer irreversible thermal damage.

It is necessary to avoid the potential threats posed by electromagnetic radiation people. Therefore, international standards organizations such as ICNIRP [3] and IEEE [4] have established regulations for the exposure limits of electromagnetic radiation. Moreover, standard systems for both reference levels and basic limit are also formulated accordingly. It is believed that meeting the reference level is equal to satisfying the requirements of basic limit. The Specific Absorption Rate (SAR) of electromagnetic wave and Power Density (PD) are important indicators for antenna transmission features in the mobile terminal [5,6]. These two indicators are closely connected with product safety and compulsory testing indexes for wireless communication terminals to enter into the markets.

However, 5G is still in the preliminary stage of implementation, relevant measurement standards for electromagnetic radiation are still under revision. Constant improvements are still made on measuring technologies and equipment. Compared to 4G, 5G becomes more complex in terms of modulation mode and MIMO multi-antenna scenario. This point greatly increases difficulties in measurement and it is also hard to ensure the measurement accuracy of millimeter-wave electric field. To solve the issues mentioned above, the article proposed a kind of measurement scheme for millimeter-wave electric field. In combination with IQ frequency mixing techniques, the scheme could accurately measure millimeter-wave electric field.

2. Materials and methods

2.1 Scheme Specification

The millimeter-wave electric field measurement scheme was proposed to measure the electromagnetic radiation generated by 5G terminals. As shown in Figure 1, the process for this solution was as follows: Firstly, the high frequency signal (24~40GHz) sensed by the probe was input to the Low Noise Amplifier (LNA) in the RF front-end module to amplify the received signal and suppress the increase of noise. Secondly, the output signal from RF front-end module and the signal which was generated by local oscillation circuit were fed into the down-converter and IQ demodulator. In this paper, the Phase Locked Loop (PLL) was used as the local oscillation circuit. Thirdly, the signal generated by down-converter and IQ demodulator was fed into low-pass filter. At the same time, the signal generated by LNA was also input to this model. Finally, the signal output from the low-pass filter was input into the digital signal processing module via analog-to-digital conversion to update the digital signal returned from the single chip and calculated the amplitude and phase magnitude in real time. To aviod electromagnetic interference, the RF front-end module was shielded with a thick aluminum alloy to ensure a shielding effectiveness (SE) greater than 100 dB.

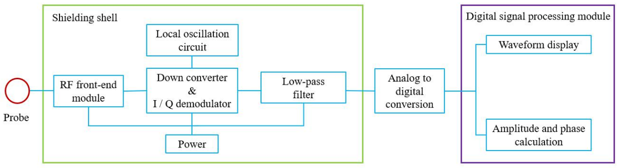


Figure 1. Scheme Architecture

2.2 IQ modulation algorithm

Two carriers were used in IQ modulation, one was the in-phase (I) component, and the other was the quadrature (Q) component, which had 90° phase shift from the in-phase component (as shown in Figure 2). One of the advantages of IQ modulation is the symmetry, which allows independent signal components to be combined into a single composite signal, and likewise, allows the composite signal to be split into its independent components. In a digital transmitter, the I and Q signals were mixed by the same local oscillator (LO). In addition, a 90° phase shifter was placed in one of the LO paths. This 90° phase shifter made the I and Q signals orthogonal to each other to ensure the two signals have no interference.

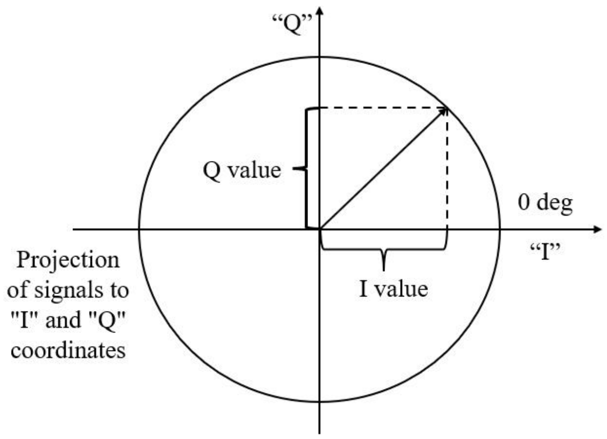


Figure 2. IQ Phasor diagram

Assume that the received RF signal f_{RF} and the input local oscillator signal f_{LO} are as follows:

$$f_{RF} = A_{RF} \cos(\omega_{RF} t + \varphi_{RF}) \quad (1)$$

$$f_{LO} = A_{LO} \cos(\omega_{LO} t + \varphi_{LO}) \quad (2)$$

Where A is the amplitude of the signal, ω is the angular frequency of the signal, and φ is the initial phase of the signal.

The orthogonal signal IQ of f_{RF} and f_{LO} can be expressed by the following equation:

$$I = A_{RF} \cos(\omega_{RF} t + \varphi_{RF}) \times A_{LO} \cos(\omega_{LO} t + \varphi_{LO}) = \frac{A_{RF} A_{LO}}{2} [\cos(\omega_{RF} t - \omega_{LO} t + \varphi_{RF} - \varphi_{LO}) + \cos(\omega_{RF} t + \omega_{LO} t + \varphi_{RF} + \varphi_{LO})] \quad (3)$$

$$Q = A_{RF} \cos(\omega_{RF} t + \varphi_{RF}) \times A_{LO} \sin(\omega_{LO} t + \varphi_{LO}) = \frac{A_{RF} A_{LO}}{2} [\sin(\omega_{RF} t - \omega_{LO} t + \varphi_{RF} - \varphi_{LO}) + \sin(\omega_{RF} t + \omega_{LO} t + \varphi_{RF} + \varphi_{LO})] \quad (4)$$

Using a low-pass filter to remove the high frequencies yields:

$$V_I = \frac{A_{RF} A_{LO}}{2} [\cos((\omega_{RF} - \omega_{LO})t + \varphi_{RF} - \varphi_{LO})] \quad (5)$$

$$V_Q = \frac{A_{RF} A_{LO}}{2} [\sin((\omega_{RF} - \omega_{LO})t + \varphi_{RF} - \varphi_{LO})] \quad (6)$$

V_I and V_Q are modulo-converted to calculate the amplitude A and phase Φ:

$$A = \sqrt{V_I^2 + V_Q^2} = \frac{A_{RF} A_{LO}}{2} \quad (7)$$

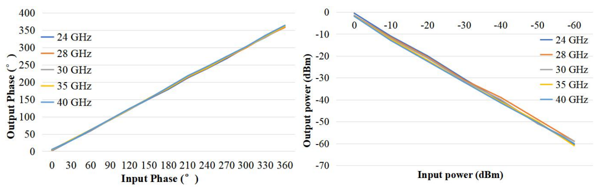
$$\Phi = \arctan \frac{V_Q}{V_I} = \varphi_{RF} - \varphi_{LO} \quad (8)$$

3. Results and Discussion

The R&S®SMW200A vector signal source was chosen as the 5G signal generator to validate this measurement scheme by adjusting its frequency and phase (Figure 3).

Figure 3. Millimeter-wave electric field measurement scheme verification experiment

The experimental results were shown in Figure 4, which shown that the input and output power obtained by the measurement scheme designed in this paper is almost linear, and the phase size is similar. According to the statistical results, the standard deviation is very small.



(a) (b)

Figure 4. The results of experiment

4. Conclusion

The millimeter-wave electric field measurement scheme based on IQ-mixing technology had shown excellent accuracy and stability in the frequency band from 24 to 40GHz. Further experiments are still in progress and we consider using probes with a wider band range to cover the whole 5G millimeter-wave band to validate the advancement of our scheme.

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