01 Jan 2023

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Recommended Citation

C. Zang et al., "Decomposition Measurement for Antenna Gain and Radio Sensitivity of Wireless Receiving System," *2023 IEEE Symposium on Electromagnetic Compatibility and Signal/Power Integrity, EMC+SIPI 2023*, pp. 70 - 73, Institute of Electrical and Electronics Engineers, Jan 2023.
The definitive version is available at https://doi.org/10.1109/EMCSIPI50001.2023.10241503

Decomposition Measurement for Antenna Gain and Radio Sensitivity of Wireless Receiving System

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***Abstract*—A general procedure for decomposition measurements for receiver antenna gain and radio sensitivity based on received signal strength indicator (RSSI) reporting is proposed in this paper. This procedure standardizes the measurement steps for eliminating nonlinear error in RSSI reporting. After path loss calibration and RSSI uncertainty calibration, the real performance of the antenna and the radio working in the actual environment of wireless receiving system can be measured. The antenna gain is obtained from the difference between RSSI reporting and transmit power, and the radio sensitivity is obtained from the transmit power. This method helps to improve the development efficiency of radio devices and shorten the development cycle. The general procedure is suitable for single-input single-output (SISO) wireless receiving system having RSSI reporting such as GSM, and Bluetooth systems.**

Keywords—decomposition measurement, RSSI, OTA test, antenna gain, radio sensitivity, SISO

I. INTRODUCTION

Designing antennas and radio frequency (RF) systems is a critical mission in the development of wireless system. The RF resources allocation and radio can be carefully designed to achieve optimum RF performance with optimized antenna. Generally, RF system and antenna are developed by different engineers who may even belong to different design groups. To achieve optimum RF performance, it is important to know the performance of each subsystem so that a synergy can be demonstrated.

If the total isotropic sensitivity (TIS) of radio frequency performance does not meet the standard, the work must be clearly assigned to the corresponding engineering team, where the specific problem can be analyzed and pinpointed. But before analyzing and positioning specific problems, measuring the real performance of the antenna and the radio working in the actual environment of wireless receiving system is necessary.

There are some issues need to overcome when measuring the real performance of antenna and radio. Due to the common mode issue, the stand along antenna measurement may not be accurate [1]. The radio performance measurement without antenna do not include the internal system noise coupling, which is a conducted sensitivity. Conducted radio sensitivity measurement is different from the radiated sensitivity, the later one has noise coupled from the antenna. The radiated desensitization problems are generally resolved through proper radio board layout, shielding and grounding. Due to common mode contribution and radio desensitization, the measurement uncertainty of antenna needs to be solved through OTA test.

The Cellular Telecommunications and Internet Association (CTIA) provides a fast test method for total isotropic sensitivity based on RSSI, which requires the radio sensitivity measurement and antenna RSSI pattern measurement [2]. Although the method provided by CTIA accelerates TIS testing with the help of RSSI, the measured results of this method are not accurate. The biggest drawback of this method is not considering the RSSI reporting error.

RSSI reflects the input signal quality of the radio input port. There are three sources of RSSI reporting error.

1) Statistical error caused by short measurement time

Engineering applications require RSSI to be updated in real time. But in measurement engineering, the time of calculating RSSI reporting can be extended , which means more sample data used to substantially reduce statistical error.

2) Truncation error caused by taking RSSI as an integer

RSSI is recorded as an integer, which creates a ± 0.5dB truncation error. An interval folding technique based on a binary tree search can be used to increase RSSI reporting resolution [3].

3) Nonlinear error related to the radio hardware

the radio hardware and the digital signal processor (DSP) algorithms caused nonlinear error up to ± 2dB. The method proposed in [4], [5] can eliminate the propagation of nonlinear error in the radio sensitivity TIS by indirectly using RSSI.

The TIS measurement process for eliminating RSSI reporting errors has not yet been unified. Standardizing the test process is necessary. The correct and well-designed measurement process is of great help to quickly and accurately complete the decomposition measurement of the antenna gain and radio sensitivity in the wireless receiving system.

In this paper, a four-step method for decomposition measurement for antenna gain and radio sensitivity of wireless receiving system is proposed to measure the real performance of receiver. Section II discusses the influence of RSSI error on TIS test based on RSSI. The test configurations and procedure are introduced in Section III, followed by the experiment and analysis in Section IV.

II. THE INFLUENCE OF RSSI ERROR ON TIS TEST

The basic framework of the TIS rapid test method based on the RSSI reporting is shown in Fig.1.

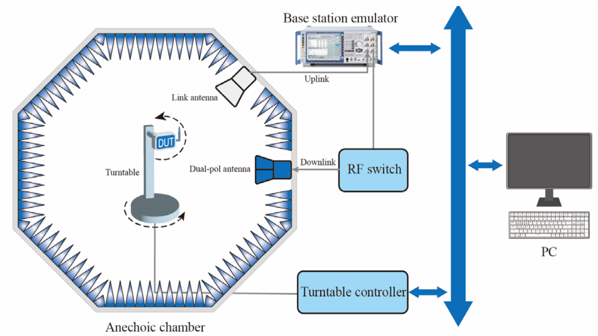

Fig. 1 The basic framework of the TIS rapid test method based on RSSI

The system framework can be simplified as:

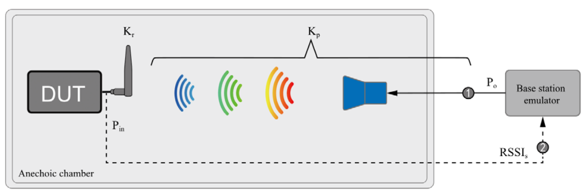

Fig. 2 Simplified block diagram of RSSI-based TIS test system

P_o is the transmit power of the base station simulator (BSE). K_p denotes the path loss. K_r is the antenna gain of the device under test (DUT). P_{in} is the signal input power of the radio.

TIS is obtained by integrating effective isotropic sensitivity (EIS) over the sphere [1], [6].

$$TIS = \frac{4\pi}{\oint \left[\frac{1}{EIS_\theta}(\theta,\phi) + \frac{1}{EIS_\phi}(\theta,\phi)\right] \sin\theta \, d\theta d\phi} \tag{1}$$

EIS can be expressed as:

$$EIS = \frac{P_s}{G_{x,DUT}(\theta,\phi)} \tag{2}$$

P_s is the minimum detectable power level of the radio receiver operating under its threshold sensitivity criteria, and has no relationship with the angle (θ,ϕ). $G_{x,DUT}(\theta,\phi)$ is the antenna gain in the direction of x polarization at the angle (θ,ϕ) [7]. In the test, the $RSSI_s$ is approximated instead of P_s.

$$P_s = RSSI_s \tag{3}$$

After substituting (2) into (1), TIS can be expressed with decibel operation as:

$$TIS = P_s - G_{AVE} \tag{4}$$

G_{AVE} denotes the antenna average gain of the DUT on the sphere. From Fig.2, the antenna gain at the angle(θ,ϕ)can be expressed as:

$$K_r(\theta,\phi) = P_o(\theta,\phi) - K_p - RSSI(\theta,\phi) \tag{5}$$

Substitute (3) and (5) into (4) to get the TIS expression:

$$TIS = K_p - P_o^{AVE} + RSSI_s + RSSI_{AVE} \tag{6}$$

P_o^{AVE}, $RSSI_{AVE}$ denote the average power transmitted by the base station simulator at all angles (θ_i,ϕ_i) on the sphere, and the average RSSI reporting of the received signal. Assuming that K_p and P_o^{AVE} are accurate, according to (5) and (6), if the RSSI value is larger than the real value, TIS will be large and the antenna performance will be underestimated. The antenna gain $K_r(\theta,\phi)$ will be large and the receiver performance will be overestimated when the RSSI is lower than the real value. Either case will mislead developers to make wrong checks, which will increase the development difficulty and prolong the development cycle.

The general form of the receiver RSSI curve is shown in Fig.3. The curve is divided into three regions—the highly nonlinear region, the approximately linear region and the saturated region. When P_{in} is low, RSSI is in the highly nonlinear region with large error, while the higher P_{in}, the higher the signal link signal-to-noise ratio and the smaller the RSSI error. Therefore, in order to make the measurement better, RSSI reporting can be adjusted in the approximate linear region by increasing the downlink power, which can effectively weaken the impact of RSSI error.

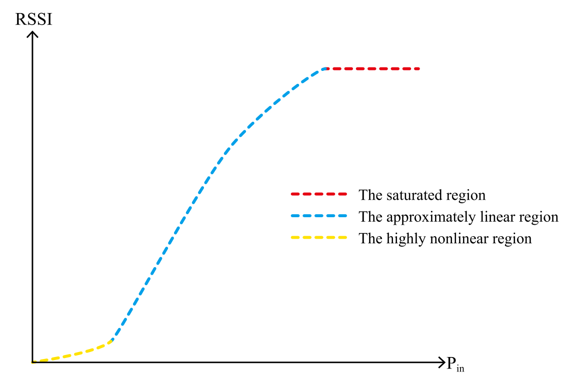

Fig. 3 The General form of receiver RSSI reporting curve

III. FOUR-STEP METHOD FOR DECOMPOSITION MEASUREMENT FOR WIRELESS RECEIVING SYSTEM

The process of measurement is divided into four steps: the calibration of the path loss, the calibration of RSSI uncertainty, the acquisition of antenna gain, and the acquisition of receiver radiation sensitivity.

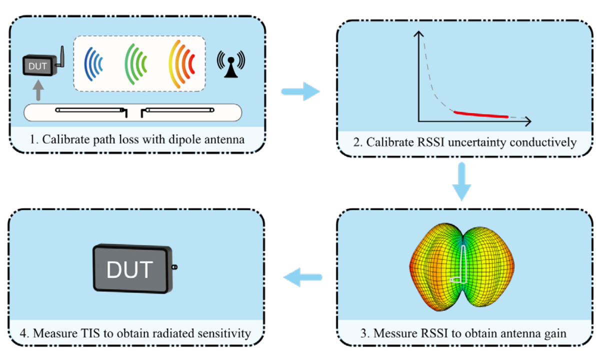

Fig. 4 Flow Chart of Receiver Decomposition Measurement

The sequence of these four steps is critical. Calibration of path loss is not only a prerequisite for OTA testing, but also a part of instrument calibration. (5) points out that the RSSI

reporting error need to be determined before getting the antenna average gain. (4) points out that the antenna average gain must be obtained before getting TIS.

A. Calibrate Path Loss with Dipole Antenna

The dipole antenna is an ideal choice for the path loss calibration [8]. Fig.5 is a schematic diagram of the path loss calibration system.

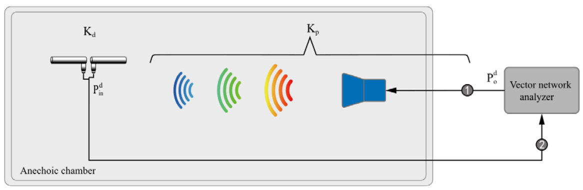

Fig. 5 Schematic diagram of the path loss calibration

The path loss K_p contains the entire path loss from the signal transmit port, through the transmit antenna, then through the wireless transmission medium to antenna. K_p is an angle-independent parameter.

In order to reduce the error of the results, the path loss is measured at high transmission power. At angle (θ_o, ϕ_o), adjust the transmit power P_o high so that P_{in} is at a higher level. Record transmit power as P_o^d and received power as P_{in}^d.

The path loss K_p can be obtained expressed as:

$$K_p = K_d + (P_o^d - P_{in}^d) = K_d - S_{21}^f \tag{7}$$

B. Calibrate RSSI Uncertainty Conductively

RSSI reporting is not equal to the actual radio input power. The difference is RSSI reporting error.

$$\Delta RSSI(P_{in}) = P_{in} - RSSI \tag{8}$$

RSSI uncertainty can be calibrated by conducted test [9]. Typical test setup illustration for conducted sensitivity measurement is shown in Fig.6, where the instrument is BSE. The difference of RSSI reporting and the BSE output power with cable loss subtracted is RSSI uncertainty. Typical RSSI uncertainty curve is shown in Fig.7.

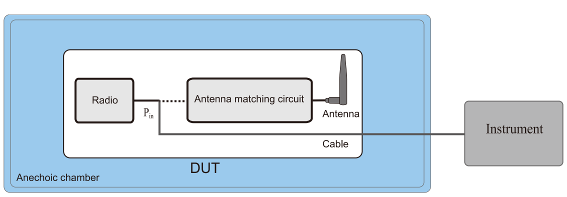

Fig. 6 Typical test setup illustration for conducted sensitivity measurement

The RSSI reporting can be expressed as a nonlinear correlation function of the radio input power P_{in}, which is not only related to the wireless system hardware, but also related to the DSP algorithms.

$$RSSI = H(P_{in}) = H\big(P_o - K_p + K_r\big) \tag{9}$$

For the same receiver, the RSSI curve at different angles only have an offset relationship along the x-axis. At angle (θ_o, ϕ_o), the RSSI curves under different downlink powers are recorded by using the power step method, as shown in Fig.8. The point $(P_{in}^s, RSSI_s)$ is sensitivity point. The horizontal coordinate is $P_{in|r} = P_o - K_p$.

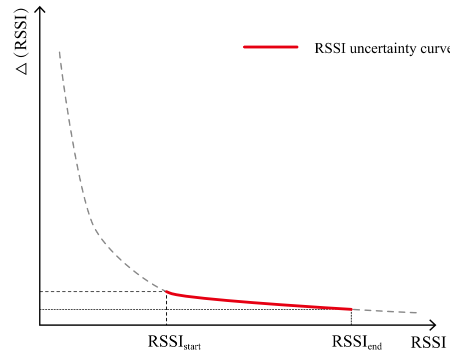

Fig. 7 RSSI uncertainty curve

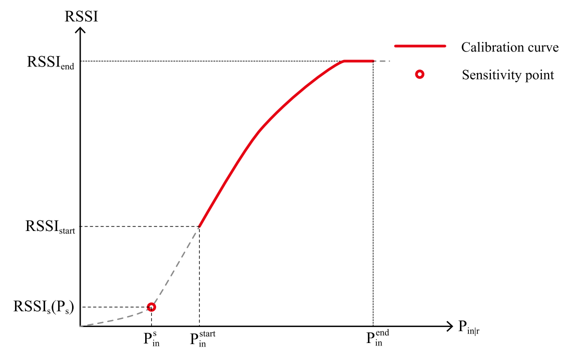

Fig. 8 RSSI calibration curve

C. Measure RSSI to Obtain Antenna Gain

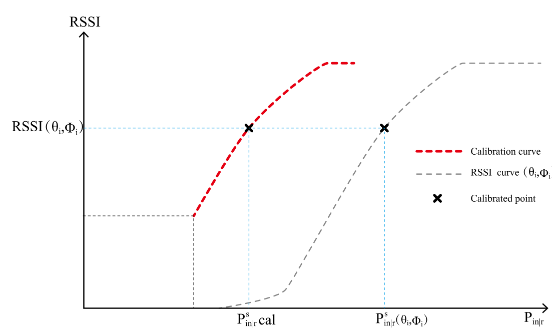

Fig. 9 Antenna gain calculation

At some other measurement angle (θ_i, ϕ_i), adjust the transmit power P_o to make RSSI reporting fall into calibration curve. Record the corresponding transmit power P_o and RSSI reporting. Compared with the calibration curve, the translation of the horizontal coordinates from Fig.9 is the antenna gain difference.

$$\Delta(K_r) = P_{in|r}^s(\theta_i, \phi_i) - P_{in|r}^s cal \tag{10}$$

The antenna gain K_r^{cal} of the angle (θ_o, ϕ_o) can be obtained from the RSSI calibration curve and the RSSI

uncertainty curve. According to K_r^{cal} and $\Delta(K_r)$, the antenna gain pattern and the antenna average gain can be obtained.

$$K_r^{cal} = RSSI_{cal} - \Delta(RSSI_{cal}) + K_p - P_o^{cal} \quad (11)$$

D. Measure TIS to Obtain Radiated Sensitivity

The difference between radiation sensitivity and antenna gain is the antenna EIS. From (7), the EIS at (θ_o, ϕ_o) can be expressed as:

$$EIS(\theta_o, \phi_o) = P_{in}^s - K_r(\theta_o, \phi_o) = P_o^s - K_p \quad (12)$$

EIS for other angles (θ_i, ϕ_i) can be expressed as:

$$EIS(\theta_i, \phi_i) = P_o^s(\theta_i, \phi_i) - K_p \quad (13)$$

Combining (10), (12) and (13), $EIS(\theta_i, \phi_i)$ is:

$$EIS(\theta_i, \phi_i) = EIS(\theta_o, \phi_o) + \Delta(K_r) \quad (14)$$

Finally, TIS is obtained by simply substituting all the obtained EIS (θ_i, ϕ_i) into (1).

$$TIS = -10lg\left[\frac{\pi}{2MN}\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}\left(10^{-\frac{EIS_\theta(\theta_i,\phi_i)}{10}} + 10^{-\frac{EIS_\phi(\theta_i,\phi_i)}{10}}\right)\sin\theta_i\right] \quad (15)$$

IV. Measurement Example

A demonstration measurement example is given below.

A. Test Setup

The measurement parameters are shown in Table 1.

TABLE 1 Measurement environment

Parameters	Value
Instruments	PC
	Vector network analyzer E5071C
	Base station emulator CWM500
	Dipole antenna
Anechoic chamber	RayZone 2800
Downlink frequency	1890 MHz
DUT	ZJ220F for LTE

B. Results

Only the final measurements are given here.

TABLE 2 The antenna average gain and TIS

Antenna average gain (dBi)	TIS (dBm)	Radio sensitivity(dB)
-2.17	-95.22	-97.39

V. Conclusion

A general procedure of decomposition measurement for antenna gain and radio sensitivity of wireless receiving systems is proposed in this paper. This procedure can measure the real performance of the antenna and the radio working in the actual environment of the wireless receiving system. The method specifies a four-step approach to decomposition measurement. Four test steps are non-interchangeable. Through path loss calibration, the accurate downlink power can be calculated. Through calibrating RSSI uncertainty conductively, the antenna gain can be calculated accurately. RSSI calibration curve accelerates EIS measurement so that TIS can be measured fast. In addition, the influence of RSSI reporting errors on TIS test method provided by CTIA is elaborated. The antenna gain and TIS are underestimated when RSSI is lager than the real value. On the contrary, when RSSI is smaller than the real value, the antenna gain and TIS are overestimated. Finally, A demonstration measurement experiment using four-step method is carried out.

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