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PREDICTION OF THE INTERFERENCE LEVEL FROM A LOW-POWER RADIO DEVICE PROVOKING THE INTERMODULATION INTERFERENCE TO THE AMPS RECEIVER

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Abstract—In this article, the harmful radiation level of electric field strength from the hostile low-power radio devices causing the intermodulation interference to the AMPS receiver has been predicted. The predicted level becomes the upper limit to avoid the intermodulation interference on the victim device. Our findings show that the quantified upper limit was 79.13 [dBμV/m] to mitigate the adverse influence from these low-power radio devices. Our results are based on the calculation, simulation, and measurement for the commercial AMPS chip. Resulting values are in a good agreement within less than 3 [dB].

1. INTRODUCTION

An interference problem occurs among the wireless devices including the low-power radio devices because the latter devices are using a shared frequency bandwidth. A prediction of radio interference between the wireless devices allows us to use the limited frequency resources more efficiently. Thus, the prediction research is adapting to a hostile radio environment that includes offender, victim, and regulation. So when the regulation is revised, there must be research to forecast about radio interference. But most of researches about the prediction of radio interference have focused mainly on the co-channel interference, and give little attention to the adjacent-channel interference as far as the immunity regulation is concerned. Furthermore, they seldom provide the academic reasoning akin to the

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analysis and measurement on the enacted regulation [1–8]. However, the scientific basis plays an important role in the field of the low-power radio devices industry.

To provide the stepping stones between the academic interest and the current regulation and also to establish the theoretical basis, a theoretical analysis has been proposed using the well-known intermodulation interference theory. It is noted that intermodulation is attributed to the adjacent-channel interference. Because there are many types of radio interference present, a prescribed type of radio interference should be selected by the purpose of its customers. So, in this study, the radio interference bringing about the intermodulation phenomenon has been targeted, because intermodulation interference generally occurs in the receivers of almost all wireless devices exposed to the nonlinear operation. In order to simplify calculation of the interference level using the intermodulation theory, two pre-conditions are assumed. The first condition is that the interference signal is unmodulated sinusoidal wave, and the second is that the receiver has the nonlinearity. In order to calculate the nonlinearity, to stick on two nonlinearity parameters of ACPR (Adjacent Channel Power Ratio) and ACLR (Adjacent Channel Leakage Ratio) is too cursory as done at present CDMA/WCDMA system. In these communication systems, however, the process of computation of intermodulation and method of measurement is ambiguous owing to consideration of the intermodulation by modulated interference signal. Furthermore the general receivers of the GSM and the CDMA are using some functions like the AGC (Automatic Gain Control) to prevent distortion of the received signal by nonlinearity of the receiver. Therefore the calculation of the exact interference level to include these matters will increase the undesirable complications. For this reason, the AMPS (Advanced Mobile Phone Service) receiver was chosen as a victim wireless device. AMPS is an ancestor to GSM and CDMA. The basic structures of almost all receivers of radio communication at present have an expandable structure of AMPS receiver [9]. As there are so many kinds of wireless devices encountered radio interference problems, it requires too heavy works to accommodate the whole class of radio devices. Thus, by choosing the AMPS receiver as in this article, not only to avoid the unnecessary inclusion of other devices but also to find the way of application to other types of wireless devices with the similar possessions.

In this article, the calculated level of electric field strength means the upper value of emission against the intermodulation interference radiated from the hostile low-power radio devices. While there are a number of interferences, what is concerned in here is the intermodulation interference with unmodulated signal.

2. THEORETICAL FOUNDATION AND CALCULATION

To understand the intermodulation interference phenomenon occurred in the AMPS receiver, a simplified case can be considered where a nonlinear system is excited by two unmodulated signals of frequencies f_1 and f_2 with the same amplitude. The transfer function of this nonlinear system is described by

$$y(t) = a_1 x(t) + a_2 x^2(t) + a_3 x^3(t) + \cdots \tag{1}$$

where a_1, a_2, and a_3 in Equation (1) are coefficients which depend on the properties of the nonlinear system. The exciting signal is given as

$$x(t) = A\cos(2\pi f_1 t) + A\cos(2\pi f_2 t) \tag{2}$$

where A is the amplitude of exciting signal in Equation (2). Substituting Equation (2) in Equation (1) and then solving gives the spectrum of $y(t)$, which is written by the following Equation (3) [10].

$$f_{IM} = mf_1 + nf_2 \tag{3}$$

In Equation (3), m and n are integers either zero, positive or negative, and $(|m| + |n|)$ indicates the order of the intermodulation product. It can be seen in Equation (3) that two exciting signals in the nonlinear system generate multiple harmonics at output of system. $2f_1 - f_2$ and $2f_2 - f_1$ are the 3rd order harmonics products which constitute the actual problem that produces the IMD3, the 3rd order intermodulation distortion. It is assumed that the two signals in Equation (2) are some interference signal. This case is the intermodulation interference with the frequencies $2f_1 - f_2$ or $2f_2 - f_1$ (the IMD3 product) which falls very near to the frequency f_s of the desired signal. Figure 1 shows the previous description of the intermodulation interference. As shown in Figure 1, the ratio of the amplitude of the output IMD3 products to the desired signal is equal to the signal to interference ratio that is the key parameter which decides the existence of radio interference.

This article will provide the calculation of the level of electric field strength which produces the intermodulation interference in the commercial AMPS receiver IC TQ5135 of the TriQuint Semiconductor. The electrical specifications of the TQ5135 are summarized in Table 1 [11]. Figure 2 shows the spectrum of the intermodulation interference in the TQ5135. Interference input signals according to the Equation (2) in TQ5135 are shown in Figure 2. Frequencies of the two signals are 881.03 MHz and 881.06 MHz with a 30 kHz frequency difference which is equal to the channel bandwidth of the AMPS system. The 3rd order harmonics element created by the exciting interference signal generates the intermodulation interference to the desired 85 MHz signal. According to the recommendation of the data sheet 966 MHz LO frequency is used.

The amount of radio interference can be determined by the signal-to-interference ratio at the output of receiver. It can be expressed in Equations (4a) and (4b) [12].

$$S/N = \frac{A_{os}}{A_{on}} = \frac{A^2_{IIP3}}{A^3} A_s \tag{4a}$$

$$A = \sqrt[3]{\frac{(A^2_{IIP3}) \cdot A_s}{(A_{os}/A_{on})}} \tag{4b}$$

where A_s and A_{os} represent the amplitudes of input and output signal. A and A_{on} are the amplitudes of the input and output interference signal respectively, while A_{IIP3} denotes the amplitude of another input arising IIP3. To determine the existence of the radio interference, the signal to interference ratio (SIR) for the AMPS receiver is needed. All of the wireless devices have the reference SIR. In case of the AMPS, it is 18 dB (7.943) [13, 14]. Therefore if A_{os}/A_{on} is under the

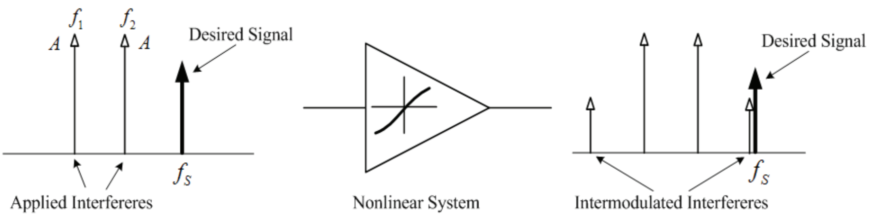


Figure 1. Intermodulation interference in a nonlinear system.

Table 1. Electrical specifications of the TQ5135 AMPS receiver IC.

Parameter	Typical Value
RF Frequency	881 MHz
LO Frequency (IC Test)	966 MHz
Conversion Gain	25 dB
Noise Figure	1.9 dB
IIP3 (Input 3rd Order Intercept Point)	−5.5 dBm (0.1187 [V])
DC Supply Current	20 mA

7.943, then the AMPS receiver becomes a victim of radio interference due to the intermodulation phenomena. Hence, corresponding A for $A_{os}/A_{on} = 7.943$ in Equation (4b) will be the amplitude of input signal to cause the radio interference. From the Table 1, the value of A_{IIP3} is 0.1187 [V]. A_s can be obtained by using the power of the minimum detectable signal value P_{mds}^{RX} of the receiver, which will be used to evaluate the Equations (5a) and (5b). The converted value of the amplitude $A_s = 0.096$ [μV] can be calculated by the following Equation (5c).

$$P_{mds}[\text{dBm}] = -174[\text{dBm}] + 10\log B_n + NF[\text{dB}] \tag{5a}$$

$$\begin{aligned} P_{mds}^{RX}[\text{dBm}] &= -174[\text{dBm}] + 10\log(30\times10^3) + 1.9[\text{dB}] \\ &= -127.33[\text{dBm}] = 1.85\times10^{-16}[\text{W}] \end{aligned} \tag{5b}$$

$$A_s = \sqrt{50(\Omega)\times1.85\times10^{-16}(\text{W})} = 0.096[\mu\text{V}] \tag{5c}$$

In Equation (5a), -174 [dBm] is the white noise of 1 Hz bandwidth, B_n represents the noise bandwidth of receiver while NF indicates the noise figure of receiver [15, 16]. In Equation (5b), a 30 kHz bandwidth was used with the one channel of AMPS system and the noise figure 1.9 [dB] as seen in Table 1. By substituting the above value in Equation (4b), the amplitude of the input interference signal can be obtained, which

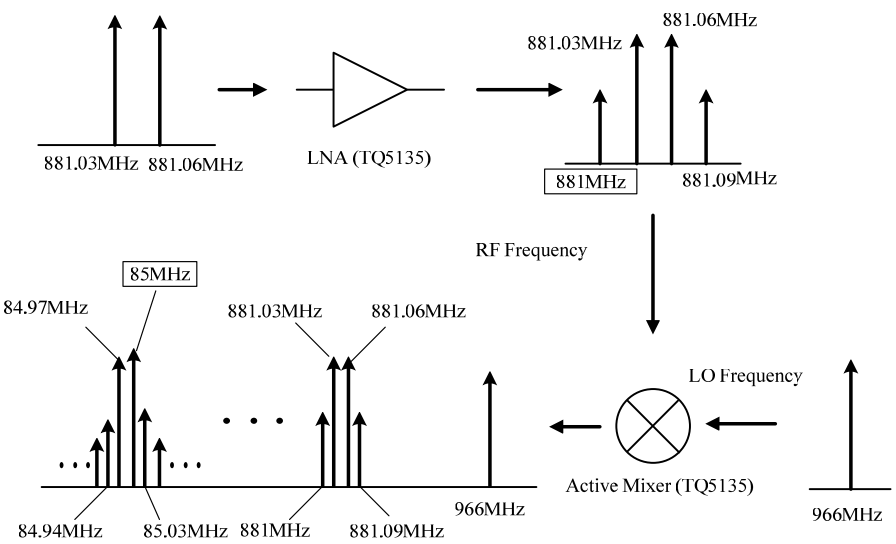


Figure 2. Frequency spectrum of the AMPS receiver IC TQ5135.

corresponds to 18 [dB] SIR as given in Equation (6).

$$A = \sqrt[3]{\frac{(0.1187)^2 \cdot 0.096 \times 10^{-6}}{7.943}} = 554.28[\mu\mathrm{V}] = 54.78[\mathrm{dB}\mu\mathrm{V}] \qquad (6)$$

The voltage in Equation (6) is appeared at the antenna terminal connected to the AMPS receiver. The value of A is determined by the incoming electric field and the antenna factor K which are related by [17]

$$E[\mathrm{dB}\mu\mathrm{V/m}] = K[\mathrm{dB/m}] + V[\mathrm{dB}\mu\mathrm{V}] \qquad (7a)$$
$$K[\mathrm{dB/m}] = 20\log f[\mathrm{MHz}] - G[\mathrm{dB}] - 29.78 \qquad (7b)$$

In here, G [dB] is the antenna gain and V [dBμV] is equal to A. The numerical values are found to be

$$E[\mathrm{dB}\mu\mathrm{V/m}] = 27.12[\mathrm{dB/m}] + 54.78[\mathrm{dB}\mu\mathrm{V}] = 81.9[\mathrm{dB}\mu\mathrm{V/m}] \qquad (8a)$$
$$K[\mathrm{dB/m}] = 20\log(881)[\mathrm{MHz}] - 2[\mathrm{dBi}] - 29.78 = 27.12[\mathrm{dB/m}] \qquad (8b)$$

It is assumed that antenna gain is 2 [dBi], and 881 MHz is the center frequency applied to TQ5135 IC. The level of the electric field strength, 81.9 [dBμV/m] shown in Equation (8a), is the emission level to deteriorate the AMPS receiver operation under the intermodulation interference.

3. SIMULATION AND MEASUREMENT

To validate the calculated level 81.9 [dBμV/m] given by Equation (8a), the simulation and measurement were conducted for TQ5135 IC. In order to simulate for TQ5135, the AMPS receiver was modeled by using the ADS (Advanced Design System) simulator of the Agilent, as shown in Figure 3. The modeling circuit consists of an LNA and an active mixer and it is similar to the structure of Figure 2.

The equation of the SIR is given as

$$\mathrm{S/N} = \frac{A_{os}}{A_{on}} = \frac{1.71\,[\mu\mathrm{V}]}{A_{on}} \qquad (9)$$

By inserting the obtained value of A_{on} from ADS simulator in Equation (9), the signal to interference ratio can be plotted against the electric field strength of the interference source, as shown in Figure 4. The value 1.71 [μV] in Equation (9) is the amplitude of the signal at output of the receiver. This value is converted to the power level of −102.33 [dBm]. In Equation (10a), 25 [dB] is the power gain of the TQ5135 receiver. The voltage value 1.71 [μV] is present in Equation (10b).

$$\begin{aligned} P_{os} &= P_{mds}^{RX} + S_{21}(\text{Total}) = -127.33[\text{dBm}] + 25[\text{dB}] \\ &= -102.33[\text{dBm}] = 5.85 \times 10^{-14}[\text{W}] \end{aligned} \tag{10a}$$

$$A_s = \sqrt{50[\Omega] \times 5.85 \times 10^{-14}[\text{W}]} = 1.71[\mu\text{V}] \tag{10b}$$

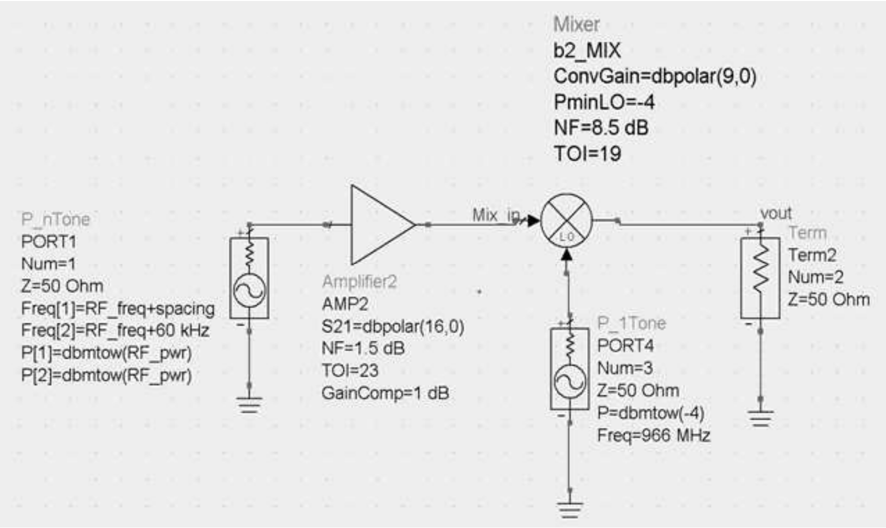


Figure 3. Circuit model of the AMPS receiver using ADS simulator.

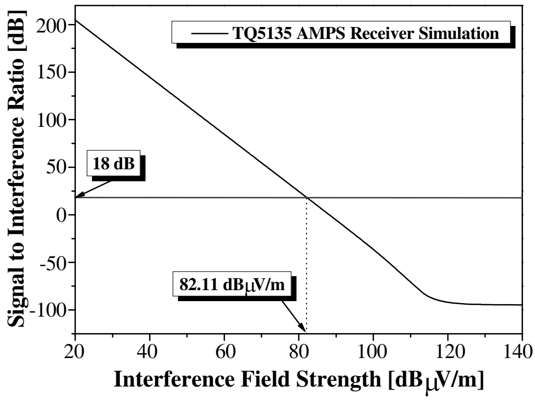
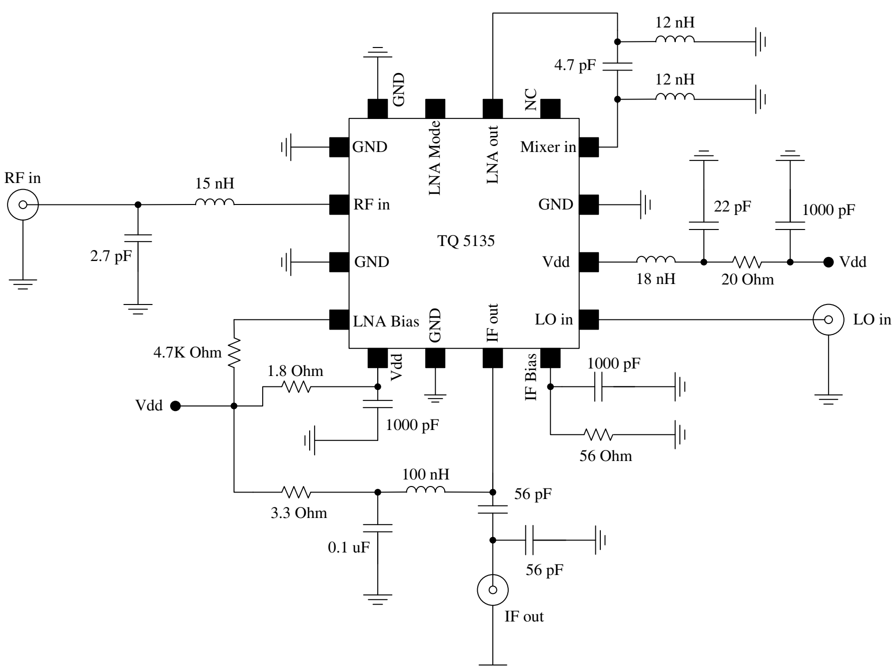


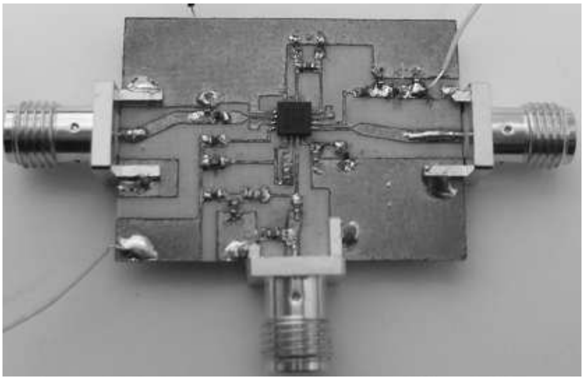
Figure 4. Simulation result of ADS model on signal to interference ratio in term of interference field strength.

At SIR = 18 [dB], the level of the interference electric field strength is 82.11 [dBμV/m] as shown in Figure 4. This simulated result is in close agreement with the calculated result of Equation (8a) within only 0.21 [dB] difference. In Figure 4, a tendency of decrease can be observed in SIR in terms of an increase in the electric field strength of the interference source. This tendency can also be predicted from Equation (4a).

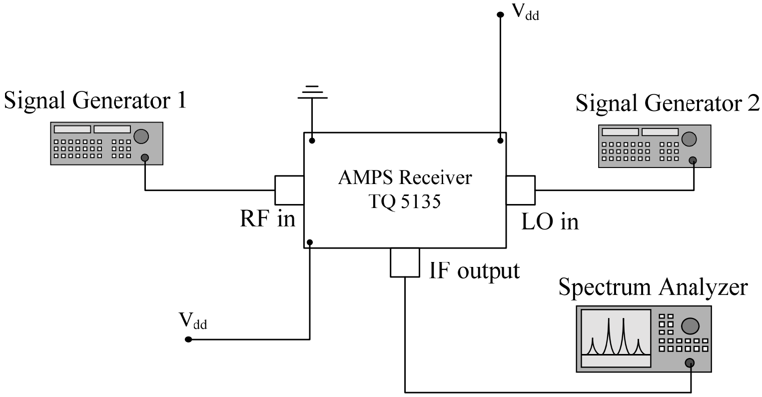
To validate the theoretical value of Equation (8a) from Section 2 and the simulated value of Figure 4, the measurement was conducted for TQ5135 IC. Figure 5 shows the schematic of the TQ5135 IC, the driving circuit of the IC, the fabricated driving circuit of TQ5135, and the measurement configuration. The driving circuit of the TQ5135 is fabricated on a Rogers 4003 substrate ($h = 0.508$ mm) with a relative permittivity of $\varepsilon_r = 3.38$. Conversion gain of the input and output is 22.55 [dB], V_{dd} is 2.8 [V] and IIP3 is 7 [dBm]. These results are satisfied with the typical condition in datasheet [11]. The two-tone signal was obtained by using Agilent E4423B as an interference source and Agilent E4423B as a LO signal generator. Measurement of the IF output signal is performed by using an Agilent E4448A spectrum analyzer.



(a)



(b)



(c)

Figure 5. Measurement of TQ5135 AMPS receiver. (a) Schematic of driving circuit. (b) Fabricated driving circuit. (c) Measurement configuration.

The same frequencies are used in measurement as set up in Figure 2. In addition to consideration of the cable loss, the measured range of input interference source level of the signal generator is varied between two extremes. The level of input source range varies from -95 [dBm] to -5 [dBm], spanned from minimum detectable to saturation. By putting the values of the amplitude of the interference source signal and the IMD signal power level in Equation (9), the measurement result can be obtained as shown in Figure 6. The amplitude of the interference source signal is converted into electric field strength and the IMD signal power level in [dBm] is converted into the [Voltage]

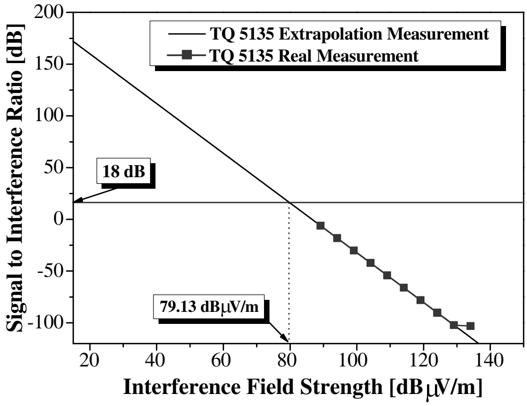


Figure 6. Measurement result of TQ5135 IC on the signal to interference ratio in term of interference field strength.

Table 2. Calculated, simulated and measured value for the AMPS receiver.

Calculation	81.9 [dBμV/m]
Simulation	82.11 [dBμV/m]
Measurement	79.13 [dBμV/m]

unit of amplitude level.

In Figure 6, the logarithmic value of the interference field strength is appeared on the abscissa and SIR on the axis of ordinates. The electric field strength level corresponding to the 18 [dB] SIR is a very weak power level. The data group belonged to measured range is indicated by a "Real Measurement" in Figure 6. The other data group out of measurement range is represented by an "Extrapolation Measurement", which was obtained by extrapolation over the measured data group. Measured data shows the propensity to diminish in SIR according to the increments in the electric field strength of the interference source. The tendency of the measurement results of Figure 6 is similar to the simulated results of Figure 4. The value 79.13 [dBμV/m] seen in Figure 6 is the threshold level of electric field strength to provoke the intermodulation interference to the AMPS receiver under the 18 [dB] SIR.

4. DISCUSSION AND CONCLUSION

In the previous sections, the theoretical interference level of 81.9 [dBμV/m] has been mentioned to cause the intermodulation interference on the AMPS receiver. It shows a difference of 35.9 [dB] with the regulation value of 46 [dBμV/m] which is an emission limit of the FCC Part 15.209 at 3 m distance from the intentional radiator in frequency bands of the AMPS communication [18]. One should rely on the FCC regulation to resolve the difference of 35.9 [dB], in there a clear guidance is the different meaning of distance between FCC and our paper. To make a straightforward comparison 81.9 [dBμV/m] should be converted to the electric field strength at 3 m. The converted electric field strength can be postulated as Equation (11) [19],

$$\begin{aligned} E_{d=3\mathrm{m}} &= 81.9[\mathrm{dB\mu V/m}]+\text{Path Loss} = 81.9[\mathrm{dB\mu V/m}]+G_t G_r\left(\frac{\lambda}{4\pi d}\right)^2 \\ &= 81.9[\mathrm{dB\mu V/m}]+(-36.91)[\mathrm{dB}] = 44.99[\mathrm{dB\mu V/m}] \end{aligned} \tag{11}$$

where the "Path Loss" is defined by the Friis transmission formula. And both G_t and G_r are set to 2 [dBi] because the FCC Part 15.204 has stipulated that measurement antenna is of the same type and of equal or less directional gain as an antenna which is authorized with the intentional radiator antenna [18]. Thus, the agreement between the two calculations is very satisfactory within less than 1 [dB]. Now, we are in a position to understand the regulation value of 46 [dBμV/m] written in FCC Part 15.209 without any quantitative description and noticeable motivation.

In this study, we predicted the occurrence of intermodulation interference on the AMPS receiver with a victim of radio interference. An unmodulated signal was used as interference source type for the low-power radio device. Theoretical electric field strength of the emission limit was 81.9 [dBμV/m], and the measured value was 79.13 [dBμV/m]. To show the adequacy of this result, the simulation was performed by using the simulation tool ADS and the measurement was undertaken for TQ5135 AMPS receiver. Table 2 shows the three independent values yielding the same results within less than 4%.

In this paper, in the light of intermodulation interference point of view the scenario of interference between the low-power radio devices and the victim AMPS receiver has been explored. During the interference modeling, the analyzed value of the emission limit enabled us to understand the role of current regulation value and provide the technical basis of regulation on the harmful radiation from the low-power radio devices. Although considerations are done for the AMPS chip, the proposed prediction technique could be useful to the other type of wireless devices suffered from the radio interference.

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