A Patch Antenna with Level-Controllable PIM Source

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1. Introduction

Intermodulation in passive devices is known as Passive intermodulation (PIM). It often becomes a serious interfere especially in base-station antennas in a mobile wireless communication system. In antenna PIM measurement, it is difficult to distinguish the self-PIM from the one from other surrounding PIM sources [1] [2]. Although standard PIM generator is attractive to solve this kind of problem, it is also difficult to realize it as an antenna because the operating frequency of an antenna depends on its application. Therefore it is useful if a standard antenna that can generate fixed PIM level and control the generated PIM level. It would be effective to assess the quality of a measurement environment.

In this paper, an antenna with level-controllable PIM sources is discussed. Through several experiments on a patch antenna, we propose several methods to control the generated PIM level. Specifically, we confirm the validity of a circular patch antenna with a diode-loaded parasitic element, and achieve the maximum controllable PIM-range of 55dB for 43dBm excitation.

2. Effect of patch element on PIM characteristics

In this paper, two-tone test using $f_1=2.05\text{GHz}$ and $f_2=2.20\text{GHz}$ is carried out to evaluate the 3rd-order reverse PIM characteristics of the antenna at $f_{PIM3}=1.90\text{GHz}$. The antenna under the test (AUT) should be designed to cover all the frequencies with small reflection. In addition, it should be designed to satisfy the maximum power rating of 46dBm. Therefore, we choose an air-loaded patch antenna with a parasitic element.

Firstly, we evaluate two patch antennas as shown in Fig.1 in terms of PIM characteristics. The antenna in Fig.1 (a) consists of two square patch elements, while the one in Fig.1 (b) does two circular patch elements. All the patch elements are made of nickel to evaluate a possibility of the antenna element as a PIM source. Each antenna has a parasitic patch element to broaden the impedance bandwidth, and mounted on a circular aluminium ground-plane with 10mm thick. The driven patch is fed by a thick silver-plated cylinder with the diameter of 7mm, where the air-gap between the feeding cylinder and the ground-plane is 6.5mm. The antenna is connected to the PIM tester using DIN-7/16 coaxial connectors. Here, it should be noted that the ground plane makes a dissimilar metallic contact against the outer shell of the connector; however, the PIM produced at the contact is negligible because the hole-diameter is designed so that the current density become small enough to avoid high PIM.

Fig.2 shows the measured S-parameter characteristics of each antenna in comparison with the calculated results using FDTD method. Each antenna has small reflection characteristics at the transmitting frequencies $f_1$ and $f_2$, which are less than -20dB. At receiving frequency $f_{PIM3}$, S11 is about -15dB. As a consequent, it is confirmed that all the antennas have similar input characteristics at the operating frequencies, and the input characteristics does not affect on their PIM characteristics.

Next, we examine the PIM characteristics of the antennas in terms of the shape of elements. Fig.3 shows the PIM characteristics of each antenna as a function of the input power, where the measurement is carried out at $P_{\text{PIM3}}=31, 34, 37, 40, \text{ and } 43\text{dBm}$. When the input power is 31dBm, the PIM level of the circular patch is lower than the floor noise of the receiver. As a consequent, the data is not plotted in the figure. Both antennas exhibit the approximate 3dB-slope characteristics. The PIM level of the square patch antenna is 5dB higher than that of the circular patch antenna. The difference may be caused by the rectangle corner of the square patch element where the high
electric field concentrated at the corner increase the nonlinearity [3]. The current density on the square patch element may be higher than that on the circular patch, because the area of the square patch element is also smaller than the one of the circular one. These lead to the difference of the observed PIM level. As shown here, element shape affects on the PIM level; however, it is not so large.

3. PIM-Generating Patch Antenna using Diode-Loaded Parasitic Element

To obtain a standard-PIM-generating antenna, a stable PIM source is required. A diode generates high and stable PIM because of its high nonlinearity. Therefore, we choose a diode as a PIM source. It is also important to control the generated PIM strength. For that purpose, we propose a patch antenna with a diode-loaded parasitic element so that the PIM level is controlled with only the alignment angle of the parasitic element.

Fig.5 shows the configuration of the proposed antenna. In this examination, we choose the antenna composed of circular patch elements because the rotation of the parasitic element has little influence on the input characteristics of the antenna. The driven patch is excited in the TM$_{11}$-mode. The parasitic element has a hole with 4mm-diameter at the centre, where the diode is mounted by soldering. Since the current on the parasitic element is excited in the $y$-direction, the current excited on the diode is determined by the alignment angle of the parasitic element $\phi$. When the current amplitude flowing in the $y$-direction on the parasitic current is denoted as $I_o$, the current on the diode is predicted as $I_o \cos \phi$. As a consequent, we estimate the power consumption of the diode as a function of the alignment angle $\phi$ as:

$$P_d = A + 10 \log_{10} \cos^2 \phi$$  \hspace{1cm} (1)

In this paper, we evaluate three types of diodes. The first one is a Schottky barrier diode (RB721Q-40: Diode-1), which is often used as a microwave detector. For a comparison propose, a current regulative diode (E153: Diode-2) and a switching diode (1S2076A: Diode-3) are also evaluated.

Fig.6 shows the input characteristics of the proposed antenna as a function of frequency, where the diode-angle $\phi$ is chosen as a parameter. It is confirmed that the alignment angle $\phi$ affects little on the input characteristics, especially at the operating frequencies. Therefore, it is negligible from the practical viewpoint.

Fig.7 shows the PIM characteristics of the antenna with a Schottky barrier diode (Diode-1) as a function of the input power. When $\phi=0^\circ$, the PIM response has 3dB-slope when the input power is 34dBm or less. On the other hand, a saturated region appears when the input power is greater than 34dBm, which is caused because the diode is excited in out-of-the-specification. It is not inherit characteristics of the patch antenna itself. We confirmed that the diode was not broken under the high power excitation such as greater than 34dBm, because the original characteristic reappeared when the input power decreased. Incidentally, the PIM response didn’t saturate when input power is 43dBm when $\phi=90^\circ$.

Next, generated PIM level versus diode-angle $\phi$ is shown as Fig.8. In this figure, solid line is the experimental value, and broken line is calculated from equation (1). The measured PIM varies periodically, which has a similar tendency with the calculation. Therefore it is confirmed that the power implied on the diode can be approximated using Eq.1. From the measurement result, generated PIM level becomes the maximum value (= -52dBm) when $\phi=0^\circ$, and become the minimum value (= -107 dBm) when $\phi=90^\circ$. The controllable range of PIM level was 55dB. Also, since this minimum value of PIM level depends on generated PIM level from the patch antenna itself, it will be possible to perfectly cancel generated PIM from the diode ideally if the diode-angle $\phi = 90^\circ$.

Fig.9 shows that PIM measurement result when the loaded diode is a current regulative diode (Diode-2) or a switching diode (Diode-3). It is similar to the result on the Schottky barrier diode (Diode-1) at the points that PIM level changes periodically for the diode-angle $\phi$, and it becomes maximum when $\phi=0^\circ$, 180$^\circ$, and becomes minimum when $\phi=90^\circ$, 270$^\circ$. However, the rate of angle variation that loaded diode is Diode-2, or Diode-3 is smaller than the one that loaded diode is Diode-1. As Table 1 shows, controllable range of Diode-1 is the largest of the three diodes. Also, PIM levels of Diode-2 and Diode-3 don’t correspond with equation (1). We consider that it is natural because these two diodes are not designed for high frequency, and that this disagreement is caused by junction capacitance, stray inductance, and so on.

Therefore, PIM level of the Schottky barrier diode has the largest controllable range of the diodes in this measurement, and can generate higher PIM level. Also the PIM level of the diode is
easy to predict. On the one hand, diodes for low frequency have an advantage of adjustment of PIM level because of its gentle angle variation.

4. Conclusion

In this paper, we measured generated PIM from the patch antenna incorporating a PIM source. Moreover when diode was loaded on the parasitic element of an antenna, we showed that we can control generated PIM level from the antenna by changing alignment angle of diode. Controllable range of PIM level differs with type of diode. When loaded diode was the Schottky barrier diode, the PIM could be approximated by a simple equation.

Acknowledgments

The authors would like to thank TELEC (Telecom Engineering Centre) for financial support and NTT DoCoMo for the supporting to our experimental setup.

References

Fig.5. $S_{11}$ characteristics of the diode loaded antenna (circular patch)

Fig.7. PIM characteristics as a function of diode alignment angle of the diode loaded antenna (Diode-1)

Fig.6. PIM characteristics of the diode loaded circular patch antenna as a function of input power (Diode-1)

Fig.8. PIM characteristics of the diode loaded antenna (Diode-2, 3)

Table 3
Controllable PIM-range of the diode-loaded antenna (Diode-1, 2, and 3)

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<tr>
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<th>PIM level [dBm]</th>
<th>Controllable range [dB]</th>
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<tbody>
<tr>
<td></td>
<td>Maximum</td>
<td>Minimum</td>
</tr>
<tr>
<td>Diode-1</td>
<td>-52</td>
<td>-107</td>
</tr>
<tr>
<td>Diode-2</td>
<td>-74</td>
<td>-112</td>
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<tr>
<td>Diode-3</td>
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<td>-118</td>
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