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Intermodulation Distortion and Compression Point Measurement of Active Integrated Antennas Using a Radiative Method

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Abstract—In this paper, a measurement procedure allowing the characterization of active integrated antennas in terms of intermodulation distortion and compression point inside of a parallel plate cell is presented. The validity of the radiative measurement is shown and compared to the traditional guided procedure. A good agreement between the two methods shows that this approach allows the evaluation of the overall linearity behavior of arbitrary complex integrated antennas and can serve as a complementary tool when the traditional guided method cannot be applied.

1. INTRODUCTION

Although an amplifier in an active antenna system often allows a better signal-to-noise ratio than passive solutions, especially for miniaturized designs, it also entails some drawbacks. Due to its nonlinear behavior near the saturation region, the active part of the antenna generates some amount of harmonics while two frequency-separated signals are applied to its input. The most undesirable ones are third order product which often cannot be filtered due to its proximity to the frequency band of interest. To estimate the linearity properties of such systems, either 1-dB compression point (1 dBCP) or the third-order interception point (IP3) measurements are commonly used.

In the case of active integrated antennas (AIA) [1], the amplifier and radiative elements are closely related and often cannot be separated. Moreover, the active part of such a type of antennas can be composed of many active elements such as transistors, PIN diodes, varactors, and active switches, producing the nonlinearities. Such complex structures lead to the fact that the traditional guided measurement (Fig. 1(a)) becomes very challenging since it requires a calculation of the contribution of the passive antenna parts and active ones. A simpler way consists in considering the whole antenna system as a non-separated block [2] and applying a radiative method of measurement instead (Fig. 1(b)).

In order to perform such a measurement, any electromagnetic field (EMF) generation system can be used. However, among all EMF generator standards, only plane wave generating cells such as TEM (Transverse Electromagnetic), GTEM (GHz Transverse Electromagnetic) or PPC (Parallel Plate Cell) allowing well defined environment are capable to produce strong and wideband plane E-field [3]. These cells are also versatile tools whose applications are numerous: EMC/EMI (Electromagnetic Compatibility/Interference) measurement, dosimetry, calibration, measurement of antenna gain, etc. from DC up to a few GHz.

In this paper, a measurement procedure allowing both the 1dBCP and IP3 of a single carrier system using a PPC is proposed. First, a PPC is briefly presented, following the description of measurement setups. Then, to validate the principle, the 1dBCP and the output IP3 are measured on an antenna where an amplifier can be separated from the radiative structure and measured alone. Finally, an active integrated monopole antenna is measured using the proposed method.

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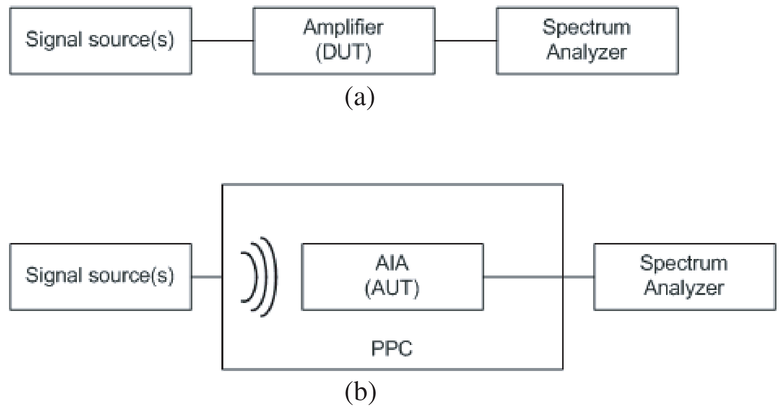


Figure 1. Methods of measurement of the linearity. (a) Traditional guided method applied to amplifiers alone (DUT: Device Under Test). (b) Presented radiative method applied to active antennas (AUT: Antenna Under Test).

2. DESCRIPTION OF THE PARALLEL PLATE CELL

The detail description of the PPC has been published in [4]. Here, we briefly recall that the PPC is a tool allowing the generation of the plane wave between its plates from DC up to the cutoff frequency of

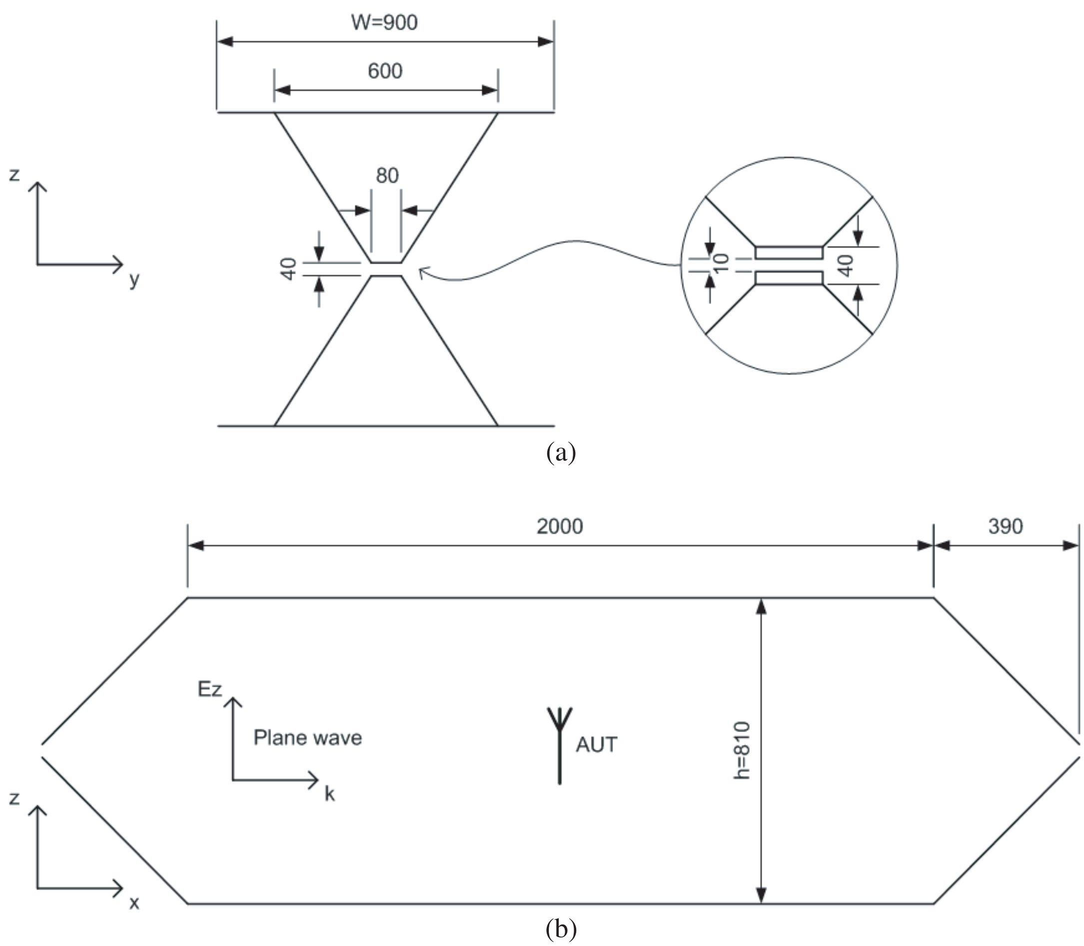


Figure 2. Geometry of the PPC. (a) YZ plane and (b) XZ plane. Dimensions are in mm.

the first higher propagation mode TE_{10}. The plates are made of aluminium and joined by two tapered parts. The cell can be seen as a microstrip transmission line where the substrate is the air, therefore the characteristic impedance, as well as the cutoff frequency of such line, depend on its dimensions.

Considering the dimensions of the PPC presented in Fig. 2, the cell has a characteristic impedance of 150 Ω and provide a TEM propagation mode up to 167 MHz inside of it. For these reasons, the cell should be fed through a 1 : 3 balanced transformer on one side and terminated by a 150 Ω resistor on the other side. The respect of the characteristic impedance is important since it minimizes insertion losses from 50 Ω devices connected to it and avoids perturbations in the E-field distribution.

3. MEASUREMENT SETUP

The measurement setup used in this paper is composed of a PPC connected to one or two signal generators depending either the 1 dBCP or IP3 is measured. In the case of the IP3, two signal generators (in our case two HP8648) are connected through a hybrid coupler (in our case Mini-Circuits ZFRSC-2050) providing two closely separated CW signals. An active antenna under test (AUT) is placed inside the cell and connected to a spectrum analyzer (in our case Agilent E4446A) with the same input impedance as the output of the antenna. In this paper, all measurements are performed at 10.65 MHz and a Δf of ±10 kHz for the OIP3 (third order interception point defined at the output) characterization.

3.1. Compression Point

The setup for the 1 dB compression point (Fig. 3) is composed of a PPC connected to a signal generator through an amplifier in order to provide a sufficient field magnitude inside the cell to saturate the antenna under test. The AUT is placed inside the cell and connected to a spectrum analyzer or a power meter.

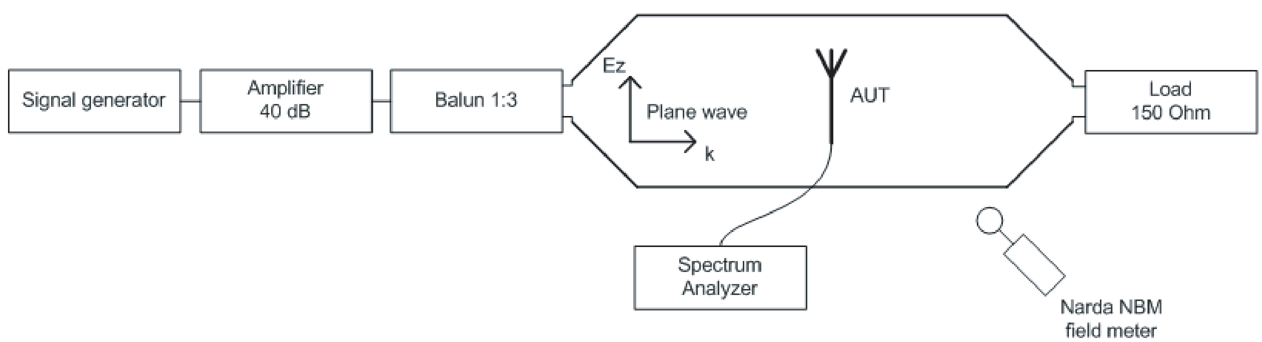


Figure 3. Measurement setup.

By increasing the power of the signal generator the output 1 dBCP is then the direct reading on the spectrum analyzer expressed in dBm. However, in the case of active antennas, it is sometimes more convenient to know the input compression point in order to know at which magnitude of the incident E-field the saturation occurs. In this case, using the field meter (in our case Narda NBM 550 with EF 0691 E-field probe) and considering the fact that the PPC is a linear system, the field at any input power can be known, so an E-field corresponding to the 1 dBCP can be obtained. A special consideration of this setup concerns the power handling of the balun and the load resistor which should be able to operate under about 30 W in our case.

3.2. Interception Point

In the case of the interception point measurement, two closely separated CW signals are injected into the cell. These signals are provided by two amplified signal generators connected through a hybrid coupler. The AUT is again placed into the cell and connected to a signal generator.

The presence of coupled active devices generating the two frequency separated tones produces a natural intermodulation depending on the isolation of the hybrid coupler. This system intermodulation should be sufficiently low (high value of the third order intermodulation distortion IMD3) in order to not mask the intermodulation of the active antenna under test. This system IMD3 should be measured at the output of the balun with taking into account the whole feeding chain. In our case, a comfortable value of -90 dBc (dB relative to carriers) has been measured at -20 dBm of power from the generators. It means that in all measurements this power of -20 dBm should not be exceeded in order to guarantee a good accuracy.

However, in some cases of highly linear and low-gain active antennas, this limited power of -20 dBm can be insufficient to perform the measurement. For this reason and instead of pushing more power from the signal generators, we use a highly linear auxiliary amplifier connected between the AUT and the spectrum analyzer separated by a 3 dB attenuator, which guarantees a good impedance matching between the two devices (Fig. 4). Knowing the OIP3 and gain of this auxiliary amplifier as well as the gain of the attenuator, the OIP3 of AUT can be calculated from the Friis equation for cascaded elements in Eq. (2):

$$\frac{1}{OIP3_{meas}} = \frac{1}{OIP3_{aux}} + \frac{1}{OIP3_{att}G_{aux}} + \frac{1}{OIP3_{AUT}G_{att}G_{aux}} \tag{1}$$

since the attenuator is a passive device the $OIP3_{att} \to +\infty$. After simplification we obtain:

$$OIP3_{AUT} = \left[G_{att}G_{aux}\left(\frac{1}{OIP3_{aux}} - \frac{1}{OIP3_{meas}}\right)\right]^{-1} \tag{2}$$

where G_{att} is the gain of the attenuator ($10^{\frac{-3\,\mathrm{dB}}{10}}$ in our case), G_{aux} the gain of the auxiliary amplifier, $OIP3_{aux}$ the third order interception point of the auxiliary amplifier and $OIP3_{meas}$ the measured third-order interception point:

$$OIP3_{meas} = P_{out} + \frac{\overline{IMD3}}{2} \tag{3}$$

Since a small difference always exists between the left and right IMD3, a mean value of the two is considered in Equation (3) in order to decrease the measurement error.

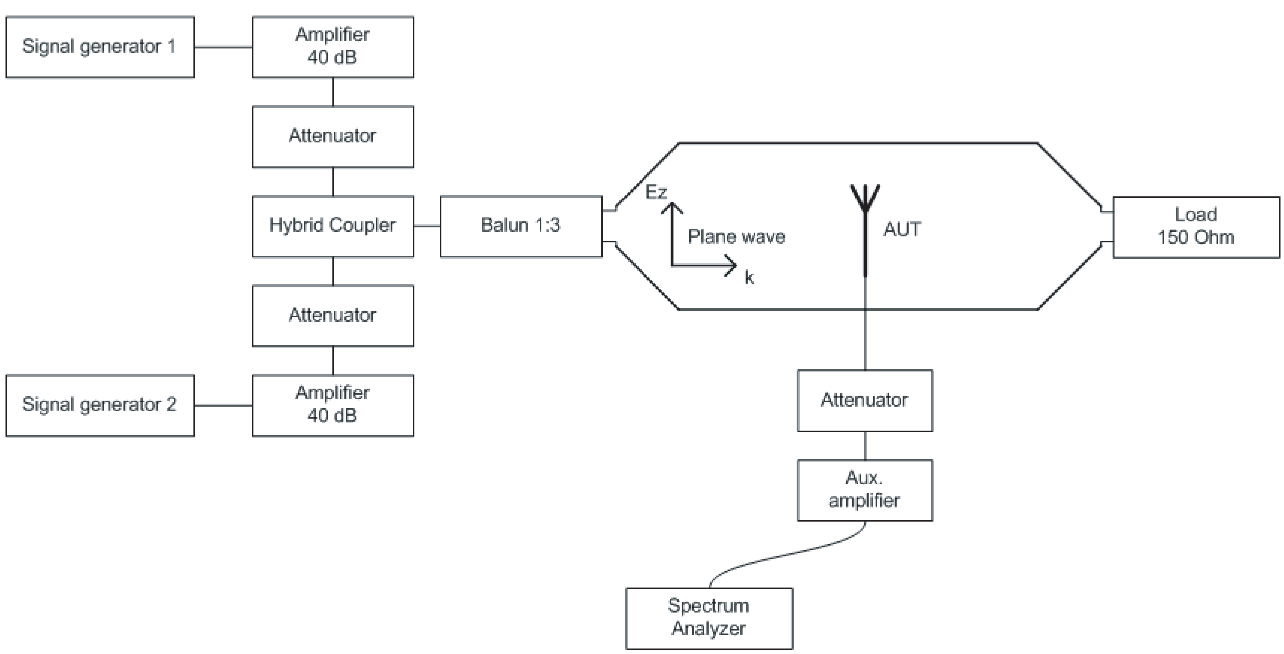


Figure 4. Measurement setup for OIP3.

4. CASE STUDY

4.1. Active Loop Antenna

In the first case, we provide a comparison of measured compression point of a commercially available Lindgren 6502 active loop to its datasheet. In Fig. 5, we can see the measured output power from the antenna with increasing magnitude of the incident E-field. The measured input 1 dB compression point occurs at an E-Field of 136 dB μV/m which is close to the value of 134 dB μV/m provided by the manufacturer (Table 1).

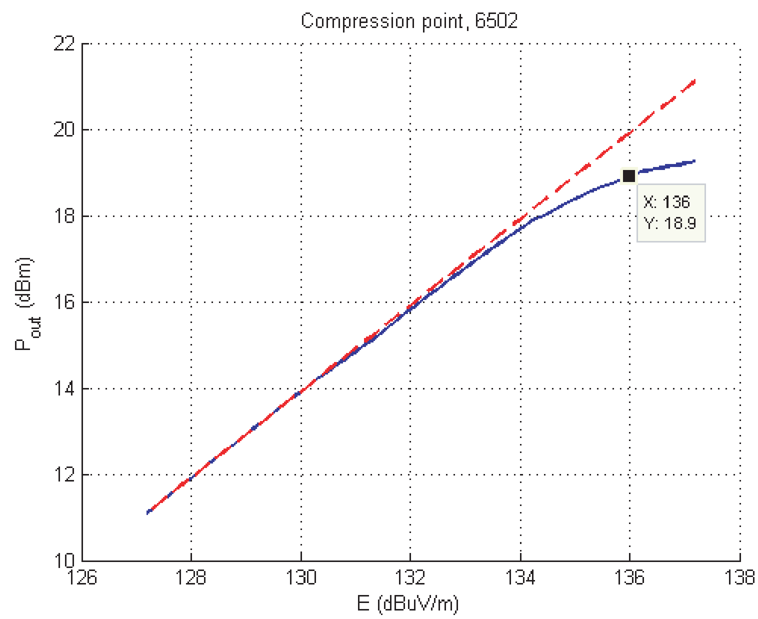


Figure 5. Compression point of the active loop antenna (Lindgren 6502) as a function of the incident E-field.

Table 1. Radiative method compared to guided measurement and the datasheet.

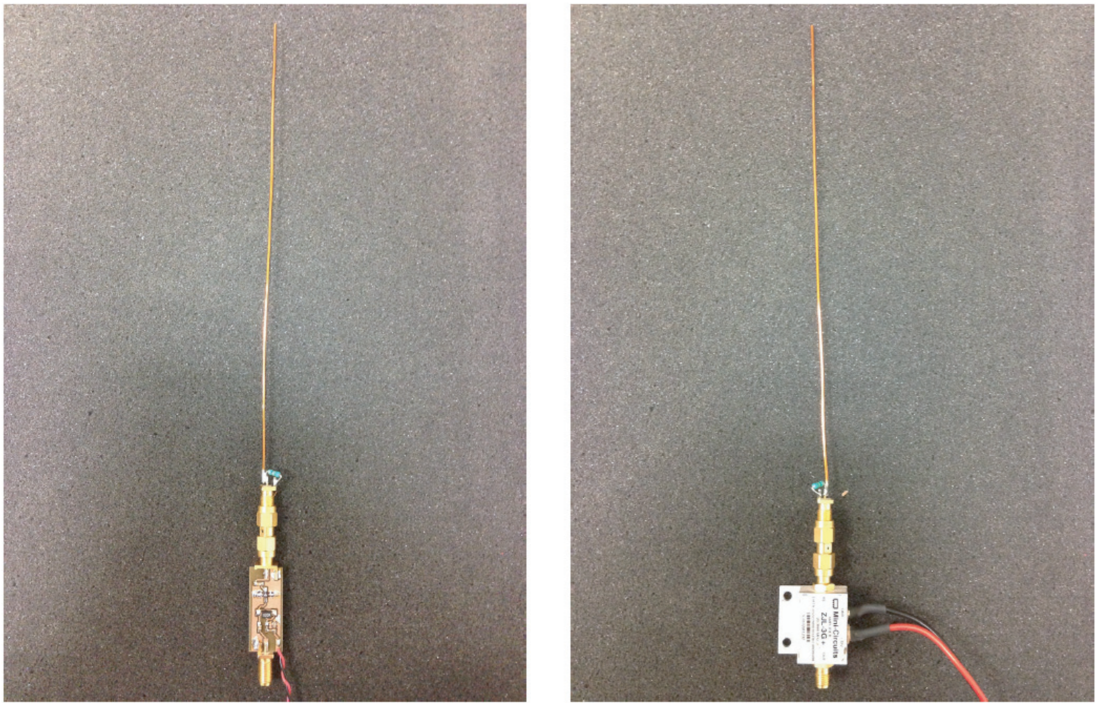
Lindgren 6502, active loop	Datasheet	Radiative measurement
E-Field at 1dBCP (dB μV/m)	134	136
Output 1dBCP (dBm)	-	18.9

4.2. Monopole with an Preamplifier

In this section, an active 20 cm preamplified monopole antenna is considered (Fig. 6(a)). The active part of the antenna consists of a 50 Ω wideband amplifier MAR-6SM specified by manufacturer OIP3 and 1 dBCP.

Since this antenna is composed of only one amplifier which can be easily separated from the monopole, the measurement of the nonlinearity can also be done in a traditional manner by connecting the generator(s) directly to the input of the amplifier.

In Table 2, we compare the datasheet values and those measured in a traditional manner or using a PPC. As a result, the datasheet values for the 1 dBCP and OIP3 are higher than the measured ones and can be explained by the particular biasing circuit of the amplifier as well as the frequency of 500 MHz at which they are specified. However, between the guided and radiative measurements, the results are in a good agreement with a deviation of 1.4 dB for the OIP3 and 0.3 dB for the output compression point.



(a) (b)

Figure 6. Preamplified monopole. (a) MAR-6SM. (b) ZJL-3G+.

Table 2. Radiative method compared to guided measurement and the datasheet.

MAR-6SM	Datasheet (@ 500 MHz)	Guided measurement	Radiative measurement
E-Field at 1dBCP (dB μV/m)	-	-	149.5
Output 1dBCP (dBm)	3.7	1.2	0.9
OIP3 (dBm)	18.1	11.8	13.2

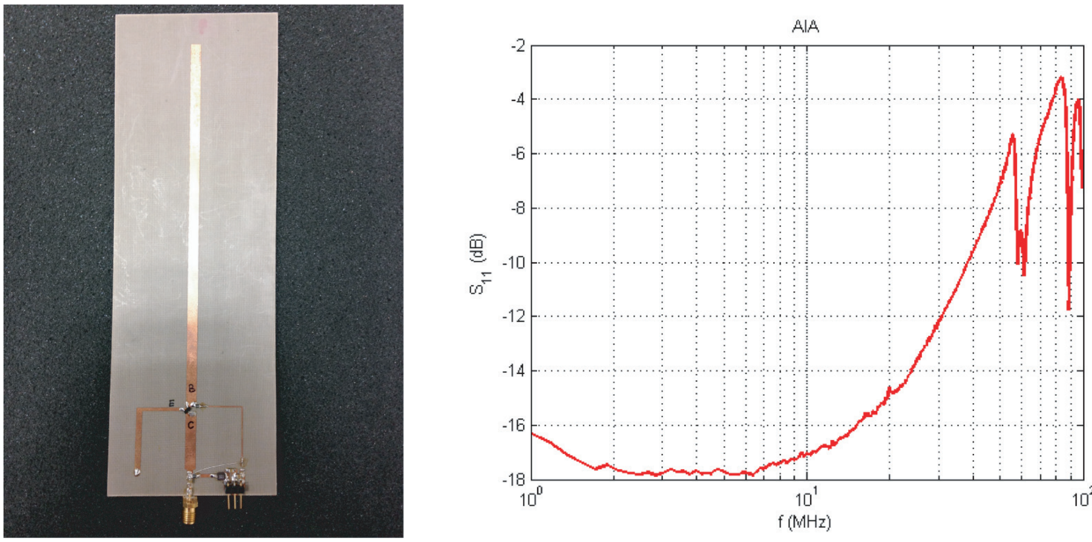
To further confirm the principle of measurement, an already polarized ZJL-3G+ amplifier with well-known characteristics haa been considered (Fig. 6(b)). The manufacturer has provided the OIP3 of 22 dBm at 2 GHz and 1 dBCP of 9.7 dBm at 20 MHz. At 10.45 MHz, the OIP3 of the amplifier alone is measured to be 22.58 dBm using a traditional guided method and 10.75 dBm for the output compression point. Once connected to the 20 cm monopole and using the radiative method, the OIP3 is measured to be 20.3 dBm and 10.03 dBm for the 1dBCP, confirming again the viability of the measurement principle (Table 3).

Table 3. Radiative method compared to guided measurement and the datasheet.

ZJL-3G+	Datasheet	Guided measurement	Radiative measurement
E-Field at 1dBCP (dB μV/m)	-	-	156.8
Output 1dBCP (dBm)	9.7 (@ 20 MHz)	10.75	10.03
OIP3 (dBm)	22 (@ 2 GHz)	22.58	20.3

4.3. Active Integrated Antenna

In this section, a real case of a highly integrated active antenna is measured in terms of compression point and interception point. This antenna based on [5] using a concept proposed by Meinke [6] is a monopole antenna with a bipolar junction transistor BFR182 making a part of a radiative structure. This antenna has been designed to work in the HF frequency band of interest and has a good matching around 10.65 MHz (Fig. 7).



(a) (b)

Figure 7. AIA. (a) Antenna design. (b) S_{11} parameter.

In this case, the traditional guided method cannot be applied, and only radiative measurement is presented in Table 4.

Table 4. Radiative measurement results for the AIA.

AIA	Radiative measurement
E-Field at 1dBCP (dB µV/m)	138.8
Output 1dBCP (dBm)	4.03
OIP3 (dBm)	19.5

5. CONCLUSION AND DISCUSSION

In this paper, two setups based on a parallel plate cell and allowing a measurement of arbitrary complex active integrated antennas in terms of the 1 dBCP and OIP3 are demonstrated. The input compression point measurement has been validated by the manufacturer data on a commercially available active antenna and has the advantage to express it in terms of the E-field magnitude. The output compression point and the third-order interception point measurement have been validated on test amplifiers that can be separated from the radiative part of the antenna and compared to a traditional guided measurement. Finally, a highly integrated active antenna based on BJT incorporated into the radiative structure has been measured in terms of the OIP3 and the compression point. As a part of a discussion, some remarks/improvements of the presented setup can be mentioned. The first one concerns the hybrid coupler. By increasing the isolation of the coupler, the system IMD3 will decrease allowing the measurement of more linear devices. Another important point concerns the auxiliary amplifier. Its gain and the OIP3 should be known with a high precision, and its OIP3 should be at least 15 dB greater than that of the AUT to obtain an accurate measurement. In our case, using an auxiliary amplifier with 38.9 dBm of OIP3, the practical measurement of the OIP3 of the AUT is then limited to around 25 dBm. Finally, as it is usual in the intermodulation distortion measurements, the internal attenuation of the spectrum analyzer should be set to a sufficiently high value in order to not distort the results.

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