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Research Paper

On upper bound for the third order intercept point of mixers

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ABSTRACT

There is no theoretical upper bound for the third order intercept point, but only practical. We approach this statement from two directions. Infinite IP3 phenomenon is first discussed. A possible reason given is series inductor at switching devices. Secondly, we indicated that an arbitrary mixer interconnected with a linear pre- and a post amplifier can produce arbitrary conversion loss and third order intercept point simultaneously.

Keywords: Mixer, intermodulation, third order intercept point, conversion loss.

INTRODUCTION

Intercept point is a basic characteristic of non-linear circuits such as mixers and amplifiers measuring the degree of non-linearity (Maas, 1986, 2003). For the traditional definition of the third order intercept point (Maas, 1986, 2003), we assume a linear dependence of the intermodulation power on the input power (Figure 1) (Maas, 2003). This definition is based on the small signal approach and the assumption is not valid for higher input power levels (Figure 2). Due to the increased non-linear effects, value of the third order intercept point is different from that at low input levels. Our problem is if there is a theoretical limitation for IP3.

Furthermore, we showed an example of a measurement with very high IP3. This is called as infinite IP3 phenomenon. In Section 3 we obtain a possible reason of the infinite IP3 phenomenon. A mixer system was thereafter built with a linear pre- and a post amplifier and a mixer in between. It was shown that the conversion loss and the intercept point of the mixer system can be adjusted arbitrarily by adjusting the amplifier gains. The significance of our work is the reason for the competition which is higher intercept point and simultaneously, a lower conversion loss decreased.

THE INFINITE IP3 PHENOMENON

As we investigate here the deviation from the traditional definition, it is important to state clearly the meaning of IP3. The main directive is that should in case the conditions of the original definition are fulfilled, our definition should coincide with that of the traditional.

Accordingly, we define IP3 as the intersection of straight lines fit on the curves of the first and third order intermodulation power in dB versus input power in dB in a predetermined range of input power. For clarity, we point out the differences between the two definitions:

1) Predetermined range of input power;
2) Both curves can deviate from straight line;
3) Slopes of both straight lines can be arbitrary.

When we measured the 1st and 3rd order intermodulation of a modified Gilbert mixer vs. input power, the Figures 3, 4 and 5 were obtained (Ladvánszky and Dortschy, 2016; Ladvánszky, 2017; Osbáth and Ladvánszky, 2016, 2015). Another example for the same phenomenon is the measurement of the diode half H mixer (Figure 6) (Ladvánszky and Osbáth, 2016).

A POSSIBLE REASON OF INFINITE IP3

In this section we intend to prove that a possible reason for the infinite IP3 phenomenon is the inductor in series with the diodes. For this reason, we investigated the two-diode

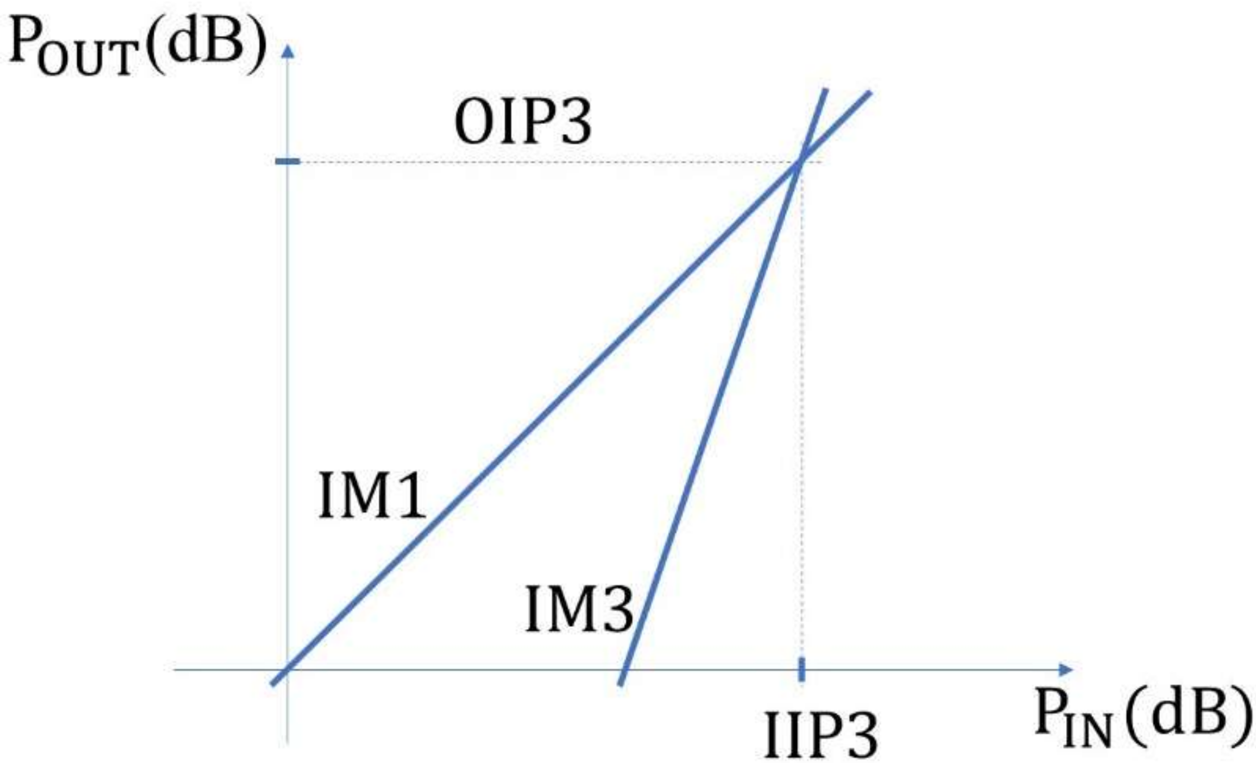

Figure 1: Traditional definitions of the nth order intercept point. Plot of intermodulation is assumed in the form of straight lines (small signal approach), with slopes 1 and 3. Notations: P_{IN}, P_{OUT}, IIP3 and OIP3 are the input and output power and third order intercept point, respectively. IM1 and IM3 are the first and third order intermodulation curves.

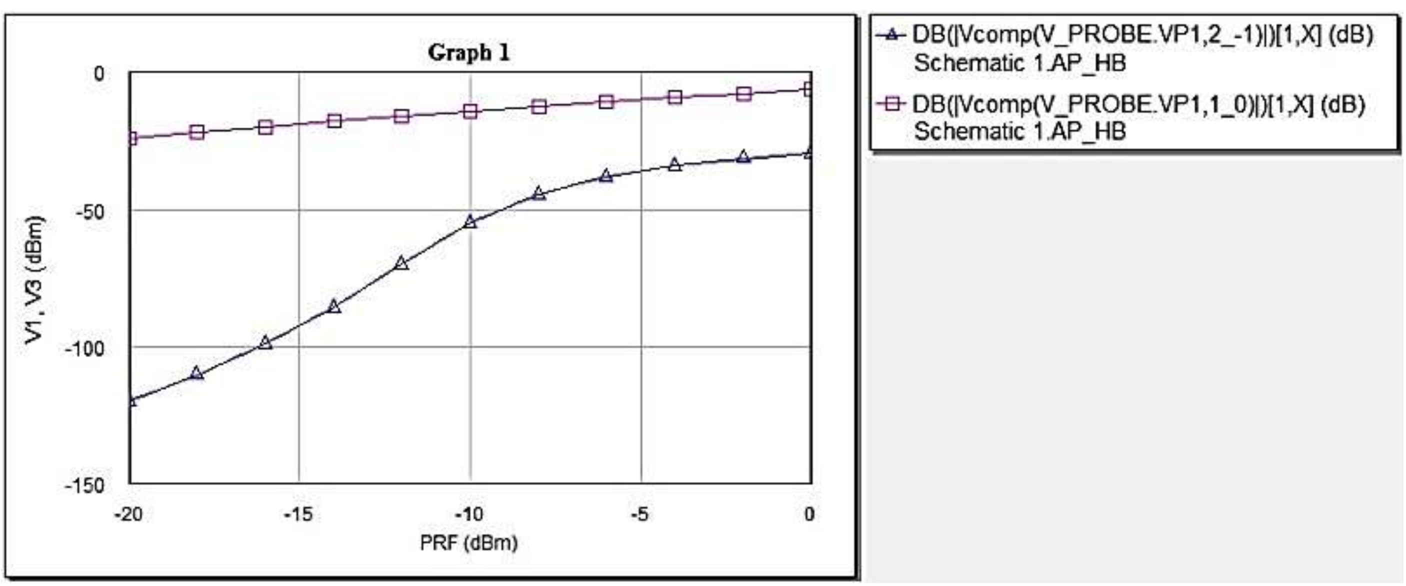

Figure 2: Higher input power levels. Dependence of the third order intermodulation power on the input power is non-linear. Notations: Squares – first order, triangles – third order intermodulation product. MATLAB analysis.

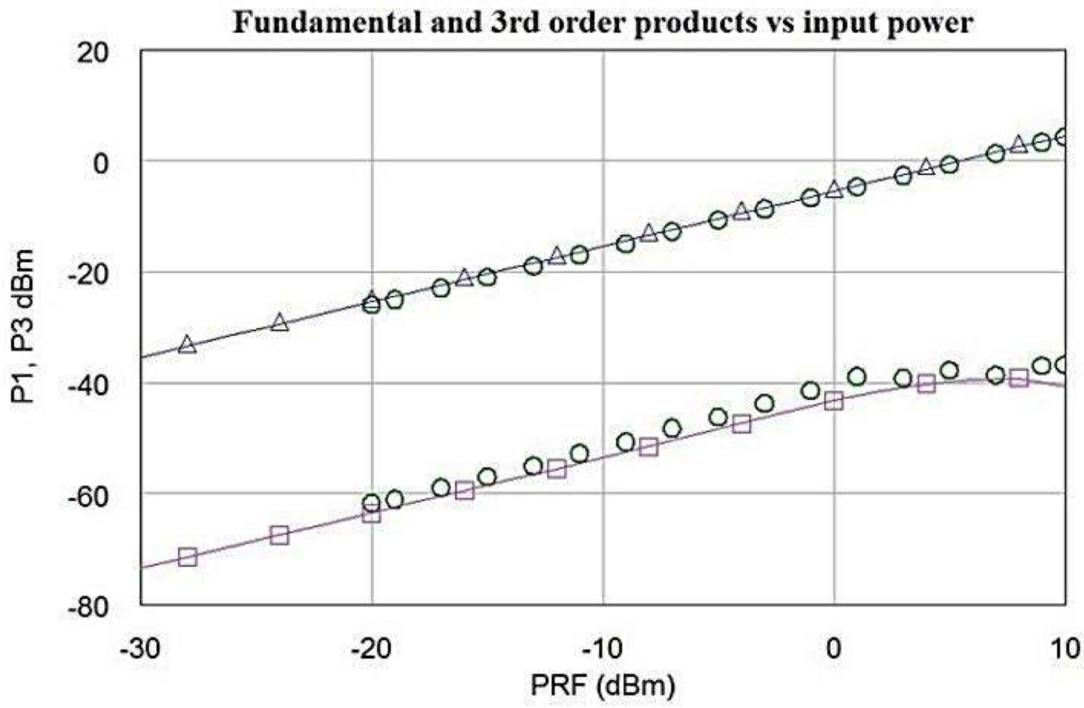

Figure 3: Power of the 1st and the 3rd order intermodulation of a modified Gilbert mixer vs. input power. The two curves can be approximated well by two parallel lines. Parallel means that the point of intersection is in the infinity. Thus, this is called as infinite IP3 phenomenon. Notations: Triangles – first order, squares – third order intermodulation products (AWR analysis), circles – measurements.

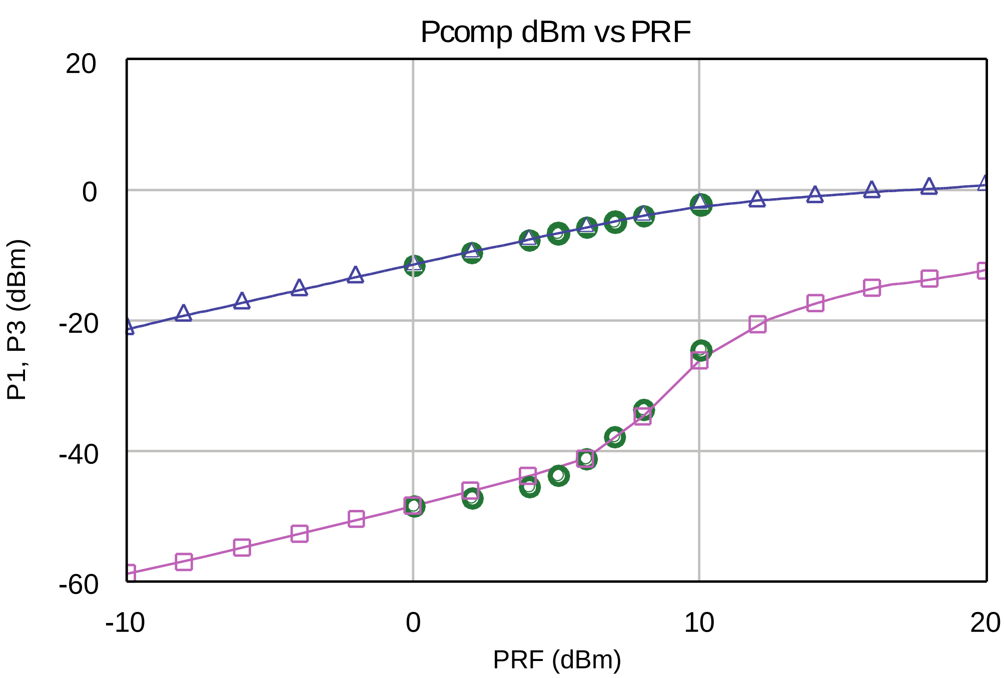

Figure 4: Intermodulation vs. input power for the diode half H mixer. Infinite IP3 phenomenon is observed here as well. Notations: Triangles – first order, squares – third order intermodulation products (AWR analysis), circles – measurements.

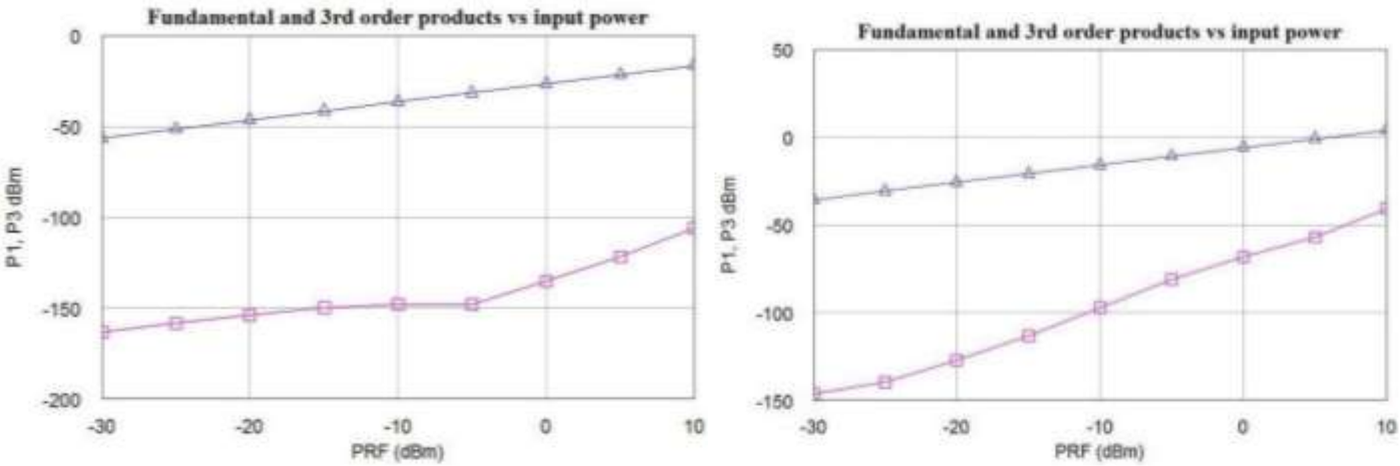

Figure 5: Intermodulation analyses for the Gilbert mixer (Figure 3). Left: Transformer self-inductances are 0.4 uH, right: 4 uH. As expected. Transformer parasitics are neglected.

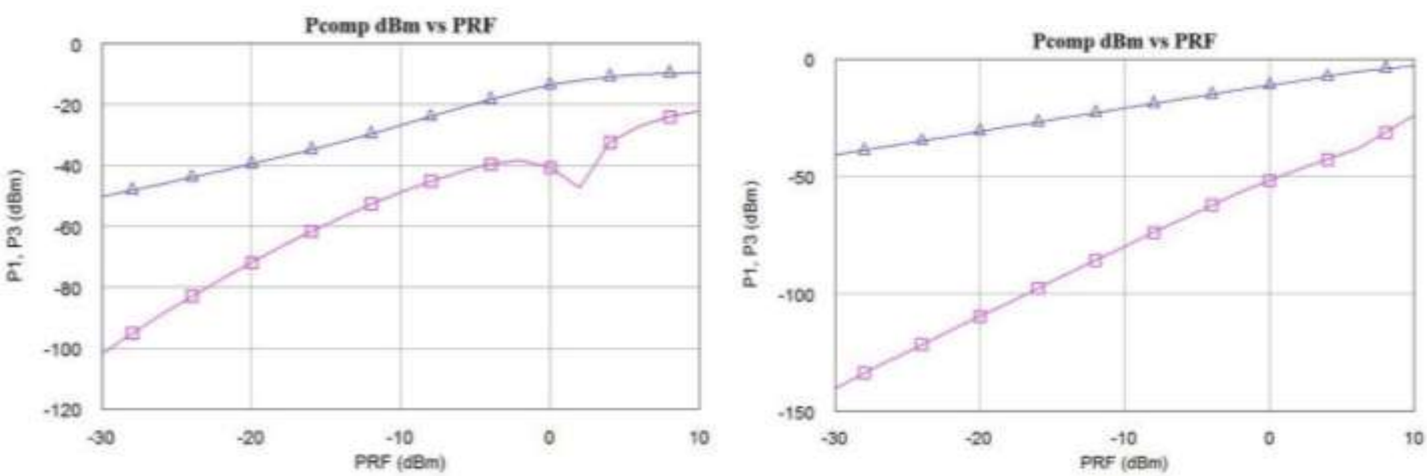

Figure 6: Intermodulation analyses for the half H mixer (Figure 4 Left: Transformer self-inductances are 0.15uH, right: 1.5uH. As expected. Transformer parasitics are neglected.

mixer in Figure 7. Thereafter, we compared the intermodulation products when the inductor value is 10 nH and 4 uH.

A WAY OF SETTING ARBITRARY IL AND OIP3

It is shown here that IL and OIP3 can be arbitrary (Ladvánszky, 2017). It was assumed that the amplifiers in Figure 8 are linear with voltage gains G and G2, respectively. We state that for a given arbitrary mixer, IL and OIP3 of the system can be arbitrary, depending on the values of G and G2. It was assumed that the whole system is resistive, that is, applying a two-tone excitation at the input, two-tone answers exist anywhere in the system containing two spectrum lines of identical amplitude.

In carrying this experiment, the first step was to consider the mixer in the middle alone and thereafter applied a two-tone excitation at the mixer input. Both sinusoids have the amplitude of Vg. Applying a proper amount of VLO (not shown in Figure 8), the first and third order inter modulation product amplitudes at the IF output are VIF1 and VIF3, respectively. IL and OIP3 of the mixer can be calculated from Vg, VIF1 and VIF3.

The amplifiers were further connected and two-tone excitation applied at the input of the mixer system with amplitudes Vg'. When G and G2 are adjusted, Vg' in parallel was also adjusted such that Vg, VIF1 and VIF3 remain unchanged. Fundamental and third order intermodulation voltage amplitudes at the IF output of the mixer system are

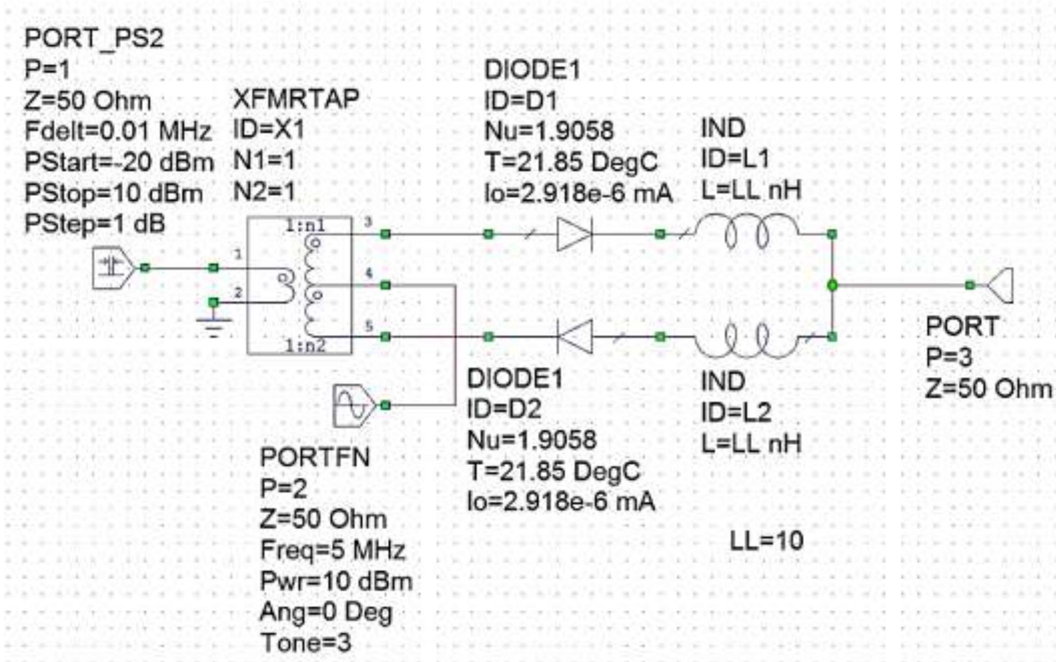

Figure 7: Circuit diagram of the two-diode mixer, a plot from the analysis program AWR.

Figure 8: A mixer system.

denoted as VIF1’ and VIF3’, respectively. The following equations can be written as:

$$\mathrm{Vg} = \mathrm{G} * \mathrm{Vg}' \quad (1)$$

$$\mathrm{VIF1}' = \mathrm{G2} * \mathrm{VIF1} \quad (2)$$

$$\mathrm{VIF3}' = \mathrm{G2} * \mathrm{VIF3} \quad (3)$$

$$\mathrm{IL} = -20 * \log10\left(\frac{\mathrm{VIF1}}{\mathrm{Vg}}\right) \quad (4)$$

$$\mathrm{IL}' = -20 * \log10\left(\frac{\mathrm{VIF1}'}{\mathrm{Vg}'}\right) \quad (5)$$

$$\mathrm{OIP3} = \mathrm{PIF1} + (\mathrm{PIF1} - \mathrm{PIF3})/2 \quad (6)$$

$$\mathrm{OIP3}' = \mathrm{PIF1}' + \frac{\mathrm{PIF1}' - \mathrm{PIF3}'}{2} \quad (7)$$

$$\mathrm{PIF1} = 10 * \log\left(\mathrm{VIF1} * \frac{\mathrm{VIF1}}{2 * \mathrm{Z0}}\right) + 30 \quad (8)$$

$$\mathrm{PIF1}' = 10 * \log\left(\mathrm{VIF1}' * \frac{\mathrm{VIF1}'}{2 * \mathrm{Z0}}\right) + 30 \quad (9)$$

$$\mathrm{PIF3} = 10 * \log\left(\mathrm{VIF3} * \frac{\mathrm{VIF3}}{2 * \mathrm{Z0}}\right) + 30 \quad (10)$$

$$\mathrm{PIF3}' = 10 * \log\left(\mathrm{VIF3}' * \frac{\mathrm{VIF3}'}{2 * \mathrm{Z0}}\right) + 30 \quad (11)$$

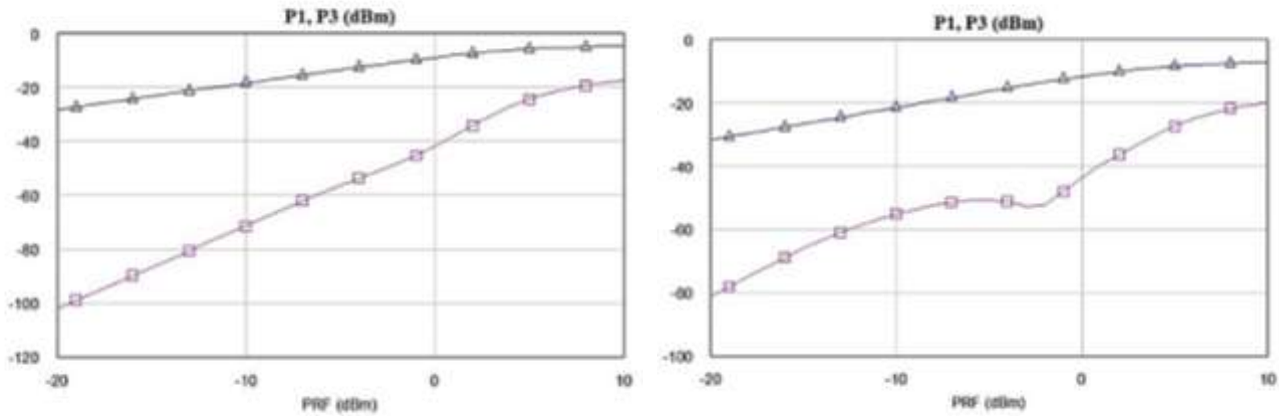

Figure 9: Intermodulation products at the inductor values of 10 nH (left) and 4 uH (right). The infinite IP3 phenomenon is clearly shown in the right Figure. Notations: Triangles – first order, squares – third order intermodulation products (AWR analysis).

From this system of equations, G and G2 can be expressed as functions of IL, IL', OIP3 and OIP3'. From Equations 4 and 5:

$$\frac{\mathrm{VIF\,1}}{\mathrm{Vg}} = 10^{-\mathrm{IL}/20} \tag{12}$$

$$\frac{\mathrm{VIF\,1'}}{\mathrm{Vg'}} = 10^{-\mathrm{IL'}/20} \tag{12a}$$

From Equations 1 and 2:

$$\mathrm{G} * \mathrm{G2} = 10^{(\mathrm{IL}-\mathrm{IL}')/20} \tag{13}$$

From Equations 2, 3, 6, 7 and 8 to 11:

$$\mathrm{OIP3}' = 15 * \log\left(\frac{\mathrm{VIF1}'^2}{2 * \mathrm{Z0}}\right) + 45 - 5 * \log\left(\frac{\mathrm{VIF3}'^2}{2 * \mathrm{Z0}}\right) - 15$$

$$= 15 * \log\left(\frac{\mathrm{G2} * \mathrm{VIF\,1}^2}{2 * \mathrm{Z0}}\right) - 5 * \log\left(\frac{\mathrm{G2} * \mathrm{VIF\,3}^2}{2 * \mathrm{Z0}}\right) + 30 \tag{14}$$

$$\mathrm{OIP3} = 15 * \log\left(\frac{\mathrm{VIF1}^2}{2 * \mathrm{Z0}}\right) + 45 - 5 * \log\left(\frac{\mathrm{VIF3}^2}{2 * \mathrm{Z0}}\right) - 15$$

$$= 15 * \log\left(\frac{\mathrm{VIF\,1}^2}{2 * \mathrm{Z0}}\right) - 5 * \log\left(\frac{\mathrm{VIF\,3}^2}{2 * \mathrm{Z0}}\right) + 30 \tag{15}$$

$$\mathrm{OIP3}' - \mathrm{OIP3} = 20 * \log(\mathrm{G2}) \tag{16}$$

$$\mathrm{G2} = 10^{\frac{\mathrm{OIP\,3}' - \mathrm{OIP\,3}}{20}} \tag{17}$$

$$\mathrm{G} = 10^{\frac{\mathrm{IL}-\mathrm{IL}'}{20} - \frac{\mathrm{OIP\,3}' - \mathrm{OIP\,3}}{20}} \tag{18}$$

CONCLUSIONS

For a prolonged period of time, a sharp competition was between mixer suppliers for higher third order intercept point. One might think there was a theoretical upper bound. In this paper, we prove the opposite statement.

Significance of these investigations increased when dynamic range was considered (Berceli, 2017). If the lower edge of the infinite IP3 region is adjusted to the value of RF input power where the third order intermodulation component just starts to be greater than the noise and the ratio between the first and third order component is the greatest, then, this ratio can be preserved for much greater RF input power levels as well, or in other words, relative distortion remains constant in a range of RF input power.

It was earlier mentioned in the Abstract that there is only a practical upper bound for the third order intercept point. This can be easily seen when we consider that in the mixer system of Figure 8, pre- and post-amplifier are not perfectly linear in practice. It is the third order intermodulation that limits the third order intercept point of the system (Maas, 2003).

A careful comparison between the two mentioned ways towards large OIP3 leads to an important conclusion, that is, how to achieve practically a very large OIP3. There is a basic difference between the two ways as Figure 9 shows there is no practical bound when series inductance is considered. However, Equation 17 shows, very large OIP3 can only be achieved when G2 is very large and this is a serious limitation.

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