Intermodulation Distortion Mitigation in Microwave Amplifiers and Frequency Converters

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Outline

• Concepts/Review

• Broadband GaN power amplifier with distortion cancellation

• Stand-alone distortion cancelling cell

• Distortion cancellation techniques for mixers
Ideally:

\[ A_1 \cos(\omega_1 t) + A_2 \cos(\omega_2 t) \]^3 = \cdots + 3A_1^2 A_2 \cos^2(\omega_1 t) \cos(\omega_2 t) + 3A_1 A_2^2 \cos(\omega_1 t) \cos^2(\omega_2 t) + \cdots

3rd order IMD
Power series model

\[ x_i(t) \xrightarrow{\text{Passive network}} x(t) \xrightarrow{\text{Nonlinear/Memoryless}} y(t) \xrightarrow{\text{Passive network}} y_o(t) \]

\[ x_i(t) \xrightarrow{H_i(\omega)} x(t) \xrightarrow{\sum_{n=1}^{N} a_n x^n(t)} y(t) \xrightarrow{H_o(\omega)} y_o(t) \]
Derivative superposition [1,2]

This method to mitigate IMD relies on modeling the FET drain current as a power series:

\[ i_{ds} = \sum_{n=1}^{N} g_{mn} v_{gs}^n \]

\[ g_{mn} = \frac{\partial^n I_{DS}}{n! \partial V_{GS}^n} \]

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HFET $f_T$ doublers [3]

$$Z_{in} = R_{i1} + R_{i2} - \frac{g_{m1}}{\omega^2 C_{gs1} C_{gs2}} + \frac{1}{j\omega} \left( \frac{1 + g_{m1} R_{i2}}{C_{gs1}} + \frac{1}{C_{gs2}} \right)$$

$$h_{21} = \frac{1 + j2f/f_T}{(jf/f_T)^2}$$

$$Z_{in} = R_{i1} + R_{i2} + \frac{1}{j\omega} \left( \frac{1}{C_{gs1}} + \frac{1}{C_{gs2}} \right)$$

$$h_{21} = \frac{2f_T}{jf}$$
1-6 GHz, 2-Watt GaN baseline amplifier
measured

measured
Distortion-cancelling GaN amplifier
recall the approximation,

\[ i_{ds} = \sum_{n=1}^{N} g_{mn} v_{gs}^{n} \]

\[ g_{mn} = \frac{\partial^{n} I_{DS}}{n! \partial V_{GS}^{n}} \]
The measured gain is shown as a black circle line, while the simulated gain is represented by an orange circle line. The frequency range is from 0 to 7 GHz. The output power is measured at 1 GHz and shown in the lower graph.
Stand-alone Distortion Cancelling Cell
Distortion-Cancelling Cell

Input

Generic Amplifier

A

Power Coupler 1

B

Auxiliary FET

C

Tunable Phase Shifter

D

Power Coupler 2

E

Auxiliary Amplifier

F

Output

\( \sqrt{2} Z_0 \)

\( \lambda/4 \)

\( Z_0 \)

\( Z_0 \)

power coupler

\( V_{DS} \)

\( V_{GS} \)

cell node “B”

auxiliary FET

\( V_{CTL} \)

phase shifter

cell node “D”
<table>
<thead>
<tr>
<th>Component</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>General purpose amp:</td>
<td>CSA-880912, Celeritek</td>
</tr>
<tr>
<td>Auxiliary FET:</td>
<td>NE34018, NEC GaAs HFET</td>
</tr>
<tr>
<td>Auxiliary amp:</td>
<td>ABP1200, Wenteq Corp.</td>
</tr>
<tr>
<td>Varactors:</td>
<td>SMV1405-079LF, Skyworks</td>
</tr>
<tr>
<td>Substrate:</td>
<td>RO3010, $\varepsilon_r = 10.2$</td>
</tr>
</tbody>
</table>
Mixers
Switched Gm mixer [4]
IF output stage
Experimental results

![Graph showing experimental results with Gain (dB) on the y-axis and LO Frequency (GHz) on the x-axis. The graph compares Meas. Gain (solid line) and Sim. Gain (dashed line).]
Experimental results

![Graph showing the comparison between measured (Meas. NF) and simulated (Sim. NF) NF (Noise Figure) values across different LO Frequency (GHz) values. The graph displays a trend where the NF values decrease initially and then increase as the LO Frequency increases. The measured NF values are shown with solid markers, while the simulated NF values are depicted with dashed lines.](image-url)
Experimental results

![Graph showing experimental results with different lines and markers for Sim. OIP3 2.7V, Sim. OIP3 1.5V, Meas. IIP3, and Meas. OIP3. The x-axis represents LO Frequency (GHz) ranging from 0.0 to 11.0, and the y-axis represents (dBm) from -30.0 to 30.0.](image-url)
Acknowledgments

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• CMC Microsystems
References


Q & A
\[ V_t = V_{t0} + \frac{\sqrt{2} q \varepsilon N_A}{C_{ox}} \left( \sqrt{2\phi_f + V_{SB}} - \sqrt{2\phi_f} \right) \]