ACPR Calculations
for Power Amplifiers

▶ useful functions and identities

▶ Units

▶ Constants

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Inputs

$P_{out} := 28dBm$ — Output Power

$IP_5 := 45dBm$ — 5th Order Intercept Point

$BW := 1.228MHz$ — Bandwidth of Transmitted Signal

$f_0 := 0MHz$ — Output Center Frequency

$f_{off} := 885kHz$ — Offset of Center Frequency for ACPR Measure

$f_{ACPRBW} := 30kHz$ — Bandwidth for ACPR Measurement

Analysis Inputs

$IP_3 := 50dBm$ — 3rd Order Intercept Point

Synthesis Inputs

$ACPR_{30\_30spec} := 45dBC$ — ACPR Requirements

Initial Calculations

f_{ACPRBW} — Lower Band Edge for ACPR Measurement

$f_1 := f_0 + f_{off} - \frac{\quad}{2}$

$f_2 := f_0 + f_{off} + \frac{f_{ACPRBW}}{2}$ Upper Band Edge for ACPR Measurement

$P_0 := 10^{\frac{P_{out}}{10}}$ $P_0 = 630.957 \frac{mW}{mW}$ Output Power

$B := \frac{BW}{2}$ Half Bandwidth

Power Density Calculations

Power Density due to both 3rd and 5th Order Distortion

$$P(IP_3, IP_5, P_{out}, B, f_0, f) := \left| \begin{array}{l} P_0 \leftarrow 10^{\frac{P_{out}}{10}} \\ \left[\frac{1}{2 \cdot B} \cdot \left(P_0 - 6 \cdot P_0^2 \cdot 10^{\frac{-IP_3}{10}} - 30 \cdot P_0^3 \cdot 10^{\frac{-IP_5}{5}} \ldots + 9 \cdot P_0^3 \cdot 10^{\frac{-IP_3}{5}} + 90 \cdot P_0^4 \cdot 10^{\frac{-IP_3}{10} - \frac{IP_5}{5}} \ldots + 225 \cdot P_0^5 \cdot 10^{-2 \cdot \frac{IP_5}{5}} \right) \ldots + \frac{1}{8 \cdot B^3} \cdot \left(6 \cdot P_0^3 \cdot 10^{\frac{-IP_3}{5}} + 120 \cdot P_0^4 \cdot 10^{\frac{-IP_3}{10} - \frac{IP_5}{5}} + 150 \cdot P_0^5 \cdot 10^{-2 \cdot \frac{IP_5}{5}} \right) \cdot \left[3 \cdot B^2 - (f - f_0)^2 \right] \ldots + \frac{10}{32} \cdot \frac{P_0^5}{B^5} \cdot 10^{-2 \cdot \frac{IP_5}{5}} \cdot \left[3 \cdot \left[5 \cdot B^2 - (f - f_0)^2 \right]^2 + 40 \cdot B^4 \right] \right] \cdot \Phi \\ + \left[\left(6 \cdot P_0^3 \cdot 10^{\frac{-IP_3}{5}} + 120 \cdot P_0^4 \cdot 10^{\frac{-IP_3}{10} - \frac{IP_5}{5}} + 150 \cdot P_0^5 \cdot 10^{-2 \cdot \frac{IP_5}{5}} \right) \cdot \frac{1}{16B^3} \cdot \left[3 \cdot B - (|f - f_0|) \right]^2 \ldots + \frac{10}{16} \cdot \frac{P_0^5}{B^5} \cdot 10^{-2 \cdot \frac{IP_5}{5}} \cdot \left[2 \cdot B \cdot \left[4 \cdot B - (|f - f_0|) \right]^3 + 2 \cdot B^3 \cdot (4 \cdot B - |f - f_0|) - (3 \cdot B - |f - f_0|)^4 \right] \right] \\ + \left[\frac{5}{32} \cdot \frac{P_0^5}{B^5} \cdot 10^{-2 \cdot \frac{IP_5}{5}} \cdot (5 \cdot B - |f - f_0|)^4 \right] \cdot \Phi(5 \cdot B - |f - f_0|) \cdot \Phi(|f - f_0| - 3 \cdot B) \end{array} \right.$$

Power Density due to 3rd Order Distortion Alone

If the output power is 5 to 10dB lower than it's 1dB compression point, the following equation may be used.

$$P_{3rd}(IP_3, P_{out}, B, f_0, f) := \left| P_0 \leftarrow 10^{\frac{P_{out}}{10}} \right.$$

$$\left[\frac{1}{2\cdot B}\cdot\left(P_0 - 6\cdot P_0^{\,2}\cdot 10^{\frac{-IP_3}{10}} + 9\cdot P_0^{\,2}\cdot 10^{\frac{-IP_3}{5}}\right) + \frac{3}{4}\cdot P_0^{\,3}\cdot 10^{\frac{-IP_3}{5}}\cdot\frac{1}{B^3}\cdot\left[3\cdot B^2 - \left(f - f_0\right)^2\right]\right]\cdot\Phi\left(B - \left|f\right.\right.$$

$$+\frac{3}{8}\cdot P_0^{\,3}\cdot 10^{\frac{-IP_3}{5}}\cdot\frac{1}{B^3}\cdot\left(3\cdot B - \left|f - f_0\right|\right)^2\cdot\Phi\left(3B - \left|f - f_0\right|\right)\cdot\Phi\left(\left|f - f_0\right| - B\right)$$

ACPR Calculations

There are two ways of measuring ACPR. The first way is by finding 10*log of the ratio of the total output power to the power in adjacent channel. This is call $ACPR_{1250\_30}$ below. The second (and much more popular method) is to find the ratio of the output power in a smaller bandwidth around the center of carrier to the power in the adjacent channel. The smaller bandwidth is equal to the bandwidth of the adjacent channel signal. This is called $ACPR_{30\_30}$ below. $ACPR_{30\_30}$ is more popular, because it can be measured easily as indicated in the measurement procedure section.

ACPR Due to both 3rd and 5th Order Distortion

$$P_{IM35}\left(IP_3, P_{out}, B, f_{ACPRBW}, f_{off}\right) := 10\cdot\log\left(\int_{f_0+f_{off}-\frac{f_{ACPRBW}}{2}}^{f_0+f_{off}+\frac{f_{ACPRBW}}{2}} P\left(IP_3, IP_5, P_{out}, B, f_0, f\right)\,df\right)$$

$$P_{IM35}\left(IP_3, P_{out}, B, f_{ACPRBW}, f_{off}\right) = -25.622\,\mathrm{dB}$$

$$ACPR_{1250\_30}\left(IP_3, P_{out}, B, f_{ACPRBW}, f_{off}\right) := P_{out} - P_{IM35}\left(IP_3, P_{out}, B, f_{ACPRBW}, f_{off}\right)$$

$$ACPR_{1250\_30}\left(IP_3, P_{out}, B, f_{ACPRBW}, f_{off}\right) = 53.$$

$$ACPR_{30\_30}\left(IP_3, P_{out}, B, f_{ACPRBW}, f_{off}\right) := P_{out} - 10\cdot\log\left(\frac{BW}{f_{ACPRBW}}\right) - P_{IM35}\left(IP_3, P_{out}, B, f_{ACPRBW}, f_{off}\right)$$

$$ACPR_{30\_30}\left(IP_3, P_{out}, B, f_{ACPRBW}, f_{off}\right) = 37.50$$

ACPR Due to 3rd Order Distortion Alone

$$P_{IM3}\left(IP_3, P_{out}, B, f_{ACPRBW}, f_{off}\right) := 10\cdot\log\left[\frac{1}{8}\cdot 10^{\frac{3\cdot P_{out} - 2\cdot IP_3}{10}}\cdot\frac{1}{B^3}\cdot\left[\left(3\cdot B - \left|f_{off} - \frac{f_{ACPRBW}}{2}\right|\right)^3 - \left(3\cdot B - \left|f_{off} + \frac{f_{ACPRB}}{2}\right.\right.\right.\right.$$

$$P_{IM3}\left(IP_3, P_{out}, B, f_{ACPRBW}, f_{off}\right) = -29.515\,\mathrm{dBn}$$

$$ACPR_{1250\_30}(IP_3, P_{out}, B, f_{ACPRBW}, f_{off}) := P_{out} - P_{IM3}(IP_3, P_{out}, B, f_{ACPRBW}, f_{off})$$

$$ACPR_{1250\_30}(IP_3, P_{out}, B, f_{ACPRBW}, f_{off}) = 57.$$

$$ACPR_{30\_30}(IP_3, P_{out}, B, f_{ACPRBW}, f_{off}) := P_{out} - 10 \cdot \log\left(\frac{BW}{f_{ACPRBW}}\right) - P_{IM3}(IP_3, P_{out}, B, f_{ACPRBW}, f_{off})$$

$$ACPR_{30\_30}(IP_3, P_{out}, B, f_{ACPRBW}, f_{off}) = 41.39$$

IP_3 Estimation

$$IP_{3find}(ACPR_{30\_30}, P_{out}, B, f_{ACPRBW}, f_{off}) := -5 \cdot \log\left[\frac{10^{\frac{ACPR_{30\_30} - 4 \cdot P_{out}}{10}} \cdot \frac{B^4}{f_{ACPRBW}}}{\left(3 \cdot B - \left|f_{off} - \frac{f_{ACPRBW}}{2}\right|\right)^3 - \left(3 \cdot B - \left|f_{off} + \frac{f_{ACPRBW}}{2}\right|\right)^3}\right] + 23$$

$$IP_{3find}(ACPR_{30\_30spec}, P_{out}, B, f_{ACPRBW}, f_{off}) = 48.678\,\text{dBm}$$

Example

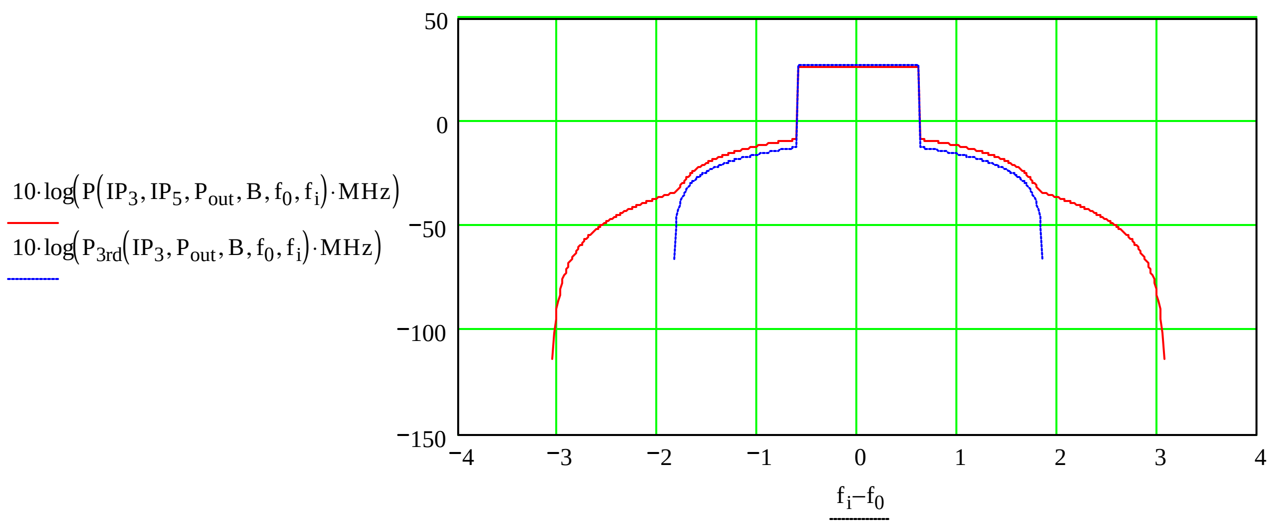
$num := 500$ — Number of Points for Plotting

$i := 1 .. num$ — Index Vector for Plotting

$N_{bw} := 5$ — Number of Bandwidths for Plotting

$$f_i := f_0 - N_{bw} \cdot B + \frac{i-1}{num-1} \cdot 2 \cdot N_{bw} \cdot B$$

$$10 \cdot \log(P(IP_3, IP_5, P_{out}, B, f_0, f_0) \cdot BW) = 27.783\,\text{dBm}$$



MHz

Measurement Procedure

Quick Method: Set Resolution measurement bandwidth to 30kHz. Put one marker at center of transmit band and another marker at 885kHz offset. The delta is the 30kHz-30kHz ACPR measurement. Add 10*log(1.25MHz/30kHz) for the 1.25MHz-30kHz ACPR measurement.

ACPR Specifications

IS-95 CDMA Base Station Specifications

$P_{out} := 10 \cdot \log\left(\frac{18W}{1mW}\right)$ $P_{out} = 42.553\,dBm$

$f_{0min} := 864MHz$ $f_{0max} := 894MHz$

$BW := 19.2kHz \cdot 64$ $BW = 1.229\,MHz$

$f_{ACPRBW} := 30kHz$

$ACPR_{30\_30spec} := 45dBC$

$f_{off} := 765kHz$ Worst Case=750kHz+30kHz/2

$f_{off} := 1975kHz$ Best Case=1980kHz-30kHz/2

$Peak\_ave := 10dB$

IS-95 CDMA Handset Specifications

$P_{outmin} := 27dBm$ $P_{outmax} := 30dBm$ Linear Power at Load

$f_{0min} := 824MHz$ $f_{0max} := 849MHz$

$BW := 19.2kHz \cdot 64$ $BW = 1.229\,MHz$

$f_{ACPRBW} := 30kHz$

$ACPR_{30\_30spec} := -42dBC$

$f_{off} := 885kHz$ Worst Case=900kHz-30kHz/2

$ACPR_{30\_30spec} := -54dBC$

$f_{off} := 1980kHz$ Best Case=1980kHz-30kHz/2

$Peak\_ave := 3dB$

$V_{ddmin} := 3.5V$ $V_{ddmax} := 4.8V$ Supply Voltage

$PAE_{min} := 35\%$ Minimum Power Added Efficiency at Maximum Power

$PAE_{min} := 20\%$ PAE with Power 15-20dB Below Maximum Power (Use to spec Iq)

$DR := 80dB$ Dynamic Range (Gain must also be linear over this range)

$VSWR_{max} := \frac{10}{1}$ Must be stable into a 10:1 VSWR for all phases

Noise := ■ Noise floor in receive band must be below

Cost := ■ Competitive Cost must be below

IS-54/IS-136 Handset Specifications

$P_{out} := 10 \cdot \log\left(\frac{■}{1mW}\right)$ $P_{out} = ■\,dBm$

$f_{0min} := 824MHz$ $f_{0max} := 849MHz$

$BW := 24kHz$

$f_{ACPRBW} := 24kHz$

$f_{off} := 30kHz$ Worst Case

$ACPR_{30\_30spec} := -30dBC$

$f_{off} := 60kHz$ Best Case

$ACPR_{30\_30spec} := -48dBC$

Peak_ave := ▮

PDC Handset Specifications

$P_{out} := 10 \cdot \log\left(\frac{▮}{1mW}\right)$ $P_{out} = ▮$ dBm

$f_{0min} := 940MHz$ $f_{0max} := 956MHz$

$BW := 21kHz$

$f_{ACPRBW} := 21kHz$

$f_{off} := 50kHz$ Worst Case

$ACPR_{30\_30spec} := -47dBC$

$f_{off} := 100kHz$ Best Case

$ACPR_{30\_30spec} := -62dBC$

Peak_ave := ▮

Comparison to Measured Results

See the paper below. This routine matches the routine in the paper identically, which matches measured results very well (within about 1dB).

References

"Linear and Rf Power Amplifier Design for CDMA Signals: A Spectrum Analysis Approach," by Qiang Wu, Heng Xiao and Fu Li, *Microwave Journal*, December 1998, pp. 22-40

"Power Amplifier Spectral Regrowth for Digital Cellular and PCS Applications," Kennedy et al., *Microwave Journal*, October 1995.

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