Power Amplifier Harmonic Calculator for MOS class-C PA

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This page calculates the harmonic content out of FET Power Amplifiers using a Fourier Analysis of the output waveform. Class C amplifiers are more nonlinear than class A and produce a greater number of harmonics. Thius sheet calculates the harmonic level & efficiency. The transfer function of a FET PA transitor is approximated to a square law above a certain theshold.

The equations used here are from class notes produced by **Jens Vidkaer** at Aalborg University, copy attached ->.

The value used for gm used here is when the FET is in the linear (Velocity Saturation) portion of the Id to Vgs curve.Vt

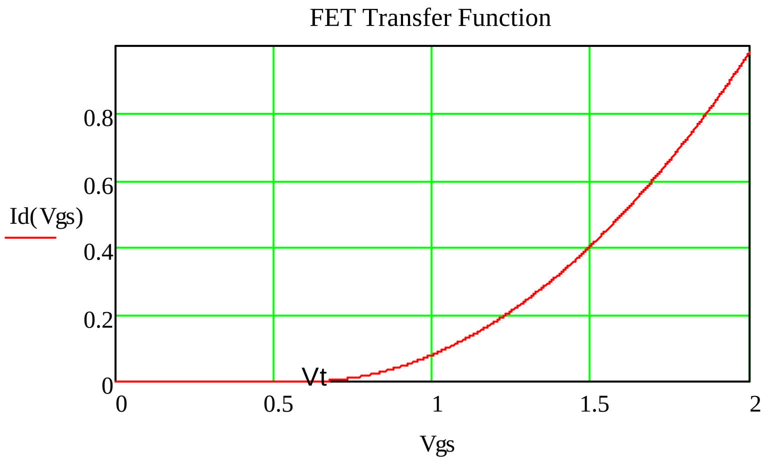
This is not a bad starting point but the equation for Id is a bit more complex.

The input signal is assumed sinusiodal.
Vpp is the input peak-peak voltage range,
Vb is the bias voltage.
? is the conduction angle.
I_p is the peak output current for this input.
gm and Vpp are only used in the first section, and then cancel out.

$Vt := 0.6V$ $\qquad gm := 500 \cdot \frac{mA}{V}$ $\qquad Vpp := 1 \cdot volt$

$$Id(Vgs) := \begin{cases} 0 & \text{if } Vgs < Vt \\ gm(Vgs - Vt)^2 & \text{otherwise} \end{cases}$$

$$?(Vb, Vpp) := 2 \cdot acos\left[\frac{Vt - Vb}{\left(\frac{Vpp}{2}\right)}\right]$$



$$y_p(?) := gm \cdot \left(\frac{Vpp}{2}\right)^2 \cdot \left(1 - \cos\left(\frac{? \cdot deg}{2}\right)\right)^2 \cdot volt^{-1}$$

$$y_0(?) := \frac{gm}{p} \cdot \left(\frac{Vpp}{2}\right)^2 \cdot \left(\frac{? \cdot deg}{2} - \frac{3}{4} \cdot \sin(? \cdot deg) + \frac{? \cdot deg}{4} \cdot \cos(? \cdot deg)\right) \cdot V^{-1}$$

$$y_1(?) := \frac{gm}{p} \cdot \left(\frac{Vpp}{2}\right)^2 \cdot \left(\frac{3}{2} \cdot \sin\left(\frac{? \cdot deg}{2}\right) + \frac{1}{6} \cdot \sin\left(\frac{3}{2} \cdot ? \cdot deg\right) - ? \cdot deg \cdot \cos\left(\frac{? \cdot deg}{2}\right)\right) \cdot V^{-1}$$

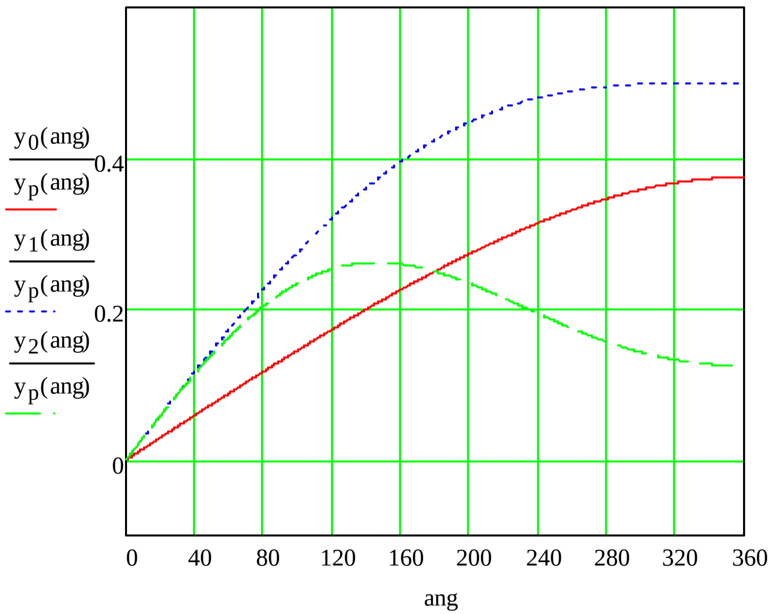
$$y_2(?) := \frac{gm}{p} \cdot \left(\frac{Vpp}{2}\right)^2 \cdot \left(\frac{? \cdot deg}{4} - \frac{1}{3} \cdot \sin(? \cdot deg) + \frac{1}{24} \cdot \sin(2? \cdot deg)\right) \cdot V^{-1}$$

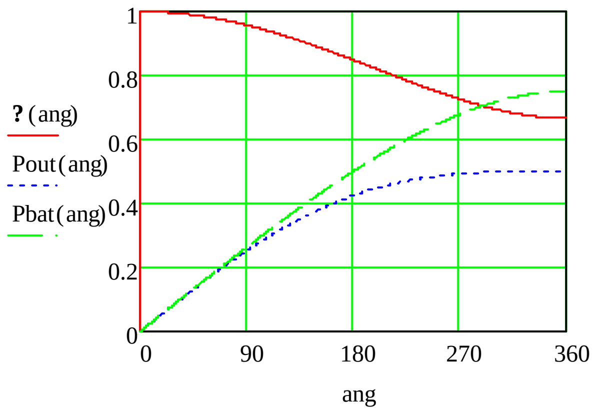
The first step is to reproduce the plots shows in the reference document --->.

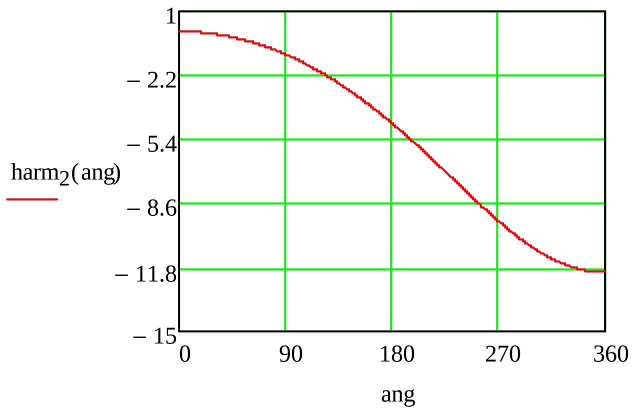
yp is peak consumption
y0 is the dc power
y1 is the wanted power, i.e. the first harmonic
y2 is the second harmonic.
I could not get the equations for y3 and above to agree with the reference document and are omitted.

The efficiency is the 'output power'/'battery power'
The ouput power is Pout
The battery power is Pbat

$$harm_2(?) := 20.\log\left(\left|\frac{y_2(?)}{y_1(?)}\right|\right) \qquad ?(?) := \frac{y_1(?)}{2\,y_0(?)} \qquad Pout(?) := \frac{y_1(?)}{y_p(?)} \qquad Pbat(?) := 2 \cdot \frac{y_0(?)}{y_p(?)}$$







Now we can calculate the level of second harmonic compared to the wanted signal for different conduction angles

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The next step is to carry out a similar analysis but this time to change the bias voltage Vb, and the peak to peak input voltage Vpp.

The threshold voltage VT for the FET is set above.

$$y_p(Vb, Vpp) := gm \cdot \left(\frac{Vpp}{2}\right)^2 \cdot \left(1 - \cos\left(\frac{?(Vb, Vpp)}{2}\right)\right)^2 \cdot volt^{-1}$$

$$y_0(Vb, Vpp) := \frac{gm}{\mathbf{p}} \left(\frac{Vpp}{2}\right)^2 \cdot \left(\frac{?(Vb, Vpp)}{2} - \frac{3}{4} \cdot \sin(?(Vb, Vpp)) + \frac{?(Vb, Vpp)}{4} \cdot \cos(?(Vb, Vpp))\right) \cdot V^{-1}$$

$$y_1(Vb, Vpp) := \frac{gm}{\mathbf{p}} \cdot \left(\frac{Vpp}{2}\right)^2 \cdot \left(\frac{3}{2} \cdot \sin\left(\frac{?(Vb, Vpp)}{2}\right) + \frac{1}{6} \cdot \sin\left(\frac{3}{2} \cdot ?(Vb, Vpp)\right) - ?(Vb, Vpp) \cdot \cos\left(\frac{?(Vb, Vpp)}{2}\right)\right) \cdot V^{-1}$$

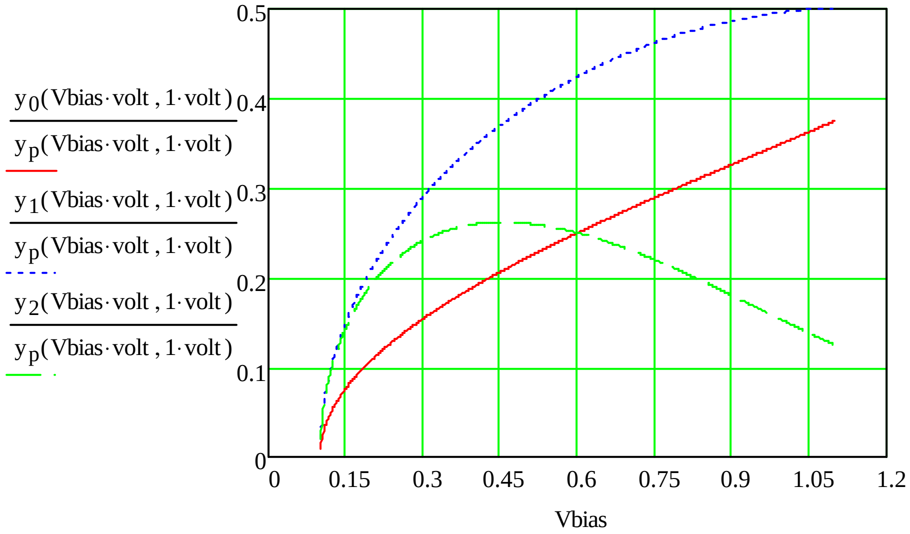
$$y_2(Vb, Vpp) := \frac{gm}{\mathbf{p}} \cdot \left(\frac{Vpp}{2}\right)^2 \cdot \left(\frac{?(Vb, Vpp)}{4} - \frac{1}{3} \cdot \sin(?(Vb, Vpp)) + \frac{1}{24} \cdot \sin(2\,?(Vb, Vpp))\right) \cdot V^{-1}$$

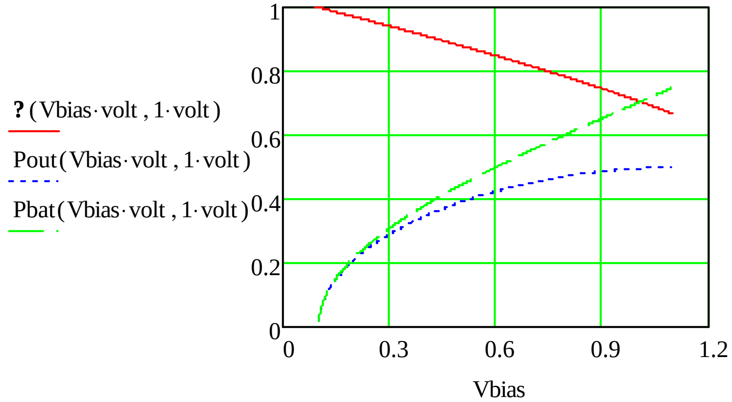
$$?(Vb, Vpp) := \frac{y_1(Vb, Vpp)}{2\,y_0(Vb, Vpp)}$$

$$Pbat(Vb, Vpp) := 2 \cdot \frac{y_0(Vb, Vpp)}{y_p(Vb, Vpp)}$$

$$Pout(Vb, Vpp) := \frac{y_1(Vb, Vpp)}{y_p(Vb, Vpp)}$$

$$harm_2(Vb, Vpp) := 20.\log\left(\left|\frac{y_2(Vb, Vpp)}{y_1(Vb, Vpp)}\right|\right)$$





Now we can calculate the level of second harmonic compared to the wanted signal as either the bias or peak to peak voltage changes.

Not as far down as I would like, and that is the point of this excercise. The square law of the FET gives a very large second harmonic compared to a bipolar. The other harmonics are well down and better than a bipolar would give.

A lesson to learn!!!