Digital Pre-distortion in GNU Radio

gr-dpd

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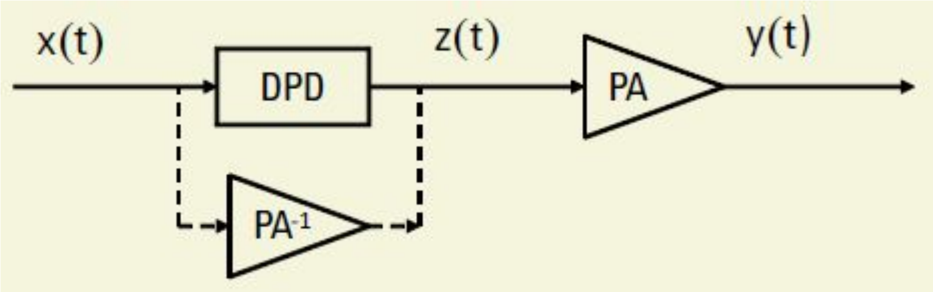
What is Digital Pre-distortion (DPD) ?

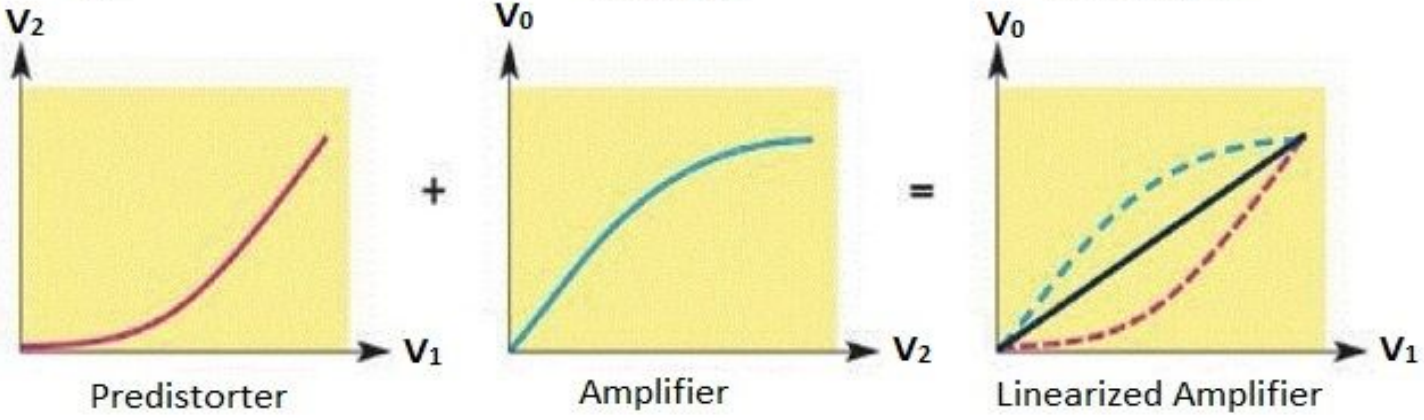
- **Digital Pre-Distortion (DPD)** is a technique to increase linearity or compensate for non-linearity in power amplifiers.
- Applies **inverse distortion**, using a pre-distorter, at the input signal of the PA to cancel the distortion generated by the power amplifier.



https://rfmw.em.keysight.com/

General Flow

- Input V_1 is pre-distorted into V_2
- PA non-linearities distort V_2 into V_0
- PA output V_0 is an amplifier version of V_1



Need for Digital Pre-distortion

- **Power amplifiers** are essential components of communication systems, but they are **inherently nonlinear,** which can cause interference, degrade bit error rate (BER) and data throughput.

- Ideally, all amplifiers should be perfectly linear but not possible due to nature of amplifier devices such as **transistors** or **vacuum tubes**.

- **DPD** is a **cost-effective** linearization technique.

- Can show improvements of up to **40%** in PA efficiency.

Power Amplifier (PA) Models in gr-dpd

Volterra-based models

Memory Polynomial (MP) Model

- MP model based Power Amplifier produces an output based on the *Memory Polynomial* formed with current block parameters.

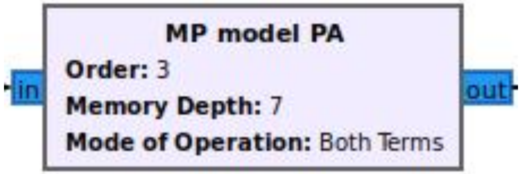
- An extension of the polynomial model to include memory or as a reduction of the Volterra series in which only products with the same time-shifts are included.

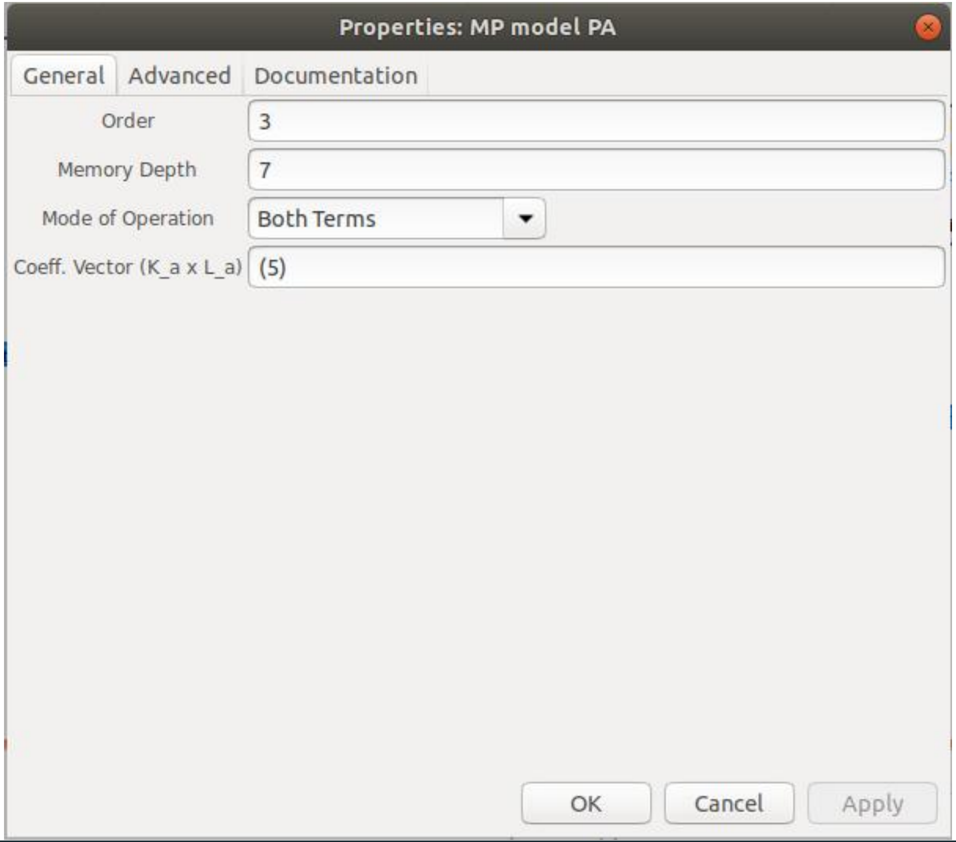
- Here is the function to describe relation between Input and Output of MP based model:

$$y_{MP}(n) = \sum_{k=1}^{K} \sum_{m=0}^{M} a_{km} x(n-m) |x(n-m)|^{k-1}$$

Where x is the input, y is the output, K is the maximum power order, M is the maximum memory depth, and a_{kq} is the kernels (coefficients) of the system.

MP Model PA Block





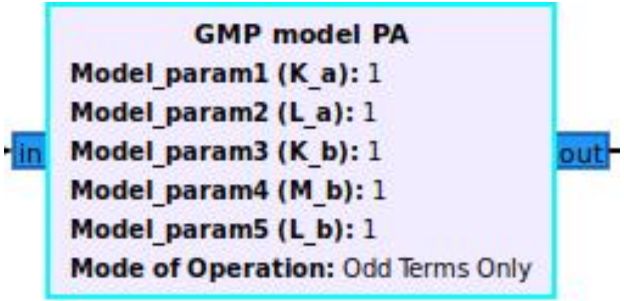
Generalised Memory Polynomial (GMP) Model

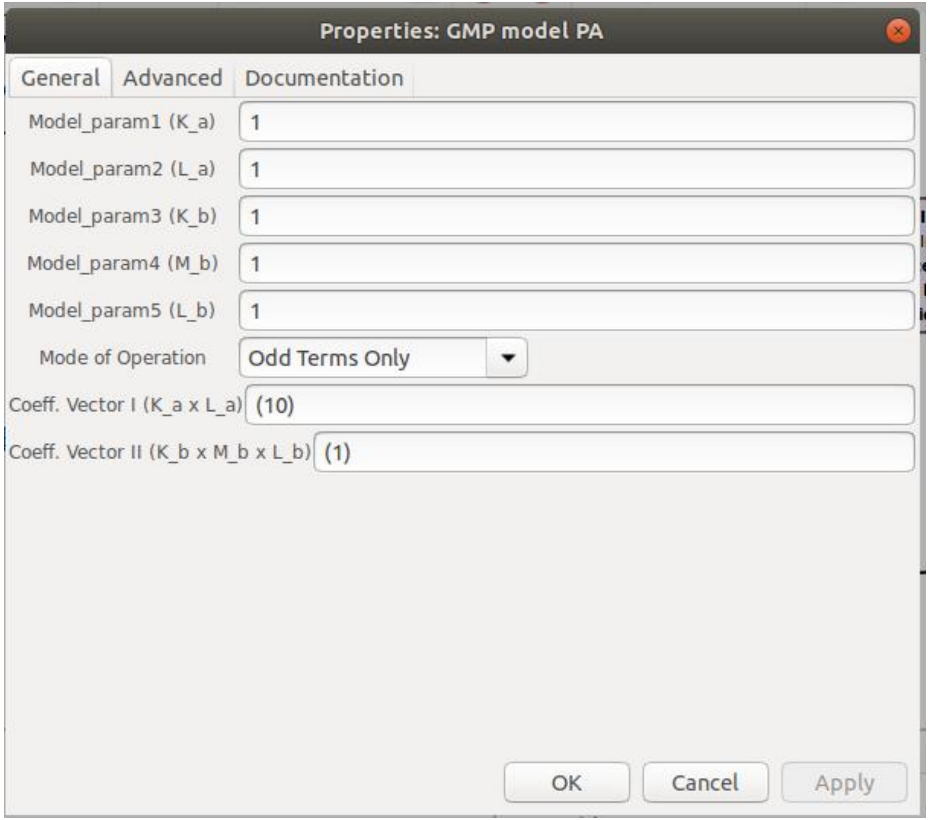
- GMP model based Power Amplifier produces an output based on the Generalised Memory Polynomial formed with current block parameters.
- Extends the MP model by also introducing products with different time-shifts, generally referred to as cross terms.
- Here is the function to describe relation between Input and Output of GMP based model:

$$z[n] = \sum_{k=0}^{K_a-1} \sum_{l=0}^{L_a-1} a_{kl} y[n-l] |y[n-l]|^k + \sum_{k=1}^{K_b} \sum_{m=1}^{M_b} \sum_{l=0}^{L_b-1} b_{kml} y[n-l] |y[n-l-m]|^k.$$

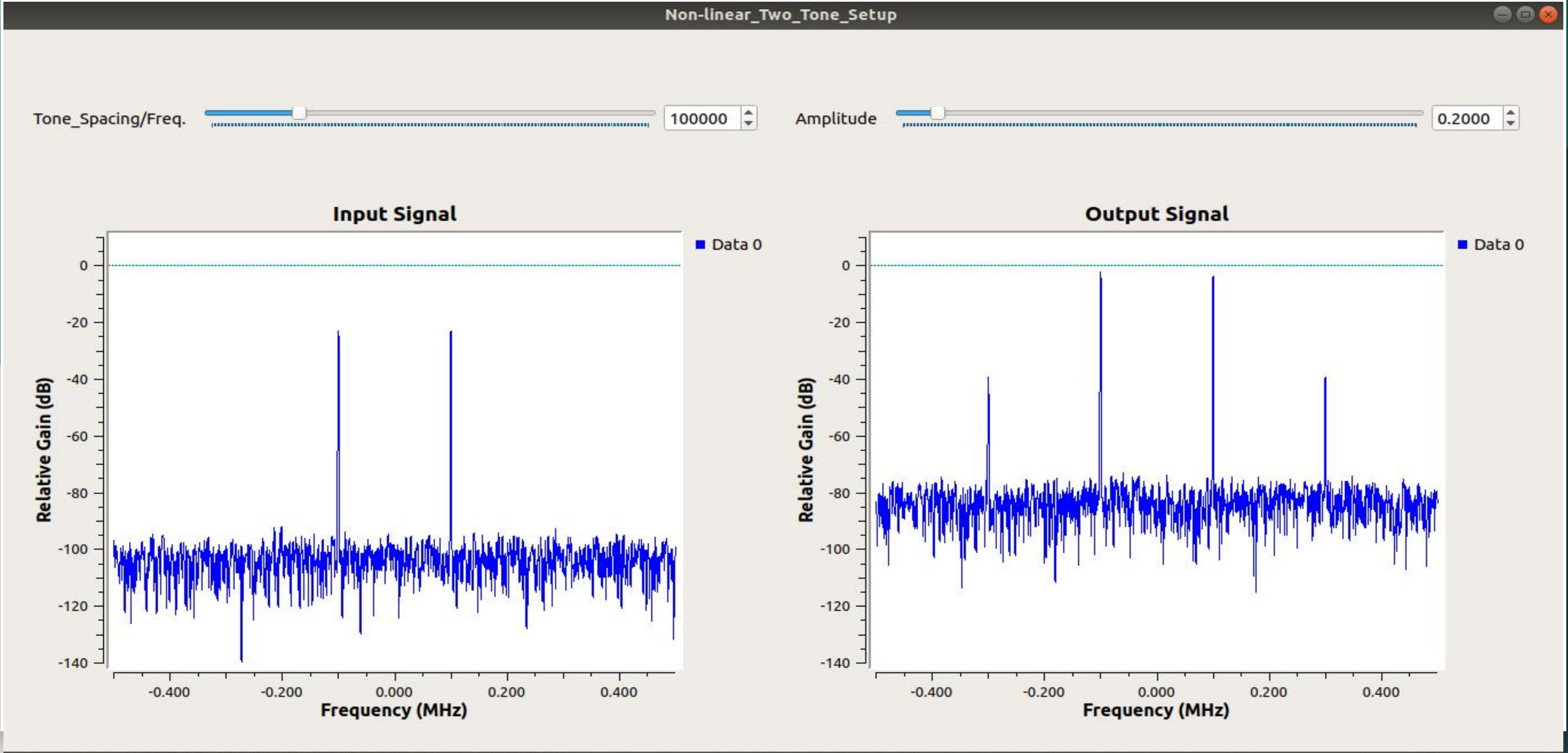
The representation on the right consists of two components, namely, the signal-and-aligned-envelope component and the signal-and-lagging-envelope component. Based on (1), the number of coefficients to be estimated are $M := K_a L_a + K_b M_b L_b$ across $\bar{M} := K_a + K_b M_b$ channels.

GMP Model PA Block





Example Output of a PA model in GRC



DPD Algorithms in gr-dpd

Recursive Least Squares (RLS) Algorithm

- *RLS postdistorter* block uses the fast RLS (Recursive Least Squares) Algorithm based on **Hyperbolics** and **Givens Rotations**.

- Major mathematical utilities to be used in the RLS Algorithm are:
  - A shift-structured **GMP vector** to store the input signal values as a **regression vector.**
  - Use of **Givens** and **Hyperbolic Givens** rotation to obtain the time updates for various parameters such as **gain vector**, **conversion factor** and **a priori output error**. [S. Pagadarai, R. Grover, S. J. Macmullan and A. M. Wyglinski]

$$w_i = w_{i-1} + \left[g_i \gamma^{-1/2}(i)\right] \left[\gamma^{-1/2}(i)\right]^{-1} \left[z[i] - y_i w_{i-1}\right]$$

Weight vector or taps are updated as shown above.

Least Mean Squares (LMS) Algorithm

- *LMS Postdistorter* block uses the LMS (Least Mean Squares) Algorithm with two methods options, namely, **Newton based** and **EMA based** methods.

- Brief of the two methods used for updation of weight vector:

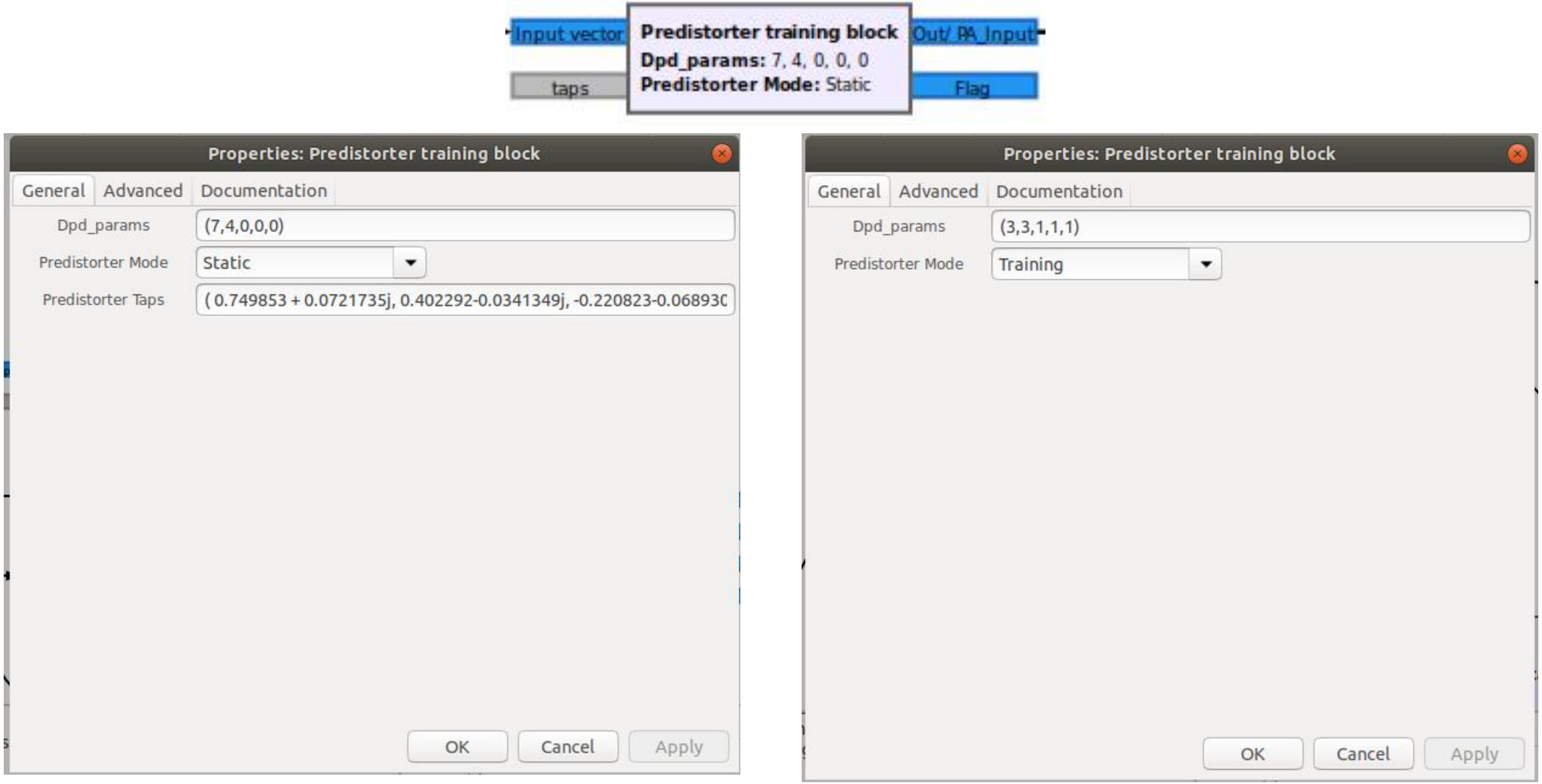
  - **<u>Newton Based</u>:** It involves calculation of error value for least squares based estimation.
    - This is weight-vector updation formula:

      w_iMinus1 = w_iMinus1 + (ls_result * learning_rate)

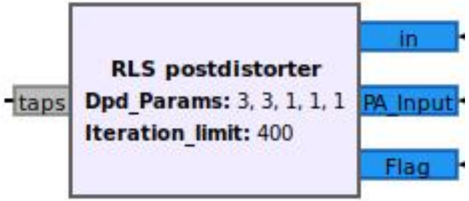
  - **<u>EMA</u>:** This directly uses the corresponding PA input and output for least squares estimation.
    - This is weight-vector updation formula:

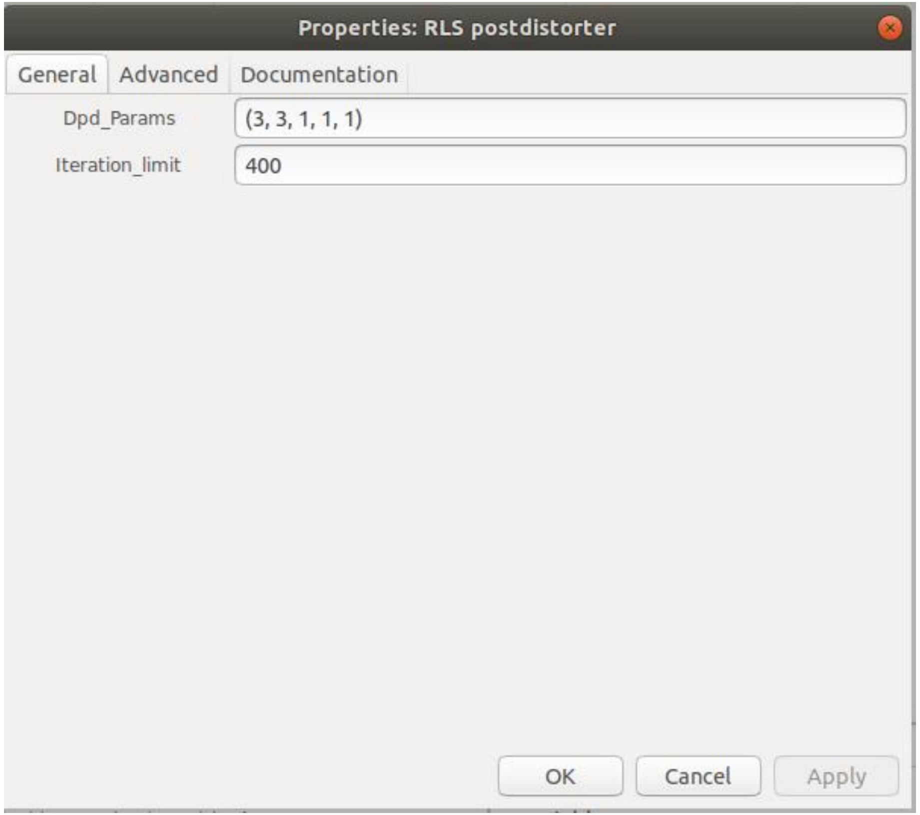
  w_iMinus1 = (w_iMinus1 * (1 – learning_rate)) + (ls_result * learning_rate)

Predistorter training block

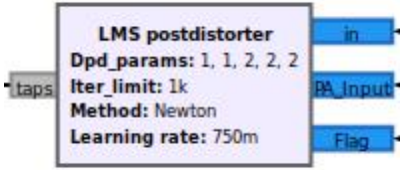


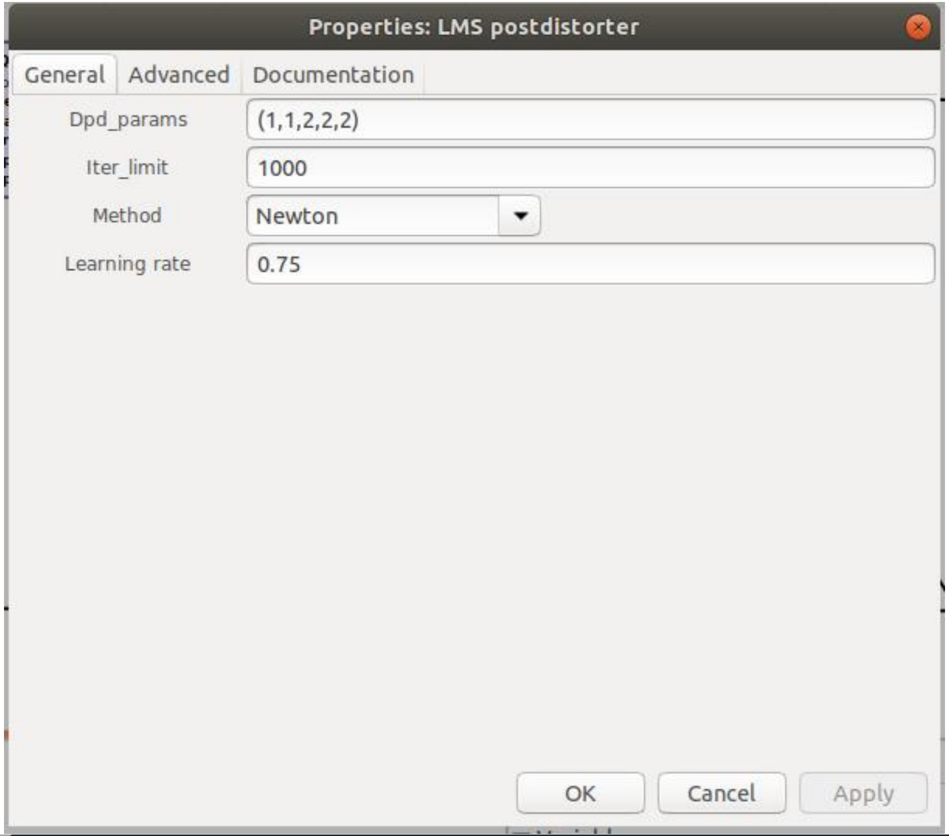
RLS Postdistorter Block



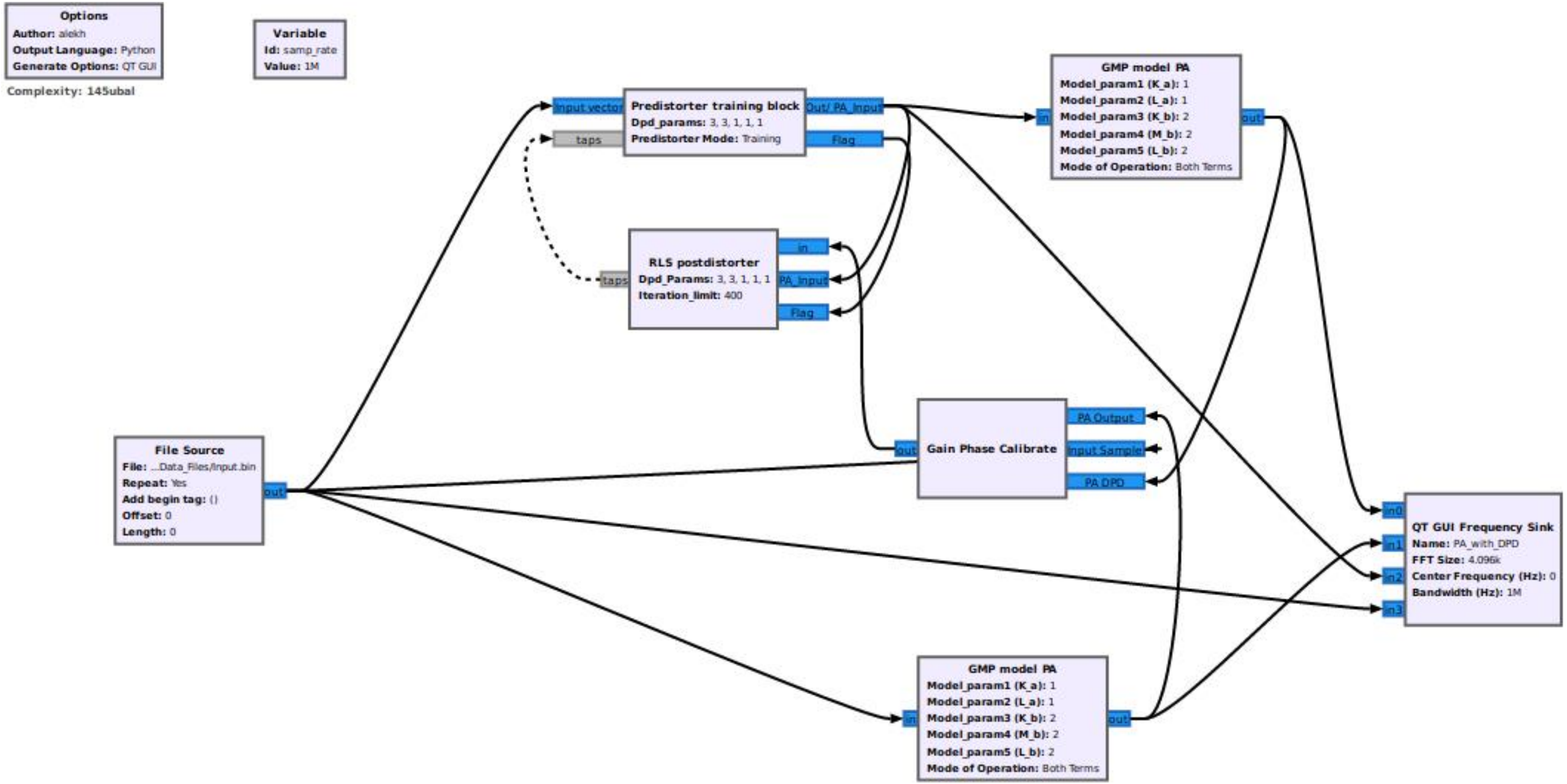


LMS Postdistorter Block

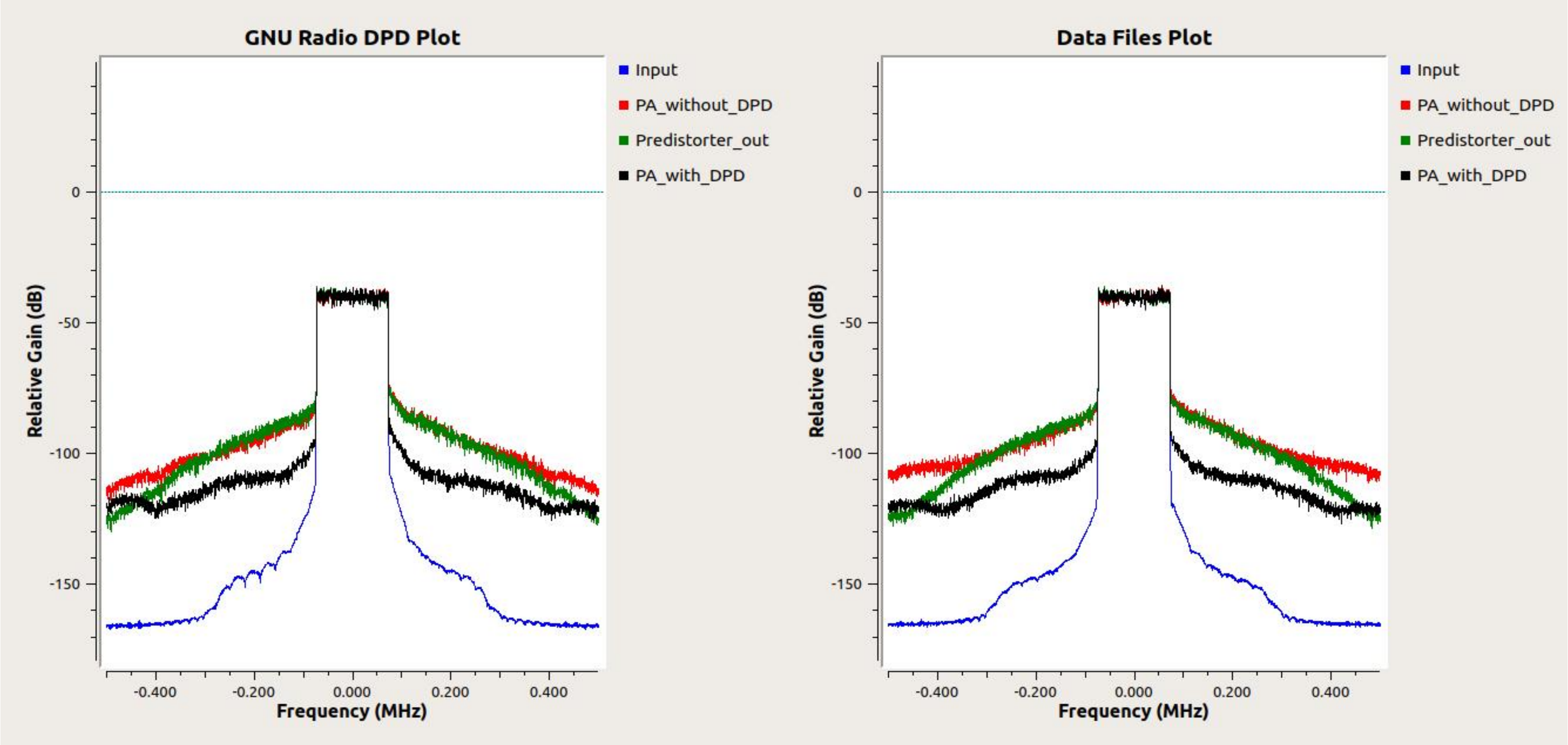




Example Flowgraph with RLS Postdistorter



DPD Output (Static Predistorter) performance comparison



Live Demo!!