Switch Mode Power Amplifier with SDR Capabilities

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Outline

A. Background: issues with switching mode PA in modern communication technology
B. Switching mode PA with SDR capabilities
C. Linearization theory and algorithm
D. Future work.
A. Switching mode PAs in modern communication technology

1. Key requirements to PA from modern communication technology
   1. Complex and high order modulation method.

      Needs a highly linear PA with a high dynamic range. For most PAs, linearity and dynamic range are conflict parameters – not least to efficiency.

   2. High power efficiency
      a. Power efficiency is the most serious issue with a linear PA. Good linearity and good dynamic range need good and sufficient high bias, which means high DC power consumption.
      b. In order to obtain both linearity and a high dynamic range, almost always the power efficiency is jeopardized.

   3. Multi-mode capability in one equipment.

      Obviously a multi-mode PA is required. The performance of the multi-mode PA should cover all co-existing systems’ requirement (if the requirements are not in conflict to each other).
A. Switching mode PAs in modern communication technology

2. An example of switching mode PA - Class F PA, a completely nonlinear amplifier

Operated in nonlinear (switching) mode, that means an ideal Class F PA is highly nonlinear. Class A and Class AB are closer to linear.

For an ideal Class F PA:
- the phase can be transferred from the input to the output with low distortion (or can at least usually be predistorted to achieve good performance),
- but amplitudes between the input and the output are severely distorted.
A. Switching mode PAs in modern communication technology

3. Key requirements to PAs from modern communication technology:

   For switching mode PA,

   1. For Complex and high order modulation application.
      Obviously a switching mode PA can’t directly be used in a system requiring high linearity and high dynamic range.
   2. High power efficiency
   3. Multi-mode system capability in one equipment.

   For switching mode PAs, normally there is no LC tank involved in the amplifying section (of course filters are needed for frequency/harmonics selection), so it is possible and easier to achieve a re-defined technology.

   So, using a switching mode PA in modern communication system is **challenging**:

   Linearization Tech.  
   Re-defining Tech.
A switching mode PA with SDR capabilities means:

1. Aided by SDR concept and technology, the AM-AM and AM-PM characteristics can be linearized.

2. Ultimately, performance can be defined in software including bandwidth, gain, operation frequency, … This is a long term goal however.

The first steps …

1. Linearization of AM-AM and AM-PM distortion.

2. Handling varying load conditions, ageing, temperature drift etc. which implies that linearization must be adaptive.
B. Switching mode PA with SDR capabilities

1. Linearization techniques, predistortion

**Predistortion, concept**

Concept illustration

Analog predistortion techniques

A cubic nonlinearity correction

Polynomial function synthesis in an analog predistortion implementation
B. Switching mode PA with SDR capabilities

2. Linearization: advantages of the SDR tech./Issues with the analog predistortion

Obviously, compared to a digital (SDR) implementation:

• an analog implementation is complex when a high order predistortion is needed (which it does for switching mode PAs).

• large amount of analog devices (such as VGAs, analog adders and multipliers) involved in the predistortion will impact the accuracy of the predistortion function seriously, which leads to a circuit design challenge or a performance degradation.
3. Redefining technology

- Software+ switch strategy/method.
- Capacitor bank, resistor bank and inductor bank as well as transistor bank.
- Software defined switching (ON/OFF)

Issues:
- The transient process between modes shifting
- The parasitic parameters introduced by switches.
B. Switching mode PA with SDR capabilities

4. Linearization/re-definition: A possible approach used in this project.

A multi-mode switching PA diagram for Bluetooth/WLAN (2.45GHz, 5GHz) with SDR predistortion

- Amp, Phase
- Limitor + Preamplifier
- Phase shifter
- Linearization/rewdefinition: A possible approach used in this project.
- SDR, Predistortion Algorithm
- Attenuator
- BT/WLAN chosen for testing purposes
B. Switching mode PA with SDR capabilities


Comments:

1. A flexible configuration for both digital implementation and analog implementation
2. The algorithm is independent from the signal path, so any change of the algorithm is free and fairly easy.
3. Be able to achieve a high dynamic range by SDR control.
4. Possibly use dynamic predistortion

Problems/challenges:

1. Because a loop structure is involved in, predistortion calculation speed is a critical requirement – propose to use a two step procedure; 1) a fast algorithm for speed, and 2) a "slower" one for infrequent updates (load variations, temperature etc.).
2. For high dynamic applications, a high dynamic range and low noise are required to the phase and envelop detectors.

A multi-mode switching PA diagram for Bluetooth/WLAN (2.45GHz, 5GHz) with SDR predistortion.

SDR for redefinition and predistortion.

To outphasing Class F PA

A test setup to generate needed signals for the outphasing PA solution.

A multi-mode switching PA diagram for Bluetooth/WLAN (2.45GHz, 5GHz) with SDR predistortion ---- SDR redefinable PA. (The blocks show the functions added to a generic outphasing Class F PA)

Transistor group can be switch on/off for a better power output
C. Predistortion theory, algorithm and implementation

Example: A typical switching mode PA: outphasing Class F PA

Principle of outphasing Class F PA

A typical AM-AM and AM-PM curves of an outphasing class F PA (transistor level simulation in 0.18µm CMOS process)
Comments on the outphasing Class F PA

Advantages:

1. Output power can be adjusted by changing the phase difference ($\tau$) between the two paths.

2. Having a better dynamic range than in-phase class F PA.

3. Easy to use in variable envelope systems or systems with power control

Features

1. Different from linear PA; switching PA are nonlinear on the whole AM interval.

2. AM-AM shows strong nonlinearity, while AM-PM is almost constant in a major part of the interval.

3. Generally, the AM-AM curve is a convex, monotonic rising function.
C. Predistortion theory, algorithm and implementation

1. Some important items must be considered in the predistortion algorithm study.

   a. The point of the max. power output \((X_m, Y_m)\) must be on the linearized curve so that the max. power of the linearized performance can be achieved physically while keeping the best amplifying performance.

   b. As mentioned previously, calculation speed is a critical requirement. So the algorithm must use as few multiplications as possible.

   c. Obviously the point number of the sample will impact the accuracy of the predistortion seriously, so the algorithm must present an accuracy estimation for the system optimization.

   d. As an added feature, the algorithm can be applied to both analog predistortion devices and digital predistortion devices.
2. Predistortion theory

a. Optimized linearization target

\[ Y = kx + C \]

\[ k = \frac{\sum (f(x_i) - Y_m)}{\sum (x_i - x_m)} \]

\[ C = Y_m - kx_m \]

b. The predistortion parameter is:

\[ \Delta x = \frac{-D_i}{f'_D(x_i)} \]

And standard deviation of the linearization Errors can be:

\[ ER_{A_{WS}} = \frac{1}{n-2} \sqrt{\sum_{i=1}^{n} \left( D_i \left( \frac{f'(x_i)}{f'(x_j)} - 1 \right) \right)^2} \]

\[ ER_{B_{WS}} = \frac{1}{n-2} \sqrt{\sum_{i=1}^{n} \left( \frac{R_x}{3n} \frac{1}{f'_D(x_i)} \right)^2} \]

Where \( R_x \) stands for the width of the whole interval of \( x \).

*WS stands for the worst case.
3. Predistortion algorithm discussion:

Discussion:

1. At the best condition the presented algorithm just needs 1 multiplication and 1 subtraction and call the memory 1 time.

2. ER_A shows that the predistortion error strongly depends on the characteristics of the nonlinear curve while ER_B implies that more sample points improve the accuracy.

3. Two strategies for practical $\Delta x$ defining:
   - using basic sample data set to define the practical $\Delta x$, this is easier for a full digital predistortion device. This strategy is called 'Direct'.
   - using interpolated data set (from the basic sample data set) to define the practical $\Delta x$, this is easier for an analog predistortion device. This strategy is called 'Interpo'.

4. Analyses shows that with sufficient sample points, the Direct and Interpo are equal to each other on predistortion accuracy.
C. Predistortion theory, algorithm and implementation

4. Simulations for various point numbers and strategies (the sample PA is as mentioned previously)

A. 'Direct' strategy Linearization result, point numbers of the sample data set: 7, 24, 61

- Linearization result with 7 points sample--Direct
- Linearization result with 24 points sample--Direct
- Linearization result with 61 points sample--Direct
C. Predistortion theory, algorithm and implementation

6. Simulations for various point numbers and strategies (the sample PA is as mentioned previously)

B. ‘Interpo’ strategy Linearization result, point number of the sample data set: 7, 24, 61

Linearized result with 7 points sample

Linearization result with 24 points sample

Linearization result with 61 points sample
C. Predistortion theory, algorithm and implementation

6. Simulations for various point numbers and strategies (the sample PA is as mentioned previously)

C. 'Interpo' strategy' linearization result,

Predistortion function for 24 points sample, and nonlinear curve

Spectrum of the nonlinear curve and the linearized curve. The blue is the original curve, the red is the distorted curve. And yellow is the linearized curve with 61 points sample set predistortion.
D. Future work

1. Optimizing the SDR predistortion theory and algorithm
2. Optimizing the outphasing modulator
3. The PA design in SOI process and tapeout.
4. The whole system tuning