Welcome to this presentation which helps to highlight the capability of Genesys in the design of power amplifiers for LTE applications.
Agenda

- Review Of Technical Requirements
- Types Of Power Amplifiers
  - Class A To Class E
- Modeling Methods Past And Present
- Slide Screw Tuner
- Optimized Amplifier
- Amplifier Measurements
- Amplifier With Driver
- Summary
Requirements

A Power Amplifier (PA) Provides The Final Stage Of Amplification Prior To The Antenna

- Must function on battery power for mobiles
  - Low power consumption=efficiency
- Linear operation
  - Spectral regrowth affected by linearity
- Potential of working into high VSWR load
  - Missing or defective antenna
- Compensate for heating effects
  - Must be dissipated within circuitry or housing
Requirements Continued

- Size
  - For mobile applications size is critical
  - Base station requirement can be size critical too
- Continuous Operation
  - Both mobile and base station PAs are required to constantly exchange information, even in standby
- Low Cost
  - As with most industries, component cost affect competitive pressures
Class A Amplifier Review

Class A

- Generally provides the highest linearity
- Continuous duty, conduction angle = 360°
- Matching is often achieved at both ports
- Efficiency is lowest < 50%
- Half of supply power is dissipated by device
- Best suited for low level PA driver stages
Class B Amplifier Review

Class B And AB Amplifiers

- Linearity is compromised due to duty cycle in Class B
- In AB operation, transformer or combiner aides in harmonic suppression
- Conduction angle of 180° optimum, typically greater
- Matching may be achieved at input port and output (Class AB)
- Efficiency is higher at 60-70%
- Component count for Class AB is doubled

Linearity is compromised due to the obvious output waveform. This is compensated by filtering networks or combining networks such as in AB operation. When used with transformers or with 180 degree combiners, the even harmonics are suppressed due to the balancing action of the combiners. To compensate for cross-over distortion in Class AB the device is bias at a point above cutoff thereby raising the effective conduction angle above 180 degrees. While efficiency is much better than Class A the component count doubles.
Class C Amplifier Review

Class C

- Higher efficiency
- Lower gain
- High harmonic content requiring significant output filtering
  - Harmonics are function of conduction angle
- Large signal condition makes matching challenging
- Conduction angle < 180°

Efficiency vs. conduction angle

\[
\eta_{\text{max}} \quad \theta
\]

See [1]
Class D Amplifier Review

Class D

- Totem pole design
- Very high efficiency approaching 100%.
- Devices must have very low on resistance
  - Devices behave as ideal switches
- Increased circuit complexity

Key to this class is the resonator at the amplifier output. The amplifier acts as an ideal switch. At first the total supply is applied to the load. At theta equal to 180 deg the amplifier switches placing the common terminal at ground. As the devices approach an ideal switch the efficiency approaches 100% because none of the power is dissipated by the devices. Very high powers can be generated using this technique.
Class E Amplifier Review

Class E

- Similar to Class D but single ended
- Low power consumption, efficiency approaching 97%
- Higher reliability due to decreased heating
- Voltage/Current management ensures non-simultaneous interval of large current and voltages
- Device must have low $V_{on}$ and higher breakdown voltage
- Additional harmonic suppression networks needed
Amplifier Configurations

Configurations That Help Improve Power Performance And Spectral Integrity

Doherty

Feed Forward

Main Cancellation Loop

Error Cancellation Loop
Mobile power requirements are generally below 1 watt whereas base station power is anywhere from 1 watt for Pico cells to 200 watts for cell sites.
Having reviewed the operational characteristics of amplifying devices we turn our attention to the methods of characterization. Starting with the intuitive model which is a result of experience and material knowledge, usually crude by today's standards. Linear s-parameter measurements are highly accurate by are limited to the linear operating range of the device. Large signal s-parameters and x-parameters offer the best method of characterizing a device. X-parameter which are derived from a large signal measurement system provide the best modeling technique for very large non-linear behavior by creating a PHD (poly harmonic distortion) model usable within ADS. The load pull method can be use to find the optimum source and load given a specific operating point. This method can also be used to generate a PHD model.
Some manufacturers offer only reference design for using their product. This limits the application possibilities. Proprietary manufacturing processes are kept from competitors who would gain knowledge from a Spice, Verilog or similar model.
Some device structures are available in several materials, each provides unique frequency and power handling capability. For base station power amplifiers which require higher output powers, LDMOS is a preferred device, while HBT devices are suitable for handheld applications. Materials shown are Silicon-Germanium, Gallium-Arsenide, Indium-Gallium-Arsenide, Indium-Gallium-Phosphide, Silicon Carbide, Gallium-Nitride.
Power Amplifier Design Process

We Will First Using Linear Methods To Evaluate The Gain And Match Of A Power Amplifier

Secondly We Will Illustrate The Method Of Load Pull In Developing A Mobile LTE PA

- The accuracy is tied directly to our model which may have been developed through actual measurements
- We will be able to optimize our design for varying bias and drive conditions to achieve both efficiency and required output power
- We will use GENESYS synthesis tools to aide in the development of matching and signal monitoring
Specifying The Amplifier

Power
• Goal of +23 dBm output power

Efficiency
• Goal of 50% or better

Gain
• Depends on source power PPL, Oscillator etc.

Linearity
• Minimum spreading of modulated spectrum
Using linear simulation and built in measurements in Genesys we plot the stability circles, as well as simultaneous match and stability circles. Note that stability circles either totally inclosing or outside the unit circle indicate unconditional stability, that is $K \geq 1$. 

**Linear Evaluation**

Evaluate Device’s Linear Parameters

- Use GENSYSYS built in measurements and plots
  - Evaluate S-parameters, conjugate match, stability
  - Evaluate performance vs. bias

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Genesys provides us with conjugate match points for input and output networks
The slide screw tuner is simply a 50 ohm slab line with a tunable slug that adds parallel susceptance to the line. As the slug approaches the line parallel capacitance is increased. This capacitance determines the reflection coefficient. The rotation or angle of the reflection is determined by the length of the line between the slug and the input port or connector.
Building a user model is simple. First define your component with Genesys’ built-in models. Here we use a combination of transmission line and shunt capacitor. How the model will be performed as a function of the input parameters. Next define the parameters to pass to the model.
We can assign a built in symbol from Genesys or draw or import our own. For the slide screw tuner an image was imported and saved in a user define symbol library called “my symbols. After assigning the symbol to our part we save it into a parts library. In this case it is a user defined library call ” My Parts”.
Our model starts as an implementation of the slab line tuner, that is with a parallel capacitance and 50 ohm line. The model input parameters consist of frequency, reflection coefficient and angle. These values are past to our model where they are parsed and equated to the model values of line length and capacitance. We can therefore project a point anywhere on or outside the Smith chart which can then be used to tune any modeled device.
Providing a user defined reflection coefficient to any network is now possible. In this example the reflection coefficients defined by the device's conjugate match are dialed into the tuners.
Since we met conditions for conjugate match we see excellent match at 1880 MHz and a peak in gain.
We now evaluate the power output and gain compression based upon a class A linear design. Saturated power is at 21.5dBm which is below our required +23dBm
As we increase the drive level large signal conditions prevail causing our input reflection coefficient to increase. This is a basic problem in design high power amplifiers.
Genesys allows us to generate new formulas and measurements. Here we have defined a new variable called power added efficiency. Note that maximum efficiency occurs at max power out.
Summary Of Performance

Linear Design Methology Does Not Meet Performance Goals
Linearity And Superposition No Longer Exits
Device Parameters Change As A Function Of Drive Level
Need An Alternative Method To Maximize Gain And Match
Load Pull Method

Uses A Known Set Of Impedances Or $\Gamma$'s To Determine The Effect On Output Power

- Method has been used since 1950's for characterizing the large signal behavior of microwave devices
- Helps to determine the best source and load conditions for large signal non-linear operation
- In commercial load pull systems, data can be used to build a set of x-parameters for incorporation into Poly Harmonic Distortion (PHD) device model in ADS
Commercial Load Pull Systems

Commercial Systems Offer Computer Controlled Device Characterization

Representative example systems from Focus and Maury microwave. Characterization and modeling can be achieved over varying bias and source/load conditions.
Traditional load pull places a tuner at the output. Source impedance is usually 50 ohm. As drive level and bias are tuned, power output contours are plotted.
To generate the power circles or locus of constant power output curves we sweep both the magnitude and angle of the reflection coefficient presented to the device.
The values used by the nested sweep are past to the slide screw tuner user model and the resulting plot of reflection coefficient values are plotted here.
Once swept data is collected the “contour” function within Genesys is used to plot the power circles. Note that in addition to power we can plot efficiency or any other measure parameter using this function.
The reason for the decrease in port measured power is due to the fact that the input indicates a lower impedance. Remember the input is not matched.
Using Tuners At Input & Output

As In The Linear Design We Add A Tuner To The Input Port

Because of the interaction between input and output of our device, attempting to successfully manually tune for maximum power and input match under large signal conditions would be a result of luck more than design.
Setting the angle and magnitude reflection coefficients at both ports as tunable and then optimizing helps to realize our goal of +23dBm. The additional power will be needed to overcome the losses in our output networks. PAE is now 47%. This could be improved by moving toward class B operation with a reduction in gain.
Gain is \(~12.6\)dB with an input return loss of \(-32dB\)
Now that we have fine tuned our network we want to substitute the tuners for actual elements. Noting the impedances corresponding to the reflection coefficients we use the MATCH synthesis tool to realize the matching network for our circuit.
After starting Match we set the frequency over which we wish to match.
We are able to specify the load or source in a variety of ways including data files
For the source match we use the conjugate of the tuners impedance to represent the actual input of the device under the drive conditions.
We have control over the default Q’s and transmission line parameters used in the synthesis tool.
As far as the matching network, numerous topologies including distributed and lumped networks are available.
We choose lumped element matching structures to reduce board layout space if we used distributed elements.
A small tuning is necessary to achieve +24dBm power.
Swept measurements help to confirm that the amplifier will work over the LTE transmit band.
It is often required to monitor both transmitted power as well as return power to meet emission requirements as well as protect the transmitter from large VSWRs. Power output requirements change as a function of distance to the cell and other factors.
To achieve a -20dB coupler at band center does not require us to design the coupler for 1880 MHz. Using a design center of 9500 MHz for a 10 dB coupler insures a -20 dB coupler at 1880 MHz with a much smaller footprint on layout.
Using advance t-line to create a microstrip coupler. Note that the length of the coupler is only 167 mils long.
Forward power coupled into port 2 is approximately -20 dB. The reason for non-zero values at the port that monitors reverse power is due to the fact that the coupler’s directivity is not infinite. This indicates the degree of isolation.
Using a modulated PRBS source we note the spectral output of our amplifier. Harmonics are present at the output but a closer view of the transmitted spectra shows that there is insignificant adjacent channel splatter.
Given the input power requirements to achieve a +23 dBm will require a driver amplifier
We mimic the procedure used to design the PA in developing the driver, including the Match synthesis. An additional step could be taken to conjugate match the interstage with Match to reduce the parts count.
Cascaded two amplifiers comes with additional issues. Non-linearity is increase along with distortion components. Inter-pulse ringing and increased spectral components. Fortunately these added components can be easily filtered. Note the important adjacent channel spectra is not notably increased.
Summary

• We Have Reviewed Amplifier Technologies
• Discussed Modeling Methods
• Developed And Used A Slide Screw Tuner For Load Pull Measurements
• Designed A Power Amplifier Using MATCH And SIGNAL CONTROL
• Verified Design With HARPEC And CAYENNE Simulation Engines
Thank You

Additional Information-
Just Google search “Agilent Genesys”

1. Register for the 5th “How-To-Design” seminar on RF Switch design
2. Get a free trial of Genesys
3. Discover new more powerful, more affordable Genesys bundles
References

- RF Power Amplifiers, Mihai Albulet, 2001, Noble Publishing
- Microwave Circuit Design, Vendelin, Pavio, Rohde, 1990, Wiley Interscience