Welcome to this presentation which helps to highlight the capability of Genesys in the design of RF antenna switches for LTE and WiMax applications
Introduction

• The evolution of modern communication standards place additional technical burdens on the equipment
• New protocols require equipment to be agile in terms of
  • Gains,
  • Modulation
  • Antenna Systems
• Standard single receiver, single antenna are past
• We will show how Genesys aids in the design, evaluation, troubleshooting and optimization of switch designs for current communication standards
Agenda

• Define design parameters
• How solid state switches are used
• Review of switch components
• Review switch types & topologies
• Propose & analyze a SP3T antenna switch for FDD;
  Analyze a SPDT antenna switch for TDD
    – For each, optimize design to meet specifications
    – Evaluate switch isolation, match, distortion, & video feed through
    – Suggest improvements
• Conclusions
For most all switch applications one or more of the above is an important parameter.
For time division duplex (TDD) the same frequencies are used for transmit and receive. The antenna is alternately switched between transmitter and receiver. Switched antenna arrays use switches to select one of several antenna to transmit or receive in a particular direction. Using digital phase steering by means of selecting fixed phase shifts to direct an antenna beam usually in steps of 22.5, 45, etc. degrees per bit.
Using schottky diodes is limited to a few applications where power is not significant. To prevent rectification the diode must be biased high enough to avoid rectification effects. Insertion loss is generally higher than GaAs Mesfet or PIN diode.
Mesfet provides higher frequency use, but bias circuitry can be more complicated. Cost is higher compared to diodes.
PIN diodes are the preferred switching device for most applications. They are inexpensive, can handle high power levels with little distortion. Their drawback is that they are bounded by a lower useable frequency and high frequency limited by their intrinsic inductance.
The lower frequency range of the PIN diode is due to the recombination lifetime of the junction. At frequencies below Tau, minority carriers have time to join which basically turns the diode into a standard rectifier. The ability to behave as a variable resistor is lost. For fast high frequency switching the key parameters are reverse junction capacitance and low Ron to minimize loss.
We examine two applications for switching. In FDD applications the transmit and receive frequencies are different, however new standards require agile antennas which can be switched to mitigate multipath and improve ERP (effective radiated power).

**Switch Applications**

**LTE FDD (Frequency Division Duplex)**
- Switched antenna SPnT
  - Example of SP3T

**LTE TDD (Time Division Duplex)**
- Antenna switched between transmitter & receiver
  - Example of SPDT
Switched beam allows the selection of one of several antenna to improve multipath and ERP.
Steering of a single antenna with multiple inputs can be accomplished by varying the phase at each input to change the pattern. Digital (as opposed to analog) phase shifting is accomplished by stepping the phase feed in discrete amounts, 11.25, 22.5, 45 etc. The phase is selected by digital WORD.
For the FDD example we use parameters common for switched beam applications

**Antenna Switch Specifications**

- SP3T: Single Pole Triple Throw
- Insertion loss $<-0.5\,\text{dB}$
- Isolation between ports $\geq -20\,\text{dB}$
- Switching time $<100\,\text{nsec}$
- Return loss at all ports $\geq -20\,\text{dB}$
A switch for selecting one of several antennas for switched beam antenna. For diode only configuration the advantage is wide frequency response, isolation between off elements is low. For diode/quarter wave line advantage is higher isolation but narrower frequency response. These configurations may expanded to many more antenna components.
Linear simulation serves to analyze the loss, reflection and isolation of our switch. Note all but the isolation specification is met. When 5 volts is applied to the bias port, that port’s diode is turned on. The remaining diodes are back bias by the voltage appearing on the cathode of the forward bias port. This is due to the voltage drop on the common port bias resistor R1.
Distortion at our selected output level of +23dBm is negligible. The issue of course is that the isolation between ports does not meet our requirements. Sufficient isolation is required if we are to limit power to an un-selected antenna.
The cause of delay overshoot and ringing is due mostly to the bias components. Use the Cayenne output to measure the ringing frequency and compare to bias elements. A judicious choice of bias elements and values can optimize the response of the switch. Other causes of delay and distortion are attributed to the ability to store and remove charge from the diodes junction. This is a factor of the diode’s parameters. For this example the switch does not meet the switching specification because ringing extends beyond 100ns.
Switching results in the modulation of our spectrum. The frequency characteristics of our bias network affect rise time, delay and ringing. The coupling capacitors at the input and output of our switches act as high pass filters. The bias network acts as a low pass filter to prevent RF. Higher cutoff frequency for the low pass reduces delay and rise time. A compromise must be made to ensure sufficient bandwidth for modulation as well as isolation.
Isolation is improved due to the halving of the diode capacitance (series connected). Improvement in insertion loss is due to the decrease in power absorb by adjacent diodes (impedance is higher in off leg). Improvement in return loss is due to increased impedance of adjacent legs which appear as parallel legs.
As before at +23dBm input little distortion is evident giving us a clean spectrum. Note the improvement in isolation at the additional cost of three diodes.
Analyzing our network with time domain shows that
Evaluation Of Bias Network

Bias network predicts resonant behavior

- Resonance @ 23 MHz
Improving Ringing

Increasing bias network frequency
• Reduced ringing amplitude
• Faster Switching

Bias Network Response

Common Port Transient

L=250mH
C=20pf

Agilent Technologies
Finalizing Switch

Addition of loss in bias network
Were Goals Met?

- SP3T: Single Pole Triple Throw
- Insertion Loss <.5dB (0.118 dB)
- Isolation Between Ports ≥ 20dB (21.8 dB)
- Switching Time <100 nsec (< 20 nsec)
- Return Loss At All Ports ≥ 20dB (28 dB)
Switch Summary

• Switch topology selected
• Analyzed switch to meet specifications
• Added additional diodes to improve performance
• Adjusted bias component values to improve Turn On Characteristics
• Verified specifications met
Antenna Switch

For Time Division Duplex protocols (TDD)

- Single Pole Double Throw Switch
Switch Topology

Many configurations to choose from
• Each network offers different characteristics
  – Number of parts
  – Isolation
  – Insertion loss
  – Switching speed
  – Ease of bias
Switch Networks

As complexity increases

- Improved performance (isolation)
- Degraded insertion loss, switch speed
- Additional component count
- Added cost
The development of this switch is to first show the inherent broad band response. The LTE Band II is then developed and optimized.
Diode only design provides the broadest bandwidth. The combination diode/transmission line provides higher isolation.
Procedure

Layout circuit and evaluate

• Use GENESYS simulation tools to evaluate
  – Matching / Isolation – linear analysis & HARBEC
  – Optimization – linear analysis
  – Distortion – HARBEC
  – Rise Time & Video Feed through – CAYENNE
  – Switching Speed – CAYENNE
  – Switching Transients - CAYENNE
The short created by the shunt diode appears as an open circuit to energy at the antenna port, this improves isolation between the transmitter port.
The shunt diode is not a pure short, there is a small residual resistance and inductance, the transmission line is then foreshorten to mitigate.
SPDT Switch Analysis

Start with Linear Analysis

- Illustrates broadband nature of the network, Cellular to WiMax
- Transmission line is tuned for optimum performance
- Insertion loss is low but isolation is lower than required

![Graph showing isolation and loss vs. frequency](image-url)
SPDT Switch Evaluation

Reflection at Transmit, Receive and Antenna Ports

- Improvements in Transmit Reflection is needed
Modified Switch

Additional Transmission Line and Diode

- Optimize for Insertion Loss and Isolation over the band of interest (1800-2040 MHz)
Optimization Of Switch

Optimize for maximum isolation for transmit frequencies
Improved loss and isolation when transmitting is due to the fact that the receiver looks more like an open with two diodes and two lines. The reason for no improvement in the isolation between transmit and receive ports is due to the fact that there is still only one back biased diode between the two ports.
Modified Switch

Improved Return Loss at all ports

-24dB Transmit, -21 Receive
Non Linear Analysis

HARBEC is used to evaluate Distortion and Loss

- Note Second Harmonic Is -100dBc
While this example shows pulse widths that are less than expected for TDD protocols, it helps to educate and illustrates the importance of rise time, pulse extension and ringing and the causes of each. As we will see, the root cause consists of bias components which we can control and diode charge current times which we have limited control over. Luckily, the bias has a larger effect.
Frequency Limited Network

Switched networks resemble bandpass networks

- As shown before, Delay and Rise Time limited by network and devices
Here we see an equivalent circuit for our bias network excluding the diode which appears as a low impedance for RF as well as the pulsed voltage. The resonance at 19MHz tends to witness the time domain response we have seen.
Evaluating Bias Network

Time domain analysis shows overshoot
Ringing frequency is confirmed by linear simulation

The peaking and ringing follows our linear analysis frequency. Cayenne is used here to verify ringing effects and will help us to mitigate the problem.
Decreasing the coupling capacitance and series inductance moves our resonance higher. This results in higher modulation frequencies or faster pulses.
Adding a damping resistance to the bias inductance over dampens our network reducing ringing. Note that the frequency response shows little evidence of resonance.
Improving Pulsed Response

Results of changing DC blocks and driver components
Improving Pulsed Response

Improved switching transients at receiver port

- Video pulse reduced
- Isolation, Transmitter to Receiver -22dB
Pulsed Transmitter

• Transmitter is turned off in receive mode
• Switch is thrown prior to transmitter turn on
Pulse Transmitter

Delayed switching reduces transmitted transients
Final Switch Synopsis

Spectrum at antenna port

- Note that the peak power is less than +23dBm Why?

\[ \text{On/Off Ratio} = 0.25 \]

\[ \text{Desensitization} = 20 \cdot \log (\text{Ratio}) = -12.041 \text{dB} \]

\[ P = 22.95 - 12.041 = 10.9 \]

Power is spread across spectrum. The desensitization is \(10\log \text{[pulse rep]}\)
Were Goals Met?

SPDT: Single Pole Double Throw

• Insertion Loss < .5dB (0.04 dB)
• Isolation Between Ports ≥ 20dB (31 dB Rcv mode)
• Switching Time < 50 nsec (< 10 nsec)
• Return Loss At All Ports ≥ 20dB (24 dB)
Design Summary

• Switch topology selected
• Analyzed switch to meet specifications using HARBEC and CAYENNE
• Added additional diode to improve performance
• Adjusted bias component values to improve pulse characteristics
• Verified specifications met with time domain analysis
Thank You

Additional Information—
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1. Register for the 6th “How-To-Design” seminar on MIMO Array Antenna design
2. Get a free trial of Genesys
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