RF Domain Channel Emulation Techniques with SAW Filters

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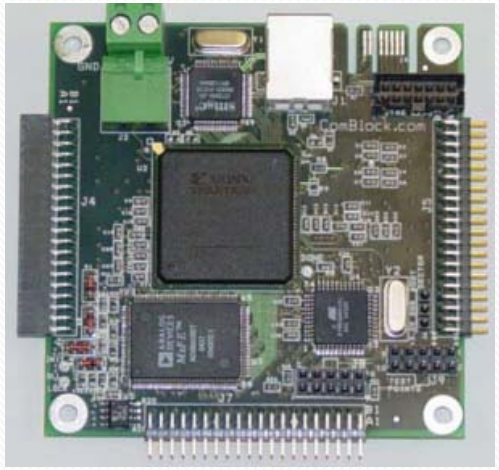
- Motivation
- Channel Model
- SAW Devices
- Emulation techniques
- Measurements
- Conclusion

Conventional Channel Emulators

- Apply pre-determined channel models to digital baseband signals
- Requires up and down conversion stages
- Expensive process, additional errors
  - e.g. ADC/DAC quantization errors, IQ impairments, phase noise
- Flexible, it can emulate any channel model
- Large form factor
- Complex device

ACE MX MIMO Channel Emulator

N5106A PXB Baseband Generator and Channel Emulator



Com-1232 Channel Emulator

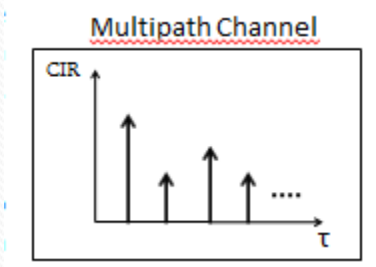
Proposed Channel Emulator

- Apply a pre-determined channel model to RF signal
  - e.g. ITU vehicular A/B channel model
- No need to digitalize
- Cheap, small, and simple design for a selected channel model is possible
- Requires new design for each channel model because of the fixed delays
  - One channel model for each design
- Small form factor
- Easy to built

Channel Model

- Channel impulse response can be modeled as

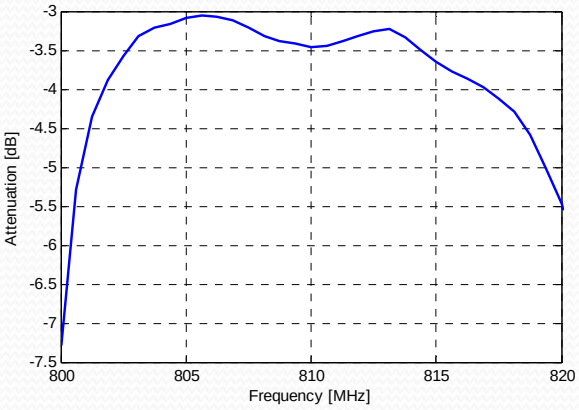
$$h(t) = \sum_{i=0}^{M-1} \alpha_i(t)\, \delta(t - \tau_i)$$



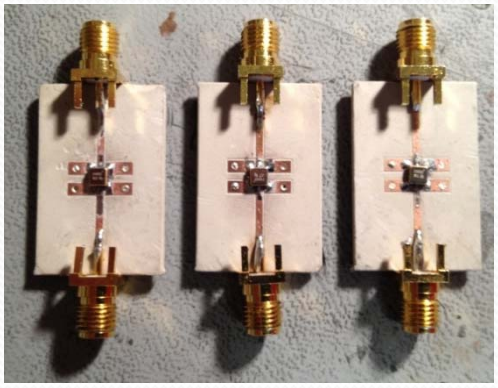
- Each term shows the amounts of the delay, attenuation and phase shift introduced to the signal
- A channel impulse response can be artificially generated using attenuator, phase shifter, and delay elements
- As a delay element, cables can be used, either. However, to generate 100 ns delay 333 m cable is required

SAW Devices

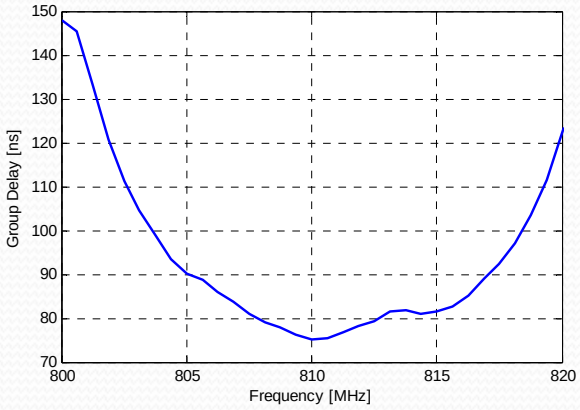
- SAW (Surface Acoustic Wave) devices convert electrical signals to acoustic waves
- As a delay element, we propose to use SAW filters by exploiting the lower speed of acoustic waves compared to the electrical signals



Pass band response of the SAW filter



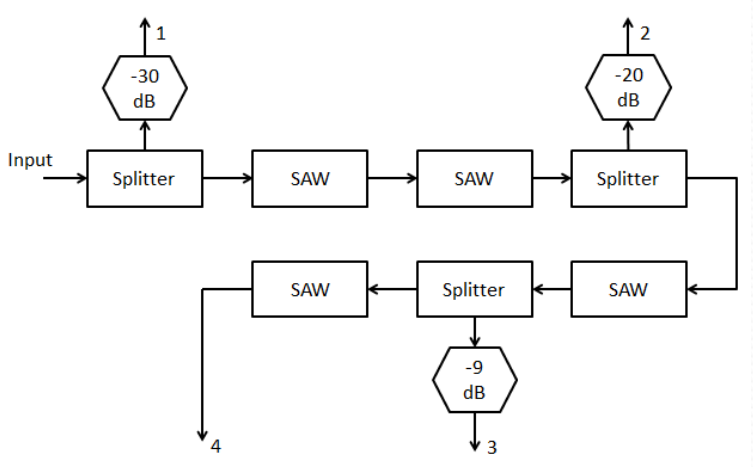
SAW filters



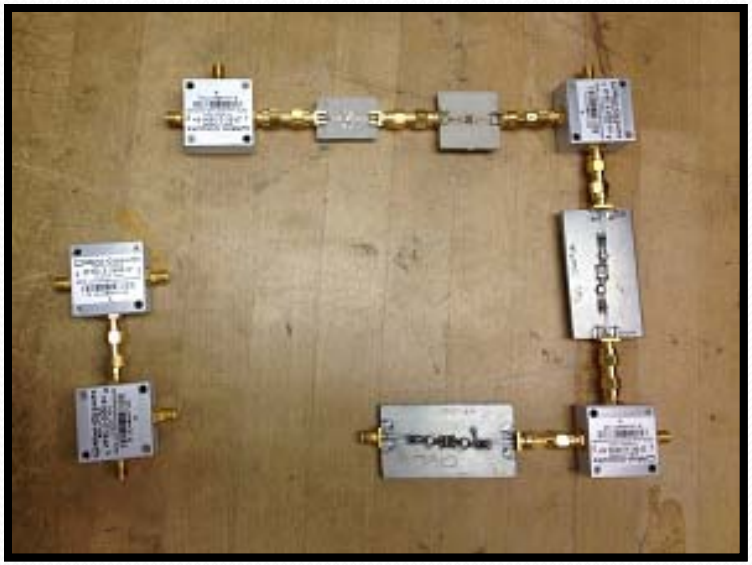
Group delay of the SAW filter

Cascade Connection

- Emulates pre-determined channel
- Each tap's amplitude and phase are individually controllable
- Doppler spread can be emulated using variable attenuator on each tap

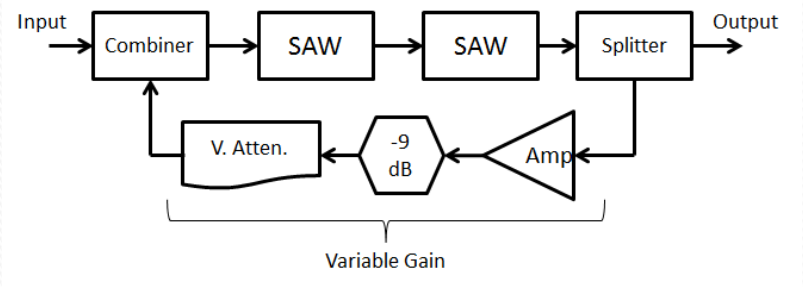


An example emulator for cascade connection technique

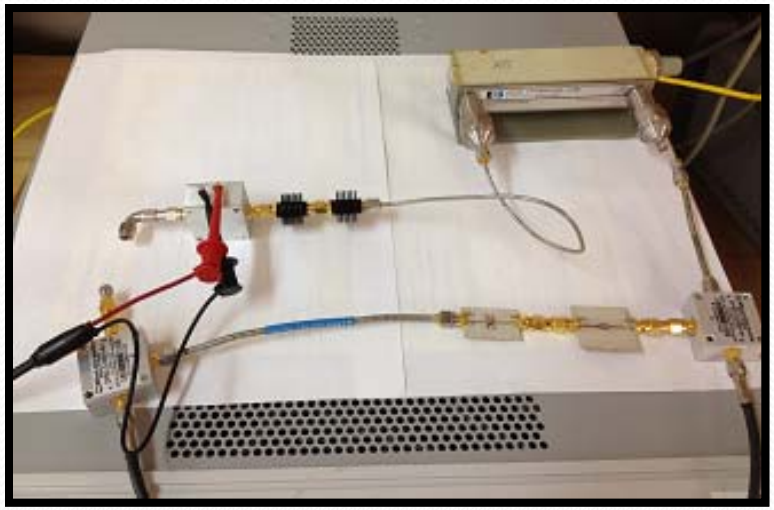


Feedback Technique

- Emulates larger maximum excess delays using single SAW device
- Variable loop gain controls maximum excess delay
- Consecutive taps have a fixed phase and amplitude difference
- Independent tap control is a challenge



An example emulator for feedback technique



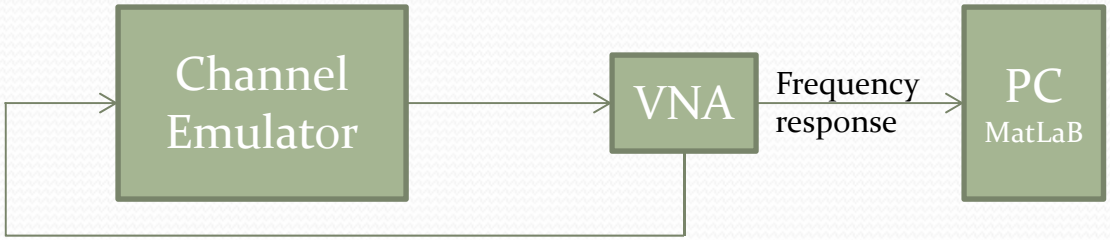
Measurements

- Components
  - Triquint 856526 – 810 MHz SAW Band pass filter:
    - 10 MHz pass bandwidth at 810 MHz with 3.5dB loss and 80ns group delay
  - EPCOS LE61A – 810 MHz SAW Band pass filter:
    - 10 MHz pass bandwidth at 810 MHz with 10dB loss and 140ns group delay
  - ZFSC-2-2500 – Power splitter/combiner:
    - 10 to 2500 MHz operation bandwidth with 3.4 dB insertion loss at 810 MHz frequency
  - ZFL-1000LN – Low noise amplifier:
    - 23.6 dB gain with +15V DC feed
- Equipment
  - Agilent PSA series spectrum analyzer – E4440A
  - Agilent ENA series network analyzer – E5062A
  - Agilent vector signal generator – E4438C

Measurements

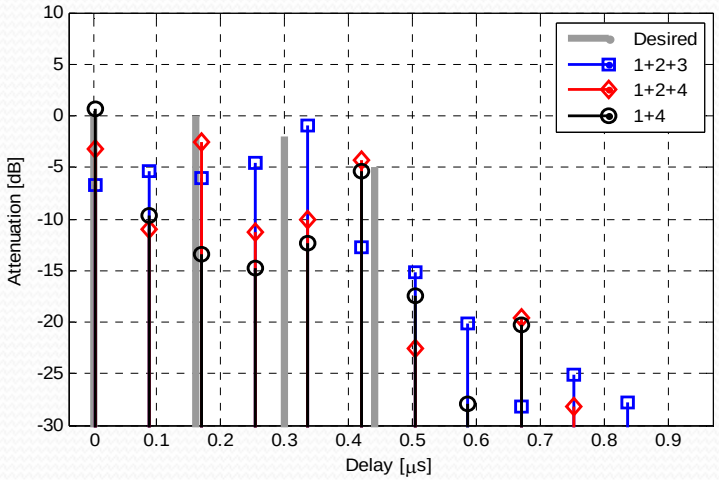
- Measurement methods
  - Power delay profile measurement with Zadoff-Chu sequence

  - Frequency response measurement with network analyzer

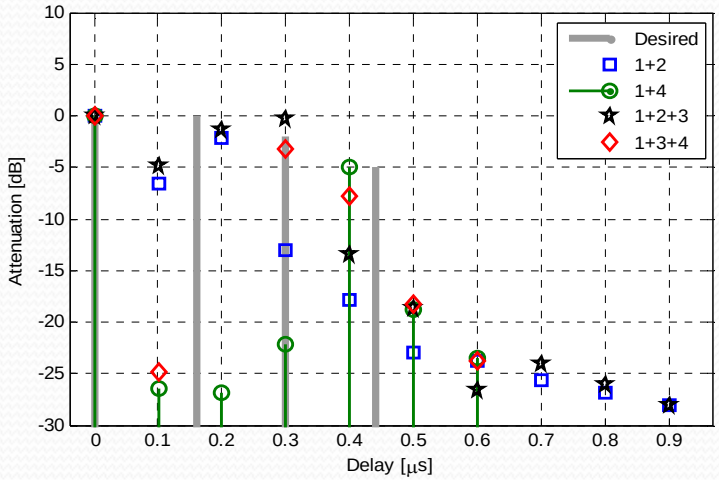


Measurements

- Cascade Technique, power delay profile

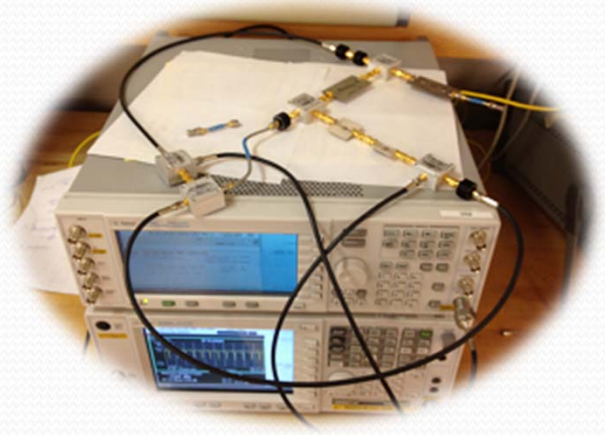


Zadoff-Chu Measurement



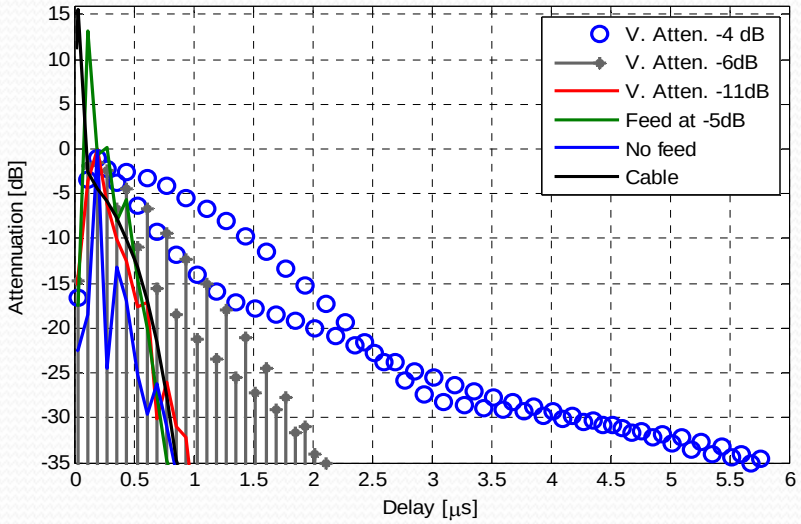
VNA Measurement

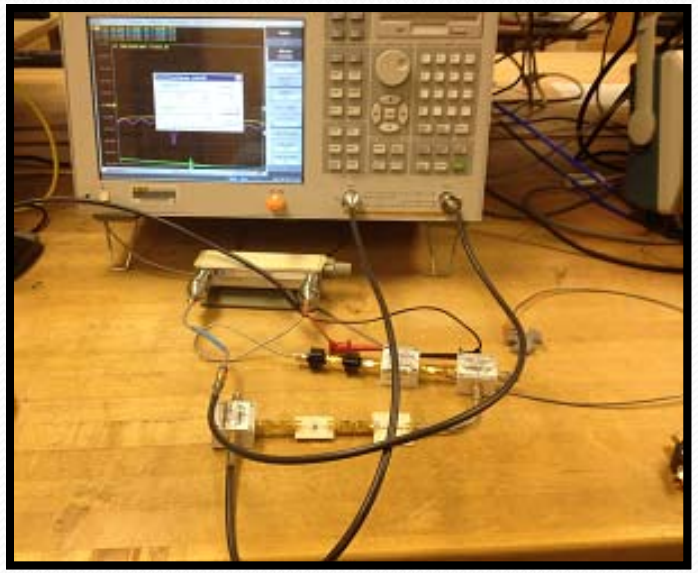
- Measured channel is close to the desired channel
- Both measurements confirms each other
- Measurement and design errors has been observed
  - e.g. Limited BW, Non-flat pass band filter



Measurements

- Feedback Technique, power delay profile





- Change on the maximum excess delay with the loop gain is observed
- Up to 4μs maximum excess delay is observed
- With special observations the measurement is clarified
  - i.e. Cable, No feed, Feed at -5dB

Conclusion

- SAW devices can be used in channel emulators
- RF domain channel emulators are designed
- The design can be implemented as RF component
- Simple, small, and cheap channel emulators for any specific channel model (e.g. ITU vehicular channel model)
- The cascade connection technique is used to emulate a pre-determined channel
- The feedback technique is very useful to generate an exponential decaying channel and to create large maximum excess delays
- Doubly dispersive channel solutions by digital amplitude and phase controller.

Questions?

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THANK YOU