RF DOMAIN CHANNEL EMULATION TECHNIQUES WITH SAW FILTERS

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ABSTRACT

Conventional channel emulators apply pre-determined channel models to baseband digital signals. However, processing on the baseband signal and utilizing down and up conversion stages result in an expensive emulator which also introduce additional distortions at these stages. In this paper, low cost and small size channel emulator implementation techniques are introduced using surface acoustic wave (SAW) devices. In the first technique, a pre-determined channel is introduced on the RF signal with using a number of SAW filters. In the second technique, an exponential decaying channel with controllable decaying factor is generated using a single SAW filter. As a result, simple, small, and cheap channel emulator for a specific channel model at a fixed carrier frequency is provided with SAW technology.

1. INTRODUCTION

The growth in the communication technology and the demand in the market require development of new communication devices. Therefore, there is a need on the equipment for emulation, measurement, and verification to evaluate new systems before the mass production of the device. An important evaluation for the communication systems is to test the device in realistic channel scenarios. In a laboratory environment, testing a long range communication system might be a challenging task due to the difficulty of realizing practical multipath channel scenarios. A wireless channel may include the effects of additive noise, multipath fading, and dispersion both in time and frequency. One of the efficient solutions to test the system in realistic channels is usage of channel emulators to introduce those effects. In the literature, several methods are presented to emulate these effects. Channel emulators to introduce the effect of additive white Gaussian noise on baseband signals are presented in [1]-[4]. An IIR filter is implemented in [5] to obtain Doppler Effect on emulated channels. Also, Doppler spread is introduced to wireless signals in reverberation chamber [6]. On the other hand, doubly dispersive channel emulators are proposed in [7] and [8] to generate the channel effects on baseband signals. It is also possible to find channel emulators, which use reverberation chambers, in the literature [9], [10].

Conventionally, channel emulators generate the effects of wired/wireless channel based on pre-determined channel models, and those effects are applied on the baseband signals. Therefore, they require down and up conversion stages which result in expensive equipment with large-form factor. Also, each conversion level introduces additional hardware distortions (e.g. ADC/DAC quantization errors, IQ impairments, phase noise) to the signal beside the desired channel characteristics.

Surface acoustic wave (SAW) devices convert electrical signals to acoustic waves which travel through the surface of an elastic material [11]. Since acoustic waves travel slower than electrical signals, SAW device can be designed to introduce large group delays which can be exploited to generate multipath delays in laboratory environments. In this paper, in order to obtain a low cost channel emulator with small-form factor, we propose two different RF domain channel emulator techniques using SAW devices. The first approach aims to introduce a pre-selected channel impulse response (CIR) on RF signal. On the other hand, the second approach aims to introduce larger maximum excess delay. As a result of the proposed techniques, low cost and controllable channel emulators with small-form factors are designed utilizing the group delays of SAW filters.

2. EMULATION TECHNIQUES

A wireless channel can be modeled with its impulse response as

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

where $\alpha_i(t)$ is ith complex channel tap coefficient, τ_i is the delay of ith tap, and M is the number of resolvable taps. As it can be seen from CIR, the signal is spread in time by the channel. Each tap in CIR shows the amounts of the delay, attenuation and phase shift introduced to the signal. Therefore, a channel impulse response can be artificially generated using attenuator, phase shifter, and delay elements. As a delay element, cables can be utilized [12]. However, considering the delays in wireless channels, e.g., varying 10 ns to 100 µs, very long cables are required. For

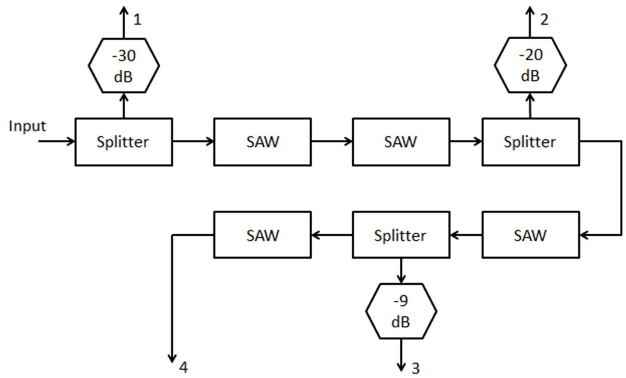

Figure 1. An example block diagram for cascade technique.

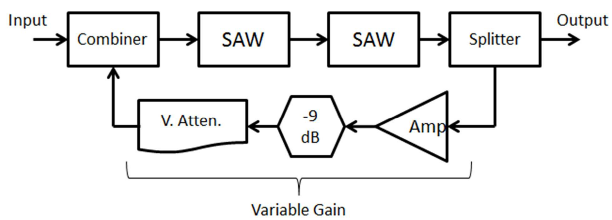

Figure 2. An example block diagram for feedback technique.

example, to generate 333 ns delay, 100 m cable has to be used and it requires large-form factor. In the proposed approaches, instead of cables, SAW filters are used to introduce delays on taps, and they are implemented in 10x10 mm chips.

2.1. Cascade Connection Technique

In our first approach, a pre-determined time dispersive channel is emulated with the proper combination of the delayed RF signals. Each tap of the channel is generated by getting braches from a cascade connected SAW devices. Then, these outputs can be individually attenuated and phase shifted to create desired channel effect when they are combined. Doppler spread also can be introduced on the individual branches by affecting the amplitude and phase to emulate mobility for wireless channel emulation [5].

An example block diagram for cascade connection is shown in Figure 1. Branch outputs are split with power dividers and connected to attenuators to keep the power of outputs at desired levels. Between the first and the second branches, two SAW filters are cascaded to increase the delay between first and second taps.

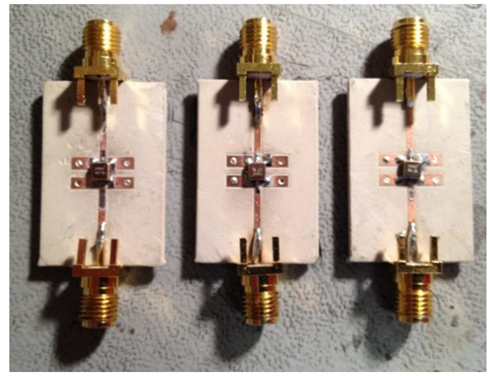

Figure 3. Implementation of SAW filters.

2.2. Feedback Technique

In our second approach, only one SAW device is used and its output is fed back to the input to emulate an exponentially decaying channel. By changing the loop gain of the circuit, maximum excess delay of the channel is controlled effectively.

An example block diagram for the feedback technique is given in Figure 2. In the forward channel, instead of one SAW filter, two of them are cascaded to increase the delay as in the first approach. While the amplifier on the feedback channel is used to compensate the insertion loss of the components, the variable attenuator (V. Atten.) is added to the loop to control the maximum excess delay of the emulated channel. The amplifier, variable attenuator, and the fixed attenuation (-9 dB) introduce variable gain on feedback.

The biggest advantage of this technique is that it can emulate an exponential decaying channel using only one SAW filter. The emulated channel may have much larger maximum excess delay comparing to the previous technique. However, in this technique, amplitude and the phase of the emulated channel taps are related to each. Thus, the amplitude and the phase of the each tap cannot be changed independently. In other words, the phase and amplitude differences between two consecutive taps are fixed but controllable by the loop gain and phase.

3. PERFORMANCE EVALUATION

The proposed approaches are implemented in a laboratory environment. In the experiments the following components are used:

- Triquint 856526 – 810 MHz SAW Band pass filter: 10 MHz pass bandwidth at 810 MHz with 3.5 dB loss and 80ns group delay.

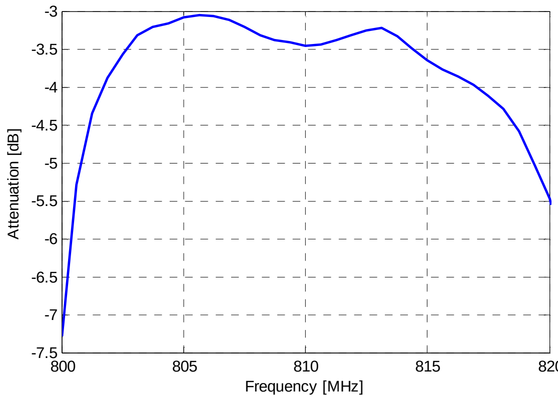

Figure 4. Pass band response of the SAW filter.

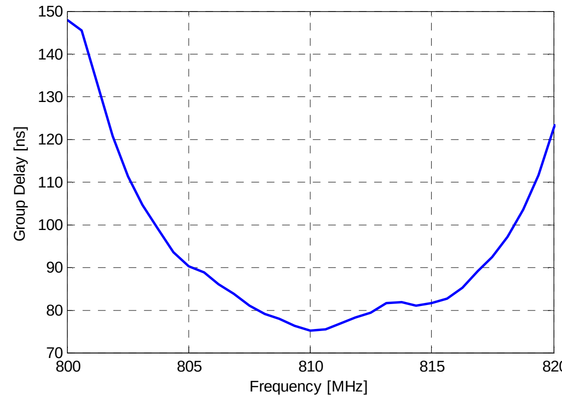

Figure 5. Group delay of the SAW filter.

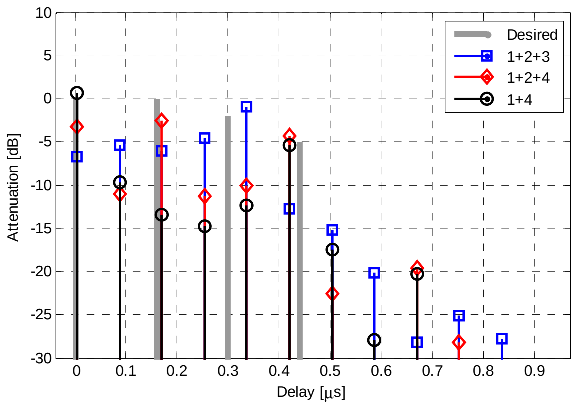

Figure 6. Zadoff-Chu sequence measurement results for the cascade technique.

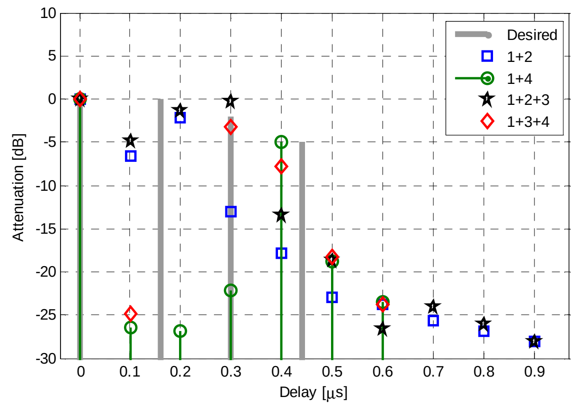

Figure 7. Network analyzer measurement results for the cascade technique.

- EPCOS LE61A – 810 MHz SAW Band pass filter: 10 MHz pass bandwidth at 810 MHz with 10 dB loss and 140 ns 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.

The SAW filters are soldered on a board for easy usage as in the Figure 3. After soldering these filters on boards, the group delay and filter responses of the complete board for Triquint 856526 are measured as in Figure 4 and Figure 5, respectively. As it is seen from the figures, the group delay and the frequency responses of the filter are not flat which introduce error to the emulator.

The following list of equipment is also used in the measurements:

- Agilent PSA series spectrum analyzer – E4440A
- Agilent ENA series network analyzer – E5062A
- Agilent vector signal generator – E4438C

Block diagrams in Figure 1 and Figure 2 are implemented in the laboratory to test the proposed techniques. In the cascade technique, first two and in the feedback technique all the SAW filters are implemented with Triquint 856526. The last two SAW filters in the cascade technique are implemented with EPCOS LE61A. The emulated channel effects are observed by CIR measurements. In the measurements, Zadoff-Chu sequences are used, since Zadoff-Chu sequences are orthogonal with its cyclically shifted versions. The received signal is cross correlated with the selected Zadoff-Chu sequence to observe channel impulse response. The readers are referred to [13] for further details on the cross correlation process with Zadoff-Chu sequences.

In the experiment, Zadoff-Chu sequences are transmitted by the vector signal generator and received by the vector signal analyzer. The equipment is controlled via Matlab software. Figure 6 shows the measured CIR obtained via Zadoff-Chu sequences for the cascade connection technique. In the figure, the combinations of the different taps are given. For example, the blue line with square markers shows the results for the combination of the first,

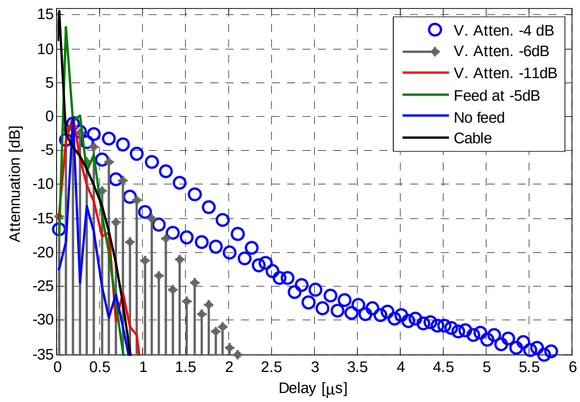

Figure 8. Zadoff-Chu sequence measurement results for feedback technique.

second, and the third output (1+2+3). The delays of the taps are measured at the expected instants as given in Figure 6. However, the measured taps are spread in time because of the measurement technique and the undesired effects of the components, e.g. group delay ripple, synchronization error on the equipment, and the band limitations of the SAW filters. The frequency response of the emulated channel is also measured by network analyzer and converted to CIR as given in Figure 7. The results in Figure 7 and Figure 6 agree with each other.

Figure 8 shows the CIR measured via Zadoff-Chu sequence for the proposed feedback technique. All of the results are scaled with a fixed value to have 0 dB power on first tap at the desired output. Solid black line shows the CIR of the cable as reference. The CIR of cable is observed as a Dirac function with some measurement errors. The solid blue line shows the forward channel measurement without feedback. On the other hand, the CIR of the feedback loop is given as the solid green line while variable attenuator is set to 5 dB. Comparing the black and green lines, 2 dB loss is measured in the loop which means the power difference between consecutive taps will be 2 dB. The rest of the plots show the CIR for the complete circuit output with different settings of the variable attenuation. As in Figure 8, the attenuation value apparently changes the maximum excess delay introduced by the emulator. The provided setup is able to emulate exponential decaying channel with up to 4 µs maximum excess delay before the feedback gets unstable.

4. CONCLUSION

Two channel emulator techniques are presented to emulate the delay spread of the channel using SAW filters. For both techniques, emulated channels are measured via a transceiver pair and a network analyzer. The results show that the emulated channels introduce desired channel effects on RF signal. While cascade connection technique is used to emulate a pre-determined channel easily, the feedback technique is very useful to generate an exponential decaying channel and to create large maximum excess delays in the laboratory for education and device test purposes. Compared to the conventional emulators, the proposed channel emulation techniques with SAW filters can provide simple, small, and cheap channel emulators for any specific channel model (e.g. ITU vehicular channel model) at a fixed carrier frequency (e.g. 915 MHz). However, it is hard to provide flexibility on the channel tap. As a future work, Doppler spread will be emulated on each tap for the cascade connection technique to generate controllable doubly dispersive channel by wide range digital amplitude and phase controller.

5. ACKNOWLEDGE

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