UCLA Samueli Electrical & Computer Engineering

Digital MicrowaveLab

Cognitive-IoV with Simultaneous Sensing and Communications via Dynamic RF Front-End, Award No. 2128570

PIs: Yuanxun Ethan Wang <ywang@ee.ucla.edu>,UCLA & Georgios Giannakis georgios@umn.edu, Univ. of Minnesota

Dynamic RF Front-Ends

Time-varying transmission lines (TVTL) and filters consist of passive transmission-lines and resonators in which the inductance or capacitance is modulated by the voltage of an electromagnetic wave called pump wave – hence the "time-varying" aspect. They can be used as fundamental building blocks that to create RF front-ends that are capable of advanced signal processing. The operation of these circuits possess both passive and active characteristics. They are fundamentally low loss and low noise - comparable to that of passive components. while the parametric gain of the time-varying operation can be used to compensate for the loss of the passive components and improve the overall noise performance

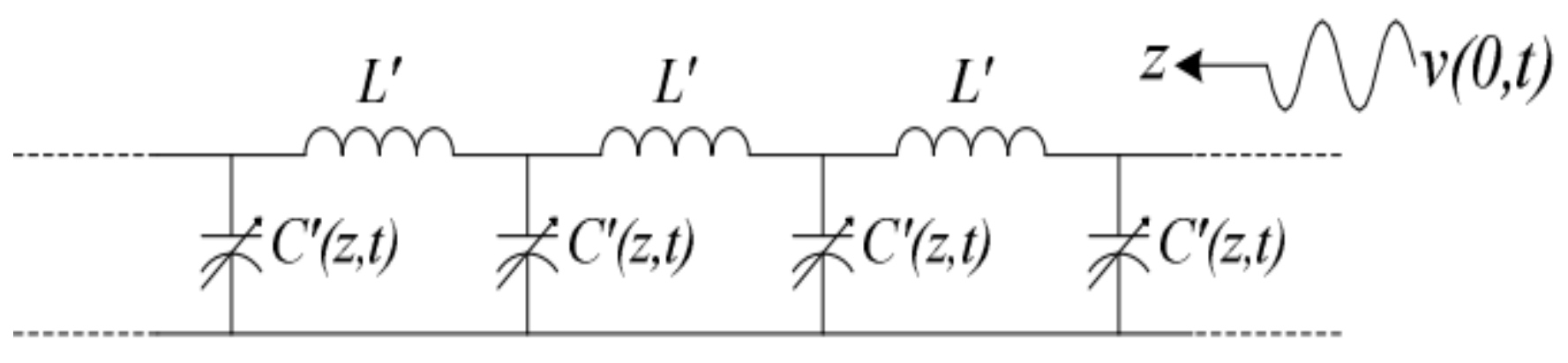

Figure 1: *Time-varying transmission line. Capacitance per unit length is a function of time and space*

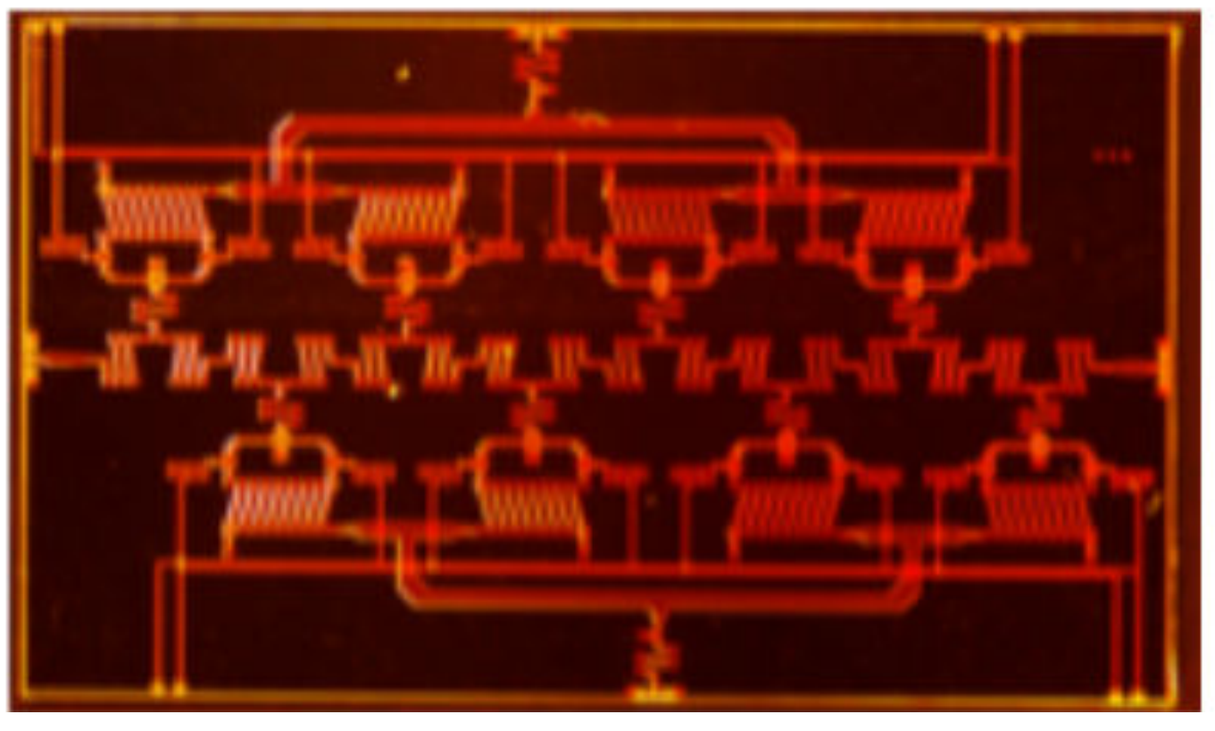

Figure 2: *Physical realization of MI-TVTL consisting of microstrip line periodically loaded with varactor diodes*

Basic Operation

The two frequencies, the original RF and the up-converted RF, are cross-coupled through a carrier tone. By properly choosing the modulation frequency, the upper-sideband can be pushed beyond the cutoff, leaving only the signals at the two frequencies to propagate. As such, the TV device can be modeled as a 4-port linear network. This enables cross-coupling between the two tones (ω_s and ω_{p-s}).

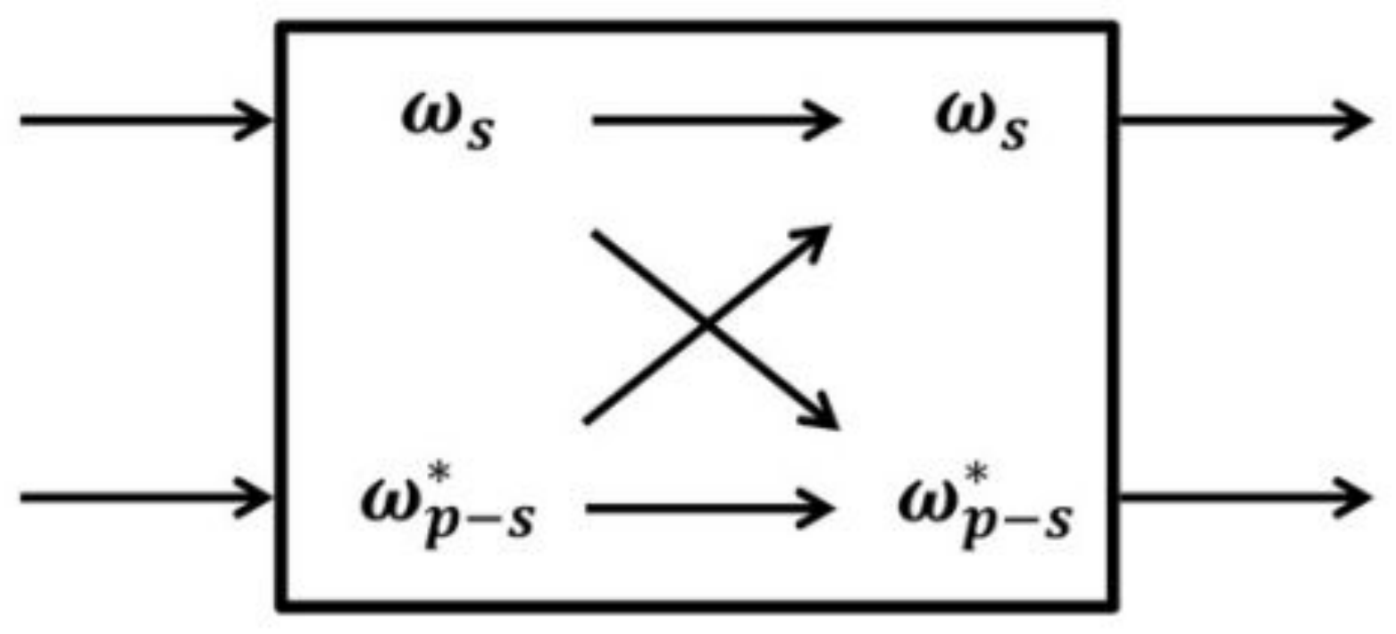

Figure 3: *Representation of the TV device by a four-port linear network*

$$\begin{bmatrix}\tilde{V}_s^-(z)\\ \tilde{V}_{m-s}^{*-}(z)\end{bmatrix} = \begin{bmatrix} t_{11} & t_{12}\\ t_{21} & t_{22}\end{bmatrix}\begin{bmatrix}\tilde{V}_s^+(0)\\ \tilde{V}_{m-s}^{*+}(0)\end{bmatrix}$$

Equation 1: *Matrix Equation between outgoing and incoming signals at the two tones*

Tunable Peak Amplifier

An interesting feature can be noted when feedback and resonance is introduced to the TVTL. The feedback enables the circuit to accumulate a strong resonance and produce a large parametric gain. This amplification effect features extremely high Q, high gain, low noise, and high frequency selectivity.

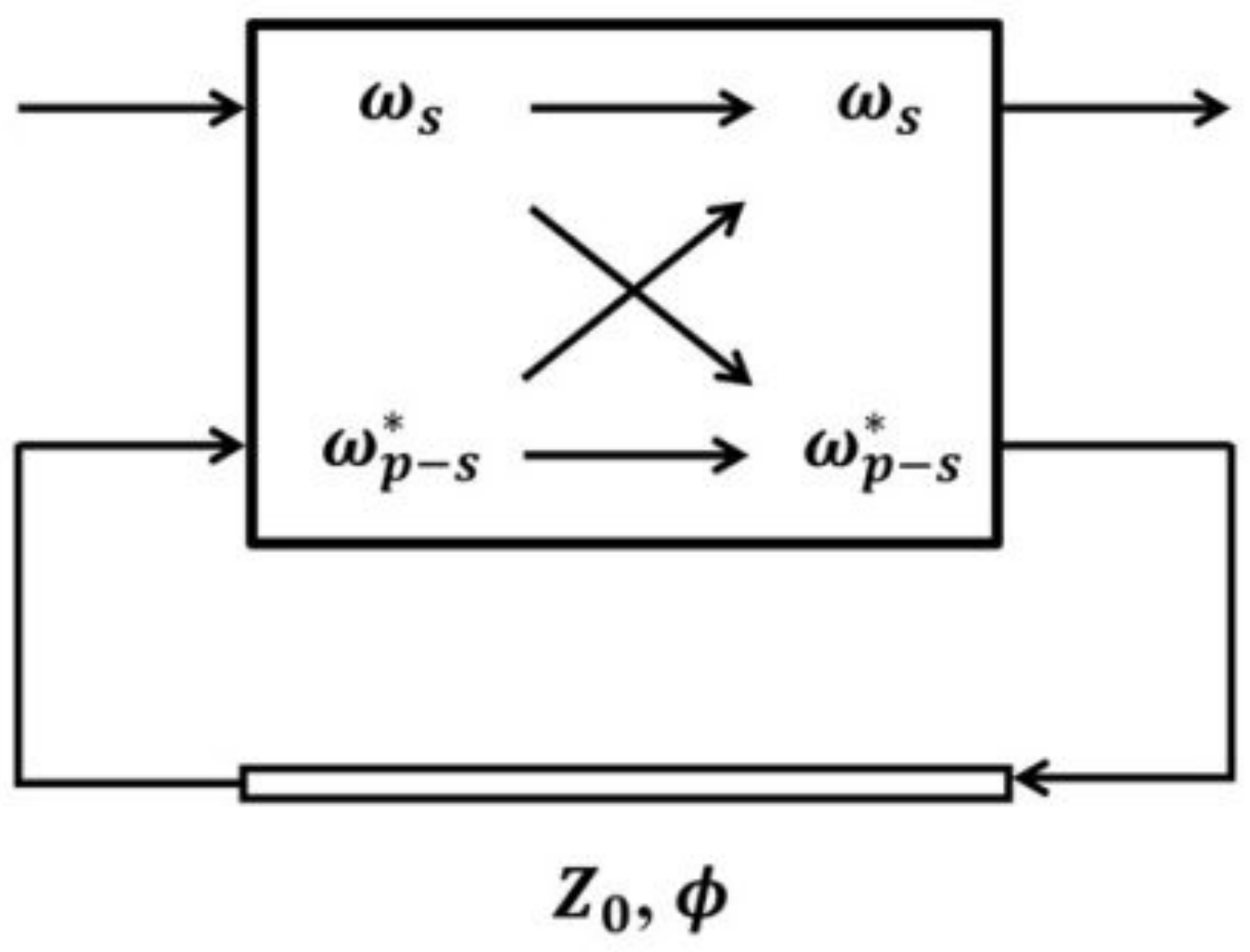

Figure 4: *Representation of the Tunable Peak Amplifier using the TVTL*

$$\tilde{V}_s^-(z) = \left(t_{11} + \frac{t_{12}t_{21}}{1-t_{22}}\right)\tilde{V}_s^+(0) = G_{ss}\tilde{V}_s^+(0)$$

Equation 2: *Gain Equation at the original signal frequency for the Tunable Peak Amplifier*

Tunable Bandpass Filter

Another approach is to transform the tunable bandpass amplifier into a tunable bandpass filter. This not only amplifies the in-band signal, but also attenuates the out-of-band frequencies.

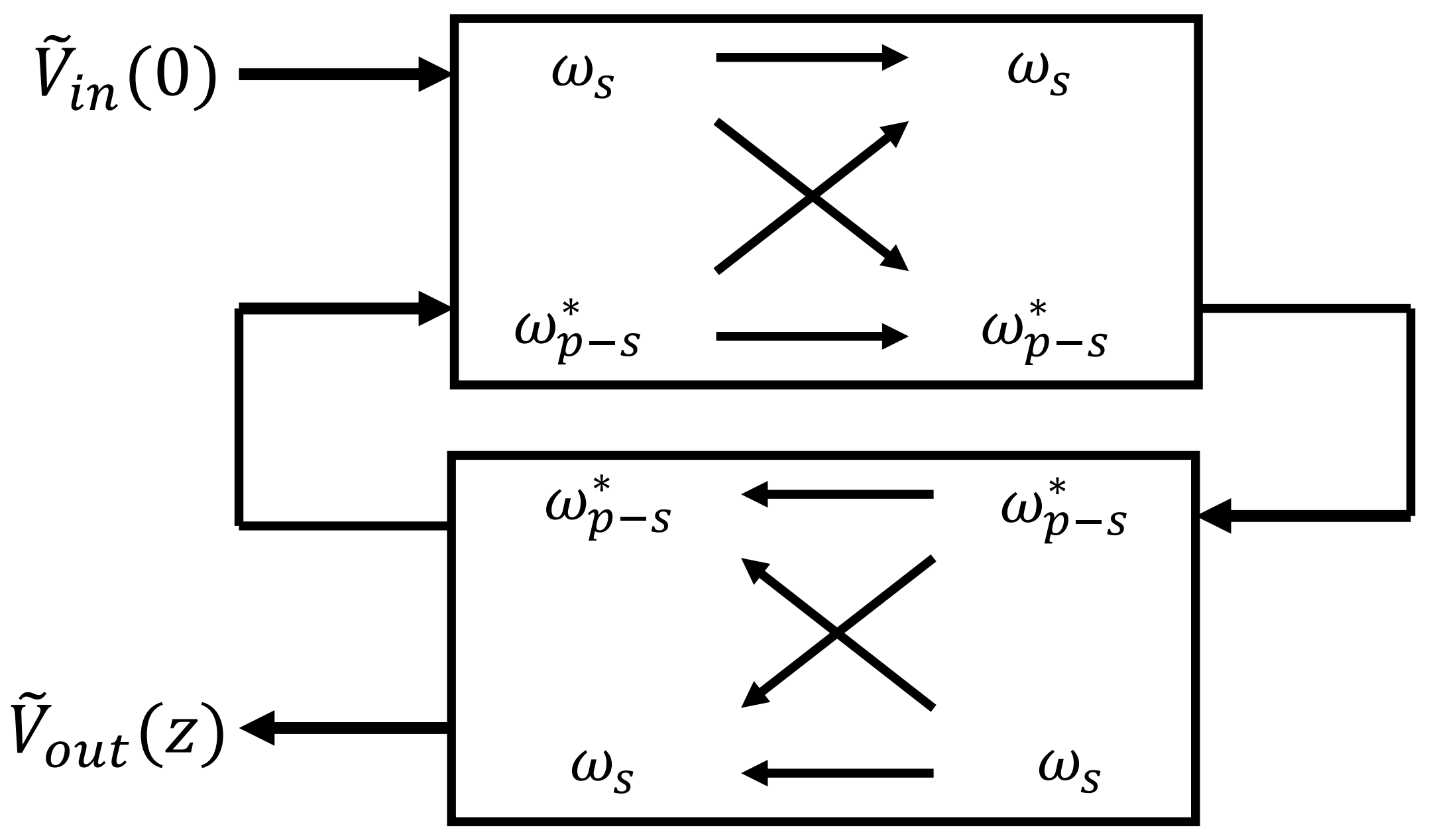

Figure 5: *Representation of Tunable Bandpass Filter using the TVTL*

$$\tilde{V}_{out}(z) = \frac{t_{12}t_{21}}{1-t_{22}^2}\tilde{V}_{in}(0) = G_{ss}\tilde{V}_{in}(0)$$

Equation 3: *Gain Equation at the original signal frequency for the Tunable Bandpass Filter*

Tunable Peak Amplifier Results

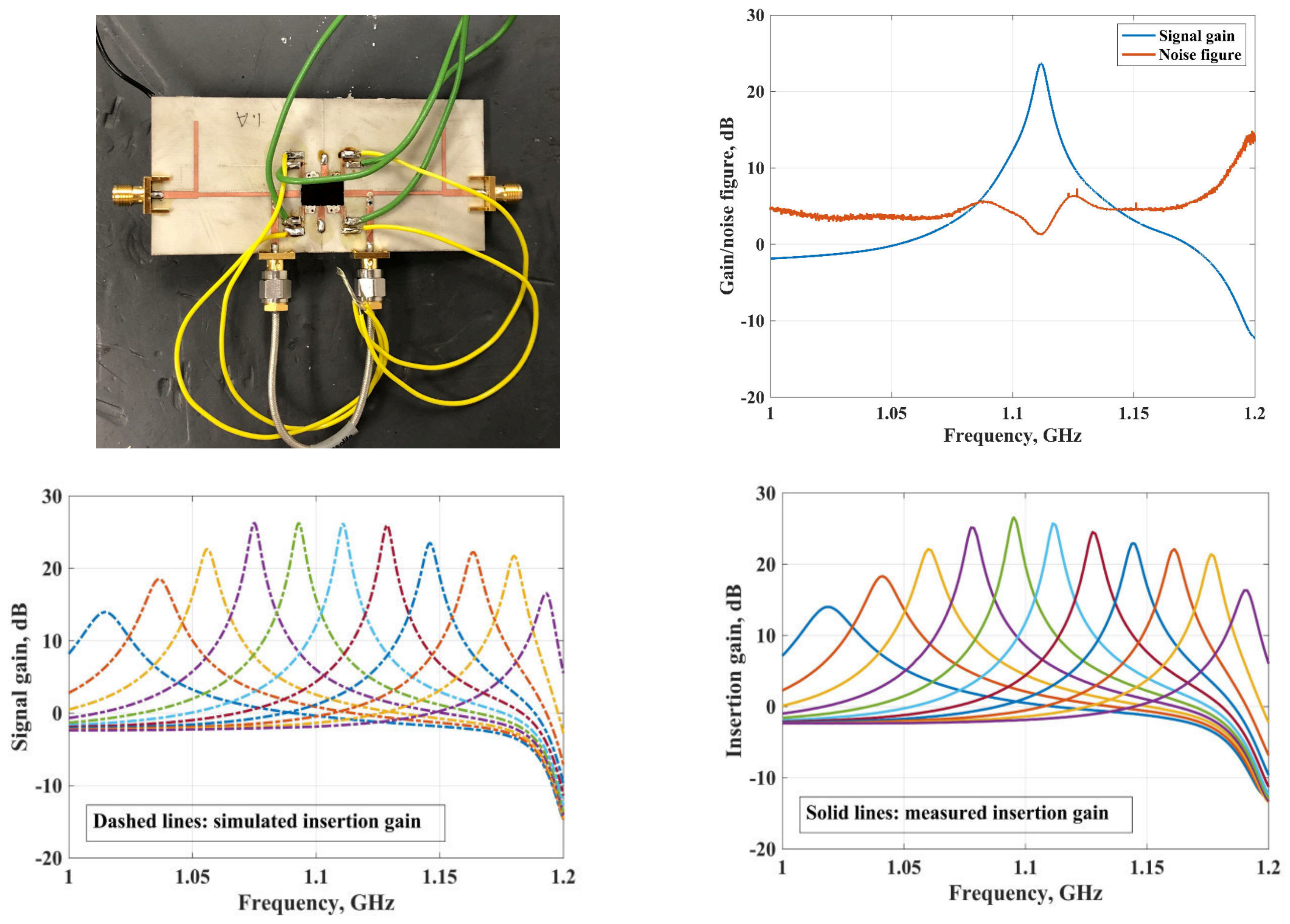

Figure 6: *Simulation results (left) and measured results (right) for the tunable peak amplifier showcasing frequency selectivity and tunability*

Tunable Bandpass Filter Results

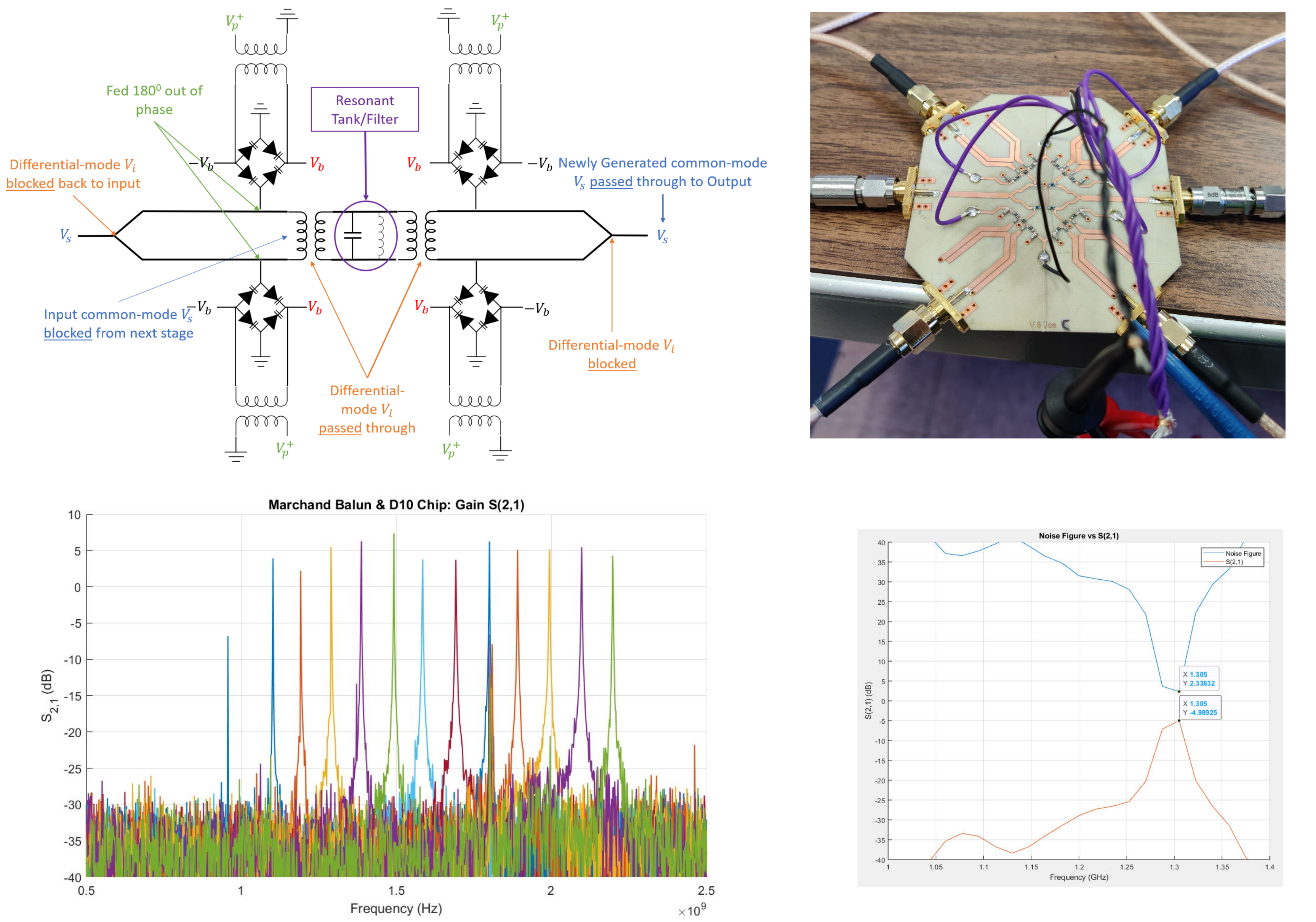

***Figure 7:** Measured results for the tunable bandpass filters showcasing frequency selectivity and tunability*