Nonreciprocal Exponential Amplification in Time-varying Transmission Line (TVTL)

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Time-varying transmission line (TVTL) has recently been introduced as one of the most promising devices that offer nonreciprocal frequency translation without using magnetic material (Qin et al., 2014). Its sinusoidal parametric amplification with almost no noise penalty is widely discussed and applied in building components and systems such as circulator (Qin et al., 2014) and frequency translational RF receiver (Wu et al., 2017).

Exponential parametric amplification is another parametric amplification mode in TVTL that has not yet been fully explored. It can be achieved by carefully selecting the cutoff frequency of TVTL to terminate the upper sideband of converted signal with short circuit, i.e., $V_{m+s}(z) = 0$. Once the upper sideband of converted signal is suppressed, the relationship between the amplitude of signal, $V_s(z)$, and the amplitude of lower sideband, $V_{m-s}(z)$, becomes:

$$\frac{d}{dz}\begin{bmatrix} V_s(z) \\ V_{m-s}(z) \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{4}\xi_1\beta_s \\ -\frac{1}{4}\xi_1\beta_{m-s} & 0 \end{bmatrix}\begin{bmatrix} V_s(z) \\ V_{m-s}(z) \end{bmatrix}$$

where $\xi_1 = \frac{C_m}{C_1}$ is the capacitance modulation index. The solutions to the set of equations are as follows,

$$\begin{cases} V_s(z) = V_0 \cosh(\frac{1}{4}\xi_1\sqrt{\beta_s\beta_{m-s}}z) \\ V_{m-s}(z) = -V_0\sqrt{\frac{\beta_{m-s}}{\beta_s}}\sinh(\frac{1}{4}\xi_1\sqrt{\beta_s\beta_{m-s}}z) \end{cases}$$

which indicate exponential amplification effect at both ω_s and ω_{m-s}.

Recent measurements on a 24-unit TVTL chip that was fabricated with Northrop Grumman Aerospace System 0.2 um GaN HEMT MMIC process have validated the above theory of non-reciprocal exponential parametric amplification at the original signal frequency ω_s. The gain/loss is observed to increase exponentially at the original frequency once the upper sideband of converted signal is beyond the cutoff frequency of TVTL. More than 1 dB gain is derived at 2.35 GHz with a 25 dBm carrier power driven at 6 GHz. Furthermore, when sweeping the frequency of the carrier, a corresponding frequency shift in signal gain/loss is also observed in measurements, which agrees with the theoretical predictions.

In this presentation, the mathematical derivations and measurement results mentioned above will be carefully discussed. Potential applications in wireless transceiver based on these effects will be introduced as well.