Spectral and Noise Performance of Nonlinear Transmission Line Frequency Multipliers

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In this paper, the theoretical and measured spectral performance of nonlinear transmission lines (NLTLs) and their applicability to frequency multiplication is presented. A NLTL, through nonlinear dispersion in large signal, will sharpen the edge of a sinusoidal signal creating a time domain edge that is rich in harmonics, making a very effective frequency multiplier. While the design of NLTLs has been widely published in the context of harmonic and shock-wave generation[1], this work, to the best of our knowledge, presents the theoretical and experimental noise performance of NLTLs for the first time. The results presented in this paper demonstrate a near ideal $20 \cdot \log_{10} N$ phase noise multiplication as referenced to the additive phase noise of the fundamental with N being the multiplication coefficient. Theoretical analysis of the noise properties of NLTLs, confirmed by measurements, shows that the effect of the DC return path biasing and the overall change in phase shift of the NLTL in large signal sinusoidal excitation has the most dramatic influence in additive phase noise and is confirmed by measurement.

The additive phase noise of a pair of Picosecond Pulse Labs LPN7100 NLTLs was characterized with a 19-dBm input signal at 200MHz. The output additive phase noise measured at the 200MHz fundamental and 2-GHz 10-th harmonic shows a nearly ideal 20·log10N phase noise multiplication with a measured phase noise of -172dBc/Hz and -151dBc/Hz (10kHz offset), respectively. In comparison, a Herotek step recovery diode (SRD) based frequency multiplier measured in the same manner exhibits a nearly 40·log10N noise relation of -179dBc /Hz at 200MHz to -150dBc/Hz at 2GHz.

Two diode multipliers are dominated by shot noise during the forward conduction cycle while SRDs may be susceptible to both shot noise and recombination noise but produce higher harmonics. NLTLs operate with the diodes in capacitive reverse bias a majority of the time. Varactor diodes in reverse bias have been shown to add no more noise than discrete capacitors and inductors[2]. Theoretical analysis of the NLTL provides a first order phase noise source to be based on the large signal model of a voltage variable phase shifter with an equivalent DC noise. The equivalent DC noise resistance provides a baseband noise source and is upconverted by the amount of $dV/d\varphi$ voltage variable phase shift of the NLTL and is observed as phase noise. A discrete NLTL at 200MHz input with harmonics well past 2GHz is used to validate this theory. Additive phase noise at the fundamental is measured to be between -163dBc/Hz and -182dBc/Hz using a cross correlation measurement system and depends on equivalent DC bias resistance. The measured phase noise corresponds closely to the values calculated by the developed theory. The optimized results are equivalent to the best published two diode frequency multipliers with the added benefit of significant harmonics to the 20[th] harmonic.

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[1]M. J. W. Rodwell, M. Kamagawa, R. Yu, M. Chase, E. Carman, and K. S. Giboney, " GaAs Nonlinear Transmission Lines for Picosecond Pulse Generation and Millimeterwave Sampling," IEEE Trans. Microwave Theory Techn., vol. 39, no. 7, pp. 1194-1204, July 1991.

[2]F. G. Ascarrunz, A. Zhang, E. S. Ferre, and F. L. Walls, "PM Noise Generated by Noisy Components," 1998 IEEE International Frequency Control Symposium, pp. 210-217.