Electronic frequency divider as a tool for phase/frequency noise analysis

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Abstract: We demonstrate experimentally that the electronic frequency divider can be used as a simple tool for measuring phase/frequency modulation noise in the beat note and also provide theoretical explanation for that.
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1. Introduction

Frequency/phase noise of an oscillator can be defined as the fluctuations of its output frequency/phase. Frequency noise characterization and measurement of narrow-linewidth lasers is very important for fields like optical frequency metrology and precision measurement [1]. Many proposed methods for measuring frequency noise, such as phase-locked loop frequency discriminator based method [2], recirculating delayed self-heterodyne method [3], method based on delay-line approaches [4], require sophisticated instrumentation and strict conditions. Here we propose the use of electronic frequency divider (EFD) as a simple but elegant tool for quick measurement of frequency modulation noise in the radio frequency (RF) spectrum of beat note by presenting experiment and theoretical model.

2. Theory and experiment

Theoretically, the sinusoidal frequency modulation of a sinusoidal signal with modulation index β and modulation frequency f_m is described by

$$x(t) = A_c \cos(2\pi f_c t + \beta \sin(2\pi f_m t) \tag{1}$$

where f_c is the carrier frequency and A_c is the amplitude of the signal being modulated. The function of EFD is to divide the phase of an input signal by its division ratio (N). Division of the phase of Eq. (1) by N yields Eq. (2) for $\beta \le 1$ and Eq. (3) for $\beta >> 1$ which tell that only f_c and β will always be divided by N.

$$x(t) = A_c \cos(2\pi \frac{f_c}{N} t) - A_c \sin(2\pi \frac{f_c}{N} t) \frac{\beta}{N} \sin(2\pi f_m t) \tag{2}$$

$$x(t) = A_c \sum_{n=-\infty}^{n=+\infty} J_n(\frac{\beta}{N}) \cos(j 2\pi \frac{f_c}{N} t + 2\pi n f_m t) \tag{3}$$

Fig. 1 shows the schematic of experimental setup to analyze the output of EFD subjected to frequency modulated input signal. In Fig. 1, the output of diode laser (DL) has been applied to acousto-optic modulator (AOM) through fiber collimator (FC) and collimating lens to produce two frequency shifted modes at AOM's output. The voltage-controlled oscillator (VCO) and an amplifier is used as an RF drive for AOM and also to generate frequency modulation in the 1st order mode of AOM by varying VCO's output frequency in time around AOM's drive frequency using function generator at its input as shown. The 0th order mode of AOM has been coupled into fiber through collimating lens and FC before applying it to an electro-optic phase modulator (EOM) to generate frequency modulation. Then these two modes are combined through 50:50 fiber coupler before applying to photodiode (PD) to generate beat note which forms an input for EFD. Since the modulation index of a frequency modulated signal

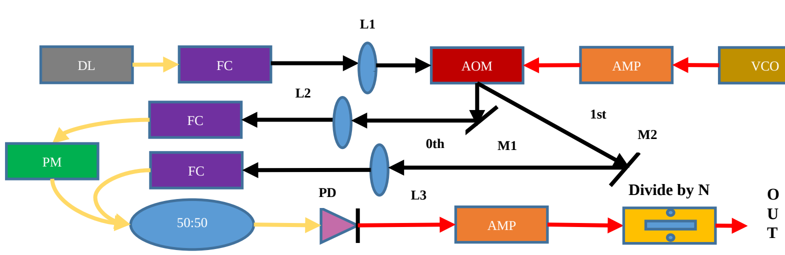

Fig. 1. Schematic of experimental setup. DL: Diode laser; FC: Fiber Collimator; M1,M2: Mirrors; L1,L2,L3: Collimating lenses; AOM: Acousto-optic modulator; Amp: Amplifier; VCO: Voltage-controlled oscillator; FG: Function generator; PM: Electro-optic phase modulator; 50:50: Fiber coupler; PD: Photodiode; Divide by N: EFD; Yellow arrow: single mode fiber; Black arrow: free space path; Red arrow: Electrical cable.

generated using EOM is much lower than that of VCO, the former is referred to as phase modulation (PM) while the latter is referred to as frequency modulation (FM) here.

3. Results and discussion

Using the experimental setup of Fig. 1, we have analyzed the cases of FM and PM for different division ratios (N) of EFD. Fig. 2 show the results of single sided output spectrum of EFD's output. In particular, the black traces of Fig. 2(a), (b) & (c) show the output for division ratios 1, 2 and 64 respectively for FM input whereas Fig. 2(d), (e) & (f) show the output for division ratios 1, 2 and 32 respectively for PM input. Comparing Fig. 2(a), (b) & (c) it can be seen that as the division ratio is increased the width of output spectrum is decreased. Moreover, from Fig. 2(c) the

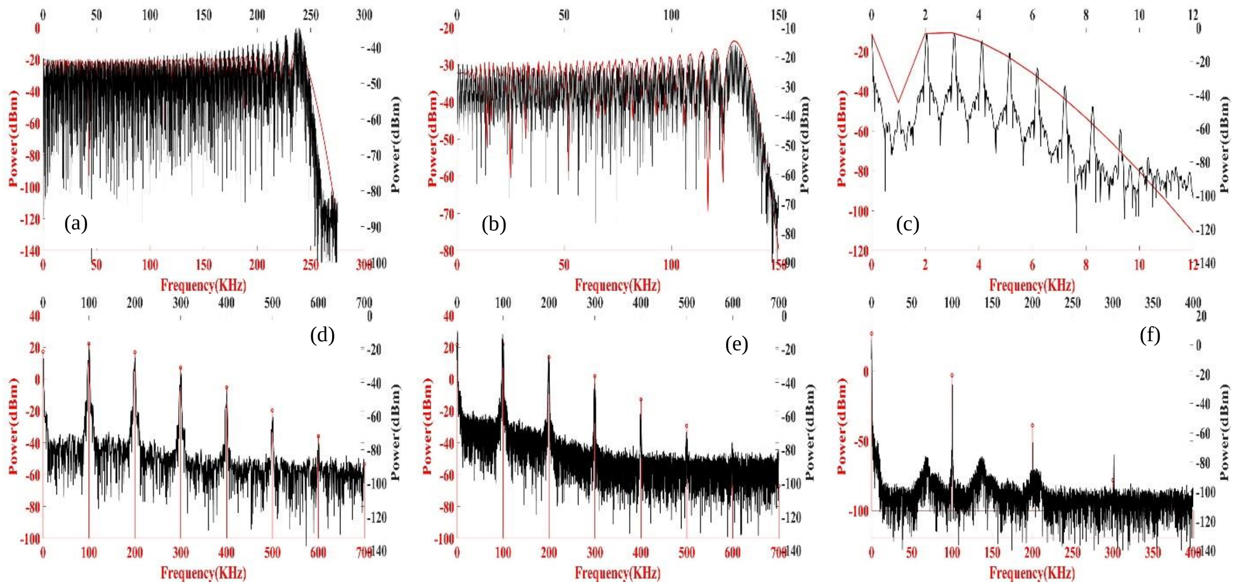

Fig. 2. Comparison of theoretical simulations (red trace) and experimental data (black trace) of output of electronic frequency divider for different division ratio and for different modulation format at input. (a) divide by 1 of FM, (b) divide by 2 of FM, (c) divide by 64 of FM (d) divide by 1 of PM, (e) divide by 2 of PM, (f) divide by 32 of PM.

modulation sidebands at 1 KHz can be observed which was the original rate of modulation applied to the first order mode and was not evident in Fig. 2(a) and Fig. 2(b). Doing the comparison of black traces in Fig. 2(d), (e) & (f) for PM input it can be deduced that as the division ratio is increased the amplitude of the sidebands at far end get reduced. So in both cases the amplitude of sidebands at far end get reduced by EFD which appear as spectral narrowing and theoretically it can be explained through division of β by N as dictated by Eqs. (2) & (3). However, for FM input EFD can also reveal initially unknown rate of modulation. The theoretically simulated red traces, for newly derived value of β according to N, in each plot of Fig. 2 closely match experimental traces which dictate an agreement between theory and experiment. Two x-axis of each plot in Fig. 2 has same normalized frequency scale while two y-axis differ in scale due to inaccuracies resulting from the calibration of conversion factor at each device.

4. Conclusion

The use of electronic frequency divider as a tool for the measurement of phase/frequency modulation noise has been proposed. Theoretically, it has been shown that the modulation index of a frequency modulated input will be divided by the division ratio of the divider. Experimentally, the spectral width of an input is shown to decrease as the division ratio increases while revealing the rate of modulation simultaneously for large modulation index inputs.

5. References

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