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EXPERIMENTAL STUDIES OF NOISE IN A DUAL MODE OSCILLATOR

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ABSTRACT

We present preliminary results of an experimental study of phase modulation and amplitude modulation noise in a specific type of dual mode oven controlled crystal oscillator. Our experiments indicate some correlation between the amplitude modulated and phase modulated noise in two anharmonically resonant oscillations. No correlation was found between the PM noise in both oscillations.

INTRODUCTION

The purpose of this paper is to discuss preliminary results of an ongoing investigation of amplitude modulation (AM) and phase modulation (PM) noise in dual mode oven controlled oscillators (DMOCXO). A DMOCXO has two anharmonic resonant modes. Since both modes share the same environmental effects, DMOCXOs have a wide range of applications in precision measurement and temperature sensing applications. [1] Of particular interest is the potential to greatly reduce long term frequency drift attributed to oven aging and frequency changes due to thermal transients. The problem is that the effects of an additional mode on the noise performance of the mode of interest are not well documented. Our objective is to characterize the correlation between the AM and PM noise in each resonant mode of a DMOCXO and document the effects of dual mode (DM) operation on the noise performance of the fifth overtone (5OT) in 100 MHz SC cut quartz resonators of medium electrode size (3.05 mm). We have approximately 40 resonators made with different polishing and masking processes and small medium and large electrode areas that have been previously characterized for PM noise at the 5OT in single mode (SM) operation. Since the medium electrode resonators with no masking more closely fit the standard design of current resonators, we chose two resonators with different SM operation PM noise performance, for our measurements. R1 had the median SM PM noise performance of its batch, and R14 had the optimum SM PM noise performance of the same batch. [2]

MEASUREMENT EQUIPMENT

The DMOCXO used in our experiments, consists of a dual mode test bed (DMTB) and removable DM resonators. The fundamental mode (f_1), is centered usually about 20.002 500 MHz ±1 kHz, and the 5OT is usually centered around 99.999 850 MHz ± 100 Hz. The DMTB consists of separate excitation and separate output stages for the two resonant modes, with only the oven, the input and output diplexers, and the resonator, in common. Tested low noise isolation amplifiers were added at both outputs of the DM oscillator to prevent feedback and provide additional channels.

The AM noise was measured using a conventional diode detector AM measurement system. A three cornered hat cross correlation PM measurement system was used to measure the single sideband PM noise in the 5OT. [3,4]

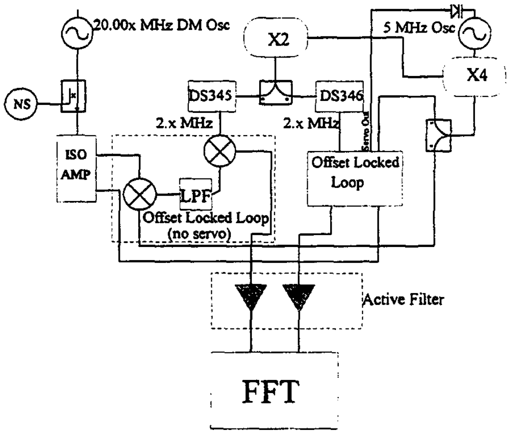

Figure 1. Modified 20.00x MHz PM measurement system

The single-sideband PM noise in the fundamental (f_1) was measured using a modified PM measurement system shown in Figure 1. In this approach, the fundamental is locked to a 5 MHz low noise OCXO using an offset-locked loop. A multiplier chain provides a 20 MHz signal that is mixed with the fundamental. The output is low pass filtered and mixed with a signal from a direct digital synthesizer (DDS). The mixer output drives the phase locked loop and an IF amplifier to a signal analyzer. To ensure phase coherence and low noise, the DDS was locked to the low noise 5 MHz source. A (1/1000) divider at the output of the DDS reduced the digital noise. To verify that the PM noise added by our modified PM noise measurement system (at the f_1) was negligible, we constructed a second channel and verified the single channel results of the modified PM noise measurement system.

Cross correlation measurements on the PM noise of two different carrier frequencies were made using single channel combinations of the measurement systems described above. Cross correlation measurements were also made on the single channel AM and PM measurements of one frequency, i.e. the cross correlation of the 100MHz PM with the 100 MHz AM, and of both frequencies, i.e. the cross correlation of the 20 MHz AM with the 100 MHz PM. Typically the channels with the lowest noise were used in the cross correlation measurements. The gain of each channel was measured using the noise source method. [5] The cross correlation gain was calculated as the logarithmic average of the single channel gains.

MEASUREMENT RESULTS

Previous measurements on the 5OT by Ferre-Pikal et al indicated that the 1/f PM noise in some resonators varied with drive current. [2] We tried to determine if the drive current of one mode had an effect on the PM noise of the other mode by measuring the PM noise in SM and DM operation. However, turning an additional mode on caused a frequency shift and made it unclear if the PM noise degradation was attributable to changes in drive current. Figures 2, 3, and 4 are normalized SM and DM PM noise measurements of the f_1 and 5OT oscillations for Resonators 1 and 14. They are normalized by adding 30log(f) to the measured PM noise.

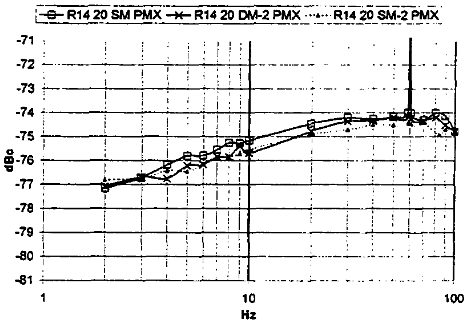

Fig. 2. Normalized 20 MHz (f_1) PM noise measurements of Resonator 14 in SM and DM operation.

The f_1 (20 MHz) PM noise shown in Fig. 2 for Res. (Resonator) 14 indicates little sensitivity of the PM noise to DM or SM operation, even though the frequency shifted by about 150 Hz. Similar results were obtained for Res. 1. The 5OT (100 MHz) PM noise appeared to be more sensitive to the presence of the f_1. The traces labeled SF and FS in Figures 3 and 4, respectively, represent the PM noise of the 5OT in DM operation with the f_1 operating at different mechanically tuned frequencies. Table 1 shows the different operating frequencies for each measurement. The PM noise performance of the 5OT seems to degrade as the f_1 is tuned in frequency even though the drive level in all our measurements remained unchanged.

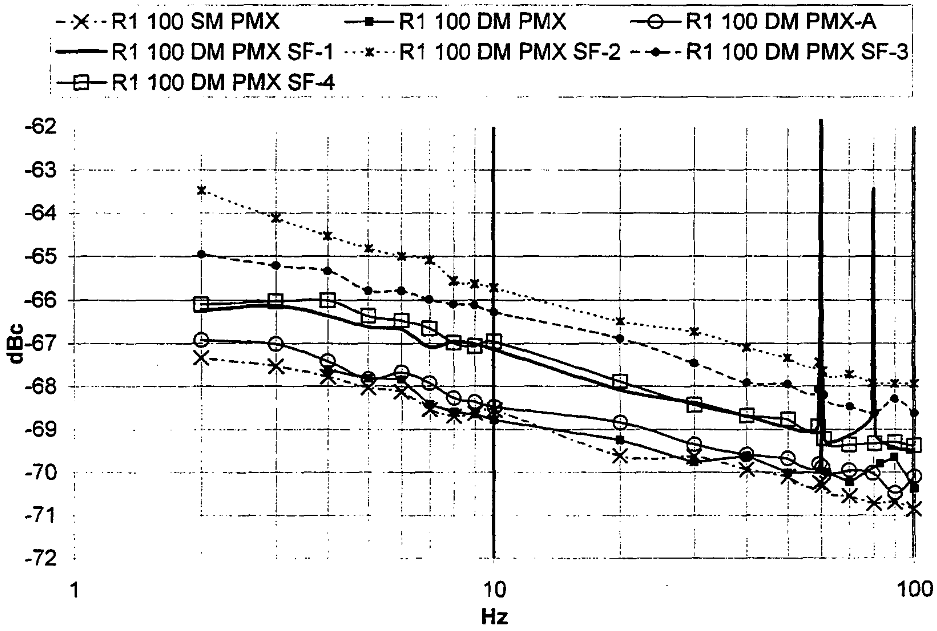

Figure 3. 100 MHz (5OT) PM noise measurements of Res. 1 in DM and SM operation.

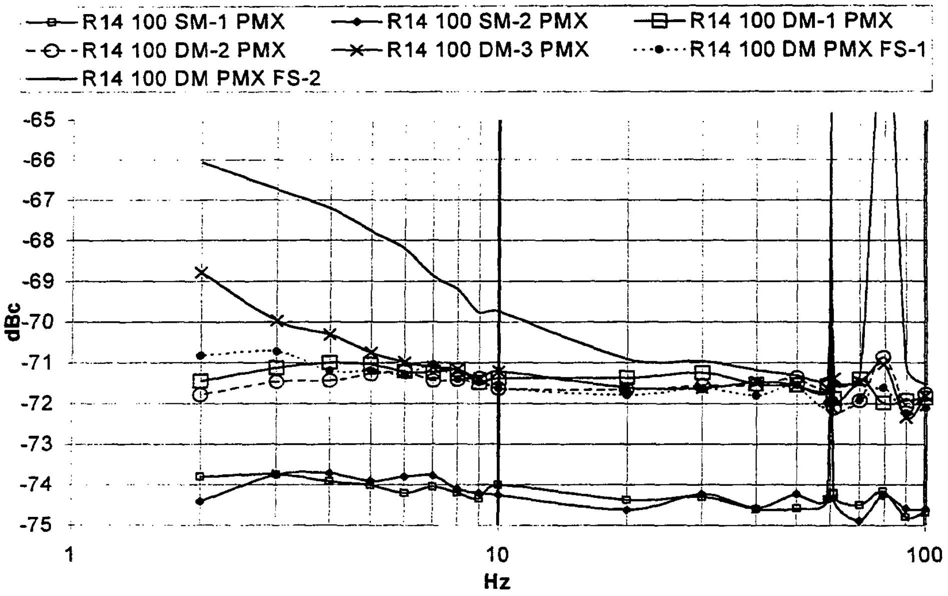

Figure 4. Normalized 100 MHz (5OT) PM noise measurement in Res. 14 for DM and SM operation

Table 1. 5OT frequency at different f_1 frequencies for Resonator 1 (SF traces in Fig. 3) and resonator14 (FS traces in Fig. 4).

Label	Frequency of f_1	Frequency of 5OT
Resonator 1		
SF-1	20.002 708 MHz	99.999 962 MHz
SF-2	20.002 043 MHz	99.999 942 MHz
SF-3	20.003 023 MHz	99.999 957 MHz
SF-4	20.001 605 MHz	99.999 914 MHz
Resonator 14		
FS-1	21.907 274 MHz	99.999 841 MHz
FS-2	20.003 165 MHz	99.999 850 MHz

The observed frequency pulling suggested some interaction between modes, however, cross correlation measurements of the 20 MHz (f_1) PM noise and the 100 MHz (5OT) PM noise, shown in Fig. 5 and 6 suggests that the PM noise in the two oscillations is independent.

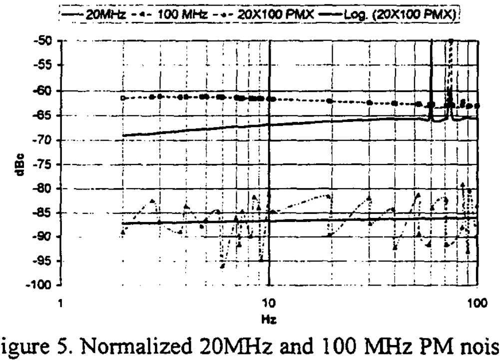

Figure 5. Normalized 20MHz and 100 MHz PM noise cross correlation measurement for Res. 1.

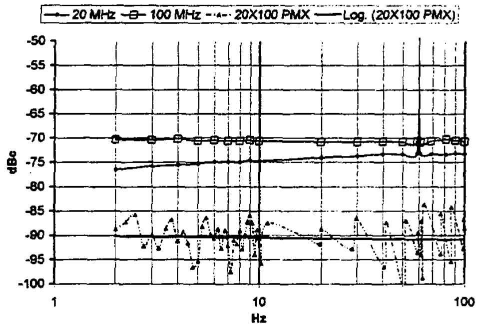

Figure 6. Normalized 20 and 100 MHz PM noise cross correlation measurement for Res. 14.

At 100 percent correlation the cross correlation trace would be a geometric average of the single channel traces. If there is no correlation between the single channel measurements, we expect the cross to average away as (5) log (N), where N is the number of averages. [3,4] At 2000 averages we would expect at least 16.5 dB of rejection, roughly the difference between our measured cross and the geometric mean of the single channel traces. In addition, we would expect that the cross correlation trace would become smoother with more averaging. In all our cross correlation measurements of the 20 MHz PM noise and 100 MHz PM noise, we observed that the cross correlation trace averaged lower but did not become smoother.

Cross correlation measurements of AM noise and PM noise were taken at both resonant frequencies (Figs. 7 and 8). Fig. 7 depicts cross correlation of the 100 MHz AM noise and 100 MHz PM noise. The 20

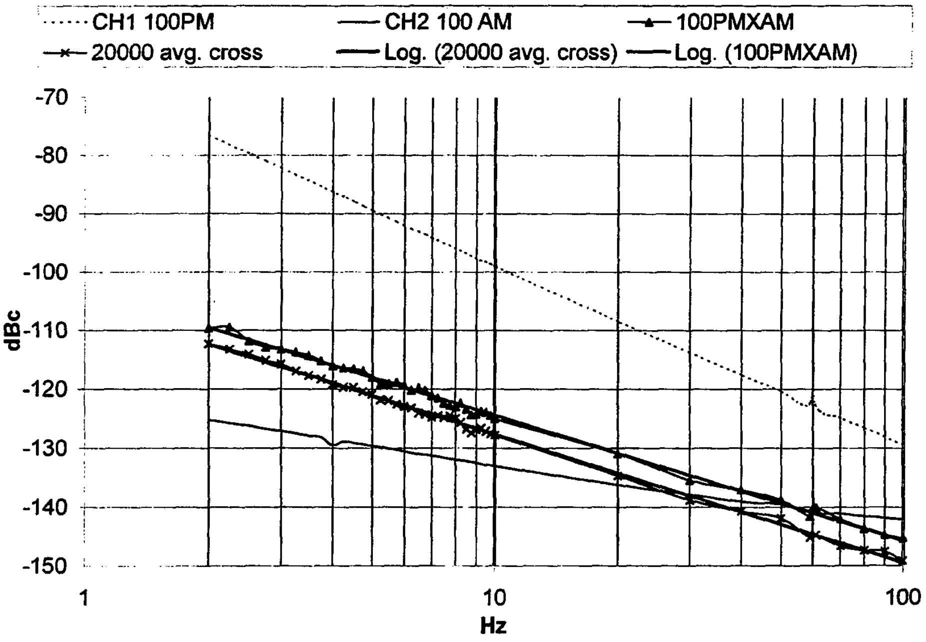

Figure 7. Res. 14 correlation between the 100 MHz PM noise and 100 MHz AM noise in DM operation

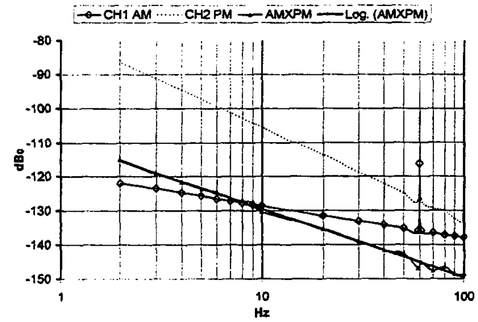

Figure 8. Cross correlation measurement of the AM noise with the PM noise at 20 MHz for Res. 14.

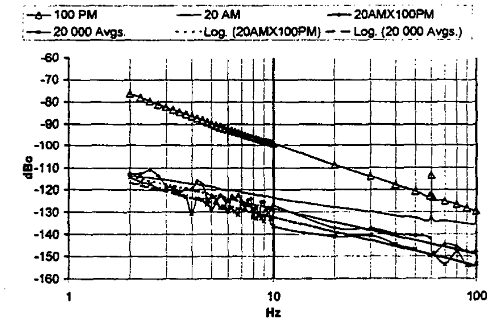

Figure 9. Correlation between the 20 MHz AM noise and 100 MHz PM noise for Res. 14.

MHz PM noise and 20 MHz AM noise cross correlation measurement is shown in Fig. 8. In both measurements the PM and AM noise seemed to be slightly correlated.

The 100PMXAM trace in Figure 7 represents the cross correlation between the AM and PM noise at 2000 averages, the trace labeled 20000 avg. cross is the same measurement at 20000 averages. If they were uncorrelated, we would expect the 20000 average trace to be about 5 dB lower than the 2000 average trace. In Fig. 7 we observe that at 20000 averages the cross correlation is close to 3 dB lower than at 2000 averages, this would indicate some correlation between the AM and PM noise of the individual frequencies. In addition, the cross correlation traces in Figs. 7 and 8 are smoother and their slopes ($\approx f^{-2}$) correspond to the slope of the geometric mean of the single channel PM noise and AM noise measurements.

Figures 9 and 10 show cross correlation measurements between the PM noise in one resonant frequency and the AM noise in the other resonant frequency. Although the cross correlation averages below the single channel traces in Figure 9, the averaging rate is roughly half as large as we would expect if there was no correlation. The f^{-2} slope observed in all the PM noise and AM noise cross correlation measurements indicate that there a small amount of correlation between the AM noise in one resonant frequency and the PM noise of the other resonant frequency.

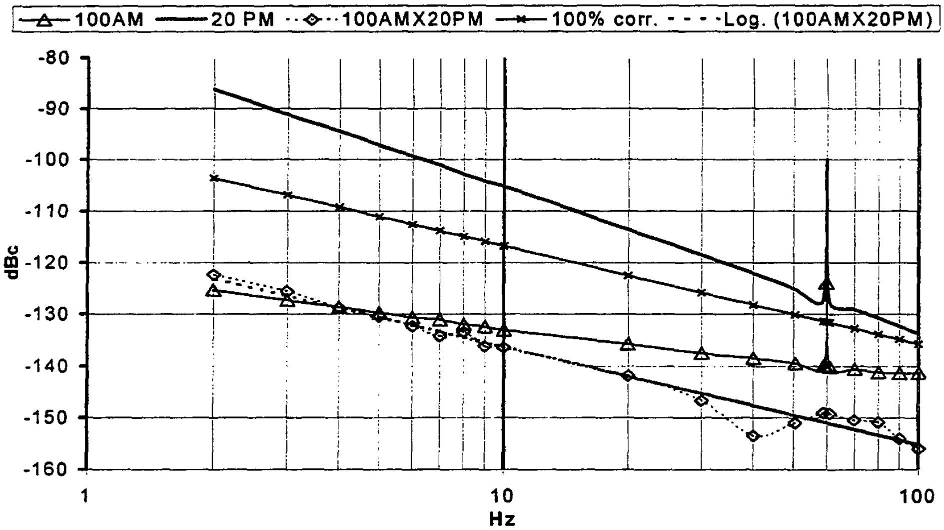

Figure 10. Correlation between the 20 MHz PM noise and 100 MHz AM noise in Res. 14.

DISCUSSION OF RESULTS

PM noise measurements in DM and SM operation indicate some interaction between the modes in our DM oscillator. It is unclear that the frequency pulling observed when tuning either mode is attributable to mode to mode interaction in the crystal. The use of mechanical jumpers to toggle the modes, and small impedance changes in the diplexers probably account for most of the observed cross mode tuning interactions. Experiments done on the 5OT in DM operation (Figure 4) indicate that the PM noise performance degrades when we move the f_1. The measured 5OT PM noise increased when the 5OT was pulled farther from its optimized frequency by the f_1. The cross mode PM noise correlation analysis in both resonators suggests no measurable frequency or phase modulation between the modes.

The PM and AM correlation analysis performed on the individual tones and cross both tones indicates some PM to AM correlation in our oscillator. If the AM noise was 100% correlated to the PM noise, you would expect the correlation curve to be the geometric mean of the both, as shown in Figure 12 by the calculated trace labeled "100% corr", and to intersect with the AM and PM noise curves at some Fourier frequency above 100 Hz. The 100AM trace in Figure 12 intersects the 100AMX20PM trace close to 3 Hz. This indicates that the component of the PM noise attributable to AM to PM conversion is at least 32 dB below the total PM noise, or, less than .07 % of the total noise. The same applies to AM noise attributable to PM to AM conversion. The 20AMX100PM at 2000 averages, intersects the 100 AM about 36 dB from the PM. In the same tone AMXPM measurements, Figs. 8, 9, and 10, we also see very small correlation.

From our measurements, we can infer that the mechanisms in our DMOCXO that produce AM and PM noise in the separate modes are largely independent. We observed that the largest contributing factor to PM noise degradation in the 5OT is the frequency "pulling" caused by tuning the f_1.

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