FLICKER NOISE OF PHASE IN RF AMPLIFIERS AND FREQUENCY MULTIPLIERS: CHARACTERIZATION, CAUSE, AND CURE

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Summary

The high phase stability of atomic frequency standards has called for the development of associated electronic equipment of equivalent or superior stability. We have surveyed the performance of existing high quality frequency multipliers and RF amplifiers which operate in the range of 5 MHz to microwave frequencies. We were most interested in the phase noise in the range of Fourier frequencies, f, of about 10^{-2} Hz to 10^{+3} Hz, since most electronic servo systems in existing atomic frequency standards use modulation frequencies which fall within this range. This range also includes the passive linewidths of existing atomic frequency standards.

We found that all state-of-the-art, solid state amplifiers and frequency multipliers in our survey had random phase fluctuations (phase noise) of significant intensity and with a spectral density proportional to 1/f (flicker noise of phase). Surprisingly, the flicker noise of phase was found to be approximately the same in most of the apparatus included in the survey. The typical one-sided spectral density of the phase noise was about $(10^{-11.2}$ radian$^2)/f$ when referred to the input frequency, and the best performance was only 6 dB better. This performance was independent of the input frequency over at least the surveyed range of 5 MHz to 100 MHz, and did not depend upon the multiplication factor. This noise level exceeds by about 20 dB the stability which is needed for full compatibility with existing hydrogen atom masers and with proposed high flux cesium beam designs.

Through our laboratory experimentation, this flicker noise of phase was shown to be due to intrinsic, direct, phase modulation of the RF carrier by the transistors. No large differences in the flicker noise intensity were found among different types of transistors, whether field effect or bipolar (including overlay), silicon or germanium, high f_T or medium f_T, high DC flicker noise or low DC flicker noise, and hermetic can or plastic. With the knowledge that the active elements invariably cause phase noise via intrinsic, direct, phase modulation, we could predict that negative feedback, and only negative feedback, could reduce the phase noise.

By systematically applying local RF negative feedback (emitter degeneration) to each of the transistors in an apparatus, we have realized typically more than 30 dB (up to 40 dB in some cases) reduction of the flicker noise of phase in amplifiers and frequency multipliers. No other circuit

improvements were found which yielded significant additional reduction of the flicker noise of phase. Individual silver mica capacitors (80% of our stock) gave excessive flicker noise of phase, but, by testing and selecting capacitors, this source of noise could always be avoided. Selection of individual transistors had relatively little effect, typically no more than 4 dB.

This improved performance of amplifiers and frequency multipliers comfortably exceeds the requirements for compatibility with contemporary and proposed atomic frequency standard systems. At the Frequency Control Symposium we will discuss

1. our survey of the state-of-the-art,
2. the measurements which proved that the active elements (transistors) were the unavoidable source of the flicker noise of phase,
3. the use of local RF negative feedback as the only practical means of achieving extremely low flicker noise of phase,
4. the measured performance of our new amplifier and frequency multiplier designs, and
5. the outlook for possible similar improvements in oscillators, mixers, and other phase-processing electronic equipment.