A 10 GHz OPTOELECTRONIC OSCILLATOR WITH CONTINUOUS FREQUENCY TUNABILITY AND LOW PHASE NOISE

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Abstract

A 10 GHz optoelectronic oscillator (OEO) with continuous frequency tunability and low phase noise is presented. By means of coarse tuning (selecting different RF filter) and fine tuning (tuning control voltage of phase shifter), we demonstrated the OEO can operate at any frequency on X-band (~10 GHz, and any frequency on the interested frequency range up to at least 45 GHz) with very low phase noise.

Introduction

As a feedback loop oscillator, optoelectronic oscillator (OEO) can generate a RF/microwave signal with high frequency purity, low phase noise, and an intrinsic frequency spacing. The intrinsic frequency spacing depends on the loop length which dominated by the fiber length. Usually a RF bandpass filter is used in the feedback loop to make OEO operating at one particular frequency and suppress all other operation modes[1].

The block diagrams of frequency tunable OEO are shown in Figs.1 and 2. Essentially, we may make the OEO operate at a particular frequency by selecting a particular narrow bandpass filter (one of F_1 to F_n, shown in Fig.1) or tuning the tunable filter (TF shown in Fig.2), which is called as frequency coarse tuning[2]. The tuning step (tuning resolution) is the OEO intrinsic frequency spacing which dominated by the fiber length. It is obvious that the tuning resolution is limited by the intrinsic frequency spacing. If we want to get higher tuning resolution (smaller tuning step), we have to use very high Q bandpass filter to pick up the particular frequency and suppress all others. For an OEO operating at 10 GHz with 100 kHz frequency spacing, a narrow bandpass filter with Q about 5000 to 10000 has to be inserted in the loop for suppress the side mode (frequency) down to more 40 dB lower than the main mode. If the frequency spacing is reduced to like 100 Hz or less, it is very difficult to make a efficient bandpass filter to pick up a single frequency signal and suppress all others, especially a tunable narrow bandpass filter.

Since the intrinsic frequency spacing depends on the whole loop, we can insert an electronic (RF) phase shifter to make a fine tune of the whole loop length (phase). In Figs. 1 and 2, the control voltage of the phase shifter in the loop can be adjusted so that the OEO operating frequency can continuously shift more than one intrinsic frequency spacing, which is called fine tuning.

In this paper, a frequency continuously tunable OEO is proposed. We take a 2 km single mode fiber (SMF) as the OEO delay line which made a 100 kHz frequency spacing, two bandpass filters (f_{c1}: 10.2 GHz, f_{c2}: 11.1 GHz) to make OEO operate at different frequency and adjusted the phase shifter control voltage to make a fine tuning. The OEO operated at 10.4 GHz for filter 1, and 11.2 GHz for filter 2. Both of fine tune ranges are more than 100 kHz. During the two tuning ranges, the RF output power difference is within 1.6 dB. The phase noise can reach –105 dBc/Hz at 1 kHz for 10.4 GHz, and –98 dBc/Hz at 1 kHz for 11.1 GHz.

Frequency Tunable OEO Setup

Fig.3 shows the configuration of proposed frequency tunable OEO and phase noise measurement setup. A distributed feedback (DFB) laser diode was used as the light source which generated a 8 mW 1.55 μm single mode laser beam. The 10 GHz modulator was used to modulate the laser beam with RF / microwave signal. A RF amplifier (A1) was used to amplify the electric energy and drive the modulator. A 2 km single mode fiber (SMF, fiber 1) was used as the OEO delay line which made a 100 kHz frequency spacing. The photodetector (PD1) converted modulated optical signal to electronic signal. Filter 1, filter 2 and RF switch made OEO operate at different frequency point (called frequency coarse tuning). A voltage control RF phase shifter combining with frequency controller made the operating frequency of OEO can continuously shift over more than 100 kHz (the OEO intrinsic frequency spacing). The 10 percent (10 dB) optical coupler takes a part of optical energy of OEO out for monitor and measurement. Fiber 2 (12 km), photodetector 2 (PD2), amplifier 2 (A2) and a phase shifter combining with a mixer were used to measure phase noise.

Experiments and Results

Phase noise performance

We take two commercial RF bandpass filters as the frequency coarse tuning parts. The spectra of the filters are shown in Figs. 4 and 5. Filter 1 is operating with center frequency of 10.25 GHz, bandwidth of 277 MHz (Q value of 37), and 1.5 dB insertion loss. Filter 2 is with center frequency of 11.1 GHz, bandwidth of 628 MHz (Q value of 18), and 2.4 dB insertion loss. Figs. 6 and 7 show the phase noise performance of OEO with filter1 and filter 2. Both of them can reach about –100 dBc/Hz at 1 kHz (-105 dBc/Hz for filter 1 and –98 dBc/Hz for filter 2). Since the Q value is not high enough (only 37 and 18 for filter 1 and filter 2, respectively), the phase noise performance is slightly different for different filter.

Frequency tunability

Besides taking RF bandpass filters as the frequency coarse tuning parts, we also inserted a voltage control microwave phase shifter into OEO loop. By tuning the control voltage of the phase shifter, we made the OEO's operating frequency continuously shift more than 100 kHz (the intrinsic frequency spacing of this particular OEO) at both of 10.2 GHz and 11.1 GHz points. The frequency fine tuning performance (vs. the control voltage of the phase shifter) is shown in Fig.8. The spectra of continuous tuning with filter 1 and filter 2 are shown in Figs. 9 and 10. The output power difference of OEO over the whole tuning range is within 0.6 dB at 10.4 GHz point, and 1.6 dB at 11.2 GHz point.

Conclusions

An OEO can generate a high frequency purity RF/microwave signal with an intrinsic frequency spacing. We made it operate at a particular frequency point with different narrow bandpass filter and can change the operating frequency by selecting different filter. For this approach (called as coarse frequency tuning), the minimum frequency change (tuning step, or tuning resolution) is the intrinsic frequency spacing. Meanwhile we adjusted the control voltage of the phase shift in the loop to continuously change the OEO operating frequency more than one intrinsic frequency spacing, which is called fine tuning. In our experiment setup, a 2 km single mode fiber (SMF) was used as the OEO delay line which made a 100 kHz frequency spacing. We used two bandpass filters (f_{c1}: 10.2 GHz, f_{c2}: 11.1 GHz) to make OEO operate at different frequency and adjusted the phase shifter control voltage to make a fine tuning. The OEO operated at 10.4 GHz for filter 1, and 11.2 GHz for filter 2. Both of fine tune ranges are more than 100 kHz. During the two tuning ranges, the RF output power difference is within 1.6 dB. The phase noise can reach –105 dBc/Hz at 1 kHz for 10.4 GHz, and –98 dBc/Hz at 1 kHz for 11.1 GHz.

Acknowledgments

The authors would like to thank A. Kirk and W. Diener for their help in the measurement. This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration and supported by U.S. Air Force Laboratories.

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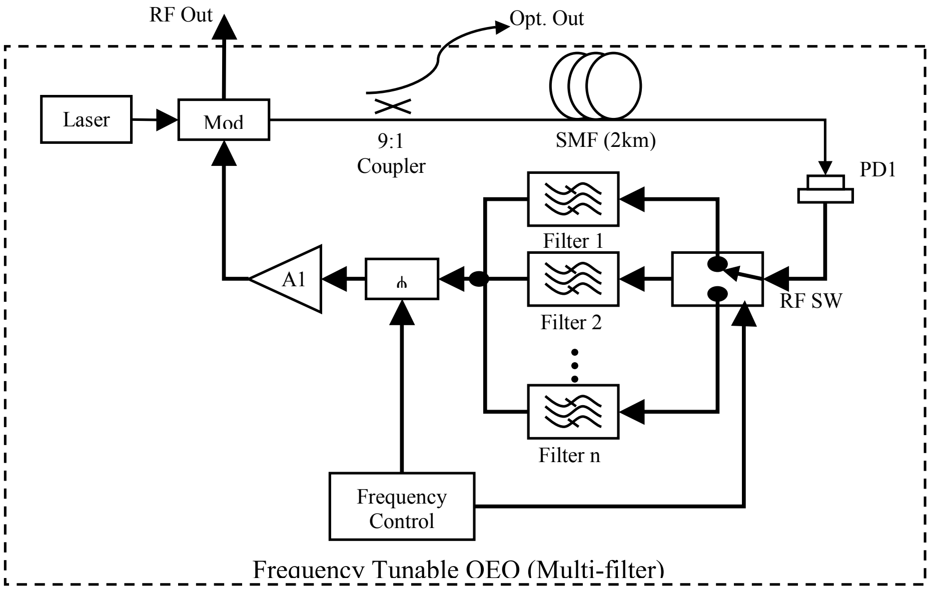

Fig.1 Frequency tunable OEO with multi-filter.

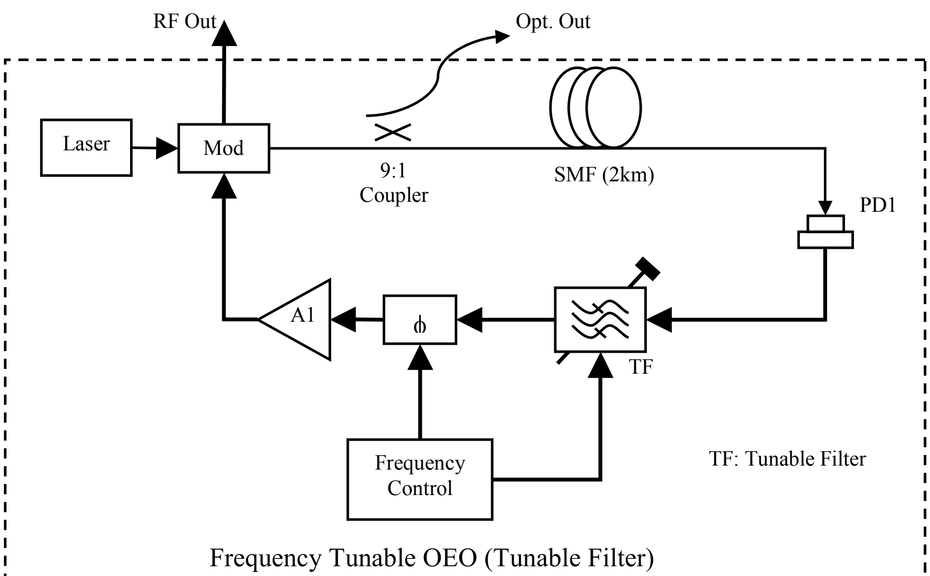

Fig.2 Frequency tunable OEO with tunable filter.

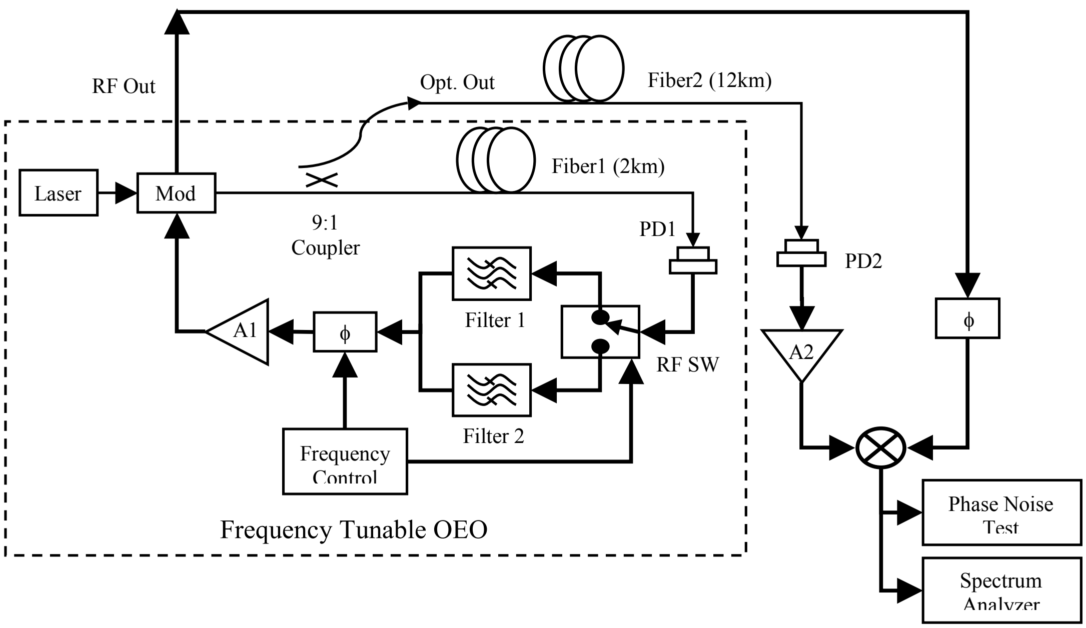

Fig.3 Frequency tunable OEO and testing setup.

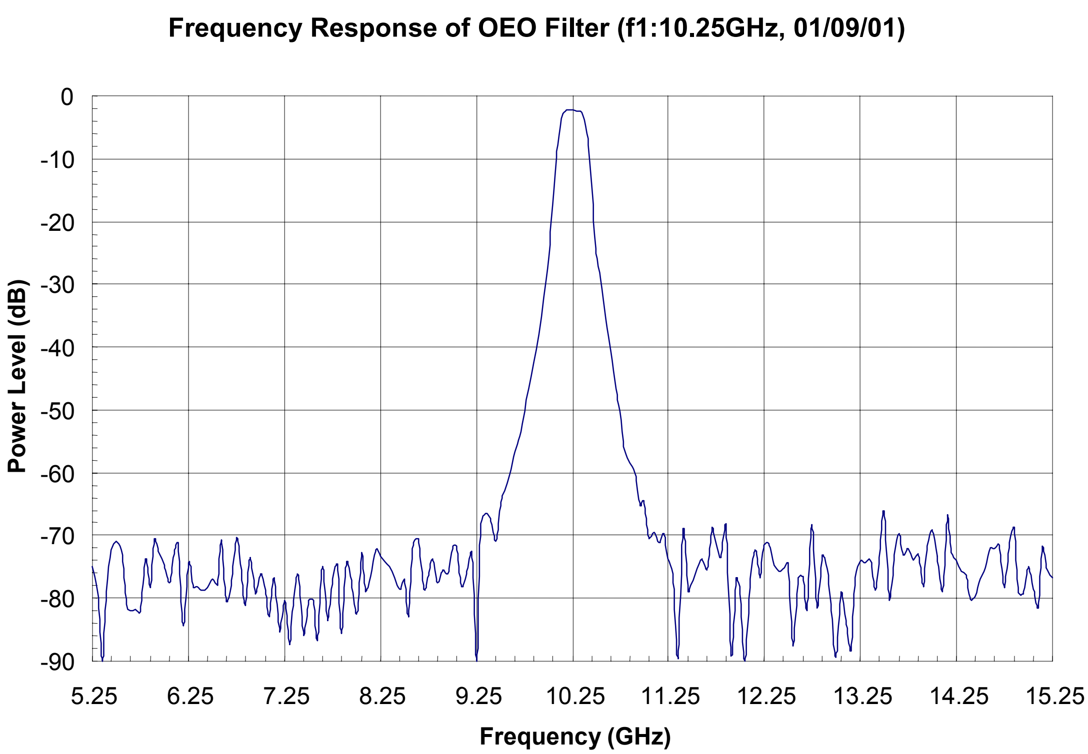

Fig.4 Frequency response of OEO filter 1.

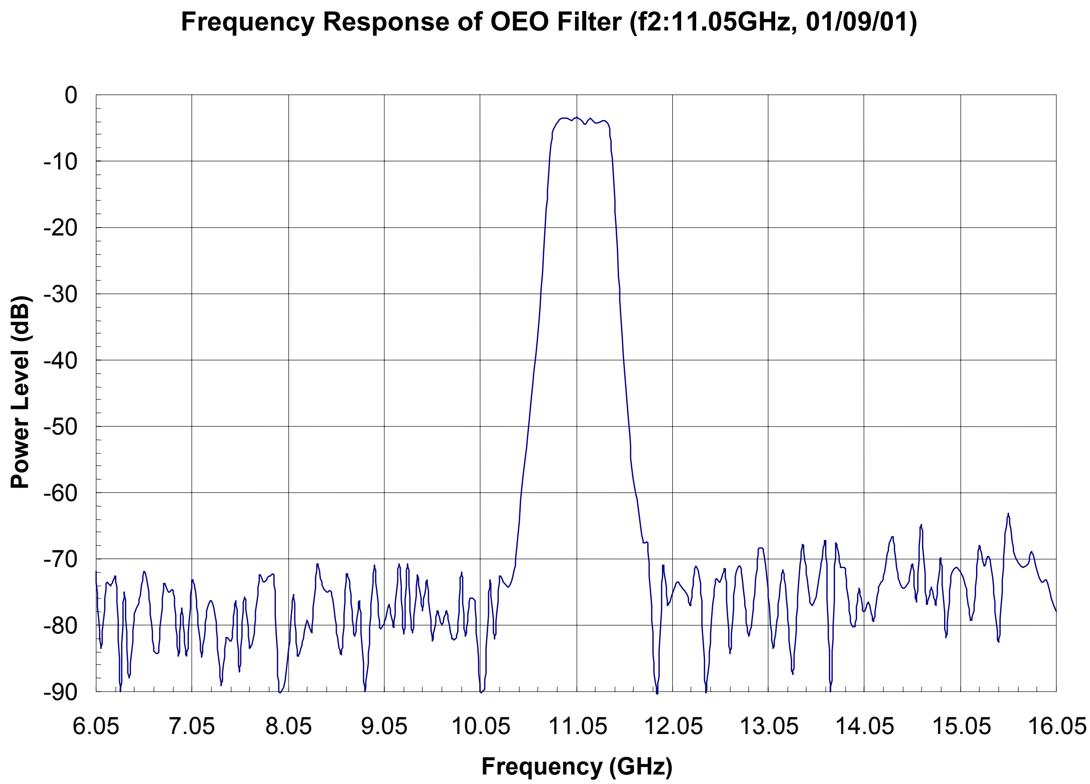

Fig.5 Frequency response of OEO filter 2.

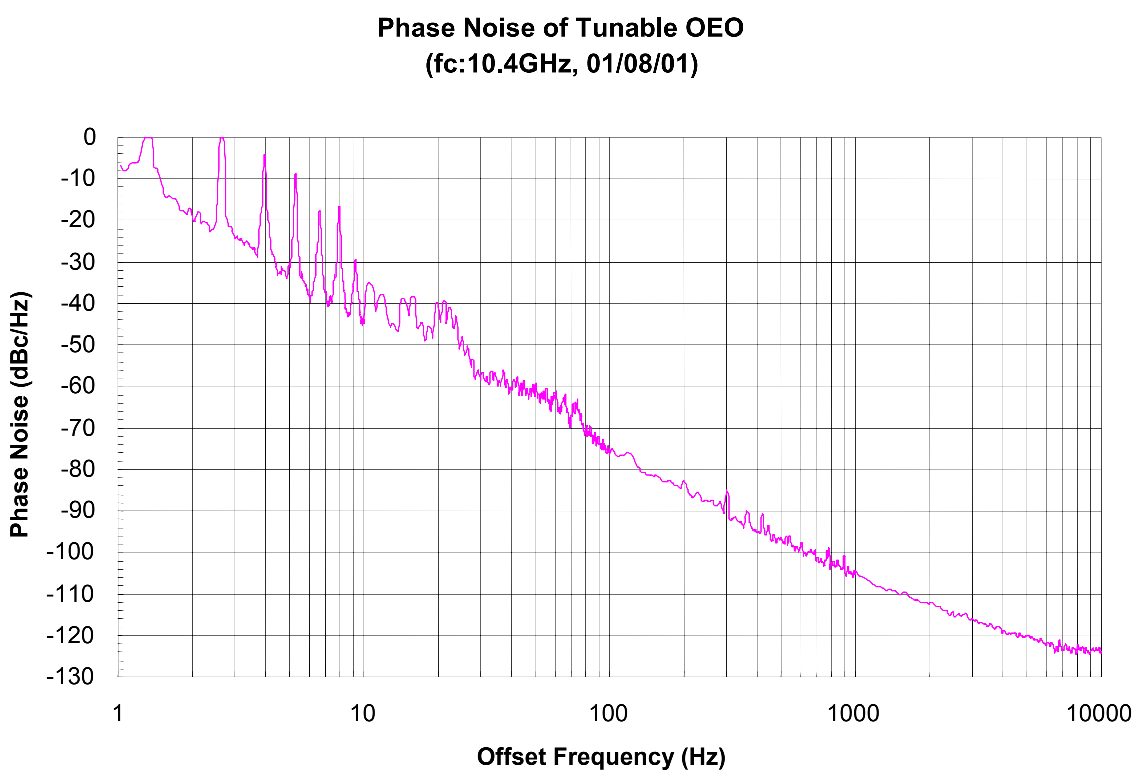

Fig.6 Phase noise of tunable OEO with filter 1.

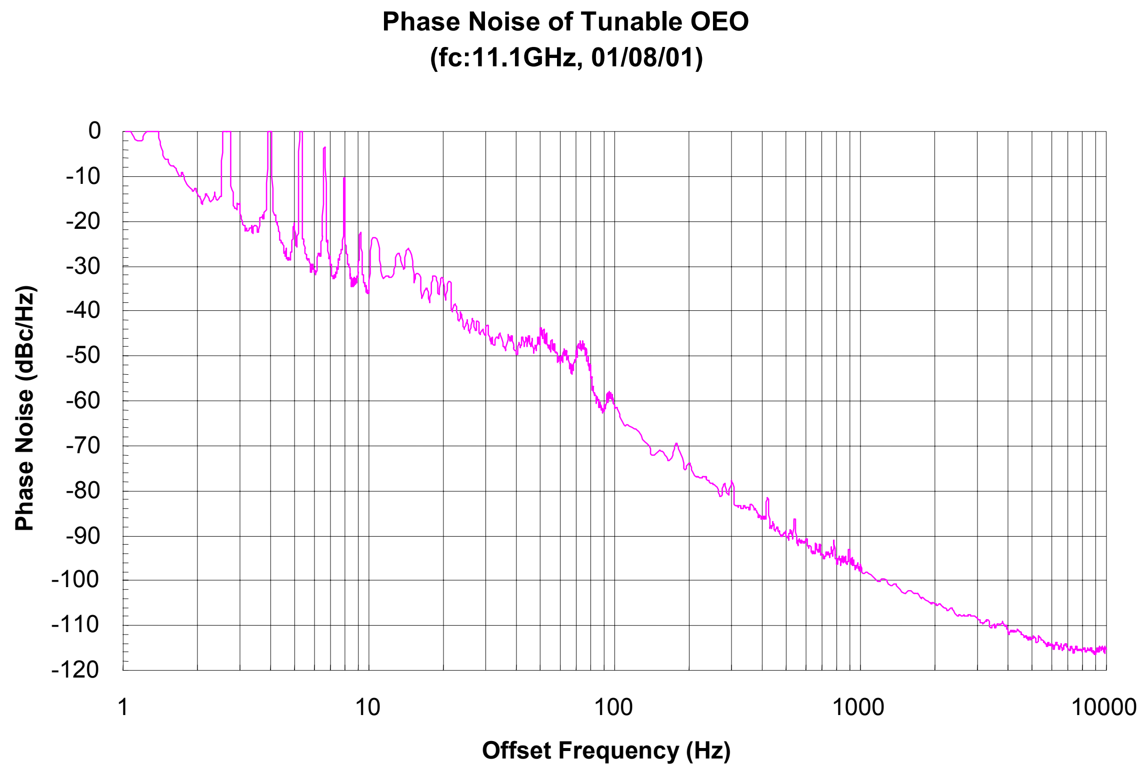

Fig.7 Phase noise of tunable OEO with filter 2.

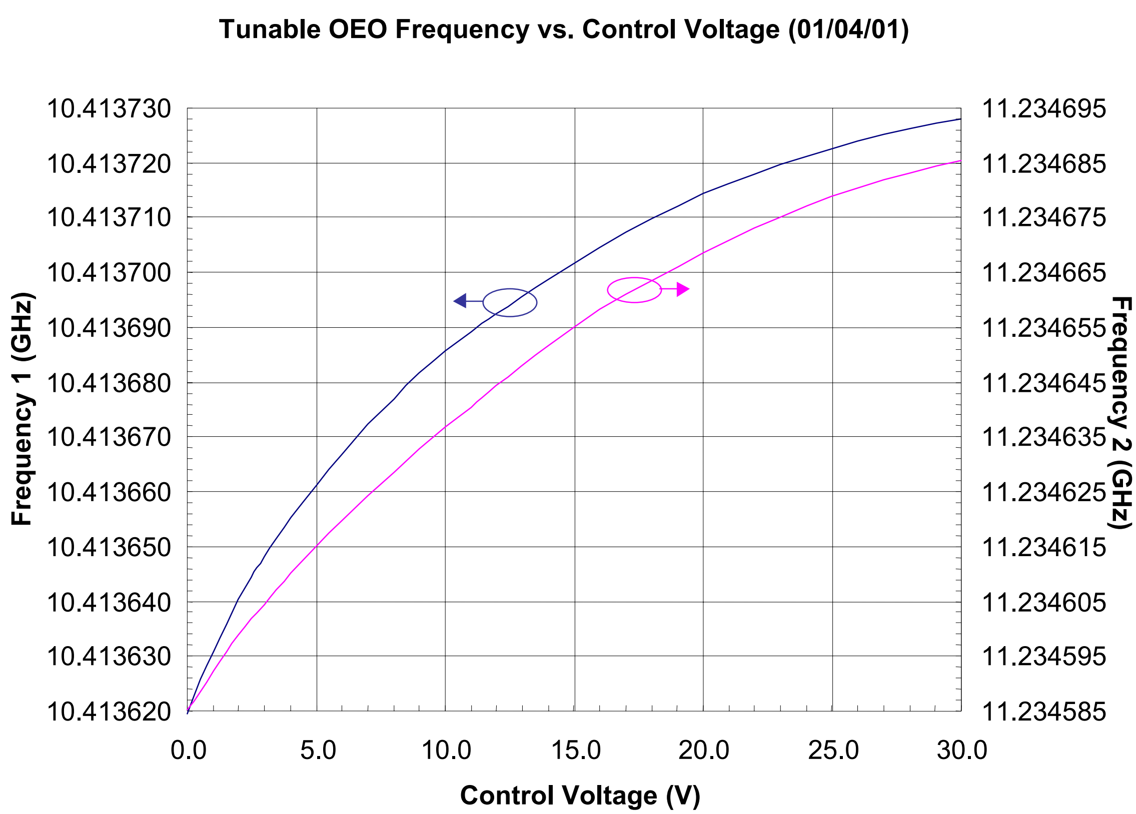

Fig.8 Tuning frequency range of the OEO vs. the control voltage.

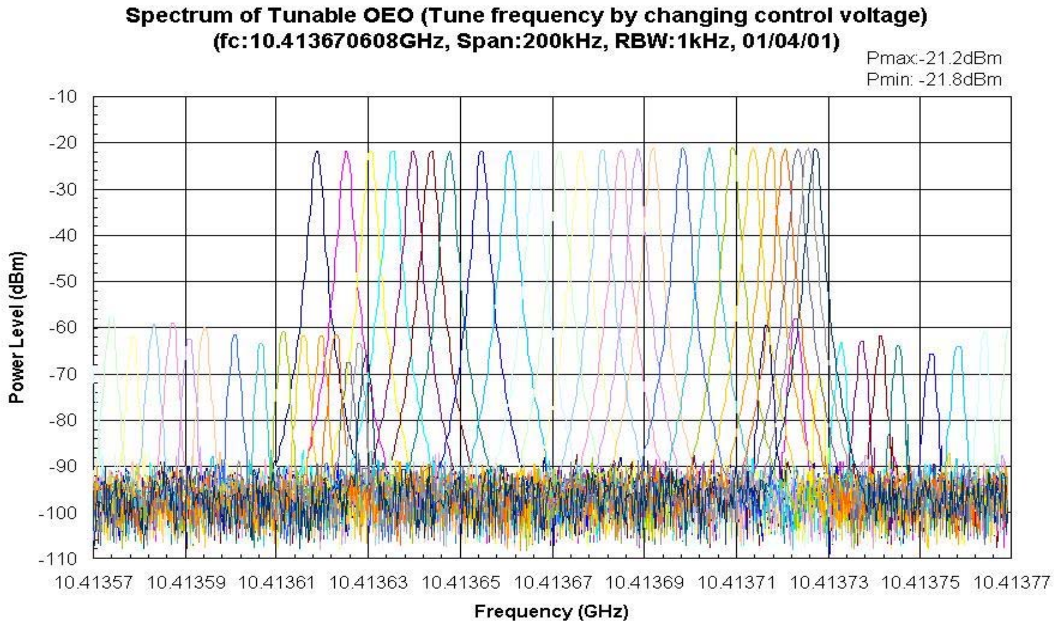

Fig.9 Spectra of frequency tunable OEO with filter 1.

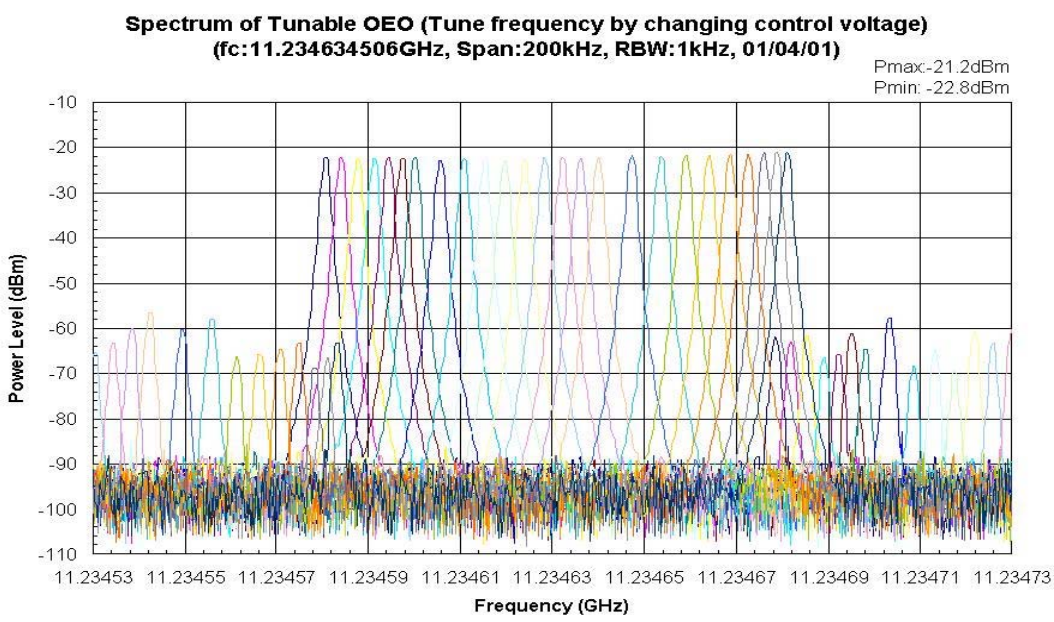

Fig.10 Spectra of frequency tunable OEO with filter 2.