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Injection-Lock-Type BAW Oscillator Aiming for Self-Oscillating Atomic Clock
自励発振型原子時計のための注入同期式ＢＡＷ発振器

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1. Introduction

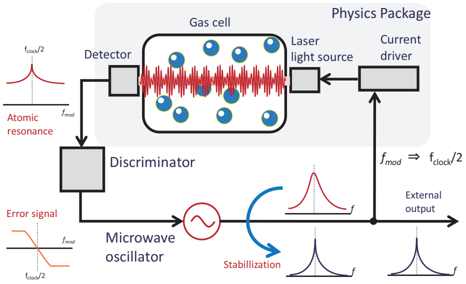
We are focusing on self-oscillating atomic clocks equipped with the injection-lock-type oscillator, where the huge digital discrimination system based on a conventional lock-in amplifier can be shortcut by directly feeding back the clock frequency of Rb (6.834 GHz) from an atomic resonator to the microwave oscillator. In this report, we address the development of an injection-lock-type BAW oscillator, which is a key component for constructing self-oscillating atomic clocks. The developed oscillator can deliver a signal obtained by dividing the 6-GHz-band injected frequency by 2 in synchronization with the injection signal around the clock frequency.

2. Injection-lock-type BAW oscillator

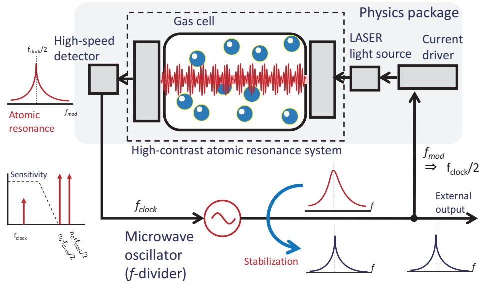
We developed an injection-lock-type oscillation circuit using a BAW resonator as a key component to construct a self-oscillating atomic clock[1–3]. Conventionally, a low-Q on-chip inductor is connected to an injection-lock-type oscillator as an element providing inductive characteristics. This is intended to expand the locking range by supressing the Q factor. On the other hand, a low Q factor has a disadvantage of increasing the risk of sudden unlocking, and in an atomic clock consisting of multiple system blocks, there is little need to widen the locking range by changing the design of the oscillator alone. Also, as can be seen in Fig. 1, in the atomic clock, the oscillator itself serves as an interface for providing a clock to an external system, and the reduction of phase noise, spurious, and harmonic frequencies is always required. Therefore, an acoustic wave device with excellent frequency selectivity of inductive characteristics instead of the on-chip inductor, especially a BAW resonator with high Q, was adopted for the injection-lock-type oscillator in this research[4,5].

3. Fabrication of BAW oscillators

Figure 2 shows a circuit topology and a photograph of the prototype oscillator on a PCB board. The typical characteristics of the BAW resonator used in the prototype were as follows: resonance frequency f_r, 3.141 GHz; antiresonance frequency f_a, 3.230 GHz; Q at resonance Q_r, 1458; Q at antiresonance Q_a, 326; and effective coupling coefficient k_t^2; 6.67%. Originally, frequency screening is performed during touchstone evaluation to strictly match the atomic resonance (CPT resonance), but it was not performed here as a preliminary trial. Therefore, the adopted BAW

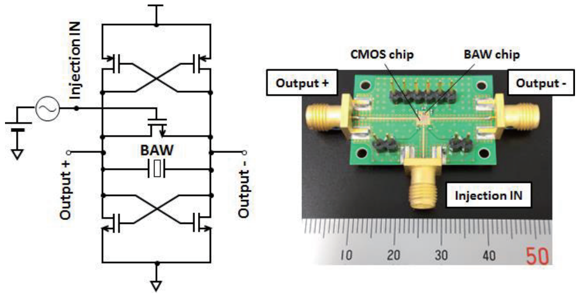


(a) Conventional system



(b) Self-oscillating system in proposal

Fig. 1 Conceptual illustration of compact microwave atomic clock



(a) (b)

Fig. 2 Injection-lock-type BAW oscillator: circuit topology (a), and photograph of PCB-mounted oscillator (b)

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resonator has a resonance frequency lower than the desired frequency, and the characteristic impedance of the resonator is shifted to the low-impedance side. The reason why the Q_r is higher than the Q_a is based on the above-mentioned impedance downshift. The CMOS chip shown in Fig. 2(b), which is an inverting amplifier, was designed using the 65 nm rule and was processed in the external fab.

4. Evaluation of injection-lock characteristics

Figure 3 shows the oscillation spectrum when the 6-GHz-band signal is injected into the fabricated BAW oscillator. In this evaluation, an RF signal with a power of 0.0 dBm and a frequency of 6.34 GHz was superimposed on a 1.0-V DC bias and injected from the injection-IN port shown in Fig. 2. In Fig. 3, the injected signal was outputted as a subpeak of about −50 dBm intensity, and a main peak of 7.14 dBm intensity was observed successfully at a half frequency (3.17 GHz) of the injected RF signal. As the frequency of the RF signal is changed, the frequency of the main peak can follow it within a range width of about 80 MHz.

Injection locking is induced by the nonlinearity of the amplifier. Therefore, a so-called “Arnold tongue” is observed in which the locking range can be increased by intensifying the power of the injected RF signal. Figure 4 shows locking modes for the power and frequency of the injected RF signal. Here, a divided-by-2 mode was observed in the gray area, and it was clearly observed that the width of the divided-by-2 mode is expanded by intensifying the RF signal power.

5. Conclusion

An injection-lock-type BAW oscillator was developed as a key to constructing a self-oscillating atomic clock. The developed oscillator outputs the signal divided by 2 in synchrony with the 6 GHz band injection RF signal. The width of locking range depends on the power of the injection signal, and was 80 MHz for an injection signal in which an RF signal of 0.0 dBm was superimposed on a DC bias voltage of 1.0 V. If a self-oscillating atomic clock that directly feeds back the clock frequency of Rb atoms (6.834 GHz) is realized, the digital discriminator based on a lock-in amplifier, which is an obstacle to chip scale downsizing, can be shortcut. The atomic clock system can be significantly reduced in size. The injection-lock-type BAW oscillator proposed in this paper can play a key role in greatly promoting the development of this self-excited oscillation-type atomic clock and the chip design of the atomic clock system.

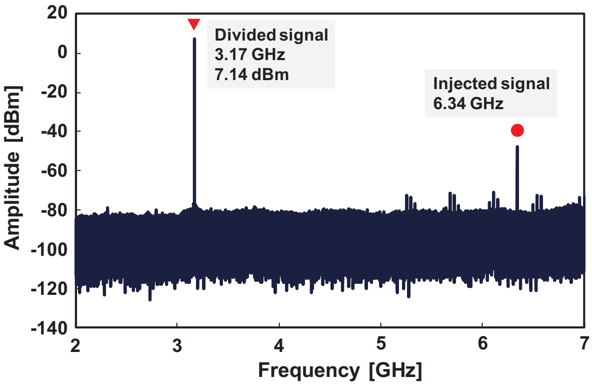

Fig. 3 Oscillation spectrum under the injection rocking

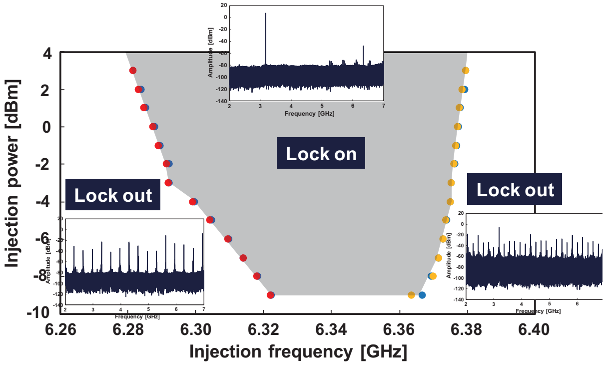

Fig. 4 Injection power dependence of locking range

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