Letters

Ultra-Wideband SAW Correlator

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***Abstract*—A surface acoustic wave (SAW) correlator that satisfies FCC bandwidth requirements for ultra-wideband (UWB) operation has been built and tested. The correlator operates within the 3.1 to 10.6 GHz bandwidth region and uses bi-phase shift keying (BPSK) modulation to achieve a spreading of the main lobe to a 25% bandwidth. This device is capable of spreading or de-spreading a UWB signal directly to or from base-band to microwave frequencies.**

I. Introduction

It has been pointed out recently that a surface acoustic wave (SAW) correlator can provide a means of performing the complex signal processing required for ultra-wideband (UWB) transmission and reception [1]. The SAW correlator can passively spread or de-spread an input signal directly from baseband to the UWB operating frequency. Applied in this manner, a SAW correlator serves as the heart of a UWB radio, eliminating high-powered signal processing electronics.

Complete system implementations of SAW correlators in UWB networks have been proposed, as correlators permit selectivity on the basis of code as well as frequency. A multi-code UWB implementation scheme using SAW correlators with chirp modulation has been proposed and analyzed [2]. Several different spectral-encoded UWB communication systems using SAW devices have been presented [3]. However, in order to implement any of these various proposed approaches, it has been necessary to first fabricate SAW correlators that operate within the Federal Communications Commission (FCC) designated band for developmental UWB communication devices. Fabrication difficulties arise due to the high center frequency and wide bandwidth needed in the correlator. The frequency requirements translate into small, isolated geometries in the correlator that are lithographically difficult to fabricate.

UWB SAW correlators that operate below the officially sanctioned UWB band have been previously reported [1]. The use of advanced electron beam lithographic techniques has now enabled the fabrication of bi-phase shift keyed (BPSK) correlators with an operating frequency from 3.1 to 4.2 GHz. This operating frequency and bandwidth satisfy the FCC designation for experimental UWB communications equipment [4].

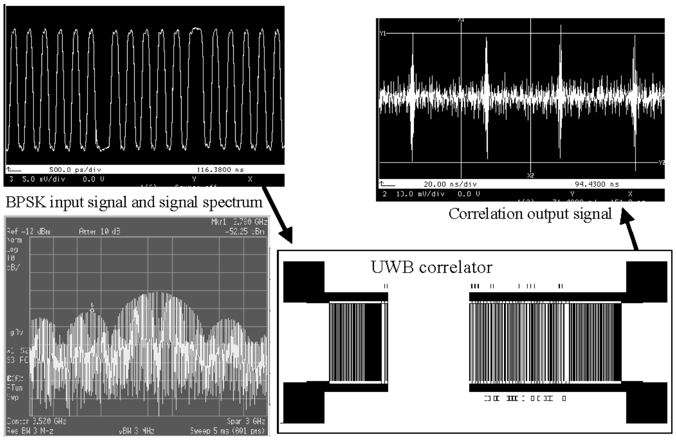

Fig. 1. UWB SAW correlator with −3 dBm BPSK input signal centered at 3.63 GHz, input signal spectrum indicating the signal's 25% bandwidth, and the resulting output signal with a 5:1 peak-to-sidelobe correlation peak.

II. Application

The operation of a correlator as a UWB radio is shown in Fig. 1. The SAW correlator receives the BPSK sinusoidal input from an antenna. The correlator input transducer converts the electrical signal into an acoustic Rayleigh wave, with its energy confined to the surface. The wave travels across the crystal surface, in this case YZ-cut lithium niobate, and interacts with the output interdigitated transducer (IDT). The correlator acts as a matched filter and produces a signature peak voltage output when the acoustic BPSK signal matches the time-reversed signal encoded into the output transducer.

The correlator operates passively, taking the place of high-powered, high-speed digital electronics. For very short range applications (< 2 m) it is possible to operate the correlator without a preamplifier. In these applications, the radio can consist of an antenna, the correlator, a demodulating detector, and a voltage comparator. The demodulating detector can be a passive microwave diode detector. In that case, the only powered electronics operate at baseband frequencies, making it possible to build a very low-powered radio.

We tested the correlator as a receiver without a preamplifier. Using a 1.9-mA, 1.5-V powered SiGe detector, we obtained output signals of 180 mV for a 0 dBm input signal.

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III. Design and Fabrication

We designed the correlators on YZ-cut lithium niobate due to the high (4.5%) electromechanical coupling coefficient and our previous experience with the material. The frequency of operation and wave propagation velocity determine the minimum dimension. We used a split finger design to mitigate finger edge acoustic reflections, giving a minimum physical feature size of $\lambda/8$. The finger pitch was 0.12 μm, but the fingers were drawn 0.08 μm wide, providing a bias to enable the electron beam lithography to obtain the final desired dimension.

The lowest center frequency, f_0, and bandwidth, BW, which will both satisfy fabrication constraints for a correlator and the FCC guidelines for UWB operation are $f_0 = 3.63$ GHz and BW $= 25.2\%$. This bandwidth is calculated using the formula:

$$\mathrm{BW} = \frac{2\,[f_H - f_K]}{[f_H + f_L]},$$

with f_H and f_L being the upper and lower frequencies at which signal amplitude is -10 dB down from the peak. We used six finger pairs per chip, resulting in a main lobe width of 1.21 GHz and a -10 dB bandwidth of 915 MHz. The input IDT used a single chip for an equivalent bandwidth. The code used was a 31-chip m-sequence code, of which there are six orthogonal variants [5].

The correlator could benefit from frequency domain apodization to lower the sideband levels, if the correlator will be used as part of a transmitter. The FCC EIRP requirement below 3.1 GHz is -51.3 dBm. To balance out attenuation across the output IDT, a linear finger weighting was used; however, the correlator output was not apodized. Consequently, high-power applications may require the use of a separate high-pass filter between the antenna and the correlator to satisfy the EIRP requirement.

The correlators were fabricated using a two-mask process (Fig. 2). The first mask was programmed into an electron beam machine where many different energies were chosen according to layout location to obtain the correct overall exposure. The first mask was used to perform a liftoff operation on 500 Å aluminum for the correlator fingers. The second mask is photolithographic and was used for a liftoff operation on 2-μm-thick gold used to pattern bus-bars and pads.

The finger lithography is limited to fairly coarse discrete steps, since a change in 0.01 μm of minimum feature size translates into a center frequency shift of 9% or 330 MHz. Also, the mass loading of the thin aluminum fingers tends to shift the final frequency down by an unpredictable amount. To compensate for these two effects, a final tuning operation is done by performing a wet aluminum etch on the entire wafer. This thins the aluminum fingers and enables a fairly exact selection of final operating frequency.

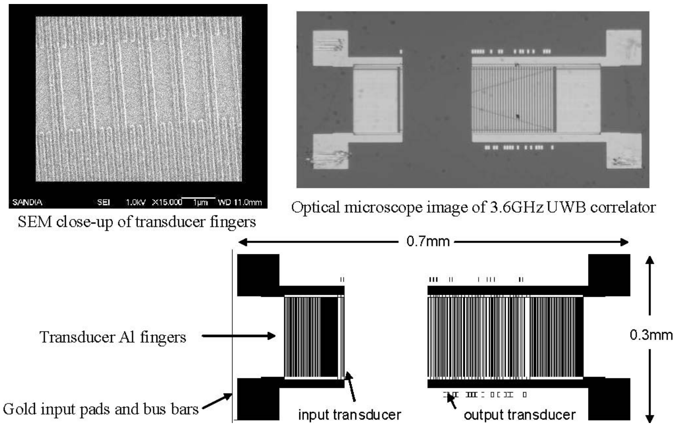

Fig. 2. SAW correlator surface lithography, electron, and optical microscope images.

We found that packaging of the devices invariably led to some signal degradation. The high operating frequency of the correlators necessitated direct mounting of the devices on a Duroid waveguide. In addition, minimal length 3-mil-wide gold ribbon bonds were used for connections. These steps minimize but do not completely eliminate package-induced parasitic signal degradation.

IV. Test Results

The correlators produce strong correlation peaks with typical peak-to-sidelobe (PSL) ratios of 5:1. The maximum theoretical PSL for a correlation operation with a periodic input signal is equal to the number of chips, 31:1 in our case. Maximum observed PSL in fabricated correlators is $(4\mathrm{N}_{\mathrm{chips}})^{1/2}$ or about 11:1 for a 31-chip correlator [6]. We believe but cannot yet confirm that surface and finger-edge variations are limiting the PSL below maximum obtainable levels.

For a -3 dBm BPSK input signal, we obtained a voltage correlation peak signal of 15 mV. This represents an insertion loss of 23 dB, which is a large loss but still an impressive result, considering the complex signal processing performed by the correlator. We observed that changes that tend to increase parasitic capacitances also tend to degrade the signal.

V. Conclusion

A SAW correlator capable of operating within the FCC guidelines for UWB communication has been fabricated and tested. Future work will focus on decreasing insertion loss. We believe no single factor significantly limits component performance.

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