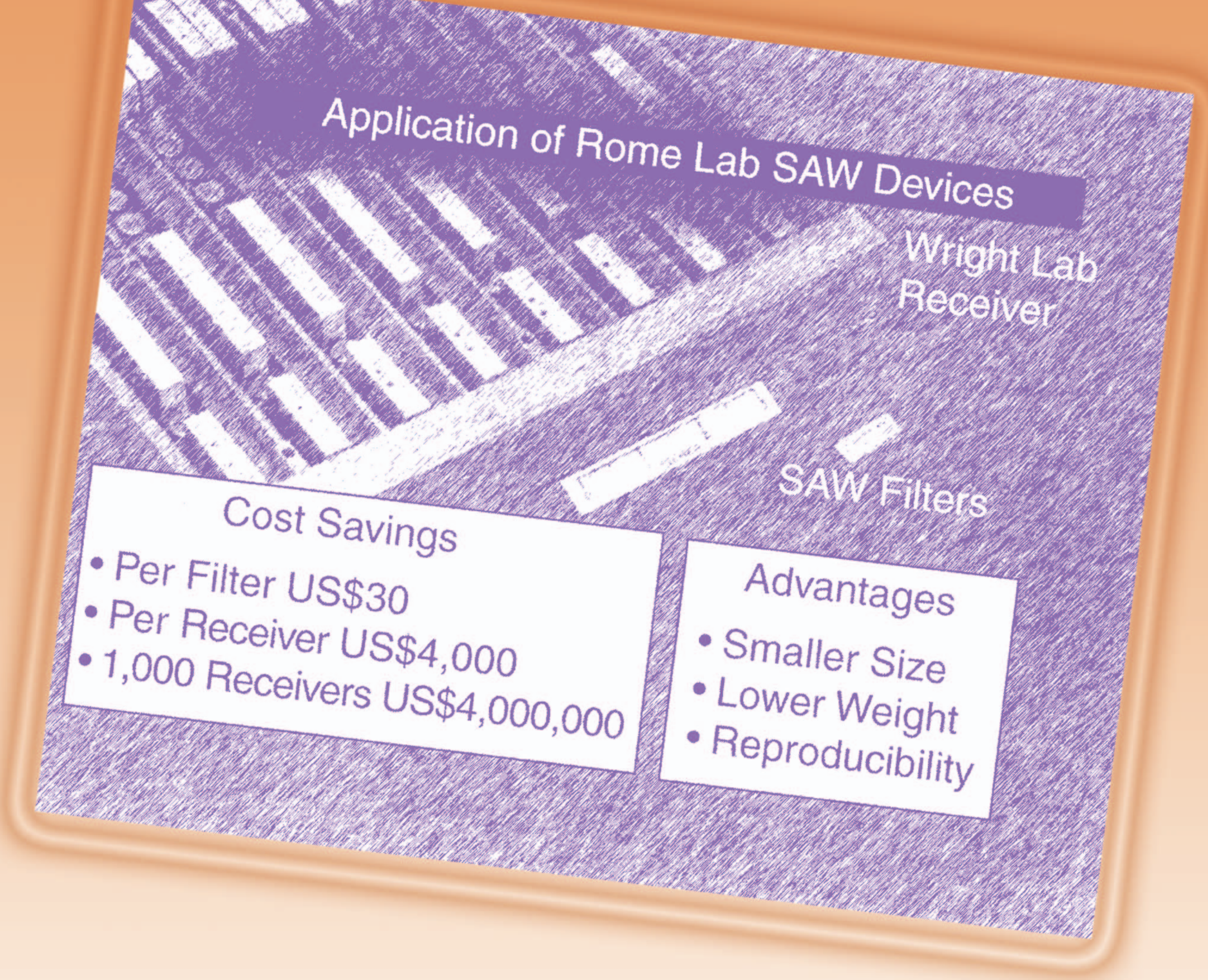


# High Quality

## *Ken Laker's pioneering research on surface acoustic wave (SAW) filters.*

**Paul H. Carr**

Ken Laker advanced surface acoustic wave (SAW) filter and resonator technology with significant decreases in the size, weight, and cost of oscillators, fast frequency-measuring filter banks, and compact fast-frequency- hopping synthesizers. His compact SAW resonator chip at 780 MHz had a Q factor of almost 5,000, five times that of larger electromagnetic equivalents. His technique of designing withdrawal-weighted SAW transversal filters increased out-of-band rejection from 30 dB to more than 60 dB. He was awarded a U.S. patent for his technique of connecting multiple SAW transducers to an electromagnetic transmission line input to a frequency synthesizer.

Kenneth Laker performed his pioneering research on surface acoustic wave (SAW) components while serving from July 1973 to July 1977 as a lieutenant and then captain at what is now the Air Force Research Laboratory, Hanscom Air Force Base. It was an exciting time to be

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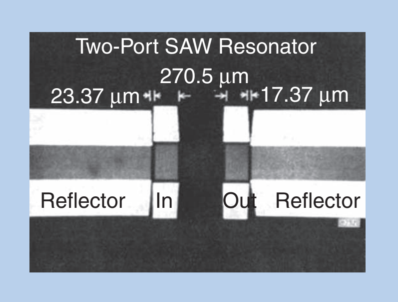


**FIGURE 1:** Two-port SAW resonator chip with interdigital input and output transducers.

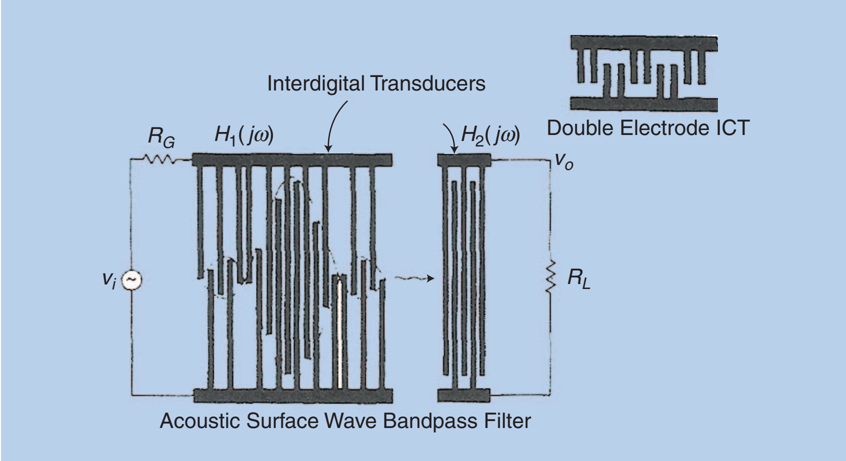


**FIGURE 3:** SAW transversal filter with an apodized, length-weighted input transducer and a nonapodized output.

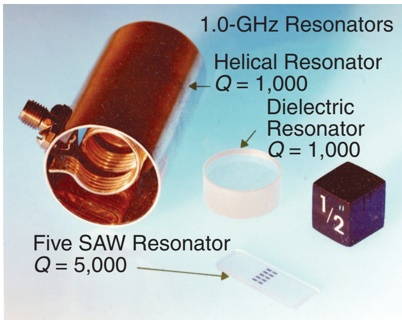


**FIGURE 2:** Five SAW resonators on a piezoelectric quartz chip. The SAW devices are much smaller and have a higher Q factor than competing technologies.

working on SAW technology, which is superior to lumped-constant circuits for making miniature, low-cost, planar filters.

Laker set a new record Q factor of 5,000 for resonators at 780 MHz with the tiny SAW chip shown in Figure 1 [1]. Figure 2 shows that the planar SAW resonators are much smaller than high-dialectic constant and helical resonators, whose Q factor was about 1,000. The SAW chip consists of aluminum metal grating lines on temperature-compensated, ST-cut quartz. They are fabricated by adopting the same low-cost techniques used to make integrated circuits.

The input interdigital transducer in Figure 1 converts, via the piezoelectric effect, the 780-MHz electromagnetic signal into SAWs propagating to the right and the left. They form standing waves as they are reflected back and forth between the reflectors, which consist of 1-$\mu$m-wide aluminum lines spaced 1 $\mu$m or one-half wavelength apart. The output interdigital transducer converts the SAW energy back into electromagnetic energy.

When Ken joined our laboratory, we were able to design and fabricate transversal SAW filters with 30-dB rejection by apodizing or length-weighting the lines of the interdigital input transducer (Figure 3). Ken developed new techniques for designing withdrawal-weighted transducers (Figure 4) that increased the rejection to more than 60 dB.

The length-weighting or apodizing function of the transducer in Figure 3 is a truncated (sinf)/f function. If an impulse is applied across the electrodes, the surface wave is the spatial replica of the overlap or weighting function. The frequency response of the filter is the Fourier transform of the truncated (sinf)/f function. If the transducer could be made infinitely long, it would generate a correspondingly long (sinf)/f function whose Fourier transform would be rectangularly shaped, with no side lobes. This would be an ideal "brick wall" filter. Contiguous banks of these filters enable one to measure the frequency of an incoming pulse instantly, in real time, for a high-probability-of-intercept spectrum analyzer (Figure 5).

Length limitations of the transducer force one to truncate the (sinf)/f function. The Fourier transform filter function is thus a rectangular shaped function with side lobes (Figure 5). Practically, the lowest side lobe achievable with a single apodized transducer filter was 30 dB down due to diffraction spreading of the SAW and other second-order effects.

As stated, the use of Ken's withdrawal-weighted filter as an output transducer with an apodized input filter enabled us to obtain more than 60 dB of rejection. The weighting with withdrawal-weighted interdigital transducers (IDTs) is achieved by removing certain electrodes from a uniform IDT [2]. Because all electrodes

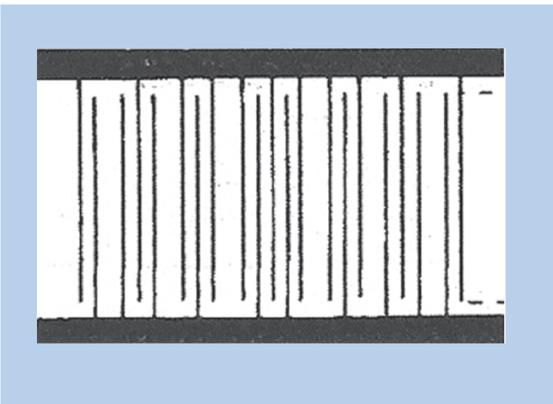

**FIGURE 4:** Withdrawal-weighted SAW interdigital transducer.

*Laker set a new record Q factor of 5,000 for resonators at 780 MHz with the tiny SAW chip.*

are of the same length, distortion due to diffraction is minimal, and more important, two weighted IDTs (either two withdrawal-weighted IDTs or an apodized IDT and a withdrawal-weighted IDT) can be cascaded within the same filter.

When electrodes are removed selectively from an IDT, however, the normal electric fields that appear under each electrode change in both shape and strength according to the surrounding electrode configuration; therefore, a change in both the magnitude and phase of the acoustic response results [3]. In order to make the filter synthesis tractable, Ken assumed that each electrode couples significantly to only those electrodes within a "three-near-neighbor" proximity of the electrode in question. With this approximation, excellent agreement between theory and experiment has been obtained [4].

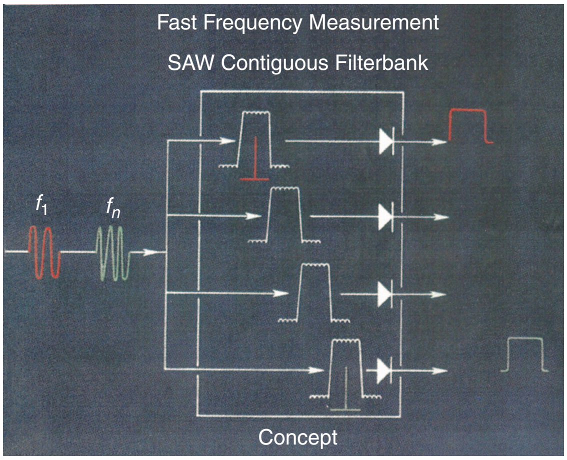


**FIGURE 5:** Schematic of contiguous filter bank for fast frequency measurement of pulses.

We have fabricated an eight-channel SAW contiguous filter bank in the UHF frequency range for fast frequency measurement. When the compact planar thin-film SAW filters are compared with their lumped-constant filter counterparts, shown in Figure 6, substantial savings in size, weight, and cost can be noted.

These advantages of contiguous SAW filter banks are also applicable to ultrafast frequency-hopping synthesizers [5]. In this application, the input transducers must all be connected to the multiple-frequency input source. There are a number of ways of doing this. For example, they may be connected in series or in parallel. Ken examined all the possibilities and concluded that two parallel branches of eight transducers connected in series resulted in minimum insertion loss. For this advance, he was granted a U.S. patent titled "Method and Means for Coupling a Multiplicity of Surface Acoustic Wave Transducers into a Single Electromagnetic Transmission Line" [6].

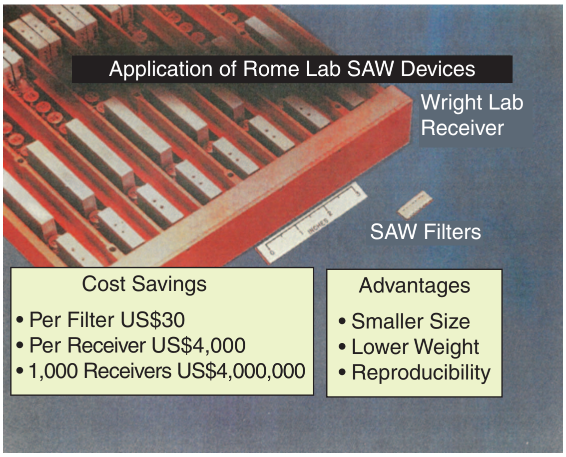


**FIGURE 6:** Photograph of an eight-channel lumped-constant filter bank showing the size, weight, and cost advantage of equivalent SAW filter banks.

Ken Laker advanced SAW resonator and filter technology with significant decreases in the size, weight, and cost of oscillators, fast frequency-measuring filter banks, and compact fast frequency-hopping synthesizers.

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## About the Author

**Paul H. Carr** received B.S. and M.S. degrees in physics from Massachusetts Institute of Technology and a Ph.D. in physics from Brandeis University. He was chief of the microwave physics branch of the Air Force Cambridge Research Laboratories from 1967 to 1995. In 1979, he was elected a Fellow of the IEEE "for contributions to microwave acoustics and their use as signal-processing components." His 80 papers and ten patents have contributed to miniature, low-cost signal-processing components for radar, communications, TV, and cell phones. The John Templeton Foundation awarded him a grant for the philosophy courses he taught at the University of Massachusetts, Lowell, from 1998 to 2000. This inspired his book *Beauty in Science and Spirit.*