This Week's Citation Classic

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Fox A G & Li T. Resonant modes in a maser interferometer.
Bell Syst. Tech. J. **40**:453-88, 1961.

This paper showed that a laser beam bouncing back and forth between a pair of mirrors can resonate for a number of modes of energy distribution. For each of these transverse modes there is a different characteristic phase velocity and attenuation per transit. A computer simulation technique was used to obtain these important parameters. [The *SCI*® indicates that this paper has been cited over 595 times since 1961.]

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"Our paper has been frequently cited because it was the first to point out that an open-sided resonator containing a laser medium should have unique modes of propagation. Since this resonator had been used for many years in optics without ever observing such modes, some people were surprised by this prediction.

"In making plans for building the first gas laser it was important to know the losses of the resonator in order to find the gain needed from the active medium. Estimates were being made assuming that the light intensity would be uniform over the mirrors. I felt sure that this was wrong because as the waves bounced back and forth between the mirrors, diffraction should progressively weaken the intensity at the edges of the mirrors. I enlisted the collaboration of Tingye Li, and we planned a way to make a computer simulate what would happen to an initially uniform plane wave after it was launched within the resonator. To our delight, the computer showed that the intensity distribution at the mirrors fluctuated wildly at first but after a large number of transits it settled down into a roughly cosine shape with a maximum in the center and low values at the edges. From then on, after each transit the wave recreated at one mirror the same intensity distribution that it had when it left the other mirror. We called this self-consistent solution the lowest order mode. By measuring the diminution of intensity per transit at the center of the mirrors we could determine the diffraction loss of the mode, and found it to be orders of magnitude smaller than the previous estimates. This happily meant that much less gain would be needed to get a laser to operate.

"The starting fluctuations in the computer solution were found to be due to the presence of higher order modes in our assumed initial distribution. Because these had higher losses than the lowest mode, they were more rapidly attenuated so that eventually only the lowest mode was left. However, by studying the fluctuations we were able to deduce the loss and other characteristics of some of these higher modes which can also exist in a laser.

"The early skepticism about modes vanished when gas lasers first operated and our computer predictions were confirmed. Several years passed before theorists were able to construct a good existence proof showing that an open resonator could have steady state modes, and during this time there was some opinion that a computer should not be trusted to do what a smart mathematician could not.

"Meanwhile, Li and I extended our technique to other geometries of resonator and to lasers with non-uniform gain profiles and with saturable gain.[1] Even today, many of the resonator systems in actual use can be studied only by computer techniques similar to the ones we first used. Contributions by many others, building on these mode concepts, have refined our understanding not only of open resonators but also of their duals in open transmission media having no continuously guiding sidewalls."

1. **Fox A G & Li T.** Effect of gain saturation on the oscillating modes of optical masers.
IEEE J. Quant. Electronics **QE-2**:777-83, 1966.