

13.4: Electrodynamic-acoustic devices

13.4.1: Magneto-acoustic devices

One of the most common electro-acoustic devices is the loudspeaker, where larger units typically employ a magnetic solenoid (see Section 6.4.1) to drive a large lightweight cone that pushes air with the driven waveform. The frequency limits are within the mechanical resonances of the system, which are the natural frequencies of oscillation of the cone. The low frequency mechanical limit is typically set by the resonance of the rigid cone oscillating within its support structure. An upper mechanical limit is set by the natural resonance modes of the cone itself, which are lower for larger cones because the driven waves typically propagate outward from the driven center, and can reflect from the outer edge of the cone, setting up standing waves. The amplitude limit is typically set by the strength of the system and its linearity. As shown in Section 6.1.2, mechanical motion can generate electric voltages in the same systems, so they also function as microphones.

Another magneto-acoustic device uses magnetostriction, which is the shrinkage of some magnetic materials when exposed to large magnetic fields. They are used when small powerful linear motions are desired, typically on the order of microns. To obtain larger motions the drive head can be connected to a mechanically tapered acoustic transmission line resembling a small solid version of a trumpet horn that smoothly matches the high mechanical impedance of the driver over a large area to the low mechanical impedance of the small tip. The small tip moves much greater distances because acoustic power is conserved if the taper is slow compared to a quarter-wavelength, much like a series of quarter-wave transformers being used for impedance transformation; small tips moving large distances convey the same power as large areas moving small distances. Such acoustic-transmission-line transformers can be used in either direction, depending on whether high displacements or high forces are desired.

13.4.2: Electro-acoustic devices

The simplest electro-acoustic device is perhaps a capacitor with one plate that is free to move and push air in response to time-varying electric forces on it, as discussed in Section 6.2.2. These can be implemented macroscopically or within micro-electromechanical systems (MEMS).

Some materials such as quartz are piezo-electric and shrink or distort when high voltages are placed across them. Because this warping yields little heat, periodic excitation of quartz crystals can cause them to resonate with a very high Q , making them useful for time-keeping purposes in watches, computers, and other electronic devices. These mechanical resonances for common crystals are in the MHz range and have stabilities that are $\sim 10^{-4}$ – 10^{-6} , depending mostly on temperature stability; larger crystals resonate at lower frequencies. They can also be designed to drive tiny resonant loudspeakers at high acoustic frequencies and efficiencies for watch alarms, etc.

By reciprocity, good piezo-electric actuators are also good sensors and can be used as microphones. Mechanical distortion of such materials generates small measurable voltages. The same is true when the plate separation of capacitors is varied, as shown in Section 6.6.1. Mechanically tapered solid acoustic waveguides can also be used for impedance transformations between low-force/high-motion terminals and high-force/low motion terminals, as noted in Section 13.4.1. Levers can also be used for the same purpose.

13.4.3: Opto-acoustic-wave transducers

When transparent materials are compressed their permittivity generally increases, slowing lightwaves passing through. This phenomenon has been used to compute Fourier transforms of broadband signals that are converted to acoustic waves propagating down the length of a transparent rectangular rod. A uniform plane wave from a laser then passes through the rod at right angles to it and to the acoustic beam, and thereby experiences local phase lags along those portions of the rod where the acoustic wave has temporarily compressed it. If the acoustic wave is at 100 MHz and the velocity of sound in the bar is 1000 m/s, then the acoustic wavelength is 10 microns. If the laser has wavelength 1 micron, then the laser light will pass straight through the bar and will also diffract at angles $\pm \lambda_{\text{laser}} / \lambda_{\text{acoustic}} = 10^{-6} / 10^{-5} = 0.1$ radian. Several other beams will emerge too, at $\sim \pm 0.2, 0.3$, etc. [radians]. There will therefore be a diffracted laser beam at an angle unique to each Fourier component of the acoustic signal, the strength of which depends on the magnitude of the associated optical phase delays along the rod. Lenses can then focus these various plane waves to make the power density spectrum more visible.

If several exit ports are provided for the emerging light beams, one per angle, the laser beam can effectively be switched at acoustic speeds among those ports. If 100 exit ports are provided, then the rod length L should be at least 100 wavelengths, or 1mm for the case cited above. At an acoustic velocity c_s of 1000 m/s a new wave can enter the device after $L/c_s = 10^{-3}/1000 = 10^{-6}$ seconds.

13.4.4: Surface-wave devices

Only compressive acoustic waves have been discussed so far, but acoustic shear waves can also be generated in solids, and exhibit most of the same wave phenomena as compressive waves, such as guidance and resonance. The dominant velocity in a shear wave is transverse to the direction of wave propagation. By generating shear waves on the surface of quartz devices, and by periodically loading those surfaces mechanically with slots or metal, multiple reflections are induced that, depending on their spacing relative to a wavelength, permit band-pass and bandstop filters to be constructed, as well as transformers, resonators, and directional couplers. Because quartz has such high mechanical Q , it is often used to construct high- Q resonators at MHz frequencies.

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