19.1 INTRODUCTION

The measurement of the simple interval transit time, or slowness, of downhole formations has been accomplished by a variety of logging devices. Despite the seeming simplicity of this measurement, which extracts only a part of the information contained in the complex acoustic waveform, a number of innovations were necessary to make valid measurements under a variety of borehole conditions. This chapter starts by examining the techniques prevalent in borehole acoustic logging tools up to the mid-1980s.

After reviewing the typical log presentation format, the performance of sonic logging tools is contrasted with other porosity-sensitive devices, most of which are more sensitive to borehole conditions. One of the limitations of conventional acoustic tools is a shallow depth of investigation. An early enhancement of tool design increased the transmitter–receiver distance. These long spacing sonic tools were developed to overcome the perturbations caused by alteration of the formation near the borehole.

Newer acoustic devices employ arrays of receivers, both monopole and dipole, some at extremely long spacing. Wavetrain recording and signal processing help avoid some of the defects which mar conventional sonic logging under certain conditions. To provide reliable $V_s$ measurements, even in slow formations, dipole sources have been designed to produce a borehole flexural wave from which the formation shear velocity can be extracted from multidetector waveform data. In addition to shear measurements, newer devices also provide a measurement of the tube wave or Stoneley wave. All these measurements allow applications beyond the conventional estimation of porosity, that are primarily related to rock properties. They have to do with the
detection and delineation of fractures, prediction of rock failure, or sanding – useful information for perforation or for drilling mechanics. Ultrasonic devices operating in the range of 1 MHz have opened the door to acoustic borehole imaging. These can be used in the detection of naturally occurring fractures and, in another application, the evaluation of the cementing of cased wells.

19.2 TRANSDUCERS – TRANSMITTERS AND RECEIVERS

Acoustic measurements rely on the production of a pulse of pressure which is applied, through the borehole mud, to the formation. Two types of transducers have been in use both as acoustic source generators and receivers. One type is based on the magnetostrictive behavior of certain materials. For these, application of a magnetic field causes a volume reduction in the material. Consequently the sudden application of a magnetic field initiates a pressure pulse which is completed upon the removal of the magnetic field. This is accompanied by a subsequent volume relaxation.

The general form of the magnetostrictive transducer used in logging is a torus. The magnetic field is produced by supplying current to a coil which completely wraps the toroidal core material. Since the magnetostrictive material is also magnetized, it can operate as a receiver. Any impinging compressional acoustic energy will cause volume distortions in the core and thus vary the magnetic field which threads the coil windings. This changing magnetic field will produce a voltage at the terminals of the coil which is representative of the acoustic signal.

The second type of device in common use is based on ceramic materials, such as BaTiO$_2$, which have piezoelectric properties. This dielectric material responds to an applied electric field by changing its volume. A typical monopole source is a cylindrical shell of ceramic. Applying a voltage pulse between the inner and outer surfaces of the ceramic shell produces a subsequent fluctuation in its volume that can generate a pressure disturbance. As a receiver, the incoming compressional wave distorts the ceramic, setting up a polarization charge, which appears as a voltage across the two surfaces of the cylindrical shell.

The output power and operating frequency of both types of devices are limited by surface area and material properties. The dimensions dictated by logging sondes result in frequencies from 1 to 25 kHz. As a transmitter, the application of a voltage pulse results in a “ringing” at the central frequency which lasts for several periods.

As mentioned in the previous chapter, the reliable borehole measurement of shear velocity awaited the development of the dipole source. An early identification of this problem and solution was made by Kitsunezaki [1] who sketched out a few ideas for transducers, including an electromagnetically actuated double-ended piston, similar to a speaker, that is currently used today. Such a device, seen in Fig. 19.1, when activated, produces a positive pressure pulse on one side of the tool and a negative pressure on the other; and then the cycle reverses.

Although a dipole source can also be constructed of two oppositely phased ceramic monopole transducers (see Fig. 19.2) they generally are not capable of coupling enough energy into the formation wall at low frequencies to be of practical use.