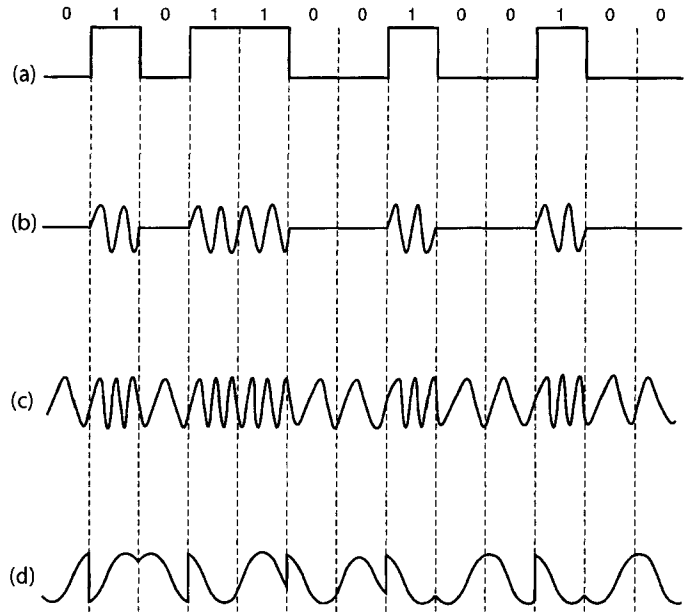

Figure 1.10: (a) An electrical bit stream and the resulting electric field patterns when it is converted to optical domain using (b) ASK, (c) FSK, (d) PSK modulation formats.

Although the use of FSK and PSK formats was explored during the 1980s in the context of coherent lightwave systems [20], these formats were nearly abandoned during the 1990 because of the complexities associated at the receiving end. The situation changed after 2000 when it was realized that the use of PSK is essential for improving the spectral efficiency of WDM systems. Modern WDM systems employ advanced modulation formats in which information is encoded using both the amplitude and phase of the optical carrier [29]. The basic idea behind the new formats can be understood by employing the complex notation for the electric field in Eq. (1.2.5) and introducing the so-called phasor as $A = ae^{i\phi}$. Figure 1.11 shows four modulation formats in the constellation diagrams, where the real and imaginary parts of A are plotted along the x and y axes, respectively. The first two configurations represent the standard binary ASK and PSK formats in which either the amplitude of the phase of electric field takes two values marked by circles. The third one shows the quadrature PSK (or QPSK) format in which the optical phase takes four possible values. This case, discussed in considerable detail in Chapter 10, two bits are transmitted during each time slot, and the effective bit rate is halved. Borrowing from the microwave communication terminology [48], the effective bit rate is called the *symbol rate* (or baud). The last example in Figure 1.11 shows how the symbol concept can be extended to multilevel signaling such that each symbol carries 4 bits or more. An additional factor of two can be gained if one transmits two orthogonally polarized symbols simultaneously during each symbol slot.