Chapter 1

PASSIVE WIRELESS MICROSYSTEMS

Passive wireless microsystems such as wireless transponders, radio-frequency identification (RFID) tags, wireless microsensors, and biomedical implants, harvest their operational power either from radio-frequency waves emitted by their base station or from other energy sources such as vibration and solar. The absence of bulky batteries not only minimizes the physical dimension and implementation cost of these microsystems, it also removes the need for maintenance. As a result, passive wireless microsystems can be embedded in products or implanted in living bodies permanently to provide the unique identification of the products or living bodies in which they reside, to provide the precision measurement of the parameters of the products or living bodies, and to carry out control actions in a micron scale that otherwise cannot be performed. The key intrinsic attributes of passive wireless microsystems include small size, battery-less and maintenance-free operation, programmability, and wireless accessibility.

Passive wireless microsystems have found a broad range of emerging applications include implantable bio-microelectromechanical-systems (MEMS) pressure sensors [1, 2], retinal prosthetic devices [3–6], swallowable capsule endoscopy [7–9], multi-site pressure sensors for wireless arterial flow characterization [10], embedded micro-strain sensors for product performance and safety monitoring, wireless temperature sensors for human bodies and environmental monitoring [11–14], radio-frequency identification tags for object tracking in logistics automation [15, 16] and replacing bar codes in retailing, warehouse inventory automation, e-tickets, e-passports, and low-cost high-security product authentication keys to replace existing product authentication means such as holograms, water-marks, invisible barcodes, security threads, chemical, and DNA markers that are often too costly to be used for general goods [17].
1.1 The Spectrum

Communications between a passive wireless microsystem and its base station typically take place in ISM (Industrial, Scientific, and Medical) bands. ISM bands are open frequency bands that allow for operation without a license. The most widely used ISM bands are 13.553-13.57 MHz, 902-928 MHz, 2.4-2.4825 GHz, and 5.725-5.850 GHz [18]. The maximum power of the radio-frequency waves emitted by an antenna in ISM bands is regulated by Federal Communications Commission (FCC) in the United States. Effective isotropic radiated power (EIRP), which is defined as the power that would have to be supplied to an ideal antenna that radiates uniformly in all directions in order to get the same electrical field strength that the device under test produces at the same distance, is widely used to quantify the amount of the radiation power from an antenna. EIRP is computed from [19]

\[ EIRP = 10 \log \left( \frac{4\pi E^2 r^2}{0.377} \right), \]  

where \( E \) is the electrical field strength and \( r \) is the distance from the antenna. FCC part 15 rules govern the transmission power permitted in ISM bands. For example, the maximum transmitter output power fed into an antenna is 30 dBm (1 Watt) and the maximum EIRP is 36 dBm (4 Watts) in 902-928 MHz and 2.4-2.4825 GHz ISM bands.

Wireless communications between a passive wireless microsystem and its base station can take place either in the near field or the far field of the antennas of the base station. Near-field coupling is viable for frequencies up to a few tens of MHz with the characteristics of a low data rate, a large antenna dimension, and a short link distance. The low upper bound of the frequency is mainly due to the low self-resonant frequency of the coupling coils between base stations and passive wireless microsystems. Far-field coupling occurs at ultra-high frequencies (UHF) and microwave frequencies and offers the advantages of a high data rate, a small antenna dimension, and a long link distance. Biomedical implants are located in the near field mainly due to the high loss of electromagnetic waves in living bodies at high frequencies. Other near-field passive wireless microsystems include smart cards, access cards, e-passports, etc. Transponders and RFID tags are typically located in the far field of the antenna of their base station to take the advantages of the low loss of electromagnetic waves in air.

1.2 The Challenges

Although the emerging applications of passive wireless microsystems are quite broad, the performance of these microsystems is commonly affected by a