Estimating the amount of harvestable ambient RF and microwave power from the omnipresent electromagnetic sources is of vital importance when designing a wireless device that makes use of ambient microwave power harvesting (AMPH) as a power source. This paper studies and looks into the underlying RF and microwave rectification mechanism at low input ambient power levels, specifically -30 dBm and below. A fundamental theory is formulated and developed, which is able to correctly predict the efficiency of a rectifier including the effects of matching network insertion losses through an easy-to-understand analytical model. The suggested model provides a direct design guideline in determining and choosing the optimal diode for a predetermined application. Based on the developed theoretical framework, the diode characteristics that have a direct impact on the microwave power conversion efficiency are discussed in detail. Three different Schottky diode rectifiers were designed on the basis of the tools described in this paper, thereby validating the proposed model and highlighting the influence of critical diode parameters on its performances. The measured results are then compared with those predicted by the proposed model and state-of-the-art microwave power rectifiers, showing a good model accuracy and also a 10% improvement in the rectifying efficiency for the low input power levels of interest.