

1.5

The Power Wall

Figure 1.15 shows the increase in clock rate and power of eight generations of Intel microprocessors over 25 years. Both clock rate and power increased rapidly for decades, and then flattened off recently. The reason they grew together is that they are correlated, and the reason for their recent slowing is that we have run into the practical power limit for cooling commodity microprocessors.

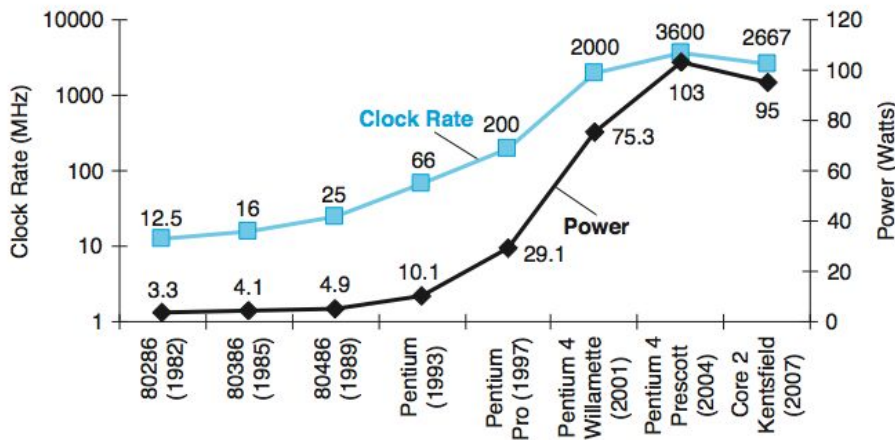


FIGURE 1.15 Clock rate and Power for Intel x86 microprocessors over eight generations and 25 years. The Pentium 4 made a dramatic jump in clock rate and power but less so in performance. The Prescott thermal problems led to the abandonment of the Pentium 4 line. The Core 2 line reverts to a simpler pipeline with lower clock rates and multiple processors per chip.

The dominant technology for integrated circuits is called CMOS (complementary metal oxide semiconductor). For CMOS, the primary source of power dissipation is so-called dynamic power—that is, power that is consumed during switching. The dynamic power dissipation depends on the capacitive loading of each transistor, the voltage applied, and the frequency that the transistor is switched:

$$\text{Power} = \text{Capacitive load} \times \text{Voltage}^2 \times \text{Frequency switched}$$

Frequency switched is a function of the clock rate. The capacitive load per transistor is a function of both the number of transistors connected to an output (called the *fanout*) and the technology, which determines the capacitance of both wires and transistors.

How could clock rates grow by a factor of 1000 while power grew by only a factor of 30? Power can be reduced by lowering the voltage, which occurred with each new generation of technology, and power is a function of the voltage squared. Typically, the voltage was reduced about 15% per generation. In 20 years, voltages have gone from 5V to 1V, which is why the increase in power is only 30 times.

EXAMPLE

ANSWER

Relative Power

Suppose we developed a new, simpler processor that has 85% of the capacitive load of the more complex older processor. Further, assume that it has adjustable voltage so that it can reduce voltage 15% compared to processor B, which results in a 15% shrink in frequency. What is the impact on dynamic power?

$$\frac{\text{Power}_{\text{new}}}{\text{Power}_{\text{old}}} = \frac{(\text{Capacitive load} \times 0.85) \times (\text{Voltage} \times 0.85)^2 \times (\text{Frequency switched} \times 0.85)}{\text{Capacitive load} \times \text{Voltage}^2 \times \text{Frequency switched}}$$

Thus the power ratio is

$$0.85^4 = 0.52$$

Hence, the new processor uses about half the power of the old processor.

The problem today is that further lowering of the voltage appears to make the transistors too leaky, like water faucets that cannot be completely shut off. Even today about 40% of the power consumption is due to leakage. If transistors started leaking more, the whole process could become unwieldy.

To try to address the power problem, designers have already attached large devices to increase cooling, and they turn off parts of the chip that are not used in a given clock cycle. Although there are many more expensive ways to cool chips and thereby raise their power to, say, 300 watts, these techniques are too expensive for desktop computers.

Since computer designers slammed into a power wall, they needed a new way forward. They chose a different way from the way they designed microprocessors for their first 30 years.

Elaboration: Although dynamic power is the primary source of power dissipation in CMOS, static power dissipation occurs because of leakage current that flows even when a transistor is off. As mentioned above, leakage is typically responsible for 40% of the power consumption in 2008. Thus, increasing the number of transistors increases power dissipation, even if the transistors are always off. A variety of design techniques and technology innovations are being deployed to control leakage, but it's hard to lower voltage further.