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**Theory 14**

## Microprocessors & Microcontrollers

A **microprocessor** is a rather versatile electronic integrated circuit that has a fixed set of instructions that allow it to do several things:

- It contains a Central Processing Unit (CPU) that performs basic mathematical computations (add, subtract, multiply, divide).
- It has the capability of interacting with a Basic Input Output System (BIOS) that starts a computer up by communicating with all the other functions within the computer. In particular, it can load and prepare for use the Operating System (OS) of the computer. In the PC world, the best known OS is Microsoft Windows, while in the Apple world the OS is the proprietary Apple Snow Leopard (OS-X).
- It can access external memory that stores the data used by the computer.
- It can access peripherals through the BIOS such as keyboards, printers, pointing devices (mice, trackballs, and tablets), sound devices, disk and CD players/recorders, input/output ports such as serial (RS-232) ports, universal serial bus (USB) ports, wireless ports, and all the other external hardware devices that a computer can have.

The history of the microprocessor starts in 1971when the Nippon Calculating Company asked Intel to design a 4-chip set for their new adding machine. Intel responded that they would prefer to put all the functions that NCC wanted on a single chip, which they called a microprocessor. Thus was born the Intel 4004, which was a 4-bit device that operated at the blinding speed of 100 kHz. and contained 2,300 transistors. The 4004 could only provide two functions: addition and subtraction, but it did them at a speed that nobody had ever seen before.

The following year, Intel introduced the 8008, an 8 bit chip that processed 8 times faster than the 4004 and contained 3500 transistors. Two years later came the 8080, also an 8 bit machine with a 2 MHz. clock speed and 4500 transistors. Four years later (1978) produced the 8086, also an 8 bit machine, 3 times faster than the 8080 and 29,000 transistors.

From this data and extrapolating, Gordon Moore postulated that the number of transistors that could be placed on a microprocessor chip would double every two years and a comparable device would be half the price after 2 years. Moore's law has been uncannily accurate for nearly 40 years. In 2019, the AMD Ryzen 64 bit microprocessor runs at 4.7 GHz. with 3.9 BILLION transistors.

| Date | Name | Developer | Clock | Process | Transistors (millions) | Cores per die / Dies per module | threads per core |
|------|------|-----------|-------|---------|------------------------|--------------------------------|------------------|
| 2010 | POWER7 | IBM | 3–4.14 GHz | 45 nm | 1200 | 4, 6, 8 / 1, 4 | 4 |
| 2010 | Itanium "Tukwila" | Intel | 2 GHz | 65 nm | 2000 | 2, 4 / 1 | 2 |
| 2010 | Opteron "Magny-cours" | AMD | 1.7–2.4 GHz | 45 nm | 1810 | 4, 6 / 2 | 1 |
| 2010 | Xeon "Nehalem-EX" | Intel | 1.73–2.66 GHz | 45 nm | 2300 | 4, 6, 8 / 1 | 2 |
| 2010 | z196 | IBM | 3.8–5.2 GHz | 45 nm | 1400 | 4 / 1, 6 | 1 |
| 2010 | SPARC T3 | Sun | 1.6 GHz | 45 nm | 2000 | 16 / 1 | 8 |
| 2010 | SPARC64 VII+ | Fujitsu | 2.66–3.0 GHz | 45 nm | ? | 4 / 1 | 2 |
| 2010 | Intel "Westmere" | Intel | 1.86–3.33 GHz | 32 nm | 1170 | 4–6 / 1 | 2 |

| Date | Name | Developer | Clock | Process | Transistors (millions) | Cores per die / Dies per module | threads per core |
|---|---|---|---|---|---|---|---|
| 2011 | Intel "Sandy Bridge" | Intel | 1.6–3.4 GHz | 32 nm | 995[53] | 2, 4 / 1 | (1,) 2 |
| 2011 | AMD Llano | AMD | 1.0–1.6 GHz | 40 nm | 380[54] | 1, 2 / 1 | 1 |
| 2011 | Xeon E7 | Intel | 1.73–2.67 GHz | 32 nm | 2600 | 4, 6, 8, 10 / 1 | 1–2 |
| 2011 | Power ISA BGQ | IBM | 1.6 GHz | 45 nm | 1470 | 18 / 1 | 4 |
| 2011 | SPARC64 VIIIfx | Fujitsu | 2.0 GHz | 45 nm | 760 | 8 / 1 | 2 |
| 2011 | FX "Bulldozer" Interlagos | AMD | 3.1–3.6 GHz | 32 nm | 1200[55] | 4–8 / 2 | 1 |
| 2011 | SPARC T4 | Oracle | 2.8–3 GHz | 40 nm | 855 | 8 / 1 | 8 |
| 2012 | SPARC64 IXfx | Fujitsu | 1.848 GHz | 40 nm | 1870 | 16 / 1 | 2 |
| 2012 | zEC12 | IBM | 5.5 GHz | 32 nm | 2750 | 6 / 6 | 1 |
| 2012 | POWER7+ | IBM | 3.1–5.3 GHz | 32 nm | 2100 | 8 / 1, 2 | 4 |
| 2012 | Itanium "Poulson" | Intel | 1.73–2.53 GHz | 32 nm | 3100 | 8 / 1 | 2 |

| Date | Name | Developer | Clock | Process | Transistors (millions) | Cores per die / Dies per module | threads per core |
|------|------|-----------|-------|---------|------------------------|----------------------------------|------------------|
| 2013 | Intel "Haswell" | Intel | 1.9–4.4 GHz | 22 nm | 1400 | 4 / 1 | 2 |
| 2013 | SPARC64 X | Fujitsu | 2.8–3 GHz | 28 nm | 2950 | 16 / 1 | 2 |
| 2013 | SPARC T5 | Oracle | 3.6 GHz | 28 nm | 1500 | 16 / 1 | 8 |
| 2014 | POWER8 | IBM | 2.5–5 GHz | 22 nm | 4200 | 6, 12 / 1, 2 | 8 |
| 2015 | z13 | IBM | 5 GHz | 22 nm | 3990 | 8 / 1 | 2 |
| 2015 | A8-7670K | AMD | 3.6 GHz | 28 nm | 2410 | 4 / 1 | 1 |
| 2017 | Ryzen | AMD | 3.2–4.1 GHz | 14 nm | 4800 | 8, 16, 32 / 1, 2, 4 | 2 |
| 2017 | z14 | IBM | 5.2 GHz | 14 nm | 6100 | 10 / 1 | 2 |
| 2017 | POWER9 | IBM | 4 GHz | 14 nm | 8000 | 12, 24 / 1 | 4, 8 |
| 2017 | SPARC M8[56] | Oracle | 5 GHz | 20 nm | ~10,000[57] | 32 | 8 |
| 2019 | Ryzen 2 | AMD | 2-4.7 GHz | 7 nm | 3900 | 6, 8, 12, 16, 24, 32, 64 / 1, 2, 4 | |

A **microcontroller** on the other hand is a specialized integrated circuit that contains all the peripheral devices described above (bios, memory, operating system, CPU, input/output ports) all on a single chip. Microcontrollers are generally dedicated to a specific task as opposed to a microprocessor that can be adapted to many different tasks. You would use a microprocessor in a personal computer; you would use a microcontroller to run a smart microwave oven.

There are several microcontroller manufacturers in the market today, but perhaps the best known is the Microchip Corporation with their venerable PIC line of microprocessors. Microchip started business in 1989 with a relatively unsophisticated 8-bit microcontroller operating at 20 MHz. What REALLY kicked Microchip off was the invention of what is called RISC (Reduced Instruction Set Code) that made programming the chips relatively simple and fast. That and keeping pricing WAY down was Microchip's secret weapon. While a fairly sophisticated microprocessor might run $150 or so, a fairly sophisticated PIC can be had in the range of $1 - $3

In PARTICULAR, the PIC 16F688 ($1.35 in small quantities) is going to be of some SIGNIFICANT use to us.

# List of available PIC microcontrollers

PIC10F202
PIC10F206
PIC10F222
PIC10F320
PIC10F322
PIC10LF320
PIC10LF322
PIC12C508
PIC12C508A
PIC12C509
PIC12C509A
PIC12C671
PIC12C672
PIC12CE518
PIC12CE519
PIC12CE673
PIC12CE674
PIC12F1501
PIC12F1571
PIC12F1572
PIC12F1612
PIC12F1822
PIC12F1840
PIC12F508
PIC12F509
PIC12F510
PIC12F519
PIC12F609
PIC12F615
PIC12F617

PIC12F629
PIC12F635
PIC12F675
PIC12F683
PIC12F752
PIC12HV609
PIC12HV615
PIC12HV752
PIC12LF1501
PIC12LF1552
PIC12LF1571
PIC12LF1572
PIC12LF1612
PIC12LF1822
PIC12LF1840
PIC16C432
PIC16C433
PIC16C505
PIC16C54
PIC16C54A
PIC16C54C
PIC16C55
PIC16C554
PIC16C557
PIC16C558
PIC16C55A
PIC16C56
PIC16C56A
PIC16C57
PIC16C57C

PIC16C58B
PIC16C620
PIC16C620A
PIC16C621
PIC16C621A
PIC16C622
PIC16C622A
PIC16C62A
PIC16C62B
PIC16C63
PIC16C63A
PIC16C642
PIC16C64A
PIC16C65A
PIC16C65B
PIC16C66
PIC16C662
PIC16C67
PIC16C71
PIC16C710
PIC16C711
PIC16C712
PIC16C715
PIC16C716
PIC16C717
PIC16C72
PIC16C72A
PIC16C73A
PIC16C73B
PIC16C745

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PIC16C74B
PIC16C76
PIC16C765
PIC16C77
PIC16C770
PIC16C771
PIC16C773
PIC16C774
PIC16C781
PIC16C782
PIC16C923
PIC16C924
PIC16C925
PIC16C926
PIC16CE623
PIC16CE624
PIC16CE625
PIC16F1454
PIC16F1455
PIC16F1459
PIC16F1503
PIC16F1507
PIC16F1508
PIC16F1509
PIC16F1512
PIC16F1513
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PIC16F1518

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PIC16F15313
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PIC16F15325
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PIC16F15355
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PIC16F15375
PIC16F15376
PIC16F15385
PIC16F15386
PIC16F1574
PIC16F1575
PIC16F1578
PIC16F1579
PIC16F1613
PIC16F1614
PIC16F1615
PIC16F1618
PIC16F1619
PIC16F1703
PIC16F1704
PIC16F1705
PIC16F1707
PIC16F1708

PIC16F1709
PIC16F1713
PIC16F1716
PIC16F1717
PIC16F1718
PIC16F1719
PIC16F1764
PIC16F1765
PIC16F1768
PIC16F1769
PIC16F1773
PIC16F1776
PIC16F1777
PIC16F1778
PIC16F1779
PIC16F1782
PIC16F1783
PIC16F1784
PIC16F1786
PIC16F1787
PIC16F1788
PIC16F1789
PIC16F1823
PIC16F1824
PIC16F1825
PIC16F1826
PIC16F1827
PIC16F1828
PIC16F1829
PIC16F18313

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|---|---|---|---|---|---|
| PIC16F18323 | PIC16F506 | PIC16F724 | PIC16F884 | PIC16LF15345 | PIC16LF1776 |
| PIC16F18324 | PIC16F526 | PIC16F726 | PIC16F886 | PIC16LF15354 | PIC16LF1777 |
| PIC16F18325 | PIC16F54 | PIC16F727 | PIC16F887 | PIC16LF15355 | PIC16LF1778 |
| PIC16F18326 | PIC16F57 | PIC16F73 | PIC16F913 | PIC16LF15356 | PIC16LF1779 |
| PIC16F18344 | PIC16F59 | PIC16F737 | PIC16F914 | PIC16LF15375 | PIC16LF1782 |
| PIC16F18345 | PIC16F610 | PIC16F74 | PIC16F916 | PIC16LF15376 | PIC16LF1783 |
| PIC16F18346 | PIC16F616 | PIC16F747 | PIC16F917 | PIC16LF15385 | PIC16LF1784 |
| PIC16F1847 | PIC16F627 | PIC16F753 | PIC16F946 | PIC16LF15386 | PIC16LF1786 |
| PIC16F18854 | PIC16F627A | PIC16F76 | PIC16HV540 | PIC16LF1574 | PIC16LF1787 |
| PIC16F18855 | PIC16F628 | PIC16F767 | PIC16HV610 | PIC16LF1575 | PIC16LF1788 |
| PIC16F18856 | PIC16F628A | PIC16F77 | PIC16HV616 | PIC16LF1578 | PIC16LF1789 |
| PIC16F18857 | PIC16F630 | PIC16F777 | PIC16HV753 | PIC16LF1579 | PIC16LF1823 |
| PIC16F18875 | PIC16F631 | PIC16F785 | PIC16HV785 | PIC16LF1613 | PIC16LF1824 |
| PIC16F18876 | PIC16F636 | PIC16F818 | PIC16LF1454 | PIC16LF1614 | PIC16LF1825 |
| PIC16F18877 | PIC16F639 | PIC16F819 | PIC16LF1455 | PIC16LF1615 | PIC16LF1826 |
| PIC16F19155 | PIC16F648A | PIC16F83 | PIC16LF1459 | PIC16LF1618 | PIC16LF1827 |
| PIC16F19156 | PIC16F676 | PIC16F84 | PIC16LF1503 | PIC16LF1619 | PIC16LF1828 |
| PIC16F19175 | PIC16F677 | PIC16F84A | PIC16LF1507 | PIC16LF1703 | PIC16LF1829 |
| PIC16F19176 | PIC16F684 | PIC16F87 | PIC16LF1508 | PIC16LF1704 | PIC16LF18313 |
| PIC16F19185 | PIC16F685 | PIC16F870 | PIC16LF1509 | PIC16LF1705 | PIC16LF18323 |
| PIC16F19186 | PIC16F687 | PIC16F871 | PIC16LF1512 | PIC16LF1707 | PIC16LF18324 |
| PIC16F19195 | PIC16F688 | PIC16F872 | PIC16LF1513 | PIC16LF1708 | PIC16LF18325 |
| PIC16F19196 | PIC16F689 | PIC16F873 | PIC16LF1516 | PIC16LF1709 | PIC16LF18326 |
| PIC16F19197 | PIC16F690 | PIC16F873A | PIC16LF1517 | PIC16LF1713 | PIC16LF18344 |
| PIC16F1933 | PIC16F707 | PIC16F874 | PIC16LF1518 | PIC16LF1716 | PIC16LF18345 |
| PIC16F1934 | PIC16F716 | PIC16F874A | PIC16LF1519 | PIC16LF1717 | PIC16LF18346 |
| PIC16F1936 | PIC16F72 | PIC16F876 | PIC16LF1526 | PIC16LF1718 | PIC16LF1847 |
| PIC16F1937 | PIC16F720 | PIC16F876A | PIC16LF1527 | PIC16LF1719 | PIC16LF18854 |
| PIC16F1938 | PIC16F721 | PIC16F877 | PIC16LF15313 | PIC16LF1764 | PIC16LF18855 |
| PIC16F1939 | PIC16F722 | PIC16F877A | PIC16LF15323 | PIC16LF1765 | PIC16LF18856 |
| PIC16F1946 | PIC16F722A | PIC16F88 | PIC16LF15324 | PIC16LF1768 | PIC16LF18857 |
| PIC16F1947 | PIC16F723 | PIC16F882 | PIC16LF15325 | PIC16LF1769 | PIC16LF18875 |
| PIC16F505 | PIC16F723A | PIC16F883 | PIC16LF15344 | PIC16LF1773 | PIC16LF18876 |

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|---|---|---|---|---|---|
| PIC16LF18877 | PIC17C42A | PIC18F2420 | PIC18F25K22 | PIC18F442 | PIC18F45K42 |
| PIC16LF1902 | PIC17C43 | PIC18F2423 | PIC18F25K40 | PIC18F4420 | PIC18F45K50 |
| PIC16LF1903 | PIC17C44 | PIC18F2431 | PIC18F25K42 | PIC18F4423 | PIC18F45K80 |
| PIC16LF1904 | PIC17C752 | PIC18F2439 | PIC18F25K50 | PIC18F4431 | PIC18F4610 |
| PIC16LF1906 | PIC17C756 | PIC18F2450 | PIC18F25K80 | PIC18F4439 | PIC18F4620 |
| PIC16LF1907 | PIC17C756A | PIC18F2455 | PIC18F25K83 | PIC18F4450 | PIC18F4680 |
| PIC16LF19155 | PIC17C762 | PIC18F2458 | PIC18F2610 | PIC18F4455 | PIC18F4682 |
| PIC16LF19156 | PIC17C766 | PIC18F248 | PIC18F2620 | PIC18F4458 | PIC18F4685 |
| PIC16LF19175 | PIC18C242 | PIC18F2480 | PIC18F2680 | PIC18F448 | PIC18F46J11 |
| PIC16LF19176 | PIC18C252 | PIC18F24J10 | PIC18F2682 | PIC18F4480 | PIC18F46J13 |
| PIC16LF19185 | PIC18C442 | PIC18F24J11 | PIC18F2685 | PIC18F44J10 | PIC18F46J50 |
| PIC16LF19186 | PIC18C452 | PIC18F24J50 | PIC18F26J11 | PIC18F44J11 | PIC18F46J53 |
| PIC16LF19195 | PIC18C601 | PIC18F24K20 | PIC18F26J13 | PIC18F44J50 | PIC18F46K20 |
| PIC16LF19196 | PIC18C658 | PIC18F24K22 | PIC18F26J50 | PIC18F44K20 | PIC18F46K22 |
| PIC16LF19197 | PIC18C801 | PIC18F24K40 | PIC18F26J53 | PIC18F44K22 | PIC18F46K40 |
| PIC16LF1933 | PIC18C858 | PIC18F24K42 | PIC18F26K20 | PIC18F4510 | PIC18F46K42 |
| PIC16LF1934 | PIC18F1220 | PIC18F24K50 | PIC18F26K22 | PIC18F4515 | PIC18F46K80 |
| PIC16LF1936 | PIC18F1230 | PIC18F2510 | PIC18F26K40 | PIC18F452 | PIC18F47J13 |
| PIC16LF1937 | PIC18F1320 | PIC18F2515 | PIC18F26K42 | PIC18F4520 | PIC18F47J53 |
| PIC16LF1938 | PIC18F1330 | PIC18F252 | PIC18F26K80 | PIC18F4523 | PIC18F47K40 |
| PIC16LF1939 | PIC18F13K22 | PIC18F2520 | PIC18F26K83 | PIC18F4525 | PIC18F47K42 |
| PIC16LF1946 | PIC18F13K50 | PIC18F2523 | PIC18F27J13 | PIC18F4539 | PIC18F55K42 |
| PIC16LF1947 | PIC18F14K22 | PIC18F2525 | PIC18F27J53 | PIC18F4550 | PIC18F56K42 |
| PIC16LF707 | PIC18F14K50 | PIC18F2539 | PIC18F27K40 | PIC18F4553 | PIC18F57K42 |
| PIC16LF720 | PIC18F2220 | PIC18F2550 | PIC18F27K42 | PIC18F458 | PIC18F6310 |
| PIC16LF721 | PIC18F2221 | PIC18F2553 | PIC18F4220 | PIC18F4580 | PIC18F6390 |
| PIC16LF722 | PIC18F2320 | PIC18F258 | PIC18F4221 | PIC18F4585 | PIC18F6393 |
| PIC16LF722A | PIC18F2321 | PIC18F2580 | PIC18F4320 | PIC18F45J10 | PIC18F63J11 |
| PIC16LF723 | PIC18F2331 | PIC18F2585 | PIC18F4321 | PIC18F45J11 | PIC18F63J90 |
| PIC16LF723A | PIC18F23K20 | PIC18F25J10 | PIC18F4331 | PIC18F45J50 | PIC18F6410 |
| PIC16LF724 | PIC18F23K22 | PIC18F25J11 | PIC18F43K20 | PIC18F45K20 | PIC18F6490 |
| PIC16LF726 | PIC18F2410 | PIC18F25J50 | PIC18F43K22 | PIC18F45K22 | PIC18F6493 |
| PIC16LF727 | PIC18F242 | PIC18F25K20 | PIC18F4410 | PIC18F45K40 | PIC18F64J11 |

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|---|---|---|---|---|---|
| PIC18F64J90 | PIC18F66J93 | PIC18F8520 | PIC18F86J99 | PIC18LF24J50 | PIC18LF44J50 |
| PIC18F6520 | PIC18F66J94 | PIC18F8525 | PIC18F86K22 | PIC18LF24K22 | PIC18LF44K22 |
| PIC18F6525 | PIC18F66J99 | PIC18F8527 | PIC18F86K90 | PIC18LF24K40 | PIC18LF45J10 |
| PIC18F6527 | PIC18F66K22 | PIC18F8585 | PIC18F8720 | PIC18LF24K42 | PIC18LF45J11 |
| PIC18F6585 | PIC18F66K40 | PIC18F85J10 | PIC18F8722 | PIC18LF24K50 | PIC18LF45J50 |
| PIC18F65J10 | PIC18F66K80 | PIC18F85J11 | PIC18F8723 | PIC18LF25J10 | PIC18LF45K22 |
| PIC18F65J11 | PIC18F66K90 | PIC18F85J15 | PIC18F87J10 | PIC18LF25J11 | PIC18LF45K40 |
| PIC18F65J15 | PIC18F6720 | PIC18F85J50 | PIC18F87J11 | PIC18LF25J50 | PIC18LF45K42 |
| PIC18F65J50 | PIC18F6722 | PIC18F85J90 | PIC18F87J50 | PIC18LF25K22 | PIC18LF45K50 |
| PIC18F65J90 | PIC18F6723 | PIC18F85J94 | PIC18F87J60 | PIC18LF25K40 | PIC18LF45K80 |
| PIC18F65J94 | PIC18F67J10 | PIC18F85K22 | PIC18F87J72 | PIC18LF25K42 | PIC18LF46J11 |
| PIC18F65K22 | PIC18F67J11 | PIC18F85K90 | PIC18F87J90 | PIC18LF25K50 | PIC18LF46J13 |
| PIC18F65K40 | PIC18F67J50 | PIC18F8620 | PIC18F87J93 | PIC18LF25K80 | PIC18LF46J50 |
| PIC18F65K80 | PIC18F67J60 | PIC18F8621 | PIC18F87J94 | PIC18LF25K83 | PIC18LF46J53 |
| PIC18F65K90 | PIC18F67J90 | PIC18F8622 | PIC18F87K22 | PIC18LF26J11 | PIC18LF46K22 |
| PIC18F6620 | PIC18F67J93 | PIC18F8627 | PIC18F87K90 | PIC18LF26J13 | PIC18LF46K40 |
| PIC18F6621 | PIC18F67J94 | PIC18F8628 | PIC18F95J94 | PIC18LF26J50 | PIC18LF46K42 |
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| PIC18F6628 | PIC18F67K90 | PIC18F86J11 | PIC18F96J94 | PIC18LF26K40 | PIC18LF47J53 |
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| PIC18F66J10 | PIC18F8390 | PIC18F86J16 | PIC18F97J60 | PIC18LF26K80 | PIC18LF47K42 |
| PIC18F66J11 | PIC18F8393 | PIC18F86J50 | PIC18F97J94 | PIC18LF26K83 | PIC18LF55K42 |
| PIC18F66J15 | PIC18F83J11 | PIC18F86J55 | PIC18LF13K22 | PIC18LF27J13 | PIC18LF56K42 |
| PIC18F66J16 | PIC18F83J90 | PIC18F86J60 | PIC18LF13K50 | PIC18LF27J53 | PIC18LF57K42 |
| PIC18F66J50 | PIC18F8410 | PIC18F86J65 | PIC18LF14K22 | PIC18LF27K40 | PIC18LF65K40 |
| PIC18F66J55 | PIC18F8490 | PIC18F86J72 | PIC18LF14K50 | PIC18LF27K42 | PIC18LF65K80 |
| PIC18F66J60 | PIC18F8493 | PIC18F86J90 | PIC18LF23K22 | PIC18LF43K22 | PIC18LF66K40 |
| PIC18F66J65 | PIC18F84J11 | PIC18F86J93 | PIC18LF24J10 | PIC18LF44J10 | PIC18LF66K80 |
| PIC18F66J90 | PIC18F84J90 | PIC18F86J94 | PIC18LF24J11 | PIC18LF44J11 | PIC18LF67K40 |