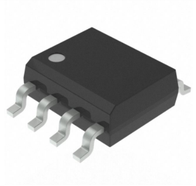
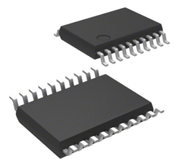
PERFORMANCE AND DEVELOPMENT WORKFLOWS

Microcontroller / Features	ATTINY412	SAMD11C	XIAO RP2040	XIAO ESP32-C3	ATTINY1624	CONCLUSIONS
Image						
Architecture	ATtiny412 uses an 8-bit processor architecture, which means that it works with 8-bit data and memory addresses at the same time. Uses Harvard architecture.	The SAMD11C uses a 32-bit architecture, allowing it to handle data and execute instructions faster than 8- or 16-bit microcontrollers. Uses Harvard architecture.	32 bit Uses Harvard architecture.	RISC-V 32-bit Microprocessor Uses Harvard architecture.	The ATtiny1624 uses the 8-bit AVR architecture, which is known for its efficiency in terms of power consumption and performance in embedded applications. Uses Harvard architecture.	Higher capacity (32bits): SAMD11C, XIAO RP 2040 and XIAO ESP 32-C3 All the microcontrollers use the Harvard architecture.
Clock frecuency	"Attiny412 includes an internal oscillator that can be used as a clock source. The typical frequency of the internal oscillator can be 20 MHz. 16/20MHZ LOW POWER INTERNAL RC OSCILLATOR • 32,768khz Ultra Low Power (ULP) Internal RC Oscillator • 32,768khz external crystal oscillator • CLOCK INPUT EXTERNAL "	The SAMD11C has a clock frequency range of up to 48 MHz. This means it can operate at a clock speed of up to 48 million cycles per second.	flexible clock up to 133MHz	four-stage pipeline that supports a clock frequency of up to 160 MHz	It can operate with a clock frequency of up to 20 MHz, allowing you to perform fast and efficient operations.	Higher speed: XIAO RP2040 and ESP32-C3
Flash memory	The capacity of the Flash memory in the ATtiny412 is up to 4 kilobytes (KB). This means that it can store up to 4096 bytes of program code.	The SAMD11C has flash memory of up to 16 KB. This means it can store up to 16,384 bytes of data or program instructions. Flash memory can be programmed using a microcontroller programmer or via a programming port built into the microcontroller	flash memory 2MB	4MB onboard Flash	It has an integrated 16 KB Flash memory for program code storage. This allows the implementation of medium to small applications on the microcontroller.	Higher data transfer XIAO RP2040 and ESP32-C3
RAM memory	The ATtiny412 has 256 bytes of RAM memory.	The SAMD11C has a RAM memory of up to 4 KB. This means that it can store up to 4,096 bytes of temporary or variable data while a program is running on the microcontroller.	264 KB de SRAM	Features 400 KB of SRAM	It has 512 bytes of SRAM memory for volatile data storage and 256 bytes of EEPROM memory for non-volatile data storage.	Larger memory: XIAO RP2040 and ESP32-C3
Communication interfa	The ATtiny412 is equipped with a variety of integrated peripherals that extend its capabilities and facilitate the implementation of various functions in embedded systems. Some of the integrated peripherals include timer/counters (TC), a PWM capture/comparison module (PWM), analog-to-digital converters (ADC), an event system (Event System), and a clock generator (CLK). The timers/counters are useful for measuring time intervals, the PWM module allows the generation of PWM signals to control motor speed and light intensity, the ADC facilitates the conversion of analog signals to digital for processing, the event system simplifies the interconnection between peripherals, and the clock generator allows adjusting the operating frequency. Pins:	USART (Universal Synchronous/Asynchronous Receiver/Transmitter): This interface allows synchronous or asynchronous serial communication. It is useful for communication with peripheral devices that use protocols such as UART, SPI or I2C. SPI (Serial Peripheral Interface): This interface allows serial synchronous communication between devices. It is useful for high-speed data transfer between the microcontroller and other devices, such as sensors or displays. I2C (Inter-Integrated Circuit): This interface allows synchronous serial communication between devices using only two data lines. It is useful for communication with low speed devices such as sensors and memory devices. ADC (Analog-to-Digital Converter): The SAMD11C has an integrated analog-to-digital converter, which allows the conversion of analog signals into digital signals. It is useful for reading analog sensors, such as temperature or light sensors. DAC (Digital-to-Analog Converter): The SAMD11C also features a built-in digital-to-analog converter, which allows the conversion of digital signals into analog signals. It is useful for generating analog control signals, such as reference voltages or motor control signals.	1 interface I2C, 1 interface UART, 1 interface SPI, 1 interface SWD Bonding pad.	I2C: I2C (pronounced I-squared C, or sometimes IIC for inter-integrated circuit) uses two lines (standard, fast, and fast plus modes) to control other devices; one line is clock (SCL), while the other is data (SDA). It has three modes, which are summarized in the following table. Please note that the rise/fall time values presuppose the installation of typical series resistors on the inputs and outputs. UART: Universal Asynchronous Receiver-Transmitter (UART) is similar to I2C. These interfaces have a maximum data rate of about 5 Mbps. UART devices are also easy to work with since no clock is sent between the devices; everything is done asynchronously. Note that the internal (system) clock of each UART device must operate at a multiple of the baud rate (that is, each bit is sampled N times). Only two threads are used for communication between a single controller device and a single downstream device. SPI: The SPI protocol is similar to I2C. A total of four lines are used on this bus and the components can be arranged in two possible ways. If a single controller device is used to activate a single downstream device, this is simply a point-to-point topology. Activation of multiple devices depends on the number of chip select outputs provided by the controller (standard mode). The second mode uses the daisy chain connection, in which a single device selection output successively activates each of the devices in the daisy chain itself. https://resources.altium.com/es/p/i2c-vs -spi-vs-uart-how-layout-these-common-buses I2S	It supports various serial communication protocols, including UART, SPI and I2C, making it easy to communicate with other devices and sensors. Pins:	The most versatile serial communication protocols belong to the XIAO ESP32-C3
Integrated peripherals	The ATtiny412 is equipped with a variety of integrated peripherals that extend its capabilities and facilitate the implementation of various functions in embedded systems. Some of the integrated peripherals include timer/counters (TC), a PWM capture/comparison module (PWM), analog-to-digital converters (ADC), an event system (Event System), and a clock generator (CLK). The timers/counters are useful for measuring time intervals, the PWM module allows the generation of PWM signals to control motor speed and light intensity, the ADC facilitates the conversion of analog signals to digital for processing, the event system simplifies the interconnection between peripherals, and the clock generator allows adjusting the operating frequency..	1.62 V a 3.63 V.	SPIx2 PWM UARPx2 Timer RTC I2Cx2 ADC&TS Reset Control Power on state machine Sysctrl Sysinfo Watchdog	I2C protocol: Use two lines (standard, fast and fast plus modes) to control other devices; one line is clock (SCL), while the other is data (SDA) SPI Protocol: Point-to-point topology asynchronous serial communication is an interface bus commonly used to send data between microcontrollers and small peripherals such as shift registers, sensors and SD cards.UART Protocol: It has a maximum speed of 5mbps Universal Asynchronous Transmitter-Receiver and is a simple two-wire protocol to exchange serial data.	• The ATtiny1624 has a total of 20 GPIO pins available for use. This includes digital I/O pins that may also have specific functionality assigned to them, such as UART, SPI, I2C, etc. • It has a 12-bit ADC with up to 11 analog input channels. • The ATtiny1624 has two 16-bit timers (TCA0 and TCB0) and one 8-bit timer (TCA1). • It has a USART module that allows asynchronous or synchronous serial communication with other peripheral devices. • It has an SPI module that provides a synchronous serial interface for high-speed communication with other devices. • It has an I2C/TWI module that allows serial communication. • Analog Comparators: It has two analog comparators that can be used to compare two analog signals and generate a digital output based on the relationship between them. • Watchdog Timer. Features a watchdog timer module that provides a safety feature that automatically resets	The most versatile integrated communication protocols belong to the XIAO ESP32-C3
Power consumption	The ATtiny412 has a very efficient power consumption, making it suitable for power-constrained applications. In active mode, typical current consumption at 3V and 25°C can be on the order of microamps per MHz clock frequency..		3.3V/5V DC	Circuit operating voltage: 3.3V@200mA Charging current: 50mA/100mA Input voltage (VIN): 5V **Work Modes and Descriptions** **1. Modem-sleep:** A. 160 MHz: All peripheral clocks disabled: 23 mA All peripheral clocks enabled: 28 mA B. 80 MHz: All peripheral clocks disabled: 17 mA All peripheral clocks enabled: 22 mA **2. Light-sleep:** Current consumption: 130 μA **3. Deep-sleep:** RTC timer + RTC memory: 5 μA **4. Power off:** CHIP_PU is set to a low level, and the chip is powered off: 1 μA	Active Execution Mode: • Typical clock frequency of 1 MHz and a supply voltage of 3.3V. Standby Sleep Mode (Idle Mode): • In this mode, power consumption can be significantly reduced, typically in the microampere (μA) range. Deep standby sleep mode (Power-down Mode): • In this mode, power consumption is further minimized and can be as low as just a few nanoamperes (nA).	SAMD11C has the lowest power consumption, which means a longer lifespan. All the other microcontrollers studied consume from 3.3V to 5V (except the AtTiny412 which consumes from 3V). Energy consumption will depend on its use.
Development tools	To develop applications with the ATtiny412 microcontroller, you can use a variety of development tools. Atmel Studio, an integrated development environment (IDE) from Microchip, provides a complete set of tools, including code editor, debugger and compiler. AVR-GCC is an option for C or C++ language development, offering flexibility in the choice of development environment. Hardware programmers and debuggers, such as AVR ISP, are essential for loading and debugging code on the ATtiny412. Atmel START, an online platform, facilitates initial project setup and code generation. In addition, the availability of simulators, detailed documentation provided by Microchip, and participation in online communities, such as forums and web resources, are valuable for development and troubleshooting. These tools and resources combined provide extensive support for effective development with the ATtiny412.	SAM D11 Xplained Pro Kit: Development platform with integrated peripherals. Atmel Studio: Integrated Development Environment (IDE). Atmel START: Online tool to configure and generate code. Atmel ICE: Programming and debugging tool. Atmel-ICE Probe Adapter: Adapter to connect Atmel ICE to the SAMD11C. Atmel Studio Extension for Visual Studio Code: Extension to use Visual Studio Code as an IDE.	C++ Python C Arduino (IDE) MicroPython (Tonny) CircuitPython (any code editor)	1. Arduino IDE 2. PlatformIO 3. Espressif IDF (IoT Development Framework) 4. MicroPython and Thonny IDE 5. Visual Studio Code (VSCode) 6. Espruino Web IDE **Arduino IDE:** User-friendly IDE supporting C/C++ programming. Requires installation of the ESP32 board support package. **PlatformIO:** Open-source ecosystem for IoT development. Supports C, C++, and other languages. Can be used as a plugin for various code editors. **Espressif IDF (IoT Development Framework):** Official framework by Espressif Systems. Primarily for C/C++ programming. Offers low-level control over ESP32 peripherals.	Atmel Studio Microchip MPLAB X IDE AVR-GCC y AVRDUDE PlatformIO	The microcontrollers that use free languages are XIAO RP2040 and ESP32-C3
Compatibility with boards		SAM D11 Xplained Pro: Evaluation board with integrated peripherals. ATSAMD11-XPRO: Evaluation board with integrated peripherals. ATSAMD11G18A-XPRO: Evaluation board with integrated peripherals. ATSAMD11D14AM-XPRO: Evaluation board with integrated peripherals.		1. EPaper Breakout Board 2. Seeed Studio CAN Bus Breakout Board 3. Seeed Studio XIAO Expansion Board 4. BeagleBone Series 5.Odyssey series 6.Quantum Development Board 7. Raspberry Pi series	ATtiny412 ATtiny814 ATtiny1614 ATtiny3214 ATtiny416 ATtiny817 ATmega328P ATmega2560	Microcontrollers are compatible with various boards. The choice will depend on your use.