United States Patent [19]

Bobba

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[54] **SYSTEM AND METHOD FOR TESTING ANALOG TO DIGITAL CONVERTER EMBEDDED IN MICROCONTROLLER**

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[51] **Int. Cl.**^{5} **H03M 1/10;** G06F 11/00

[52] **U.S. Cl.** **341/120;** 371/27; 324/73.1; 364/571.01; 364/553

[58] **Field of Search** 341/120, 131, 139; 371/25.1, 27, 24, 26, 15.1, 16.1; 324/73.1; 364/553, 571.02, 571.07, 571.01, 550

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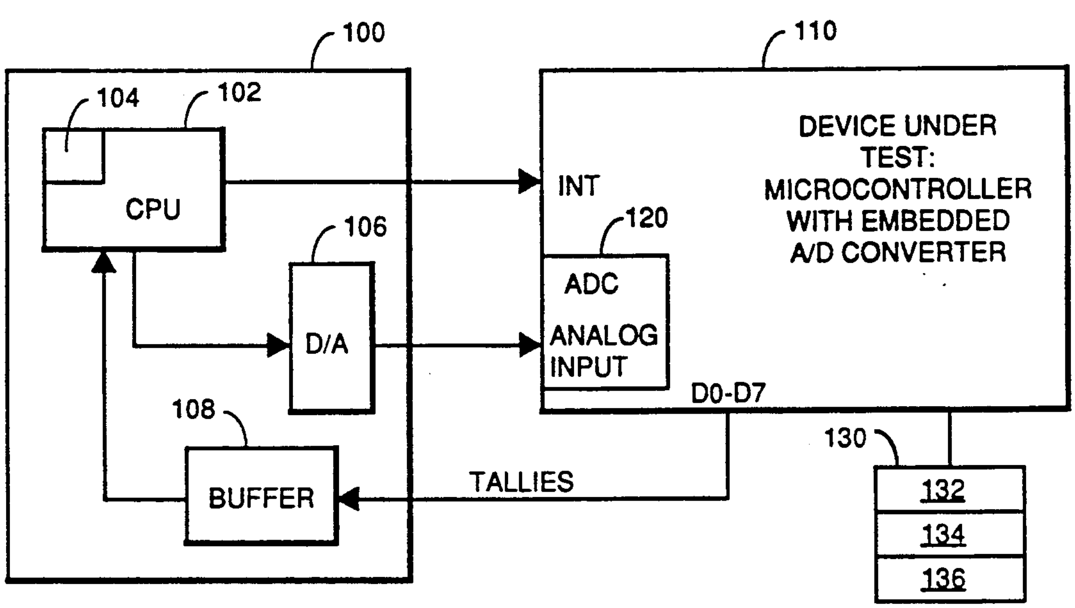
[57] **ABSTRACT**

A tester system tests the transfer characteristics and operability of an analog to digital converter (ADC) embedded in a microprocessor. The tester generates a sequence of analog signal test values, and prompts the microprocessor to read and convert each test value. The microprocessor sets up a table in its internal memory, the table having one tally value for every possible code output by the embedded ADC. After the embedded ADC converts each test value, the microprocessor reads the digital value output by the embedded ADC and increments a corresponding tally value in its internally stored table. When the sequence of tests is completed, the microprocessor transmits the entire table of tally values to the tester. The tester then performs a well known set of calculations on the tally data to determine the transfer characteristics and operability of the embedded ADC. By performing all tally operations in the microprocessor under test, the test sequence can be performed much more quickly than if each converted value were separately transmitted by the microprocessor to the tester. In addition, the tallying operation of the microprocessor simulates normal operation of the microprocessor while performing analog to digital conversions, and thus the embedded ADC is subjected to electromagnetic noise characteristic of the microprocessor under normal operation.

16 Claims, 2 Drawing Sheets



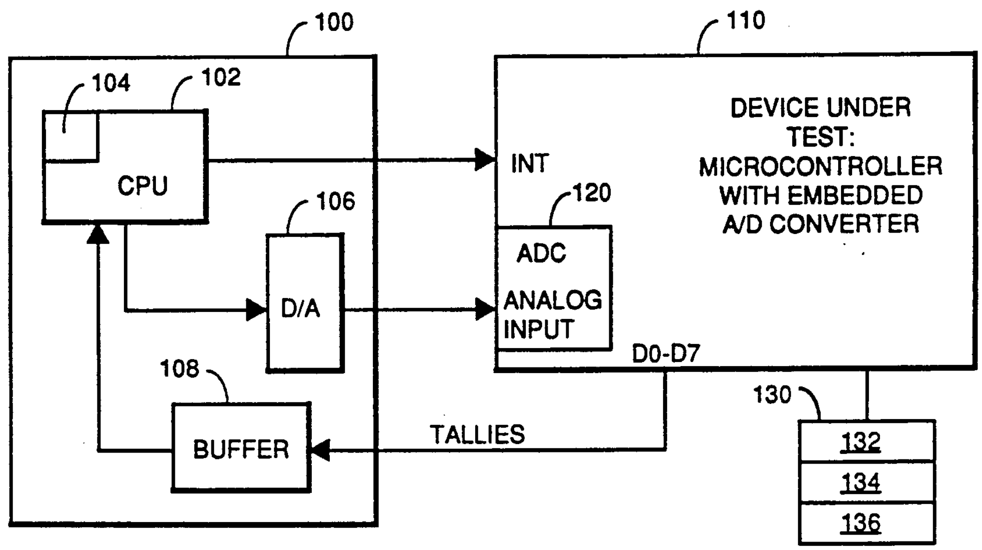


FIGURE 1

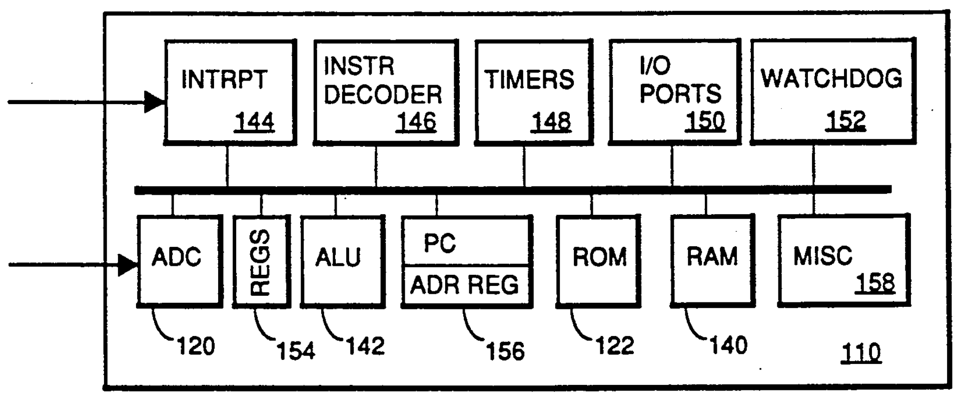


FIGURE 2

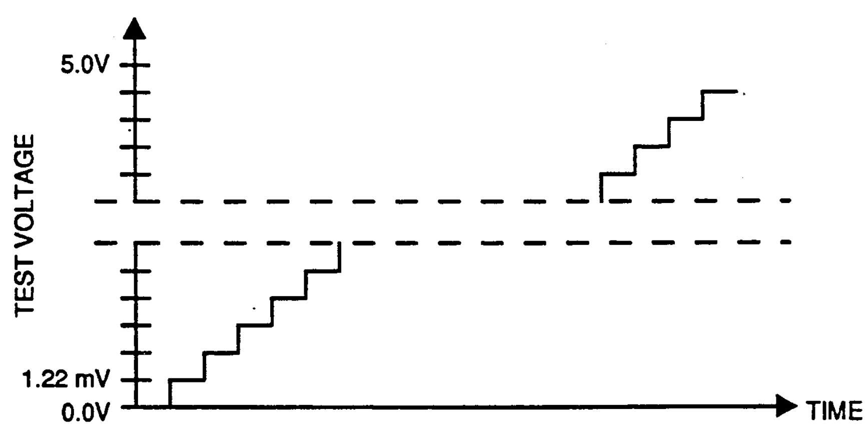


FIGURE 3

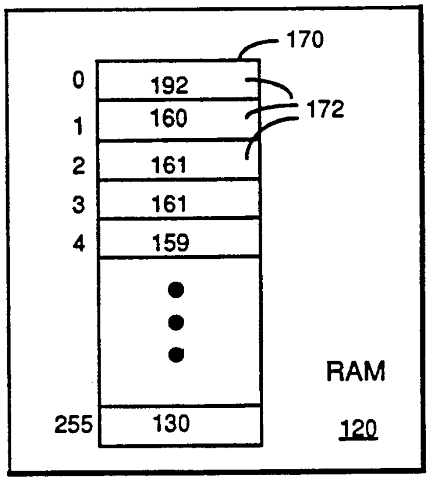


FIGURE 4

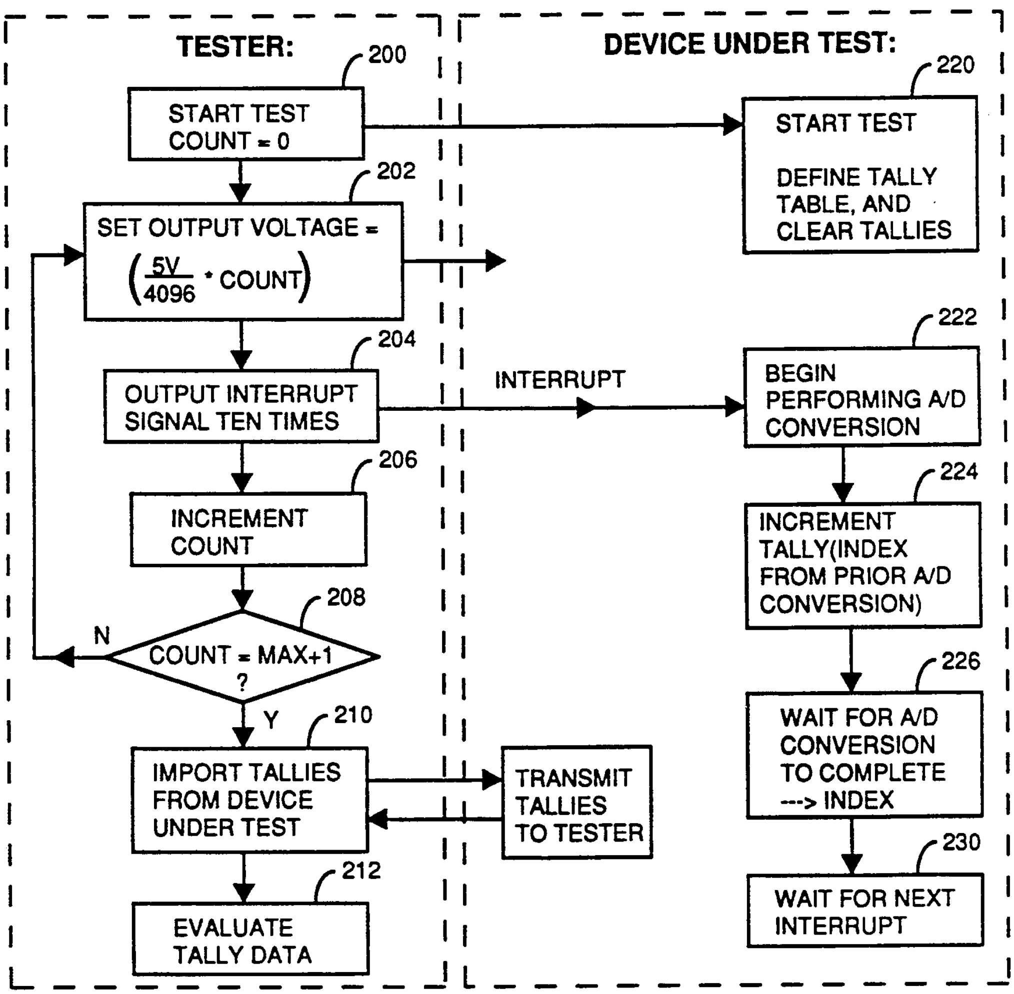


FIGURE 5

SYSTEM AND METHOD FOR TESTING ANALOG TO DIGITAL CONVERTER EMBEDDED IN MICROCONTROLLER

The present invention relates generally to testing complex semiconductor circuits, and particularly to methods and systems for testing the accuracy and linearity of an analog to digital converter which is embedded in a microcontroller or microprocessor.

BACKGROUND OF THE INVENTION

A number of microcontroller and microprocessor products now include an embedded analog to digital converter (ADC). This means that there is an ADC on the same semiconductor chip as the rest of the microcontroller's circuitry. For example, the COP888CF single chip CMOS controller made by National Semiconductor has an embedded ADC. In fact, that particular microcontroller has eight ADC channels (i.e., eight separate analog signal input connections). The development of such microcontrollers is a continuation of the trend toward putting all the circuitry needed for a programmable controller onto a single chip.

While complex semiconductor circuits with embedded circuits are convenient when building a product that needs a simple controller, such as a microwave oven controller, the presence of such embedded circuits makes it difficult to fully test the operation of the circuit.

Previous methods of testing embedded ADCs on digital VLSI test systems perform one conversion at a time. In other words, one analog signal is sent to the device under test, and the converted digital value is then read by the tester. The device under test is programmed to perform a conversion and then send the results of the conversion to the tester. Testing each possible output code of the ADC typically requires dozens of conversion and read sequences. Since the number of conversions typically used to test an eight bit ADC is in the range of 20,000 to 200,000, this testing method is very slow.

Another major disadvantage of the prior art methods of testing embedded ADCs is that the testing conditions do not match normal operating conditions. More specifically, when an embedded ADC is used in an actual application, the microcontroller will be performing many other operations, including computations, reading and writing data to and from registers and memory, and so on, all of which generate electromagnetic noise in the microcontroller. Standard prior art testing methods do not create the electromagnetic noise which is encountered during normal microcontroller operation.

SUMMARY OF THE INVENTION

In summary, the present invention is a tester system and method for testing the transfer characteristics and operability of an analog to digital converter (ADC) embedded in a microprocessor. The tester generates a sequence of analog signal test values, and prompts the microprocessor to read and convert each test value. The microprocessor sets up a table in its internal memory, the table having one tally value for every possible code output by the embedded ADC. After the embedded ADC converts each test value, the microprocessor reads the digital value output by the embedded ADC and increments a corresponding tally value in its internally stored table. When the sequence of tests is completed, the microprocessor transmits the entire table of tally values to the tester. The tester then performs a set of calculations on the tally data to determine the transfer characteristics and operability of the embedded ADC.

By performing all tally operations in the microprocessor under test, the test sequence can be performed much more quickly than if each converted value were separately transmitted by the microprocessor to the tester. In addition, the tallying operation of the microprocessor simulates normal operation of the microprocessor while performing analog to digital conversions, and thus the embedded ADC is subjected to electromagnetic noise characteristic of the microprocessor under normal operation.

Another important advantage of the present invention is that it enables an embedded ADC to be tested using a relatively inexpensive tester. In particular, the test equipment of the present invention does not need to perform measurements "on the fly"—all it needs is an accurate digital to analog converter for generating test voltages, plus a CPU with a few standard interface circuits for sending digital messages to and from the device under test.

BRIEF DESCRIPTION OF THE DRAWINGS

Additional objects and features of the invention will be more readily apparent from the following detailed description and appended claims when taken in conjunction with the drawings, in which:

FIG. **1** is a block diagram of a test apparatus for testing an analog to digital converter embedded in a microprocessor.

FIG. **2** is a block diagram of the circuits in a typical microcontroller having an embedded ADC.

FIG. **3** depicts a sequence of analog test signals used in a preferred embodiment.

FIG. **4** is a block diagram of a table of tally values stored in the random access memory of a microcontroller being tested.

FIG. **5** is a flow chart of a testing method in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The terms "microcontroller" and "microprocessor" are used interchangeably herein, both terms being used to refer to single chip data processing circuits. A microcontroller or microprocessor which has an "embedded ADC" is one with an analog to digital converter circuit on the same chip as the microcontroller or microprocessor's other circuitry.

Each digital value output by an analog to digital converter (ADC) is herein called a "code" or "output code". An eight bit ADC can output **256** distinct output codes, while a ten bit ADC can output **1024** distinct output codes.

Referring to FIGS. **1** and **2**, the test apparatus **100** in the preferred embodiment includes a data processing unit **102**, including test control software **104**, a digital to analog converter (DAC) **106** with sixteen bit resolution, and a buffer **108** for transmitting data values received by the test apparatus to the data processing unit **102**.

The device under test is a microprocessor **110** having an embedded analog to digital converter (ADC) **120**, herein called the embedded ADC. The embedded ADC **120** typically has a resolution of eight or ten bits (i.e., 256 distinct output values or 1024 distinct output values). For the purposes of the explaining the invention, it is assumed that the embedded ADC **120** has a resolution of eight bits.

Most microcontrollers have the ability to execute instructions stored externally to the microcontroller **110**, in addition to software stored in an internal ROM **122**. The test system in the preferred embodiment includes a memory **130** external to the microcontroller which includes software **132–136** which is used while testing the embedded ADC **120**. In particular, externally stored software **132** is used to initialize the microcontroller's internal random access memory (RAM) **140** by defining a table of values that will be described in more detail below with reference to FIGS. **4** and **5**. Software **134** accumulates and stores data in the RAM **140** while the embedded ADC **120** is tested with a sequence of test values. Software **136** transmits the resulting table of values to the tester's data processing unit **102** at the conclusion of the test sequence.

The internal circuits of the microcontroller **110** generate noise which may or may not affect the operation of the ADC **120**. FIG. **2** shows some of the common circuits found in most such microcontrollers, including an internal random access memory **140**, arithmetic logic unit (ALU) **142**, interrupt processing circuit **144**, instruction decoder **146**, timers **148**, input/output port circuits **150**, a watchdog circuit **152**, register logic **154**, program counter and address register circuits **156**, and other miscellaneous circuitry **158**. The present invention exercises at least some of these internal circuits while testing the operation of the ADC **120**, thereby subjecting the ADC **120** to electromagnetic noise characteristic of the microcontroller **110** under normal operation.

In the preferred embodiment, the tester's DAC **106** has a resolution of sixteen bits while the embedded ADC **120** being tested has a resolution of only eight bits. Referring to FIG. **3**, this enables the tester **100** to generate test voltages which take the form of a staircase of increasing voltage values within the nominal voltage range corresponding to each output code of the embedded ADC **120**. For example, if the voltage range for a particular output code (e.g., output code **1**) is 19.53 millivolts to 39.06 millivolts, the tester **100** will generate a staircase of N distinct test voltages within that range while testing the embedded ADC **120**, where N is a positive integer such as eight or sixteen.

In the preferred embodiment, the tester **100** outputs sixteen voltage steps within the range assigned to each distinct output code of the embedded ADC **120**. For an eight bit ADC **120** operating in a circuit with a maximum voltage swing of five volts, each distinct output code corresponds to a voltage range of about 19.53 millivolts (i.e., 5 volts divided by 256). To provide a staircase of test voltages with sixteen steps per output code, the tester generates test voltages which increase by about 1.22 millivolts per step, as shown in FIG. **3**.

Referring to FIG. **4**, a table **170** of "tally values" is stored in a table inside the microcontroller's RAM **120**. Tallying works as follows. For an eight bit ADC there are 256 distinct output codes. Therefore, for this ADC **120** the test software will define a tally table **170** having 256 entries **172** for storing tally values, with values of zero initially stored in every entry. Then, every time the ADC **120** performs a conversion, an entry corresponding to the output code generated by the ADC is incremented. In other words, if the output code from the ADC is equal to thirty-one (i.e., 1F hex), then entry thirty-one in the table **170** is incremented.

To generate a meaningful set of tally values, the tester **100** prompts the embedded ADC **120** to perform a large number of conversions while the input test voltage is within the voltage range corresponding to each distinct output code. For instance, in the preferred embodiment, the tester software **104** is set up to initiate 160 ADC conversions for each ADC output code. Thus, at the end of the test all the entries in the tally table **170** (except for possibly the first and last entries) for a perfect ADC **120** would be equal to 160.

FIG. **5** is a flow chart of the test software **104** in the tester **100** and the microcontroller's software **132–136** which is used while testing the embedded ADC **120**. The tester initiates the beginning of the test by sending a first signal to the microcontroller and setting an internal counter (COUNT) to zero (step **200**). The microcontroller **110** responds by defining and clearing a tally table **170** in its internal RAM **120** a tally table **170** (step **220**).

Next (step **202**), the tester sets the output voltage to be generated in accordance with the following formula:

$$\text{TEST VOLTAGE} = \left(\frac{5\ \text{Volts}}{4096} \cdot \text{COUNT}\right)$$

where 5 volts is the fully voltage range in which the ADC **120** is being tested, 4096 is the number of voltage steps being used, COUNT denotes the current voltage step being generated.

Once the test voltage has been set up, ten interrupt signals are sent to the microcontroller **110** (step **204**) so as to prompt the embedded ADC **120** to convert the test voltage ten times The microcontroller and its embedded ADC **120** respond to each interrupt signal by performing an ADC conversion, thereby generating an output code, which serves as an index into the tally table **170**. The indexed entry in the table (i.e., the tally for the output code generated by the embedded ADC **120**) is then incremented.

More specifically, in response to each interrupt signal, the embedded ADC **120** begins to perform an analog to digital conversion of the test voltage. However, it takes about a dozen of the microcontroller's CPU cycles for the conversion to be completed. During this time, the output code from the previous analog to digital conversion is used as an index into the tally table **170**, and this indexed entry in the table is then incremented (step **224**). Then the microcontroller waits for the current analog to digital conversion to complete (step **226**), thereby generating the output code (or index) to be used for tallying during the next test cycle. Finally, the microcontroller waits for the next interrupt signal from the tester (step **230**). Thus the process of performing an analog to digital conversion using the embedded ADC is overlapped with the tallying operation using the results of the prior analog to digital conversion.

After the tester has output ten interrupt signals (box **204**) for the current test voltage, it increments its internal counter COUNT (box **206**) and tests to see if the counter is equal to a predefined maximum value which corresponds to the last test voltage (box **208**), which in this example would be a value of 4096. If the value of

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