Design and Implementation of USB-based Microwave Power Sensor

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***Abstract*—According to the limitations of desk microwave power measurement instruments used in system setup and product line field, a brand new minisize power measurement design based on USB interface is proposed. Firstly, the design principles of analog channel, digital signal processing and the USB interface for the power sensor is introduced. Then the design fundamental of the USB communication to the host is presented. The vivid implementation of the software on the DSP, USB firmware and the PC host is fully discussed. This design features small size, light weight and programmable USB interface, which supports the Interchangeable Virtual Instruments (IVI) driver and thus simplifies the program procedure. The PC based platform allows for lower cost than traditional power meters and power sensors, and with a laptop PC it is ideal for field portable power measurement and remote multi-channel monitoring applications using all kinds of USB hubs.**

KeyWords—RF & microwave; power measurement; USB interface; digital signal processing; interchangeable virtual instrument

I. INTRODUCTION

In the field of RF & microwave power measurement, the common setup for power measurement tends to be the combination of meter plus multi-wire cable plus power sensor. This construction equips a meter with a variety of power sensors to fulfill the lab multiple purposes. But each time a sensor is connected to the meter, it has to be calibrated to guarantee the power traceability using the built-in calibrator, which further enlarges the dimensions. This type of configuration bears such large volume and fussy connection that it is not an ideal choice to be used in field and product line. A portable, easy-to-use and user-friendly device needs to be introduced to improve the cost and efficiency.

Universal Serial Bus offers the plug-and-play capability and can operate at both full and high speed. The extendable bus ability makes the multi-channel measurement easier. With the combined functionality of power meter and sensor in a standalone instrument, it has to be accessed by the host PC using the Standard Commands of Programmable Instrument (SCPI) or Interchangeable Virtual Instruments (IVI) drivers. As a USB-based intelligent instrument, the USBTMC-USB488 compatibility is necessary to provide plug-and-play environment and to emulate the operation of the traditional GPIB instruments [1,2]. This type of USB-based solution especially improves the productivity as you can monitor multiple channels on one screen instead of monitoring multiple power meters simultaneously.

II. THE SYSTEM HARDWARE DESIGN

Nowadays, the most popular power sensing component is the low-barrier Schottky diode detector. Diodes convert RF signals to DC by way of their rectification proper-ties, which arise from their nonlinear current-voltage (i-v) characteristic. This demands the digital detection-curve correction techniques, such as linear calibration, frequency corrections and temperature compensation for the raw ADC data. This design need to realize these data processing procedures within its internal DSP and only transmits the final power level to the host computer through USB port, which can dramatically decrease the host resource consumption. To qualify the accuracy and repeatability of power measurement, the temperature detecting circuit, the zeroing/calibrating circuit, the chopping driver circuit and other assistant circuits are integrated into the design [3,4]. The basic block diagram is briefly shown in Fig. 1.

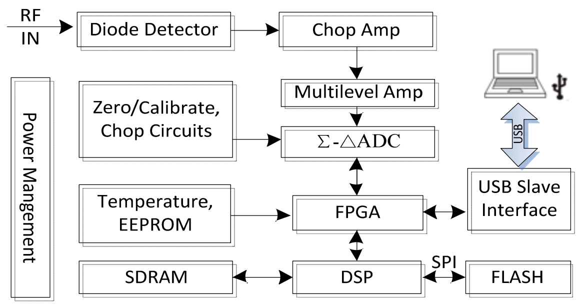

Figure 1. The block scheme of USB-based sensor

A. *Analog Signal Conditioning and Data Acquisition*

As we know, when a low power level microwave signal is applied to a diode detector, the output may be a low-level DC voltage with an order of nV. If the low-level voltage is directly amplified, the 1/f noise from the sensor elements and the preamplifier together with the drifts (temperature and aging drift) will be appeared in the subsequent amplifier with larger amplitude [5]. So the techniques of amplitude modulation amplification are considered to modulate the weak signal to a high frequency carrier. After necessary processes, such as DC-block, AC amplification, filtering and so on, the modulated signal can be sampled directly or demodulated synchronously to recover a relatively high-level DC signal.

Chopping amplification is the particular case of the modulation amplification in the area of weak signal application. The practical way to handle such tiny DC voltages is to chop them to form a square wave, and then amplify them with an AC-coupled system. In this article, it uses the electronic switches to build the modulator, which are called chopper here. As shown in Fig.2, the detected tiny DC signal from the dual-diode is chopped to form a square wave, which has the same frequency as the chopping frequency. To expand the measurement dynamic range, a range switch circuit is adopted. After the DC-block capacitor, the signal then enters the AC-coupled amplification system. After pre-amplified, the relatively high-level AC signal is split into two paths. The high gain and low gain paths are identical, except for an extra 100x gain in the high gain path. The signals from the two paths are sampled by a 16bit Σ-Δ ADC synchronously. Selection of data between the two samplers on different paths is performed by DSP under particular arithmetic. The selection is fast and transparent to the user.

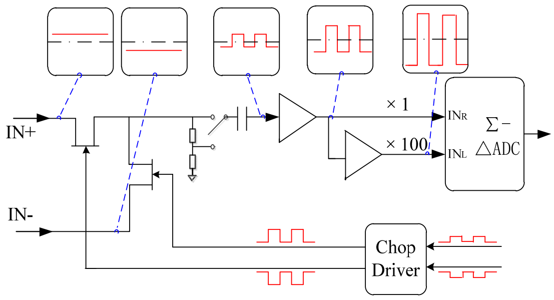

Figure 2. Simplified block diagram of signal conditioning circuits

B. Digital Signal Processing

Considering the 500mA power supply capacity of the USB interface and the project's data processing demands, we choose the low-power high performance TI DSP of TMS320C6747 as the main CPU. Together with the external SDRAM and serial flash, the processor is in charge of the general control and data processing.

Since the DSP carries out the de-chopping function, the ADC sampling clock is synchronized to the chopping frequency and there must be enough sampled data in a chopping cycle. Attention should be paid to the transition spikes and slowgoing area of the chopped main signal, which are caused by the frequent switches of FET. Obviously, these data are not correct and should be abandoned.

By comparing the statistical results of the chopped signals, we found out that the position and number of point concerned with the spikes and slowgoing area tend to be the same. So a de-chopping periodic window function can be constructed to restore the amplified DC signal and eliminate the corrupted data simultaneity. The de-chopping sequence should have the same point as the data point. As shown in Fig.3, during the time of spikes and slowgoing area, the sequence takes the value of zero; during the time of positive ADC value, the sequence takes 1; and during the time of negative ADC value, the sequence takes −1. Thus the de-chopped ADC value can be calculated by multiplying the chopped sequence and the window function.

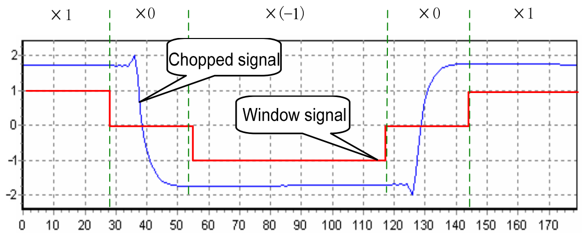

Figure 3. The chopped signal and the de-chopping window

C. USB Device Interface Circuit

The USB device interface makes use of the high integrated, low power USB microcontroller CY7C68014A. This design actualizes the Bulk, Interrupt and Control transfer modes [6]. For the convenience of communication with host and firmware update, the slave FIFO transfer mode is chosen. In this mode, the host and DSP both can read and write the buffers without the participation of the microcontroller. This increased the transferring speed and the configuration diagram is illustrated in Fig. 4.

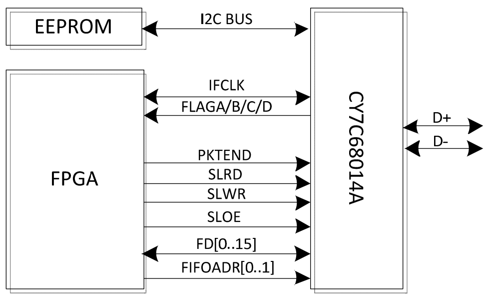

Figure 4. USB configuration diagram

In this design, the slave FIFO is configured to be asynchronous. The endpoint 2 is configured as OUT, which is responsible for receiving the commands from host to DSP; the endpoint 6 is configured as IN, which is responsible for receiving the measurement results and configuration data from DSP to host. The FLAGA/B/C/D is configured to indicate the states of the FIFO. All these configurations are defined in the firmware of the USB microcontroller.

III. SOFTWARE DESIGN

As a general RF & microwave hand-held instrument to be connected to PC or other instrument seamlessly, the USB power sensor needs to support the Visual Instrument Software Architecture (VISA) interface and the USB-TMC protocol. When the PC or instrument has installed the VISA library supporting the USBTMC, the sensor can be classified as a USB Test & Measurement device and can be accessed just as a traditional GPIB instrument.

The software work mainly centers on the USB firmware, the DSP software and the host application.

A. USB Firmware Design

The firmware which is stored in the exclusive EEPROM controls the entire USB communication. It also defines the slave FIFO mode configuration and fulfills the USBTMC protocol to support the control transfers and interrupt transfers. When first plugged into USB connector, the USB microcontroller enumerates automatically and downloads the firmware and USB descriptor tables over the cable. Next, it enumerates again, this time as a device defined by the downloaded information from the EEPROM. The firmware flow chart is shown in Fig.5.

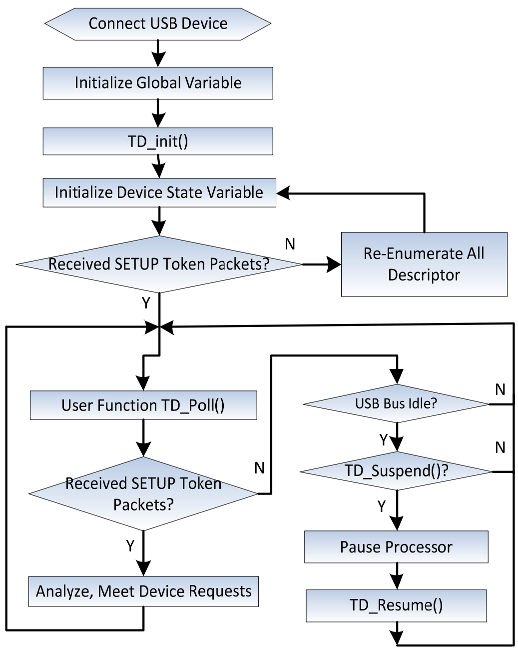

Figure 5. Flow chart of USB firmware

B. DSP Software Design

The Digital Signal Processor is the CPU for the sensor. It is responsible for the data processing, including linear calibration, frequency corrections and temperature compensation. It also controls the automatic zeroing and calibration process. For the USB communication, the DSP generates an independent thread to query the programming command from the host and interprets the received data to be the programming commands according to the USBTMC protocol. Subsequently, the DSP packets the measurement results or the desired data as the USMTMC standard format and sends them to the host through the FIFO.

Fig.6 shows the vivid flow chart of USB communication. The DSP is in idle mode waiting for the state flag FLAGA to be zero and endpoint 2 is not empty. When it happens, the DSP immediately read the data from the host. The readin data may be a single setting or querying command, or a combination of querying request and a data requesting command. When DSP is required to send data back to the host, it will add a BULK-IN data header to the data according the USBTMC command and then send it to the host through endpoint 6. The bit of bTag of the returned data header should to be the same as the bTag of the received requesting command.

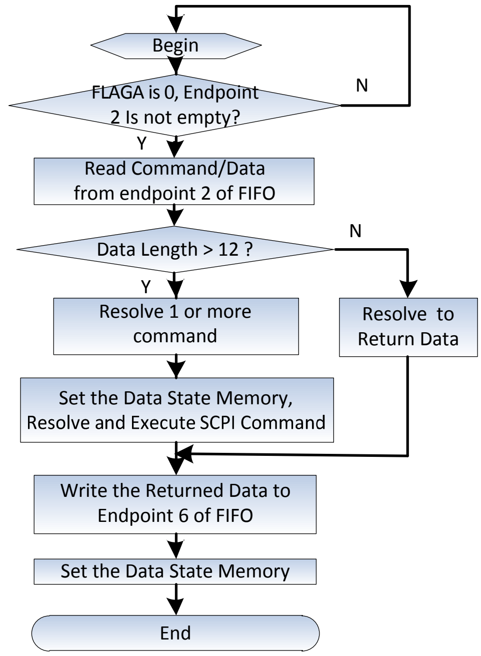

Figure 6. Flow chart of USB commutation in DSP

C. Host Driver and Application Design

When the host is a PC with Windows operating system and installed the VISA library supporting USBTMC, it can automatically identify the USB sensor as a USB Test & Measurement device. There is no need to install the special driver. Here, the VISA library is a set of high-class application interface and the user can operate the sensor just by calling the interface functions offered by the VISA library. When setting up a power measurement system, user can call the same API function to make an operation through different hardware programming interfaces, such as USB, LAN or GPIB.

The application on host can first call viFindRsrc() function to search for the USBTMC device on USB bus and then open the USB device by calling viOpen() function. Thus the user can freely call the functions of viWrite(), viRead() and viQueryf() to access the sensor. In the end, viClose() is called to close the device. Shown in Fig. 7 is the device management and power measurement application screen.

When the host operating system, Windows CE for example, cannot support the VISA library, there are two methods to access the USB sensor. One way is to design the special stream driver, which not only supports one BULK-IN, BULK-OUT and INTERRUPT-IN endpoint definition respectively, but also adds and subtracts the USBTMC data header. The other way is only to design a normal driver and the host application is responsible for adding and subtracting the USBTMC data header.

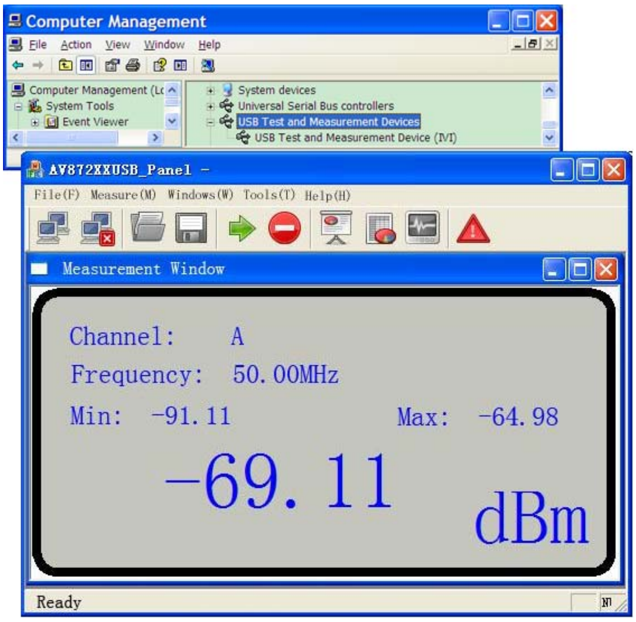

Figure 7. USB sensor hardware and the application view

IV. CONCLUSION

With the virtual instrument in mind, this design combines the diode detection techniques, the weak signal amplification technique, the digital signal processing technique and the high speed USB technique to build a distinguished minitype power measurement instrument. The design can achieve a accurate average power measurements with 10MHz to 40GHz frequency measurement range and -60dBm to +20dBm power measurement range.

Benefitting from the USBTMC protocol and USB plug-and-play connectivity, this design can enable fast and simple setup of power measurement system for Automatic Test Equipment (ATE). It can be used to monitor one channel power. For applications that require multi-channel power measurements like satellite communication system and product line field, this design is also an ideal cost competitive solution by using LAN-USB or WiFi-USB HUB. Also, Being USB-powered, this design requires no external power supply, making it ideal for putting in a laptop case for field servicing.

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