USING EMBEDDED SOFTWARE FOR ACHIEVING HIGHER PRECISION IN POWER DETECTORS

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Abstract

Accurate power measurement is essential in satellite communication systems, particularly for power generated by BUCs, due to regulations for the transmitted power connected with issues like transponder saturation, power limits for VSAT system connected with intermodulation interferences, etc. Many of the more expensive and powerful BUCs have integrated power detectors as a feature, but this is not the case with low power and customer defined devices, where output power is calculated on the basis of the gain of the device. On the other hand this gain is dependent from frequency, temperature, ageing and other factors. Here comes the need of an accurate power detector module. There are many power detectors present, but they also suffer from the same “symptoms” of frequency and temperature non-linearity, which again bring us to the problem of precise measuring of generated power.

As a solution of this problem a power measuring device will be presented. Its main feature is an embedded software algorithm which using data from internal temperature sensor, data for the used frequency, and reading from a power detector micro-chip, calculates an accurate power value based on a predefined calibration tables. These tables are populated with data measured in closely monitored environment and signal power generated and measured by high quality calibrated laboratory equipment.

The achieved results are real time readings with error of less than 0.5dB of the power generated by a Ku-band BUC in the whole frequency range and in a wide temperature range. This gives us the possibility of controlling output power more accurately and use the maximum permitted power for our up-links instead of using less power as a buffer for not transmitting more than expected.

1. INTRODUCTION

Power measuring is tightly connected with history of design and usage of RF equipment. Since early days there are three basic methods for sensing and measuring average power at RF and microwave frequencies. Each of the methods uses a different kind of device to convert the RF power to a measurable DC or low frequency signal. The devices are the thermistor, the thermocouple, and the diode detector.

In modern days power measuring has become very accurate in laboratory power meters using the previously mentioned methods. With the development of microchip technology, there is a high demand for smaller and more accurate power detectors. Most of the contemporary powers detecting MMICs are giving accurate linear reading just for a specific frequency range and surrounding conditions. Combining the power of digital microprocessors and embedded software with power detecting MMICs, these devices can be used in ranges where the results are non-linear, and achieve results with reasonable accuracy.

2. MAIN TEXT

Creating a small portable power meter with accurate results is challenging task. If used only analog technology this device may not be able to meet dimension and price requirements especially in higher frequency ranges. Using digital microprocessors with embedded software can reduce the requirements for the initial power detecting microchip without compromising the accuracy of the power reading. The main problem is that most power detectors’ output signal is linearly proportional to the measured power only in specific ranges of frequencies and temperatures. Outside this ranges the detectors are still working but the proportionality with the power levels measured is no more linear. This non-linearity and the deviation of the output signal because of temperature change are the main sources of error in power measurement. This error can be significantly reduced by using digital microprocessors. If this non-linear characteristic is measured in a controlled calibrated laboratory the user will know how the detector is acting outside of its linear range. If enough of these measurements for different frequencies and temperatures are made, a full picture of the detector's characteristic can be made. In software aspect these measurements can be viewed as a multidimensional array of data of corresponding output voltage to a specific power level and second or third variable parameter. For example reduction of the error from frequency and temperature deviation is needed, then a three dimensional array of data which stored output voltage values corresponding to a specific power level, frequency and temperature is necessary. This process will be referred as calibration of the detector. For the purpose of calculating actual power level from these calibration measurements a backward calculation using interpolation or extrapolation is done, for this purpose the microprocessor need to have the current temperature, frequency and detector's output voltage. The frequency is inputted as a parameter via the communication protocol, the temperature is measured from the same temperature sensor used during the calibration and the detector's voltage is measured directly on the ADC input.

In this article software and hardware requirements and solutions will be discussed, as well as the needed laboratory equipment and procedure for calibrating the detector. In parallel an example of real device of this kind with real parameters and results will be given, for the purpose of better understanding of the problem and its solution.

2.1. Power meter requirements

A device called power meter is required to measure accurate microwave power levels and return a corresponding message for the user or other equipment to be used. There are several requirements towards the power detector module.

2.1.1. Accuracy

The main requirement is accuracy: this means the error between detector readings and real power of the microwave signal to be as small as possible.

2.1.2. Frequency range

Another requirement is the operating frequency range in which the accuracy is maintained in certain level.

2.1.3. Operating conditions

Third important requirement is operating conditions, such as temperature range, humidity levels etc.

2.1.4. Others

Additional requirements towards the detector module are physical dimensions, type of connection with power transmitting structure (waveguide or cable), coupling and others.

As an example a power meter for Ku-band BUC output power is presented. It must operate in the frequency range from 14 to 14.5 GHz, and in conditions from -50 to +70˚C. Its accuracy must be less than 0.5dBm error. It should be connected at the waveguide exit of the BUC.

2.2. Hardware requirements

Power meter is created by several basic modules and each one has its own requirements.

2.2.1. Power detector microchip

Power detector microchip is the main module of the power meter. Its function is to detect microwave power and produce a DC voltage corresponding to the power level in its dynamic range. In the ideal case the produced DC is in linear scale proportional to the measured RF power. In reality the linear part of it power-DC characteristic is in some part of the frequency range. Outside of this linear range the power detector chip is still outputting a DC voltage but in non-linear proportion to the RF power. Embedded software will be used to overcome this nonlinearity and still read correct power levels.

2.2.2. Microprocessor

Microprocessor with at least two analog to digital convertor (ADC) channels is to be used for interpreting the power detector DC voltage. It is important that the ADC's sensibility is enough to make difference in the change of the detector's output voltage even in non-linear characteristic. Additional requirements towards the microprocessor are to have enough memory for storing software program and calibration data, faster clock for real time calculations, communication protocol for returning calculated power level and input of initial data for operating frequency and temperature, calibration data and other commands.

2.2.3. Other

Other devices that are part of the power meter are temperature stable reference voltage source and temperature sensor. Optional devices may be additional data memory, communications interface such as RF modem of RS-232 to USB converter etc.

In the example device a “Linear Technology” power detector linear in the 10MHz to 6 GHz frequency range is used. The microprocessor is 72MHz ARM Corex-M3 controller with 16 channels 12-bit ADC. For communications a 333MHz modem is used.

2.3. Software requirements and solutions

The requirements towards the software have several aspects.

2.3.1. Accuracy of calculation

The most important one is accuracy of calculation. This is achieved by storing as much calibration data as possible depending on the available memory. Another key issue for accurate calculation is that the precision of the calibration data must be at least 0.01 dBm for the power level. Stable reference voltage level is also critical for the accuracy; usually the supply voltage for microprocessors which is also used for reference for the ADC is not temperature stable enough. That is why before each measurement from the detector a measurement from a temperature stable voltage source is made to which the detector's output voltage is compared. This is done in the calibration procedure as well in the operating mode when calculating the measured power level.

2.3.2. Calibration data

The ideal case is when all the available memory is filled with data covering the whole range of frequencies and temperatures in which the device will be used. In this case the operating conditions will always be within the calibration data and interpolation will be used for calculating the measured value. If the calibration points are with smaller steps the error will be smaller. On the contrary if less calibration points are present the bigger error will be.

If for some reason the calibration process is compromised and there is partial calibration, sometimes the operating conditions will be outside of the covered calibration measurements, than extrapolation is the method for calculating the power level.

In both cases an algorithm for finding the closest data is needed. This can be achieved by using a second array of the same dimensions like the arrays of calibration data but filled with flags for valid data.

Additional array of temperature measured with the built-in temperature sensor during the calibration procedure is needed. The data in this array will be slightly different from the theoretical value and will be used in calculation of the power. The procedure for gathering this data will be discussed later in the calibration procedure description.

2.3.3. Communication protocol

Communication protocol is needed for interacting with the microcontroller for several reasons. They include: reading writing and editing calibration data; inputting operation frequency; reading measured power level; reading device parameters; updating the software; and any other features that can be performed from the microcontroller.

The communication can be done over any interface that is supported by the microcontroller (SPI, UART, and I2C) or with the help of peripheral communication device such as RF modems serial-to-USB convertors and others.

In the example device a 16x16x16 array is used for covering the whole range of frequencies from 14 to 14.5 GHz and a temperature range from -50 to 70˚C. For each temperature/frequency points an array with 16 power levels from -50 to 10 dBm and the corresponding power detector output voltage is recorded. The calibration memory was partially filled with only 3 calibration temperatures at 30, 50 and 70˚C. The frequency range was covered with 11 points with 0.05 GHz step.

2.4. Calibration equipment and procedure

The calibration process is very important for the proper calculation of the measured power in real operation.

The equipment needed for calibration is a temperature chamber for setting different calibration temperatures; power source capable of producing power levels in a broad dynamic range through the whole frequency range in which the power meter will be calibrated; laboratory calibrated power meter which is going to measure the real power at the calibrated power meter probe, this values will be added in the calibration database; PC which is going to synchronize the calibration process and communicate with the calibrated device to add the measured values.

The procedure consists of several steps which repeat for each desired calibration temperature. First the temperature is set in the chamber, and then a frequency sweep is started with predefined calibration frequency values. For each frequency a power sweep is performed with power defined in the dynamic range of the power meter to be used. For each power level, the actual power in the power meter is measured with the laboratory calibrated power meter and then this value is send to the calibrated device together with the current frequency and temperature. Upon receiving this data in the form of a command to add new calibration value the microprocessor measures the voltage from the detector and stores it in the corresponding part of the calibration array.

Since the temperature is regulated from the chamber, the built-in temperature sensor might have a different reading. For that purpose upon each command for adding a new calibration value, a reading from the sensor is taken. After all points for the given temperature are taken a mean value from the built-in temperature sensor readings is saved in the microcontroller for making the calculations when the device is making the calculations of the power level measured at the probe.

After populating all the desired power levels with corresponding voltages for each frequency-temperature combination the calibration process is completed.

In the example device the calibration is done in a laboratory with a combination of HP VNA and 40W BUC from Wavestream as power source and HP power meter. Both this equipment and the calibrated device were connected with PC for the purpose of automatic calibration. The calibration software and UI was written in Python 2.7.

3. CONCLUSION

At the end of this article a conclusion can be made that the power of modern microprocessors in combination with proper software and calibration can extend the usage of power detector MMICs outside of the frequency range for which they were originally designed. The accuracy of such devices depends mainly on the number of calibration points recorded and on the algorithm for choosing the calibration values from which the actual power level is calculated.

In the example a calibration for frequency and temperature was made, but in theory it may be any other parameter that is including error in the measurement. The results in the test device were meeting the criteria of less than 0.5dBm error from the real power level with actual biggest error of 0.31 dBm.