Volume 2, Issue 5, May 2012 ISSN: 2277 128X
International Journal of Advanced Research in Computer Science and Software Engineering
Research Paper
Available online at: www.ijarcsse.com

# A Robust and Simple Micro-Controller Based Frequency Response Analyzer

**Janamejaya Channegowda and G.Saravana Ilango**
*Department of Electrical and Electronics Engineering*
*National Institute of Technology – Tiruchirappalli,*

*Abstract*— **Robustness in the frequency response of electrical components is critical in building state of the art power electronic systems. A frequency response analyzer also called a network analyzer is used to determine the frequency response of an electrical network. Practical components have non-idealities such as parasitics, which need to be measured before their use in a design. Efficient design of electrical components over a high frequency range is vital for improving the overall performance of the electrical circuit. A frequency response analyzer is used to measure the impedances of active and passive components over a wide range of frequencies. This paper deals with the design of an robust micro-controller based frequency response analyzer whose frequency range is from 10Hz to 10MHz. The design, components used and the layout implemented are presented in this paper. Details related to the hardware and firmware are also explicitly explained for ease of design.**

*Keywords*— **Network analyzer, Fourier co-efficients, closed loop systems, parasitics, frequency response, Direct Digital Synthesis**

## I. Introduction

Advent of large number of electrical power circuits demand robust electrical components. The need for the introduction of such robust components is to maintain quality of service and increased lifetime. The parasitics of active and passive components need to be factored into the design of the power circuit [2].Power supply design requires determination of the performance functions [1]. This involves perturbations of the various inputs to the power supply. Standard procedures to introduce perturbation in voltage, current and duty cycle make use of a frequency response analyzer [3]. The frequency response helps to verify if the system has been properly modeled and designed. A frequency response analyzer also known as a network analyzer is used to determine the parameters such as input admittance, output impedance, control voltage gain, control current gain and audio susceptibility of power converters such as buck, boost and buck-boost and also the frequency response of switched-mode power supplies [4]. There are several network analyzers available in the market with a wide frequency range. They are very accurate but extremely expensive.

The characteristics of a good frequency response analyzer are:

- Excitation signal with varying magnitude to perturb the test circuit.
- Very high operating frequency range.
- Input and Output channels to measure the voltages of excitation signal and response signal.
- Ability to extract the test frequency over a narrow bandwidth.

Some of the commercially available network analyzers are:

1. Agilent / HP 4194A - Impedance Gain Phase Analyzer [16],
2. AP Instruments (Model: 200) [17],
3. Solartran frequency response analyzer (Model: FRA1250) [18].

### A. Motivation

Recent research [4] suggests that the process of frequency response analysis can be done with the help of a signal generator in conjunction with an high frequency oscilloscope. Although this process requires less resources and can be done with the available equipments in the laboratory, it is time consuming and tedious [5]. While both high frequency oscilloscopes and signal generators are used in frequency response analysis, little attention has been given to the use of frequency response analyzers operating at high-dynamic range. The key focus of this paper is on the hardware design and fabrication of a simple and robust micro-controller based frequency response analyzer, whose frequency range is sufficient for evaluating most closed loop system performances in power electronics area.

### B. Related Work

Substantial work is yet to be carried out on the design and implications of frequency response analyzer [6]. Some of the previous work [7] [8] [9] related to network analyzers are:

1. In [10] by Sriya Dupakuntla et.al., a direct digital synthesis based network analyzer with an analog

 

multiplier measurement channel for measuring frequency response of an RLC series resonant circuit has been implemented. This paper discusses some of the future avenues such as inclusion of an isolation transformer to a network analyzer for determining loop gain measurement of a switched mode power supply.

2. Similarly [11] describes the analysis of multi resonant passive circuit using high speed DACs in conjunction with an network analyzer. We take some of the previous analytical insights from the papers described above for the design of a robust frequency response analyzer. Earlier versions of network analyzers had a few limitations such as: low frequency range (10Hz to 1MHz), use of additional ADCs for measuring Fourier coefficients, unpredictable output response for passive electrical circuits and inability to utilize the potential of the central processing unit to the maximum possible extent.

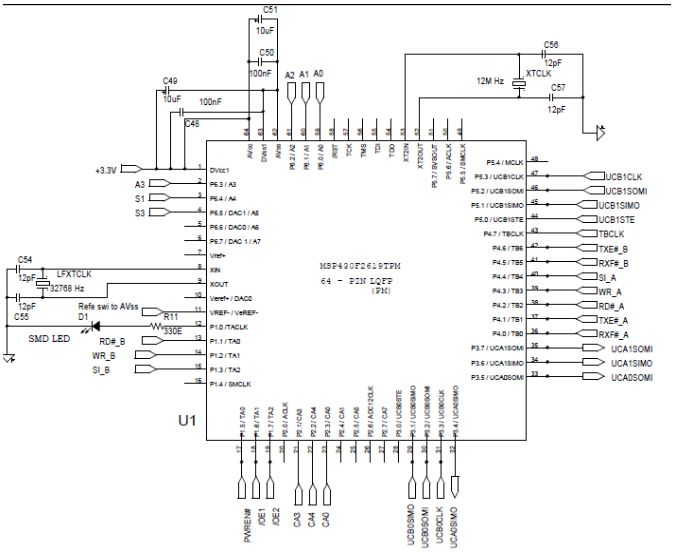


Fig. 1. The schematic diagram of the 16-bit core MSP430F2619TPM micro-controller used as the central processing unit of the frequency response analyzer

## II. SOFTWARE TOOLS USED

The following are the software tools used in successful burning of the frequency program into the micro-controller and for extraction of the Fourier co-efficients for obtaining the frequency response of the capacitor.

1. OrCAD Capture, version: 9.10, is a very easy-to-use tool to draw the schematics for the proposed frequency response analyser.
2. Code Composer Studio, Version: 4.1, was the integrated development tool used for Debugging and Compiling the frequency response program.
3. OrCAD Layout Plus, Version: 16.3, is a circuit board layout tool that accepts a layout-compatible circuit schematic and generates an output layout that is feasible for PCB fabrication.
4. MATLAB, Version: 7.5, was the simulation tool used in the PC to plot the frequency response plots from the Fourier co-efficients .

## III. PRINCIPLE OF OPERATION

In this paper, we propose a new design for a frequency response analyzer using a 16-bit MSP430 micro-controller. The proposed design facilitates the measurement of impedances of passive components such as inductors, capacitors and resistors over a wide frequency range. The block diagram of the proposed framework is shown in Fig.3 along with the schematic diagram of the components.

Table. 1. A brief summary about the chip details and features of the designed board.

| Sl. No. | Device | Package | Functionality |
|---|---|---|---|
| 1 | MSP430F 2619 | LQFP (Low-profile Quad Flat Package) | Used to enter the word corresponding to a particular frequency into the DDS. It also has the 12 bit , 8 channel ADCs required for the Analog to digital Conversion |
| 2 | AD9834 | TSSOP (Thin Shrink Small Outline Package) | Used to produce the excitation signal. It is programmed via a three wire Serial peripheral interface |
| 3 | AD811 | PDIP (Plastic dual-in-line packaging) | Used as a buffer and a gain providing amplifier |
| 4 | DG403 | SOIC (small-outline integrated circuit) | Used as a high speed analog SPDT switch to select a particular channel. |
| 5 | AD835 | PDIP (Plastic dual-in-line packaging) | Used to multiply the response of the circuit under test with the excitation signal and also to square the sine and cosine signals to obtain the output and input Fourier co-efficients respectively |
| 6 | FT2232D | LQFP (Low-profile Quad Flat Package) | USB communication IC, the IC receives the digital output from the micro-controller, it stores these values temporarily in memory 93C56 and then transmits it to PC through one of the USB ports |
| 7 | 93C56LI | PDIP (Plastic dual-in-line packaging) | Used as a temporary storage memory in conjunction with the USB interfacing chip |
| 8 | 74HC244 | PDIP (Plastic dual-in-line packaging) | Used as non-inverting buffer between the MSP430 microcontroller and the signal generator IC |

The Fig.1 shows the MSP430 micro-controller which is at the heart of the designed network analyzer. The micro-controller is operated at a operational speed of 12 MHz, powered by a 3.3 volt DC power source. The MSP430 consists of a 120 kB programmable memory, loaded with a frequency response program. The frequency response program can be tested by using the target board; see Fig.6. The frequency response program takes as input.

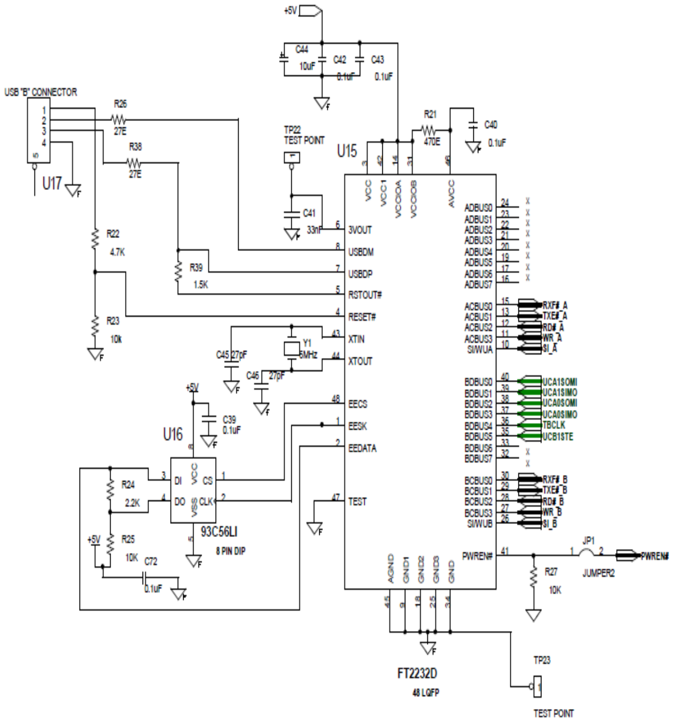


Figure 2: The detailed schematics of the USB interface IC (FT2232D) and the EEPROM IC (93C56LI)

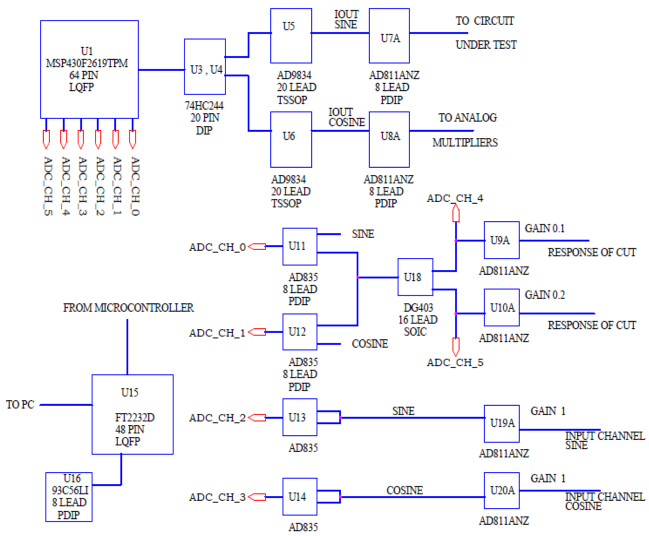


Figure 3: Control block diagram of the designed frequency response analyzer

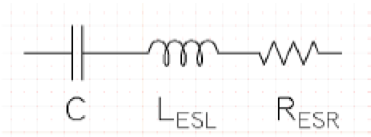


Figure 4: A capacitor with parasitic components

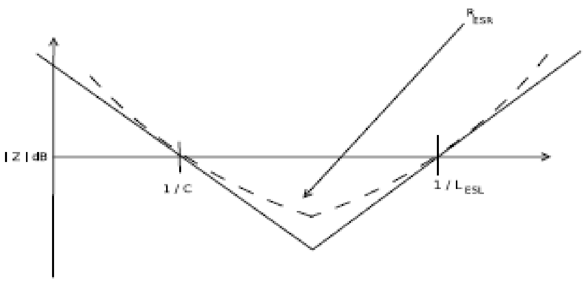


Figure 5: Plot depicting the impedance of the capacitor as a function of frequency

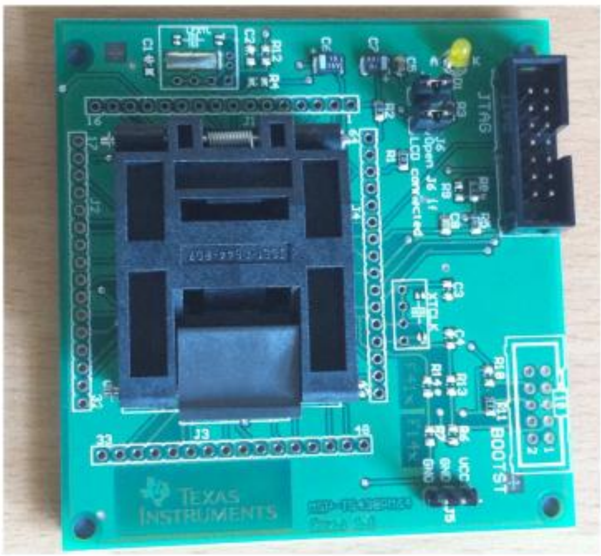


Figure 6: Target board of the MSP430F2619 microcontroller

 

Table 2: Cost of the designed frequency response analyzer

| Sl. No. | Device | Quantity | Cost/ Unit | Total Cost |
|---|---|---|---|---|
| 1 | MSP430F2619 | 1 | $19.4 | $19.4 |
| 2 | AD9834 | 2 | $10.4 | $20.8 |
| 3 | AD811 | 6 | $8.86 | $53.16 |
| 4 | DG403 | 1 | $2.45 | $2.45 |
| 5 | AD835 | 4 | $20.4 | $81.6 |
| 6 | FT2232D | 1 | $12.87 | $12.87 |
| 7 | 93C56LI | 1 | $0.53 | $0.53 |
| 8 | 74HC244 | 1 | $0.8 | $0.8 |
| 9 | Overall Total Cost | | | $191.69 |

The frequency of operation of the circuit under test, and generates a hexadecimal word corresponding to that frequency. The generated word is fed as input to two signal generator ICs; see Fig.3.

The output of one of the signal generator IC is a sine wave, which is buffered via a high performance video operational amplifier before giving it to the circuit under test. The output from the other signal generator is a cosine wave which is used for the calculation of the Fourier co-efficients. The response generated by the circuit under test, is buffered by a set of high performance video operational amplifiers of different gains. The output of these two Op amps; channel-4 and channel-5, is sensed by the two ADC channels of the micro-controller. When the signal in either of the channels reach an analog value of +1 volt, the micro-controller commands the SPDT switch to change over to the other channel which is given as one of the inputs to the analog multipliers. This behaviour of the micro-controller to switch between channels 4 and 5 is attributed to the fact that, the analog multiplier can take a maximum voltage of +1 volt as input. The other input to these multipliers are the sine and the cosine waves. The DC components of the outputs of these multipliers are the Fourier coefficients; see Fig.7.

The equation for the Fourier series is given as follows:

$$f(\omega t) = \sum_n a_n \cos(n\omega t) + b_n \sin(n\omega t) \qquad (1)$$

Where $f(\omega t)$ is a continuous periodic wave form with period $2\pi$. The Fourier co-efficients are:

$$a_0 = \frac{1}{2\pi}\int_0^{2\pi} f(\omega t)\, d(\omega t) \qquad (2)$$

$$a_n = \frac{2}{\pi}\int_0^{\pi} f(\omega t)\cos(n\omega t)\, d(\omega t) \qquad (3)$$

$$b_n = \frac{2}{\pi}\int_0^{\pi} f(\omega t)\sin(n\omega t)\, d(\omega t) \qquad (4)$$

The extraction of these DC components is done by connecting the outputs of the analog multipliers to the ADC channels of the micro-controller. The MSP430 micro-controller is equipped with a fast 12-bit, 8 Channel ADC with a conversion time of 10 microseconds. The micro-controller converts these Fourier coefficients to digital values and sends them to the USB interface IC. These Fourier coefficients are temporarily stored in the EEPROM before sending it to the PC; see Fig.2. In the PC the calculation of gain and phase are carried out and plotting with respect to frequency is achieved.

The equations for gain and phase of the circuit under test are given by:

$$Gain(dB) = 20 * \log_{10}\left(\frac{\sqrt{(a_0^2 + b_0^2)}}{\sqrt{(a_i^2 + b_i^2)}}\right) \qquad (5)$$

$$Phase = \tan^{-1}\left(\frac{b_0}{a_0}\right) - \tan^{-1}\left(\frac{b_i}{a_i}\right) \qquad (6)$$

Where $a_0$, $b_0$, $a_i$, $b_i$ are the output and input Fourier coefficients. Graphs are plotted with frequency along the x axis and gain along the y axis.

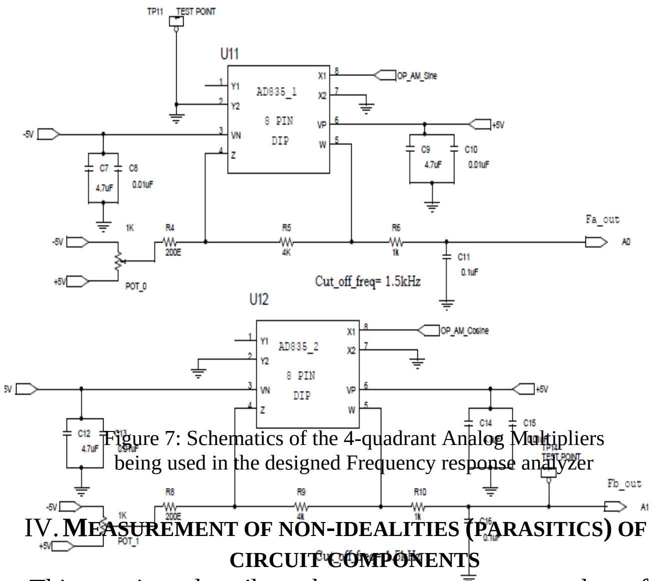


Figure 7: Schematics of the 4-quadrant Analog Multipliers being used in the designed Frequency response analyzer

## IV. MEASUREMENT OF NON-IDEALITIES (PARASITICS) OF CIRCUIT COMPONENTS

This section describes the measurement procedure for characterizing the circuit components. The parasitics present in a capacitor are shown in Fig.4 for the sake of clarity. The impedance for the circuit is given by:

$$Z = \frac{1 + scR + s^2 LC}{sC} \qquad (7)$$

The impedance thus obtained is superimposed over the gain plot described above. The value of R and L for which the gain plot and the impedance plot overlap represents the parasitics of the capacitor. The value of R and L are described as Equivalent Series Resistance (ESR) and Equivalent Series Inductance (ESL)

 

### *A. Impact of ESR and ESL on the performance of power capacitors*

Recent research [12] [13] [14] [15] suggests the use of power capacitors in power electronic systems for handling large amounts of power. The value of ESR and ESL, at very high frequencies tend to deviate the capacitor from its ideal characteristics. A lower value of ESR in a power capacitor would ensure reduction of power loss in the circuit. Similarly, a reduced value of ESL will ensure that the capacitor can operate over a large frequency range.

## V. AVENUES FOR FUTURE RESEARCH

Future research would include the development of frequency response analyzer for analyzing frequency response plots of isolation transformers. Analysis of frequency response of partial and complete power circuits along with the analysis of each of the building blocks. Inclusion of current booster for the measurement of impedance of ultra-capacitors. Elimination of high speed SPDT switch using variable gain amplifiers. Efforts can also be made to get precise frequency plots by effectively increasing the bandwidth of the excitation signal.

## VI. CONCLUSION

The paper proposes the design of a robust and simple frequency response analyzer and its use in estimating the parasitics present in a capacitor. Detailed hardware description related to the use of components, method for obtaining frequency response for passive elements were highlighted. This paper also highlights the use of signal generator IC for producing variable frequency test signals.

## ACKNOWLEDGMENT

The authors would like to thank the Department of Electrical and Electronics Engineering, National Institute of Technology, Tiruchirappalli for facilitating the research work

## REFERENCES

[1] B.Swaminathan, V. Ramanarayanan, *Application of network analyzer in measuring the performance functions of power supply*, Journal of Indian Institute Science, vol. 86, pp. 315-325, 2006.

[2] C. Wang, J. Mao, G. Selli, S. Luan, L. Zhang, J. Fan, D. Pommerenke, R.DuBroff, and J. Drewniak, *An efficient approach for power delivery network design with closed-form expressions for parasitic interconnect inductances*, IEEE Transactions on Advanced Packaging, vol. 29, no. 2, pp. 320-334, 2006.

[3] S. Doerner, T. Schneider, and P. Hauptmann, *Wideband impedance spectrum analyzer for process automation applications* Review of Scientific Instruments, vol. 78, p. 105101, 2007.

[4] R. Ridley, *Frequency response measurements for switching power supplies*, in Unitrode Power Supply Design Seminar, pp. 1999-00, 1999.

[5] S. Ryder, *Diagnosing transformer faults using frequency response analysis*, Electrical Insulation Magazine, IEEE, vol. 19, no. 2, pp. 16-22, 2003.

[6] T. Neugebauer and D. Perreault, *Parasitic capacitance cancellation in filter inductors*, IEEE Transactions on Power Electronics, vol. 21, no. 1, pp. 282-288, 2006.

[7] I. Novak, *Measuring milliohms and picohenrys in power distribution networks*, Design Con, 2000.

[8] K. Naishadharn, *Experimental equivalent-circuit modeling of smd inductors for printed circuit applications*, IEEE Transactions on Electromagnetic Compatibility, vol. 43, no. 4, pp. 557-565, 2001.

[9] S. Wang, F. Lee, and W. Odendaal, *Controlling the parasitic parameters to improve emi filter performance* in Nineteenth Annual IEEE Applied Power Electronics Conference and Exposition, vol. 1, pp. 503-509, 2004.

[10] S. Dupakuntla and V. Ramanarayanan, *A DDS based network analyzer with an analog multiplier measurement channel*. National Power Electronics Conference, Indian Institute of Technology , Roorkee, 2010.

[11] S. Jagadale, D. De, and V. Ramanarayanan, *An inexpensive digital network analyzer*, 35th Annual Conference of IEEE in Industrial Electronics , pp. 201-206, 2009.

[12] L. Haixue, Main problems of modern power quality, *International Journal of power system technology* - BEIJING, vol. 25, no. 10, pp. 5-12, 2001.

[13] K. See and J. Deng, *Measurement of noise source impedance of smps using a two probes approach*, IEEE Transactions on Power Electronics,, vol. 19, no. 3, pp. 862-868, 2004.

[14] A. Waizman, *CPU power supply impedance profile measurement using FFT and clock gating*, in IEEE Electrical Performance of Electronic Packaging, pp. 29-32, 2003.

[15] V. Ricchiuti,*Power-supply decoupling on fully populated high-speed digital pcbs*, IEEE Transactions on Electromagnetic Compatibility, vol. 43, no. 4, pp. 671-676, 2001.

[16] Agilent/HP 4194A - Impedance Gain Phase Analyzer 40MHz, http://www.alliancetesteq.com/node/17408

[17] AP 200 Parallel Frequency Response Analyzer, http://www.ridleyengineering.com/downloads/AP200Notes.ppd

[18] Solartron Analytical 1250A Frequency Response Analyzer, http://www.solartronanalytical.com/1250AFRAPage.htm

 