# PowerComposer Demo - Software-level Power Estimation for TI C5510 DSPs

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## Abstract

*PowerComposer is a software tool for estimation of the power consumption of the TI C5510 DSP. The tool analyses the assembly code being executed and provides an estimate of its average and instantaneous current consumption.*

## 1. Introduction

In the past decade, the consumer-oriented mobile device market has experienced rapid growth. One of the most critical factors in the design of handheld portable electronics is reducing power consumption. Major innovations in design for power are required to meet market expectations for increased functionality and improved battery life.

Current and emerging mobile applications incorporate signal processing tasks demanding significant computational complexity. Medium performance Digital Signal Processors (DSPs) are incorporated or embedded in today's cell phones, MP3 players, digital cameras and digital video recorders. One of the problems facing systems designers is estimating and optimising the power consumption of these DSPs.

The traditional approach to power estimation is hardware measurement via a current probe and oscilloscope. The main disadvantage of this technique is the time required to set-up, calibrate and conduct measurements using the hardware. Board builds may also be needed to provide access to the power supply system. As an alternative, Texas Instruments (TI) provides a spreadsheet for estimating power consumption [1]. The spreadsheet utilizes clock frequency and voltage as the main parameters - ignoring any dependency of power consumption on the instructions actually being executed. In experiments it was found that the current consumption of the processor can vary by up to 120% between different instructions (NOP versus Dual MAC). Thus, for accurate power estimation, the instructions being executed must be taken into consideration.

This paper describes a software tool for estimating the current consumption of the Texas Instruments' C5510 DSP. The tool is provided as a plug-in for the standard TI Code Composer Studio (CCS) Integrated Development Environment (IDE). The tool performs an analysis of the assembly code being executed by the Instruction Set Simulator (ISS) within the IDE and provides estimates of the mean and instantaneous current consumption of the DSP. Power estimation is based on a power model developed for the processor using hardware measurements.

The tool allows for fast and cost effective power estimation for the processor, facilitating power optimisation at the software level. Unlike hardware measurements, the tool provides the user with insight regarding the main causes of power consumption. Unlike previous tools which simply provide estimates of the average long term power consumption, PowerComposer provides estimates of the instantaneous, cycle-by-cycle power consumption. This allows designers to control current variation for optimisation of RF reception, power supply design and current smoothing to protect against cryptographic side-channel attacks.

The remainder of the paper is structured as follows. Section 2 describes the power model. Section 3 details the tool. Section 4 presents the results obtained from the tool. Finally, section 5 concludes the paper.

## 2. Power Model

The power model was developed by analysis of current measurements obtained using the Spectrum Digital C5000 DSP Starter Kit (DSK) [2]. Each instruction was embedded in a long loop and the current measured. A Hall effect current probe was used to measure the current. A Host PC was used to automatically generate stimuli programs, to download and run the programs on the DSK, to upload the measurements from the digital oscilloscope and to analyse the results in Matlab. The power measurement system is designed so as to allow rapid re-targeting to processors other than the C5510. The stimuli programs are generated from a database of assembly instructions and the measurement process is scripted and semi-automatic.

The dependence of current consumption on the instructions being executed was assessed. It was found that current consumption could be estimated based on Tiwari's Instruction Level Power Analysis (ILPA) model with a number of extensions [3]. The Tiwari model proposes that the energy consumption due to execution of a program can be estimated based on the energy consumption of each individual instruction plus an overhead due to switching between different instructions. The model was extended to capture the effects of addressing mode, degree of parallelism and pipeline state on current consumption. It was found that current consumption has very little dependency on data switching.

The Tiwari model allows estimation of the long term average current consumption but does not capture the dynamics of current variation with time. A model was developed to relate the ILPA estimates to the instantaneous current as measured by the oscilloscope. An instantaneous model was developed based on the assumption that the power supply system behaves as a Linear Time Invariant (LTI) system. System identification techniques were used to determine the impulse response of the power supply system. Based on this, the instantaneous current consumption was calculated as the output of the ILPA model convolved with the impulse response of the power supply system.

## 3. Software Tool

The power model was embodied in a plug-in for the CCS IDE. The plug-in analyses the assembly level instructions executed by the CCS ISS. The plug-in parses the instructions to extract the features relevant to power estimation. The plug-in compares the features with those of previously calibrated instructions stored in a database. The current consumption of the parsed instruction is taken to be equal to that of the most closely matching calibrated instruction. The output of the ILPA model is applied to the instantaneous model to determine the cycle-by-cycle current consumption of the processor.

The tool is designed so as to allow easy porting to other processors. The tool provides a GUI for ease of use by the programmer. Graphical representations of current consumed with time are provided to aid analysis.

## 3. Results

The accuracy of the tool was assessed by comparison of current estimates with measurements obtained using the experimental set-up. Long-term average current consumption was estimated using PowerComposer and compared with measurement. Experiments were conducted across a range of DSP benchmarks [7]. The results are provided in Table I. In all cases, accuracy was greater than 96%.

**Table I**. Mean current estimation accuracy

| *Benchmark* | *Estimated Current (mA)* | *Measured Current (mA)* | *Error (%)* |
|---|---|---|---|
| dual conv | 16.90 | 17.13 | 1.34 |
| cifft | 20.26 | 20.92 | 3.15 |
| autocorr | 15.89 | 16.37 | 2.93 |
| power | 15.33 | 15.45 | 0.77 |
| log10 | 16.76 | 16.98 | 1.29 |
| expn | 18.46 | 18.40 | 0.32 |

The accuracy of instantaneous current estimation was assessed by comparison with measured current traces. The results are presented in Table II. In all cases, the square correlation coefficient was greater than 97% and worst case instantaneous error less than 16%

**Table II.** Instantaneous current estimation accuracy

| **Benchmark** | **Worst Case Error (%)** | **Correlation Coefficient$^2$ (%)** |
|---|---|---|
| Cfft | 6.42 | 87.25 |
| Iir4 | 15.5 | 97.67 |
| Log10 | 8.44 | 94.93 |
| Jpeg_qize | 10.46 | 93.31 |

## 4. Conclusion

The paper presents a tool, PowerComposer, for estimation of the power consumption of the TI C5510 processor based on an analysis of the assembly code being executed. The tool is provided as a plug-in for TI's standard IDE. The tool has been shown to provide an accuracy of 97% or greater in estimating long-term average power consumption over a range of DSP benchmarks. The tool has been shown to provide a correlation of 96% or greater in estimation of instantaneous current when compared with measurement. Future work includes source level power analysis and modelling of other processors.

## 5. References

[1] Texas Instruments Inc., "TMS320C5510 Power Spreadsheet", C5510_power_v1_2.xls.
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