Parametric Characterization of DC-DC Converters using Source Measure Units

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Power electronic devices and systems are increasingly playing an important role across many industries, from automotive to medical to consumer electronics. For example, in automotive systems, these units power the electric motors for hybrid and fully electric vehicles. In computers and power supplies, they regulate output power to the motherboard. At the heart of any power electronic system lies the DC-DC converter, a device which can adjust input voltage to any number of different output voltage combinations. This is important for many electronics applications since there are usually many parts of a circuit operating at different voltage requirements. Other power electronic devices include motor drives (rectifier/inverter systems) for permanent magnet synchronous or induction motors. For this note, we will showcase the most common types of DC-DC converters, and then use a source measure unit to characterize the most important parameters of one of these types of converters.

Overview of Switched Mode DC-DC Converters

A switched mode DC-DC converter uses pulse width modulation and feedback control to regulate its output voltage. The switching characteristics leads to less loss and thus higher efficiencies compared to linear regulators which do not employ a switching scheme. This in turn leads to less board space and heat sinking requirements.

The main types of Switched Mode converters include:

- Buck Converters
  - These converters output a lower voltage then their input
- Boost Converters
  - These converters output a higher voltage then their input
- Buck-Boost Converters
  - Buck-Boost converters have the ability to act as both a buck or boost converter, with the ability to invert the polarity of the input voltage
- Flyback Converters
  - A type of buck-boost converter that utilizes isolation between the input and output voltages
- Cuk Converters
  - Similar to a buck-boost converter but with an output capacitor that allows continuous current
- SEPIC Converters
  - A buck boost converter where the output is the same polarity as the input

Switched mode DC-DC converters and linear regulators are typically rated on three important properties:

Efficiency

This is the most important characteristic of any converter. This is the ratio of the output power to the input power, usually expressed as a percentage. Mathematically expressed as (Pout/Pin) * 100, where Pout = Vout * Iout and Pin = Iin * Vin. Higher efficiency means less power drain on the input source and less heat dissipation on the circuit, allowing a smaller heat sink. Switching regulators usually operate around 70-90% efficiency.

Load Regulation

This specifies the percent change in output voltage to changes in load conditions such as load current or load resistance. It is defined a change in output voltage divided by change in load current (or load resistance), $\Delta Vout/\Delta Iout$ or $\Delta Vout/\Delta Rload$.

Line Regulation

This specifies the change in output voltage to changes in input voltage, or $\Delta Vout/\Delta Vin$.

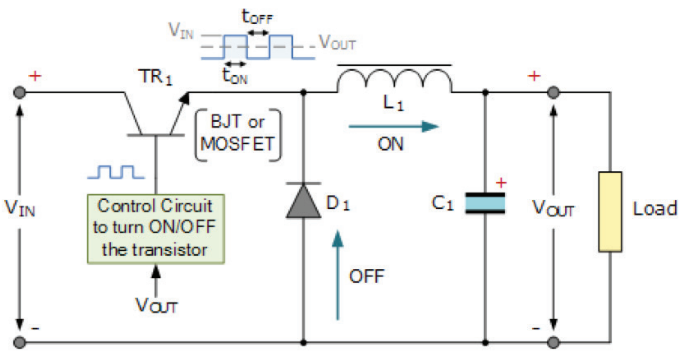


Figure 1: Typical diagram of a switching converter

Basics of Source Measure Units

An SMU is a device capable of simultaneously sourcing voltage/current and measuring (sinking) voltage/current. It does this with a built-in current and voltage source as well as a built-in volt and ammeter.

SMU's are ideal for performing current/voltage sweeps of semiconductors under test, and measuring DC response. This is due to its ability to source highly precise voltage/ current at high resolution, as well as sink and precisely measure voltage and/or current.

These devices under test could be:

IGBT's
MOSFETS/BJT's
Linear Regulators
Switched Mode Regulators

The four quadrant Zone of Operation refers to the maximum voltage it can source (sink) and maximum current it can source (sink) when operating in any one quadrant

Based on the graph, for the GS820-765601 option which we use for this demonstration, the GS820 can source/sink up to 7 V and 3.2 A in the inner range, and source/sink up to 18 V and 1.2 A at the outer range.

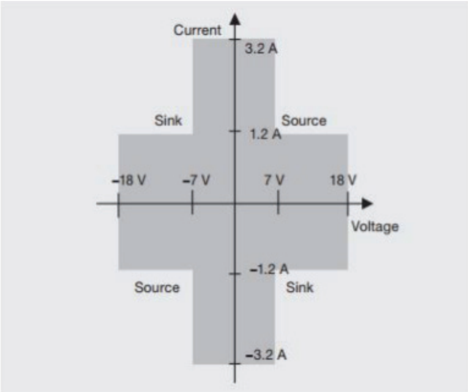


Figure 2: Current and voltage zone of operation for the GS820

The Yokogawa GS820 is able to achieve this by varying its internal series resistance to achieve the current source/ sink set-point and measuring the feedback current. If it detects the current feedback is at or over the range permitted at the voltage quadrant, the GS820 goes into current limiting mode and prevents any increase in amp set-point. Similarly, if the current feedback is at the limit of the quadrant, and the voltage set-point exceeds the allowable quadrant value, the unit goes into voltage limit mode to prevent a set-point increase.

Since the GS820 has two channels, two sets of voltage and current measurements or sourcing can be achieved. Channel to channel isolation ensures that both the GS820 and the DUT are safe from over voltage/current conditions

This enables us to create different combinations of test setups on the two channels, i.e. varying source voltage and measuring current feedback on channel 1, and sourcing current and measuring voltage feedback on channel 2. Other, more complicated sweeps such as ramp, logarithmic, or pulse can be performed on this unit, but for the purposes of this note, we will focus on linear, program based sweeps

In this note, we will

1. Hold a constant input voltage, and sweep the load current of the regulator and monitor Input and Output Power
2. Hold a constant input voltage, and sweep the load current of the regulator and monitor output voltage
3. Sweep the input voltage and monitor output voltage of the regulator

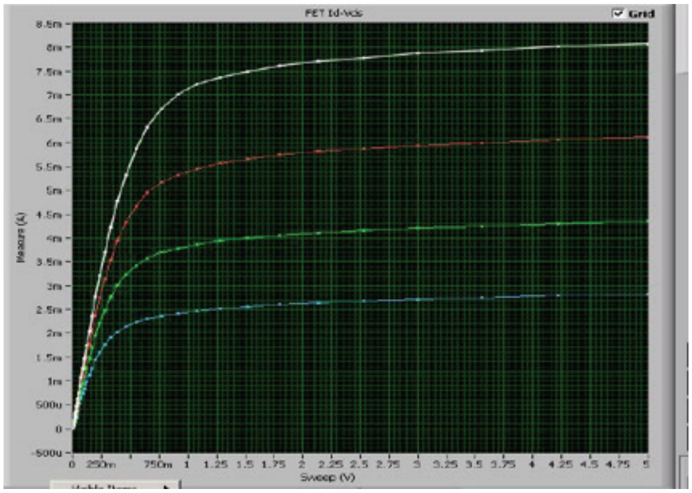


Figure 3: I-V Curve Trace

Setting Up The Test

To start off, I will create three program files in a csv format, which store the sweep routines and three setup files which will automatically import preset parameters to the GS820 for our tests, which are described below:

- On channel 1, we will source a constant 12V, and measure current on the input of the converter. On channel 2, we will sink load current from 0-3.2 A in steps of 50mA and measure output voltage
- On channel 1, we will source a constant 18V, and measure current on the input of the converter. On channel 2, we will sink load current from 0-3.2 A in steps of 50mA and measure output voltage
- On Channel 1, we will sweep the input voltage from 0-18 V in 200mV steps, and log the output voltage on channel 2.

Once finished, the results will be logged to a file on the RAM of the GS820 called Results.csv. We will use this file to generate the test results for load current vs Efficiency (12Vin), Efficiency (18Vin), Vout (12Vin), Vout (18Vin), and finally input voltage vs output voltage.
For this application note, we will use the GS820 to measure the three important characteristics of DC-DC converters discussed earlier. Our test bed will be an MP1584 Buck Switched Mode Regulator from Monolithic Power Systems ®

Specifications:

Supply Voltage (Vin) -0.3V to 30V
Output Voltage (Vout) 0.8V to 25V
Rated Load Current of 3 A
Programmable switching frequency from 100kHz to 1.5MHz
Output Ripple < 30mV
Working Temperature -45~85° C

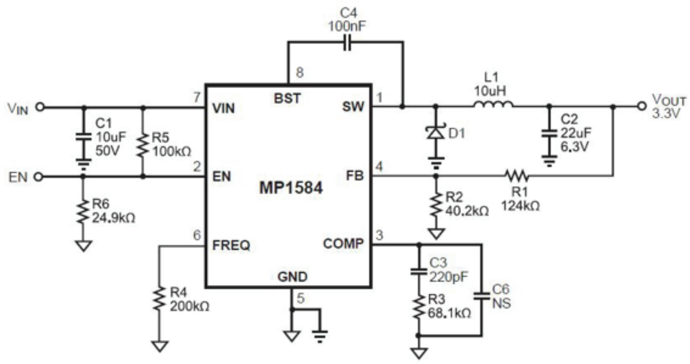


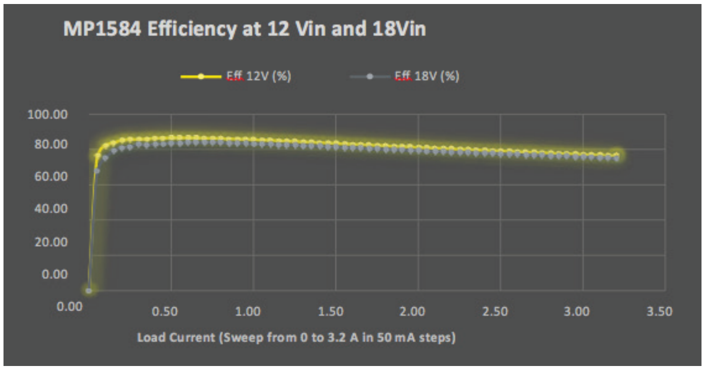
Figure 4: Schematic of MP1584

Interpreting Test Results

Efficiency Test

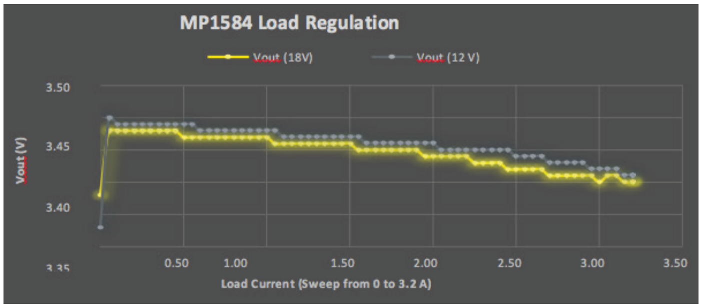
I select the three columns titled Load Current, Efficiency 12V and Efficiency 18V and create a scatter plot of the data by. The results can be seen below. As load current is swept from 0 to less than 0.55 A, efficiency of the converter hits a peak of 86.5% at 12 Vin and 83.72% at 0.70 A at 18 Vin.

As load current increases above 0.70 A, the efficiency then starts to decrease to a final value of 76% at 12Vin and 74.74% at 18Vin, at 3.2 A load current. This behavior is characteristic of switched mode converters, since higher currents lead to higher losses past the peak efficiency.



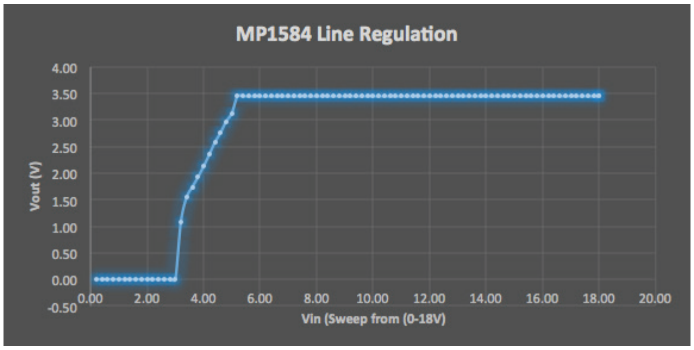
Load Regulation

The load regulation plot shows output voltage as a function of load current at constant input voltage, 12Vin and 18Vin, respectively. This plot was created by selecting columns titled Load Current, Vout (12V), and Vout (18V). Here, the output voltage drops from 3.45V to 3.35V across the full range of load current. A high-quality switching regulator must maintain the output voltage across a certain tolerance regardless of changes in load current/resistance. Here we see the output voltage within 100 mV for both 12V and 18V inputs.



Line Regulation

Here we see the behavior of the regulator when exposed to changing input voltage conditions. This plot was created by selecting channel 1 sourced voltage and channel 2 measured voltage. This curve is characteristic of many switched mode regulators as the voltage input is increased, the output voltage reaches a point of stability, at 3.50 V.



Conclusion

Following the steps above, one can quickly and easily perform custom I/V sweeps to characterize important properties of switched mode regulators. Tests results are conveniently logged to a csv file on the built in RAM for easy viewing and data manipulation. Utilizing highly accurate voltage/current sourcing and sinking capabilities, the Yokogawa GS820 can be used to validate as stated parameters on semiconductor manufacturer's datasheet, or characterize those not listed. Its two channels allow many different combinations of I/V measurements.

For detailed information on Yokogawa's source measure units, please visit us at http://tmi.yokogawa.com/us/products/generators-sources/source-measure-units/.