APPLICATION NOTE ANP24

SP6656 for Dynamically Adjusting Output Voltage

Introduction

The SP6656 is a high efficiency 400mA synchronous buck regulator that's ideal for portable applications using a Li Ion battery input. This part has a large feature set that includes 20uA quiescent current for high light load efficiency and 0.3 ohm internal power switches that provide high efficiency across a wide range of output currents and output voltages down to 1.0V. Examined in this application note is the SP6656 Output Voltage Set feature which allows for dynamically adjusting the output voltage between 2 different set output voltages. It will show how to determine the output divider network used to control the dual output voltages along with the dynamic performance of different output voltage ranges and selected networks.

The need for Dynamically Adjusting Output Voltage

An example of a DSP core voltage requirement is listed below:

Electrical Specifications

5.2 Recommended Operating Conditions

			MIN	NOM	MAX	UNIT
CV_{DD} $CV_{DD1/2/3/4/A}$	Device supply voltage, core†	Low Power Standby mode‡	1	1.1	1.675	V
		Active mode	1.525	1.6	1.675	

Figure 1. Texas Instrument OMAP 59XX family

Each DSP or microprocessor electrical specification table lists a core voltage with both active mode voltage level and a low power standby mode voltage level. The lower voltage at low power standby mode allows the core to consume less battery current when digital processing is not required, which can be a substantial amount of time for portable applications, thus improving the overall efficiency. Fast output voltage response without overshoot or ringing is required in the dynamically adjustable output function in order to get the core voltage to the active mode quickly and back to sleep mode smoothly. The SP6656 output voltage control uses a proprietary on-time control method which can quickly switch from discontinuous conduction mode (DCM) for light load to continuous conduction mode (CCM) for moderate to heavy loads. This pulse width modulated (PFM) control technique switches faster from DCM to CCM and can utilize low ESR ceramic output capacitors. The switching frequency is allowed to vary in light load DCM in order to save quiescent current and battery energy during the relatively long period of time in between pulses at light load. In moderate to heavy loads the SP6656 switching frequency is much faster and relatively constant for a given set of input and output conditions. Switching frequency curves for CCM mode will be shown for the different set of applications discussed.

The SP6656 Schematic and Output network

The SP6656 application schematic is shown below. Typical 10uF input and output capacitors are used and a 1uF and 10ohm resistor is used for an RC filter on the V_{IN} pin to ensure switching noise on the PV_{IN} input does not affect the internal SP6656 reference and control circuits. These components can be small 0603 and 0402 case sizes. The inductor selected is typically 10uH and a 1210 case size can be used to deliver the best selection of efficiency and smallest size for the 400mA applications the SP6656 is capable of, but other values such as 4.7uH can be used.

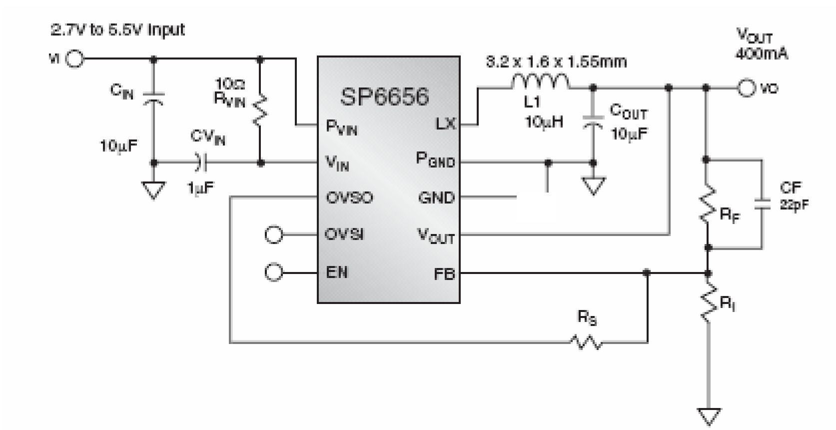
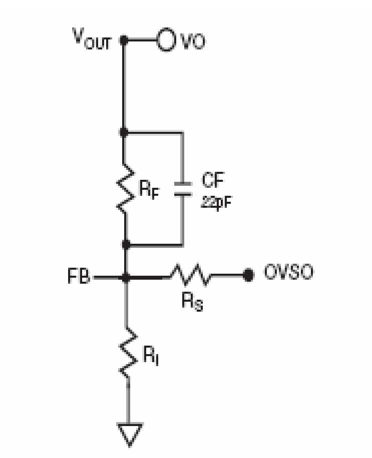


Figure 2. SP6656 Schematic

In the SP6656 output divider network shown below, the OVSO pin of the SP6656 will provide a short to ground through an internal NMOS switch when the OVSI digital input pin is given a high level. This OVSO connection is what provides the dynamically adjustable output voltage. The CF capacitor is a feed-forward capacitor which provides the AC coupling of the output voltage ripple to the feedback pin FB, ensuring good AC response. Later we will discuss the selection of these components for some actual applications.



OVSI	OVSO	Output Voltage
0	Open	$V_{OUT\_LOW} = 0.8\,(R_I+R_F)/R_I$
1	Short to GND	$V_{OUT\_HIGH} = 0.8\,(R_A+R_F)/R_A$

Table 1. Output Voltage Selection

Note: $R_A = \dfrac{R_I R_S}{R_I + R_S}$

Figure 3. SP6656 Output Divider Network and Table

Switching Frequency of the SP6656 for Output Voltage conditions

In order to properly select the feed-forward capacitor CF for best AC response we need to know the switching frequency of the SP6656 for the operating conditions. Figure 5 shows the output ripple frequency in continuous conduction mode when the SP6656 is under moderate to heavy output load. For V_{OUT} = 1.0V, we will use the lowest frequency of 400KHz for our calculations and for V_{OUT}=2.8V we will use the lowest frequency of 200KHz for our calculations. This will cover the range of outputs for most of the applications of dynamically adjusted output.

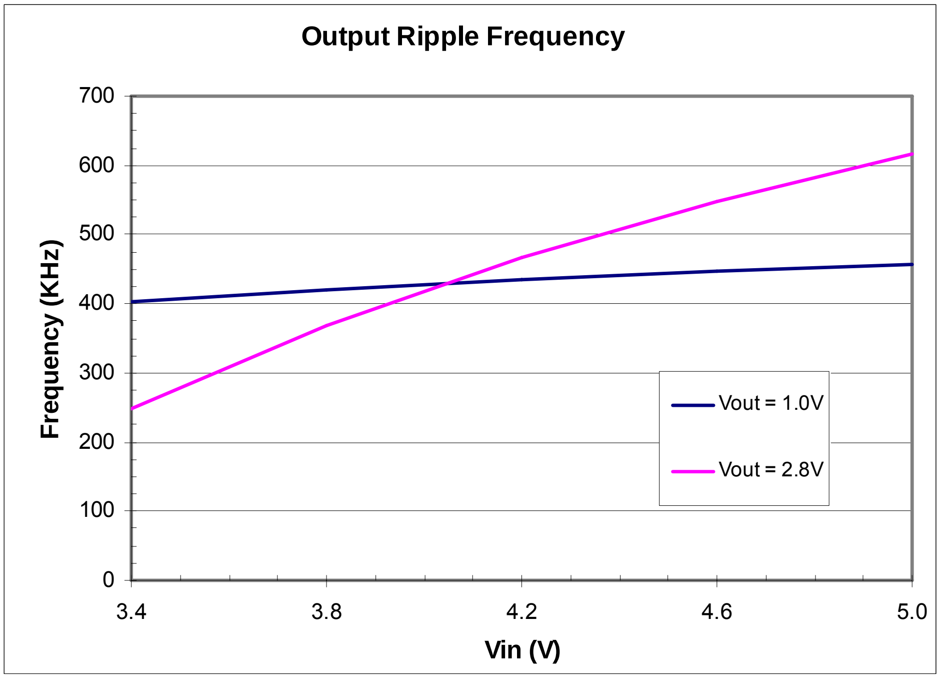


Figure 4. SP6656 Output Ripple Frequency Curve

Calculation of the Feed-forward Capacitor CF

The equations for determining the output divider resistors are given in figure 3. But how is the feed-forward capacitor CF value determined? Proper selection of the CF capacitor will determine the best AC response for the SP6656 output under fast changing conditions such as a dynamically controlled output as well as for a load step applied to the output. We will calculate the effective resistance of the feedback node in order to determine the time constant RFB*CF which will determine the time response of the output divider network. We then calculate the CF capacitor and finally select the actual CF value to use on an evaluation board and take experimental data to show the output response.

Output Voltage change from 1.0V to 1.35V: Calculations of Feed-forward capacitor
For good AC response, we need to make:

Feed-forward frequency << Output Ripple Frequency = 400kHz
Let's make Output Ripple Frequency = 5* Feed-forward frequency

Feed-forward frequency = 400kHz/5 = 125kHz

Feed-forward frequency = 1/[(2*3.14)*RFB*CF]

RFB*CF = 1/[125kHz*2*3.14] = 1.27 usec

Where RFB is the effective resistance of the output divider network as seen by the feedback pin FB node. This becomes the parallel resistance of RI, RS and RF:

RFB = RI//RS//RF = 200K//113K//50K = 29.5K ohms

CF = RFB*CF/RFB = 1.27 usec/29.5K ohms = 43pF

Calculations show a CF value of about 47pF. In the actual application, it was will be shown that a CF value of the next standard size of 68pF works the best. Data shown below.

Output Voltage change from 1.8V to 2.8V: Calculations of Feed-forward capacitor
For good AC response, we need to make:

Feed-forward frequency << Output Ripple Frequency = 250kHz
Let's make Output Ripple Frequency = 5* Feed-forward frequency

Feed-forward frequency = 250kHz/5 = 50kHz

Feed-forward frequency = 1/[(2*3.14)*RFB*CF]

RFB*CF = 1/[50kHz*2*3.14] = 3.18μsec

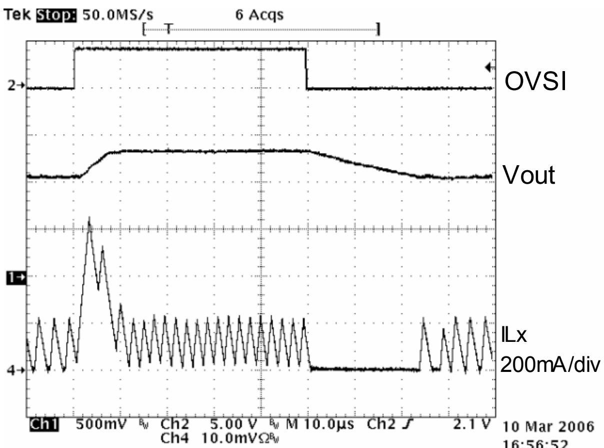
Where RFB is the effective resistance of the output divider network as seen by the feedback pin FB node. This becomes the parallel resistance of RI, RS and RF:

RFB = RI//RS//RF = 200K//200K//249K = 71.3Kohms

CF = RFB*CF/RFB = 3.18 usec/71.3Kohms = 45pF

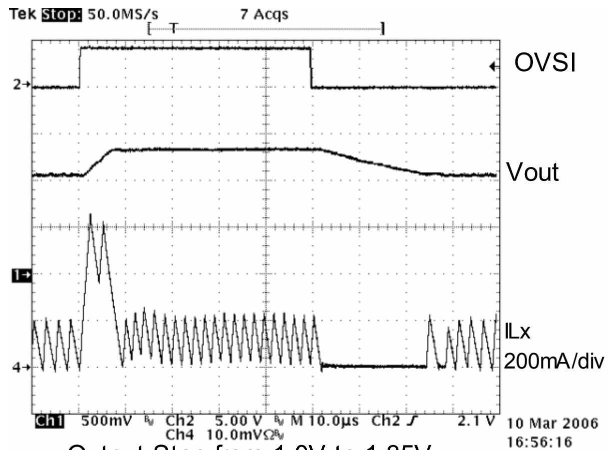
Calculations show a CF value of about 47pF. In the actual application, it will be shown that a CF value of the next standard size of 68pF works the best. Data shown below.

Output Voltage change from 1.0V to 1.35V:
Evaluation Board results below show a smooth transition from 1.0V to 1.35V output in less than 10µsec without overshoot. Note the use of CF = 68pF which is a little larger than the calculated 43pF, but the performance was found to be smoother.



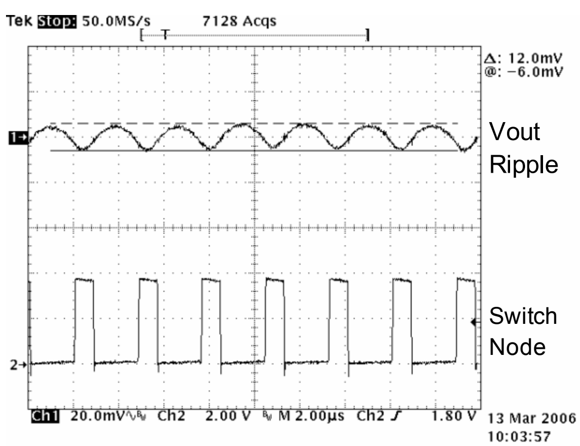
Output Step from 1.0V to 1.35V
Vin=3.6V, Rload=13 Ohm

Figure 5. 3.6Vin Output Step 1V to 1.35V



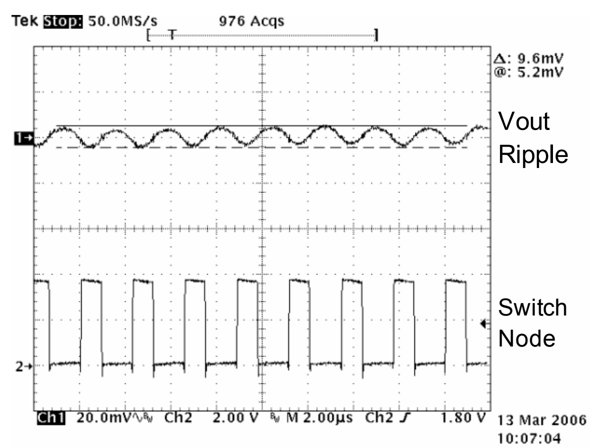
Output Step from 1.0V to 1.35V
Vin=4.2V, Rload=13 Ohm

Figure 6. 4.2Vin Output Step 1.0V to 1.35V



Vin=3.6V, Vout=1.0V, Iout=100mA

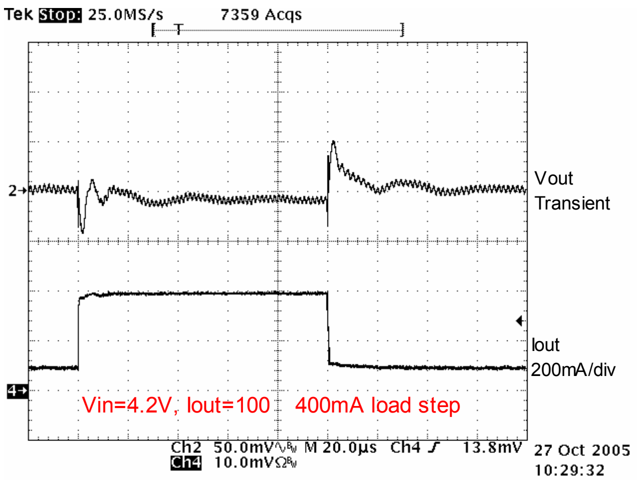
Figure 7. Ripple 1.0V Output



Vin=3.6V, Vout=1.35V, Iout=100mA

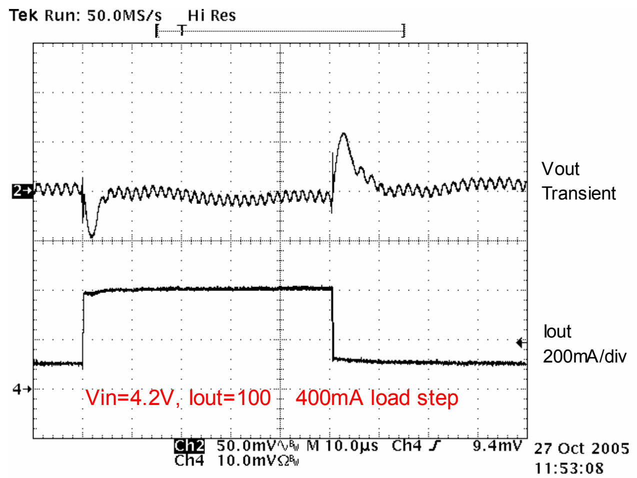
Figure 8. Ripple 1.35V Output

Output Voltage change from 1.8V to 2.8V:
Evaluation Board results below show a smooth transition from 1.8V to 2.8V output in less than 60usec without overshoot. First we show the use of CF = 47pF produces a load step response that has some ringing, but for CF = 68pF transient response is smoother. Next we show the 1.8V to 2.8V output transition: for CF = 120pF the output response is too slow at 80µsec, but for 68pF the output transitions faster and smoothly in a little over 40µsec.



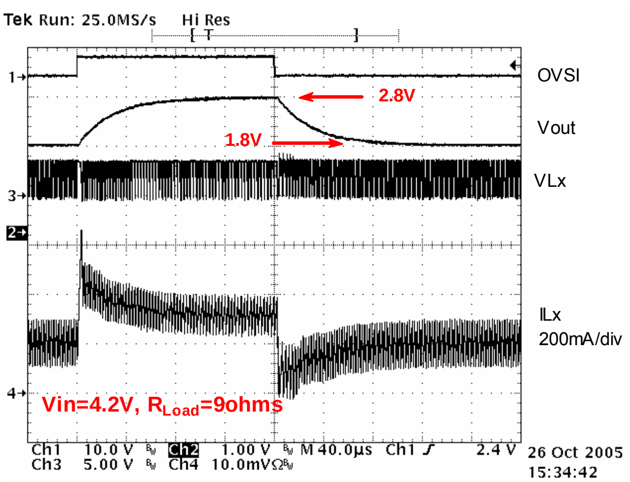
RF=249K, Rl=200k, Rs=200K, CF=47pF
Vout=1.8V

Figure 9. Load Step 1.8V Out, CF = 47pF



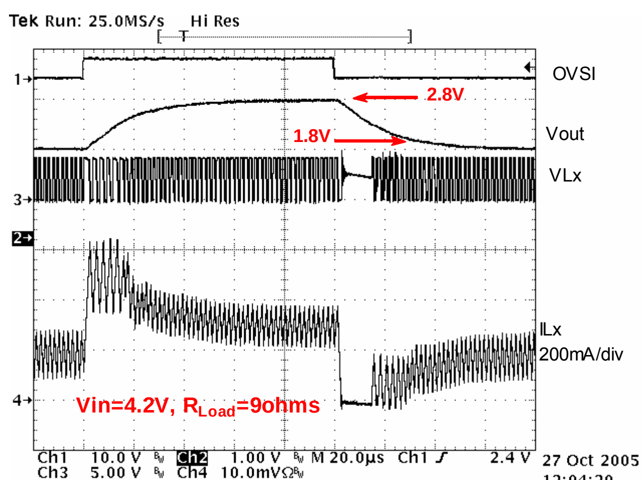
RF=249K, Rl=200k, Rs=200K, CF=68pF
Vout=1.8V

Figure 10. Load Step 1.8V Out, CF = 68pF



RF=249K, Rl=200k, Rs=200K, CF=120pF

Figure 11. 1.8V to 2.8V Out, CF = 120pF



RF=249K, Rl=200k, Rs=200K, CF=68pF

Figure 12. 1.8V to 2.8V Out, CF = 68pF

Summary
There is a need in portable products for the DC/DC converters to feature dynamically adjusting output voltage to change levels of the core voltage between active mode and low power standby mode for DSP and microprocessors. The SP6656 dynamically changing output voltage has the capability to provide fast and smooth level shifting between low power standby mode and active mode. The selection of the output voltage network components has been introduced and optimum feed-forward capacitance selection has been shown. For output networks with a FB to GND resistor RI of 200K ohms, the optimum feed-forward capacitor CF of 68pF has been shown to provide best performance in speed and smooth output transition.

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