ADP1621 Application Notes for Positive to Negative

Analog Devices

1. Solution for Positive Input to Negative Output

Using Cuk circuit with ADP1621 to generate a negative output voltage from a positive input. Cuk topology provides low input and output ripple due to using input and output inductors. The DC coupling capacitor also provides capacitive isolation from input and output as well as protection from Swith failure.

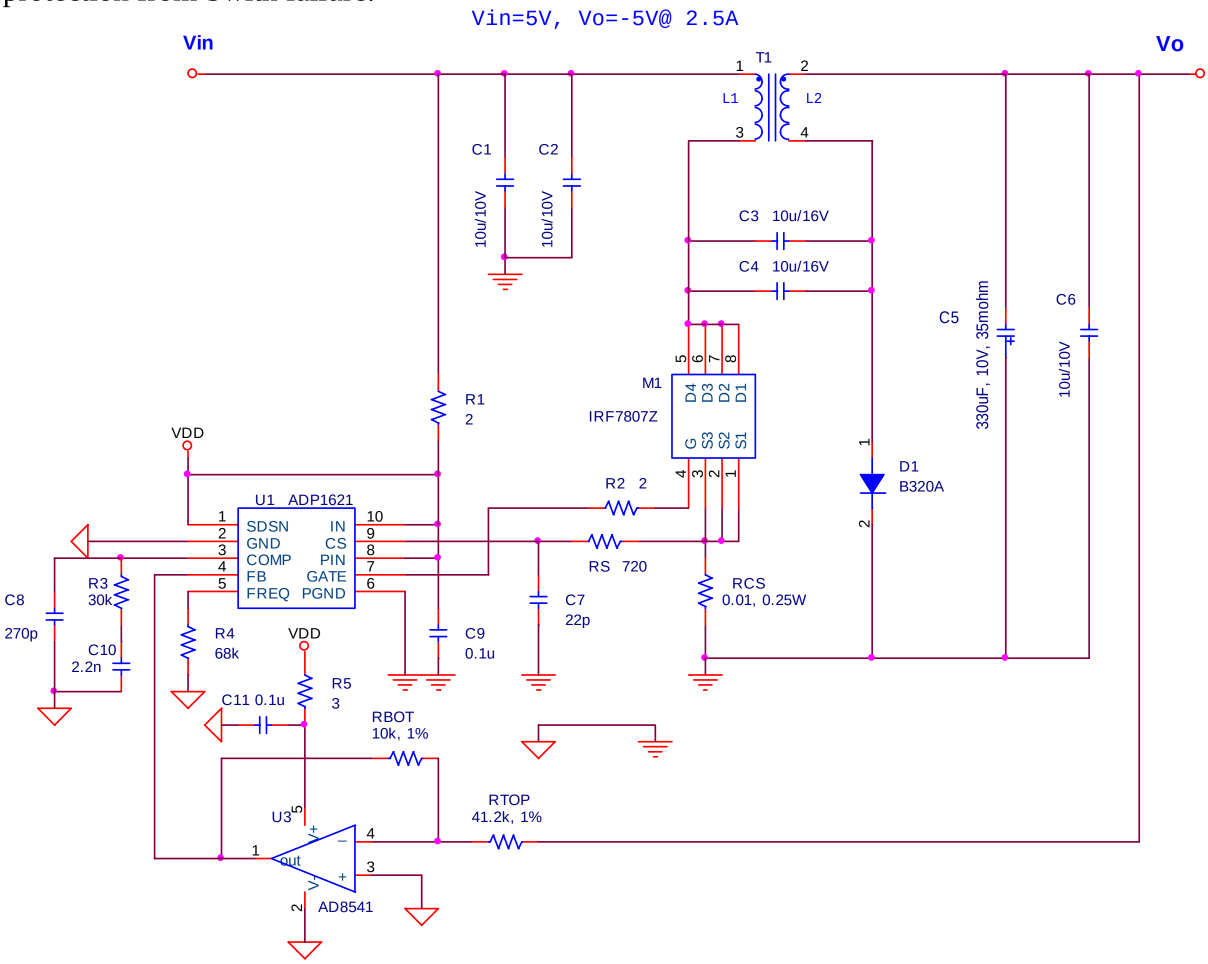
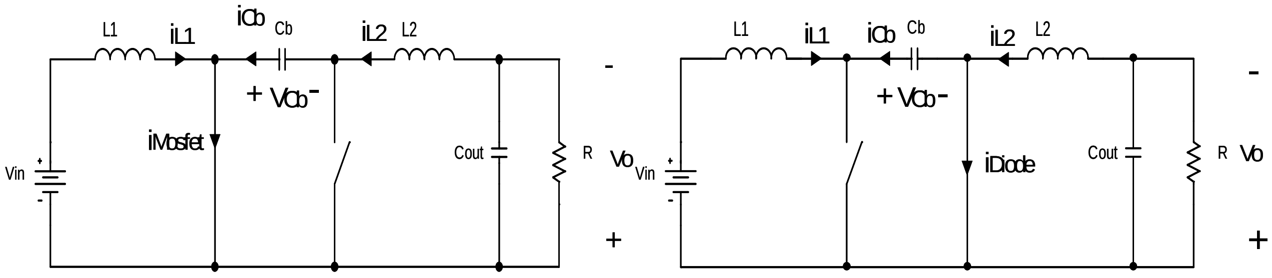


Fig 1. Positive to Negative Circuit

Fig 1 shows the schematic of the Cuk circuit using the ADP1621 and Fig 2 shows the basic operation of the Cuk circuit. During the on time of the FET, the inductor current flow through the FET and during the off time, current flow through the output diode. Inductor was both used in the input and output results in continuous current in the input capacitor and output capacitor.

the duty cycle of the Cuk circuit in CCM is:

$$D = \frac{|Vo|}{|Vo| + Vin} \qquad [1]$$



a) Switch On　　　　b) Switch Off

Fig 2. Cuk Circuit Operation Mode in CCM

2. Components Selection

2.1 Inductor

Since in Cuk Circuit there have two inductors, so separated inductor or coupled inductor can be used. Using separated inductor is easy for layout, but coupled inductor can reduce the PCB size and also can reduce the input and output ripple. The inductance is calculated at full load current and minimum input voltage. The following equations are calculated under uncoupled inductors and CCM operation.

Using the equation [2] and [3] to calculation the inductor value:

$$L1 = \frac{|Vin| \cdot D}{\Delta I_{L1} \cdot fs} \qquad [2]$$

$$L2 = \frac{|Vo| \cdot (1-D)}{\Delta I_{L2} \cdot fs} \qquad [3]$$

Here $\Delta I_{L1} = Krp_{L1} \cdot \frac{Io \cdot D}{1-D}$, $\Delta I_{L2} = Krp_{L2} \cdot Io$, the value of Krp_{L1} and Krp_{L2} are between 20% to 40%.

If coupled inductor with 1:1 turn ratio is used, the inductance value in [2] and [3] can be replaced by 2L due to mutual inductance. Maintain the same ripple current in the inductor, using the equation [4] to calculate the coupled inductor value:

$$L1 = L2 = L = Max\left\{\frac{|Vo| \cdot (1-D)}{2 \cdot \Delta I_{L2} \cdot fs}, \frac{|Vin| \cdot D}{2 \cdot \Delta I_{L1} \cdot fs}\right\} \qquad [4]$$

Here L is the inductance value in parallel configured

When select the inductor, RMS current and saturation current need considered.

For the uncoupled inductor, the RMS and the saturation current need larger than:

$$I_{RMS(L1)} = \sqrt{(Io \cdot \frac{D}{1-D})^2 + \frac{\Delta I_{L1}{}^2}{12}} \qquad [5]$$

$$I_{RMS(L2)} = \sqrt{Io^2 + \frac{\Delta I_{L2}{}^2}{12}} \qquad [6]$$

$$I_{Sat(L1)} = \frac{Io \cdot D}{1-D} + \frac{\Delta I_{L1}}{2} \text{ and } I_{Sat(L2)} = Io + \frac{\Delta I_{L2}}{2} \qquad [7]$$

For coupled inductor, make sure the RMS and saturation current in parallel configure need to larger than:

$$I_{RMS(L)} = \sqrt{Io^2 \cdot [1 + (\frac{D}{1-D})^2] + \frac{Vin^2 \cdot D^2}{24 \cdot L^2 \cdot fs^2}} \qquad [8]$$

$$I_{Sat(L)} = \frac{Io}{1-D} + \frac{Vin \cdot D}{2 \cdot L \cdot fs} \qquad [9]$$

2.2 DC Coupling Capacitor

the DC coupling capacitor store the energy and transfer it from input to output. Generally, the DC coupling capacitor is determined by the high RMS current which flows in it. The RMS current rating of this capacitor must larger than:

$$I_{RMS(Cb)} = \sqrt{Io^2 \cdot \frac{D}{1-D} + \frac{\Delta I_{L2}{}^2}{2} \cdot D + \frac{\Delta I_{L1}{}^2}{2} \cdot (1-D)} \qquad [10]$$

The voltage on the DC coupling capacitor is $Vin + |Vo|$ [11]

The capacitance is calculated by the equation [12]:

$$C_{Cb} = \frac{Io \cdot D}{\Delta V_{Cb} \cdot fs} \qquad [12]$$

Here the ΔV_{Cb} is the voltage ripple on the DC coupling capacitor, generally 2% to 5% of the voltage on this cap is recommended.

2.3 Output capacitor

The capacitance and ESR of the output capacitor have a major impact on the performance of the circuit including output ripple and transient response.

Generally, the voltage ripple caused by the ESR of capacitor. So select a capacitor with the ESR smaller than the result of equation [13]

$$ESR = \frac{\Delta Vo}{\Delta I_{L2}} \qquad [13]$$

here ΔVo is the output ripple.

The RMS ripple current rating of the output capacitor needs to be greater than:

$$I_{RMS(Cout)} = \frac{\Delta I_{L2}}{\sqrt{12}} \quad [14]$$

2.4 Power Mosfet , Sense Resistor and Current Limit Resistor Selection

If the maximum voltage on the drain of the Power Mosfet (which is Vin+Vo, but need to consider the spike) is less than 30V, then the circuit can using the lossless current sensing(using the Mosfet Rdson) in order to improve efficiency and eliminate the sense resistor like the Fig 2_A shows. For higher swith voltage, there need a sense resistor Rcs connected to the Mosfet Source like Fig 2 (B) shows.

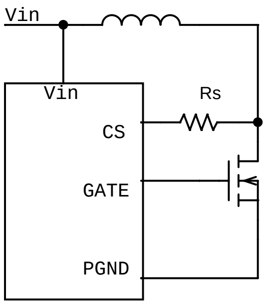


Fig 2_A

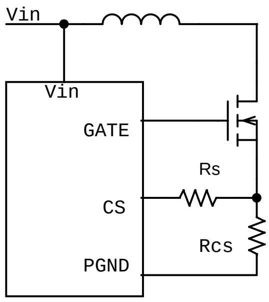


Fig 2_B

The peak current on the Mosfet is:

$$I_{Peak(Mosfet)} = \frac{Io}{1-D} + \frac{\Delta I_{L1} + \Delta I_{L2}}{2} \quad [15]$$

ADP1621 using the peak current through the Mosfet to do the current limit, so the limit output current is given by:

$$Io_{Limit} = \left(\frac{0.1 - 70u \cdot Rs \cdot D}{Rcs} - \frac{\Delta I_{L1} + \Delta I_{L2}}{2} \right) \cdot (1-D) \quad [16]$$

Rcs is the current sense resistor, if lossless current sense used , the Rcs=Rdson of the Mosfet

Rs is the resistor between the CS PIN to the Rcs, using for slope compensation when duty cycle is larger than 50%. If the duty cycle is larger than 50%, using the equation [17] to make sure the control is stable.

$$Rs > \frac{|Vo| \cdot Rcs}{140u \cdot fs} \cdot \left(\frac{1}{L1} + \frac{1}{L2}\right) \quad [17]$$

So if lossless current sense used , when select the Mosfet, make sure the Mosfet Maximum Rdson can meet the equation [16] and [17] both.

The RMS on the Mosfet is: $I_{RMS(Mosfet)} = \sqrt{\left[\left(\frac{Io}{1-D}\right)^2 + \frac{(\Delta I_{L1} + \Delta I_{L2})^2}{12}\right] \cdot D}$ [18]

The Mosfet voltage rating need to be higher: $V_{Mosfet} = |Vo| + Vin$. [19]

2.5 Diode Selection

To maximize efficiency, a fast switching diode with low forward drop and low reverse leakage is desired.

The voltage on the diode is : $V_{Diode} = |Vo| + Vin$. [20]

the average current on the diode is: $I_{Diode(Ave)} = Io$ [21]

The Power dissipated by the diode is : $P_{Diode} = V_{F(Diode)} \cdot Io$ [22]

For low voltage application, Schottky Diode is recommended.

2.6 Input Capacitor

The Input voltage source impedance determines the size of the input capacitor, which is typically in the range of 10uF to 100uF. A low ESR capacitor is recommended and the RMS of ripple current rating need larger than: $I_{RMS(Cin)} = \frac{\Delta I_{L1}}{\sqrt{12}}$ [23]

2.7 Output Voltage Setting

$$Vo = \frac{R_{Top}}{R_{Bot}} \cdot Vref \quad [24]$$

Here Vref is the reference in the ADP1621, Vref=1.215V.

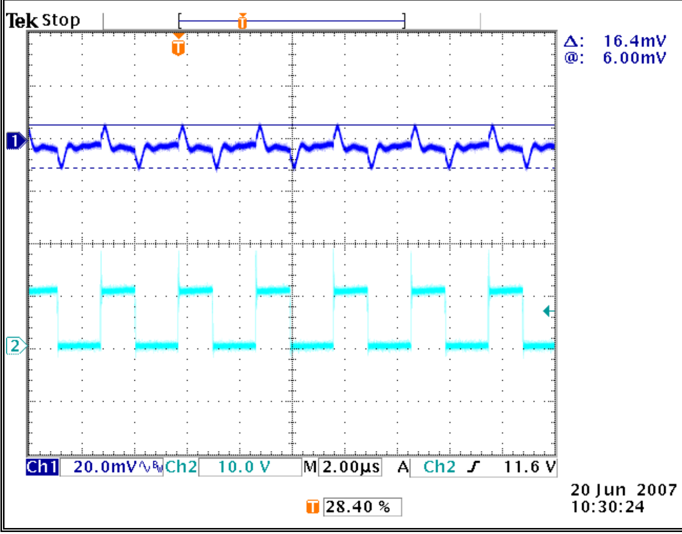
3. Bom List of the Application in Fig 1.

Vin= 5V, Vo= - 5, Io=2.5A

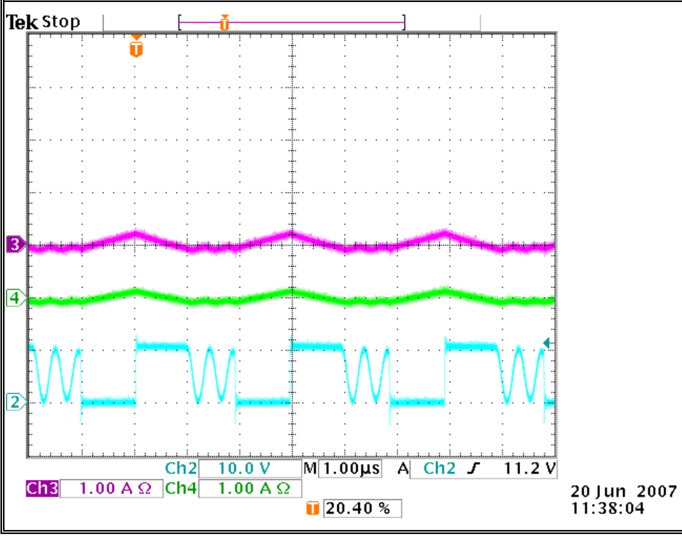
Part	Part Name	Type	Parameter	Footprint	Vendor
C1	GRM31MR61A106KE19	Ceramic Capacitor	10uF,10V, X5R	c1206	Murata
C2	GRM31MR61A106KE19	Ceramic Capacitor	10uF,10V, X5R	c1206	Murata
C3	GRM31CR71C106KAC7L	Ceramic Capacitor	10uF,16V, X7R	c1206	Murata
C4	GRM31CR71C106KAC7L	Ceramic Capacitor	10uF,16V, X7R	c1206	Murata
C5	10TPB330M		10V,330uF		Sanyo
C6	GRM31MR61A106KE19	Ceramic Capacitor	10uF,10V, X5R	c1206	Murata
C7	*	Ceramic Capacitor	22p	c0603	*
C8	*	Ceramic Capacitor	270pF	c0603	*
C9	*	Ceramic Capacitor	0.1u	c0603	*
C10	*	Ceramic Capacitor	2.2nF	c0603	*
C11	*	Ceramic Capacitor	0.1u	c0603	*
D1	B320A	Schottky Diode	3A, 20V	SMA	Diodes
T1	DRQ127-100	Inductor	10uH		Coiltronics
M1	IRF7807Z	Mosfet	30V, 8.7A	so8	IR
R1	*	Resistor	2	r0603	*
R2	*	Resistor	2	r0603	*
R3	*	Resistor	30k	r0603	*
R4	*	Resistor	68k	r0603	*
RBOT	*	Resistor	10k,1%	r0603	*
RCS	*	Resistor	0.01,1%,0.25W	r1206	*
RS	*	Resistor	720	r0603	*
RTOP	*	Resistor	41.2k,1%	r0603	*
U1	ADP1621	Controller	*	msop10	ADI
U2	AD8541	Amp	*	SOT-23-5	ADI

4. Test Waveforms

Test Subject : output ripple	Figure 1	
	Vin	5V
	Vout	-5V
	Load	2.5A
	CH 1	Output ripple
	CH 2	SW
	CH 3	
	CH 4	



Test Subject : DCM Switching waveform	Figure 2	
	Vin	5V
	Vout	-5V
	Load	0.1A
	CH 1	
	CH 2	SW
	CH 3	L1 Current (input)
	CH 4	L2 Current (Output)



Test Subject : CCM Switching waveform

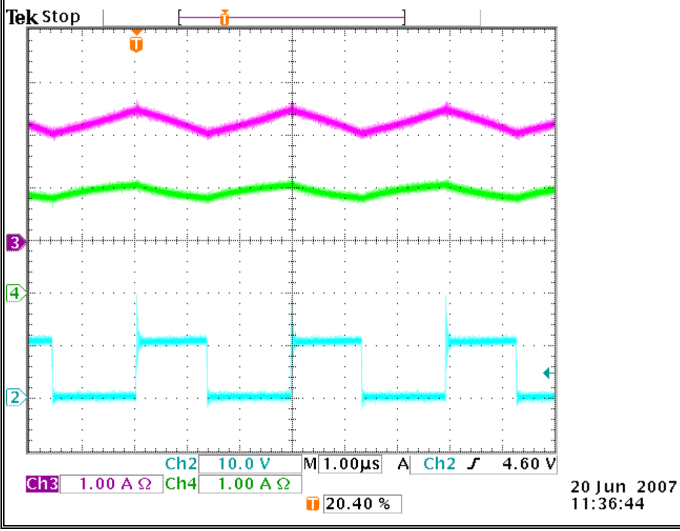


Figure 3	
Vin	5V
Vout	-5V
Load	2A
CH 1	
CH 2	SW
CH 3	L1 current (input)
CH 4	L2 current (output)

Test Subject : Load Transient Response

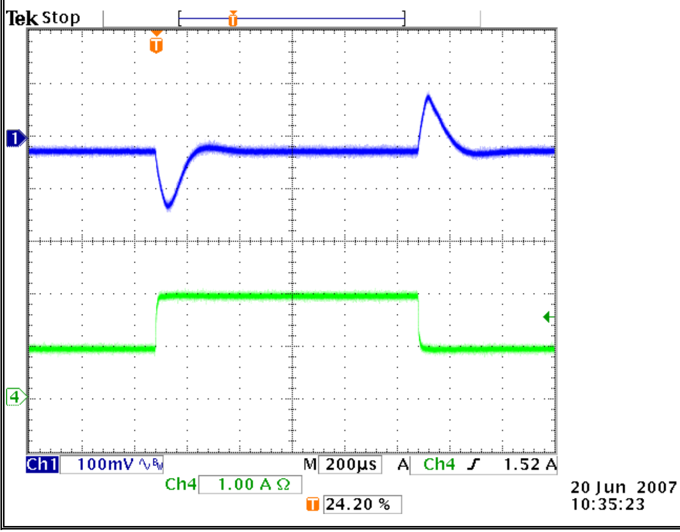


Figure 4	
Vin	5V
Vout	-5V
Load	
Load current: 1A-2A-1A	
CH 1	Output Voltage
CH 2	
CH 3	
CH 4	Load Current

Test Subject : Efficiency

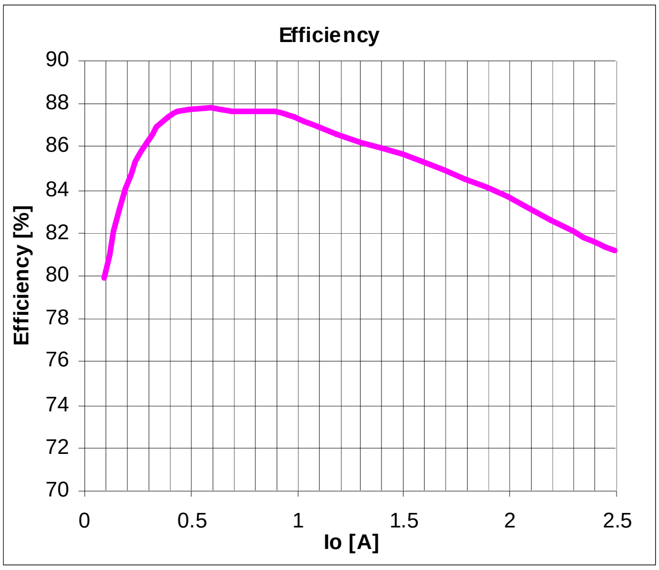


Figure 5	
Vin	5V
Vout	-5V
Load	
CH 1	
CH 2	
CH 3	
CH4	

5. Reference

6.1 ADP1621 Datasheet
http://www.analog.com/en/prod/0%2C2877%2CADP1621%2C00.html