SMART MATERIAL

CL-51
Energy Harvesting Circuit
User Manual

Version 2.0

CONTENTS

1. OVERVIEW

The CL-51 is an energy harvesting electronic circuit board. It accepts the alternate current (AC) output of a piezo electric generator device, often referred to as PEH or PEG, as input and generates a 3.3V or 5V stabilized, direct current (DC) as output.

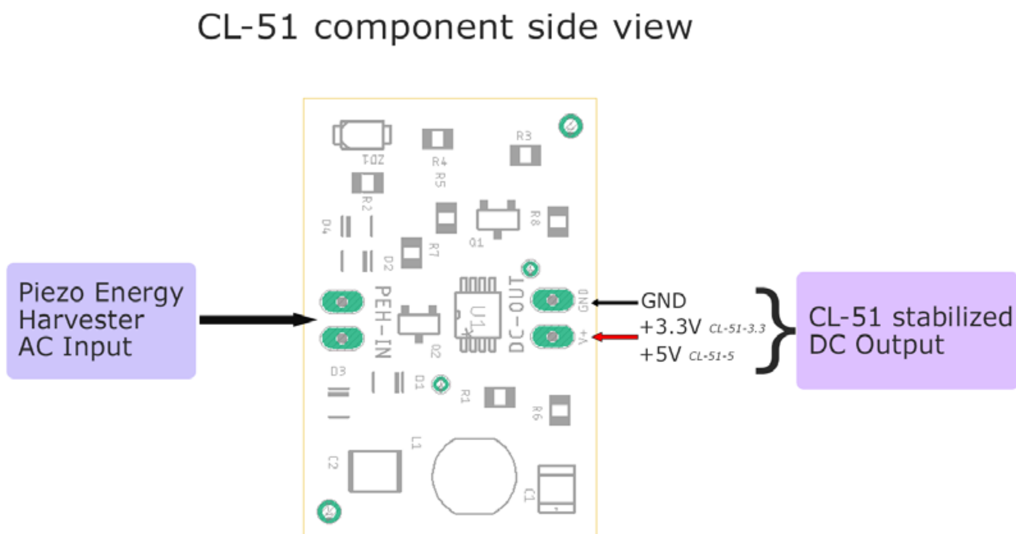

Fig 1: In- and Output CL-51

A Piezo Energy Harvester (PEH) transforms mechanical or kinetic energy into electric energy in the form of an electric charge; or, if its output is connected to any type of electric impedance, as an electric current. A Piezo Electric Harvester, or PEH can be best understood as an alternating current source with a capacitor and resistor connected in parallel.

The CL-51 retrieves the harvested energy from a PEH. The CL-51's basic functions are:

- It rectifies the AC current input from the PEH with a bridge rectifier,
- stores the harvested electric energy in a capacitor of 10µF, which is typically larger than the capacitance of the PEH,
- generates a stabilized DC voltage as output from the retrieved electric energy.

The CL-51 was specifically designed for the P2 type MacroFiberComposite™, MFC as the Piezo Energy Harvester, PEH.
The CL 51 will operate with most other types and brands of piezo electric energy harvesters that operate in the d_{31} mode, as long as the minimum

input energy requirements are met.
The CL-51 is available in two different versions:

- with a fixed +3.3V DC output (CL-51-3.3),
- or a fixed +5V DC output (CL-51-5).

The output voltage of the CL-51 version is marked on the back side.

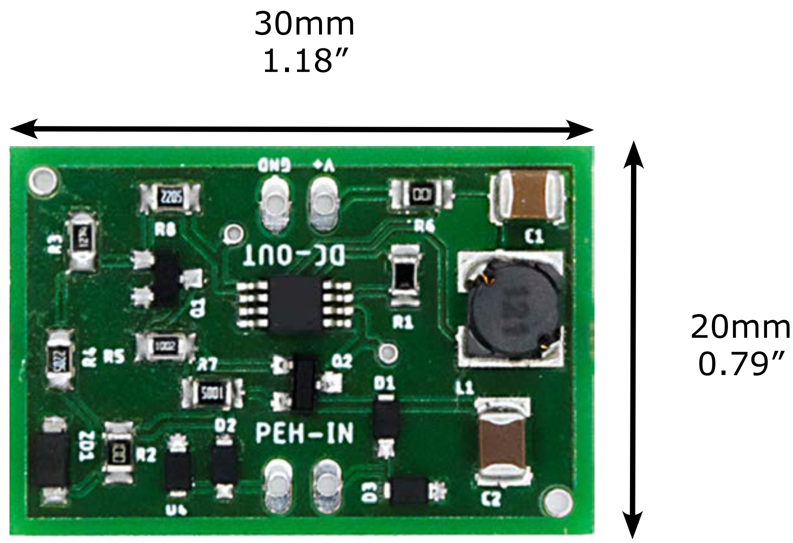

Fig 2: CL-51 component side

Fig 3: CL-51 back side, marked 3.3V DC output

2. WHAT COMES WITH THE CL-51?

The CL-51 package contains the following items:

1. The CL-51 printed circuit board (PCB).
2. Two male connector headers through hole 2 position 0.100” (2.54mm).
3. Two male connector headers through hole, right angle 2 position 0.100” (2.54mm).
4. One 2 Position receptacle connector 0.100” (2.54mm), through hole gold.

The various connectors are included as loose items and require soldering. This allows you to configure the CL-51 for various applications, including:

- solder wires to the CL-51 board,
- solder the two male connectors to the back (non-component) side of the C-51 board for Fritz-board application,
- solder the receptable connector to the ***PEH-IN*** through holes to connect the CL-51 directly to an MFC Cantilever C-Series in a 90° angle,
- solder the right angle male connectors for a low profile interconnection.

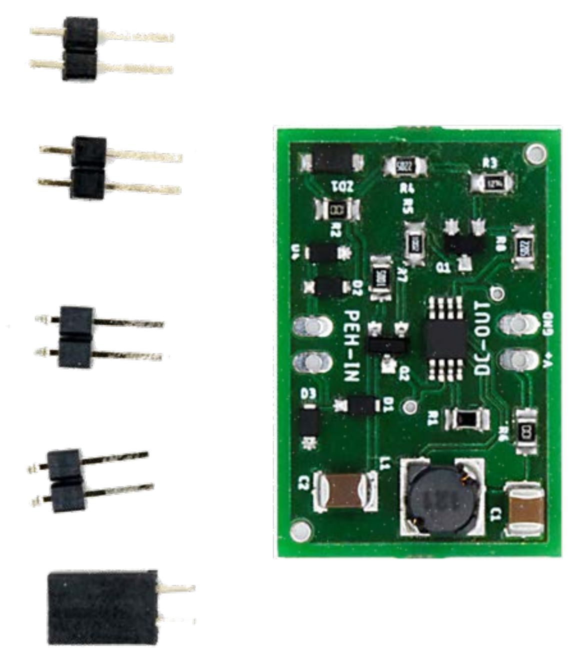

Fig 4: CL-51 and included connectors

3. SPECIFICATIONS

3.1 GENERAL SPECIFICATIONS

Operating Conditions	Ambient Temperature -25°C to 85°C
	Relative Humidity up to 85%, noncondensing
Mechanical	PCB dimensions: W x L x H = 20mm x 30mm x 7mm.
	PCB weight approx. 7 g
Input Connector	***PEH-IN,*** piezo electric harvester input, two wire, AC no polarity preference
Output Connector	***DC-OUT,*** stabilized DC voltage output, two wire, GND (Ground), V_+ (+3.3V or +5V)

3.2 ABSOLUTE MAXIMUM RATINGS

Max. Input Voltage	± 95V AC
Max. Input Current	100mA
Max. Output Current	50mA, no short circuit protection

3.3 ELECTRICAL AND PERFORMANCE CHARACTERISTICS

Output Voltage	3.3V DC or 5V DC, depending on the CL-51 version, ± 0.1% line regulation
Typical Output Power	0 - 148mW @ 3.3V 0 - 225mW @ 5V depending on the available, harvested input energy
Typical Efficiency	82% at 1mA output current 86% at maximum output current
Min. input energy for output to activate	~2.9mJ (CL-51 completely discharged)
Min. usable energy	> 2.4mJ
Input voltage clamp	43V (DC side of the bridge rectifier)
Min. input current	0.9µA
Max. usable input current	57mA

4. OPERATIONS

The CL-51 has a variable input impedance, which is a function of the

- internal charge level of the on-board capacitors,
- the state of the control electronics and
- the load connected to the output of the CL-51.

The output voltage of a PEH is a function of the electric current that the PEH is generating, the PEH internal impedance, and the impedance connected to the PEH output, i.e., the CL-51.
Due to the variable input impedance of the CL-51, the voltage measured at the ***PEH-IN*** terminals will vary during energy harvesting operation. With the CL-51 connected to the PEH, the voltage oscillation will typically measure between 0V to ±26V and can be in a no-load condition (no load is connected to ***DC-OUT)*** as high as ±43V.

The CL-51 will use a certain amount of the harvested energy for performing its functions. This amount is typically between 30-20% of the harvested energy.
The CL-51 has three typical operational modes, depending on the harvested energy generated by the PEH. If the CL-51 has been disconnected from an energy source for several minutes, it requires an initial amount of energy before entering into mode 2. or 3.

1. The CL-51 is not activating ***DC-OUT***

   The PEH current is less than 15µA; the amount of harvested energy is too low. The CL-51 will stay in the off mode. ***DC-OUT*** will remain at 0V.

   TIP: A simple way to troubleshoot this condition is to measure the input voltage of the PEH at the ***PEH-IN*** *terminals with a high impedance probe (>50MOhm). If the voltage is not reaching ~23V at <u>any time</u>, the supplied current or harvested energy is too low. Increase the strain on the PEH.*

2. The CL-51 is switching ***DC-OUT*** on intermittently

   The energy harvested by the PEH is <u>less</u> than the energy required for the load, connected to ***DC-OUT***, to operate continuously***.*** This is one of the common operational modes of the CL-51. The CL-51 collects harvested energy from the PEH in an on-board capacitor over time. After the collected energy reaches a threshold of ~2.4mJ, the CL-51 activates ***DC-OUT*** and provides a stabilized DC output voltage of 3.3V or 5V, depending on the CL-51 version.

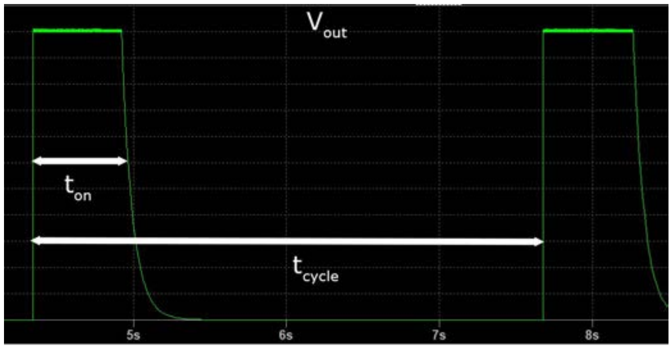

Fig 5: CL51 intermittent DC-OUT mode

Fig 5 shows a typical waveform for intermittent ***DC-OUT*** cycles. The ***DC-OUT*** on-time $\mathbf{t_{on}}$ is the rate to discharge the collected energy into the load, until the stored and continuously collected energy reaches a threshold below ~0.6mJ. The cycle time $\mathbf{t_{cycle}}$ minus $\mathbf{t_{on}}$ is the time required to reach ~2.4mJ of stored energy again.

3. The CL-51 keeps the ***DC-OUT*** on continuously

   The energy harvested by the PEH is higher than the energy required for the load, connected to ***DC-OUT***, so it will operate continuously. After the initial charge-up period, the CL-51 provides a stabilized, continuous DC output voltage of 3.3V or 5V, depending on the CL-51 version.

No-load or load setups with an energy input from the PEH that exceeds the load requirements might trigger the internal circuit protection.
This protects the circuit against over-voltages in excess of 43V. The circuit is only triggered after the stored energy reaches values of more than ~10mJ and temporarily short-circuits any excess energy. It will not disable standard operation.

Caution should also be exercised when connecting a PEH to the CL-51. Especially when the PEH is actively harvesting energy, or, is not completely discharged, it might have a high voltage charge at its output connections. As outlined before, a PEH is a capacitor and can generate voltages in excess of ± 95V in an open circuit condition. If connected to the CL-51, such high voltage charges can cause transient voltage peaks, which can damage the CL-51.

5. ENERGY VS. POWER

Electrical energy and electrical power are often used in a way suggesting that they are interchangeable. ***They are not!***
Energy and Power are closely related, but they are not the same. This is an important fact to understand if designing energy harvesting applications.

Energy is defined as the capacity to do ***work***. Work can be in the form of kinetic energy, potential energy and thermal energy. It is also correct to say, that if you are doing work to an object, you give the object energy. Furthermore, you can add energy to an object by transferring heat. This is the first law of thermodynamics: The total energy of a system can be increased by doing work on it or by adding heat.

Energy is measured in **Joule, J** (SI unit). One Joule is equivalent to 1 Nm (one Newton times one meter) and 1 Ws (one Watt times one second). Examples for how to calculate energy:

$$\boldsymbol{Kinetic\ Energy} = \frac{\mathbf{1}}{\mathbf{2}}\,\boldsymbol{mv^2}\ (m = mass, v = velocity)$$

$$\boldsymbol{Potential\ Energy} = \boldsymbol{mgh}\ (m = mass, g = gravity, h = height)$$

One of the energy calculations which is used for the CL-51, is the stored energy in a capacitor:

$$\boldsymbol{Energy\ Capacitor} = \frac{\mathbf{1}}{\mathbf{2}}\,\boldsymbol{CU^2}\ (C = Capacitance, U = Voltage$$

Power is the ***rate*** of doing work or the ***rate*** at which energy is used, produced, or transferred.

$$\boldsymbol{Power} = \frac{\boldsymbol{Energy\ Used}}{\boldsymbol{Time\ Taken}}$$

The unit of power is the unit for energy divided by the unit for time. In SI units this is Joule divided by seconds, which is given the name **Watt**, **W**.

Many people are familiar with the electrical energy amount of a kWh (kilo Watt hour). It is important to understand that you spend the same amount of energy if you are using 1kW for one hour or 1W for one thousand hours. Or, it is the same amount of potential energy as when a crane is lifting a 1ton stone block 20m up in 1min or 1hour. But the required power for the motor of the crane is higher if you lift the block in 1min instead of 1hour because the time interval is different.

How does this relate to energy harvesting circuits?
As mentioned in the overview, the CL-51 stores the harvested energy in a capacitor. A capacitor can discharge stored energy in a very short time. In comparison, a battery can typically store a larger amount of energy than a capacitor, but can discharge it only during a much longer period of time.

In combination with a piezo electric harvester (PEH), a piezo electric harvesting circuit can be seen as a power booster, changing the time the collected and stored amount of energy from a PEH is supplied to a consuming circuit (not an energy booster, which is not possible in this universe!). Since the energy amount has to remain the same, the energy harvesting circuit will distribute the energy in periods of On-cycles with higher power discharge ratings and periods of Off-cycles, if the energy supplied by the PEH is less than the energy required by the consuming circuit for the same period of time.

6. FURTHER RESOURCES

Follow our popular in-depth tutorials on our YouTube channel **SmartMaterialCorp.**