Light-controlled oscillator uses solar cell junction capacitance

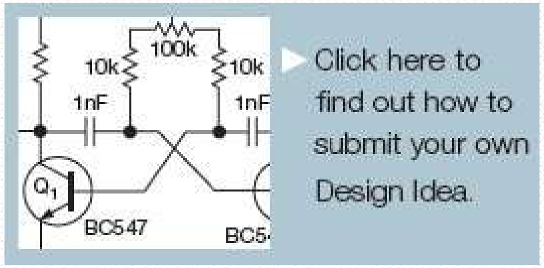
sajjad Haidar -August 08, 2013

Any PN junction diode can be used as a variable capacitor in reverse biased mode, as well as in the forward biased mode before the knee voltage. The capacitance is usually very small as the junction size is small. Though the varactor diode is specially designed for higher capacitance, it's still limited to a few hundred picofarads. A solar cell can also be used in some circuits as a variable capacitor. As its junction size is much larger than the usual diodes, much larger variation of capacitance is expected. There is a drawback using a solar cell as a capacitor: the reverse saturation current is also much higher, causing it to act like a leaky capacitor. Still, a solar cell can be used in some oscillator ciruits to achieve a widely tunable frequency.

A Pierce oscillator was implemented using a **BS170** MOSFET and a positive feedback network consisting of L1, C4, and C5. The amplifier gain was adjusted, choosing bypass capacitor C2 = 2nF, for nearly sinusoidal output at an oscillation frequency around 250kHz. A solar module (IXYS **SLMD121H04**, open circuit voltage: 2.52V; short circuit current: 50mA) was connected in series with C8 (100nF) to capacitor C5. When the solar-module capacitance (C_{solar}) varies, the series equivalent of C_{solar} and C8 paralleled with C5, also changes. The frequency of oscillation is given by the following equation:

$$\omega = \frac{1}{\sqrt{L\, C_T}}$$

$$\text{Where, } C_T = C_5 + 1/\left[\frac{1}{C_{solar}} + \frac{1}{C_8}\right]$$



Two power LEDs (Bridgelux: **BXRA-W0240**) connected in series were used to illuminate the solar module, powered by a 24V variable power supply. The LEDs were mounted on a heatsink and were placed ~ 5cm above the solar module. The whole area of the solar module (43mm x 14mm) was illuminated uniformly by the LEDs. Voltage across the solar module terminals was also measured at testpoint TP with changing illumination.

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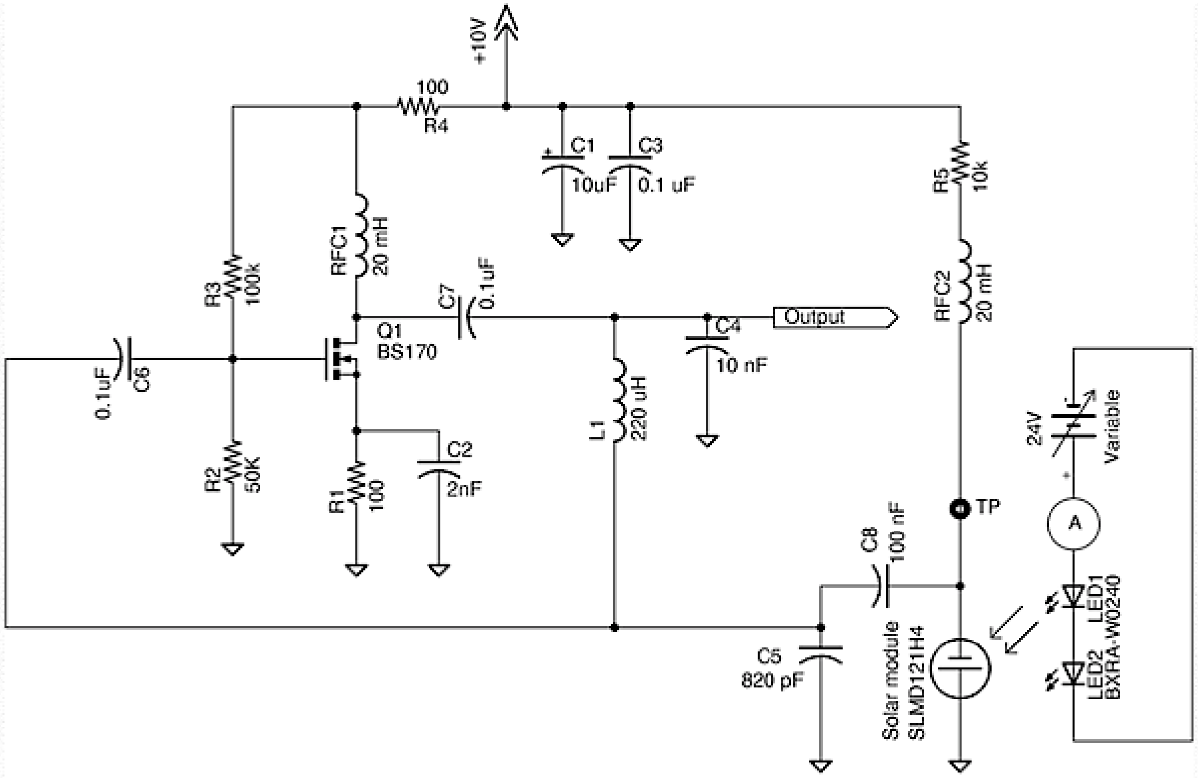

Figure 1: Light-controlled Pierce oscillator

Initially, the solar module was put inside a small black box, and the voltage at TP read 6.2V, giving dark saturation current of 380μA. Frequency of oscillation under darkness was 246kHz. With only ambient light, the frequency reduced to 245kHz. As the LED current was increased, oscillation frequency continued going down; at 330mA, the frequency was 116kHz. Beyond a LED current of 330mA, the total capacitance, C_T, was not changing much, leaving the tuning range from 246 to 116kHz. The tuning characteristic is shown in **Figure 2**.

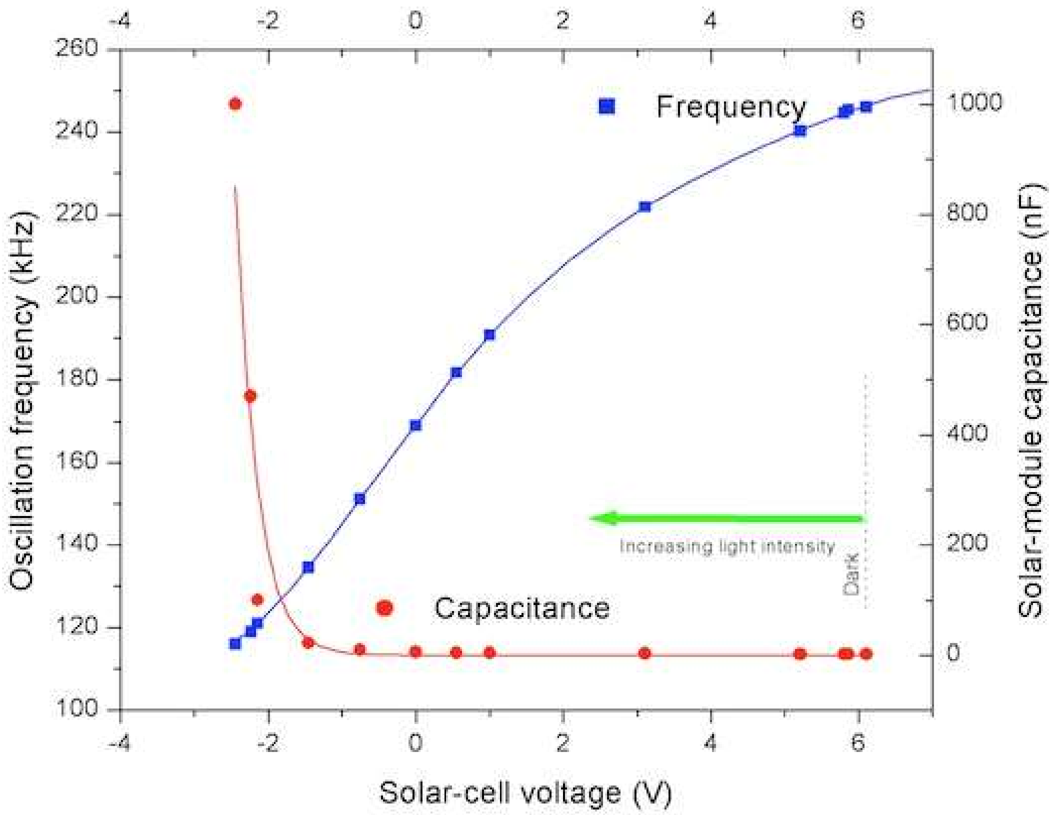

Figure 2: Solar cell voltage vs. capacitance & frequency

The solar module capacitance was approximated by putting different capacitances in place of the solar module. In a separate test, short circuit current for the solar module was measured under illumination, keeping the same separation (~ 5 cm). At 330mA LED current, the corresponding short circuit current of the solar module was 14.5mA; the light intensity was found from the data sheet of the solar module to be ~ 400 W/cm^2.

It should be mentioned that throughout the tuning range, the output amplitude varied as the closed loop gain varied due to changing capacitance and leakage in solar module. To achieve constant amplitude, an additional circuit would be needed.

References:

1. G. Gonzalez, "Foundations of Oscillator Circuit Design", Artech House Inc., MA, USA, 2007.

Appendix 1: Solar cell capacitance

Voltage (V)	Frequency (kHz)	Capacitance (nF)
6.1	246.1	1.45
5.86	245.4	1.5
5.8	244.7	1.6
5.21	240.2	1.8
3.11	221.8	3
1	190.7	4
0.55	181.6	4.7
0	169	6
-0.76	151.1	10
-1.46	134.5	22
-2.15	121	100
-2.24	119	470
-2.45	116	1000

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- Build your own capacitance meter
- VFC makes simple capacitance meter
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12 Comments

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Vinyasi Qx

Thank you for this article. I was hunting for an article which verified my hunch that a solar cell could be fed voltage to vary its capacitance by altering its dimensions. This article confirms it by inference. So, I've included a shortcut (redirecting to here) in my circuit simulation which depends on this idea.

http://tinyurl.com/solarosc
http://is.gd/parametricsangulani

h t t p : / / t i n y u r l . c o m / s o l a r o s c
h t t p : / / i s . g d / p a r a m e t r i c s a n g u l a n i

Jul 1, 2018 5:44 PM EDT

0 | 0 Reply

sajjad haidar

Hi Deloca:

It is nice to know your analysis. I put C8, to limit the maximum usable capacitance to be less than C8 (due to series combination) and to prevent the leakage current (solar module) from stopping the oscillation. At higher capacitance values the measurement of mine may not be that accurate, I mean there is an error margin. So I am not sure about the equality of the module capacitance to that of C8 at the point of inflection.

Aug 20, 2013 4:59 PM EDT

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Deloca

Thanks for the appendix data on the capacitance.

The plot appears 1/C versus V to be linear with R^2 coefficient of 0.987. The resulting capacitance relationship appears to be roughly

C =12/(V + 2),

(nF when V in volts). One issue that I seem to pick up is the inflection in the 1/C plot around 2V. I notice that the capacitance at that voltage is the same as that of C8. Could that (the value of C8) be significant?

Aug 20, 2013 8:47 AM EDT

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WKetel

This is quite interesting in that I had never considered the use of the junction capacitance of a solar cell for any purpose at all. I have used power diodes for frequency control capacitances and that worked quite well, but using the solar cell, and then using light to change the capacitance, is a first. It really ought to be useful in some application, possibly for some high voltage isolation arrangement where it could use simply generated light instead of other methods. And possibly the effect could be linearized a bit, which would improve the usefulness. Thanks for sharing this unique design.

Aug 18, 2013 4:59 PM EDT

0 | 0 Reply

sajjad haidar

Hello Michael:
Thanks for your comments. The solar module used in the circuit consists of 4 solar cells connected in series. If The module is tested with a small load connected (e.g.10K Ohm), under high illumination, we would get ~ 2.4 V and dark voltage would be ~ 0V. Though the module is connected to 10 V with a 10 K resistor in series, maximum reverse voltage across the solar module cannot be 10 V at dark because of leakage current. Higher the illumination, the higher is the photo-current and less is the reverse bias. At the maximum achievable voltage (~2.4V), capacitance becomes high, as it leads to basing the solar module towards the knee voltage in the forward bias.

Sajjad

Aug 15, 2013 11:29 PM EDT

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sajjad haidar

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Sajjad

Aug 15, 2013 11:29 PM EDT

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Reply

sajjad haidar

Hello Deloca:
Thanks for your suggestion. Yes I admit that, it would have been better to use log scale for capacitance. Variation of capacitance from 0V to 6V is barely visible in Fig. 2. However I have the measured data, I would be happy to share those with anyone, who is interested in.

Thanks
Sajjad

Aug 15, 2013 11:04 PM EDT

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Reply

Deloca

Thanks for your reply. Could you write to Michael Dunn to post the data on a link within your DI? He's very much on the ball on such matters.

Aug 17, 2013 4:50 AM EDT

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Reply

Michael Dunn

I've added an appendix with the capacitance values. On the ball and at your service ;-)

Aug 19, 2013 7:54 PM EDT

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Reply

Deloca

Hellooooooooo! Anybody home?

Aug 15, 2013 11:49 AM EDT

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Reply

Deloca

An interesting circuit, but the linear axes of the solar-cell module capacitance versus its voltage in Figure 2 fails to capture an essential parametric variation. I would suggest instead using a log(capacitance) versus cell voltage. As it appear, it would seem that the capacitance is zero for cell voltages higher than one volt - which is practically the entire range.

Aug 10, 2013 6:16 AM EDT

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Reply

Michael Dunn

Might you obtain more capacitance variation with a lower reverse bias voltage? If I understand correctly, the diode bias as-is would go from 10V at no light to 7.5V at full illumination.

Aug 8, 2013 5:17 PM EDT

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Reply