A Triggered Monostable Blocking Oscillator

Used in legacy *Channel Repeaters*

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August 21, 2012

Abstract

Along this document, a complete description of the previous generation of repetitors is offered. It allows the designer to better understand the requirementes for good interoperability between the different types of repetitors.

History of changes

This document version has been checked by:

This document version has been approved by:

Date	**Pages**	**Changes**
August 30, 2011	All	Initial submission
September 21, 2011	All	Deleted pulse definition chapter. Moved to Standard Blocking Definition Document [1]
August 21, 2012	All	Minor changes in the title page.

System Description and Purpose This documents exposes how to design a Monostable Blocking Oscillator used in old *Channel Repetitor* boards. A blocking oscillator offers an easy, and low-cost way of obtaining a sharp pulse of fixed width.
By following the instructions given here, an *optimal* Monostable Blocking Oscillator can be built.

Contents

1 Triggered Monostable Blocking Oscillator

1.1 References and tips

A blocking oscillator is usually employed in synchronization applications due to its simplicity, the little number of elements required -one BJT, a transformer, few diodes, resistances and capacitors- and the sharp slope of the rising edge it provides. Because of these reasons, a monostable blocking oscillator is selected for the pulse conversion over other possibilities –such as flyback converters, for instance.
An intuitive introduction to pulse converters can be found in [2], where the blocking oscillator is sketched pretty simplisticly. Millman's book, [3], offers an easy and straightforward view on the pulse top state of the circuit.
The more mathematical insight of the switching state is found in Linvill's classical literature [4] and [5], which warns the reader of the aproximations taken out for the sake of simplicity. It should be noted that, for a proper switching analysis, some values of the model -such as base resistance- are usually difficult to find in the datasheet of the manufacturers, and must be inferred –a Ning-Tang method for the base resistance, i.e. Apart from this, it is a good advice to carefully checking these values in the SPICE models provided by the manufacturers. Some manufacturer's base resistance parameter model corresponds to the intrinsic value of it and not to the intrinsic plus extrinsic one, as it is requiered for a good matching with the mathematical analysis. This will produce a misleading simulation which will turn out into an unexpected outcome for the designer. Thus, we encourage not to give 100% confidence to the simulation results due to this innacuracies with respect to the aproximate model used in the analysis.
A comprehensive study of the switching state based on an extension of Linvill's aproximation is done in [6]. However, we have considered it as overcomplicated compared to the more reasonable original Linvill's aproximation.
Last but not least, Norman's guide for the design of monostable blocking oscillator [7] constituted the invaluable help which serves as the reference of this design.

1.2 Topologies evaluated

Three blocking oscillators circuits were considered for the Pulse Converter Units in CTDAH. The first two are positively collector-emitter feedbacked and the later has a base-collector feedback.

Circuit 1
This circuit can be found in [5]. The main drawbacks it presents lay on the charge it produces the output load and a worse triggering option

compared to Circuit 2.

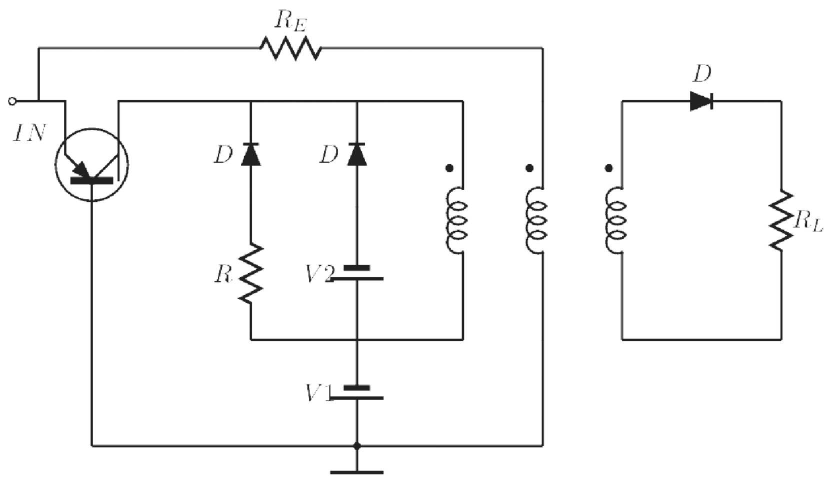

Figure 1: Linvill's circuit, taken from [5]

Circuit 2

It is the circuit chosen for the design. With the inclusion of a resistance in the positive feedback loop it is really simple to accomodate the pulse width to the designer needs.

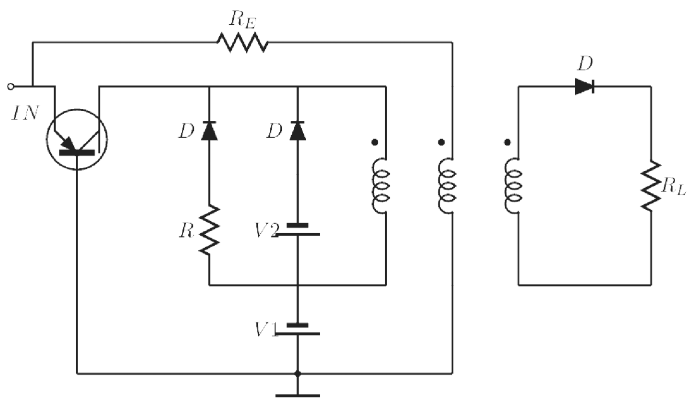

Figure 2: Norman's circuit, taken from [7]

Circuit 3

However it is the most intuitive among all the designs, the triggering is not as independent from the input as Circuit 2.

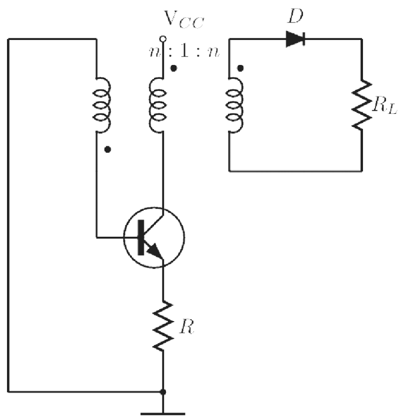

Figure 3: Millman's circuit, taken from [3]

1.3 Analysis of the chosen topology

The analysis follows the flow pointed out in [7]. The complete mathematical resolution of the switching state from [4] is included. Furthermore, the fixed-point methond algorithm is added to clarify how the normalized natural frequency of the circuit is gotten.

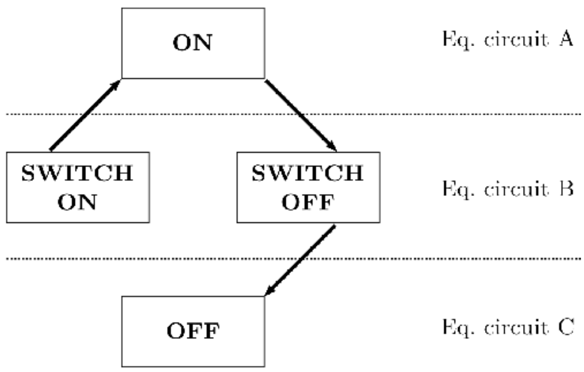

Figure 4: States and equivalent circuits

1.3.1 Switching on

When it is switching both on and off, an equivalent circuit is shown in the figure below. Emitter resistance and capacitance are omitted for simplicity. The critical value while switching lies on obtaining the *natural frequency* of the circuit. This value is closely related with the *transformer turns-ratio* and, given the aproximations of the model, an optimun turns-ratio can be calculated. If this turns-ratio is used, the fastest rise time will be achived an no ringing will be obtained, ideally.

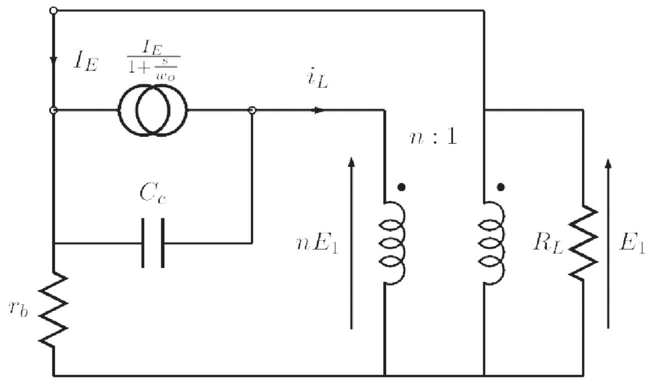

Figure 5: Eq. circuit B: switching

Kirchoff's equations

The electrical relationship of the circuit are:

$$\frac{E_1}{R_L} + I_E - ni_L = 0 \tag{1}$$

$$\frac{E_1}{r_b} + \frac{I_E}{1+\frac{s}{w_o}} - I_E - (n-1)E_1C_ss = 0 \tag{2}$$

$$i_L - \frac{I_E}{1+\frac{s}{w_o}} + (n-1)E_1C_ss = 0 \tag{3}$$

Fundamental equation

Operating the previous equations yields:

$$(\frac{s}{w_0})^2 + \frac{s}{w_0} \cdot \frac{G_L+g_b}{(n-1)^2C_cw_0} - \frac{g_b}{C_cw_0(n-1)} = 0 \tag{4}$$

That can be greatly simplified by normalizing the natural frequency and performing the following changes of variable:

$$x = \frac{s}{w_0} \qquad n-1=\Delta \qquad \frac{g_b}{C_cw_0} = k \qquad \frac{g_b+G_L}{C_cw_0} = k \tag{5}$$

$$x^2 + x(1+\frac{l}{\Delta^2}) - \frac{k}{\Delta} = 0 \tag{6}$$

However, as Δ is a design parameter we can rewrite the equation to:

$$\Delta^2(x^2+x) - k\Delta + xl = 0 \tag{7}$$

If a value of the normalized natural frequency of the circuit, x, is lower than x_{max} two possible optimal *turns-ratios* will exist. If it is higher than x_{max} no real *turns-ratios* exist. We can find an optimal value of Δ that corresponds to x_{max}, by obtaining a double root of the previous equation. Hence:

$$k^2 - 4(x_{max}^3 + x_{max}^2)l = 0 \tag{8}$$

We can get the *normalized natural frequency* by applying iterations by a fixed-point method, given that it converges –because we expect a value close to 1

$$x_{max_i} = \frac{k}{2\sqrt{l(x_{max_{i-1}} + 1)}} \qquad i = 1, 2, 3 \ldots \tag{9}$$

Results

The expected *rise-time* is:

$$t_{rise} = \frac{2.3}{x_{max} w_0} \tag{10}$$

for an optimal *turns-ratio* is:

$$\Delta_{opt} = \frac{k}{2(x_{max}^2 + x_{max})} \qquad n_{opt} = \Delta_{opt} + 1 \tag{11}$$

Subsequently, getting a good rise-time depends mainly on choosing the optimal *turns-ratio* value and using a fast switching bipolar transistor in the design.
TIP: as stated in [7], the triggering signal must be active for $3t_{rise}$, so as to effectively switching the cirucit state.

1.3.2 On state

The on-state is related with the value of the *magnetizing inductance* in the collector and the *positive feedback resistor*. With this two parameters the designer is able to chose the *pulse width*.

Kirchoff's equations

From the collector we can get the following equation:

$$i_c = \frac{V_p}{n^2(R_L + r_{EBt})} + \frac{V_p}{n^2 R_L} + \frac{V_p t}{L} \tag{12}$$

During the on-state we can define $h_{FB_t} = \frac{i_c}{i_E}$, thus the previous equations can be rewritten as:

$$\frac{V_p h_{FB_t}}{n(R_L + r_{EBt})} = \frac{V_p}{n^2(R_L + r_{EBt})} + \frac{V_p}{n^2 R_L} + \frac{V_p t}{L} \tag{13}$$

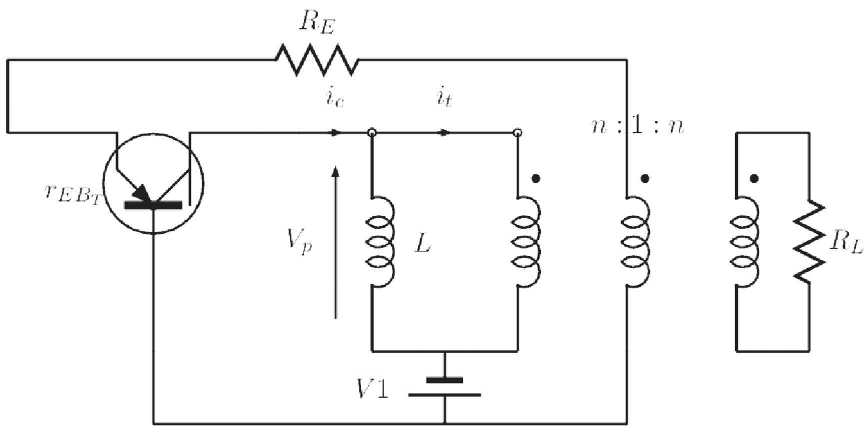

Figure 6: Eq. circuit A: on-state

Results

When the transistor is close to leave its saturation state, we can change all its parameters for the large signal model ones. This yields to obtaining the *width* of the pulse:

$$T_p = \frac{L(h_{FB} - 1)}{n^2[R_E + r_E + (1 + h_{FB} r_B)]} - \frac{L}{n^2 R_L} \tag{14}$$

As it is noted in [7], adding R_E helps to desensitizing the circuit from r_E

1.3.3 Switch off

The switch-off state is governed by the same equations of the switch-on state.

1.3.4 Off state: *Recovery time*

Off-state is reached when the circuit completely removes all the current from the *magnetizing inductor* through the snubber consisting of the *diode* and *discharge resistor*. Once the current is completely removed, a new triggering can be faced by the monostable oscillator.

Kirchoff's equations

At the end of the on state, the magnetizing current is:

$$I_L = \frac{V_P T_P}{L} \tag{15}$$

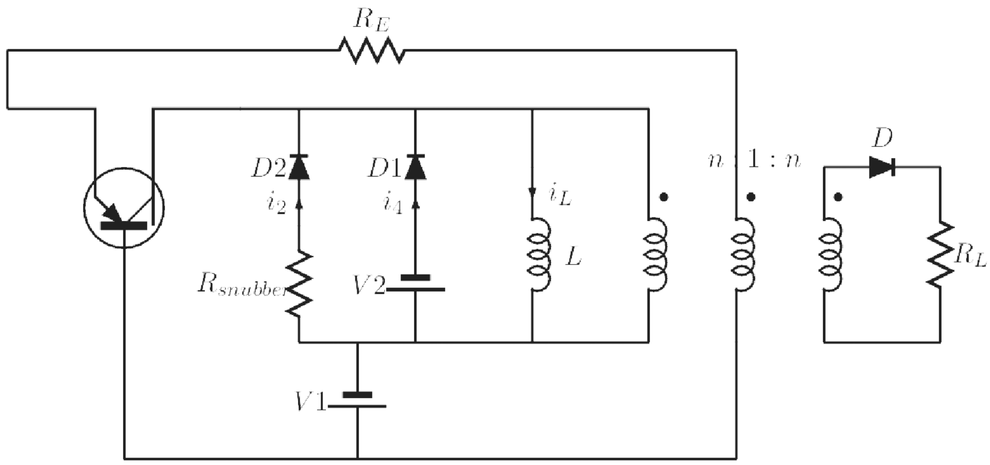

Figure 7: Eq. circuit C: off-state

The magnetizing inductance current must equal the current flowing out of the two multipoles formed by the diode and the resistor and the diode and the zenner diode. The multipole consisting of the diode and the resistor helps to avoid overdamping while switching off. In the second case, the current decreases linearly until the diode acts as an open circuit. From this time on, the only multipole draining current from the inductor is the one with the resistor. The discharge equation is:

$$i_L = \frac{V_2}{R_c}[1 + \frac{R_c}{L}(t - t_3)]e^{-\frac{t-t_3}{L/(2R_c)}} \qquad t \geq t_3 \tag{16}$$

The critical damping happens with a snubber resistor value of:

$$R_c = \frac{1}{2}\sqrt{\frac{L}{C_s}} \tag{17}$$

where C_s is the **shunt capacitance** formed by the addition of the *collector capacitance of the bipolar transistor*, the *transformer self capacitance* and the *wiring capacitance.*
The resistance of $R_{snubber}$ should be less than R_c, so as to avoid overdamping:

$$R_{snubber} < R_c \tag{18}$$

Implicit equation

The residual current in the inductance, I_R, will be:

$$I_R = \frac{V_2}{R_c}[1 + \frac{R_c}{L}(t_4 - t_3)]e^{-\frac{t_4-t_3}{L/(2R_c)}} \qquad t = t_4 \tag{19}$$

that cannot be resolved, but it is bounded by:

$$I_R < \frac{V_2}{R_{snubber}} e^{-\frac{t_4 - t_3}{L/R_{snubber}}} \tag{20}$$

Thus, operating along the two recovery stages as in [7]:

$$T_R = \frac{V_1 T_p}{V_2} + \frac{L}{R_{snubber}} (log \frac{V_2}{R_{snubber} I_R} - 1) \tag{21}$$

Results

First, we must set a threshold for I_R.

Then, the resistance of $R_{snubber}$ that makes $T_{R_{min}}$ is:

$$R_{snubber} = \frac{V_2}{I_R} \tag{22}$$

but must comply with:

$$R_{snubber} < R_c \tag{23}$$

for avoid overdamping.

References

[1] C. Gil Soriano. Standard Blocking Output Signal Definition for CTDAH board, September 2011. `http://www.ohwr.org/documents/109`.

[2] W.A. Stanton. *Pulse technology.* Wiley, 1964.

[3] J. Millman and H. Taub. *Pulse, digital, and switching waveforms: devices and circuits for their generation and processing.* McGraw-Hill, 1981.

[4] J.G. Linvill and J.F. Gibbons. *Transistors and active circuits.* McGraw-Hill electrical and electronic engineering series. McGraw-Hill, 1961.

[5] J.G. Linvill and R.H. Mattson. Junction transistor blocking oscillators. *Proceedings of the IRE*, 43(11):1632 –1639, nov. 1955.

[6] J. McDonald. Circuit models to predict switching performance of nanosecond blocking oscillators. *Circuit Theory, IEEE Transactions on*, 11(4):442 – 448, dec 1964.

[7] P. Norman and E.J.E. Smith. The design of transistor blocking oscillators. *Proceedings of the IEE - Part B: Electronic and Communication Engineering*, 106(18):1251 –1259, may 1959.