Comparison of BJT and MOSFET Astable Multivibrators: A Theoretical and Simulation Study for Teaching Basic Electronics

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Extended Abstract

In teaching electronics fundamentals, theoretical knowledge of semiconductor devices can be conveyed through the behavior of simple circuits. One of the most instructive transistor-based circuits is the astable multivibrator. Despite its more than 100-years history and structural simplicity, it simultaneously demonstrates several key phenomena that would otherwise be discussed separately in introductory electronics courses.

First, the circuit allows one to illustrate the operation of transistors and the differences between various types of transistors. In this circuit, two extreme regions are visible: cut-off and saturation for bipolar junction transistors (BJT) and cutoff and linear (ohmic) region for field-effect transistors (FET), similarly for metal-oxide-semiconductor FET (MOSFET). There is a fundamental difference in the operation of transistors here, which can lead to confusion when learning the basics of electronics, where, despite other similarities between BJT and FET/MOSFET, the saturation region occurs under different biasing conditions.

Second, unlike linear amplifier examples, which are limited to the active region, the astable multivibrator emphasizes large-signal behavior and switching dynamics, which are also essential for understanding digital electronics.

Third, the circuit introduces the concept of positive feedback. The cross-coupled configuration allows students to observe how regenerative action leads to rapid state transitions, offering an intuitive understanding of instabilities and self-sustaining oscillations.

Fourth, the presence of capacitors enables the study of time-dependent behavior. Students can directly relate exponential charge and discharge processes to the RC time constant, combining circuit theory with transient analysis. This also provides a practical context for understanding how analog time-domain processes generate periodic signals. Furthermore, the astable multivibrator provides an accessible example of a nonlinear dynamic system. The oscillation mechanism, based on threshold-triggered switching, helps bridge the gap between linear circuit analysis and more advanced topics such as relaxation oscillators and state transitions. This circuit provides a natural starting point for discussing practical limitations, including the effects of component tolerances, temperature dependence, and nonideal transistor behavior. These aspects are essential for developing an engineering understanding of real-world electronic systems.

For these reasons, the astable multivibrator is a powerful educational tool, combining analog and digital electronics while introducing basic concepts about the behavior of nonlinear systems. It allows discussion of:

- BJT operation regions (cut-off, active, saturation),
- MOSFET operation regions (cut-off, saturation, linear),
- differences in control and behavior of BJT ad MOSFET,
- bias resistor selection,
- positive feedback and oscillation conditions,
- RC charging and discharging,
- digital flip-flop principles,
- device limitations (current gain β, reverse junction voltages for FET; transconductance, threshold voltage, channel resistance for FET),
- mixed circuits in the case of CMOS realization.

In the context of design of CMOS integrated circuit (IC) astable multivibrators provide a valuable platform for hands-on learning. Students can design and simulate circuits in selected technologies, exploring how device parameters, load capacitances, and transistor sizing influence circuit behavior. Moreover, exercises illustrate the process of implementing timing circuits as ICs, bridging the gap between discrete-component prototyping and practical CMOS ASIC design. This approach reinforces students' understanding of the impact of component characteristics and environmental conditions on CMOS circuit performance.