The problem:
To provide a pulse source of constant frequency with a duty cycle that is adjustable by an external input signal. Such a circuit would be most useful as a switching mode voltage regulator and could also find use as a switching source for a variety of control systems.

The solution:
A circuit in which the above requirements are met and which may easily be synchronized by an external signal without interfering with the operation of the duty cycle control.

How it's done:
Assume transistor T₂ is on. The capacitor C₁ has previously charged to potential V₁. With T₂ on, capacitor C₁ supplies a voltage -V₁ to the base of T₁, thus holding it off. The current source formed by transistor T₃ and its bias resistors R₃₁, R₃₂, R₃₃, causes this potential to increase linearly with time according to:

\[ V_{beT₁} = -V₁ + \frac{It}{t₁} \]

where \( V_{beT₁} \) is the base-emitter voltage of T₁, \( I \) the current produced by T₃, and t time. When \( V_{beT₁} \) equals the "on potential" (i.e. forward bias potential)
of $T_1$, $T_1$ turns on and $T_2$ turns off due to cross coupling. Thus, the duration of the off time of $T_1$ is given by $t_1 = (V_{be} + V_1) - \frac{c_1}{I}$ where $V_{be}$ is the forward bias voltage drop of $T_1$. Similarly, the duration of the off time of $T_2$ is given by $t_2 = (V_{be} + V_2) - \frac{c_2}{I}$.

The total duration of a cycle of the oscillator is then $T = t_1 + t_2 = \frac{c_2}{I} (V_1 + V_{be}) + \frac{c_2}{I} (V_2 + V_{be})$.

If $C_1 = C_2$, we have $T = \frac{C}{I} (V_1 + V_2 + 2V_{be})$.

Since $V_1$ and $V_2$ are derived from the differential amplifier $T_5$, $T_6$, $T_7$, $T_8$, $R_5$, $R_6$, $R_7$, $R_8$, $R_9$, the sum $V_1 + V_2$ is constant. Thus, the frequency of operation is constant, but the duty cycle, or equivalently, the off time of $T_1$, is a linear function of $V_1$ (see previous equation for $t_1$). $V_1$ is in turn a linear function of the control input signal. The duty cycle is thus controllable at constant frequency. The diodes $D_1$ and $D_2$ serve to decouple the charging of capacitors $C_1$ and $C_2$ from the power supply $+V$. Resistor $R_{16}$ and Zener diode $D_3$ provide a reference input so that the duty cycle is a function of the difference between the control input and the reference voltage of $D_3$.

The circuit may, therefore, also be used as a pulse duration modulator.

Notes:
1. The operation of the circuit is unchanged if a more complex differential amplifier is used instead of $T_5$, $T_6$, $T_7$, and $T_8$. Resistor $R_9$ may be replaced by a transistor current source network similar to transistor $T_3$, $R_{31}$, $R_{32}$, and $R_{33}$. Any other constant voltage source may be used in place of $D_3$ or it may be replaced by a resistor voltage divider network.

2. Inquiries concerning this innovation may be directed to:
   Technology Utilization Officer
   Goddard Space Flight Center
   Greenbelt, Maryland 20771
   Reference: B69-10512

Patent status:
No patent action is contemplated by NASA.
Source: John Elson Johnson of University of Michigan under contract to Goddard Space Flight Center (XGS-10033)