The Phantastron

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There are several ways to generate the saw-tooth waveform used as the time base in an oscilloscope. Probably the earliest is the use of a gas triode (such as an 884 or 885) as a relaxation oscillator. Many simple oscilloscopes use an astable multivibrator, usually based on 2 triodes. Professional oscilloscopes use triggered sweep, generally based on proprietary circuits surrounding a Miller integrator. However, there is another way: the Phantastron.

What a great name! The Phantastron is a circuit that uses all 3 grids of a pentode in a non-trivial fashion to generate a saw-tooth wave. I first encountered the Phantastron in a Popular Electronics article from 1960 [1] describing the construction of a miniature oscilloscope. It used what they called a Miller integrator, based on a 6AU6, as the horizontal time base. The theory of operation of the circuit was not described, and it wasn't until years later that I understood how it really worked.

The Phantastron is based on a Miller integrator, so I will start there. John M. Miller was an engineer with the National Bureau of Standards, and he published a pivotal paper in 1920 in the Bulletin of the Bureau of Standards [2]. (By the way, Miller later led radio research at Atwater Kent [3]) Miller noted that the gain of a tube (or indeed most 3-terminal amplifiers) causes capacitance from the grid to the plate to appear to be larger at the amplifier input. This will be familiar to any electrical engineer as the Miller effect, and the capacitance between the input and output of an amplifier is often called the Miller capacitance.

A Miller integrator is an amplifier with a capacitor between the output and input, and performs the calculus operation of integration. Consider the circuit in Figure 1. Start the analysis by turning V1 off by pulling the grid negative with SW1. The plate is at B+, and the capacitor is fully charged at about 260V. If we flip the switch, V1 starts to come on. However, as V1 turns on, the plate voltage drops, which causes the control grid voltage to go more negative (because C1 is discharging thru R1), which tends to cut the tube off again. This is a negative feedback loop that keeps the current flowing out of the capacitor at a constant rate. In this way, the plate voltage will drop at an almost constant rate determined by C1 and R1, generating one tooth of a saw-tooth wave. As soon as the plate voltage drops too low, the circuit goes quiescent again until the switch is flipped back. When the switch is flipped back, the tube turns off, and the (hopefully faster) ramp back up is determined by R2 and C1.

There are other ways to "flip that switch". Consider Figure 2. The third grid from the cathode (the suppressor grid) is usually just grounded and forgotten. However, if it is made negative, it can turn the tube off, thereby allowing C1 to charge back up to start the process of generating a ramp. This is the phantastron as described in [6] and [7]: a 1-shot sawtooth generator. If the suppressor grid can be made to receive the right pulse after the ramp is generated the circuit would free-run.
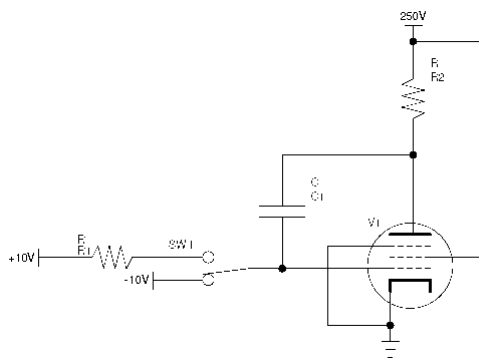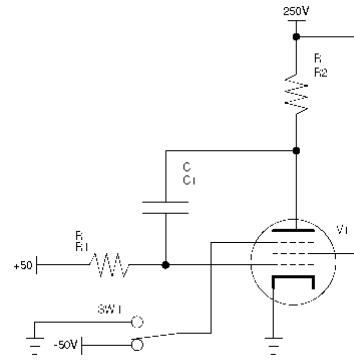
Figure 1: Basic Miller Integrator

Figure 2: Miller Integrator with suppressor control.

A free-running Phantastron uses the screen grid to "kick" the suppressor grid. [4] [5] Figure 3 shows the Phantastron as described by Popular Electronics [1], with element values. The screen grid (second grid) of the pentode is connected to B+ thru a large resistor. When the plate voltage is high, the circuit works normally because there is little drop across this screen resistor. However, when plate voltage is low at the end of a ramp, the screen current starts to increase (because the screen grid is more positive than the plate). This increase in screen current causes a drop in screen voltage. The screen is capacitively coupled to the suppressor grid (thru C2), so when the screen voltage drops, the suppressor voltage also drops, further decreasing plate current and further increasing screen current. This circle of events rapidly cuts the plate current to zero, keeping screen grid current high, and a negative voltage on the suppressor grid. With no plate current, the plate voltage must start to rise again as C1 charges back up. While the plate is rising, the control grid voltage is pulled high because of C1, and this maintains the high screen current. The plate current remains at zero, however, because the suppressor grid is still negative. Eventually, when the plate reaches a high enough voltage that it overcomes the negative voltage on the suppressor, the plate current will start to rise, causing a drop in screen current, an increase in screen and suppressor voltage, and the screen grid voltage will rapidly return to its high value. The circuit is back in its normal state, and the Miller integrator will start to produce a new ramp. At the end of the ramp, the process repeats itself. This circuit produces a continuous saw-tooth wave.
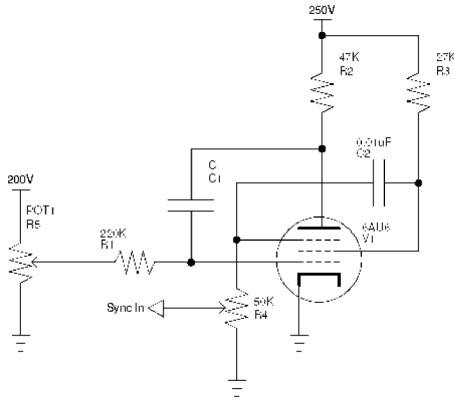
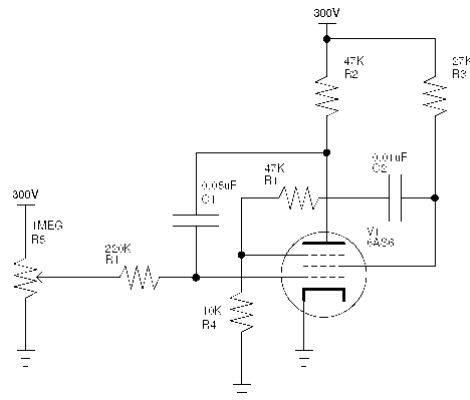**Figure 3: Popular Science Oscillator**   **Figure 4: 6AS6 based oscillator**

There is certainly positive feedback happening because the screen is coupled to the suppressor grid. This configuration (coupling the suppressor to the screen grid) is the basis for the transitron oscillator [5], which would be an excellent topic for a future article. In essence, the Phantastron is a transitron oscillator controlling a Miller integrator, all with one tube. The oscillator can be synchronized by injecting a signal into the suppressor grid as shown in Figure 3.

The circuit shown in Figure 3 (from [1]) using a 6AU6 suffers from a problem: it is not *guaranteed* to free-run. It will generally free-run at start-up, however if the tube is forced "on" and the capacitors are allowed to settle, then it will not oscillate until it receives a kick on the suppressor grid. This is because the gain on the suppressor grid is not large enough to sustain the positive feedback. The characteristics of the suppressor grid of most pentodes are not specified, and as a result there may be significant differences between similar looking tubes. I did find that some 6AU6's worked better than others. Reference [5] suggests that the VR116 and 6F33 (rarely found in North America) were designed for transitron operation. Terman [7] recommends the 6AS6 for Phantastron operation.

The detailed specifications of the GE 6AS6 [8] include curves describing the operation of the suppressor grid. I modified the Popular Electronics circuit slightly to use a 6AS6, (Figure 4) and in this configuration I got a larger sawtooth wave, and found that it always oscillated. Figure 5 shows my bread-boarded Phanstron using the 6AS6, and Figure 6 shows the plate waveform (upper trace 50V/division) and the screen grid current (lower trace, 10mA/div). Notice that over 150V of swing is available on the plate, which is enough for a 1" CRT. The peaks in screen grid current at retrace are clearly visible.
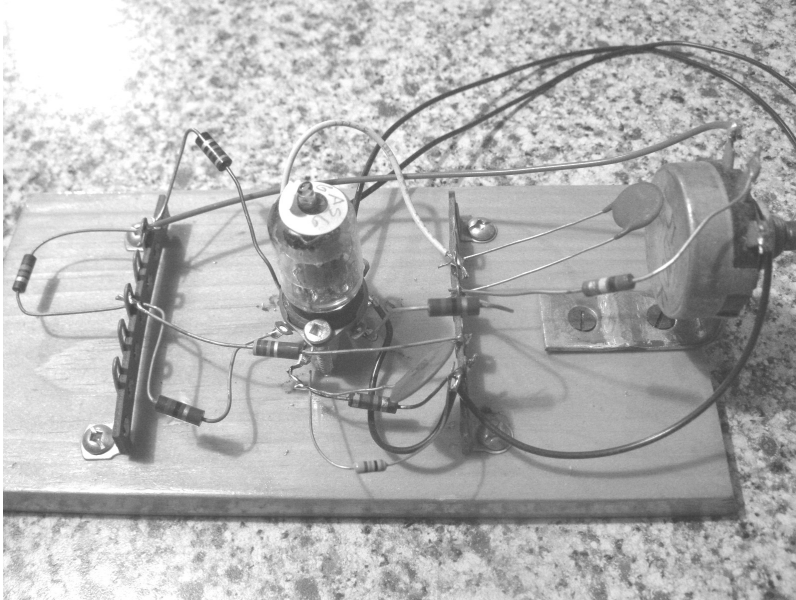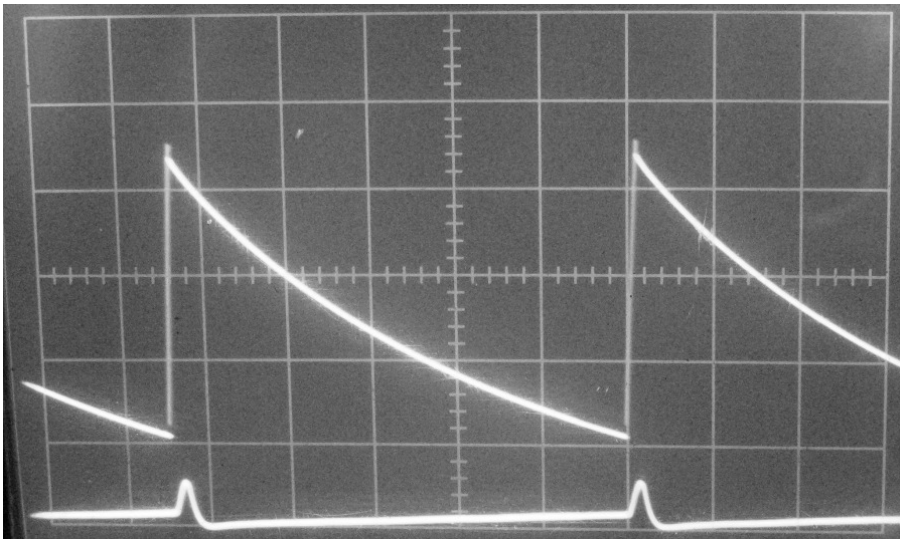
Figure 5: Phantastron oscillator

Figure 6: An operational Phantastron

Apparently, the Phantastron has been used in television sweep circuits, mainly in Europe. Why has it not been more widely used? I believe a major limitation is that the charging of C1, the "retrace time", is thru a resistor, rather than being forced by a switch (a Triode in a multivibrator). This limits the maximum frequency at which a satisfactory waveform can be achieved. I have not tried to optimize the circuit with the 6AS6, however my guess is that the maximum practical frequency would be about 1MHz. However, in terms of a clever circuit concept, it is fascinating.

References:

[1] "The Min-O-Scope", Charles J. Schauers, August 1960, Popular Electronics.

[2] "Dependence of the input impedance of a three-electrode vacuum tube upon the load in the plate circuit", J. M. Miller, in the Bulletin of the Bureau of Standards, 1920.

[3] "John Milton Miller", http://en.wikipedia.org/wiki/John_Milton_Miller

[4] "Some Basic Circuits used in Tektronix Instruments", John Mulvey, Tektronix, FIP-11 An expansion of lecture notes prepared in 1958 by, Product Information. Third revision, Sept., 1964,

[5] "The Transitron" http://www.r-type.org/articles/art-135.htm

[6] "Reference Data for Radio Engineers" 4th ed., ITT Corporation. 1956.

[7] "Electronic and Radio Engineering", F. E. Terman, McGraw-Hill,1955

[8] Frank's tube pages: www.tubedata.info