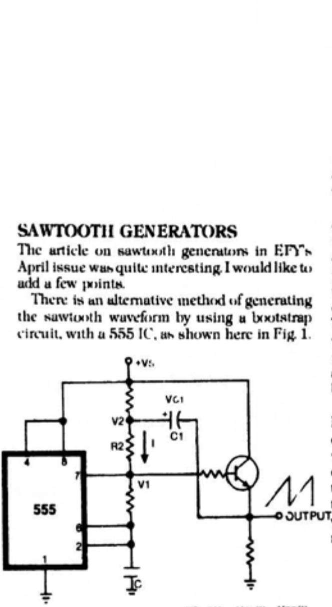
SAWTOOTH GENERATORS

The article on sawtooth generators in EFY's April issue was quite interesting. I would like to add a few points.

There is an alternative method of generating the sawtooth waveform by using a bootstrap circuit, with a 555 IC, as shown here in Fig. 1.



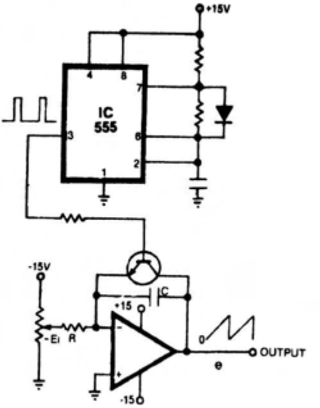
$$I(t) = \frac{V2 - V1}{R2} = V_{C1}(t) - V_{BE}(t)$$

The advantage of this circuit over the one published is that the sawtooth output is automatically buffered.

A versatile method of generating sawtooth waveforms is shown in Fig. 2. It consists of an op-amp integrator whose capacitor is intermittantly reset by a narrow pulse train from, say, a 555 IC based pulse generator. The ramp output equation with time 't' is

$$e_o = -\frac{E_i}{RC} \cdot t$$

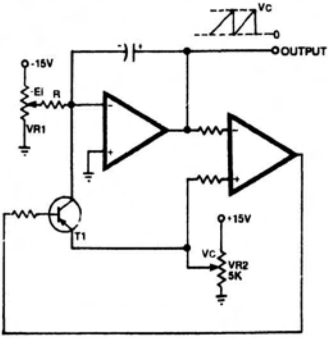
Note that the sawtooth frequency is decided by the interval of the 555 IC pulse train, while the ramp amplitude is decided by either input DC voltage E_i, or input resistor R, or the feedback capacitor C. Thus we can have a voltage con-



trolled sawtooth amplitude through variations of E_i or manually adjusted amplitude through a variable R or a potentiometer providing E_i.

Obviously, the pulse generator and integrator can be combined together simply by comparing the integrator output with a fixed voltage in a comparator with hysteresis. When the sawtooth output rises above the comparison voltage plus hysteresis width, the comparator output switches the discharging transistor on. The capacitor is rapidly discharged until the voltage comes below the comparison voltage minus hysteresis width. The cycle continues and the comparison voltage and hysteresis can be chosen to give suitable sawtooth amplitudes.

One such circuit is shown in Fig 3. Here, however a direct hysteresis is not used. The comparison voltage V_c itself is brought to zero when the transistor is turned on, simultaneously discharging the capacitor, giving a sawtooth from zero to V_c always. The advantage of the circuit is that the frequency is controlled by voltage E_i from potentiometer VR1 (or externally) and the amplitude is controlled by voltage



tage V_c from the potentiometer VR2.

One major advantage of the op-amp sawtooth generators is that resistors can be switched for various ranges, rather than capacitors, which give better control since resistors of each range can be carefully selected. For example, various fixed values of R can be selected for various ranges and potentiometer VR1 can be varied for various frequencies in each range for the circuit of Fig. 3.

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The author, Mr A.K. Narayanan, replies:
Mr Biswas's circuits were a pleasure to go through. The bootstrap circuit (Fig. 1) will be useful where waveform linearity is not the greatest concern. This circuit is, in fact, a first step towards achieving constant-current charging of the capacitor. Intuitively, one can grasp the attempt to equalise the AC voltages at both ends of R2, by feeding the AC content of voltage V1 back through the emitter follower and C1. This results in reducing AC currents in R2, thus providing a near-constant current into C. But a brief analysis will show that C1 has to be large enough so that dV_{c1}/dt tends to be zero.

This will, mainly, place a lower limit on frequencies where satisfactory operation is possible. Nevertheless, this circuit could be the choice if only one extra transistor is to be optimally used.

In the circuit of Fig 2, notice that the 555 is not controlled by any signal or parameter derived from the output. The lack of a closed-loop control has inherent problems. For example, if the 555 pulse width is greater than a critical requirement, the output gets a flattened bottom. But remember, it is the open 'loop' nature of the circuit that gives it the feature of independent frequency adjustment.

The most interesting of all is the circuit of Fig 3. The ramp-up is easy to understand when T1 is off. The discharge of the capacitor occurs when T1 is on, at a rate equal to dVo/dt, which is approximately equal to (VC/RC)-(Ee/R), where Re is the potentiometer equivalent resistance looking out from the emitter of T1. Our requirement is rapid discharge, i.e. we have to maximise Ve/Re. It can be seen that if the comparator doesn't switch fast enough to turn off T1 on time the output may even go to $-V_{cc}$, since the discharge rate is high. (By the way this circuit can be modified, by including a series resistor to control the discharge current, to make a good triangular wave generator.)

A certain problem while building op-amp circuits is slew rate. This keeps op-amp based circuits to a few kHz range if reasonably good specifications are placed on the waveform.

Thank you, Mr Biswas, and hope the readers found the discussions useful.