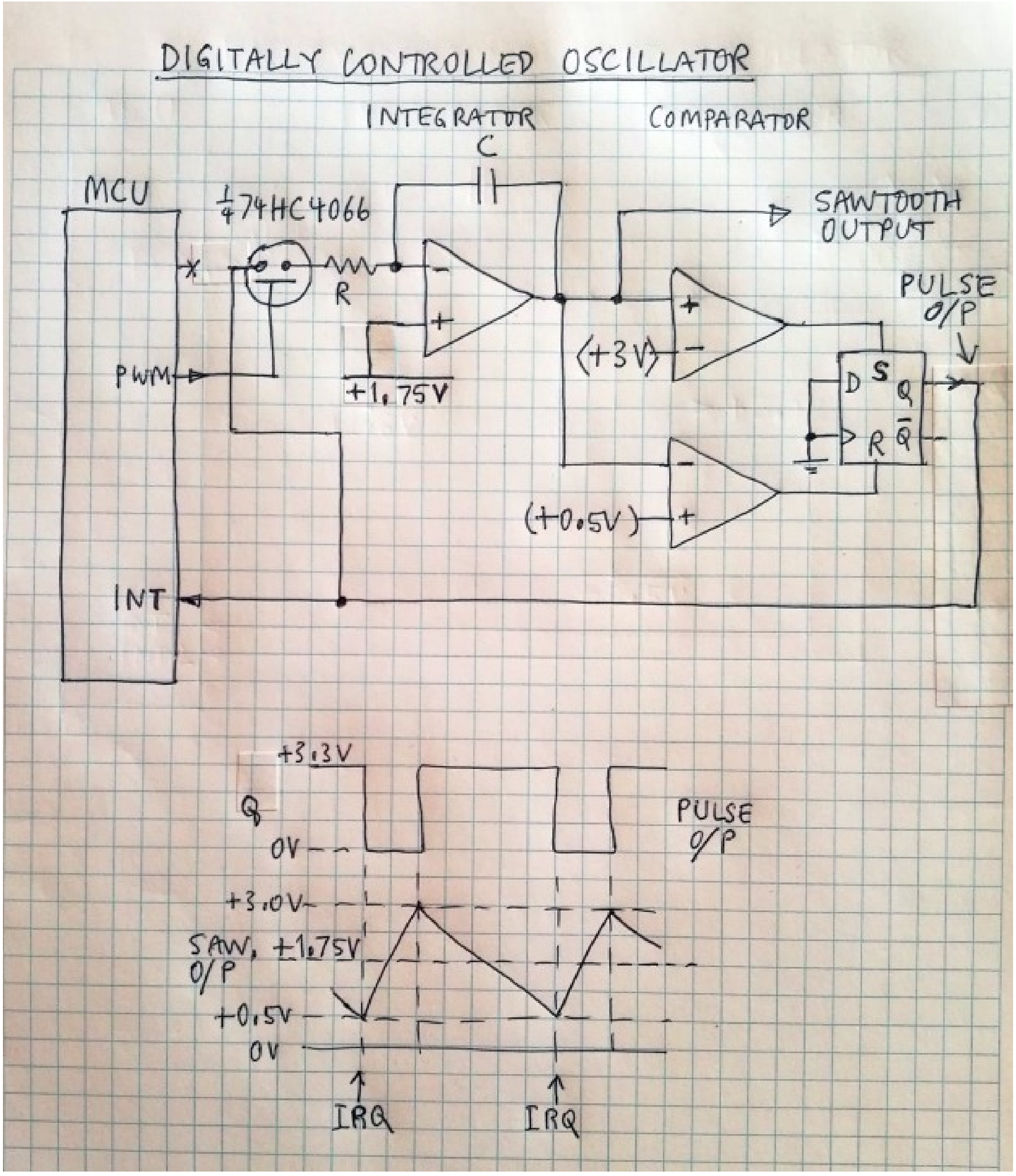
Digitally Controlled Oscillator for Hybrid Synthesizer Application

The sketch below shows the oscillator concept. The schematic partly resembles a simple analog VCO, except that in a VCO the integrator slope (hence output frequency) is voltage-controlled (using a transconductance amplifier with exponential V-to-I input transfer function).

Instead, the DCO uses a micro-controller PWM output (variable-duty pulse at a frequency well above audio, e.g. 40kHz) to control the integrator slope (1 / RC). The effective resistance R' of the integrator is inversely proportional to the PWM duty. For example, if R = 1k and the duty d = 0.5 (50%) then the effective R' is 2k, i.e. R' = 1 / d.



The oscillator works as follows: Let the PWM duty be fixed at 1.0 (100%). Then the capacitor charge/discharge rate is 1/RC. While the flip-flop output Q is low (0), the integrator input is 0V and C will be discharging and so the (inverting) op-amp voltage will ramp up until it reaches the comparator upper threshold (3.0V). Then the flip-flop is set (Q = 1) and the integrator input is now +3.3V (= Vcc) and C will be charging. The op-amp output voltage will ramp down until it reaches the comparator lower threshold (0.5V). Then the flip-flop is reset (Q = 0) and the cycle repeats. In this case, the MCU does nothing... the output frequency is constant. The integrator output waveform is a symmetrical triangle.

The frequency is varied by the adjusting the integrator slope via the PWM duty which determines the value of RC. An asymmetrical sawtooth output can be produced by making the charge and discharge slopes different. The flip-flop output (Q) is fed into an MCU digital input capable of generating an interrupt request. This input has two functions: 1. to inform the MCU of the output ramp polarity (charge or discharge), and 2. to allow the MCU to measure precisely the output period, hence frequency, preferably using a 16-bit hardware timer/counter peripheral.

Although a look-up table may be used to set the PWM duty to obtain the (approximate) output frequency required, a closed-loop feedback algorithm should be used to obtain optimum accuracy. A closed-loop control system requires lower resolution for the PWM output signal than an open-loop implementation. Thus, a low-end MCU such as an 8-bit AVR or PIC with a 20MHz system clock should be adequate.

A major benefit of this technique (compared to a VCO) is that the output frequency is precise and stable. Another benefit (compared to digital sampling algorithms) is that it avoids aliasing completely, so it can deliver the full richness of a pure sawtooth wave.

The oscillator frequency may be set digitally, e.g. using a serial interface (UART, SPI) or by a control voltage input to the micro-controller ADC. A precise exponential voltage-to-frequency (pitch) transformation can be performed in software. An additional MCU analog (CV) input may be provided to allow fine tuning of oscillator frequency.

Furthermore, modulation of output pulse width and triangle-wave symmetry can be implemented by providing a CV input for this purpose. Alternatively, the MCU software could incorporate a transient generator (*aka* “envelope shaper”) function to modulate the output waveform symmetry. The transient parameters (attack, decay, etc) may be settable via a serial interface (UART, SPI).

It is assumed that some or all audio processing downstream of the oscillator(s) would be done with analog circuitry, e.g. mixer, variable-frequency filter, variable-gain attenuator, etc. The analog circuitry can be dramatically simplified using a micro-controller to set various audio parameters (mixer levels, filter frequency, resonance, audio output amplitude, etc) as implemented in many contemporary analog/hybrid synth’s.

I guess there could be commercial synth's that already use this or a similar implementation for the oscillators, because it's such a delightfully simple and effective technique, but I haven't seen any articles or schematics with it, so I am claiming this as an original idea. 😊

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