Electric Guitar SUSTAIN CIRCUIT

by John Edwards

THERE ARE ALREADY MANY CIRCUITS AROUND WHICH PROVIDE THE SUSTAIN FUNCTION FOR GUITARS, AND HERE IS YET ANOTHER ONE. ESSENTIALLY, THIS IS AN AUTOMATIC GAIN CONTROL, WHICH IS ARRANGED SO THAT THE GAIN IS INCREASED AS THE INPUT SIGNAL DIES AWAY, SO SUSTAINING THE OUTPUT AMPLITUDE FOR AN EXTENDED TIME.

Some of the other circuits are simple, some are complex – this one is in the middle. Some of the simple circuits are also functionally quite elegant, although perhaps a bit picky about the actual components such as FETs used as gain control resistors. However, others are functionally a bit questionable and act more like limiters.

The described circuit can be adjusted over a very wide range of input signal levels, and has the merit of being flexible in the choice of components. It is easy to 'special' part the LM3080, an Operational Transconductance Amplifier (OTA) which is used as the variable gain element. There is a quad op-amp too, which is shown as the common or garden LM324, but the TLC27M74 from Texas Instruments would be a good alternative if you have one. Both are low current drain devices. None of the op-amp inputs or outputs has to approach the supply rails very closely except for one, which has to be able to go down to about 0.6V above the negative rail, and both of the mentioned devices will do this.

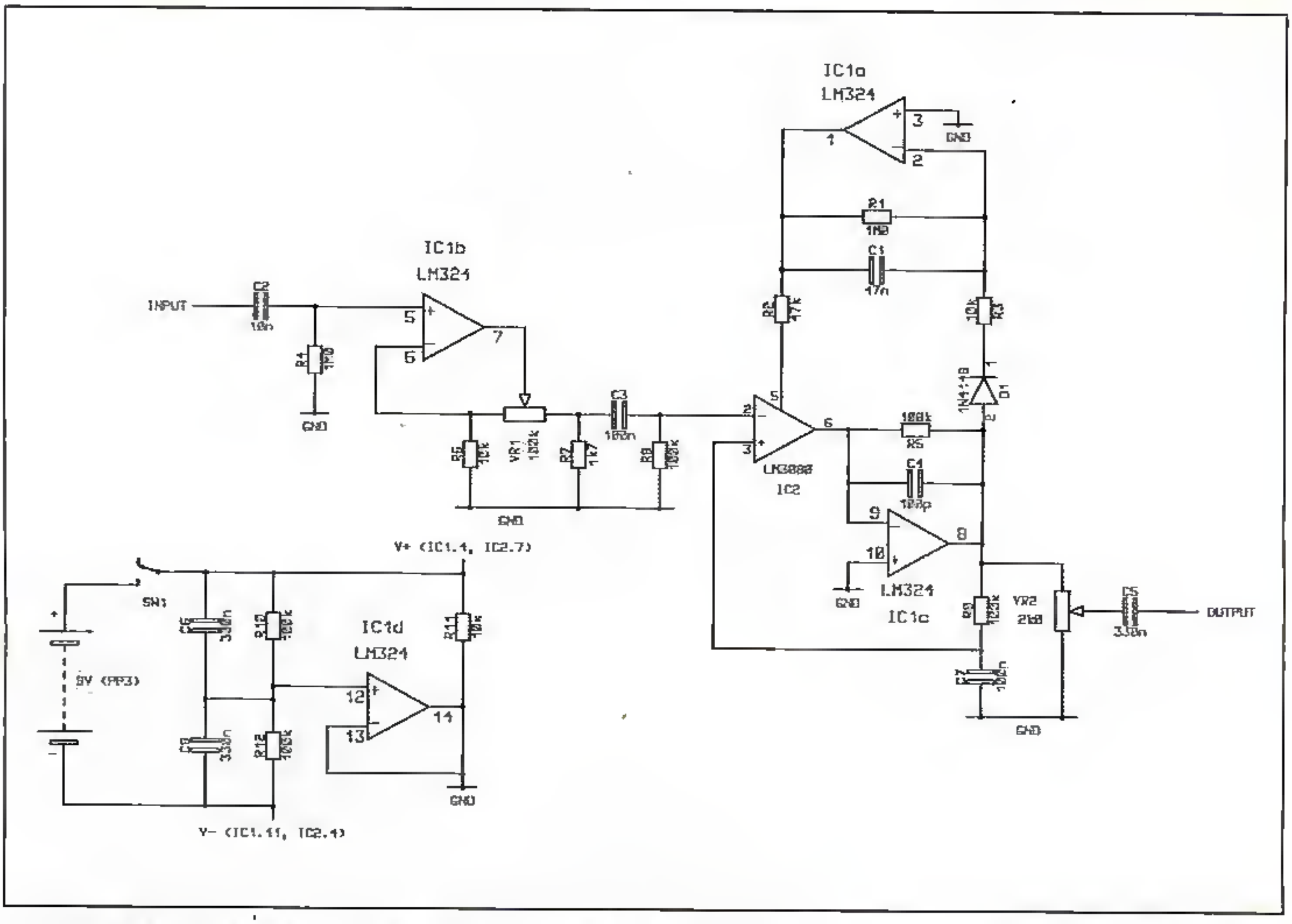
An OTA is a variation on the op-amp circuit. A normal op-amp supplies a high voltage gain, the output voltage typically being up to 100,000 (or much more) times the differential input voltage for 0Hz signals. The OTA, however, provides a current output proportional to the differential input. It has a transconductance (also known as 'gm') of mA/V rather than a gain of V/V. The value of the gm is set by a bias current, and in the LM3080 works out at around 20 times the bias current per volt input. So a bias current of 100uA will produce gm=2mA/V. This only works over a small input range though, as the maximum output current is about the same as the bias current, after which there is no further increase. The voltage appearing at the output doesn't affect the current, as long as it gets no closer than about 1V to either supply. So, for instance, a resistor connected to the output will convert the current output directly to a voltage output, where the voltage gain is equal to (gm x resistance)

The circuit is shown with a single 9V battery supply, and an op-amp section is used to generate a ground reference set mid-way. The circuit will operate quite reasonably over a wide supply range without any changes, and even four AA cells should be just about possible. Not needing a true central tap in the supply has the merit that even the on/off switch can be simple. Indeed, this could be on one of the level pots – something you couldn't do with a tapped supply.

Operation

Power is supplied when SW1 is closed. The + line goes to IC1.4 (that is, the op-amp IC1 pin 4) and IC2.7. The – line goes to IC1.11 and IC2.4. Between them the current drawn is no more than a couple of mA. Op-amp section IC1d generates a 'ground' reference for the signal on the output IC1.14. This is connected to the +ve supply by resistor R10, which draws a little current from the output stage of the op-amp, so shifting it's operation just into class A, for the lowest impedance and fastest response. Little load is placed on the output due to the ground referenced components.

The input signal is applied to IC1b via C2, which with R4 provides a high impedance input with a low frequency -3dB response set at16Hz. IC1b is a non-inverting amplifier with the gain



set by VR1 and R6. Only the section of VR1 on the R6 side comes into the gain equation, providing a range of x1 to x5.5. The other part of VR1 adjusts the attenuation between op-amp output IC1.7 and the inverting input of the OTA. The attenuation ranges from x1 to x21 (i.e. a gain of x1 to x1/22). Combined, this gives a range of adjustment from the signal input to the OTA of x1/22 to x5.5.

The OTA is operated open-loop, and the maximum differential input voltage for linear operation is around 50mV, depending on your definition of linear. Above this level in either polarity the output current will be reaching its limit, which is the same as the bias current supplied to pin IC2.5. As the input signal increases above +/-50mV the output current waveform will become increasingly clipped off. The maximum signal level for linear operation with the gain right down (x1/22) will therefore be about 1.1V peak (a 0dBm signal in 600 ohms). With the gain right up (x5.5) then 9mV is all that is permitted. Beyond that, the circuit becomes a limiter.

The adjusted input signal is passed to the OTA inverting input through C3 which with R8 acts as a high-pass filter set at 16Hz. R8 also provides a DC path for the input bias current of the OTA. Assuming there is an OTA gm bias current into IC2.5, then there will be a current signal out of IC2.6, which is passed to the inverting input of the op-amp IC1c. This is operating as a normal inverting amplifier with the OTA substituted for the input resistor, and R5 the feedback resistor, with C4 providing high-frequency cut above 16kHz. The IC1c output is passed out from the circuit through VR2, with isolation through C5. Pin IC1c.9 is held virtually at the level of IC1c.10, which is the averaged op-amp output signal. This will be very near zero, and is fed back to null any offset drift due to OTA input bias changes. The averaging filter R9 and C7 has a high cut off frequency of 16Hz, so it has little effect on the actual signal.

If part of the signal cycle from the final op-amp stage exceeds about 560mV positive, then diode D1 will be conduct, and the output of the integrator (ICa.1) will fall towards the negative supply. This reduces the voltage across the OTA bias resistor R2 (the OTA end of which is at 0.6V above the negative supply), and so the bias current also reduces. This directly lowers the gm of the OTA, and so the amplitude of the final output signal. This gain reduction continues until a balance is reached where there is just sufficient current passed through D1 at the signal peak to counteract the de-integration current drain of R1. If the input signal level now falls, (a note dies away), then the peaks will also reduce, and D1 will conduct less or not at all. The integrator output will rise toward ground as C1 discharges, increasing the OTA bias and so tending to maintain the output signal level. Eventually, as the signal continues to fall, the integrator will arrive at ground and no further increase in OTA gain can be made. From this point, the output signal starts to track the input signal decay, and the sustain period is over.

The gain of the OTA/op-amp stage is gm times R5. As gm is 20 times the bias current, which is about 4V/R2 maximum, then the maximum gain of the stage is (20x4/47k x100k) which is x170. For an output signal at 560mV peak, this means the input to the OTA would have to be 3.3mV peak. If the input gain has been set to make the full signal 50mV at that point, then the sustain will hold the full level until the input has decayed away to 1/15 of the initial level. How long this is depends on the actual input signal decay rate. From that point, the output level will start to follow the input signal down. Note that if the input starts at a lower level, then the circuit runs out of sustain earlier; reducing the input gain therefore has the effect of reducing the sustain time. This does NOT effect the peak output level, which remains a fraction of 560mV as set by VR2.