Bootstrapping

(an old technique with many uses)

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Introduction

"Bootstrapping" is an old circuit design technique that has been around for decades. It is basically an example of positive feedback, which serves to change (effective) impedance levels or maintain currents constant. Of course care has to be taken with positive feedback, otherwise instability can result and of course many oscillator circuits rely on this for operation.

With modern integrated electronics, fabricated directly on silicon or other semiconductor materiel, circuit techniques such as bootstrapping are no longer of much use, since active devices are plentiful; circuit techniques of economy and clever tricks are of less importance. Nevertheless, its always useful to be aware of these techniques.

In this short article I will look at some applications of bootstrapping and also an analysis of one such technique.

Applications

1) Bootstrapped Linear Ramp Generator.

An example of using bootstrapping to maintain a current constant. Fig1 applies.

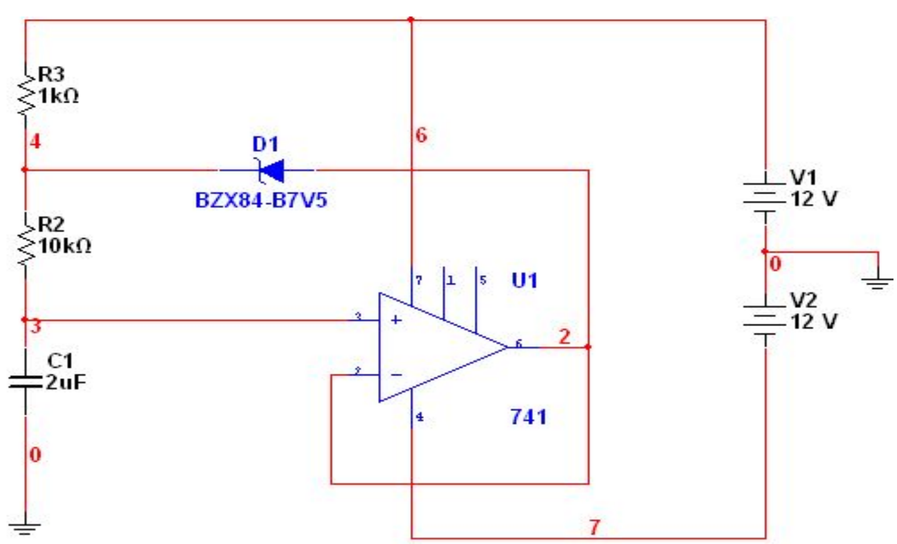

Fig 1: Bootstrap ramp generator

Here, C1 charges towards the supply rail via R1 and R3. U1 is a unity gain, high impedance buffer. Hence if the potential on C1 changes by an amount delta V, then the amplifier output also changes by delta V. The Zener diode D1 is biased by R3 and the voltage across it is constant. Any change in bias current (due to delta V) just slides up and down the Zener characteristic. Therefore the potential at node 4 also changes by delta V. The potential difference across R2 is therefore maintained constant, resulting in a constant current supply to C1 - and hence a linear dV/dt. A switch across C1 resets the circuit (not shown).

This simple example nicely illustrates bootstrapping; the voltage at node 4 is "pulled up by its own boot straps" - ie the voltage at node 3, and thus maintains the potential difference across R2 constant. Therefore the expense of a constant current supply is saved just by the addition of D1

2) Bootstrapped Tuned Circuit - Regeneration (or reaction)

Early radio receivers of the TRF type relied on the Q of a tuned circuit to select signals. The later Superhetrodyne receiver design, uses a frequency changer, to convert all signals to a constant frequency. A narrowband amplifier (IF amplifier) is used to amplify the fixed frequency signals with good rejection of other unwanted signals.

The trick in the TRF Reciever, is to apply positive feedback to the tuned circuit (bootstrap) in order to reduce the circuit resistance and loading to achieve a higher Q and thus improve selectivity. Fig 2

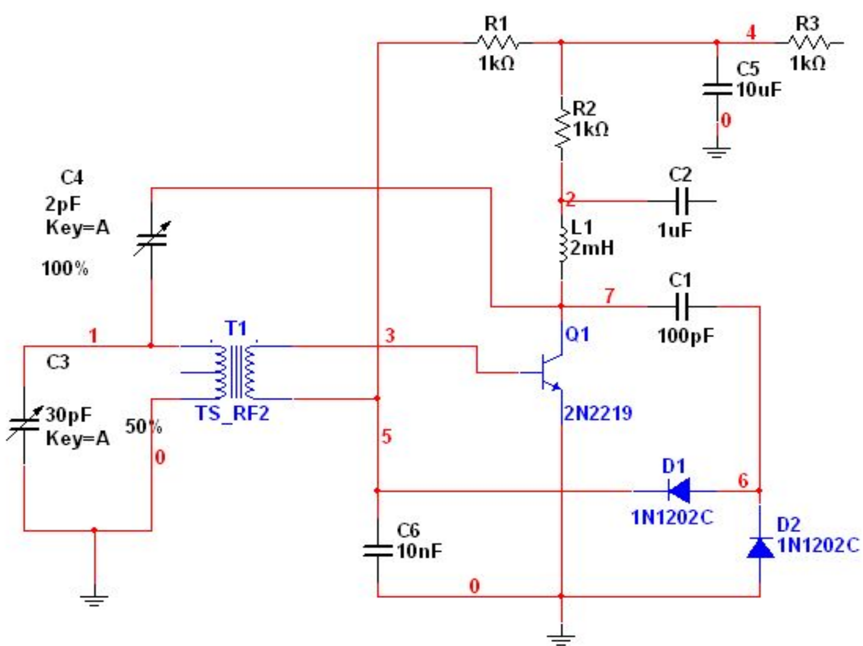

Fig 2: Simple TRF. C4 applies regeneration to T1 and C3

The Q factor of C3 and T1 is limited by the loading effect of the transistor reflex stage and winding resistance of T1. The signal applied via C4 (adjusted for correct phase) acts to cancel the resistive loading effects which increases the Q. Note if too much feedback is applied, the circuit will oscillate. The analysis of this circuit is very interesting. The tuned circuit has a 2nd order transfer function, and the feedback (reaction) reduces the damping factor and therefore increases the Q. Of course if too much feedback is applied and the damping factor becomes zero, oscillations will result. The performance is not as good as the Superhetrodyne, but the cost of a local oscillator plus mixer and IF amplifier is saved.

3) Bootstrapped Load Resistance

One of the problems designing multi-stage amplifier circuits, is that the input impedance of a subsequent stage will load the output impedance of the previous stage. Since the gain of a stage is given by gm x RL, then reduction of RL by loading will reduce the gain. Of course one can buffer a stage using a high input impedance emitter follower to minimise the effect, and in integrated circuits, extra transistors are plentiful. Alternatively in integrated circuits, an active load is used, utilising the Early voltage high impedance characteristic. However, simple Bootstrapping can again be used to increase the effective load impedance, compensating for the loading effect of the next stage . Fig 3 applies.

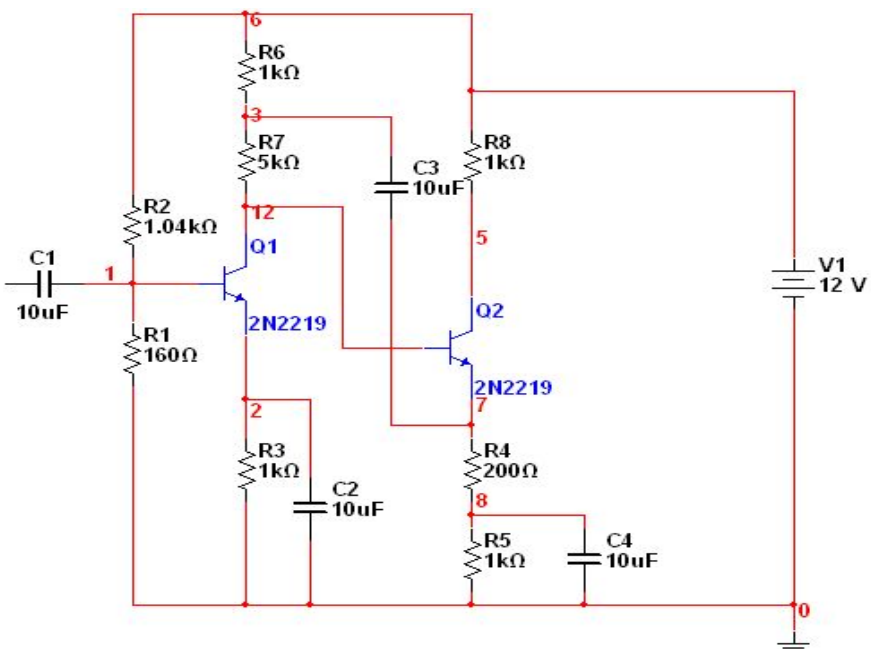

Fig 3: Bootstrapped First Stage Q1

In this circuit, Q1 is a high gain common emitter stage, and if on its own, would have a stage gain of around 230 at room temperature. Unfortunately, the following stage Q2, directly coupled, loads the first stage, such that its gain is now only about 100. The second stage has a gain of approximately 5. Hence, whilst one would have wanted a gain of about 1000 overall, in practice this is in fact around 500 due to the loading effect.

The addition of C3, bootstraps resistor R7, increasing the overall gain to 1300. This illustrates the usefulness of the technique, with just the addition of a simple capacitor. The capacitor, DC blocks the connection, but applies a signal in phase to R7 and increases the *effective* load of R7 + R6. Lets see how it does this.

Consider the circuit in Fig 4

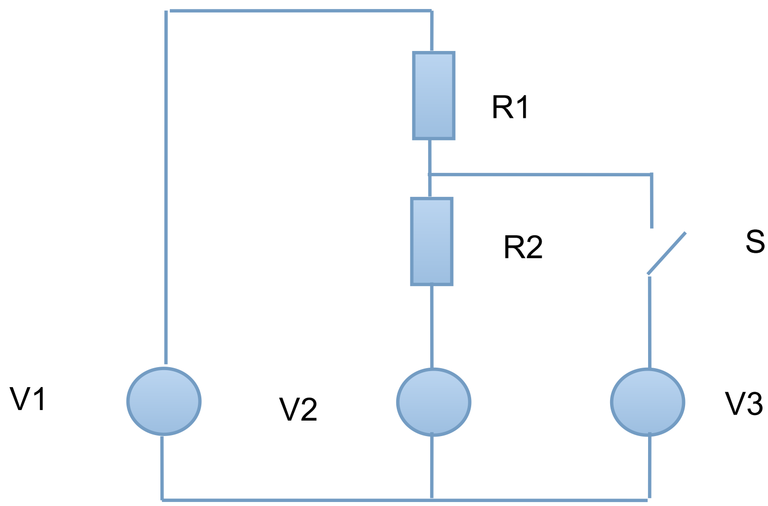

Fig 4 Bootstrap Analysis

With S open:

Let I be the current through R1, R2 and V2.

Hence

$$I = \frac{V_1 - V_2}{R_1 + R_2}$$

and so the Load for V2 is just

$$R_{L1} = \frac{V_1 - V_2}{I}$$

and substituting for I we get

$$R_{L1} = R_1 + R_2$$

simple

Now with S closed and V3 < V2

The current through S is

$$I_s = \frac{V_1 - V_3}{R_1}$$

And now I is:

$$I = \frac{V_2 - V_3}{R_2}$$

So the *effective* load seen by V2 is:

$$R_{L2} = \frac{V_1 - V_2}{I}$$

and substituting for I:

$$R_{L2} = \frac{R_2(V_1 - V_2)}{V_2 - V_3}$$

The ratio of RL2 to RL1 - i.e. after and before S closed is

$$\frac{R_{L2}}{R_{L1}} = \frac{R_2(V_1 - V_2)}{(R_1 + R_2)(V_2 - V_3)}$$

Now V3 is associated with V2 - that is signal fed back, so let

$V_3 = KV_2$ where K < 1

Hence

$$\frac{R_{L2}}{R_{L1}} = \frac{R_2(V_1 - V_2)}{(R_1 + R_2)(V_2 - KV_2)}$$

Lets try a few numbers to illustrate this.

Let V1 = 10v, V2 = 5v, K = 0.9, R1 = 1k, R2 = 4k

So with S open, Load seen by V2 is

$$R_{L1} = R_1 + R_2 = 4k + 1k = 5k$$

Now close S

The ratio of the effective loads is now

$$\frac{R_{L2}}{R_{L1}} = \frac{5k(10-5)}{(1k+5k)(5-0.9\times 5)} = 8$$

Hence the bootstrap has increased the effective load by 8 times in this example, that is 8 x 5k = 40k. Therefore the addition of a simple capacitor in Fig 3, more than compensates for the loading effect of Q2.

Note well, if K = 1, then (V2 - KV2) = 0 - resulting in infinity (divide by zero) therefore the bootstrap voltage must always by less than the node being bootstrapped ie K < 1

4) Bootstrapped Input Resistance

We can also use the bootstrap trick to increase the input impedance of a circuit. This is not really of interest since the wide use of MOSFET transistors makes this redundant.

Still here is a circuit for passing interest. Fig 5

Here R1 and R2 provide the bias network for the transistor. Unfortunately, it also shunts the input resistance (R1 // R2 // Rin). So we attempt to isolate Rin from the bias network by inserting a series resistor R3. The larger R3, the better the isolation from the shunting effect. We therefore bootstrap R3 by using the bootstrap capacitor C1. The effect of this should be apparent from the previous circuit. The input is applied to the base and sees an input resistance of Rin + R4. This would normally be shunted by R1 // R2. The bootstrapped resistor R3 greatly reduces the shunting effect.

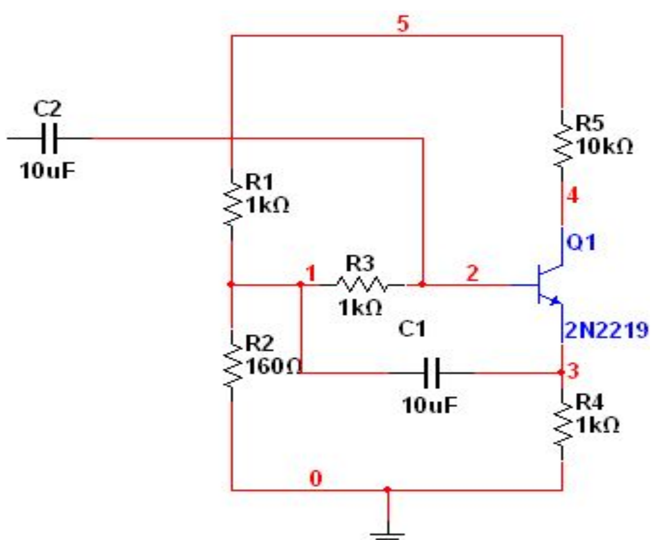

Fig 5: Bootstrapped Input

Conclusions

These techniques are of less interest these days. However this does not mean they should be forgotten. There are sometimes novel situations where old techniques can be of value and cost effective.

A famous Engineer once said: “An Engineer is someone who can do for a pound, what any fool can do for ten pounds”