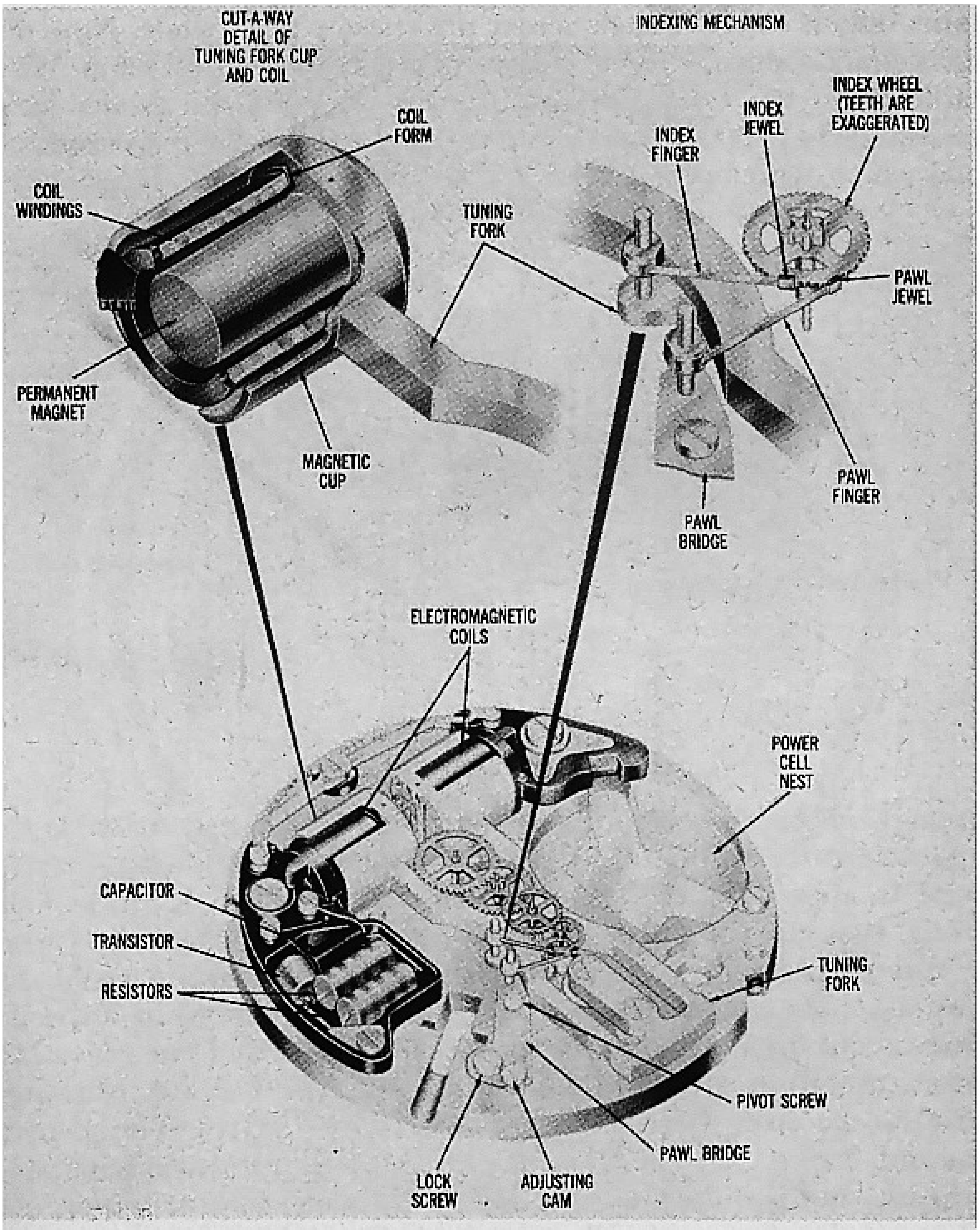
Sean's "How it works" Page.

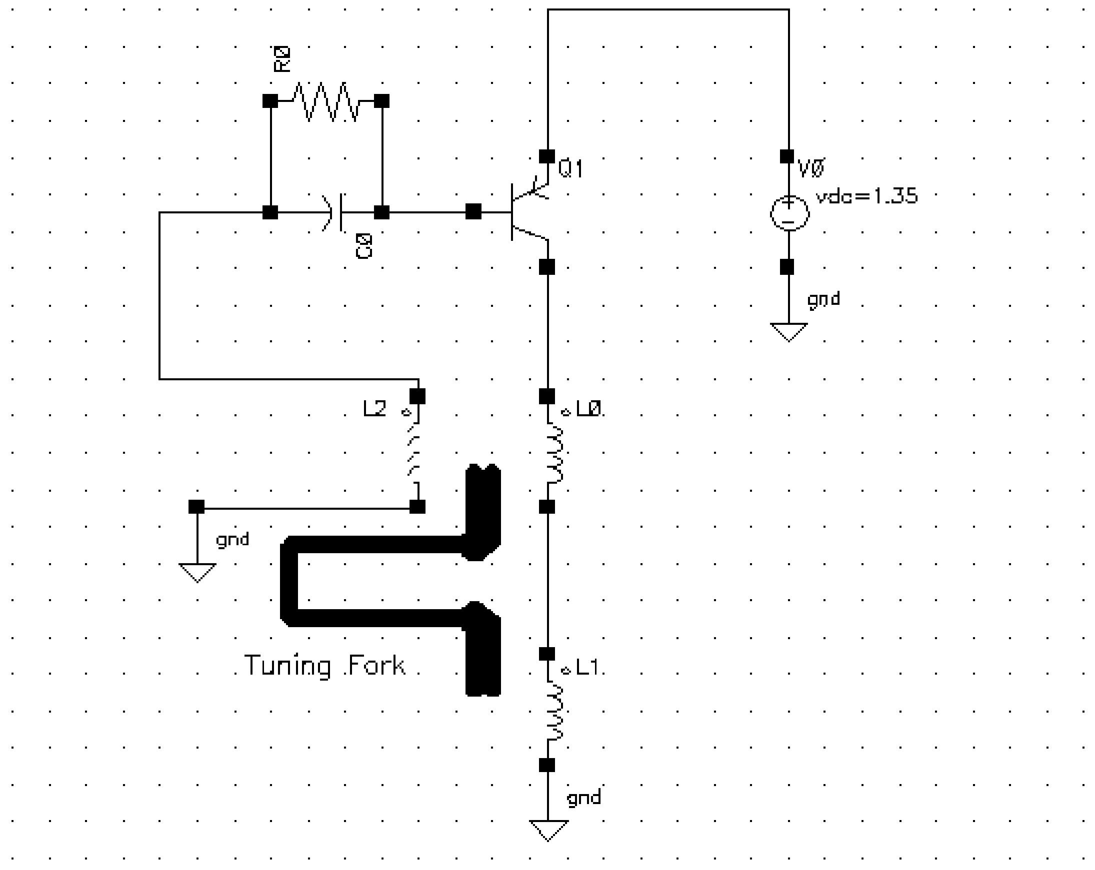
Well, all that time I spent at The University of Liverpool (the real one) maybe wasn't wasted after all (although my bank manager wouldn't agree with that) . Here's the basics behind the Bulova Accutron. First of all though we need some basic electronics and electro-magnetics. There are only two things we really need to know, the principle of electromagnetic induction and the basic operation of a 'pnp' bipolar transistor.

The two ends of the tuning fork tines in your Accutron both have very powerful nickel alloy permanent magnets attached to them which sit inside coil formers. Over these formers are wound three coils. Two of these are 'drive' coils, the third being used as a sensing device. A drawing of the arrangement is shown below. This is actually a 218 movement but for our purpose the 214 differs only in detail.



(Image taken from Bulova Accutron 218 Technical note , Bulova Watch Inc).

A schematic of the circuit is shown below.



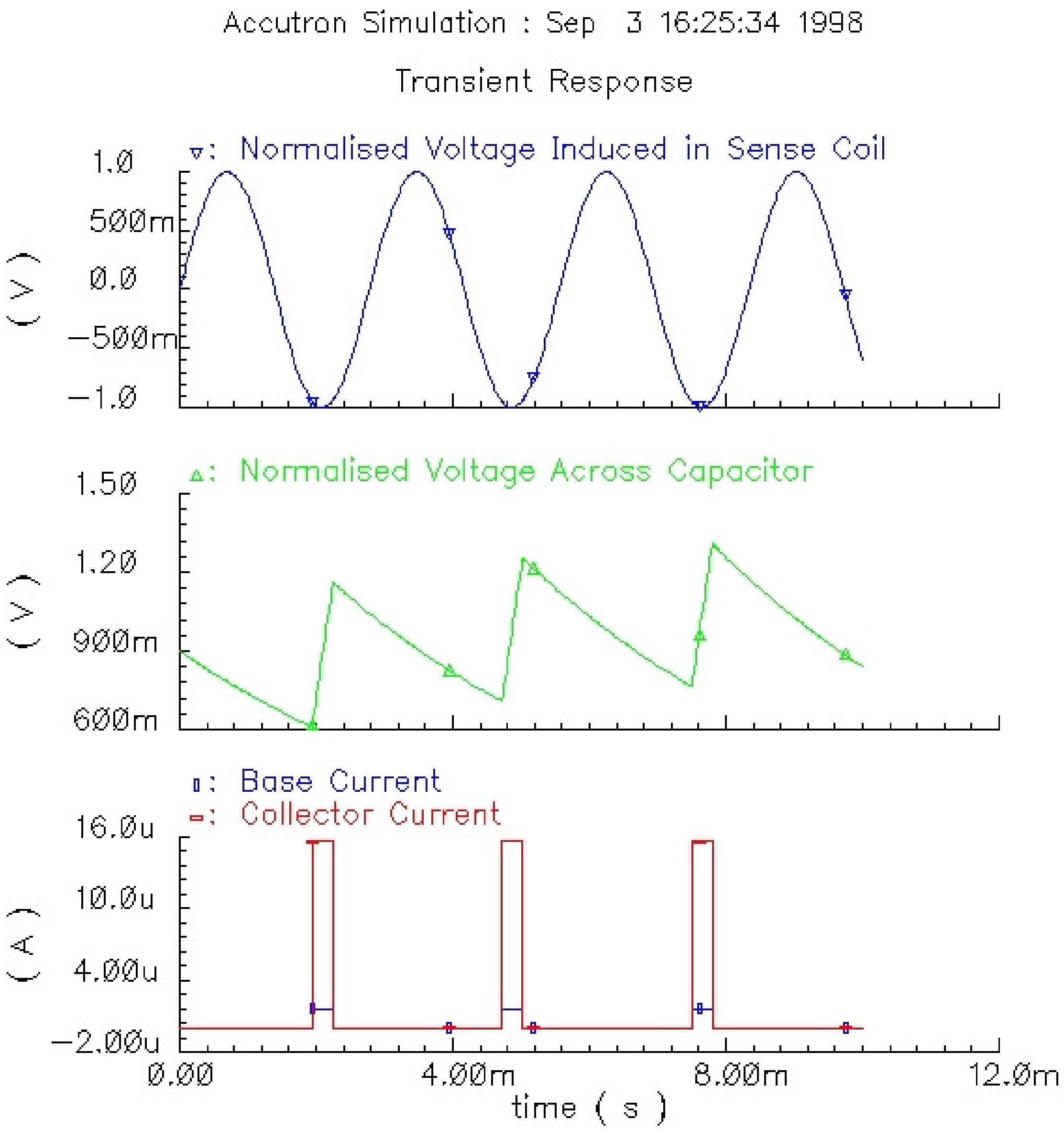
Two thousand turns of one coil (L2) are used as a sensing winding with the remaining 14000 turns serving as the impulse coils (L0 and L1). The RC network in the base of the transistor (R0 and C0) acts as a self start mechanism and also has some effect on the stability of the circuit and its ability to correct for shock induced positional error of the fork tines.

To begin with assume that C0 is charged and that R0C0 >> 1/Fo where Fo is the natural frequency of oscillation of the fork (Fo=360 Hz). The magnets, vibrating with the tuning fork induce a voltage in the sense coil (L2) which applies a voltage to the base of the transistor (Q1). This voltages is at its maximum (although -ve wrt the emitter) when the magnets are at peak velocity, which is as the tuning fork passes through its rest position or zero displacement point (ZDP). The transistor turns on when the voltage at its base falls below the turn on voltage (about 0.3 V below the voltage at the emitter) and a current pulse flows in the collector circuit through L0 and L1, giving an impulse to the tuning fork thus sustaining its motion. It is important to note that the impulse is delivered with the forks close to their rest position as is required for good time keeping. The magnets of course also induce a voltage in the drive coils. In the steady state the transistor provides a very sharp pulse of current and the amplitude of the pulse is limited by the induced EMF on the drive coils. With the transistor on and saturated the induced EMF in the drive coils 'backs off' about 80 % of the cell voltage (1.35 V). This has the advantage of prolonging the life of the cell considerably (a running 214 movement pulls around 7 uA).

If the system receives a mechanical shock then the vibration amplitude with be momentarily either increased or decreased. If the amplitude is increased, then the fork's velocity will be greater as it passes through the ZDP and consequently the EMF induced in the drive coils will be greater. This in turn means that a weaker impulse current is delivered and a rapid return to steady state is facilitated. Conversely if the disturbance results in an initial decrease in vibration amplitude then the slower velocity of the magnets through ZDP results in a stronger impulse (lower induced EMF in the drive coils and so higher impulse current) and the system again returns rapidly to its steady state condition.

When a new cell is inserted into the watch the capacitor is initially un-charged and looks like a short circuit. This means that there is only the sense coil in series with the base of the transistor to ground. This constitutes a resistance of about 2.25 k Ohm and so an initial base current pulse of about 0.5 mA flows (1.35-0.3/2.25K). This is easily enough to drive the transistor into saturation and send a correspondingly high current pulse through the drive coils. If we assume that only about 0.1v is dropped across the transistor then we can calculate (knowing the resistance of the drive coils is about 16 k Ohm) that the initial drive current is some 63 uA or five times the normal impulse. This gives a sufficient 'kick' to the tuning fork to start the movement. The circuit then rapidly settles into its steady state and the voltage on the base of the transistor rises to an average value of just above the turn on voltage (ie slightly more positive than would be needed to turn on the transistor).

Some voltage and current wave forms for an Accutron running in steady state are shown below. Before going any further it should be pointed out that the capacitor and coil voltage curves are normalized to their respective maxima ie the traces are not to scale . In practice the capacitor voltage swing is much smaller than the trace below would suggest. The difference between charge and dis-charge time constants is also much greater (see later).



The R-C network R0/C0 as well as affording a self start mechanism also adds a further stabilizing function. The discharge time constant is much larger than the charge time constant and so the capacitor voltage adjusts so that the point at which the transistor 'turns on' further compensates any shock induced error. If , for example the fork is deflected to a greater degree than its nominal then the speed through the ZDP is greater and so the EMF induced in the sense coil is larger. This means that the capacitor charges to a higher voltage and so the transistor turns on later in the next cycle and for a shorter period. Thus the system has negative feedback which ensures a rapid return to steady state.

The resonant frequency of a simple tuning fork is given by the equation:

Fo=k(t/l^2)*sqrt(Q/p)

Where k is some constant
t=thickness of tines
l=length of tines
p=density of material
Q=Young's modulus

This formula only holds for simple forks with rectangular cross sections and uniform profiles. The Accutron fork is a very complex re-entrant shape and has massive tine ends. Calculating the value for Fo and assessing energy losses must have proven very difficult without the aid of digital computers. These days we would 'fracture' the fork mathematically and use a finite element type of computation. In an ideal tuning fork (in vacuum) energy is only lost to internal friction as the mounting point is a perfect node ie it doesn't vibrate). In real life however energy is also lost through the mounting (if this was not so then musical tuning forks wouldn't sound when the handle is pressed against a suitable resonator). The calculation of these losses again represents a Herculean task when placed in a 1950s context.

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