01 Apr 1991

Analysis of Two Circuits for Detecting Superconducting Transition Temperatures

Terry Bowness

ANALYSIS OF TWO CIRCUITS FOR DETECTING SUPERCONDUCTING TRANSITION TEMPERATURES

Terry Bowness

Introduction

When measuring the transition temperature of large numbers of high T_c superconducting samples it is desirable to have available equipment that is both easy to operate and reliable. In addition, should anything malfunction, the device should be relatively simple to repair. One method of measurement involves placing a sample in the magnetic field of an inductor, the inductor being an active member of some type of oscillating circuit. There are many standard oscillator designs which can be used for this type of application. In this report two such circuits, the tunnel diode and Hartley oscillators, will be examined and evaluated on their potential as measurement devices for superconductor transition temperatures.

Experiment and Observations

Indirect measurement of transition temperatures is possible via direct measurement of the resonant frequency of some oscillator circuit. Placing any conductor in the time-varying magnetic field of an inductor will create eddy currents in that conductor, thereby decreasing the inductance, L, of the inductor. Consider for example a parallel LC circuit whose resonant frequency is simply

$$w = (L{*}C)^{-.5}.$$

Clearly, a change from $L = L_o$ to $L = .25L_o$ would double the frequency. A superconducting sample occupying space in the magnetic field of an inductor would have little effect on L until the transition temperature is reached, at which point the sample's eddy currents would cause significant change in L and, as a result, w.

The shape of the inductor is important here. A previous experiment utilized a cylindrical coil wound around an insulating tube of 1/8" inner diameter and 1/4" outer diameter. Inside the tube was placed some amount of superconducting powder. Samples generally come as solid discs, so rather than grinding each one up as was done before we opted to wind a flat coil 5/8" in diameter, one layer thick from 28 gauge copper wire.

The Tunnel Diode Oscillator

The first to be examined is the tunnel diode oscillator (TDO). Illustrated in Figure 1, this circuit's resonant frequency is expressed as[1]

$$f := \frac{1}{\left[2\pi (L\,C)^{.5}\right]}\left[1 - \frac{C}{\left[G^2 L\right]}\right]^{.5}$$

After turning up several diodes it was determined that only about 120 mV_{dc} across the diode was needed to produce oscillation. The resulting sinusoidal output ranged from 400 to 500 mV_{pp}. With no sample attached to the coil the circuit specified in Figure 1 resonated at 7.85 MHz.

The TDO falls short in several areas. For one, the diode itself is relatively expensive, several dollars. Given the ease with which one can be inadvertantly fried, the TDO is

FIGURE 1--TUNNEL DIODE OSCILLATOR

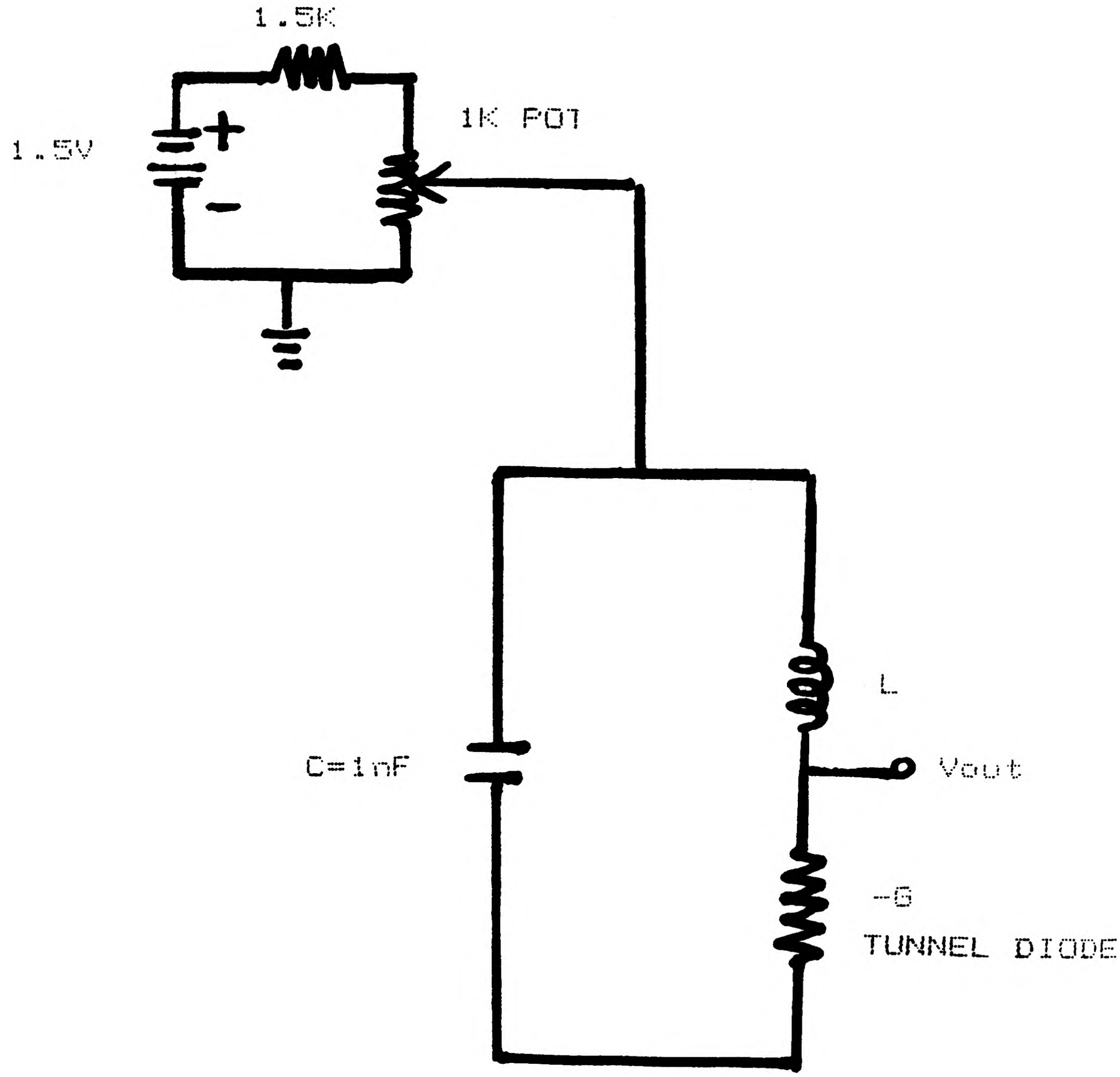
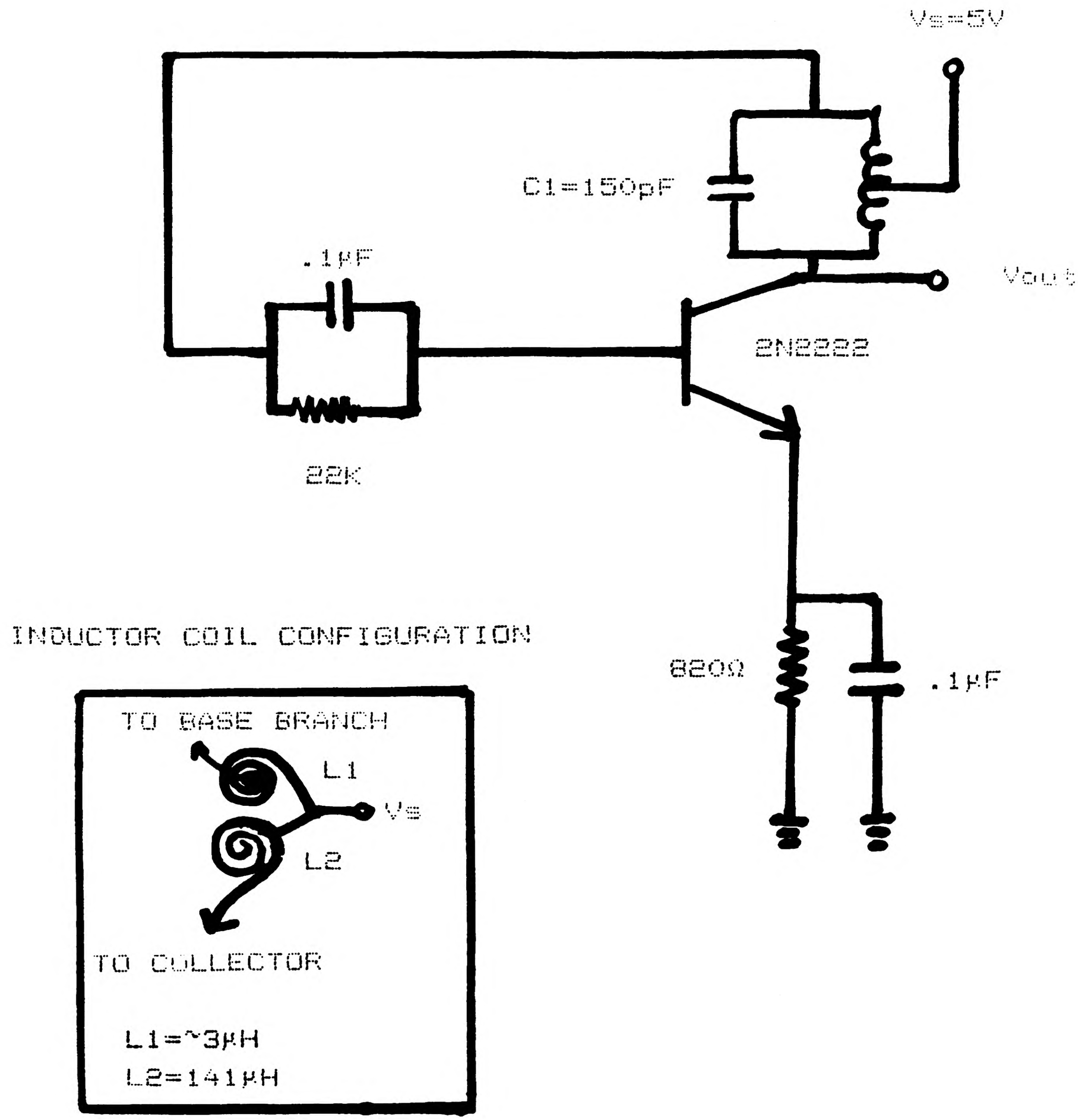


FIGURE 2--HARTLEY OSCILLATOR



unreliable and could quickly become unnecessarily expensive. Furthermore, this circuit was seen to be extremely sensitive to environmental conditions. A region exists from about one to five feet away in which the presence of a human being causes all oscillation to cease. Finally, the output voltage is too small; a voltage follower would be needed to send the signal to a scope or meter with a relatively low input impedance.

The Hartley Oscillator

We turn now to the Hartley oscillator shown in Figure 2. This design is of interest particularly because of its simplicity. One problem present in actually building this circuit arose from the supply voltage being connected to a center-tapped coil. Again, it was important that a flat inductor be used. The arrangement worked by having two of them face-to-face as shown in the Figure 2 insert. Through trial and error it was found that the relative size, position, and winding direction of one to the other is very crucial.

With the component values listed in Figure 2 the output was a healthy 6 V_{pp}. No need for a voltage follower here! Below is a sketch of v_o.

The Hartley oscillator fails in one crucial way: at superconducting temperature the transistor does not operate. For it to work, the transistor must be separated from the rest of the circuit or isolated from the cold in some other way. Despite this obstacle, the Hartley oscillator is exxtremely reliable; it is composed of no special components, and is, unlike the TDO, not extremely susceptible to outside interference.

One noteworthy observation was made as the circuit (sans transistor) was dunked into a cup of liquid nitrogen. The frequency dropped initially but then increased to level off above the original, room-temperature frequency, f^o. Sample data from one particular dunk shows

f_o = 904.5 kHz
liquid nitrogen f_{min} = 886 kHz
liquid nitrogen f_{max} = 967 kHz

This sort of behavior was also observed when a cylindrical coil was substituted for the flat ones.

Conclusions

To build a device for simultaneously measuring the transition temperature(s) of several superconducting samples it would be beneficial to explore the possibilities of oscillators other than the two described in this report. The TDO is easily damaged yet very simple. The Hartley oscillator is quite simple and dependable but hindered by the necessity of having to isolate the transistor. It would be wise to examine designs not employing transistors or special parts such as tunnel diodes.

References

1. "Contactless Transition Temperature Measurements in High T_c Superconductors", Matt Commens.

Much of the information throughout this paper was provided by Dr. D. M. Sparlin.