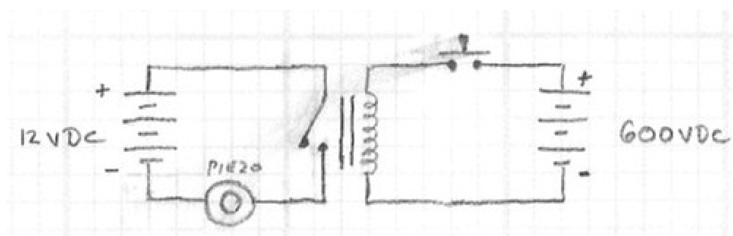
Electronic Radiation Canary
by: aetherwave

This project started in early 1998 after encountering an article posted on the Internet complaining about the high cost of radiation detection equipment. Upon investigating for myself, I had to agree with his conclusion that the radiation detectors were being priced above what the average consumer could afford. Another problem was that most of the radiation detectors that were being offered were designed as tuned survey equipment, requiring frequent and costly recalibration. They were also inconvenient, often requiring both hands to operate and demanding constant visual scanning of indicator lights or dials.

The average person only needs a low-cost early-warning device of rough calibration that could be carried on the belt or in a purse. Similar to the canaries that were carried into coal mines to signal miners about the presence of poisonous gasses, this “canary” would signal the presence of radiation. For example, a firemen could be wearing such a detector. Upon entering a building, if the canary sounded, they would know to immediately exit the building. The fire captain could then dispatch a team equipped with normal radiation survey equipment to determine exactly what was tripping the alarm, and exactly how much radiation was present.

How it works

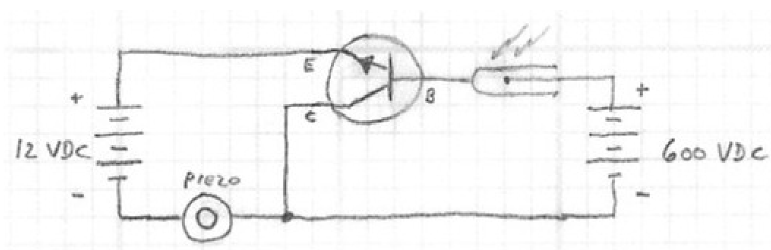
A lot of people have misconceptions about how a radiation alarm works. In its simplest form, a radiation alarm would consist of a normally-open push button switch, a relay, a buzzer, and two batteries (see illustration 1).



1. an electromechanical alarm

Upon being alerted of possible radiation (say for example I was visually monitoring a [Kearney detector](#)) I would push the button (an act which lowers the voltage resistance between the wires enough for current to flow), which causes the relay coil (a high-voltage coil in this example) to energize. The energized coil would close the relays leaf-switch allowing low-voltage electricity to flow through the piezo buzzer (sounding the alarm).

To further refine the system, the electromechanical parts could be replaced with entirely electronic devices. The electromechanical relay we will replace with a NPN transistor (most standard transistors can handle high voltages of low current), and the briefly pressed mechanical push button switch we will automate with a high voltage / low current Geiger – Müller switch (see illustration 2).



2. an electronic radiation alarm

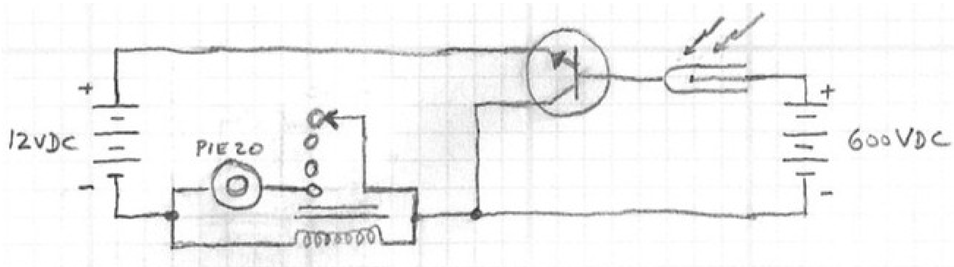
Most persons have had experience with NPN transistors and know how they work. Electricity flowing through the transistor from the “Base” to the “Collector” is functionally equivalent to the energized relay coil closing a leaf-switch... it allows electricity to flow from the “Emitter” to the “Collector” (the fact that the two batteries are no longer physically isolated on separate circuits is irrelevant for our purposes, because their schematic flow-tracing is still functionally separated as battery-GM-transistor-*return* and battery-transistor-piezo-*return*).

Although you may have never seen a Geiger – Müller switch, it is a simple switch consisting of a gas-filled metal container with an isolated wire in its center. The center wire is connected to the “Positive” side of the battery, and the metal casing to the “Negative” side. Similar to the way a solar-cell becomes momentarily conductive when a photon particle passes through it; when a particle of gamma radiation passes through the gas, it opens a momentarily conductive channel that allows electrical current to flow from the center wire to the metal case. Although briefly less resistant than the surrounding gas, the channels resistance is still very high, requiring high pressure (voltage force) to be applied to push electrons through. As the channels resistance increases back to that of the surrounding gas, voltage will no longer be able to push electrons through, and current flow will stop.

Now, whenever a particle of gamma radiation strikes the switch, safe low current 600vdc electricity momentarily flows through the transistor, which allows 12vdc higher current electricity to then flow through the piezo buzzer for the duration, causing the buzzer to “chirp”.

Further refinements

One of the problems with any radiation detection device is that it can be triggered by background radiation coming from both outer space and the earth itself (you can actually see this radiation if you build yourself a Cloud Chamber). It would become pretty annoying if for example while sitting in your home the alarm would chirp, say, once a minute. One way to counter this problem would be to add a step-relay into the circuit (see illustration 3).



3. a desensitized alarm

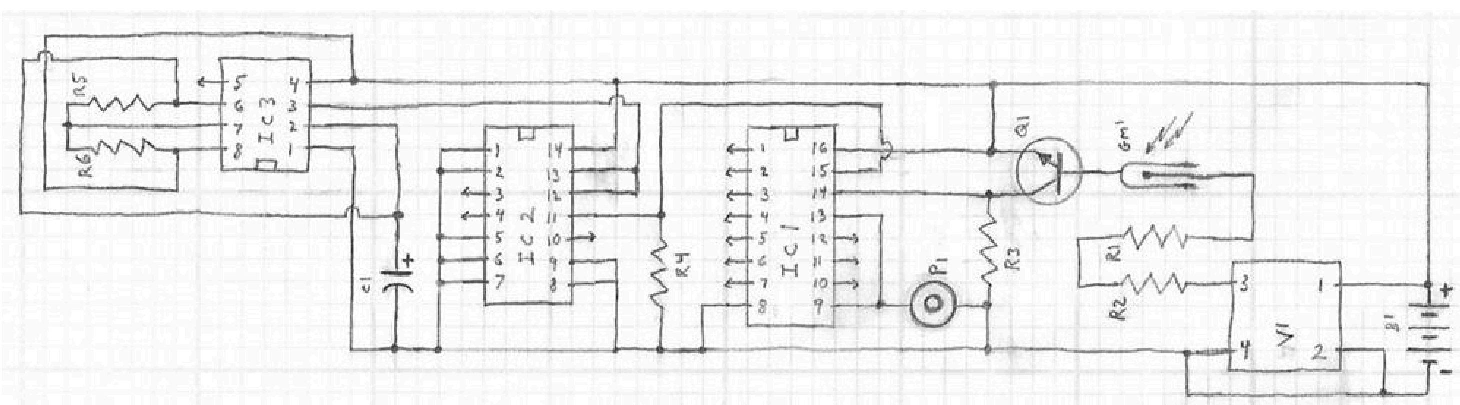
For illustration purposes we are adding a four position continuously-cycling mechanical step-relay. Now let us assume that background radiation was striking the alarm approximately once every minute like before. Instead of electricity always flowing directly through the buzzer, it now also energizes a relay coil, causing the step-relays switch to cycle to the next contact point. Electricity will now flow through the buzzer only when the contact switch is in position four. Therefore the buzzer will only chirp at a more tolerable rate of, in our example, about once every four minutes.

Unfortunately, de-sensitizing the alarm to background radiation also desensitizes it to the so-called dangerous radiation. However the tradeoff is acceptable, as this device is intended to merely be an alarm (like a smoke detector) and not a calibrated survey device. Radiation classified as dangerous is just the same as background radiation; it's just that it is coming at you at a very rapid rate (its the quantity that makes it harmful). Instead of, as in our above example, one particle per minute; the radiation may be coming at you at a rate of, say, one particle every quarter second (often much faster). Even using the step-relay to reduce the alarms sensitivity by one fourth, the alarm would still be chirping at you at the frightening example rate of about once per second.

Fortuitously this very same great separation between the rate of background radiation and the rate of dangerous radiation can be used to make our final refinement. Let's replace the step-relay with one that has a button to reset the contact switch back to position one whenever it is pushed. Now let's assign a person (or better yet add a timer) that will push the reset button once every three minutes. Assuming the previous example rate of background radiation, the contact switch will never get to position four before the timer resets the relay. As such, the example background radiation will never make the alarm chirp. Only in the presence of the more frequently arriving "dangerous" radiation will the alarm sound, because this radiation will advance the relays contact switches many times between each of the timers slow resets of the relay.

My canary circuit

Illustration 4 shows the final schematic diagram for the electronic radiation canary. To keep costs down, all but two parts (the 50x isolated LV-DC to HV-DC converter, and gamma detector) are standard (1998 catalog) Radio Shack components (including wire, case, etc.). For continuous home use, the small battery could be swapped with a higher capacity battery (or with a common AC to DC "wall wart" house electricity converter).



4. radiation canary schematic

When built, all the electronic components will fit inside a small project box about the size of a VHS camcorder battery. Total price for the project is around 100 dollars (approximately $40 for the GM switch, $50 for the isolated DC to HV DC converter, and $10 for the other components [1998 US Dollar prices]).

= Transistor high-voltage side =

Let's begin our examination of the canary schematic at the 12vdc battery [B1] on the far right side. Originally I wanted the unit to operate 24/7, and I initially chose a common #23 alkaline battery due to its size (this battery is often used in wireless doorbells buttons, garage door remotes, and older car alarm remotes). Unfortunately, like a flashlight left on for a long period, the active circuit (mostly the IC chips) drained this small battery below operating voltage in less than four days. This somewhat negated its usefulness as an always-on belt device that I wanted to change the battery in only once a month (I was however being somewhat overly optimistic, as even hearing aid batteries which operate 24/7 only last about a week). However, the canary will easily operate for months when attached to a large capacity (and unfortunately physically larger) battery such as the sealed lead acid batteries used in uninterruptable power supplies (or virtually indefinitely when run from an AC power line to 12 volt DC adapter).

The circuit also requires a 600vdc battery to power the Geiger – Müller (GM) switch. As batteries of that voltage are quite costly, I took a different approach and replaced the battery with a 50x isolated DC to HV DC converter [V1]. This electronic module acts like a DC transformer, converting 12vdc into low current 600vdc. The module [V1] I used was a bulky commercially manufactured EMCO GP06, which I happened to already own. There is however no requirement to use a commercially manufactured DC-DC converter, and at least two DIY circuits, a basic and a low ripple design, have been posted on the Internet. For convenience I have included two other substitutable converter schematics in the Appendix.

On the EMCO GP06 [V1] the positive side of the battery [B1] is connected to pin 1, and the negative side to pin 2 (note that "common" pins 2 and 4 have been externally tied together to form a common bus). The positive high-voltage output pin 3 is routed through a 4.4meg ohm Series limiting resistor (the schematic shows two 2.2meg ohm resistors [R1 & R2] connected in Series [Radio Shack 271-8051], because Radio Shack does not normally stock single 4.4meg ohm resistors). Note that resistors [R1 & R2] are used in a corresponding way as a pressure regulator on household piping, to ensure the proper functioning of [GM1] (*so for high-voltage schematic flow-tracing R1 & R2 can be considered as just a wire*).

The high-voltage electricity flows through [R1 & R2] to the center wire of a GM switch [GM1], where it waits until a particle of radiation strikes the GM switch. The GM switch I chose was a LND 714. This particular detectors advantage is that it will activate with mild radiation, yet it will not saturate (stick in the "on" position) in strong radiation environments (saturation issues are the primary reason why special "Civil Defense" meters, rather than normal "survey" meters, should be used around nuclear fallout).

Whenever gamma radiation strikes the GM switch [GM1], high-voltage electricity (approximately 600v low current in this example) will pass through the GM switch from the center wire to the casing. The flow will only last briefly before the switch returns to its normally off position (thus the switch acts like a momentarily pushed button).

Flow travels from the casing of the switch to the Base of a NPN transistor [Q1]. The high-voltage will then pass through [Q1] to the Collector. The transistor I used was a silicon 2N4401 [Radio Shack 276-2058]. While the high-voltage current is low, it is sufficient to cause [Q1] to allow any higher current low-voltage waiting on the Emitter to also flow to the Collector (essentially acting like a switch controller).

From the Collector of [Q1], the high-voltage electricity flows to the positive side of a [Radio Shack 271-1335] 10K ohm resistor [R3], which acts as a suitable load to prevent both high- and low-voltage path short circuits. The high-voltage electricity flows out of the negative side of this resistor to pin 4 (the negative high-voltage return) of the DC to HV DC converter [V1], thus completing the high-voltage circuit (note that to prevent ground float, [V1] "common" pins 4 and 2 are externally tied together, as well as connected to the negative side of battery [B1]).

= Transistor low-voltage side =

The same 12vdc battery [B1] that was used to create the high-voltage on [Q1] is also used for the low-voltage. The positive side of the battery is directly connected to the Emitter of NPN transistor [Q1], where it waits. Whenever high-voltage electricity flows through the transistor from Base to Collector, the 12vdc low-voltage will also be allowed to flow through the transistor from the Emitter to the Collector.

From the Collector of [Q1], the 12vdc low-voltage will try to flow back to the negative side of [B1] to complete the circuit. Normally the electricity will flow through the positive to negative side of the 10K ohm load Series resistor [R3] located between [Q1] and [B1]. However, the counter/divider chip [IC1] may open a second Parallel lower resistance path (compared to the resistance of [R3]) which leads from the positive side of resistor [R3] to pin 14 of the counter/divider [IC1] (where it will pass unaffected through the chip to exit on pin 9), then passes through a Piezo Buzzer attached in Series between pin 9 of [IC1] and the negative side of resistor [R3]. Note that some of the high-voltage electricity will also flow through this less resistant Parallel path, but its current level is insufficient for the chip or buzzer to notice. The resistance of [R3] is high enough that sufficient 12vdc current will have been routed to activate the buzzer, causing it to sound for the duration of the brief 12vdc electrical flow.

[IC1] is electronically fulfilling the role of a desensitizing resettable continuously-cycling mechanical step-relay (see illustration 3). For [IC1] I chose the continuously-cycling ten position 4017 decade counter/divider [Radio Shack 276-2417]. The IC chip receives its power from the battery [B1] by connecting pin 16 to the 12vdc positive and pin 8 to the 12vdc negative. Note that upon chip power-down the cycle sequence will reset back to the First position. [Q1] placing a positive voltage potential on pin 14 of [IC1] performs a similar function as the transistor in illustration 3 does when it allows electricity to flow through the coil in the mechanical step-relay... it advances the circuit to the next pinout. In the same manner, further advance does not occur again until the positive voltage potential is removed and then reapplied.

The piezo buzzer [P1] I chose is a standard 12vdc low resistance type [Radio Shack 273-059]. As in illustration 3, the buzzer will only be able to sound while a relay switch connection is made and current is flowing through it. On [IC1] the ten pins 1-7 & 9-11 are functionally equivalent to the pins of a ten contact mechanical step-relay switch. I am using pin 9, which coincidentally is the ninth output position. Therefore after power-up, [GM1] will have to pulse eight times before [P1] will sound. The chip will then have to cycle ten more times before the piezo buzzer can sound again. Note that pin 13 has been tied to pin 9 in order prevent [IC1] from accidently cycling away from its current position for the full time that current is flowing through [P1].

The canary circuit just described functions equivalently to the circuit described in illustration 3. After several gamma ray detections the piezo buzzer will chirp, indicating that some radiation has been detected by [GM1]. If a long delay occurs between chirps, it is probably only background radiation that is being detected.

By tying [IC1] pin 9 to pin 13, we created a situation where if the gamma rays are coming very fast (applying positive voltage to pin 13 causes all pulses to pin 14 to be ignored), the piezo buzzer will make a continuous sound until the GM detector has been moved to a place of lower gamma ray count (or the unit is turned off). Conversely, the circuit as described also has no way to completely ignore background radiation.

The timer circuit:

Not drawn in illustration 3 but mentioned in the text, was having the operator (or a timing circuit) push a reset button occasionally to return the relay cycle back to its start position. This would be done in order to clear any buildup of background radiation detections that have advanced the relay cycle forward. In illustration 4 I have included an electronic timing circuit that performs this reset function automatically, by regularly applying a positive voltage to [IC1] pin 15. Increasing the number of pulses per clock time interval to pin 15 will proportionately Decrease the canaries sensitivity (and visa-versa).

The balancing act lies in having enough default cycles occur before the piezo buzzer sounds (eight cycles in my circuit) and having enough resets occur before that final cycle number is reached (so that the canary will almost never “squawk” at all unless in the presence of significant radiation levels). Tests were made to determine the approximate rate of background radiation striking the detector. This included cosmic rays and natural earth rock radiation. Based on these tests I determined the maximum amount of radiation particles per minute expected to be detected by the GM switch from background radiation, added a slight buffer, and set the timer rate accordingly. Tests in the proximity of a dentists X-ray verified that the chosen timer reset rate was not too fast as to squelch legitimate radiation detection.

Should the canaries alarm sound, it will only do so for a short time before the timer resets [IC1] and turns off [P1]. If you have moved the detector (and hopefully yourself) far enough away from the triggering radiation source, the alarm should not sound again. If however the detector is still within close proximity to a radiation source, the alarm will again sound (the GM switch [GM1] will have pulsed enough times to sound the buzzer before the timer can again reset [IC1]), and the process will repeat all over again.

= timer wiring =

[IC3] is the timer. I chose a TLC555 timer [Radio Shack 276-1718]. To power the chip, a 12vdc positive from the battery [B1] is applied to pin 8 and a 12vdc negative is applied to pin 1. The values of external resistor [R5], external resistor [R6], and external electrolytic capacitor [C1] determine the timers pulse rate. For my purposes, I chose a 10K ohm resister for [R5], a 220K ohm resistor for [R6] [Radio Shack 271-1350], and a 47uf condenser for [C1] [Radio Shack 272-1015].

[IC3] pins 6 and 2 are tied together. [IC3] pins 8 and 4 are tied together. One side of resistor [R6] is attached to [IC3] pin 8, with the opposite side attached to [IC3] pin 7. One side of resistor [R5] is attached to [IC3] pin 7, with the opposite side attached to [IC3] pin 6. The positive side of electrolytic capacitor [C1] is attached to [IC3] pin 6, with the opposite side attached to the negative side of the battery [B1].

The output from the timer is a signal pulse that leaves on [IC3] pin 3. Please note that the output from this timer is a signal pulse that is mostly “on” (sending a 12vdc positive signal) and briefly “off”. This is the exact opposite of the kind of pulse desired to be injected onto pin 15 of [IC1] (whenever a positive 12vdc is being applied to pin 15 a reset is occurring). In order to achieve the opposite effect (a signal mostly “off” and only briefly “on”), I had to add a NAND logic gate [IC2] between [IC3] and [IC1] in order to reverse the signal. Although a single NAND gate was all I needed, the smallest chip available from Radio Shack is a 4011 Quad NAND gate (four gates on one chip) [Radio Shack 276-2411], which I had to end up using.

To power [IC2], a 12vdc positive is applied to pin 14, and a 12vdc negative is applied to pin 7. I chose to use the gate located on pins 11-13. Pins 1-2, 5-6, and 8-9 I connected to the negative side of the battery [B1] so as to disable the other three NAND gates. Normally a 12vdc positive continuously flows out of pin 11. If however a 12vdc positive is externally applied to Both pins 12 and 13, the electricity output from pin 11 will stop.

The [IC3] signal output pin3 is connected to both input pins 12 and 13 of [IC2]. [IC2] output pin 11 is connected directly to the [IC1] reset input pin 15. Since under idle conditions the [IC3] pin 3 is continuously outputting positive voltage, no voltage will be outputting from [IC2] pin 11 during this time. When at time expiration the output from [IC3] pin 3 ceases momentarily, [IC2] will be able to momentarily send a positive 12vdc to [IC1] input pin 15, resetting the [IC3] advancement cycle. Once [IC3] again outputs a positive voltage from pin 3, [IC1] reset will cease, and the chip will again be able to advance its cycle.

One side of a 10K ohm resistor [R4] is connected to [IC1] pin 15, with the other side connected to the negative side of the battery [B1]. This resister acts as a drain, removing any residual positive 12vdc that may remain on [IC1] input pin 15 after [IC2] output pin 11 ceases outputting positive 12vdc.

Appendix

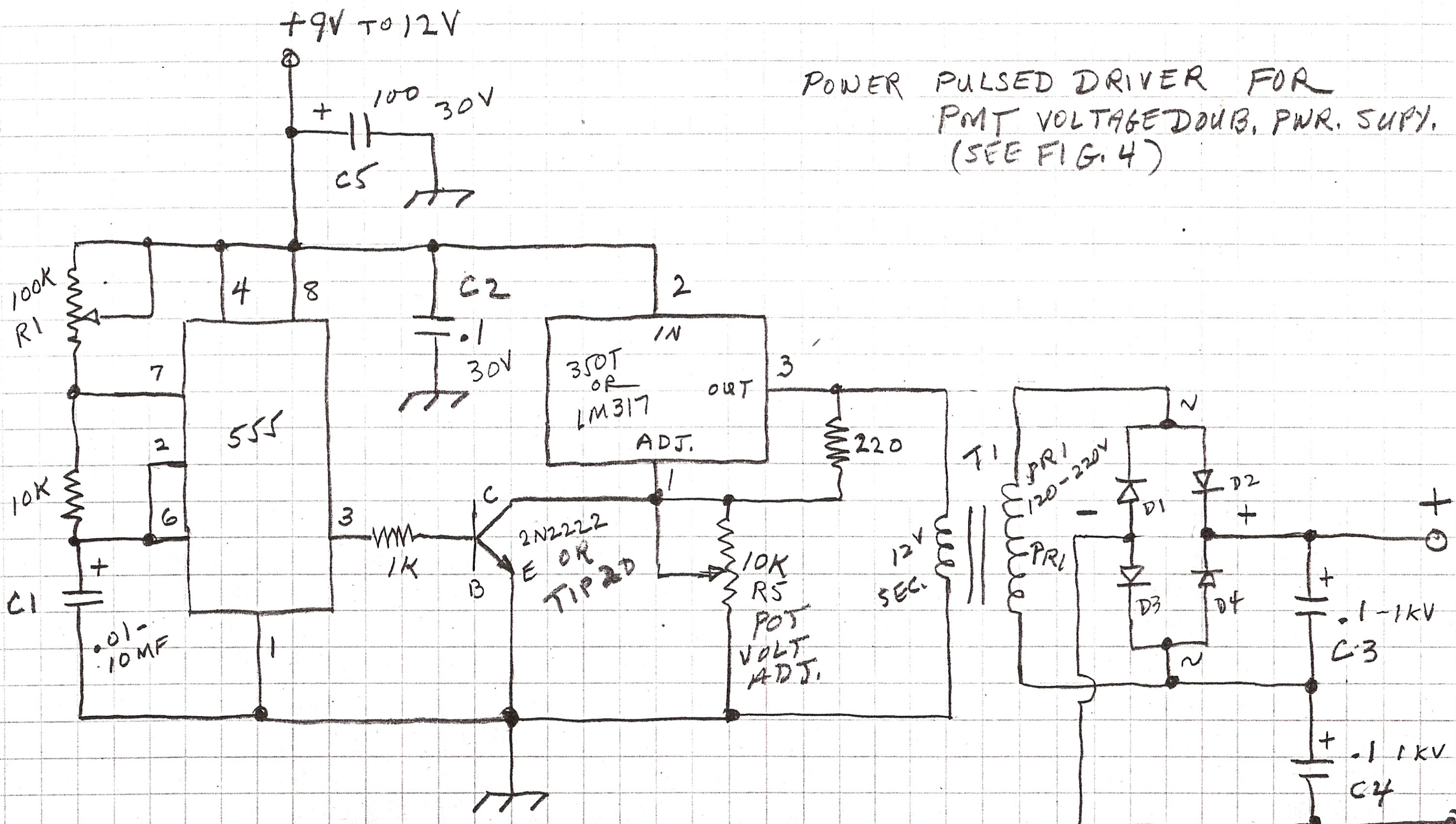
Like its namesake, I believe the Electronic Radiation Canary to be an effective early warning device (of a grade similar to household smoke alarms) for persons concerned about the possibility of encountering an unanticipated radioactive environment. Outside a laboratory it is difficult to find sources of radiation to test with. However, the device proved "good enough" at detection when placed in the close proximity of a radioactive mineral sample, and when placed in the presence of an operating X-ray machine.

Lowest cost was the primary criteria for the choice of components (Caution: To reduce premature failures, make sure you use components rated for High Voltages!). A further developed Canary circuit (including incorporating an on/off switch and such) makes a good Science Fair project.

Late News: Radio Shack has discontinued the majority of its parts line. Therefore some of the part numbers listed here are now invalid. Feel free to substitute equivalent parts from other vendors.

FIG. 5

POWER PULSED DRIVER FOR
PMT VOLTAGE DOUB. PWR. SUPY.
(SEE FIG. 4)



R1 CONTROLS RATE
R5 " AMPLITUDE = VOLTAGE ADJUST FOR
OUT PUT 10 TO 1000+ VOLTS

D1 TO D4 = 1A/1KV SI RECTY.

T1 = FILAMENT XFMR. 6 OR 12 V. SEC, } XFMR. CONECTS IN
120 OR 230V PRI. } REVERSE.

JAN. '05

TO OPERATE:

1. - SET R1 TO CREATE STABLE PULSE (CAN BE A SMALL 10 TURN POTENTIOMETER, NEEDS ONLY 1 TIME ADJ.

2. - R5 SETS OUTPUT VOLTAGE FROM APPROX. 10 TO 1000 V.

3. - C1 CAPACITY ANY THING FROM .1 TO 10 MFD. THE HIGHER THE VALUE - SLOWER THE PULSE RATE.

4. - C3 + C4 CAN BE CERAMIC - PAPER - OR MICA USED AS HI VOLT FILTERS. .1 TO .2 MFD. IS ADEQUATE, BUT SHOULD BE 1 KV OR MORE.

5. T1 IS SMALL FILAMENT XFMR 0.4 A. TO 1.0 A. OK.

e. An Inexpensive P.E.P. High Voltage Power Supply (Written by J. L. Hopkins). For those people who like to build their own electronics, the inexpensive and easily constructed P.E.P. high voltage power supply shown in Fig. 5-2 might be considered. If the unit is battery powered and without meter or case, the cost for parts can be under $20.

The objective of this design is to provide an adjustable, regulated power supply capable of battery operation (12 VDC - 18 VDC) and producing 0 to -1000 VDC at 1 mA with an input current of less than 300 mA.

1. The regulator: An LM317MP three-terminal adjustable voltage regulator ($1.95) is used to provide regulated and adjustable D.C. voltage from +1.2 VDC to +16 VDC at up to 500 mA. A 12-position wafer switch ($1.20) provides a means of selecting up to 12 different voltages. A 1K ohm 10-turn potentiometer could be used but is more expensive.

2. The oscillator: A CA555 timer (59¢) is used to provide an approximate square wave whose amplitude is proportional to the output of the regulator. The frequency of the oscillator is determined by two resistors and a capacitor. For this design the frequency is approximately 30 kHz.

3. The driver: Almost any transistor capable of 500 mA collector current can be used. In this design an NPN type 2N3866 ($2.00) is used.

4. The transformer: The use of a pot core transformer ($6.00) greatly facilitates easy construction. Four turns of #26 enamel-coated wire are wound on the spindle first. A layer of mylar tape is then applied. After each layer a layer of mylar tape should be used. Next, 400 to 450 turns of #36 enamel-coated wire is wound with a layer of mylar tape separating each of the (approximately 5) layers. The core used in this design is a 2616+PL00-3C8.

5. The output section: Four 1N4007 diode rectifiers (50¢/4) rated at 1000 V and 1 Amp. are used as a bridge rectifier. A 0.25 μF capacitor is used to filter the output. It is made by connecting 4 1.0 - μF capacitors in series. The 1.0 μF capacitors are rated at 250 V so, by connecting them in series, it gives a 0.25 μF 1000 V capacitor ($3.20/4). A 1-megohm 2-watt resistor provides a 1 mA load and, if desired, provides scaling for 0-1000 VDC by inserting a 0 to 1 mA meter.

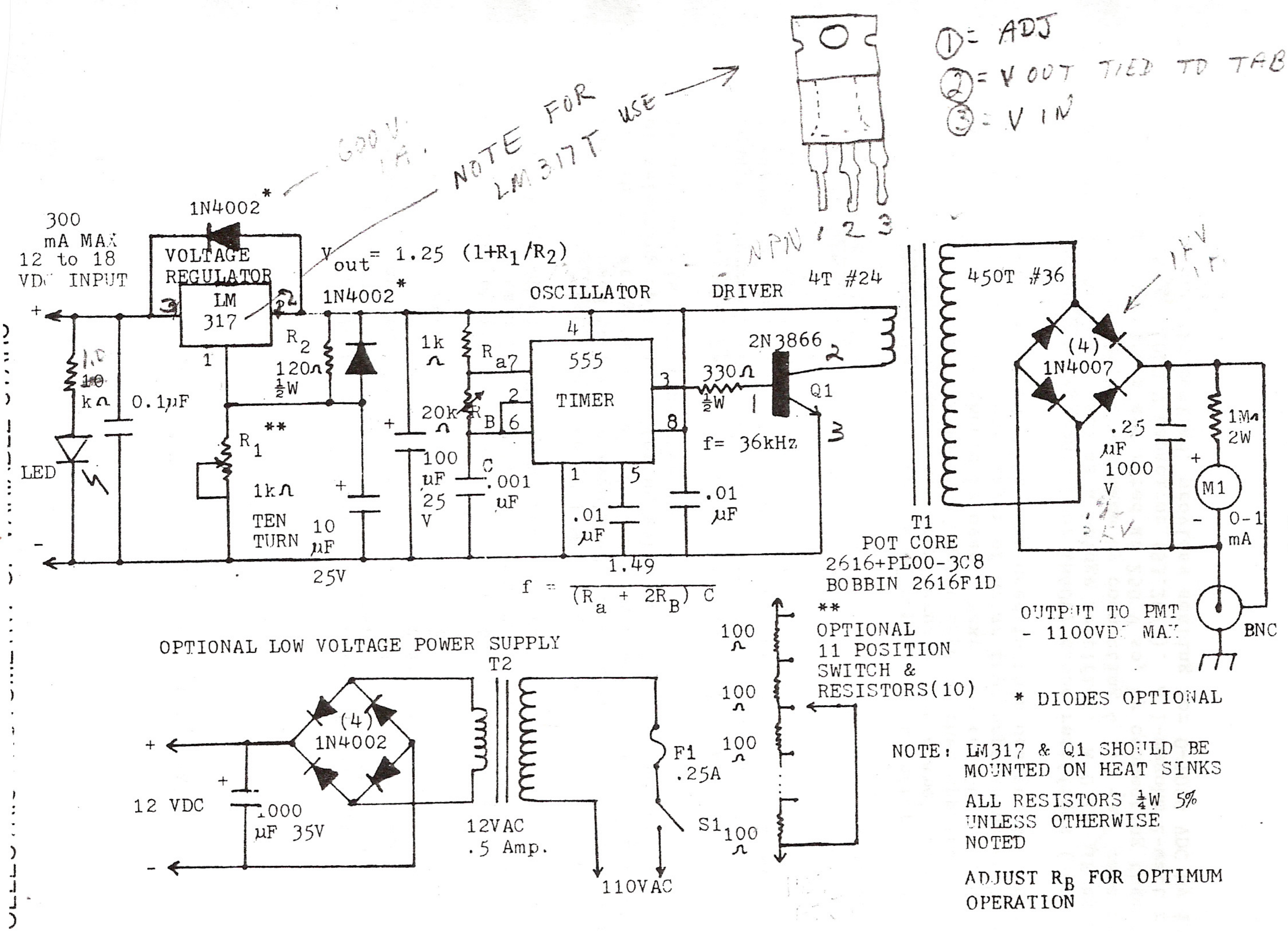


Fig. 5-2. Low cost pot core HVPS for PEP PMT.