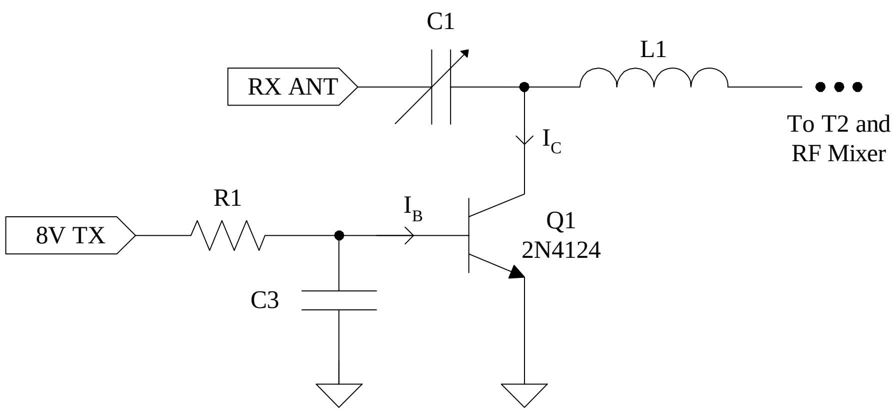
Lecture 17: Transistor Switches. Voltage Regulators.

Of the four regions for transistor operation discussed in the last lecture, only cutoff and saturation play important roles when the transistor is used as a switch.

In the NorCal 40A, Q1 is used as an *npn* transistor switch in the Receiver (RX) Switch circuit.



The operation of the RX Switch can be summarized in two steps:

1. When the key is "up," the transmitter is off so 8V TX = 0. Consequently, I_B = 0 and Q1 is "off," i.e., in the cutoff mode where I_C = 0. Current through C1 continues to L1 since the switch Q1 is "off."
2. When the key is "down," the transmitter is on so 8V TX ≈ 8 V. In this state, we want Q1 to be completely saturated so the resistance seen from collector to emitter $\equiv R_s \approx 0$.

This state is achieved when I_B and I_C are large enough to not only forward bias the EBJ, but also the CBJ. This is called saturation.

When saturated, $R_s \approx 2\ \Omega$ for the 2N4124 used in the RX Switch. Furthermore,

$$X_{\text{C1}} = \left.\frac{1}{\omega C1}\right|_{\text{rf}} \approx 650\ \Omega \approx X_{\text{L1}}$$

Consequently, R_s is very small wrt X_{C1} and X_{L1}. Therefore, Q1 operates as an effective short to ground. (This is necessary to keep the transmitted signal from entering the receiver circuit when the NorCal 40A is transmitting.)

The actual value of the saturation resistance R_s is highly dependent on I_B. See Fig. 8.6 of the text for measured values from the 2N4124.

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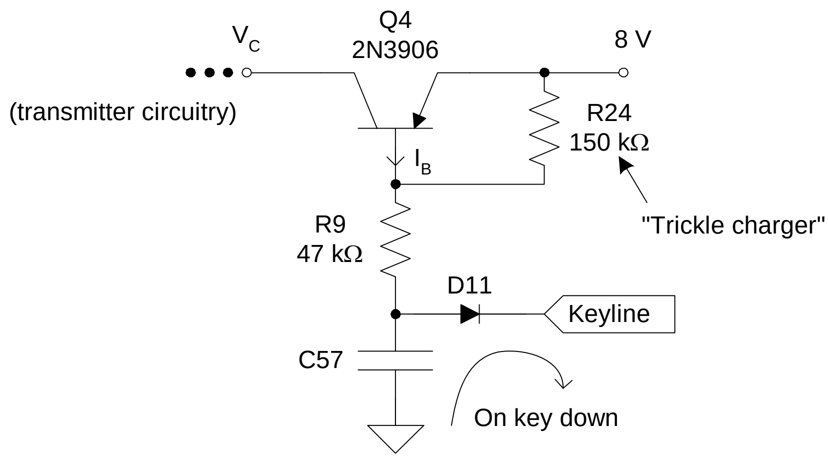
pnp Transistor Switches

The *npn* transistor makes a good short-to-ground switch. The *pnp* BJT is also used as a transistor switch, but often to connect a voltage source to a load.

In the NorCal 40A, an example of this type of switch is the Transmitter (TX) Switch:



The operation of the TX Switch can be summarized in two steps:

1. With the key up, Keyline is open circuited and C57 is fully charged to 8 V through R24. Hence, $I_B = 0$ and Q4 is cutoff. Therefore, $V_C = 0$ and the transmitter circuitry is not energized.
2. With the key down, Keyline is short circuited to ground and C57 discharges through D11 (down to the forward bias voltage of D11). Current flows in R9 and I_B.

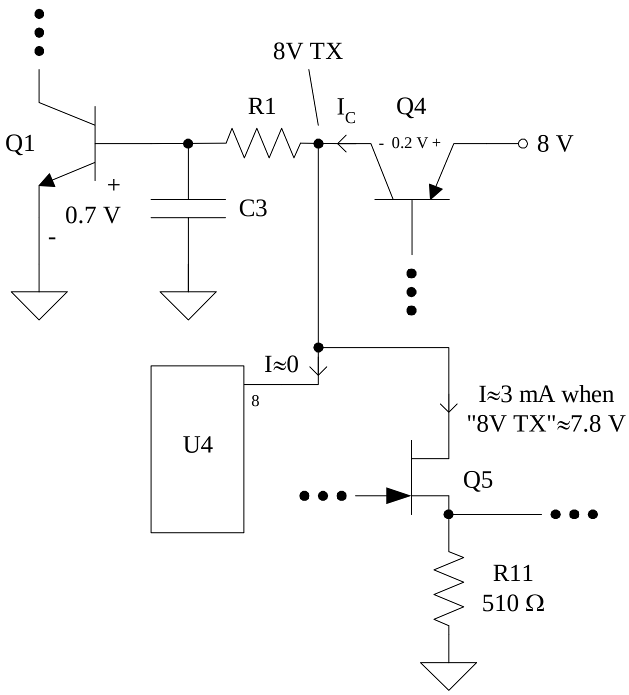
   We design this circuit so that I_B is large enough to saturate Q4. Then, with $V_{EC}\big|_{\text{sat}} \approx 0.2$ V, $V_C \approx 7.8$ V and the transmitter circuitry is energized.

   In this state (key down), we have successfully connected a voltage source to a load.

Design of the Transmitter Switch

Our task now is to design the Transmitter Switch circuit to completely saturate Q4 when the key is down. To do this, use Fig. 14 of the 2N3906 datasheet (p. 377). This figure shows V_{CE} *vs*. I_B for families of I_C.

First, let's estimate I_C when Q4 is saturated:



From this circuit, $I_C = I_{Q1} + I_{Q5} \approx \dfrac{7.8 - 0.7}{\text{R1}} + \underbrace{3\text{ mA}}_{\text{Prob.\#23}} = 6.9\text{ mA}$

In Fig. 14 of the datasheet you'll find an I_C = 10 mA curve. In our circuit, I_C will be no larger than this. Hence, from this I_C = 10 mA curve:

$$V_{EC} = 0.2 \text{ V with } I_B \approx 140 \ \mu\text{A}.$$

Consequently, we need to design the TX Switch circuit so that at key down, $I_B \geq 140 \ \mu\text{A}$.

Note that for this I_B and with I_C < 10 mA (say 7 mA as we have estimated), then Q4 is driven "deeper" into saturation. So we have a built-in safety factor using the I_C = 10 mA curve in the data sheet.

When Q4 is saturated, $I_C \not\approx \beta I_B$. Rather,

$$\beta_{\text{forced}} = \frac{I_C}{I_B} < \beta_{\min}$$

$\beta_{\min}$ is specified in transistor data sheets. This is one way to test if a transistor is saturated.

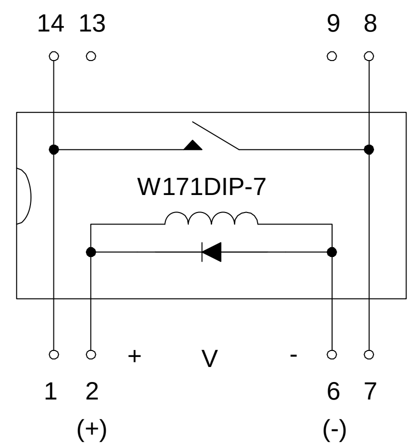
You'll complete this design and measure the results in Prob. 20.

Keying Relay

In order to make time constant and other measurements in Probs. 20, 25, and 30, you'll need to turn the key on and off relatively quickly and repeatedly.

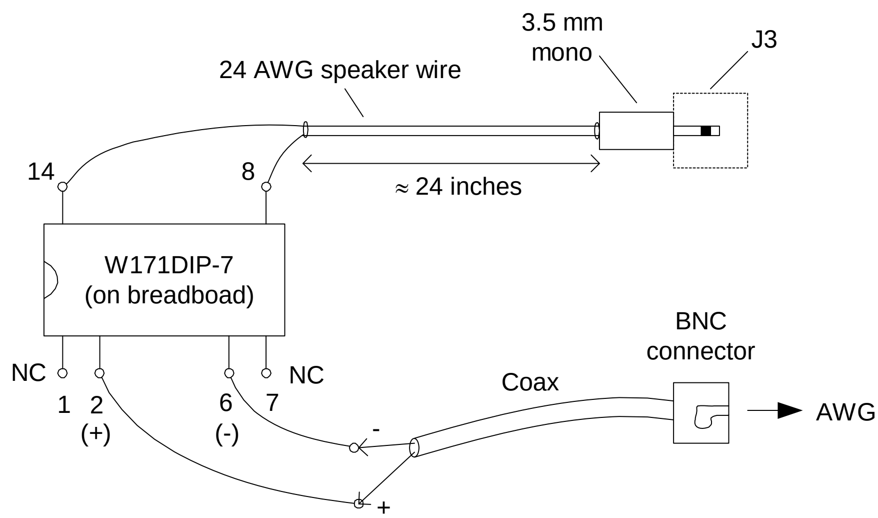
In these problems, you will use an electromechanical relay since turning the key on and off by hand will not be practical.

The relay you'll use is the W171DIP-7, which is DIP package like an IC. Very cool.



With *V* "high," the relay closes. The diode serves as a snubber diode, as we saw earlier in Lecture 4.

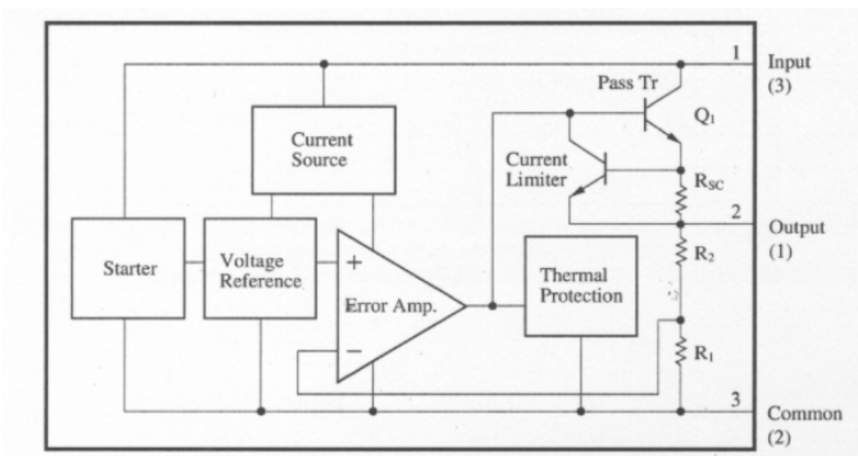
Here are connections you can use to J3 from the AWG in Prob. 20.



Voltage Regulators

Also in Prob. 20, you will install U5, which is a 78L08 voltage regulator. You don't need to know much about voltage regulators in the assembly and test of your NorCal 40A. However, we will quickly summarize this IC to provide relevant background material.

The 78Lxx series of ICs are three terminal devices that provide fixed dc output voltages, typically with currents no greater than 100 mA. Available voltages include 4, 5, 6, 7, 8, 9, 10, 12, 15, 18, 20, and 24 Vdc (among others!).



In the NorCal 40A, you are using a 78L08 which provides 8 Vdc. This voltage is used by all of your receiver and much of the transmitter circuit, except for the Driver and Power Amplifiers.

The datasheet for the AN78Lxx series (Panasonic) of voltage regulators is found on the EE 322 web page, while Appendix D of your text includes the datasheet for the MC78Lxx series (Motorola).

These voltage regulator ICs must supply a constant (or nearly constant) output voltage as:

1. the input voltage changes. This is called line regulation.
2. the load connected to the regulator changes. This is called load regulation.
3. the temperature changes (these devices generally heat up).

Here the relevant specifications for the AN78L08:

• AN78L08, AN78L08M (8V type)

Parameter	Symbol	Conditions	Min	Typ	Max	Unit
Output voltage	V_O	$T_j = 25°C$	7.7	8	8.3	V
Output voltage tolerance	V_O	$V_I = 10.5$ to 23V, $I_O = 1$ to 70mA	7.6	—	8.4	V
Line regulation	REG_{IN}	$V_I = 10.5$ to 23V, $T_j = 25°C$	—	80	175	mV
		$V_I = 11$ to 23V, $T_j = 25°C$	—	70	125	mV
Load regulation	REG_L	$I_O = 1$ to 100mA, $T_j = 25°C$	—	15	80	mV
		$I_O = 1$ to 40mA, $T_j = 25°C$	—	7	40	mV
Bias current	I_{Bias}	$T_j = 25°C$	—	2	3	mA
Bias current fluctuation to input	$\Delta I_{Bias(IN)}$	$V_I = 11$ to 23V, $T_j = 25°C$	—	—	1	mA
Bias current fluctuation to load	$\Delta I_{Bias(L)}$	$I_O = 1$ to 40mA, $T_j = 25°C$	—	—	0.1	mA
Output noise voltage	V_{no}	f = 10Hz to 100kHz	—	60	—	μV
Ripple rejection ratio	RR	$V_I = 11$ to 21V, $I_O = 40$mA, f = 120Hz	44	54	—	dB
Minimum input/output voltage difference	$V_{DIF(min)}$	$T_j = 25°C$	—	1.7	—	V
Output short-circuit current	$I_{O(Short)}$	$T_j = 25°C$, $V_I = 35V$	—	140	—	mA
Output voltage temperature coefficient	$\Delta V_O/T_a$	$I_O = 5$mA, $T_j = 0$ to 125°C	—	−0.8	—	mV/°C

Note 1) The specified condition $T_j = 25°C$ means that the test should be carried out within so short a test time (within 10ms) that the characteristic value drift due to the chip junction temperature rise can be ignored.

Note 2) Unless otherwise specified, $V_I = 14V$, $I_O = 40mA$, $C_I = 0.33\mu F$, $C_O = 0.1\mu F$, $T_j = 0$ to 125°C (AN78L08) and $T_j = 0$ to 100°C (AN78L08M)

In the NorCal 40A, the function of the 78L08 is to provide 8 Vdc from a source voltage ranging from 10-15 Vdc. Consequently, the line regulation specification is not too important here since we're converting from dc to dc.