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**STUDENT HANDOUT**

**SOLID STATE SCHEMATICS**

1. **Terminal Learning Objective:** Given a schematic, a faulty generator set electrical system, and applicable tools and test equipment, with the aid of references, repair the generator set electrical system so that it functions properly in accordance with the appropriate equipment technical manual. (1142.1.2)

2. **Enabling Learning Objective:** Given a schematic diagram of a circuit and a list of circuit operating characteristics, identify the characteristics that apply to the circuit, in accordance with TM 00038G-35. (1142.01.03bb)

**OUTLINE:**

1. **Steps Of Reading Schematics:**

a. The first step in reading a solid state schematic is to identify all the components of the circuit, and identify any component that you don't know how it works. As you look at circuit one in your handout, you will find that there are resistors, capacitors and transistors.

b. You have learned about all of these components, so you can now look to see if there are any configurations that you have not learned about. As you will see, Q2 and Q3 are directly coupled unlike transistors, Q3, and Q4 form a differential amplifier and Q2 and Q5 are directly coupled unlike transistors.

c. Now that you have identified and understand all components of the circuit, you are ready to look at the actual purpose of the circuit, which in this case is to energize the K3 relay to open the start circuit once the generator is running above 750 RPM.

2. **Color Coding Schematics:**

a. To help keep track of the many different potentials you will be dealing with, you are going to color code the schematics, with each potential a different color.

b. To keep track of the colors you will have to make some sort of a legend on the diagram. To do this, make a small box of the color to be used and write beside it what potential the color is to represent.

c. Start with the negative input and use the BLACK. Start the color at pin 1 where it says "-VDC" and follow that line all the way up to the emitter of Q5, branching off and going to the bottom of R21, R20, R19, and the bottom plate of C3.

d. Color the positive input using the RED. Start at pin 4 where it says "+28VDC" and follow the line up and around to the top of R2, branching off to the top of R7, R8, and Q2.

e. For the output, use ORANGE. Start at pin 8 where it says "To starter cutout relay K3" and follow that line down to the collector of Q5.

3. **Circuit Operation:**

a. To learn the operation of an unknown circuit it is always best to start at the output and work back to the input, identifying what must happen to get the desired result. Color code where the potential that caused this happening is felt. This may sound confusing for now but as you go along you will see what is happening, so let's get started.

b. Looking at the schematic, what must happen for the potential to flow to K3? Q5 must come on, so write "ON" between the emitter and the collector of Q5. Since Q5 is an NPN transistor, you know that a positive potential is needed on the base, so put a "+" at the base of Q5.

c. Next ask, what has to happen to give a positive potential on the base of Q5? There has to be a voltage drop across R21 with positive on the top. This positive potential will be felt on the base of Q5 to turn it on. With a BLUE colored pencil, in the legend put "Bias potential for Q5". Take this color starting at the top of R21 and trace to the bottom of R10 and across to the base of Q5.

d. Since you know that to have a voltage drop you must have current flow, ask what must happen to get current flow through R21? To get current flow from negative to positive through R21, Q2 must be turned on. You know that Q2 has to be on when Q5 is on because they are directly coupled unlike transistors. Since Q2 has to be on, write "ON" between the emitter and collector. Put "-" on the base since this is a PNP and takes a negative potential to turn it on.

e. How do you get a negative potential on the base of Q2? To get a negative potential on the base of Q2 there must be a voltage drop across R2, with positive on top and negative on the bottom which is being felt on the base of Q2. Take the color YELLOW and call it bias potential for Q2. Mark this color from the bottom of R2 to the top of R6, and then across to the base of Q2.

f. We are now back to the question of what caused the voltage drop? As before, to have a voltage drop there must be current flow from negative to positive through R2. To get this current flow, Q3 must be on. If Q2 is on, Q3 will be on because they are directly

coupled unlike transistors. Write "ON" between the collector and emitter of Q3, and since it is an "NPN" transistor, put a "+" on the base as Q3 needs a positive potential on the base to turn it on. Also note that Q3 and Q4 form a differential amplifier. When Q3 is turned on, Q4 is turned off, write "OFF" between the collector and emitter of Q4.

g. Now that you know that Q3 must be on and that it requires a positive potential, ask how to get a positive potential on the base of Q3? As you look at the schematic, you see that the capacitor C3 has it's positive plate connected to the base of Q3. Once the positive potential on this plate, which is also felt on the base of Q3, becomes positive enough, it will forward bias Q3's emitter-base junction and turn it on. Take the color PURPLE and color from the top plate of C3 to the base of Q3 and to the right hand side of R11.

h. The last question you have to ask is how to make the top plate of C3 positive? Notice that C3 is also connected to pin 2 which says high input. If this high input is a high positive input it will draw electrons off the top plate of C3 thus making it have a positive potential. Underneath high input you can put a big "+" sign to show that the high input is a high positive input.

i. To follow the circuit that you have been working on, start where you ended and backtrack to where you started. The only thing you should do is identify the input +28VDC and -VDC, which were the BLACK and RED lines, since these two colors are the references for current flow.

(1) Start at pin 2 or high input. When a high positive input is placed on pin 2, it will draw electrons off the top plate of C3, giving the top plate a positive potential. Once the positive potential from the top of C3, which is also being felt on the base of Q3, becomes large enough, it will forward bias the emitter-base junction of Q3 and turn Q3 on.

(2) When Q3 turns on, the current through R19 will increase, thus the voltage drop will increase across R19 with negative on bottom and positive on top. This increased positive potential from the top of R19 is being applied on the emitter of Q4, and will reverse bias Q4's emitter-base junction and turn Q4 off.

(3) Also while Q3 is on, there is current flow from negative through R19, Q3, R6, and R2 to positive. This current flow through R2 creates a voltage drop across R2 with negative on the bottom and positive on the top.

(4) The negative potential from the bottom of R2 is felt on the base of Q2, which turns Q2 on. When Q2 turns on, it allows current to flow from negative through R21, R10, and Q2 to positive. This current flow through R21 creates a voltage drop across R21 with negative on the bottom and positive on the top.

(5) The positive potential from the top of R21 is felt on the base of Q5 which turns Q5 on. With Q5 on, current can flow from

negative through Q5 to pin 8 or the K3 relay. The circuit is now complete.

(6) As you can see, by first working through the circuit from output to input, identifying the operation state of each component, explaining the circuit is made easy. This way of solving the operation of unfamiliar circuits is not the only way to figure out the circuits, but is usually the easiest.

4. **Purpose of Exciter/Voltage Regular:**

a. The purpose of the exciter/voltage regulator is to sense changes in the generators output and adjust the DC input to the field windings to keep the output steady. This is important since most electronic and communication equipment that you will power will not tolerate fluctuations of even .5 volts. To fully understand how the voltage regulator accomplishes this, you will look at the circuit under several conditions.

b. First you will see normal operation with no load, or in other words the generator is putting out 120 VAC.

c. You will then look at the circuit when less than 120 VAC is being produced and then when more than 120 VAC is being produced; both with no load on the generator.

d. You will finally look at the circuit when a load is put on the generator.

5. **Normal Operation (NO LOAD):**

a. When the generator is running with no load applied and is putting out 120 VAC; this 120 VAC is applied to the voltage adjust rheostat R2.

(1) R2 drops 50 volts and sends out 70 VAC. This 70 VAC is applied to J9 at pins A and B; and then it is fed into the primary side of T201.

(2) T201, CR212 and CR213 make up a conventional full wave rectifier with C202 being the filter for the rectifier circuit.

b. T201 and CR214 make up a half-wave rectifier which along with CR211 maintains a constant positive potential on base 2 of Q202. The conventional full wave rectifier network puts out a DC voltage proportional to the AC input or approximately (=) 35 VDC.

c. This output is felt across the voltage divider network made up of R212, R213, and R214. The voltage divider network places a positive potential on the base of Q201B which is directly proportional to the AC input.

d. Q201 is a self-contained differential amplifier or in other words both transistors are in the same canister. Q201A is the stable side of the differential amplifier because CR209 maintains a constant positive potential on the base of Q201A. During normal operation, the

differential amplifier is balanced in that the same amount of current flows through both sides of the differential amplifier. The current coming out of Q201A flows through R206 and R208 creating a voltage drop across R208 with negative on the bottom and positive on the top. R208 is the biasing resistor for Q204. The negative potential from the bottom of R208 turns Q204 on half way.

e. Q204, Q202, R203 and C200 make up a capacitive discharge oscillator (CDO). The current that flows through Q204 comes from the positive plate of C200 causing C200 to charge.

(1) When C200 charges to the gradient voltage of Q202, the positive potential on the emitter of Q202 will cause Q202 to come on. When Q202 turns on, a pulse of current will flow from negative through R203 into base 1 and out the emitter of Q202 to the positive plate of C200, discharging C200 and turning Q202 off.

(2) The pulse of current created while Q202 was on will create a momentary voltage drop across R203 with negative on the bottom and positive on top. The positive potential from the top of R203 will be felt on the base of Q203 causing Q203 to pulse on, then off.

f. When Q203 pulses on, a pulse of current will flow through the primary side of T202, this will induce a pulse in the secondary side of T202 which will be rectified by CR210.

(1) This secondary pulse will apply a positive potential on the gate of Q205. The positive potential will turn Q205 on during a portion of the positive alternation being applied to pins L and M of J13.

(2) This results in 28 volts of pulsating DC going to the field windings through pins R and S of J13.

g. This is how the voltage regulator works under normal operation. This may seem difficult to understand, but as you look at it again you will begin to understand it better.

6. **Low Voltage Operation NO LOAD**:

a. While you are looking at low voltage operation as well as high voltage operation, you will be using the terms; more, less, sooner, later, smaller, larger, faster, slower. When you use these terms you are using them in respect to normal operation, so if you say Q4 is on more, you mean Q4 is on more than it is under normal conditions.

b. If there is less than 120 VAC coming out of the generator, there will be less than 70 VAC being applied to pins A and B of J9 and to the primary side of T201. Therefore the rectifier circuit will put out less than 35 VDC. This smaller input voltage to the voltage divider network will place a smaller positive potential on the base of Q201B turning it on less.

(1) With side B of the differential amplifier on less, the current flowing through R209 will be less causing the voltage drop across R209 to be less.

(2) The potential at the top of R209 is the same potential at the emitter of Q201A. This increased negative potential will forward bias the emitter-base junction more, thus turning Q201A on more.

c. With Q201A on more, it will allow more current to flow through it to R206 and R208. This larger current flow will create a larger voltage drop across R208 with negative on the bottom and positive on the top. The larger negative potential from the bottom of R208 which is being felt on the base of Q204 will turn Q204 on more.

d. With Q204 on more, more electrons will be drawn off the positive plate of C200 causing C200 to charge faster. Since C200 is charging faster, it will place the gradient voltage on the emitter of Q202 sooner, causing Q202 to fire sooner. With Q202 firing earlier, the pulse of current across R203 which causes a voltage drop will appear earlier. The earlier positive potential from the top of R203 which is felt on the base of Q203 will cause Q203 to pulse on, then off, sooner.

e. Since Q203 pulses on sooner, a pulse of current will flow through the primary side of T202 sooner, which will cause the secondary pulse being created in the secondary side of T202 to appear earlier.

(1) Since the secondary pulse is created earlier, a positive potential is placed on the gate of Q205 earlier, causing Q205 to turn on earlier during the positive alternation.

(2) Since Q205 turns on earlier during the positive alternation, more voltage will be applied to the field windings thus increasing the size of the magnetic field inside the generator to increase the voltage output.

f. Even though these are some rather lengthy explanations, you must realize that this process takes place within micro-seconds, and this process can be repeated thousands of times a second.

7. **Over Voltage Operation NO LOAD**:

a. If there is more than 120 VAC being produced by the generator there will be more than 70 VAC being applied to pins A and B and of J9 and the primary side of T201. This larger input to the rectifier circuit will create a larger output or one that is more than 35 VDC. This larger output voltage is applied to the voltage divider network, which places a larger positive potential on the base of Q201B turning Q201B on more.

b. Since side B of the differential amplifier is on more then more current will flow through R209 causing the voltage drop across R209 to increase.

(1) This places a larger positive potential on the top of R209. This potential is the same potential as at the emitter of Q201A.

(2) Since the positive potential at the base of Q201A is now constant, the forward bias of the emitter-base junction will be less. Therefore, Q201A will be on less.

c. With Q201A on less, it will allow less current to flow out of it through R206 and R208, creating a smaller voltage drop across R208. The smaller negative potential from the bottom of R208 will be felt on the base of Q204 which will turn Q204 on less.

d. With Q204 on less it will pull fewer electrons off the positive plate of C200, causing C200 to charge slower. Since C200 is charging slower, it will take longer for Q202 to fire. If Q202 fires later, then the current flow through and the voltage drop across R203 will be produced later. If the positive potential at the top of R203, which is being felt on the base of Q203, is being produced later, it will cause Q203 to pulse on, then off, later.

e. Since Q203 is pulsing on later, the pulse of current through the primary of T202 will create the pulse in the secondary of T202 later.

(1) This later secondary current will place a positive potential on the gate of Q205 turning Q205 on later during the positive alternation.

(2) Since Q205 came on later, in the positive alternation less voltage will be applied to the field windings, making the magnetic field smaller, producing less AC.

f. We have now been through the three different functions that voltage regulator performs when no load is being applied to the voltage regulator.

8. **Generator Out Put Load Applied**:

a. Before you get into how the regulator circuit works when a load is being applied, let's see what happens to the generator output when you apply a load.

b. As you apply a load, you are drawing current which you do not draw with no load on the generator. The more of a load you put on the generator the more current you draw, since when you draw more current, you drain the voltage output.

c. To keep the voltage constant, you must increase the strength of the magnetic field inside the field windings as you increase the load. To increase the strength of the magnetic field, you must increase the DC voltage at Pins R and S of J13.

d. To do this the same as you did for low voltage operation would burn up components, so some other way of supplying this DC to the field windings is required.

9. **Operation With Load Applied**:

a. When a load is applied there is an AC voltage coming from the current transformers CT4, CT5 and CT6 being applied to pins A through F of J13. This AC voltage is directly proportional to the load being applied in that as the load is increased this AC voltage also increases. This AC voltage performs two functions within the regulator circuit.

(1) The first function is to apply voltage, proportional to the load, to the field windings. Since it is AC voltage and the field windings require DC the input AC must be rectified to DC. This rectification takes place in three different rectifier circuits which are made up of: CR203 and CR206, CR202 and CR205, and CR201 and CR204. As you can see these are conventional full wave rectifiers and there is one for each phase. So now there is DC voltage that is proportional to the load going to the field windings through pins R and S of J13.

(2) The second function this AC performs is to eliminate the DC voltage that was being sent to the windings when no load was being applied. To do this it is first rectified to DC and then fed into the circuit so that it eliminates C200 and all the components C200 controls.

b. The AC voltage is first fed into the full-wave bridge rectifier which is made up of T203, CR215, CR216, CR217 and CR218 with C206 serving as the rectifier filter. There is now a DC voltage that is proportional to the load coming out of the rectifier.

(1) This voltage creates a voltage drop across R204 with negative on the left and positive on the right. The positive potential from the right of R204 will be felt on the base of Q206, which will turn Q206 on.

(2) With Q206 on, current can flow from negative through Q206 and Q204 to positive. Since Q204 now has a steady current going through it, it will no longer pull electrons off the positive plate of C200, so C200 will not charge.

c. If C200 does not charge, no positive potential will be placed on the emitter of Q202, so Q202 will not fire. If Q202 does not fire, all the components that fall after Q202 in the circuit will not function. Thus the original DC voltage has been eliminated. Now the circuit is complete.

REFERENCE:

1. TM 00038G-35