Technician's Notebook

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The items in this book are tips used by many technicians to help them become more proficient in their work.

TEKTRONIX, INC.
Test & Measurement Training

Technician's Notebook

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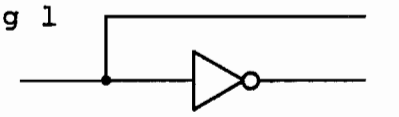
"SCHEMATIC" . . . THE LANGUAGE OF ELECTRONICS

Literate people read words composed of letter symbols on a printed page to acquire knowledge - ideas. Musicians read note symbols on a staff of lines in order to know what tone to make and how long to make it with their instruments. In like manner, electronic technicians must be able to read schematic symbols to understand how a circuit works.

Have you ever known someone . . . who . . reads . . . . very . . . slowly . . and . . . . . haltingly? These people have trouble reading the symbols that make up words, so putting words together to grasp their overall meaning is difficult. Many technicians have studied the fundamentals of electronics and made good grades in school but somehow have not become literate in the language of "schematic". Consequently they read schematics with difficulty, . . slowly . . . . and . . haltingly.

After a year or so in the trade, a technician should be able to instantly spot a cascode stage, a paraphase amp, a constant current source, a comparator, a level shifter, etc. and understand what they are accomplishing in the circuit. When you look at fig 1, do you see a compliment circuit?

fig 1



If you see a high level at A, do you know what level you should see at B or C? And that B and C are always opposite one another in level? You say, "How could anyone not know that?" Don't laugh. I've been guilty of things like this - and I teach this stuff. Sometimes, just redrawing a familiar circuit in a different way (without changing the circuit) completely baffles technicians.

Why? Much of the problem is in not understanding the overall purpose of the language of "schematic" . . . and in not trying to become fluent in that language. How could we? No one ever told us! I've been in electronics for over 20 years and I have just realized no one ever said to me that schematics are a written language explaining how a circuit works. It's just something everyone assumes you know. I knew that schematics were drawings of the circuits but I never thought of them as a language explaining circuit function and signal flow the way words convey ideas or notes the melody of a song. If I don't understand the words, how can I know what the story is about?

Schematics are circuit descriptions using symbols instead of words. It's a lot like reading a story from hieroglyphics as Egyptologists do. You read the electronic symbol pictographs.

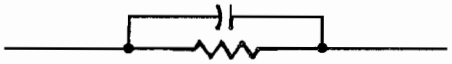
As you trace a signal path, you read the words of "schematic". It tells you what is going on in the circuit. If you know what's going on, you can devise unique ways to check the circuit. You can see the way the circuit is designed and take advantage of that knowledge to help you troubleshoot it. Reading the schematics of new equipment, like a novel, can show you how that equipment works

even though you may never have seen it before. It also helps you stand back and get an over all perspective of the circuit.

To use still another analogy, you've heard the phrase: "Can't see the forest for the trees". As we realize that this is not just a bunch of trees but a forest, we can see the ecology of the system and the role of the individual trees becomes clearer.

Granted, this is not easy at first. But it becomes easier with practice. You probably recognize the parallel R/C combination of figure 2 as a frequency peaking device (when the values are small and it is in series with a signal path). You do this without being conscious of it, just as you do with the words of a novel as you absorb the idea they express.

fig 2



You know, sometimes all it takes is a concept or looking at things in a different way for everything to fall into place.

Do you read "Schematic" ? ? ?

FINDING PARTS ON A CIRCUIT BOARD:

1. Tektronix schematics and circuit board diagrams usually have a grid system for locating parts. There are numbers down the side and letters across the top. This allows a number/letter combination to locate any part on the schematic or circuit board diagram.

2. Use the Parts Locator Chart next to each schematic to find the part on the circuit board. Be careful which column you use. One lists the coordinates for the schematic and the other lists the coordinates for the circuit board.

3. To find out which schematic a part is on, use the General Chart next to each circuit board diagram. This lists all parts on the board and which schematic to find them on.

4. Be aware that different boards can have the same part number. Always check the schematic to see which circuit board you want. (eg. If the instrument has 5 boards in it, R346 could be on 3 of them.)

5. Why should you use the charts? Because a study indicated that 57% of a technician's time is spent just locating parts (the point where he wants to attach his probe or make a measurement). Anything you do to reduce this time speeds your productivity, and it doesn't take any extra knowledge on your part. Often, board engineers put parts where you don't expect them to.

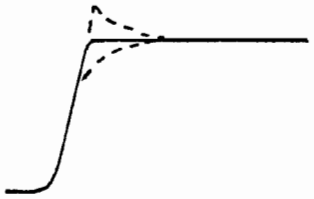
TIME / FREQUENCY DOMAINS . . . or

Why we use square waves to make transient response adjustments.

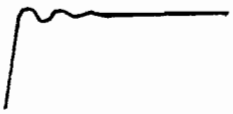
Time and frequency domains are reciprocals of each other. What ever you do in one domain is felt in the other domain. When you adjust the transient response of a vertical amplifier, you use the time domain. When you check bandpass, you use the frequency domain to verify what you did in the time domain.

A squarewave is a panoramic view of the frequency spectrum of a vertical amplifier. As you may remember, a squarewave is composed of a fundamental frequency and an infinite number of its odd harmonics. Add all these together and you get a squarewave. The center of the pulse is the lowest frequency. The further you travel along the top of the squarewave toward the corners, the higher the frequency until at the corners of the pulse is the highest frequency the amplifier is capable of passing. The squarewave pulse, then, is showing the gain curve for all of the amplifier's frequencies.

For calibration, we expand the squarewave until we see only the rise time and front corner. This is the area of highest frequency response (or bandpass).



If the top corner of the squarewave is rolled off, we know that the amplifier will not reach its specified bandpass because signals viewed through the amplifier will be smaller than they actually are at the frequencies represented by the high frequency end of the gain curve (the squarewave). If the top corner is peaked, signals viewed through the amplifier will look larger then they actually are. The whole point of calibration is to make the gain of the amplifier uniform over as wide a range of frequencies as we can.



Aberrations are changes in gain (ringing) from the front corner back along the passband of the amplifier. You probably have seen this manifest itself as a "breathing" or fluctuation in the signal gain as you increased a sinewave generator's frequency when approaching the bandpass limit of an amplifier. Aberrations must be minimized.

To adjust an amplifier in the time domain, always make the slope of the squarewave transition as vertical as possible. Make the corner as sharp as possible. Minimize aberrations as much as possible. It is standard practice to start making adjustments about 5ØnS back from the front corner and work toward the corner. You do this by adjusting the R's and C's with the largest values (range) 1st. Then successively adjust the R's and C's with smaller values (range). The smallest value component will affect only the corner itself Knowing this can also help you know which adjustments to make.

CASCODE AMPLIFIERS

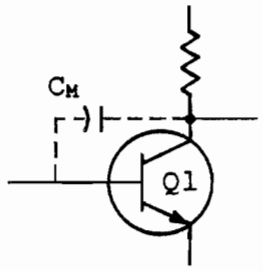


fig 1

Miller feedback from the constituent parts that make up a transistor limits its bandpass (leads, internal structure, etc.). As frequency increases through the device, this Miller feedback capacitance (C_M) feeds the out-of-phase collector signal back to the base where it begins canceling out the signal input (see fig. 1). This limits the bandpass of the device.

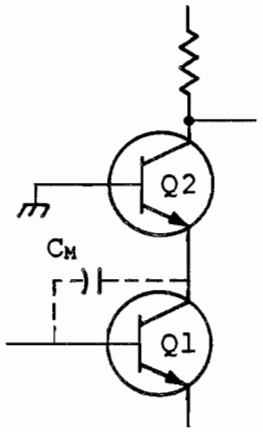


fig 2

By adding Q2 to the circuit (see fig.2), a Cascode Stage is created. By definition, a Cascode Stage is a grounded emitter stage followed by a grounded base stage. The base/emitter resistance of an "on" transistor is approximately 8Ω to 1ØΩ. The emitter of Q2 is essentially at ground. The signal voltage from Q1's collector is at ground. You can not generate much of a feedback signal to Q1's base at ground potential. Almost twice the bandpass can be generated by the Cascode pair. It is a case where the combination yields more bandwidth than either component can alone. Here in lies a trap though. Because the drive between the transistors is signal current, placing an oscilloscope probe on the collector of Q1 will show no signal. You may be led to say, "Ah ha! I have found it!" You replace Q1 and find this does not solve your problem. Oscilloscopes have voltage sensitive inputs - they do not register changes in current flow. You can see the signal again at the output of the Cascode Stage on the collector of Q2.

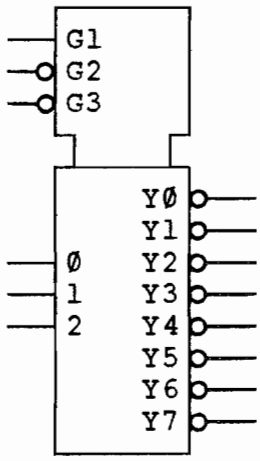
When you troubleshoot a Cascode Stage, always treat both transistors as a single unit. That is - never check 1 transistor. Always check both of them. Expect not to see a signal between the transistor pair. If the "goes-in-ta" at the base of Q1 and the "goes-out-ta" at the collector of Q2 are present, the Cascode Stage is good.

Sometimes, Cascode Amps have a small resistance (up to a few hundred ohms) between the transistor pair. That's OK. It's still a Cascode Stage. Because of the resistance, however, you may be able to see some signal between the transistors.

DECODERS & MULTIPLEXERS

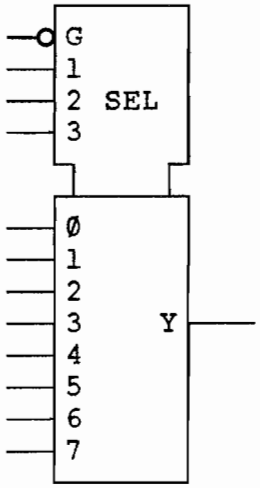
Both Decoders and Multiplexers are a type of selector. However, their function is quite different. They come in different sizes capable of selecting between 2, 4 or 8. They both use binary code to achieve their selection (one select line can count to 2, two select lines can count to 4 and three select lines can count to 8). The chips shown below are both 1-of-8 selectors.

DECODER



A Decoder is mostly used by a µP to activate a chip it wants to communicate with over its data bus. Three gates enable the chip (G1, G2, G3). These are usually tied to the µP's WR line, a synchronizing clock line and sometimes an address line. The 3 select lines (Ø, 1, 2) are connected to the µP's address bus. A binary code placed on the address bus lines connecting to "Ø, 1, 2" will activate one of the negative going output lines. These output lines are the Chip Select lines (also called clocks or strobes) that turn on a chip the µP wants to receive a byte of data over the data bus. Sometimes, the qualifying gate to the chip will be the RD line. In this case, the output line will turn on a chip so the µP can read data from it over the data bus. The output of a decoder can also be used to select other decoders, which in turn, enable the chips the µP needs to communicate with. The important thing to remember about a decoder is the binary code on the 3 select lines (Ø, 1, 2) causes one of the output lines to go active (low) when the chip is selected and that it passes no data.

M U X

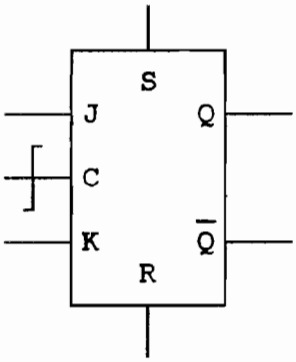


A Multiplexer is an electronic switch. The gate line (G) enables the chip. The 3 select lines (1, 2, 3) receive a binary code that connects one of the 8 input lines to the Y output. It's a selector switch. Sometimes you will see the chip turned around. In this case, Y becomes the input and the 8 lines opposite Y become one of 8 outputs. Data can pass either way through the switch. A typical application would be in a 2400 series scope in the DAC system to periodically pass an analog voltage level on to a group of DAC Ports to refresh the level on their Sample and Hold amps. Or it could be used to read the analog level of a series of pots by a µP through an A/D converter. Here, the thing to remember is the binary code on the select lines determines which one of 8 is connected to Y when the chip is selected, and the chip does pass data.

J-K FLIP-FLOP WITH SET & RESET INPUTS

Many technicians believe that the Q and $\overline{Q}$ outputs of flip-flops cannot both be high at the same time. You were taught that any time this happened the flip-flop was bad. It's not true. Tek uses these devices for the Vertical Channel Switching in the 2200 series scopes. ADD mode will set both Q outputs high. Below is a conceptual description of a Clocked J-K flip-flop with Set and Reset inputs.

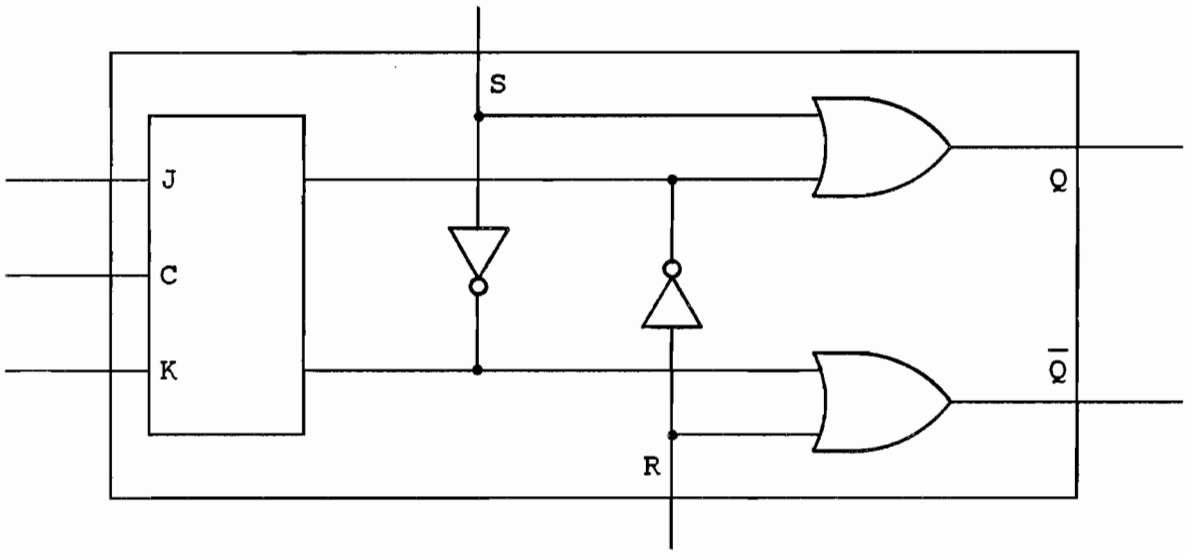
TRUTH TABLE FOR A CLOCKED J-K FLIP-FLOP WITH SET & RESET INPUTS



Note this ===>

J	K	C	S	R	Q	$\overline{Q}$
1	Ø	1	Ø	Ø	1	Ø
Ø	1	1	Ø	Ø	Ø	1
Ø	Ø	1	Ø	Ø	No Change	
1	1	1	Ø	Ø	Toggles	
Doesn't Matter			1	Ø	1	Ø
Doesn't Matter			Ø	1	Ø	1
Doesn't Matter			1	1	1	1

The flip-flop's output section below is an illustration of how both outputs can be high at the same time.

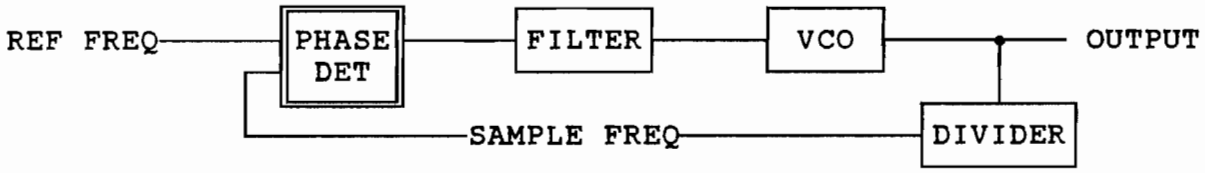


PHASE DETECTORS

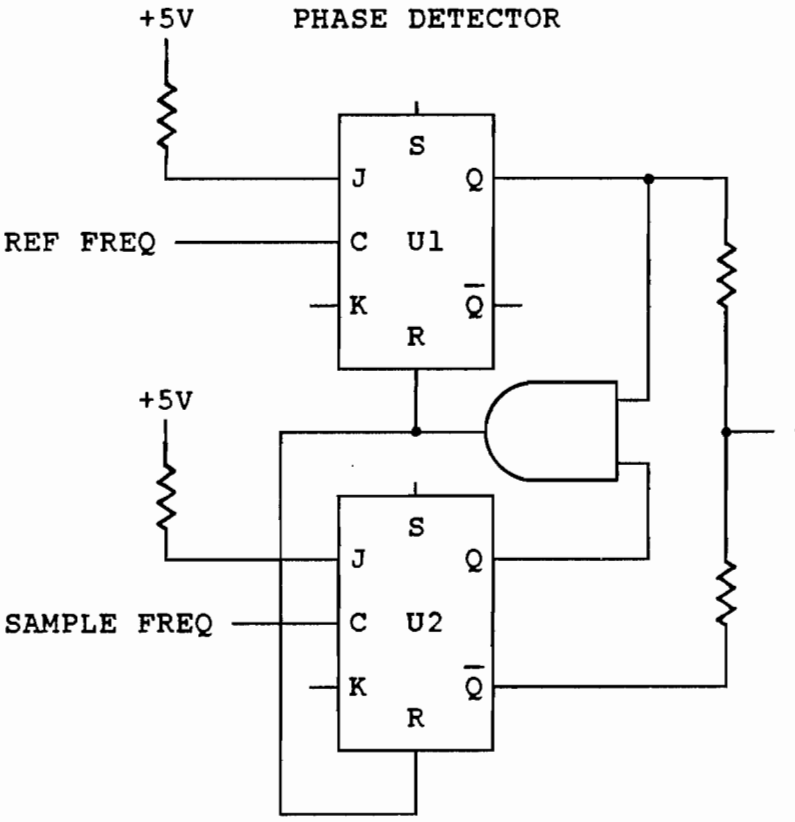
A Phase Detector is a circuit that creates + or - voltage pulses at its output if a sample frequency at one input leads or lags a highly stable reference frequency at the other input. If the 2 frequencies are synchronized, the output of the phase detector is a Null voltage.

In a Phase Locked Loop (PLL), the voltage pulses from the phase detector are smoothed into DC by an active filter circuit. The DC is applied to the control input of a Voltage Controlled Oscillator (VCO). A + voltage causes the VCO to speed up. A - voltage causes the VCO to slow down. A Null voltage causes no change in the VCO frequency.

To complete the PLL, the VCO frequency is divided down to produce the sample frequency that will equal the reference frequency when the VCO is running at its specified frequency. As you see in the block diagram below, the sample and reference frequencies are inputs to the phase detector, whose output supplies control for the VCO.



In this way, a Phase Detector causes an inherently unstable VCO to assume the stability of the Reference frequency source.



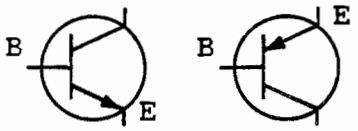
If the VCO freq lags the REF freq, U1 will clock 1st outputting a + pulse. When the VCO clocks U2, both flip-flops are reset.

If the VCO freq leads the REF freq, U2 will clock 1st outputting a - pulse. When the REF freq clocks U1, both flip-flops are reset.

If the VCO and REF freqs clock the flip-flops at the same time, the 2 outputs from U1 and U2 cancel each other out producing a Null voltage. Both flip-flops are reset immediately.

TRANSISTOR TIPS:

1. A transistor's Emitter & Base is composed of N or P material. The tip of the arrow is always N material. The wide end of the arrow is always P material - just as it is for diodes.

2. 

A like change on any transistor lead compared to its material turns it "on" (when a N lead goes negative or a P lead goes positive).

3. An unlike change compared to the lead material turns the transistor "off" (when a N lead goes positive or a P lead goes negative).

4. A change on a transistor's collector is always inverted (out of phase) compared to the change on its base.

5. A change on a transistor's emitter is always the same (in phase) compared to the change on its base.

6. Have trouble remembering which leads are which on a standard plastic case transistor? With the flat facing you and the leads pointing down, the leads read E, B, C, left to right, the way you read a book. See each equipment's service manual for the exceptions.

7. To force a transistor "off", short its base to the emitter.

8. To force a transistor "on", short its base to the collector. (It's best to do this through a 1KΩ resistor.)

9. Transistors are normally "off" devices when no bias is applied.

FET TIPS:

1. FETs are normally "on" devices when no bias is applied.

2. The 1st 5 items above in Transistor Tips also work for FET analysis (pay attention to the point and broad end of the arrow - the kind of material the lead is).

N Channel (gate is P)

P Channel (gate is N)

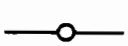
CMOS N Channel (gate is P)

CMOS P Channel (gate is N)

(The arrow on these FETs is usually tied to the source.)

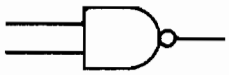
STATE INDICATORS & GATES

State indicators are used to show when the low state of an input or output line is "true" (active) or it is used to indicate inversion.



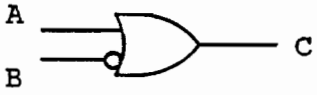
When we were taught about them, we were instructed to slide the state indicator away from the gate and analyze the function of the gate, then invert the result through the state indicator - and this works.

I use a shortcut when analyzing gates with state indicators. I read the gate and state indicator together. The symbol at the right, in the "Language Of Schematic", tells me, "Give me a high on my 2 inputs AND I will give you a low out." The logic Ø is there to tell me what will come out when both inputs are true (high). Any other combination of inputs will yield a false (high) output. I don't even have to remember the truth table for that.

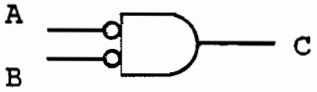


That's because <u>all schematic symbols are drawn in their "true" state.</u> If the levels feeding the input leads are as indicated by the symbol, the output will be as indicated. No state indicator on a lead indicates a logic high for that lead. A state indicator on the lead indicates a logic low for that lead - and they drew the logic "Ø" symbol there to show you (isn't that convenient?).

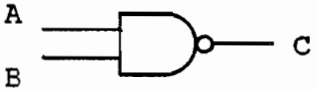
Here is what the symbols below are telling me (I've heard them say it many times).



"Give me a high on A, OR, give me a low on B, and I will give you a high out."



"Give me a low on A, AND, give me a low on B, and I will give you a high out. (Any other combination gives a low out.)



This one says, "Give me a high on A, AND, give me a high on B, and I will give you a low out."

Notice, a TRUE on the input of an OR gate disables it (does not allow signals through) for any other input lead. A FALSE on the input of an AND gate disables it (does not allow changes through) for any other input lead.

In the trade, you will not hear much said about truth tables, but you <u>will</u> hear, "this gate is enabled", or, "that gate is disabled". So you can think of a gate as having a control line and a signal line. If the control line is TRUE for an AND gate, or FALSE for an OR gate, the gate is "enabled" and the signal on the signal line (usually a squarewave) will pass to the output. Enabled gates PASS a signal. Disabled gates DO NOT pass a signal. Memorize this if you have to.

MORE ON GATES

While all gates can be disabled or enabled, there is an exception. Exclusive OR gates (XOR) or exclusive NOR gates (XNOR) can not be disabled. They are used for signal inversion.

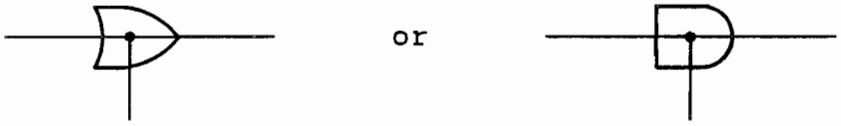
The interpretation of the XOR symbol should be, "Make my inputs dissimilar (not alike) and I will give you a high out".

The interpretation of the XNOR symbol should be, "Make my inputs dissimilar (not alike) and I will give you a low out" (notice the state indicator on the output).

To achieve signal inversion of an XOR gate's output with respect to its input, make the control line to the gate high. For no inversion, make the control line low. See the example below.

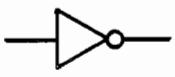
For an XNOR gate, mentally reverse the output phase again.

Another type of gate you may see on schematics is the "phantom" or "wired" gate. This is the junction of 2 runs on a circuit board that behaves as though it was a gate. The most common type is the phantom OR gate, although I have seen a few phantom AND gates. They look like the symbols below and are used to help you analyze the circuit.

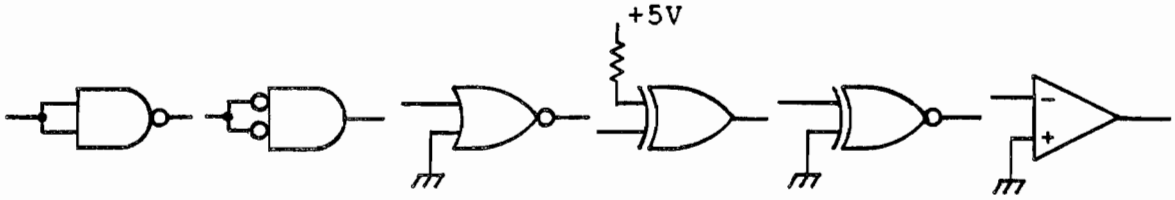


INVERTERS

Sometimes, there is confusion about inverters. For instance everyone recognizes the device at the right as an inverter.



But the devices below are sometimes not recognized as inverters.



SOME GENERAL TIPS:

1. The most difficult part of any check or measurement for a technician is, "to think of it". Think about that - it's true.

2. A Cascode Amp is a grounded emitter stage followed by a grounded base stage. This configuration allows almost twice the bandpass from the pair than can be achieved from each device alone.

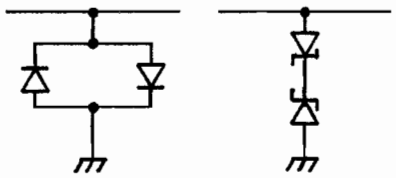
3. Treat the transistor pair of a Cascode Amp or Comparator as a unit. Don't check just 1 transistor of the pair - always check both.

4. The CHOP and Unblanking gates to the Z-axis Amplifier on many scopes can be observed out of the EXT. Z-axis Input.

5. A Capacitor can be thought of as a variable resistor whose resistance (Z) varys inversly with frequency.

6. Constant Current Sources allow very high CMRR in the stages where they are used.

7. Clamps are diode or zener configurations that limit voltage on a signal line. Sometimes the diodes are reverse biased to + and - power supplies for greater peak-to-peak signal capacity. Notice, diodes are used in parallel, zeners are used in series.



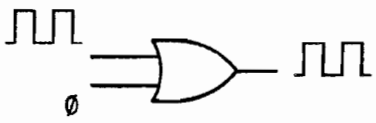
8. A Current Mirror is an amplifier configured so it has a feedback loop from its output into both inputs. The current into both inputs is equal (identical). Setting the current in the inverting loop as a reference forces the current in the non-inverting loop to match it.

9. Crowbar circuits are used to protect the load (circuits) from over voltage because a power supply has gone berserk (generates too much voltage). You will usually find these in the power supply for chips (5V, etc.) because ICs do not like overvoltage.

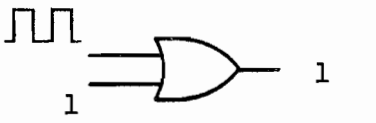
10. Differential Amps are used in circuits because of their fast switching characteristics.

11. Foldback (current limit) circuits are to protect a regulated power supply from damage if a short or heavy current demand occurs in the load (decoupling cap shorts, etc.).

12. To unblank the CRT on a scope when the Z-axis amp **is not** connected to the Beamfind switch, you can either misadjust the CRT Grid-bias to produce a dot or you can feed a 50KHz sine wave into the Ext. Z-axis input. Then turn the generator's output up until the CRT unblanks while Beamfind is held in.

13. 

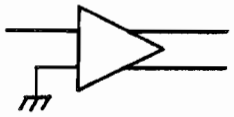
An Enabled gate is one in which all control inputs (not counting the signal line) are set so a signal will pass through. An enabled gate passes signals.

14. 

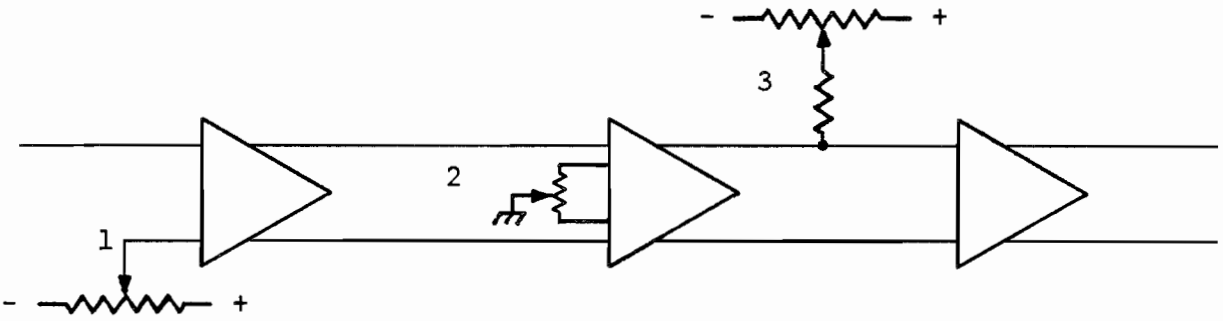
A Disabled gate is one in which any control inputs (not counting the signal line) are set so a signal will not pass through. A Disabled gate will not pass signals.

15. Both the Q and $\overline{Q}$ outputs of a flip-flop will be high at the same time if the set and reset inputs are active at the same time.

16. Prescale means to shift (offset) a high frequency to a lower frequency. In a 1GHz counter, the X1Ø Prescaler shifts all frequencies downward. 7ØØMHz becomes 7ØMHz, 1 GHz becomes 1ØØMHz, etc. Circuit design is easier with lower frequencies.

17. 
A Paraphase Amp is a differential input amplifier configured for 1 signal input and with push-pull signals out. It is sometimes called "Single Ended to Push-Pull".

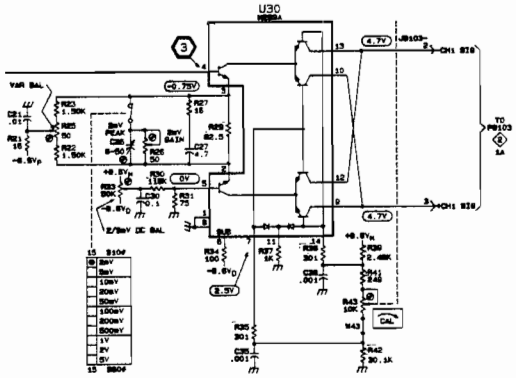
18. Push-Pull Amps are DC balanced in 3 ways (see figure below).
    (1) A Paraphase stage has its other input tied to the wiper of a pot between + & - voltage.
    (2) A Push-Pull stage has the wiper of a pot tied to GND. The pot, itself, is across the emitter resistance between the internal, input transistors.
    (3) One of the signal paths is tied to the wiper of a pot between a + & - voltage and the DC level of that line is hauled high or low with respect to the other signal path.



19. 1ØØØØ (ten thousand) series chips are ECL and are used for high speed circuits. 74ØØ (seventy-four hundred) series chips are TTL.

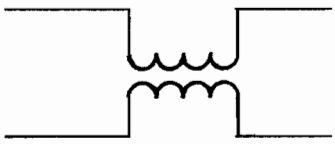
2Ø. Any 2 transistor, Differential amps you see between ECL and TTL technologies are translators from ECL to TTL. Conversion from TTL to ECL is usually only a matter of a voltage divider and level shifting.

21. Signal amplitude is about 1V to 2V in ECL and 4V to 5V in TTL. Don't forget this when measuring circuits with both types of ICs. You could think signal level is bad when it is not.

22. 

The <u>resistance</u> between the emitters of a differential stage sets the gain (P-P signal amplitude out) of the stage. The gain varies inversly with resistance. R-C networks between the emitters of a push-pull stage compensate the frequency response of the stage.

23. When <u>adjusting</u> the transient response of any amplifier system, always adjust the largest value caps and their resistors first and the smallest value caps and their resistors last.

24. 

Very small transformers with one path of a push-pull signal feeding through each winding are used as CMRR devices. Common Mode signals in each winding cancel each other out due to transformer action.

25. Unless it's in an oscillator or multivibrator, you can just lift one side of a cap to see if it is shorting the circuit to GND. The circuit noise (ripple) increases without the cap.

26. In a broken circuit where waveforms are missing, you can tell whether the circuit is hung up in its high or low state by looking at the waveform diagram and seeing if the measured level is equal to the level of the top or the bottom of the waveform.

27. A low has priority over a high in TTL circuits.

28. <u>Zeners</u> in series with a circuit path are used as Level Shifters.

29. When <u>checking transistors and diodes</u> with a meter, if the forward resistance of silicon devices is not in the range of 6ØØΩ to 7ØØΩ, the device is bad (the meter displays the junction voltage drop as the resistance readout). Use the meter's 2KΩ range.

3Ø. <u>Resolution</u> and <u>Accuracy</u> are not the same but many people tend to use the terms interchangeably. Resolution is the smallest value that can be measured. Accuracy is how close to the actual value the measurement can come. For example: A DM44 has the resolution to read and display temperature changes as small as 1°C, but it is accurate to within ±4°C (8 degrees).

31. <u>Beat Frequencies</u>: Two waveforms (signals) mixed together will produce 4 signals. You get the original 2 signal frquencies, a sum of the 2 signal frequencies and a difference of the 2 signal frequencies. The extra signals are called "beat frequencies" because they are produced as a result of beating or mixing 2 frequencies.

32. Push-Pull amplifiers produce a strong offset when one side of the signal path goes bad. An easy method to find the bad stage is to use a shorting strap. Begin at the final stage and work back toward the first stage shorting the input of each stage. The output will center each time you short an input. When the output doesn't center you are at the input of the bad stage. This is also good for finding a noisy stage (noise will not disappear when you short the input of the noisy stage).

33. Another way to troubleshoot push-pull amplifiers is to swap parts from one side to the other until the problem (symptom) changes sides (not for soldered-in transistors).

34. One way to speed troubleshooting is to use a measurement technique called "half-splitting". Apply a signal at the beginning of an amplifier string. Make your 1st measurement half way down the amplifier stages (half-split). If the signal is present, half-split the remaining stages and make another measurement, etc. If the signal was NOT present when you made the 1st measurement, half-split the first half of the stages and make a measurement, etc. In this way, you "bracket" the problem and it usually takes less measurements to find it.

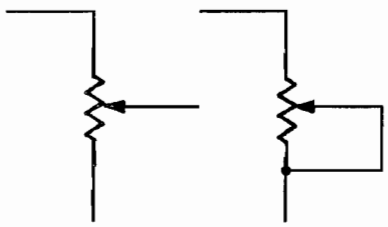
35. Be alert for NPN - PNP transistor swaps when 2 are close together on the circuit board. Sometimes technicians swap them (get them mixed up).

36. Even though you check to see which direction the tab on a dual transistor is pointing when you remove it, also check for an orientation mark on the board. Sometimes technicians put them in backward.

37. Some people confuse potentiometers and rheostats. Both are pots, but their circuit configuration is different.

    A potentiometer is a variable voltage divider. It is a voltage device.

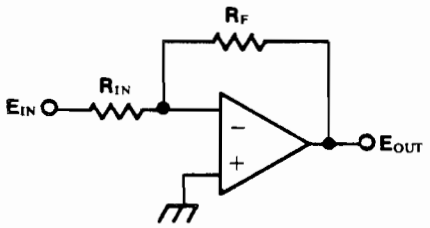
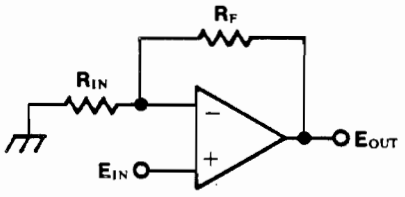
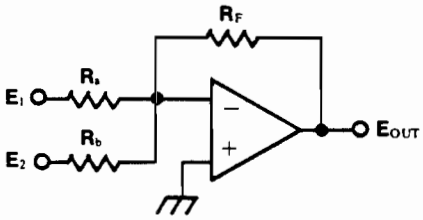
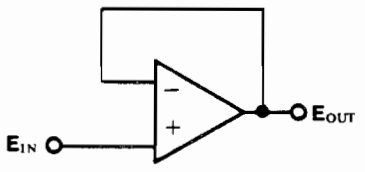
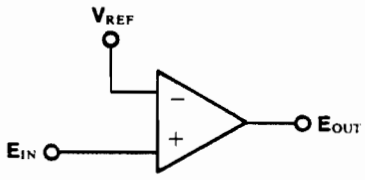
    A rheostat is a variable resistor. It is a current device (the wiper is tied to one end).

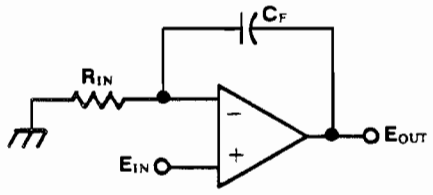
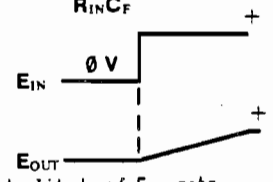
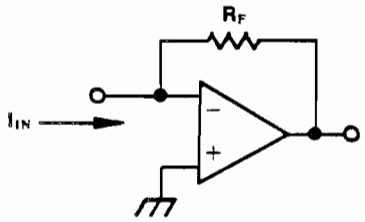


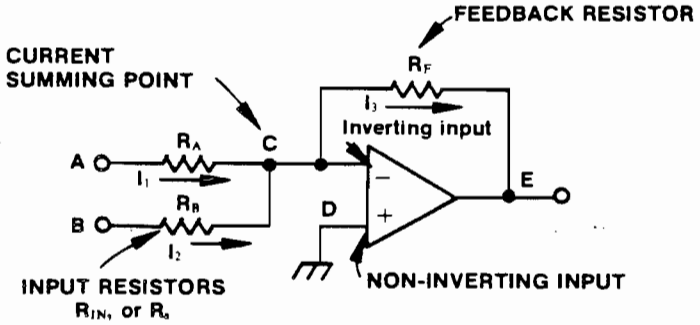
38. A PUT (Programmable Unijunction Transistor) saturates (conducts hard) when its gate is lower than its anode by Ø.6V. Pulling up on its anode past the voltage set on its gate causes it to fire. Although both PUT and SCR symbols look similar, the gate of the PUT is drawn out from its anode.

39. A SCR (Silicon Controlled Rectifier) has its gate drawn out from its cathode. It begins conducting when its gate is higher than its cathode by Ø.6V. The more cathode / gate current that flows, the harder the SCR conducts. You usually find these in "crowbar" circuits with a zener diode between the anode and gate. When the anode voltage rises high enough to turn on the zener, the gate voltage tracks (follows) the anode voltage. If the gate goes higher than the cathode, the SCR conducts.

OPERATIONAL AMPLIFIER DATA

INVERTING AMPLIFIER		$GAIN = -\frac{R_F}{R_{IN}}$ $E_{OUT} = -E_{IN}\frac{R_F}{R_{IN}}$ **INVERTS**
NON-INVERTING AMPLIFIER		$GAIN = \frac{R_F}{R_{IN}} + 1$ $E_{OUT} = E_{IN}\left(\frac{R_F}{R_{IN}} + 1\right)$ **NO INVERSION**
SUMMING AMPLIFIER		$E_{OUT} = -\left(\frac{E_1 R_F}{R_a} + \frac{E_2 R_F}{R_b}\right)$ **CAN BE WORKED FOR EACH INPUT SEPARATELY**
VOLTAGE FOLLOWER		$GAIN = 1$ $E_{OUT} = E_{IN}$ **NO INVERSION ALSO BUFFERS**
COMPARATOR		E_{OUT} **GOES HIGH ANYTIME** E_{IN} **IS GREATER THAN** V_{REF}.

INTEGRATOR		$E_{OUT} = \frac{1}{R_{IN}C_F}\int E_{IN}dt$  Amplitude of E_{IN} sets the slope of the ramp.
CURRENT AMPLIFIER		$E_{OUT} = -I_{IN}R_F$



$I_3 = I_1 + I_2$

Current into the op-amp is in the nA (negligible)

Point C is at the same potential as point D. (If point D were at a voltage level point C would be at the same level.)

POSITIVE LOGIC
L = LOW = 0 = FALSE
H = HIGH = 1 = TRUE

DIGITAL LOGIC DATA

AND

The output is high any time both inputs are high.

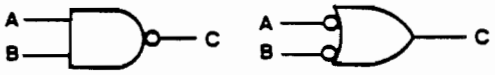
A	B	C
L	L	L
L	H	L
H	L	L
H	H	H

OR

The output is high anytime either input is high.

A	B	C
L	L	L
L	H	H
H	L	H
H	H	H

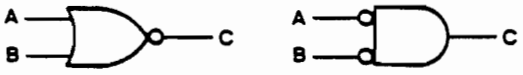
NAND



Inverted input OR

A	B	C
L	L	H
L	H	H
H	L	H
H	H	L

NOR



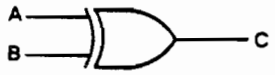
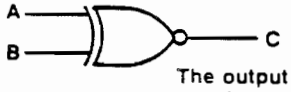
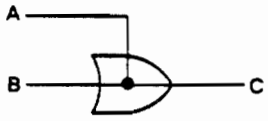
Inverted input AND

A	B	C
L	L	H
L	H	L
H	L	L
H	H	L

INVERTER

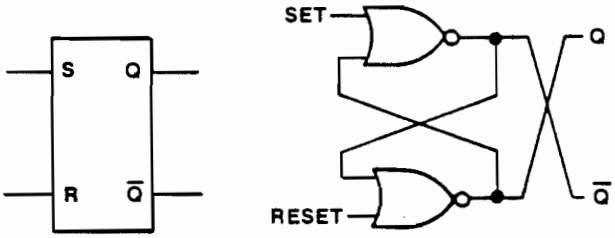
A	B
L	H
H	L

DIGITAL LOGIC DATA

Exclusive OR	 The output is high only when one input is high.	A B C L L L L H H H L H H H L
Exclusive NOR	 The output is high any time both inputs are the same.	A B C L L H L H L H L L H H H
Phantom or WIRED OR	 Not an actual gate, but performs the same function.	A B C L L L L H H H L H H H H
T.T.L. LOGIC GATES	Transistor Logic 7400 numbers Typically; input must be below +.8 V to be a low. above +2.4 V to be a high. output is +4 V when High +.5 V when Low	A floating input functions as a high.
E.C.L. LOGIC GATES	Emitter Coupled Logic 10000 numbers Typically; input must be below −1.5 V to be a low. above −1.2 V to be a high. Normally outputs are −.8 V when High −1.8 V when Low	A floating input functions as a low. Normally both inverting and non-inverting outputs are provided. Faster than T.T.L.

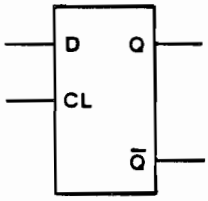
FLIP-FLOP DATA

R-S



S	R	Q	$\overline{Q}$
L	L	NO CHANGE	
L	H	L	H
H	L	H	L
H	H	UNDEFINED CONDITION	

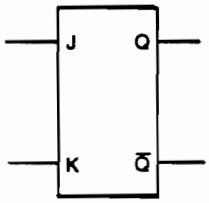
D

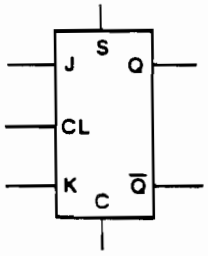


Whatever is on the D or Data input will go to the Q output when clocked.

D	Q	$\overline{Q}$
L	L	H
H	H	L

J-K

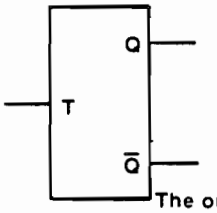


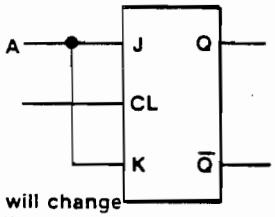


CLOCKED J K f.f. with set & clear (reset)

J	K	Q	$\overline{Q}$
L	L	NO CHANGE	
L	H	L	H
H	L	H	L
H	H	TOGGLES	

T

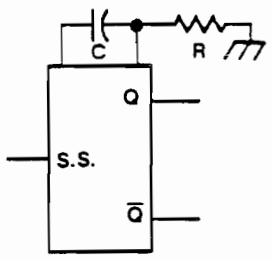




The output will change state every time a clock comes in.

A	Q	$\overline{Q}$
L	NO CHANGE	
H	TOGGLES	

SINGLE SHOT



Q output will go high any time the input goes high, and will stay high for a time determined by the RC time

There are several types of triggering conditions for the single shot.

TABLE

GREEK ALPHABET

Name	UC	Commonly Designates	LC	Commonly Designates
Alpha	A		α	Angles, Area, Absorption factor, Atten Constant, I gain CB configuration
Beta	B		β	Angles, Coefficients, Phase constant, Flux density, I gain CE configuration
Gamma	Γ	Complex propagation constant	γ	Angles, Specific gravity, Electrical conductivity, Propagation constant
Delta	Δ	Increment, Determinant, Permittivity, Variation	δ	Angles, Density, Increment
Epsilon	E		ε	Base of natural logs, Dielectric constant, Electrical intensity,
Zeta	Z	Impedance	ζ	Coordinates, Coefficients
Eta	H		η	Hysteresis, Coordinates, Efficiency, Intrinsic impedance
Theta	Θ		θ	Angular phase displacement, Time constant, Reluctance
Iota	I	Current	ι	Unit vector
Kappa	K		κ	Coupling coefficient, Susceptibility, Dielectric constant
Lambda	Λ	Permeance	λ	Wavelength, Attenuation constant
Mu	M		μ	Micro, Amplification factor, Permeability
Nu	N		ν	Frequency, Reluctivity
Xi	Ξ		ξ	Coordinates, Output coefficients
Omicron	O		o	Reference point
Pi	Π		π	3.1416
Rho	P		ρ	Resistivity, Volumn charge density, Coordinates
Sigma	Σ	Summation	σ	Electrical conductivity, Leakage coefficient, Complex propag'n constant
Tau	T		τ	Time constant, Time phase displacement, Transmission factor
Upsilon	Υ		υ	
Phi	Φ	Scalar potential, Magnetic flux, Radiant flux	φ	Phase angle
Chi	X		χ	Angles, Electrical susceptibility
Psi	Ψ		ψ	Angles, Coordinates, Dielectric flux Phase difference
Omega	Ω	Resistance	ω	Angular velocity (2πf)

TABLE

MATHEMATICAL SYMBOLS

+	Positive, Plus, Add "OR" Boolean term	⊥	Perpendicular to
-	Negative, Minus, Subtract	||	Parallel to
±	Plus or Minus, Pos. or Neg.	π	Pi, 3.1416
X or	Multiplied by "AND" Boolean term	ε	Base of natural log, 1.718
÷ or /	Divided by	√	Square root
=	Equals	∛	Cube root
≡	Identical with	n√	nth Root
≠	Not equal to	|n|	Absolute value of n
≈	Approximately equal to	n°	n degrees
>	Greater than	n'	n minutes of a degree, n prime, n feet
<	Less than	n"	n seconds of a degree, n inches, n seconds
≥	Greater than or equal to	n̄	Average value of n
≤	Less than or equal to	j	Square root of minus 1
::	Is porportional to	%	Percentage
:	Ratio	n_1	Subscript of n
∴	Therefore	( )	Parentheses
∞	Infinity	[ ]	Brackets
△	Increment or small change	{ }	Braces
∠	Angle	‾‾‾	Vinculum (bar over a term)