MICRO-AVIONICS PROPORTIONAL RECEIVER

Note that 4 channels are color coded and terminate in a "BLOCK CONNECTOR." The colors are Orange, Yellow, Green and Blue. The 3 remaining wires, White, Black, and Red provide battery power to the servos. Functions are as follows:

ORANGE	-	ELEVATOR
YELLOW	-	ENGINE
GREEN	-	RUDDER
BLUE	-	AUXILIARY

A single 4 pin connector is also provided for the Aileron function. The remaining round 6 pin connector plugs directly into the switch harness. Plug the 4 servos provided into the desired channels. All servos are directly interchangeable therefore no color coding is provided on the servo plugs. The nickle-cadmium battery pack should be fully charged as covered elsewhere under charging instructions. The single wire approximately 30" long from the receiver is the antenna and should not be changed in length. The color of the antenna wire signifies the operating frequency as follows:

BROWN	-	26.995	YELLOW	-	27.145
RED	-	27.045	GREEN	-	27.195
ORANGE	-	27.095	WHITE	-	6 Meters

MICRO-AVIONICS PROPORTIONAL TRANSMITTER

The transmitter is supplied complete with nickle-cadmium battery pack and requires only charging before being placed in operation. See charging instructions.

Attach antenna to transmitter and extend fully. Turn switch ON, note radiation meter which will read approximately 3/4 to full scale. This meter is a relative device and should not be used as a basis of comparison of power output. Turn receiver switch ON and all servos will neutralize with the exception of the engine control servo which will assume the position commanded by the transmitter control stick. Complete system should now be operational.

INSTALLATION

Possibly the greatest single source of problem with radio control equipment whether it is single channel, reeds, or full-house proportional is in its installation.

RECEIVER

Installation of the receiver should be made with the servo and power cable to the rear of the aircraft whenever possible. The antenna lead should be brought directly out of the fuselage and kept as far away from both servos and other wiring. Although this receiver is completely solid state, its light weight demands a certain degree of vibration protection. A minimum of 1/4" foam padding should be used and receiver should float loosely within.

SERVOS

Servos may be bolted directly through the rubber shock mounts to either a mounting plate or cross beams on the fuselage. Tighten screws or bolts only enough to just start compressing the rubber grommets. Excessive tightening destroys the shock absorbing effect of the grommets. Whenever possible installation should be planned so that it will not be necessary to reverse the direction of servo travel. However, upon occasion it may be necessary and is accomplished as follows:

1. Remove the (4) No. 2-56 screws holding the 3 separate sections of the servo together. Do not remove the output wheel or rack.

2. Remove the bottom cover gently as the servo amplifier is mounted in this portion and is connected to the motor and feedback element.

3. Reverse the Red and Black wire on the feedback element.

4. Reverse the White and Green wire on the motor.

5. It will now be necessary to operate the servo with the bottom cover removed for the purpose of setting its neutral.

6. Plug servo into receiver, turn both transmitter and receiver ON and note position of servo output arm. Loosen screw in center of pot wiper carrier and by inserting a pair of sharp long nose pliers into the 2 outer most holes of the wiper assembly, rotate the wiper assembly until the desired neutral is obtained. Tighten small screw in center of wiper assembly. The servo should be capable of full travel in both directions inclusive of trim when properly centered.

   Before re-assembly inspect the servo carefully for foreign material or solder blobs. Inspect motor to insure there are no wires, washers or etc. magnetically attached.

7. Fit cover assembly to servo being particularly careful that the protective rubber grommet is properly seated in the 2 halves and pot wire and motor wire are not touching the pot wiper assembly. Reinstall the (4) No. 2-56 screws. Do not tighten excessively.

PUSHRODS, BELLCRANKS AND ENGINE CONTROL LINKAGE

A good closed loop servo system will perform only as well as the manner in which it is connected to the control surface. Extreme care should be exercised in making pushrods that are "slop-free" yet as frictionless as possible. We prefer the following arrangement:

Elevator and rudder pushrods should be made from a minimum of 1/4" sq. hard Balsa. A Dubro or Williams type clevis should be used at the surface end only. At the servo end a short piece of 1/16" wire formed to fit the output arm desired. This may be simply a wire approximately 3" long with a 90° bend in one end. It may be installed by removing the output arm thus providing a positive connection. It is recommended that nylon control horns be used wherever possible to reduce wear and possible noise sources.

NOSE WHEEL

Nose wheel control is provided for at the servo by combination of output configurations. Reversal may be obtained without resorting to cross pushrods or bellcranks. The nose wheel pushrod should not be larger than .040 dia. wire to provide the necessary shock absorbing action. This should not be run through brass or aluminum tubing. If this is impossible a larger size tubing should be selected and the pushrod sleeved with teflon tubing available at a large electronic supply house. This provides both a friction and noise free installation.

ENGINE PUSHROD

The same points apply as in the nose wheel installation with the following exceptions. The engine throttle should be adjusted to match the throw of the servo, or a compensating over-travel linkage should be used. Insure that in high speed, high trim and low speed, low trim the servo nulls. This may be demonstrated by the servo buzzing although no control is commanded. In this condition the servo draws excessive current and will rapidly deteriorate the batteries.

BATTERY PACKS AND CHARGING INSTRUCTIONS

Many users of rechargeable batteries disregard some of the rules of chemistry surrounding this device. It is not a product that will stand misuse, over-charging or electrical mishandling. Our application in the radio control field puts severe demands on these batteries. Many times under the very best operating conditions we still experience battery failure due to leakage or loss of capacity. Therefore treat your battery packs with the same care and respect you would treat any other piece of electronic equipment.

The 2 nickle-cadmium battery packs are charged with 2 independent chargers. These chargers are identical with the exception of their connector plugs. Both chargers are self-limiting and will not over-charge the batteries. The charging rate for both is approximately 40MA. Although all batteries are shipped fully charged it is recommended the initial charging cycle be approximately 20 hours. After this initial charge it is suggested that the supplies be charged at least 15 hours before each days use. At least 10 flights of 10 minutes duration may be expected with an ample reserve margin with this procedure. The charging cord is plugged into the receiver pack. Plug the charger into a 110 VAC outlet. Turn receiver switch ON. An indicator light in the charger provides indication that charging is taking place. The transmitter charger is plugged into the bottom of the transmitter and connected to 110 VAC outlet. An indicator light here also indicates that charging is taking place. Do not turn transmitter switch ON while charging batteries. This will only run batteries down.

CAUTION

When unplugging the charging equipment, the charger should be removed from the AC connector before removing any other plug. Do not forget to turn receiver switch OFF upon completion of charging.

The receiver battery pack should be left disconnected from the receiver until ready for use and disconnected at the end of the flying session. This will prevent battery damage due to accidental switch turn ON for long periods of time.

RANGE CHECKING

Operational distances may vary considerably, depending on surface over which test is made, (asphalt, grass, water, etc.) height of receiver above ground, receiver antenna placement, etc. The same receiver could show response variations from 10-200 feet (with transmitter antenna removed) depending upon specific conditions. For initial tests, a range test with antenna installed on transmitter may be performed. A line of sight ground range of approximately 1/2 mile should result in solid operation of the servos.

Unless your own transmitter is turned ON, you may notice that other transmitters on adjacent channels interfere with your receiver. This is caused by the receiver running "wide open". Turning on your transmitter will activate the AGC circuit and reduce receiver gain and sharpen selectivity which prevents interference from other sources.

NOTE

The manufacturer warrants that this transmitter equipment, when used in the manner prescribed in the accompaning instructions, meets all FCC requirements regarding frequency stability, emission, etc.

WARRANTY

This equipment is warranted by MICRO-AVIONICS, INC. to be free of defects in workmanship and materials for a period of ninety (90) days from purchase. However, this guarantee is void should the manufacturer judge the defect to be caused by abuse, crashes, overvoltage, incorrect polarity, modification or other misuse by the customer. Units purchased by customer request without battery packs or chargers will not be covered by warranty.

Repairs under this warranty will be provided for at no cost to the customer except transportation, and insurance. Other repairs or frequency changing will be performed at a minimum cost of $5.00. When damage occurs which is too extensive for repair, unit replacement will be made at a cost to user equivalent to 65% of the retail price of the equipment.

In the event of trouble, return entire system direct to the factory - not to the dealer. Equipment will be serviced and returned as soon as possible. Be sure to include name and address and a brief description of the problem involved. Upon request, an estimate of repair costs will be furnished for approval before proceeding with repairs.

SPECIFICATIONS

A. TRANSMITTER:

Power output	. . . . .	One half watt
Operating voltage	. . . . .	8.4 volts D.C.
Audio modulation	. . . . .	Approx. 60 CPS
Modulation percentage	. . . . .	100%
Tuning range	. . . . .	26.995 to 27.255 MC's or all 6 meter freq.
Frequency tolerance	. . . . .	.005%
Antenna	. . . . .	54" four section collapseable whip.
Operation time	. . . . .	Five hours cont. on one charge.
Operating temperature range	. . . . .	0 - 150 degrees Fah.

SPECIFICATIONS (Continued)

B. RECEIVER:

Sensitivity	. . . . .	Less than 3 micro-volts for full control.
Automatic gain control	. . . . .	In full control from 3 - 100,000 microvolts.
Bandwidth	. . . . .	3 KC @ 6 DB
Intermediate frequency	. . . . .	455 KC
Power supply	. . . . .	4.8 VDC
Modulation percentage required	. . . . .	100
Available frequencies	. . . . .	26.995 to 27.255 MC 52.5 - 53.5 MC
Operating temperature range	. . . . .	0 - 150 degrees Fah.
Size	. . . . .	3" x 2" x 1"
Weight	. . . . .	3 Oz.

C. SERVO AMPLIFIER AND SERVOS:

Servo centering accuracy	. . . . .	Plus or minus 1%
Response time	. . . . .	Less than 16 milliseconds.
Interaction	. . . . .	None.
Torque	. . . . .	Full at any error amplitude.
Drift	. . . . .	Plus or minus 1%, 0-150 degrees Fah.
Feedback pot	. . . . .	Hot moulded carbon
Thrust	. . . . .	4.5 Lbs. min.
Outputs	. . . . .	Rotary and/or linear (both furnished).
Mounting	. . . . .	(4) 4-40 machine screws
Size	. . . . .	Width - 2.25" Height - 2.450"Less Outputs Length - 2.4 Exclusive at mounting ears 2.9 Inclusive at mounting ears
Weight	. . . . .	2.75 Oz.

GENERAL DESCRIPTION

The MICRO-AVIONICS PROPORTIONAL CONTROL SYSTEM, although similar in some respects to other Digital Control Systems, has been engineered conceptually to provide higher reliability than the competing systems. Although it has not been the desire to gain simplicity at the cost of reliability, the following text will show that a reliable system is, in fact, the simplest conceptual arrangement of the basic tools of the trade.

TRANSMITTER ENCODER

Figure 1 is a block diagram of the TRANSMITTER ENCODER. The frame rate is determined by the Astable Multivibrator consisting of Q1 and Q2, (Figure 2). Since the frame rate is nominally 16 M.S., each half of the Multivibrator will have to contribute 8 M.S. of this time. Treating the Multivibrator as two halves of the total time, it is seen that;

$$T = 0.69\, R1\, C1$$

We want a timing of 8 M.S. per half. So;

$$8 \times 10^{-3} \text{ SEC} = 0.69\, R \times 0.1 \times 10^{-6}$$

therefore

$$R1 = \frac{8 \times 10^{-3}}{0.69 \times 0.1 \times 10^{-6}} = 116 \times 10^{3} = 116K$$

R1 consists of a 100K resistor in series with a 50K pot. The pot allows adjustment of the time constant to exactly 8 Milliseconds per half, or 16 Milliseconds total.

In consideration of stability of the clock frequency we must say that the combination of R2 C1 must charge and stabilize through the base - emitter junction of Q2 in 8 M.S. Since it takes at least 5 time constants for RC to charge to some semblance of stability it may be said that;

$$5\, R2\, C1 \leq 8 \text{ M.S.}$$

$$R2\, C1 = 4.7 \times 10^{+3} \times 0.1 \times 10^{-6} = .47 \times 10^{-3}$$

$$5\, R2\, C1 = 5 \times 0.47 \times 10^{-3} = 2.35 \times 10^{-3} \text{SEC.}$$

OR

2.35 Milliseconds

2.35 M.S. is obviously much less than 8 M.S., so we have met the requirement of stability.

Again referring to Figure 2, it will be seen that the Control Functions are derived from the 4K Pot in Series with the Transistors Q2 through Q6. As Q2 turns on, the resulting Negative Transient is coupled to the base of Q3 through the Timing Capacitor C2. Since Q3 is normally on the Negative Transient will switch it off for a period determined by the setting of the arm of the Pot in the Collector Circuit of Q2, the Timing Capacitor, C2, and the base bias Resistors R3 and R4.

The expression for this timing function is:

$$T = 2.3\,RC \log \frac{E1}{E2}$$

where

$$E1 = E_{supply} + E_{pot} \quad (E_{supply} = 9V.)$$

$$E2 = E_{supply} \quad \text{(approximately)}$$

$$R = R3 + R4 \quad (125K \text{ nominal})$$

$$C = 0.047 \text{ MFD}$$

To determine the Pot Arm Voltage necessary to achieve a time of 1.5 Milliseconds, we re-write the equation as follows:

$$E1 = E2 \left(\log^{-1} \frac{T}{2.3\,RC}\right), \quad T = 1.5 \text{ M.S.}$$

$$E1 = 9.0 \left(\log^{-1} \frac{1.5}{13.5}\right)$$

$$= 9.0 \; (1.29)$$

$$= 11.6 \text{ V.}$$

Since $E_{pot} = E1 - E_{supply}$

$$E_{pot} = 11.6 \text{ V.} - 9\text{V.}$$
$$= 2.6\text{V}$$

This is approximately the voltage between the Pot Arm and the Supply Voltage when Q2 is conducting. In order to avoid interaction between channels, the Timing Capacitor must charge fully during the minimum "OFF" time of the preceding stage. The minimum "OFF" time is 1.0 Milliseconds, therefore, the charging time constant formed by the Timing Capacitor and the resistance between the arm of the Pot and the B+ end of the Pot must be less than 1/5 of 1.0 Milliseconds. Let us consider the worst case condition, where the Pot Arm is at the collector end of the Pot. Actually, the Pot Arm never gets lower than half way.

$$T = RC$$

where

$$R = 4K$$

$$C = 0.047 \text{ MFD.}$$

$$T = 4 \times 10^{3} \times 0.047 \times 10^{-6}$$

$$= 0.188 \times 10^{-3} \text{ SEC.}$$

$$= 0.188 \text{ Milliseconds}$$

Since this time constant must be less than 1/5 the minimum "OFF" time:

0.188 X 5 = 0.94 Milliseconds which is less than 1 Millisecond.

Diodes D1 through D5 together with Resistors R1 through R5 form decoupling networks to isolate Q2 through Q6 Collectors from the Differentiating Capacitors C1 through C6. This eliminates a possible source of interaction. C1, R1 forms a high pass filter which differentiates the positive pulse appearing at the Collector of Q2. When Q2 goes negative (turns back on after timed pulse), the negative transient is coupled to the base of Q8 through the "OR" gate formed by Diodes D6 through D11. The time constant of the differentiating network is chosen such that Q8 is turned off for a period not less than 200 Microseconds. Since Q8 is in series with the Oscillator Transistor Q9, the Oscillator is "spiked" off for 200 Microseconds. Miller Integrator Capacitor, C7, insures a minimum bandwidth spike by "softening" the turn on and turn off rise times of the Oscillator.

RECEIVER DECODER

The CHANNEL SEPARATION LOGIC (Figure 4) uses seven transistors, one as a Sync Separator and Logic Driver, and six in the "JOHNSON COUNTER" Decommutator.

The Sync Separator, Logic Driver operates as follows. Upon receipt of a 200 Microsec. wide positive-going pulse from the shaping amplifier, Transistor Q1 is driven into saturation, producing a negative-going pulse at it's collector. This negative pulse is used to advance the Decommutator and discharge, through D1, the Reset Timing Capacitor, C1. If no pulses are received for approximately 4 Milliseconds, such as during the Sync Pause, (6 Milliseconds minimum), C1, charges sufficiently to cause Diodes D2, D3, and D4, to conduct thereby resetting the Commutator to a state in which the next pulse will advance it to channel one.

$$R1 = 3.3K$$

$$C2 = 1.8\ MFD.$$

$$\tau = RC = 3.3 \times 10^{3} \times 1.8 \times 10^{-6} = 5.95 \times 10^{-3}\ \text{Seconds,}$$

or

5.95 Milliseconds

In this time C1 will charge to 63% of the supply voltage.

$$E_{supply} = 4.8\ V.$$

$$4.8 \times .63 = \underline{3.02\ V.}$$

Since to reset the Commutator, the Base Emitter Diode of Q2, Q4, and Q6 in Parallel and D2, D3, and D4 in series must be made to conduct and since they are Silicon Diodes with a characteristic forward drop of 0.6 V., it would take;

$$0.6\ V. \times 4 \quad \text{or} \quad \underline{2.4}\ V.$$

to start resetting the Commutator.

2.4 volts is half the supply voltage, and with a time constant of 5.95 Milliseconds it will take approximately;

$$\tau = RC \ln \left(\frac{V\,Supply}{V\,Supply - V\,Reset}\right) = 5.95 \times 10^{-3} \ln \frac{4.8}{2.4} = 4.1\ M.S.$$

Since 4.1 Milliseconds is the minimum time to reset, and 2 Milliseconds is maximum pulse spacing, there is no chance of resetting the Decommutator during any period other than the Sync Pause. Conversely, since the minimum Sync Pause is 6 Milliseconds there is no chance of the Decommutator not resetting to the proper state during the Sync Pause.

The Decommutator takes the form of a "JOHNSON COUNTER" (Figure 5), which is merely a modified ring counter or module "6" counter. This particular configuration was chosen because of it's need for only 2 decoding Diodes per Channel (Figure 6). A standard ring counter would need no decoding Diodes but would require one complete stage per channel or 10 transistors for 5 channels. We are therefore saving 4 Transistors and associated Resistors, Capacitors and Steering Diodes at the cost of the 10 Diodes used for decoding. It is felt that this is more reliable , and makes possible a smaller package. A standard "ripple through" or binary counter was considered but dropped from consideration because it is either a 2, 4, or 8 Counter, and for a 5 Channel System, the Modulo 8 , 3 stage, counter would have to be used and although the binary counter would have only 3 stages (the same number as a modulo 6 JOHNSON) it would require 3 decoding Diodes per channel instead of only two.

Referring to the BLOCK DIAGRAM (Figure 5), it will be noted that there are three R-S clocked flip-flops cascaded to form a three-stage ring-counter with the last stage fed back in such a manner that the state of the last stage determines the state of the first stage. Observing the truth table, it will be noted that starting from the reset state, succeeding clock pulses will steer "ones" into the register until the last stage is set to a "one" after which all clock pulses will set each succeeding stage back to the zero state. The Diode Decoding Matrix then separates the channels. For instance, looking at the TIMING DIAGRAM, (Figure 7) channel 1 has a positive output only when the "a" and "b" outputs are both positive. At no other time will the "and" gate conduct. The positive going output is then fed to the Servo Amp.

SERVO AMPLIFIER

The MICRO AVIONICS SERVO AMPLIFIER (Figure 8) contains 10 transistors, 8 of which are silicon. Only the Motor Drive Transistors are germanium. Complementary symmetry is used throughout to eliminate the need for a transformer or extra bias batteries. A positive lock-out scheme is used to prevent turning both motor drive, transistors on at the same time thereby burning them out. The Servo Amplifier is the pulse-width tracking type thereby offering minimum reaction time, (always equal to or less than 16 Milliseconds).

Theory of operation is as follows:

REFERENCE GENERATOR

The purpose of the REFERENCE GENERATOR, (Figure 8) (Q1 and Q2), is to provide a pulse whose width is proportional to surface position. It is basically a voltage controlled one-shot Multivibrator. It is triggered by the positive leading edge of the output pulse from the Decommutator. Before it is triggered, Q1 is normally biased on by R1 therefore Q2 is off by virtue of its bias Resistor R3 being tied to ground through Q1. C2 and R9 differentiate the input pulse producing a positive spike which is coupled through the Gate Diode D1, to the base of Q2, thereby turning it on. The negative going transient produced at the collector of Q2 is transferred to the base of Q1 through the Decoupling Diode, D2, and Timing Capacitor, C1. The negative transient turns Q1 off and initiates the one-shot action by supplying turn bias to Q2 through R2 and R3. The timing is determined by R1, C1, and the setting of the feedback Pot Arm. The expression for the timing is

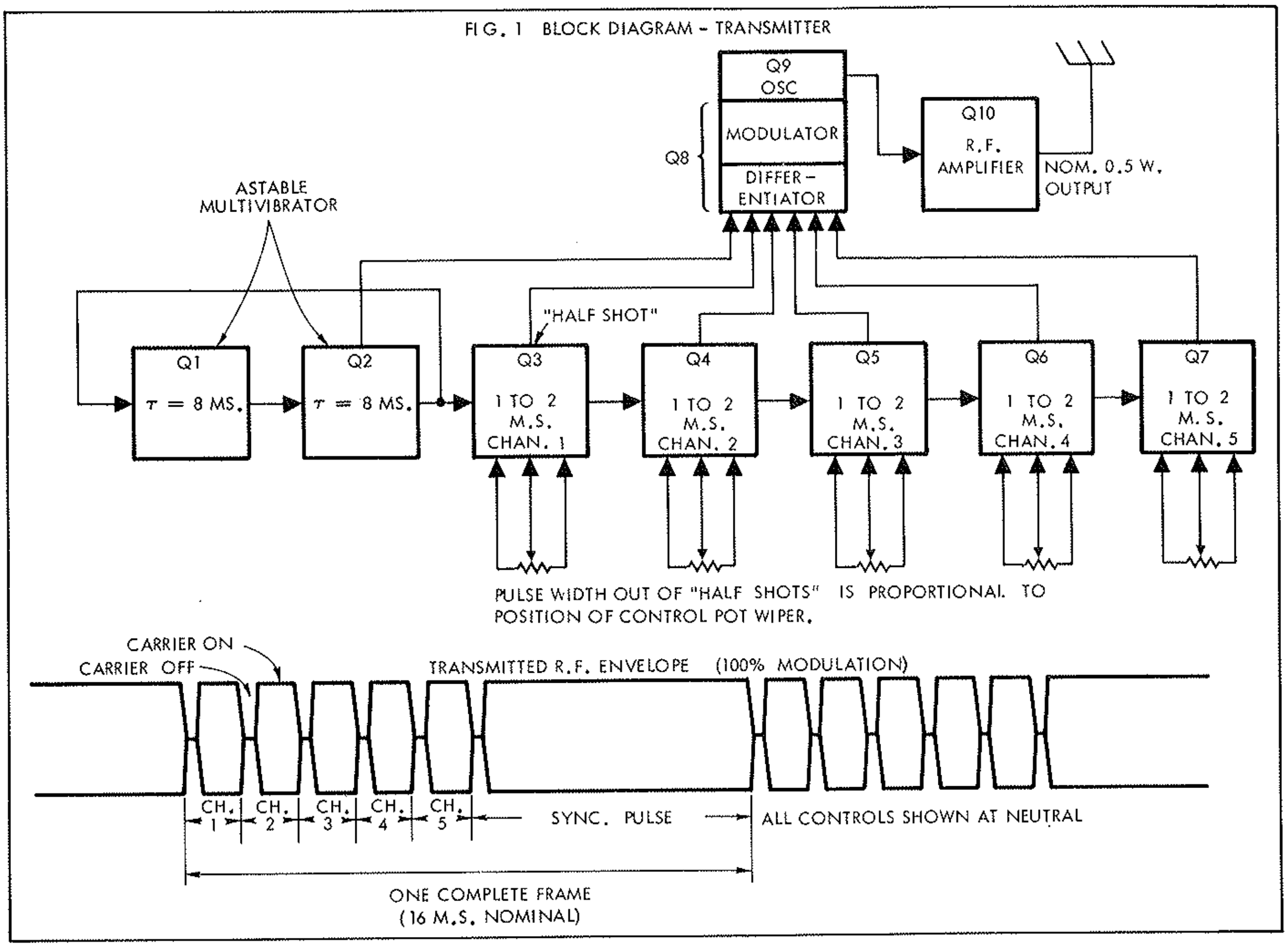
$$T = 2.3 \, RC \log \frac{E1}{E2}$$

Figure 10 shows a complete analysis of the timing of the Voltage Controlled One-Shot. As it shows, for a timing of 1.5 Milliseconds the Pot Arm will be set to a voltage approximately 2.18 V. above ground for a supply voltage of 4.8V. Figure 11 is a graph of Time versus Supply Voltage for a constant Pot setting. The reason for this variation is that the Base-Emitter Diode voltage of Q1, and the Decoupling Diode (D2) voltage does not appreciably change with supply voltage. It can be shown that if these voltages did not exist, the timing would not change with voltage. This means that the higher the supply voltage the less the timing change. The supply voltage, due to decoupling elements R25 and C10, is actually 4 Volts instead of 4.8 Volts. Again, referring to Figure 11, it is seen that the timing change between 4.0 Volts and 3.6 Volts, (the amount due to battery voltage drop during use), will amount to approximately 48 Microsec. This amounts to 4.8% of the total travel which is well within the available trim range. Variation of timing with temperature, (Figure 13) is kept to a minimum by the use of MYLAR timing capacitors. These capacitors are very stable with temperature and what drift they do exhibit is partially cancelled by the Vbe drift of the Transistors associated with the Timing Circuits. The Damping Resistor (R24) and the Pot Series Resistor (R4) determine the damping factor of the Servo. The action of the Damping Resistor is to slightly advance or retard the timing of the Reference Generator in such a manner as to make the pulse widths match before they actually do, thereby shutting the motor down early enough to allow the Servo to coast to neutral, thereby preventing excessive over-shoot with the resultant rough action.

Resistors R5, R6, R7, and R8 form a Resistive Bridge Summing Junction in which the pulse from the logic and reference are compared, Figure 12 diagrams the action of the Summing Junction. The two Transistors labelled "Normally On" represent two of the stages of the Decommutator. The Transistor labelled "Normally On" is Q2. The unbalance of resistor values in the bridge, is due to the voltage drop across the "and" Gate Diodes. The equivalent circuits indicate what the Summing Junction "sees" under the four cases of operation. The Summing Junction is capacitively coupled to the Positive and Negative Pulse Stretchers through C3 and C4. The Pulse Stretcher time constant (C5, R13, and C6, R13) together with the SCHMIDT TRIGGER hysterisis determine the minimum impulse timing. The minimum impulse timing for this Servo is approximately 6 Milliseconds, the constraints being that a minimum impulse must not drive the Servo out of the dead zone yet it must supply enough power to the motor to move the output arm against a large load. It takes about a 5 Microsecond (0.5%)

error to discharge the 1.8 MFD. Capacitor enough to actuate the SCHMIDT TRIGGER. Let us consider only the bottom (NPN) SCHMIDT TRIGGER, and Pulse Stretcher since both sides operate identically. Q4 and Q8 are normally off; Q6 is normally on. The voltage of the Collector of Q4 is normally about 0.75 Volts. Q6 is biased on through Q5 Base Emitter Junction, R12, R13, and R14. Upon receipt of an error signal at the base of Q4, Q4 conducts partially discharging C6 and turning off Q6. Q8 now turns on and C6 starts charging toward the positive supply through R13. The voltage across R19 was approximately 20 Millivolts before the error signal was received. Because the Collector Load of Q8 is much smaller it draws much more current (30 - 40 MA) so the voltage across R19 raises to approximately 400 Millivolts, thus C6 will charge to a value 400 Millivolts higher than it was before Q6 will again be turned on and Q8 turned off.

Naturally, the longer the Error Signal the longer it will take for C6 to charge up to the point where the SCHMIDT TRIGGER will reset, turning off the motor. Eventually the Error Signal becomes large enough to discharge C6 to the point where it will not re-charge to the reset point in less than 16 Milliseconds, (frame repetition time). In this case the motor will run continuously until the Error Signal is reduced to the point where the motor will start pulsing again, and then to the point where the error is not long enough to discharge C6 enough to activate the SCHMIDT TRIGGER. As long as Q8 and Q9 are conducting, the voltage at the Collector of Q8 is highly negative with respect to the base of Q5 therefore, even if Q3 conducts, discharging C5, Q5 is biased to conduction through R16 and D3 thereby keeping Q7 and Q10 biased off until Q8 and Q9 turn off. This prevents the possible burnout of Q9 and Q10. C9 bypasses R.F. interference, generated by the motor, to ground.



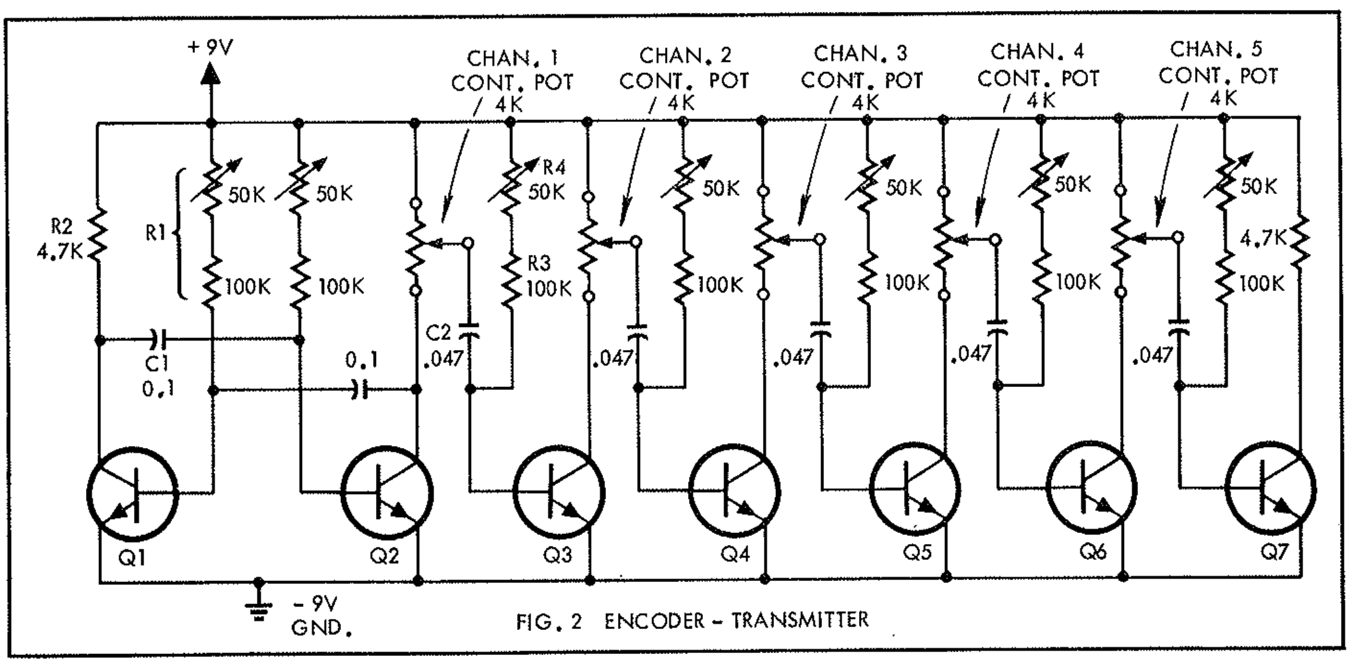


FIG. 2 ENCODER - TRANSMITTER

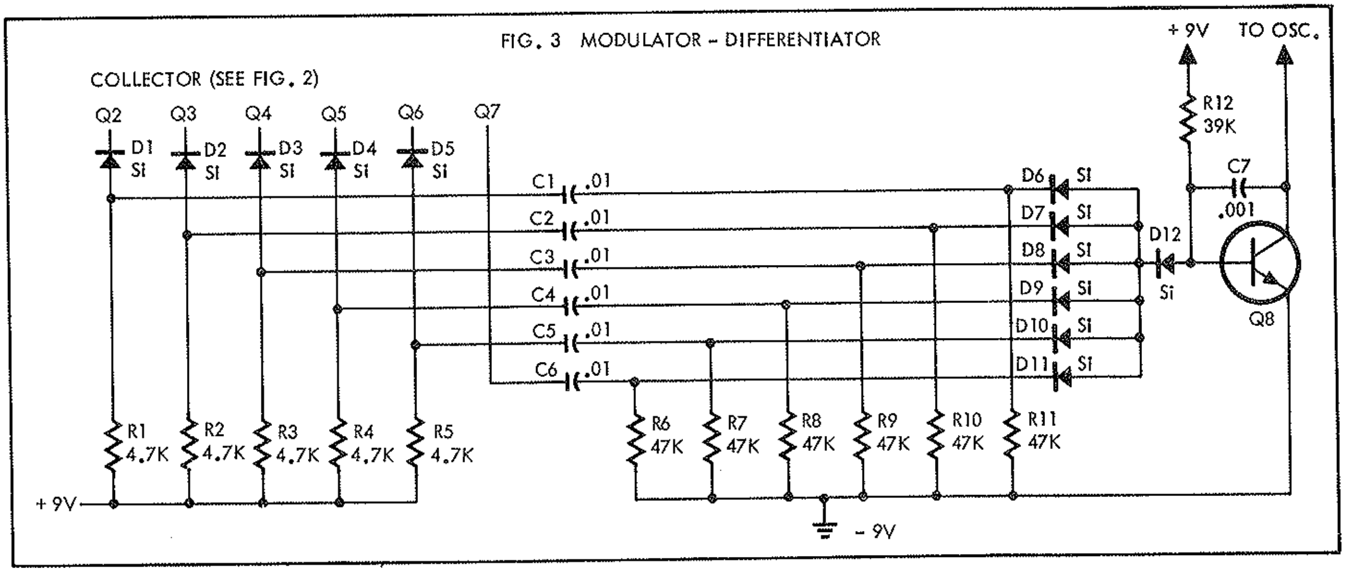


FIG. 3 MODULATOR - DIFFERENTIATOR
COLLECTOR (SEE FIG. 2)
Q2 Q3 Q4 Q5 Q6 Q7
D1 Si D2 Si D3 Si D4 Si D5 Si
C1 .01 C2 .01 C3 .01 C4 .01 C5 .01 C6 .01
D6 Si D7 Si D8 Si D9 Si D10 Si D11 Si
D12 Si
+9V TO OSC.
R12 39K
C7 .001
Q8
R1 4.7K R2 4.7K R3 4.7K R4 4.7K R5 4.7K
R6 47K R7 47K R8 47K R9 47K R10 47K R11 47K
+9V
-9V

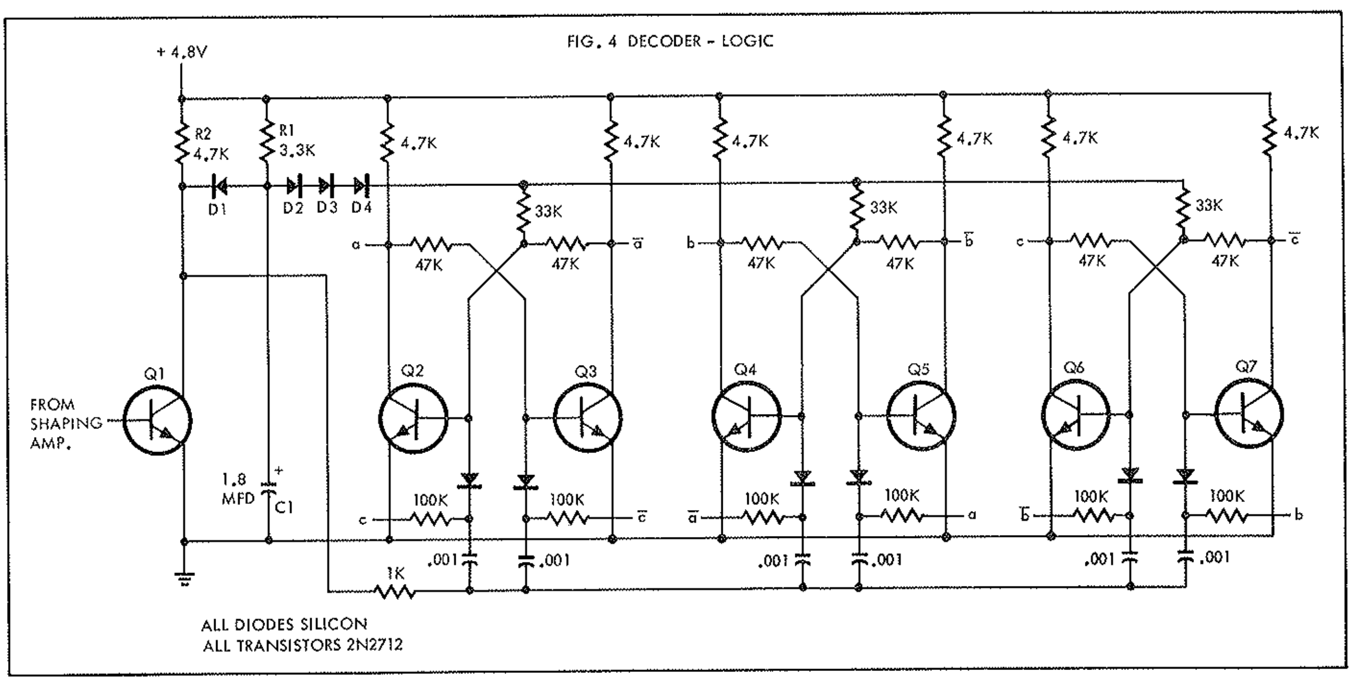


FIG. 4 DECODER - LOGIC
+4.8V
R2 4.7K
R1 3.3K
D1 D2 D3 D4
4.7K 33K 47K 100K .001
a ā b b̄ c c̄
Q1 Q2 Q3 Q4 Q5 Q6 Q7
FROM SHAPING AMP.
1.8 MFD C1
1K
ALL DIODES SILICON
ALL TRANSISTORS 2N2712

SEQUENCE

	a	b	c
RESET OR 0	0	0	0
CHAN. 1	1	0	0
CHAN. 2	1	1	0
CHAN. 3	1	1	1
CHAN. 4	0	1	1
CHAN. 5	0	0	1

DECODING

0	$\bar{a}$	$\bar{c}$
1	a	$\bar{b}$
2	b	$\bar{c}$
3	a	c
4	$\bar{a}$	b
5	$\bar{b}$	c

LOGIC

1ST STAGE $S_a = \bar{c}$
$R_a = c + \text{RESET}$

2ND STAGE $S_b = a$
$R_b = \bar{a} + \text{RESET}$

3RD STAGE $S_c = b$
$R_c = \bar{b} + \text{RESET}$

NOTE: "O" STATE IS LOW VOLTAGE
"1" STATE IS HIGH VOLTAGE

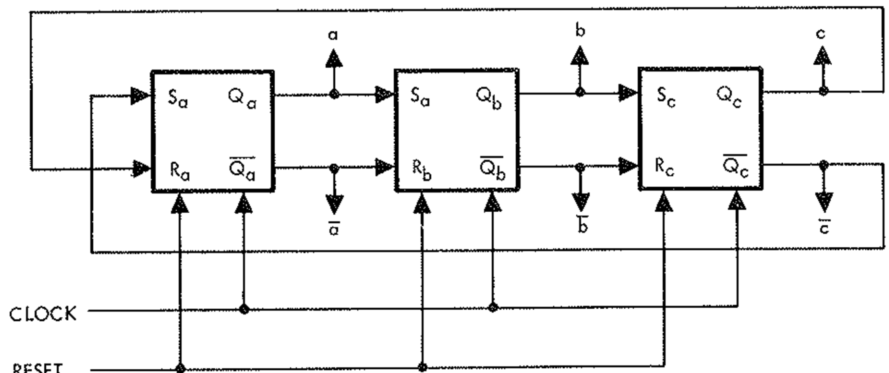


FIG. 5 BLOCK DIAGRAM - JOHNSON COUNTER DECOMMUTATOR

FIG. 6 DECODING MATRIX

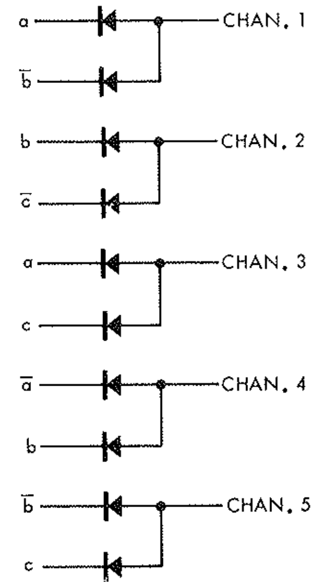
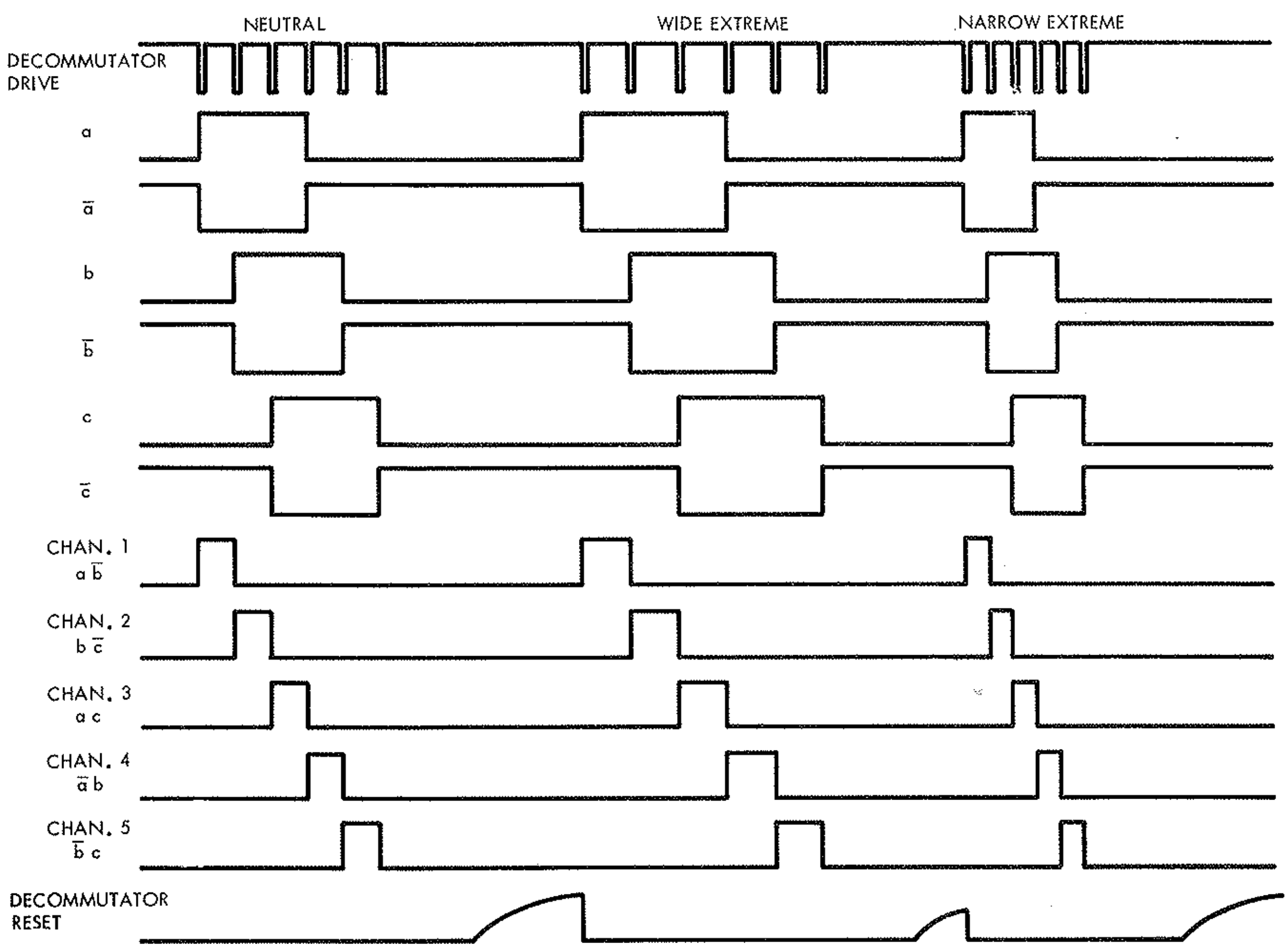


FIG. 7 DIAGRAM - DECODER TIMING



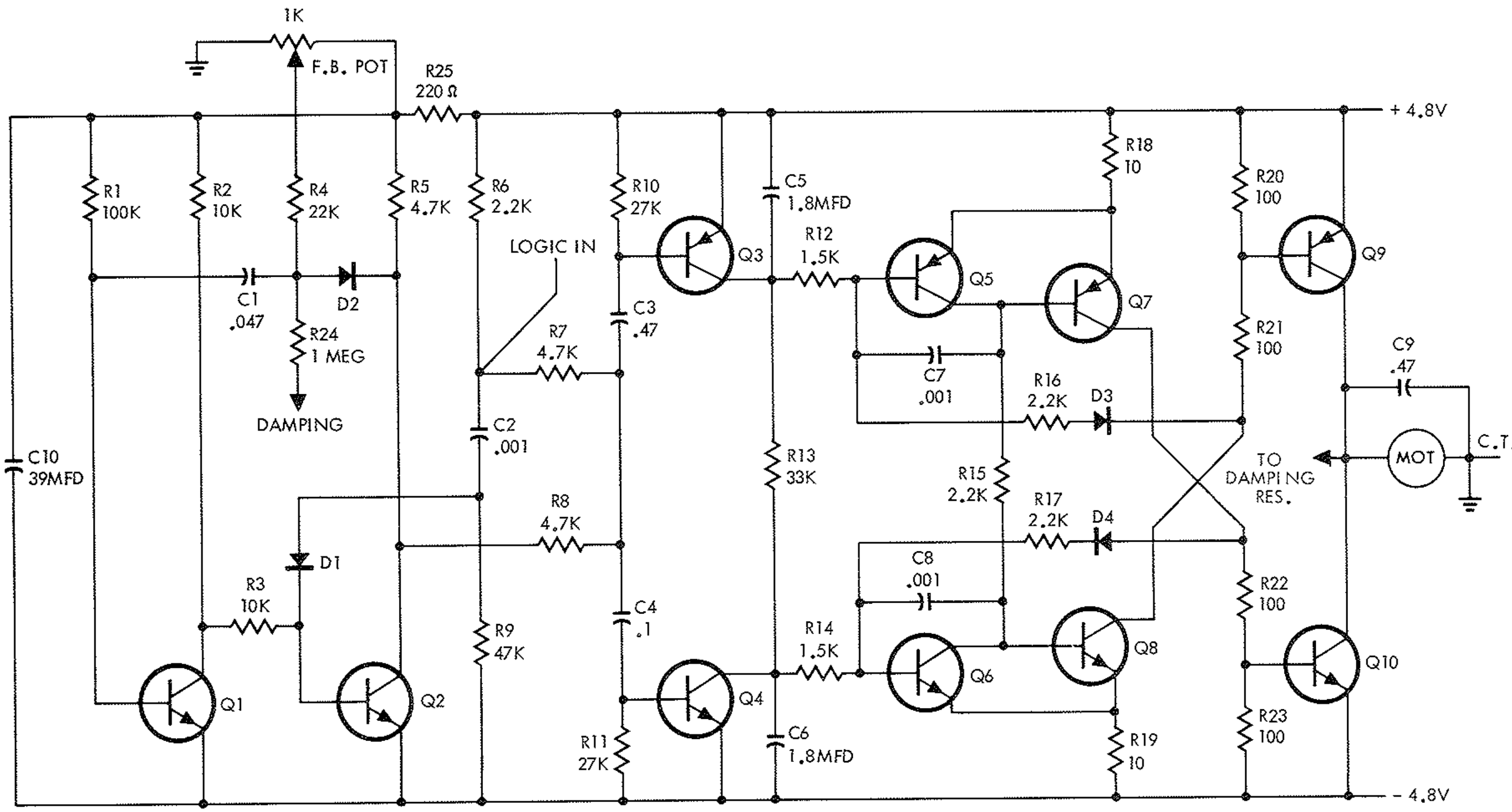
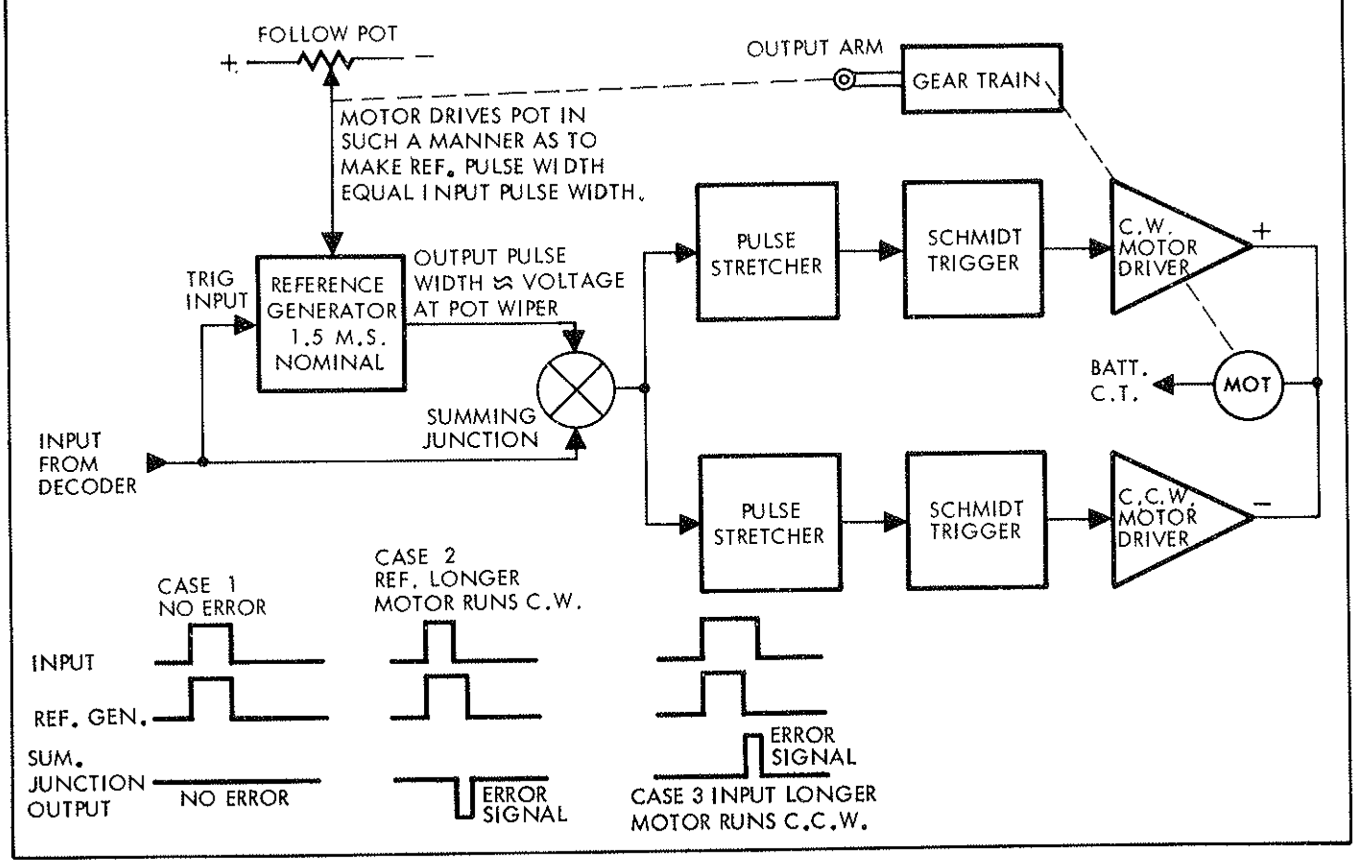
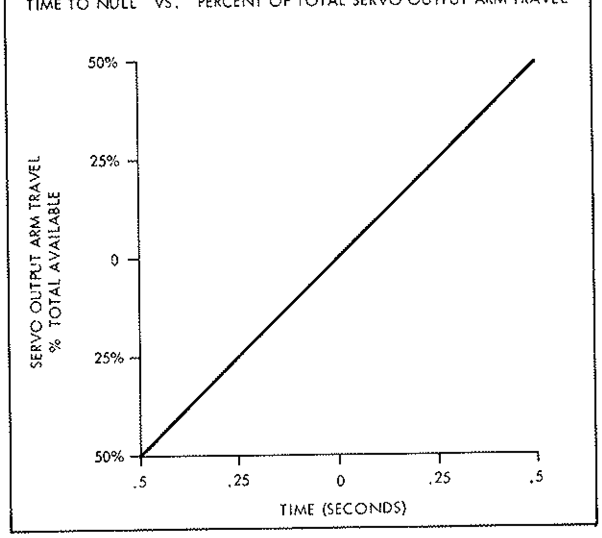


FIG. 8 SERVO AMPLIFIER

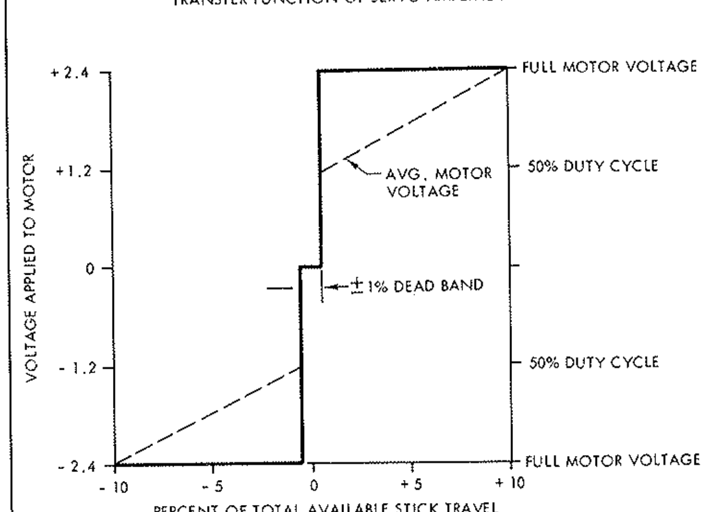
FIG. 9 BLOCK DIAGRAM - SERVO AMPLIFIER



TIME TO NULL VS. PERCENT OF TOTAL SERVO OUTPUT ARM TRAVEL

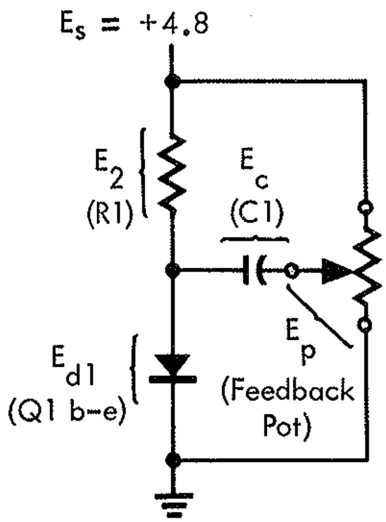


TRANSFER FUNCTION OF SERVO AMPLIFIER

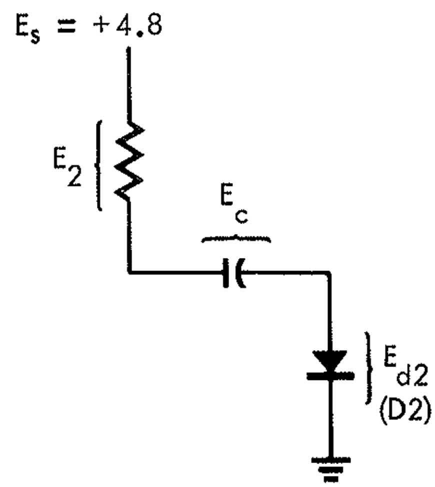


AMPLIFIER OPERATED OPEN LOOP. MOTOR RECEIVES FULL VOLTAGE PULSES STARTING WITH 50% DUTY CYCLE AT 1% ERROR. AT 10% ERROR MOTOR RECEIVES CONTINUOUS D.C. VOLTAGE. MOTOR CONTINUES TO RECEIVE CONTINUOUS VOLTAGE OUT TO THE FULL ±50% ERROR SIGNAL. (100% TOTAL).

FIG. 10 MATHEMATICAL ANALYSIS OF REFERENCE GENERATOR TIMING USING EQUIVALENT CIRCUITS



STABLE STATE EQUIVALENT CIRCUIT



QUASI-STABLE STATE EQUIVALENT CIRCUIT

The basic expression for the time which the Reference Generator will remain in the Quasi-stable State is:

$$T = 2.3\, RC \log \frac{E_1}{E_2}$$

where

T = Reference Time (1.5 Milliseconds Nominal)

2.3 = Natural log to base 10 log conversion factor

R = 100K (R1)

C = 0.047 (C1)

E_1 = Voltage across R1 at start of cycle

E_2 = Voltage across R1 at finish of cycle

deriving E_1, we see that:

$$E_1 = E_s + E_c - E_{d2}$$

but:

$$E_c = E_p - E_{d1}$$

FIG. 10 (Continued)

therefore:

$$E_1 = E_s + E_p - E_{d1} - E_{d2}$$

$$= 4.8 - 1.2 + E_p$$

$$= E_p + 3.6$$

furthermore:

$$E_2 = E_s - E_{d1}$$

$$= 4.2 \text{ V.}$$

Solving the equation for E_1 with a nominal timing of 1.5 Milliseconds:

$$E_1 = E_2 \log^{-1} \frac{T}{2.3\ RC}$$

$$= 4.2 \log^{-1} \frac{1.5 \times 10^{-3}}{2.3 \times 100 \times .047 \times 10^3 \times 10^{-6}}$$

$$= 4.2 \log^{-1} \frac{1.5}{10.8}$$

$$= 5.78 \text{ V.}$$

This is the voltage across R1 immediately after initiation of the Timing Cycle. Since E1 also equals $E_p + 3.6$ we may find the Pot Arm Voltage (E_p) by solving for E_p:

$$E_p = E_1 - 3.6$$

$$= 2.18 \text{ V.}$$

also:

$$\frac{E_p}{E_s} = \frac{4.8}{2.18}$$

therefore:

$$E_p = 0.455\ E_s$$ or 45.5% of supply voltage.

FIG. 10 (Continued)

It can now be shown how the timing will vary with supply voltage thusly: (Figure 11)

$$T = 2.3\,RC \log \frac{E_1}{E_2}$$

since $$E_1 = E_s + E_p - E_{d1} - E_{d2}$$

or $$E_1 = E_s + 0.455E_s - 1.2$$

and $$E_2 = E_s - E_{d1}$$

$$= E_s - 0.6$$

therefore $$T = 2.3RC \log \frac{E_s + 0.455\,E_s - 1.2}{E_s - 0.6}$$

Simplifying, we get:

$$T = 10.8 \log \frac{1.455\,E_s - 1.2}{E_s - 0.6} \text{ Milliseconds}$$

It may be further pointed out that if it were not for the Diodes D1 and D2, the Timing expression would take the following form:

$$T = 10.8 \log \frac{1.455\,E_s}{E_s}$$

$$= 10.8 \log 1.455$$

This says that the Timing would be dependent only on the log of the Pot Arm Ratio, therefore the supply voltage would have no effect on the Timing.

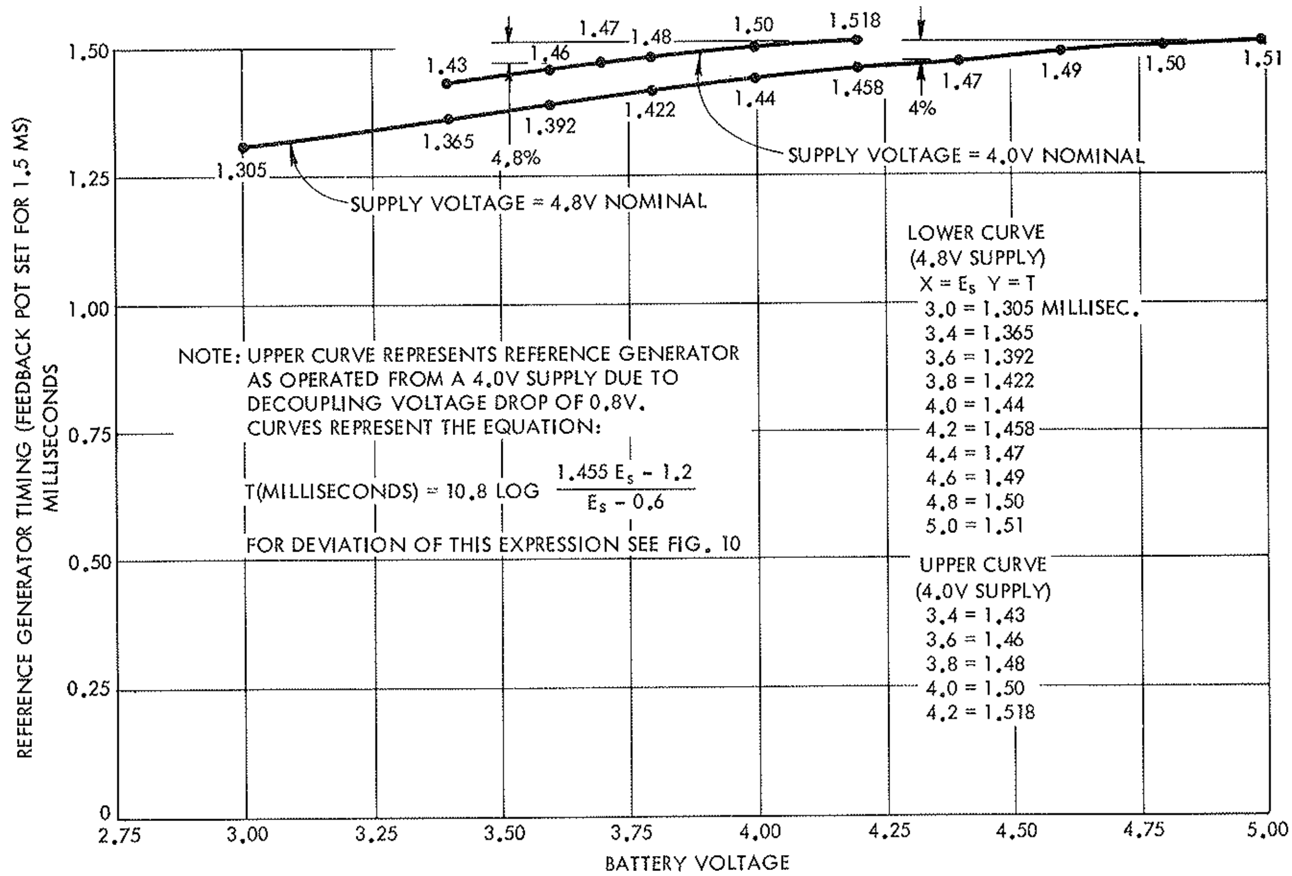
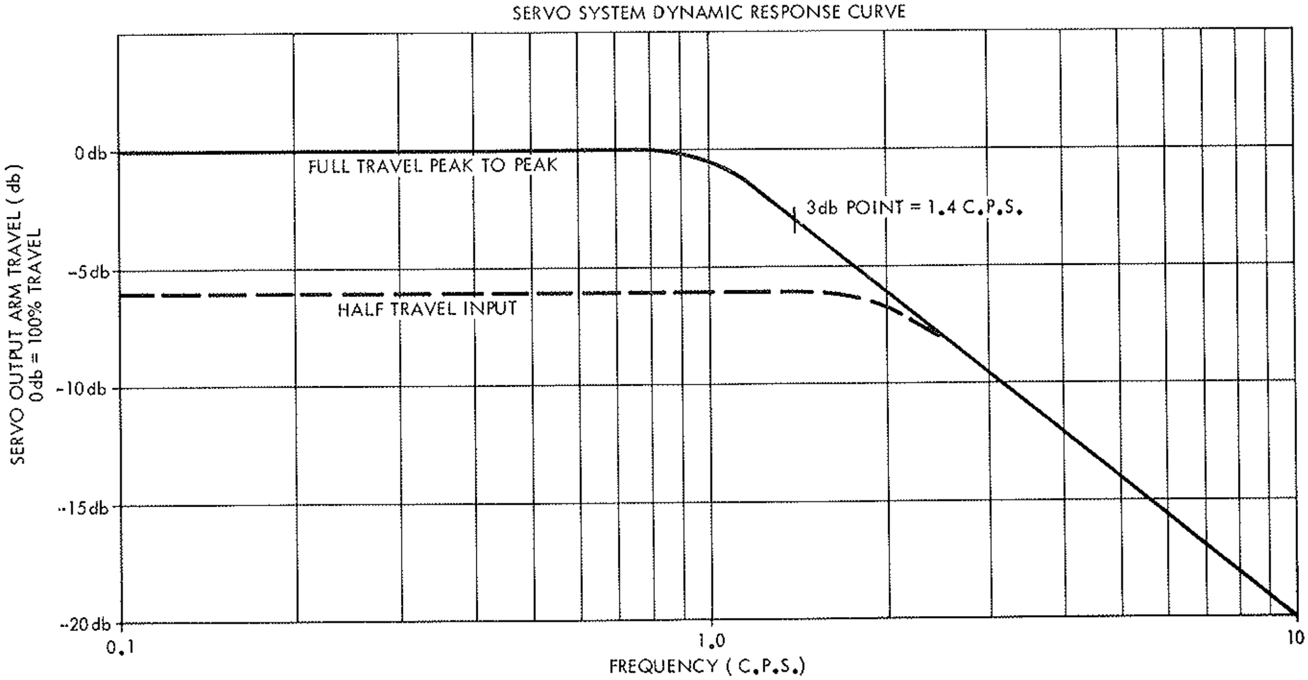


FIG. 11 VARIATION OF REFERENCE GENERATOR TIMING WITH VOLTAGE

SERVO SYSTEM DYNAMIC RESPONSE CURVE



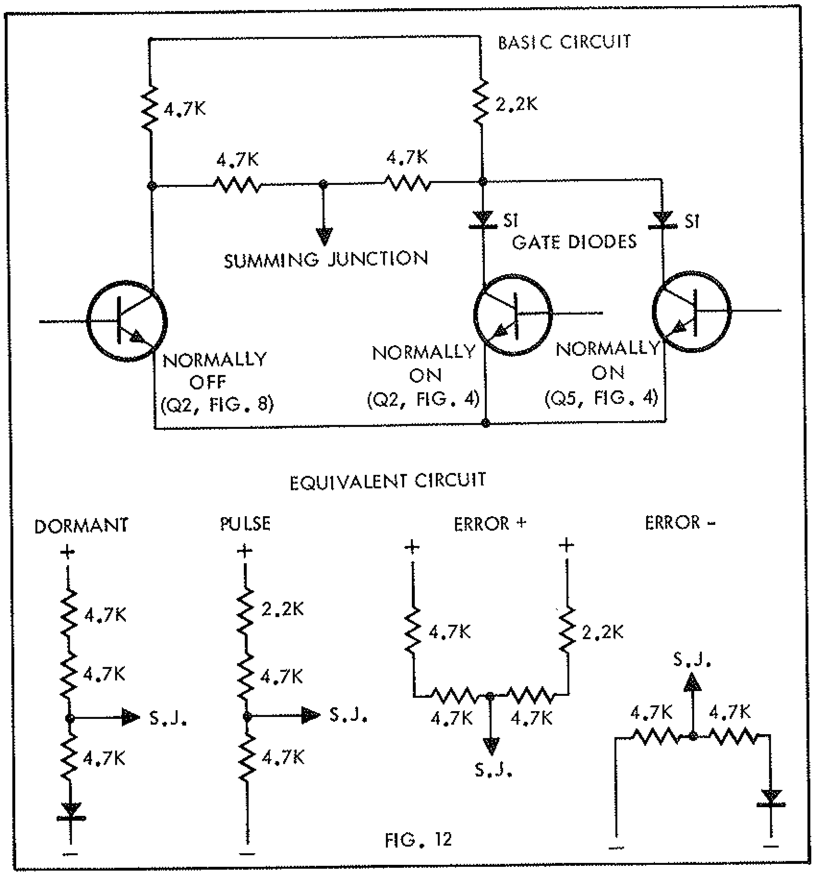


FIG. 12

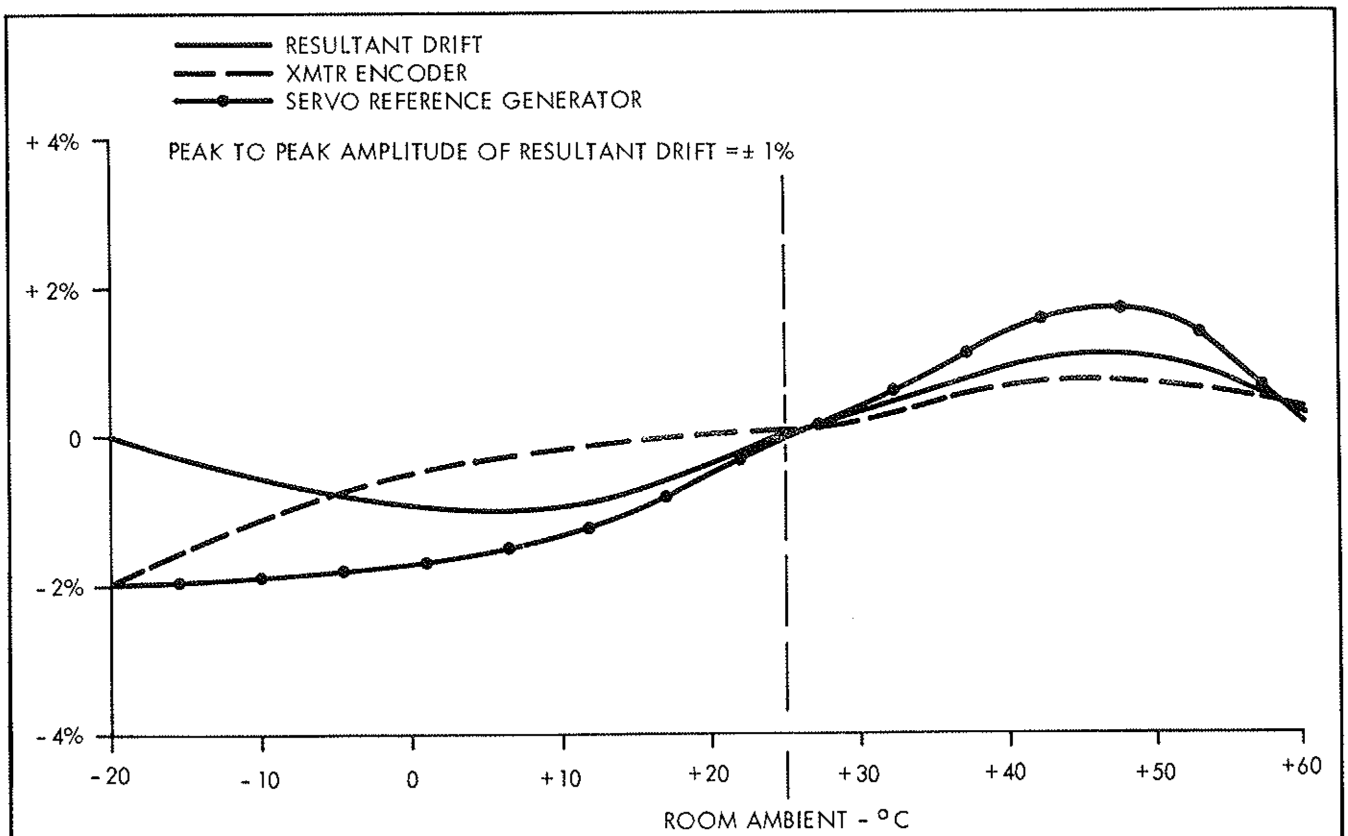
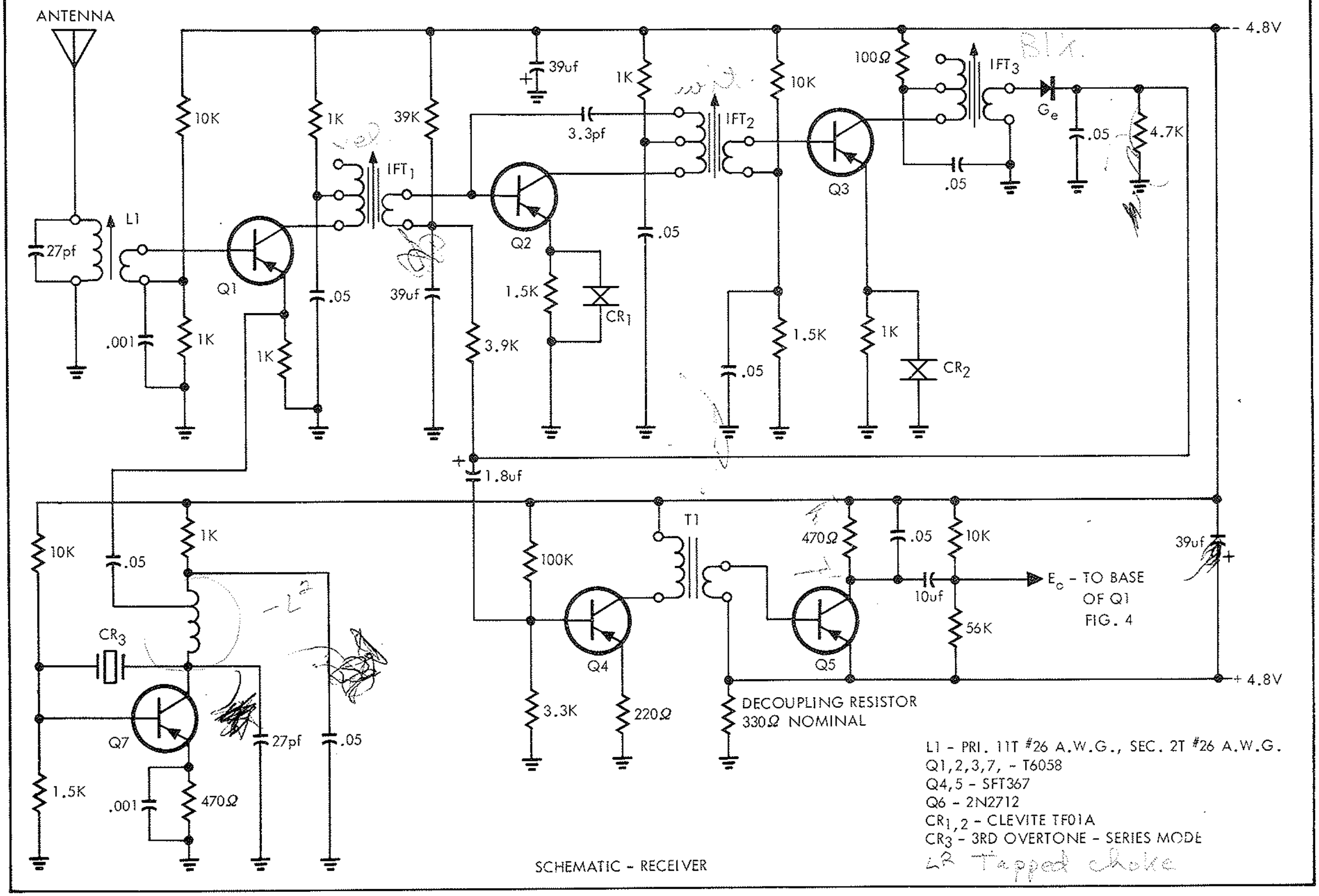


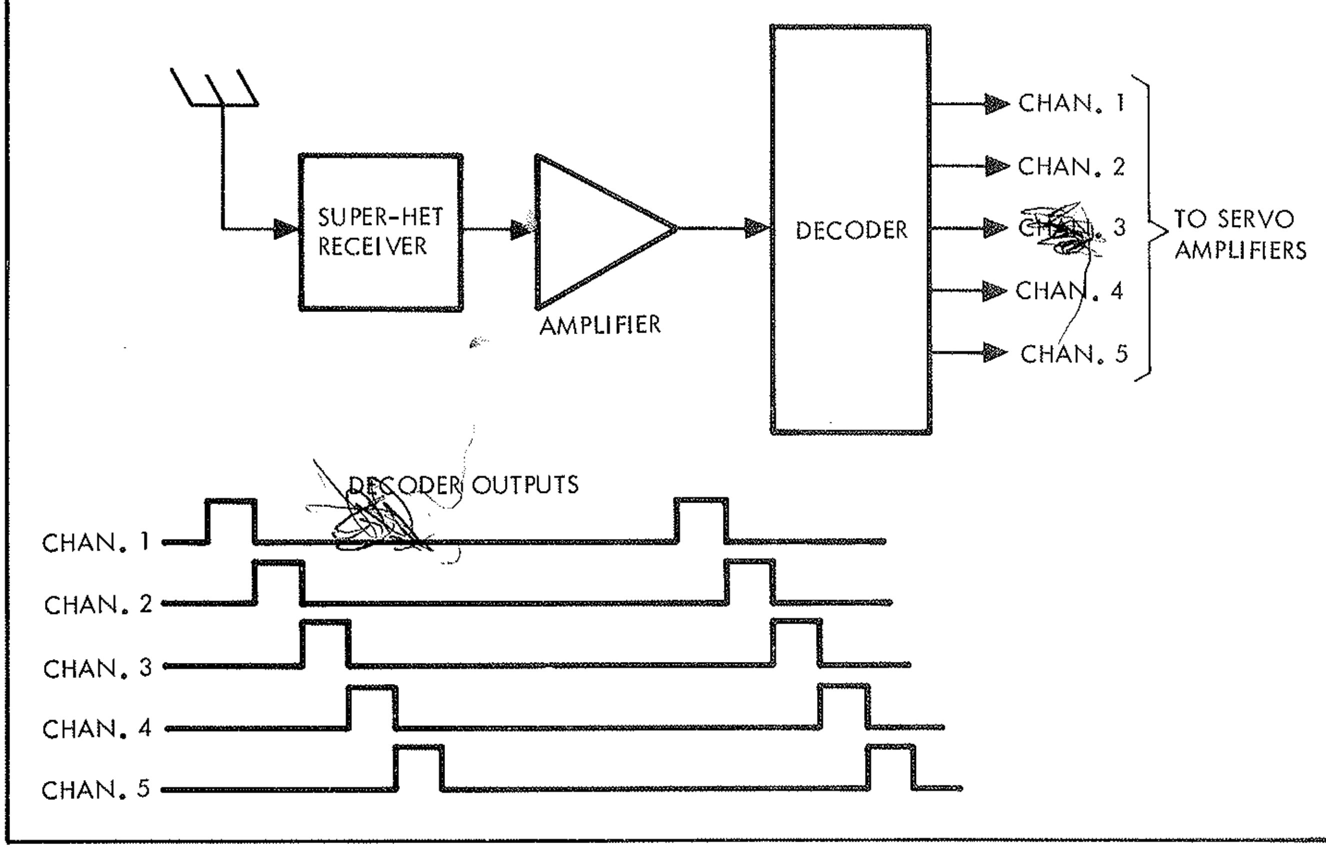
FIG. 13 SYSTEM TEMPERATURE CHARACTERISTICS

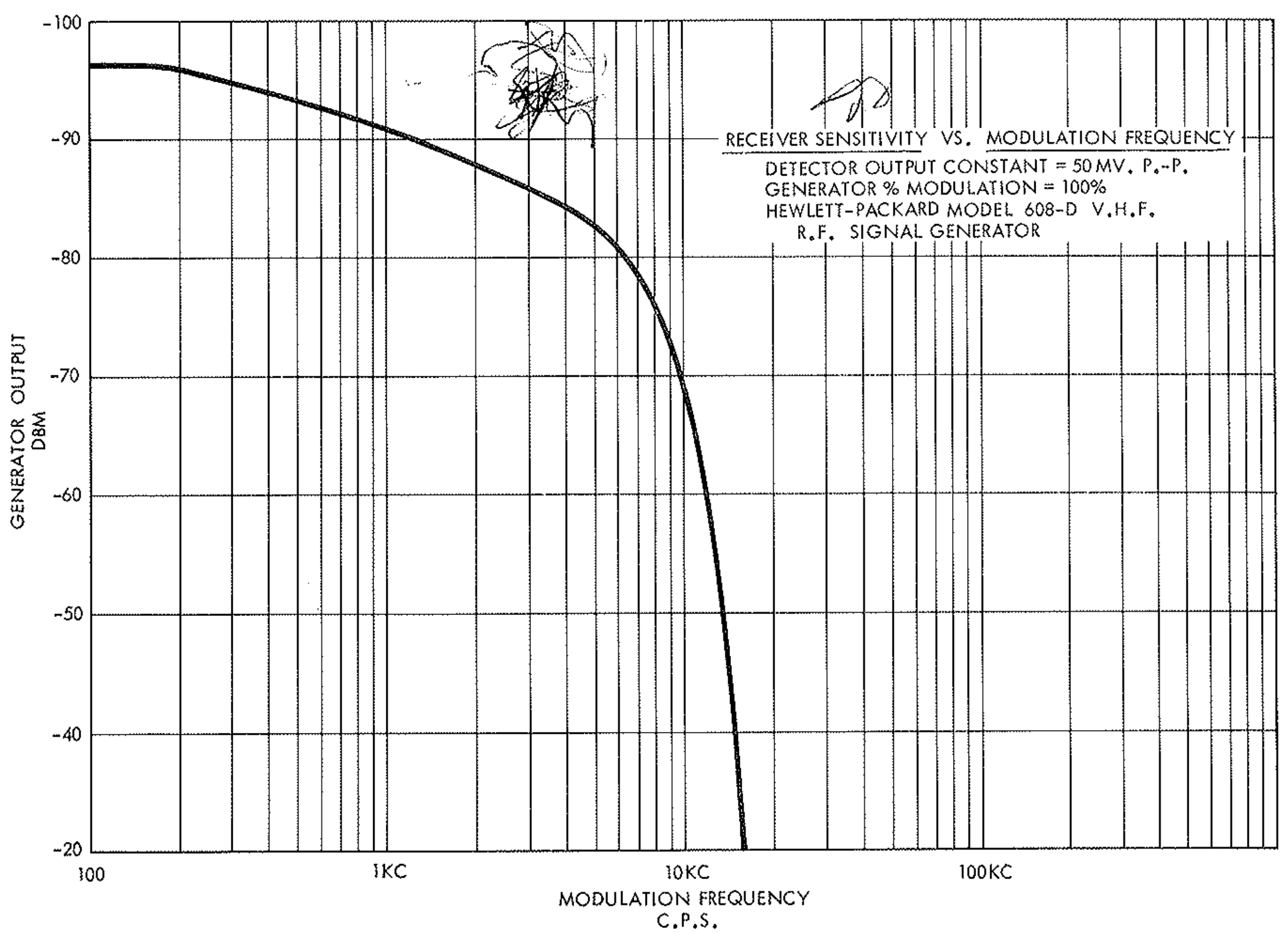


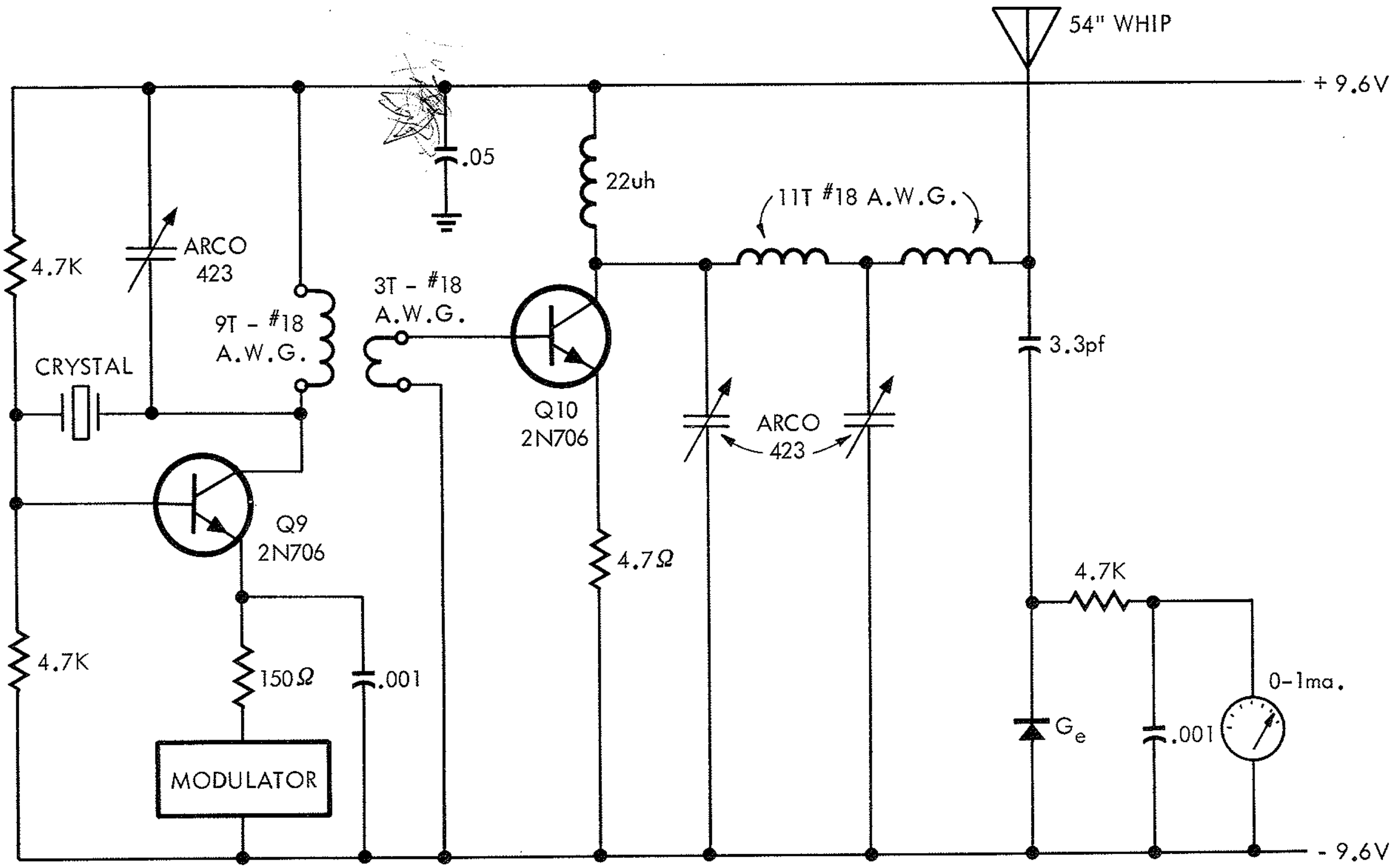
L1 - PRI. 11T #26 A.W.G., SEC. 2T #26 A.W.G.
Q1,2,3,7, - T6058
Q4,5 - SFT367
Q6 - 2N2712
$CR_{1,2}$ - CLEVITE TF01A
CR_3 - 3RD OVERTONE - SERIES MODE
L2 Tapped choke

SCHEMATIC - RECEIVER

BLOCK DIAGRAM - RECEIVER







SCHEMATIC - TRANSMITTER R.F.