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REVIEW OF ELECTRICAL POWER
SYSTEM MATH MODEL FOR COMMAND
MODULE SIMULATOR

MARCH 5, 1969

THE **BOEING** COMPANY ■ SPACE DIVISION

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ABSTRACT

This report constitutes a review of the simulation of the Electrical Power System (EPS) as part of the Command Module Simulator (CMS). The review constitutes an evaluation of CMS-MM-09A, CMS-MM-09B, and CMS-MM-09C math models.

KEY WORDS

Electrical Power System
Command Module Simulator
Pyro Battery
Battery Relay Bus
Flight Bus
Voltage
Current Drain
Fuel Cell
Switch Logic
Inverter
Reverse Current
Battery Charger
Three Phase AC Power
Conductance
Thevenin Equivalent
Norton Equivalent

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REFERENCES

1. CMS-MM-09A (S/C 103 Subs) Apollo Master Command Module Simulator Electrical Power System Logic Math Model, November 8, 1969.
2. CMS-MM-09B (S/C 103 Subs, 106 Subs) Apollo Master Command Module Simulator Electrical Power System Displays Math Model, November 28, 1968.
3. CMS-MM-09C (S/C 103 and Subs) Apollo Master Command Module Simulator Electrical Power System Bus Equations Math Model, Rev. A, November 30, 1968.
4. SM2A-03-Block II, Apollo Operations Handbook Block II Spacecraft Volumes I and II, February 5, 1968.
5. 134-900101 Advanced Functional Integrated Systems Schematics Block II, Revision J, September 30, 1968.
6. SK-10131, EPS-Control and Monitoring -D.C. Power, May 20, 1968.
7. SK-10132, EPS Power Distribution, May 17, 1966.
8. SK-10133, EPS - C/M DC Power Distribution, May 12, 1966.
9. SK-10134, Fuel Cell No. 1, May 18, 1966.
10. V36-977033, Schematic Diagram Auxiliary Circuit Breaker Panel B, RHEB. Revision F, August 22, 1968.
11. V36-771057, Wiring Assembly Circuit Breaker, Fuel Cells and Lighting, Revision B, October 11, 1967.
12. The following SCN's were used to update Math Model 9A, Rev. B:

HO9A-12	HMO9A-01	HMO9A-12	KMO9A-04
HO9A-28	HMO9A-02	HMO9A-13	KMO9A-08
HO9A-29	HMO9A-03	HMO9A-15	KMO9A-09
HO9A-30	HMO9A-04	HMO9A-17	KMO9A-10
HO9A-31	HMO9A-07	HMO9A-18	KMO9A-11
HO9A-32	HMO9A-08	HMO9A-19	KMO9A-12
HO9A-34	HMO9A-09	HMO9A-21	
HO9A-14	HMO9A-10	HMO9A-22	
	HMO9A-11		
13. The following SCN's were used to update Math Model 9B, Rev. B:

HMO9B-01	HMO9B-04	KMO9A-1
HMO9B-02	HMO9B-05	

REFERENCES (Continued)

14. The following SCN's were used to update Math Model 9C, Rev. A:

H09C-38	HM09C-01	KM09C-01
H09C-24	HM09C-02	KM09C-05
	HM09C-05	
	HM09C-06	
	HM09C-09	

1.0 INTRODUCTION

This report is in response to AVO RDMc 218. The task required review of the Simulated Electrical Power System (EPS) in the Command Module Simulator (CMS).

The EPS simulations simulate the function of the EPS in the CSM. Electrical power is transferred to the power busses and made available to the various loads. As other simulations demand electrical power, a record of power dissipation is kept by the EPS simulation. Power utilization is reflected back to the power sources in indications of voltage supplied and current drains.

The task was initiated by putting math model event logic in a more readily usable form. These flow charts are shown in Appendix A. The math model event logic sequences the solution of the detailed equations. Block diagrams of the detailed equations are shown in Appendix B. These diagrams were used to provide details of the equations quickly without reference to symbol definition lists.

2.0 OBJECTIVE

The objective of this report is to evaluate the presently Simulated Electrical Power System in the Command Module Simulators. Any deficiencies noted in math model function will be defined and suggestions for improvements will be made.

3.0 SCOPE

The math models CMS-MM-09A, 09B, and 09C were evaluated as simulations of the Electrical Power System (EPS). The actual interfaces with other simulations were not considered other than the recognition of a command for power.

An evaluation of Assembly Language Program was not accomplished. This part of the evaluation was considered beyond the scope of the present AVO. The present evaluation is limited to a review of the three EPS math models noted above. The possibility that the math models do not describe the simulation programs was not considered.

4.0 SUMMARY

<u>Problem</u>	<u>Recommendation</u>
(Ref. Section 6.1.1) The flow chart for C09AD0 calls for the solution of equation C2C3 for boolean C157. This equation is not defined in the present math model.	It is recommended that this equation be defined or deleted from the program.
(Ref. Section 6.1.2) The flow chart for program C09AD0 calls for the solution of equation C4B7. This equation is not defined in the present math model.	It is recommended that this equation be defined or deleted from this program.
(Ref. Section 6.1.3) The flow chart for program C09AE0 calls for the solution of equation C6A15 for boolean C233. This equation is not listed in the present math model.	It is recommended that this equation be defined or deleted from the program.
(Ref. Section 6.1.4) The flow chart for program C09AE0 calls for the solution of equation C6B46 for function CTOL3B. This equation is not defined in the math model.	It is recommended that equation C6B46 be added to the program with the following equality: $CTOL3B = CTOL3B + CDET1$
(Ref. Section 6.1.5) The flow chart for program C09AE0 calls for the solution of equation C6B47 for boolean C330. This equation is not defined in the math model.	It is recommended that equation C6B47 be added to the program with the following equality: $C330 = 1; \text{ if } CTOL3B > COLDT3B$ and $(CB1PBL)(C291) > (CB2PBL)(C293)$
(Ref. Section 6.1.6) The flow chart of program C09AE0 calls for the solution of C6B48 for boolean C331. This equation is not defined in the math model.	It is recommended that the equation C6B48 be added to the program with the following equality: $C331 = 1; \text{ if } CTOL3B > COLDT3B$ and $(C291)(CB1PBL) \geq (C293)(CB2PBL)$

4.0 CONTINUED

Problem

(Ref. Section 6.1.7)

CLOOP2A contains logic to determine values for booleans C801 and C802. This loop is accomplished five times. It seems that once should be sufficient. Secondly, the math model sets a counter IR1 = -5. The test to start the loop again is accomplished by incrementing IR5. It is assumed that IR5 should be replaced with IR1. Thirdly, equations C2B2 and C2B6 define values for C801 and C802 respectively but are never called up by the program.

(Ref. Section 6.1.8)

CLOOP3 contains logic to define boolean C001. C001 is also defined by equation C2B7. Although equation C2B7 is solved, it is never utilized due to the logic contained in CLOOP3.

(Ref. Section 6.1.9)

A value for (C208)(C444) is computed and stored in WTEMP16 and WTEMP17.

(Ref. Section 6.1.10)

A value for (C208)(C443) is computed and stored in WTEMP15 and WTEMP20.

(Ref. Section 6.1.11)

A value for (C208)(C445) is computed and stored in WTEMP18 and WTEMP19.

(Ref. Section 6.1.12)

Computation for CB1PCL (Equation C3B4) is in error. The variable CB2CL is used incorrectly.

Recommendation

It is recommended that the solution of boolean C801 and C802 be accomplished only once and that equations C2B2 and C2B6 be deleted from the program.

It is recommended that the logic in CLOOP3 be revised to utilize equation C2B7 in solving for boolean C001.

It is recommended that one of these storage locations be deleted.

It is recommended that one of these storage locations be deleted.

It is recommended that one of these storage locations be deleted.

It is recommended that the variable CB2CL be replaced with CB1CL in equation C3B4.

4.0 CONTINUED

Problem

(Ref. Section 6.1.13)

A test is made on CTOL1A through CTOL3C. If overload duration, CTOLnp, is less than or equal to the corresponding overload time delay, COLDTnp, a logic output should be defined. This output is not defined in the math model.

(Ref. Section 6.1.14)

The following equations are listed in the math model but not utilized in the program:

C1C12A
C2G9
C4B13
C6A4A1
C6A9A1
C6A10A
C6A14A1

(Ref. Section 6.1.15)

CLOOP8 develops logic for determining booleans C219, C220, C221, C223, C224, and C225. Equations C3B36, C3B37, C3B38, C3B41, C3B42, and C3B43 also define these same booleans but are not utilized in the program.

(Ref. Section 6.1.16)

Equation C4B4.1 - there is a decision made to set boolean C370 depending upon the magnitude of C/M Main Bus A and B voltages. If the main bus voltages are equal, boolean C370 could be a "one" or a "zero".

(Ref. Section 6.1.17)

The heat produced by Inverter #2 and Inverter #3 equations (C6A6 and C6A11) are incorrect.

Recommendation

It is recommended that a logic output be added to the decision block which sets the overload disconnect booleans C316 through C333 equal to zero. Note recommended change per dotted line in Appendix A, Figure A-4.

It is recommended that the equations be either utilized or deleted from the program.

Since the booleans are developed in CLOOP8, it is recommended that equations C3B36, C3B37, C3B38, C3B41, C3B42, and C3B43 be deleted from the program.

It is recommended that equation C4B4.1 be changed to the following:
C370 = 1; if CDCVBACM $\geq$ CDCVBBCM
C370 = 0; if CDCVBACM $<$ CDCVBBCM

It is recommended that equations C6A6 and C6A11 be revised to reflect heat produced by an inverter as a function of inverter current. This can be done by substituting C5C01 and C5C02 for C501 and C502 respectively in the present equations.

4.0 CONTINUED

Problem

(Ref. Section 6.3.1)

In equation C2A7, the booleans C200 and C201 do not agree with present spacecraft design.

(Ref. Section 6.3.2)

In the following fuel cell control equations, the boolean D550N was omitted:

C2A1, C2A2, C2A5, C2A7, C2A8, C2A9, C2A10, C2A11, C2A12, C2A15, C2A17, C2A8, C2A20, C2A21, C2A22, C2A25, C2A27, C2A28, and C2A30.

(Ref. Section 6.3.3)

The following equations are listed in the math model but not utilized in the program:

CA1A, CA1B, CB12A, CB12B, CB12C, CD6A, CD6B, CF12A

(Ref. Section 6.3.4)

Utilization of variables P5C49 and P5C48 in equation CA8 is incorrect.

(Ref. Section 6.3.5)

Utilization of variables P5C32 and P5C33 in equation CA10 is incorrect.

(Ref. Section 6.3.6)

In equation CF13, the calculation for battery charger approximate voltage is in error.

Recommendation

It is recommended that booleans C200 and C201 be switched to C201 and C200 respectively to make the software consistent with hardware design.

It is recommended that the boolean D550N (C/M-S/M not separated) be inserted in the equations listed.

It is recommended that the listed equations be utilized or deleted from the program.

It is recommended that the variables P5C48 and P5C49 be replaced by variables P5C32 and P5C33 respectively.

It is recommended that the variables P5C32 and P5C33 be replaced by P5C48 and P5C49 respectively.

It is recommended that the detailed equation for CF13 be revised to be consistent with the CF13 equations developed in the sequencing portion of the math model.

4.0 CONTINUED

Problem

(Ref. Section 6.3.7)

The utilization of boolean C032 in equation CA9 is in error.

(Ref. Section 6.3.8)

The utilization of boolean C032 in equation CA10 is in error.

(Ref. Section 6.3.9)

The utilization of boolean C032 in equation CA11 is in error.

(Ref. Section 6.3.10)

The logic loop set up for calculation of Bat B Norton equivalent conductance and current is in error.

(Ref. Section 6.3.11)

Equation CA9, calculation of S/M Bus A conductance is in error.

(Ref. Section 6.3.12)

Equation CA11, calculation of S/M Bus B conductance is in error.

Recommendation

It is recommended that equation CA9 be changed as follows:

Now: $CGSMBA = (C032)(CLOADSMA)$
~~C032~~ (-----)

Should be:

$CGSMBA = (C032)(CLOADSMA)$
~~C032~~ (-----)

It is recommended that equation CA10 be changed as follows:

Now: $CGCMBB = (C032)(CLOADCMB)$
~~C032~~ (-----)

Should be:

$CGCMBB = (C032)(CLOADCMB)$
~~C032~~ (-----)

It is recommended that equation CA11 be changed as follows:

Now: $CGSMBB = (C032)(CLOADSMB)$
~~C032~~ (-----)

Should be:

$CGSMBB = (C032)(CLOADSMB)$
~~C032~~ (-----)

It is recommended that the sequence flow for calculation of equations CD13 and CD16 be changed per the dotted line in Appendix A.

It is recommended that the term H2C12 be replaced with H2C11 in equation CA9.

It is recommended that the term H2C11 be replaced with H2C12 in equation CA11.

4.0 CONTINUED

Problem

(Ref. Section 6.3.13)

The present logic loop established to calculate the approximate battery charger voltage could result in a condition where the program would go into a continuous loop.

(Ref. Section 6.3.14)

There is no apparent reason for the logic decision developed in the sequence flows concerning the booleans C821, C822, C817, and C818.

(Ref. Section 6.3.15)

The present EPS simulation does not simulate the effect of battery temperature upon battery voltages.

Recommendation

It is recommended that the logic loop described be changed per dotted line in Appendix A.

It is recommended that the reason for the decision block be investigated for possible deletion from the program.

It is recommended that a parametric study of battery voltages dependent upon state of charge, load and temperature be undertaken and that these results be incorporated into the present EPS simulation.

5.0 CONCLUSIONS

The basic math models CMS-MM-09A, 09B, and 09C form a consistent simulation of the Electrical Power System (EPS). Since an evaluation of the Assembly Language Program was not accomplished, comments cannot be made concerning the efficiency of the simulation with respect to computer core space utilized. It is recognized that modified computer programs result in redundant variable scaling and computational procedures. If adequate memory is available for the simulation and the real time aspect of the simulation is not compromised, reprogramming of the EPS simulation is not recommended. The actual reprogramming would be more efficiently accomplished in preparation for use of the EPS simulation in future applications. The evaluation of the math models, noted above, consisted of a determination of the fidelity of the simulation models. A number of discrepancies were noted in the course of the review. These are summarized in Section 4.0 and described in detail in Section 6.0. These discrepancies were described, assuming that the math models describe the engineering content of the simulation programs.

6.0 DISCUSSION

6.1 ELECTRICAL POWER SYSTEMS LOGIC, MATH MODEL CMS¹/MM-09A

The EPS control logic controls most of the operations within the EPS. Using switch positions and event occurrences as its input, the control logic equations provide signals for the simulation of the following:

- a. Fuel Cell Control and Overload Sensing
- b. Fuel Cell, Radiator, and Ph-Hi Talkback Indications
- c. Main Bus Ties
- d. Battery Charger
- e. Availability of Power (AC/DC)
- f. AC/DC Undervoltage and Overvoltage
- g. Inverter Control and Overload Sensing
- h. AC Bus Loads
- i. Lighting, LEM, CSM, and Telecom Power (AC/DC)

6.1.1 Recommendation to Delete Equation C2C3

The sequence flow chart for C09ADO (Ref. Appendix A, Figure A-1) calls for solution of equation C2C3 for boolean C157. This equation is not listed in the present math model. It is recommended that this equation be defined or deleted from the program.

6.1.2 Recommendation to Delete Equation C4B7

The sequence flow chart for C09ADO (Ref. Appendix A, Figure A-3) calls for the solution of equation C4B7 for function C5C87. This equation is not defined in the present math model. It is recommended that this equation be defined or deleted from the program.

6.1.3 Recommendation to Delete Equation C6A15

The sequence flow chart for C09AEO (Ref. Appendix A, Figure A-4) calls for the solution of C6A15 for boolean C233. This equation is not defined in the present math model. It is recommended that this equation be defined or deleted from the program.

6.1.4 Recommendation to Add Equation C6B46 to the Present Math Model

The sequence flow chart for program C09AEO calls for solution of equation C6B46 for function CTOL3B. This equation is not defined in the math model. It is recommended that equation C6B46 be added to the program with the following equality:

$$CTOL3B = CTOL3B + CDET1$$

6.1.5 Recommendation to Add Equation C6B47 to the Present Math Model

The sequence flow chart for program C09AEO calls for the solution of equation C6B47 for boolean C330. This equation is not defined in the present math model. It is recommended that equation C6B47 be added to the program with the following equality:

$$C330 = 1; \text{ if } CTOL3B > COLDT3B \text{ and } (CB1PBL)(C291) > (CB2PBL)(C293)$$

6.1.6 Recommendation to Add Equation C6B48 to the Present Math Model

The sequence flow chart for program C09AEO calls for the solution of equation C6B48 for boolean C331. This equation is not defined in the present math model. It is recommended that equation C6B48 be added to the program with the following equality:

$$C331 = 1; \text{ if } CTOL3B > COLDT3B \\ \text{and} \\ (C291)(CB1PBL) \geq (C293)(CB2PBL)$$

6.1.7 Recommendation to Delete Equations C2B2 and C2B6 from Present Math Model

Sequence flow of CLOOP2A (Ref. Appendix A, Figure A-1) contains logic to determine the values for booleans C801 and C802. The logic results in a loop that tests E383, C659, and C660 to determine values for C801 and C802. This loop is accomplished five times. It seems that one calculation should be sufficient. Secondly, the math model sets a counter IR1 = 05. The test to start the loop again is accomplished by incrementing IR5. It is assumed that IR5 should be replaced with IR1. Thirdly, equations C2B2 and C2B6 define values for C801 and C802 respectively but are never called up by the sequencing program. It is recommended that the solution for booleans C801 and C802 be accomplished only once and that equations C2B2 and C2B6 be deleted from the program.

6.1.8 Recommendation to Change Sequencing Logic for Calculation of Boolean C001 in Equation C2B7

CLOOP3, in the sequencing flow charts (Ref. Appendix A, Figure A-1), contains logic to define boolean C001. C001 is also defined by equation C2B7. Although equation C2B7 is solved, it is never utilized due to the logic contained in CLOOP3. It is recommended that the logic in CLOOP3 be revised to utilize equation C2B7 in solving for boolean C001.

6.1.9 Recommendation to Increase the Number of Available Computer Storage Locations

A value for (C205)(C444) is computed and stored in WTEMP16 and WTEMP17. It is recommended that one of these storage locations be deleted.

6.1.10 Recommendation to Increase the Number of Available Computer Storage Locations

A value for (C208)(C443) is computed and stored in WTEMP15 and WTEMP20. It is recommended that one of these storage locations be deleted.

6.1.11 Recommendation to Increase the Number of Available Computer Storage Locations

A value for (C208)(C445) is computed and stored in WTEMP18 and WTEMP19. It is recommended that one of these storage locations be deleted.

6.1.12 Recommendation to Change Equation C3B4, AC Bus 1 Phase C Current Loading

Computation for CB1PCL is in error. This equation uses a value of CB2CL which is defined as the AC Bus 2 Common 3 Phase Loading per phase. Equation C3B4 should utilize AC Bus 1 loading values only. It is recommended that the variable CB2CL be replaced with CB1CL in equation C3B4.

6.1.13 Recommendation to Add a Logic Output in CLOOP12 of the Sequencing Portion of Math Model

In CLOOP12 (Ref. Appendix A, Figure A-4), a test is made on CTOL1A through CTOL3C. If the overload duration, CTOLnp is less than or equal to the corresponding overload time delay, COLDTnp, a logic output should be defined. This output is not defined in the math model. It is recommended that a logic output be added to the decision block which sets the overload disconnect booleans C316 to C333 equal to zero. Note the recommended change per the dotted line in Appendix A.

6.1.14 Recommendation to Add Equations to the Sequencing Portion of the Math Model

The following equations are defined but not utilized in the sequencing portion of the math model:

C1C12A	C6A4A1
C2G9	C6A9A1
C4B13	C6A10A
	C6A14A1

It is recommended that the above equations be utilized or deleted from the program.

6.1.15 Recommendation to Delete Equations C3B36, C3B37, C3B38, C3B41, C3B42, and C3B43

CLOOP8 (Ref. Appendix A, Figure A-3) of the sequencing portion of math model develops logic for determining values of booleans C219, C220, C221, C223, C224, and C225. Since the equations listed above also define these same booleans but are not utilized in the program, it is recommended that these equations be deleted from the program.

6.1.16 Recommendation to Change Equation C4B4.1, C/M Main Bus A and C/M Main Bus B Voltages

Boolean C370 is set depending upon the magnitude of C/M Main Bus A and B voltages. If the main busses are equal, boolean C370 could be a logic "one" or "zero". It is recommended that equation C4B4.1 be changed to the following:

$$\begin{aligned} C370 &= 1; \text{ if } CDCVBACM \geq CDCVBBCM \\ C370 &= 0; \text{ if } CDCVBACM < CDCVBBCM \end{aligned}$$

6.1.17 Recommendation to Change Equation C6A6 and C6A11

Equations C6A6 and C6A11 are defined as the heat produced by Inverter #2 and Inverter #3 respectively. The heat produced should be a function of the individual inverter currents. It is recommended that equations C6A6 and C6A11 be changed to reflect this by substituting C5C01 and C5C02 for C501 and C502 respectively in the present math model equations.

6.2 ELECTRICAL POWER SYSTEMS DISPLAYS, MATH MODEL CMS-MM-09B

The equations developed in this math model provide the Simulated Command Module and the IOS with visual indications of the EPS simulated status. This math model also conditions EPS signals for telemetry transmissions. No discrepancies were noted upon review of Electrical Power Systems Displays Math Model CMS-MM-09B.

6.3 ELECTRICAL POWER SYSTEM BUS EQUATIONS, MATH MODEL CMS-MM-09C

The equations developed in this math model are to provide signals for the simulation of the following:

- a. DC Bus Voltages and Loads
- b. Battery and Fuel Cell Currents
- c. Fuel Cell Sensor Currents
- d. Circuit Breaker Trip Currents
- e. Charging and Discharging of Batteries

6.3.1 Recommendation to Change Equation C2A7, Fuel Cell No. 1 Oxygen Purge Function

In equation C2A7 (Ref. Appendix B, Figure B-2A) the power for the purge function is dependent upon boolean C200 or (C201 and C561). Investigation per references 10 and 11 has revealed that power for this function is dependent upon C201 or (C200 and C561). It is recommended that C200 and C201 be switched to make the software consistent with hardware.

6.3.2 Recommendations to Change the Following Fuel Cell Control Equations C2A1, C2A2, C2A5, C2A8, C2A10, C2A9, C2A7, C2A11, C2A12, C2A15, C2A18, C2A20, C2A17, C2A21, C2A22, C2A25, C2A28, C2A30, and C2A27

All fuel cell control functions must include the boolean D550N (C/M-S/M not separated) for proper operation. It is recommended that the boolean D550N be inserted into the equations listed above.

6.3.3 Recommendation to Add Equations to Sequencing Flow Charts of Program 9C

The following equations are developed in the detailed equations of the program but are not included in the sequencing portion of the math model per the existing flow charts:

CA1A, CA1B, CB12A, CB12B, CB12C, CD6A, CD6B, and CF12A

Since the above list of equations must be computed in the math model, it is recommended that the existing sequence flow charts be revised to reflect their computation.

6.3.4 Recommendation to Change Equation CA8, Load Conductance of C/M Bus A

Calculation of C/M Bus A conductance contains two terms which are associated with main bus B. It is recommended that the terms P5C48 and P5C49 be replaced with the terms P5C32 and P5C33 respectively.

6.3.5 Recommendation to Change Equation CA10, Load Conductance of C/M Bus B

Calculation of C/M Bus B conductance contains two terms which are associated with main bus A. It is recommended that the terms P5C32 and P5C33 be replaced with P5C48 and P5C49 respectively.

6.3.6 Recommendation to Change Equation CF13, Battery Charger Approximate Voltage

A calculation of battery charger approximate voltage is obtained by making a summation of line conductances in equation CF13 (Ref. Appendix B, Figure B-51C). An equation of this nature is an obvious error. It is recommended that equation CF13 be revised to be consistent with the battery charger voltages developed in the sequencing portion of the math model (Ref. Appendix A, Figure A-10).

6.3.7 Recommendation to Change Equation CA9, Load Conductance of S/M Bus A

An error in equation CA9 is due to incorrect usage of boolean C032. The boolean C032 is defined as a main-bus-test-load-boolean. Equation CA9 should be developed to use a test load or an actual load. Therefore, equation CA9 should be changed to the following:

Now: $CGSMBA = (C032)(CLOADSMA) \# C032 \text{ (---)}$
 Should be: $CGSMBA = (C032)(CLOADSMA) \# \frac{C032}{C032} \text{ (---)}$

6.3.8 Recommendation to Change Equation CA10 Load Conductance of C/M Bus B

An error in equation CA10 is due to incorrect usage of boolean C032. The boolean C032 is defined as a main-bus-test-load-boolean. Equation CA10 should be developed to use a test load or an actual load. Therefore, equation CA10 should be changed to the following:

Now: $CGCMBB = (C032)(CLOADCMB) \# C032 \text{ (----)}$
 Should be: $CGCMBB = (C032)(CLOADCMB) \# \frac{C032}{C032} \text{ (----)}$

6.3.9 Recommendation to Change Equation CA11, Load Conductance of S/M Bus B

An error in equation CA11 is due to incorrect usage of boolean C032. The boolean C032 is defined as a main-bus-test-load-boolean. Equation CA11 should be developed to use a test load or an actual load. Therefore, equation CA11 should be changed to the following:

Now: $CGSMBB = (C032)(CLOADSMB) \# C032 \text{ (-----)}$
 Should be: $CGSMBB = (C032)(CLOADSMB) \# \frac{C032}{C032} \text{ (-----)}$

6.3.10 Recommendation to Change Sequence Flowchart for Calculating Battery B Norton Equivalent Current and Conductance

The logic loop that is presently set up for calculation of the Battery B Norton Equivalent current and conductance will set both the equivalents equal to zero regardless of the spacecraft circuit breaker configuration. It is recommended that the sequence flow for calculation of equations CD13 and CD16 be changed per the dotted line in Appendix A, Figure A-7, to correct this situation.

6.3.11 Recommendation to Change Equation CA9, Load Conductance of S/M Bus A

Calculation of S/M Bus A Load Conductance contains a term which is associated with S/M Bus B. It is recommended that the term H2C12 be replaced with H2C11.

6.3.12 Recommendation to Change Equation CA11, Load Conductance of S/M Bus B

Calculation of S/M Bus B Load Conductance contains a term which is associated with S/M Bus A. It is recommended that the term H2C11 be replaced with H2C12.

6.3.13 Recommendation to Change the Sequence Flow for Developing the Approximate Battery Charger Voltage

The present logic loop in Appendix A, Figure A-11, is in error. A condition exists where the program could go into a continuous loop because one output of a decision block is essentially tied to the input of the same decision block. It is recommended that the negative output of the decision, CVCHGC-.75 CDCVBBCM, be routed to 11E rather than 11D to avoid getting into a continuous loop.

6.3.14 Recommendation for Possible Deletion of Circuit Breaker Trip Logic

There is no apparent reason for the logic decision developed in sequence flow Appendix A concerning circuit breaker trip test booleans C822, C821, C817, and C818. It is recommended that the reason for this decision block be investigated for possible deletion from the program.

6.3.15 Recommendation to Add Battery Temperature Effects to the EPS Simulation

The present EPS simulation does not simulate the effect of battery temperature upon battery voltages. It is recommended that a parametric study of battery voltages dependent upon state of charge, load, and battery temperature be undertaken and that these results be incorporated into the present EPS simulation.

APPENDIX A

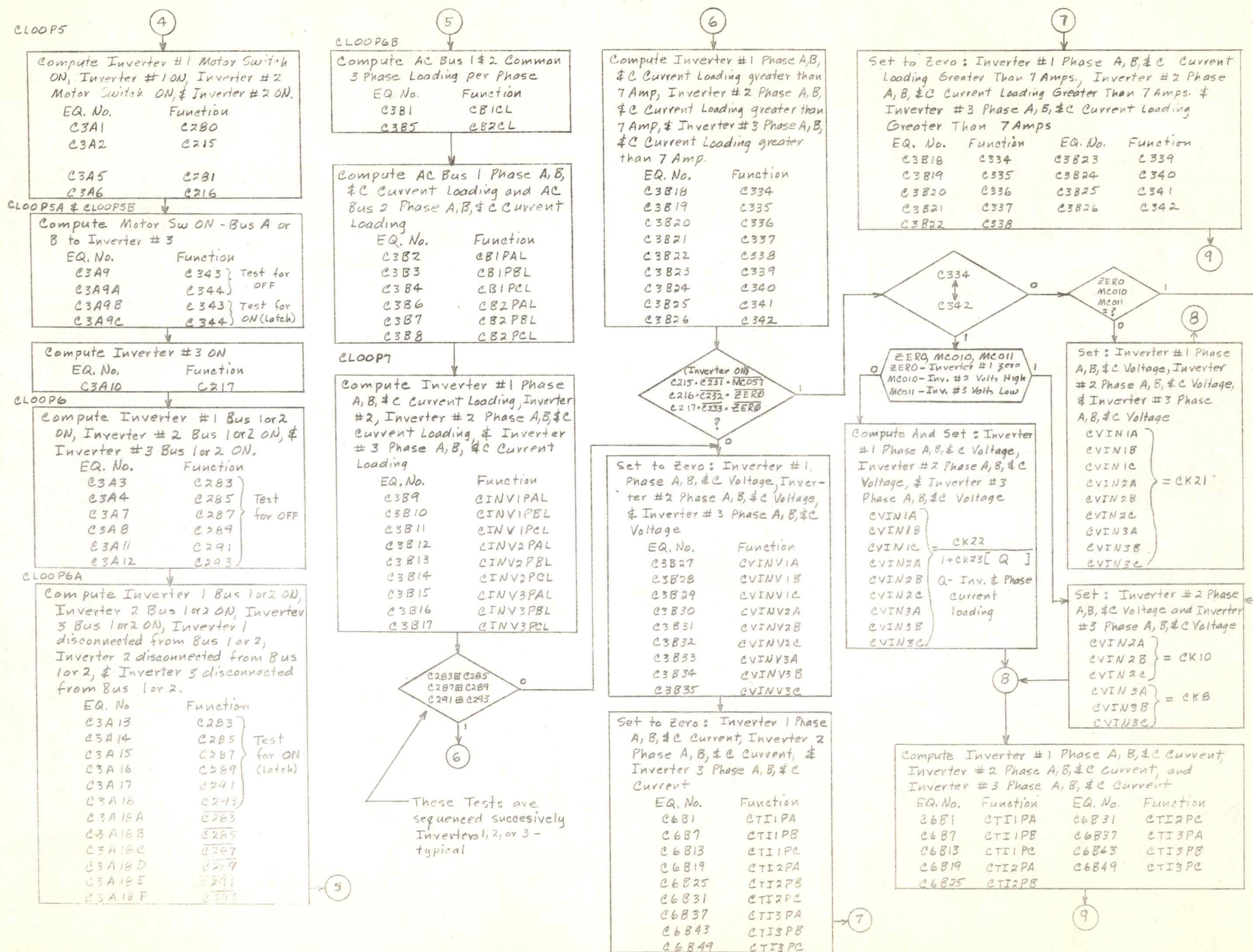
PROGRAM SEQUENCING FLOWCHARTS FOR
MATH MODELS 9A, 9B, AND 9C

APPENDIX B

BLOCK DIAGRAMS OF THE DETAILED EQUATIONS FOR MATH MODELS 9A, 9B, AND 9C

These block diagrams were developed to provide details of equations quickly without reference to symbol definition lists. Note that if a symbol definition appears more than once on a single page, it will be defined only once. The 'AND' function is a series of function events diagrammed in series. The 'OR' function is a series of functional events diagrammed in parallel. In some cases other symbols are used. A product is denoted " π " and a summation is denoted by " Σ ".





FIGA-2 PROGRAM SEQUENCE FOR CMS-MM-09A (CON'T.)

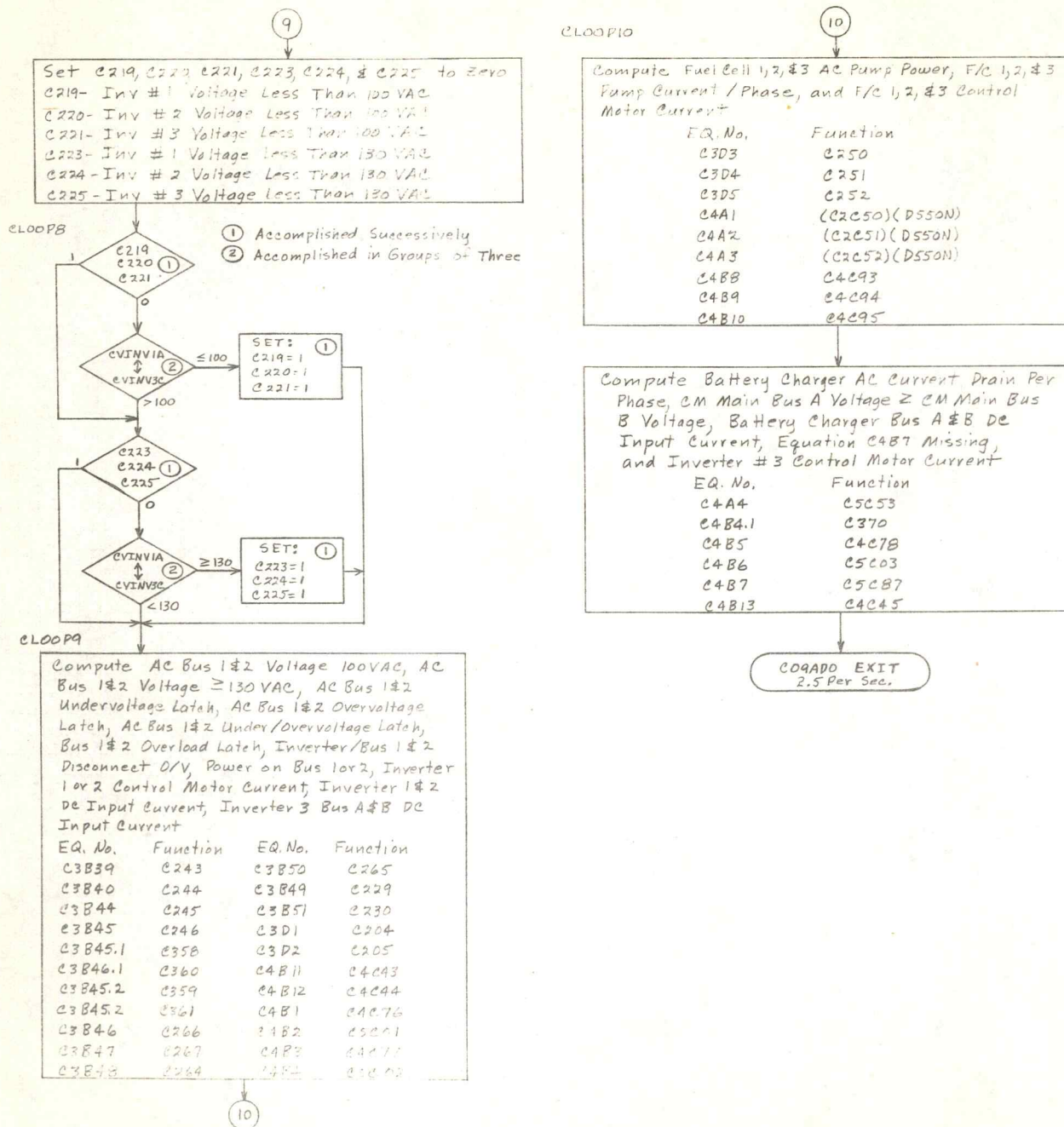
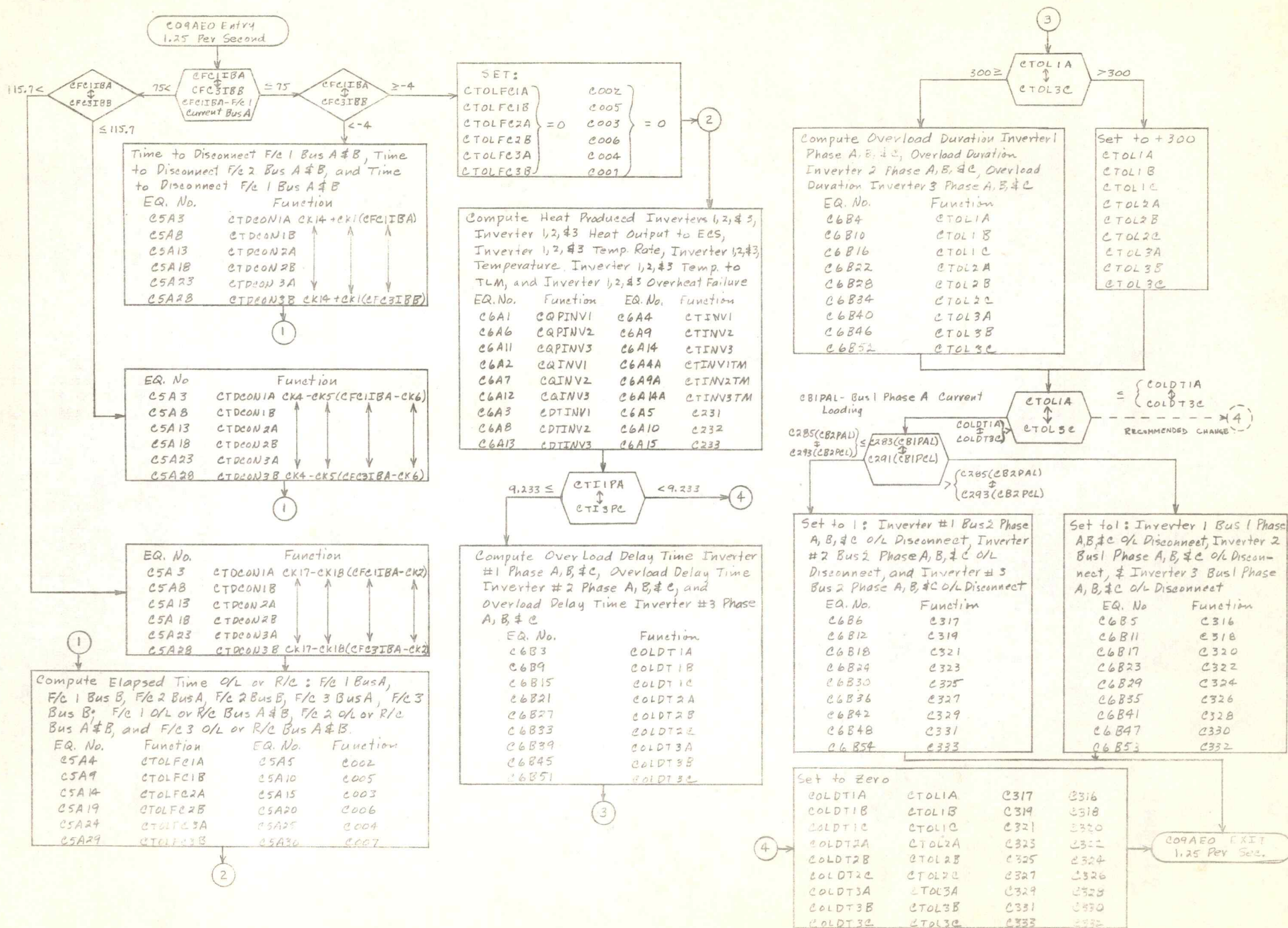
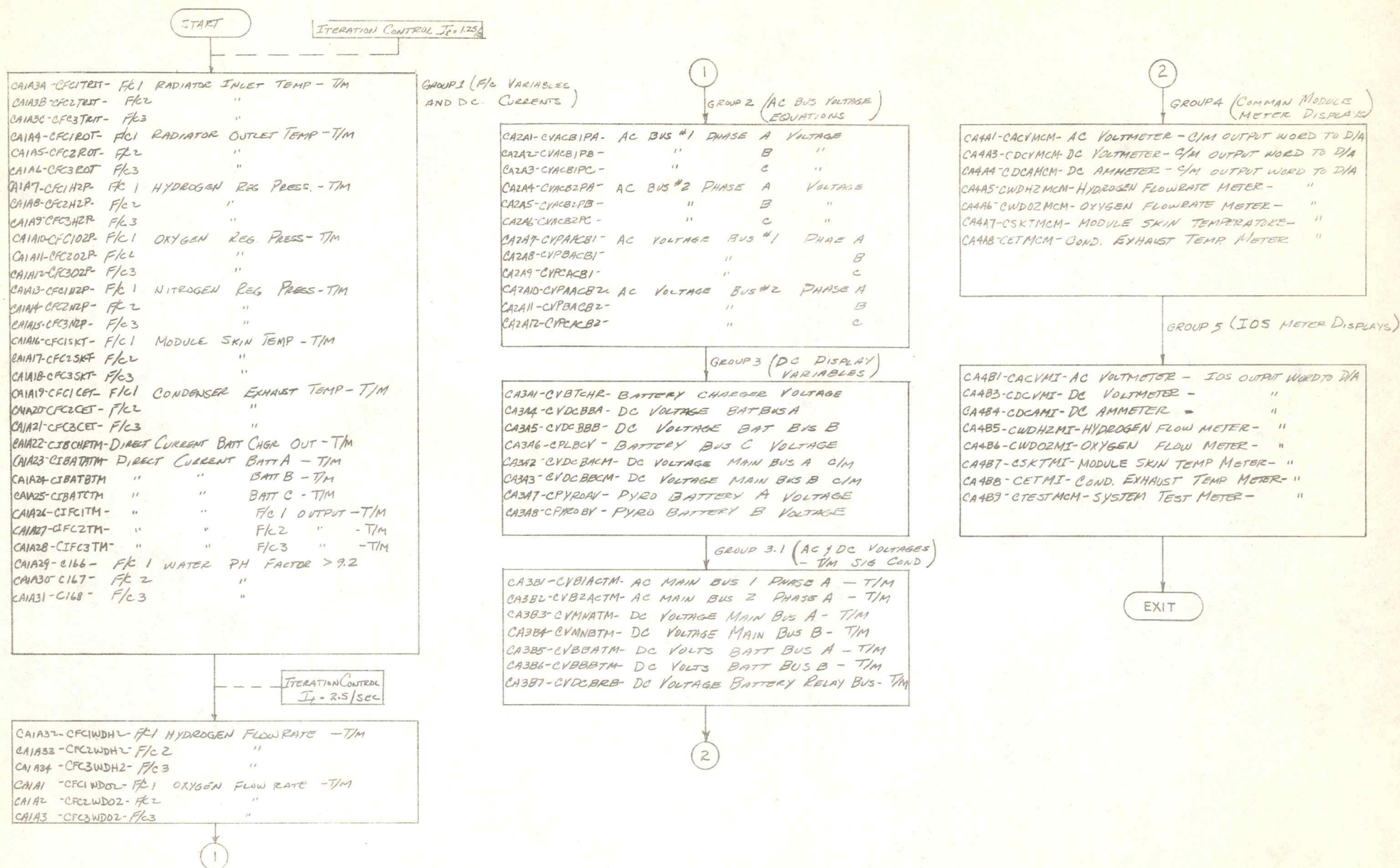


FIG.A-3 PROGRAM SEQUENCE FOR CMS-MM-09A (Cont.)



FIGA-4 PROGRAM SEQUENCE FOR CMS-MM-09A (CON'T.)



FIGA-5 PROGRAM SEQUENCE FOR CMS-MM-09B

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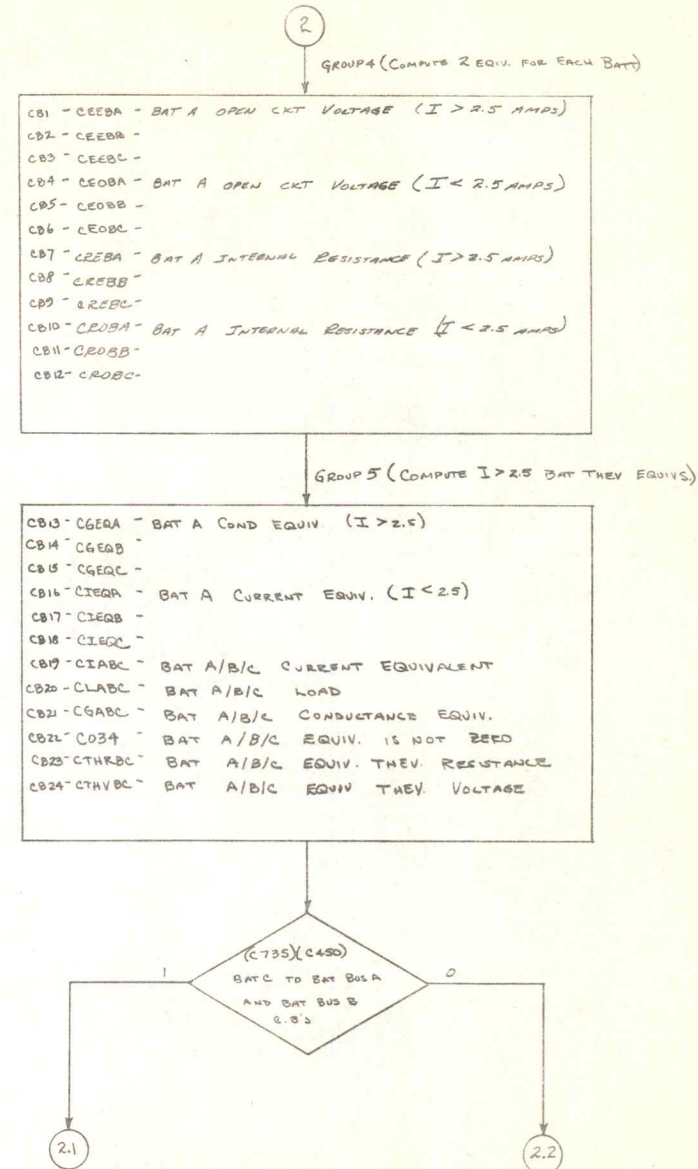
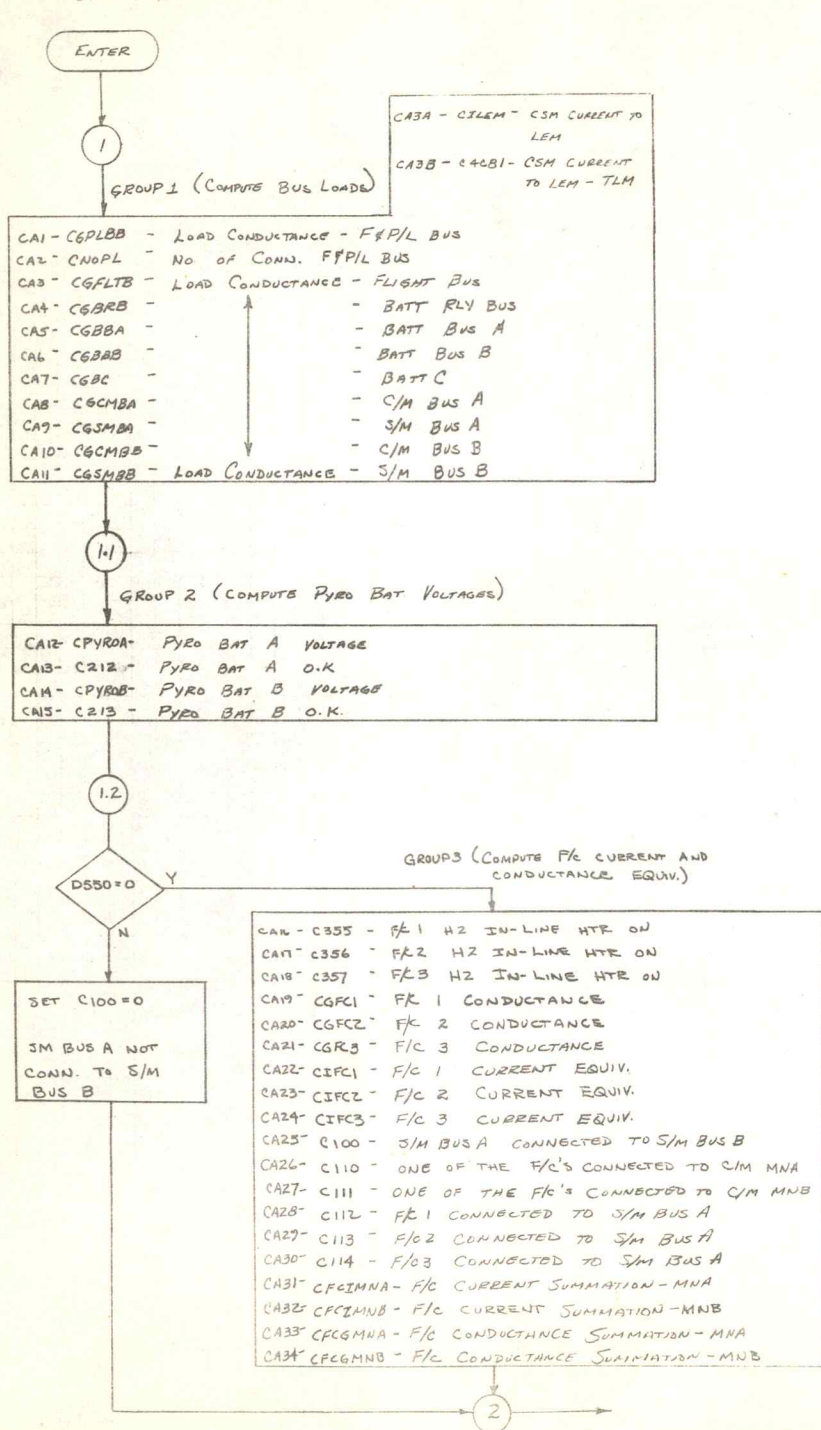


FIG. A-6 PROGRAM SEQUENCE FOR CMS-MM-09C

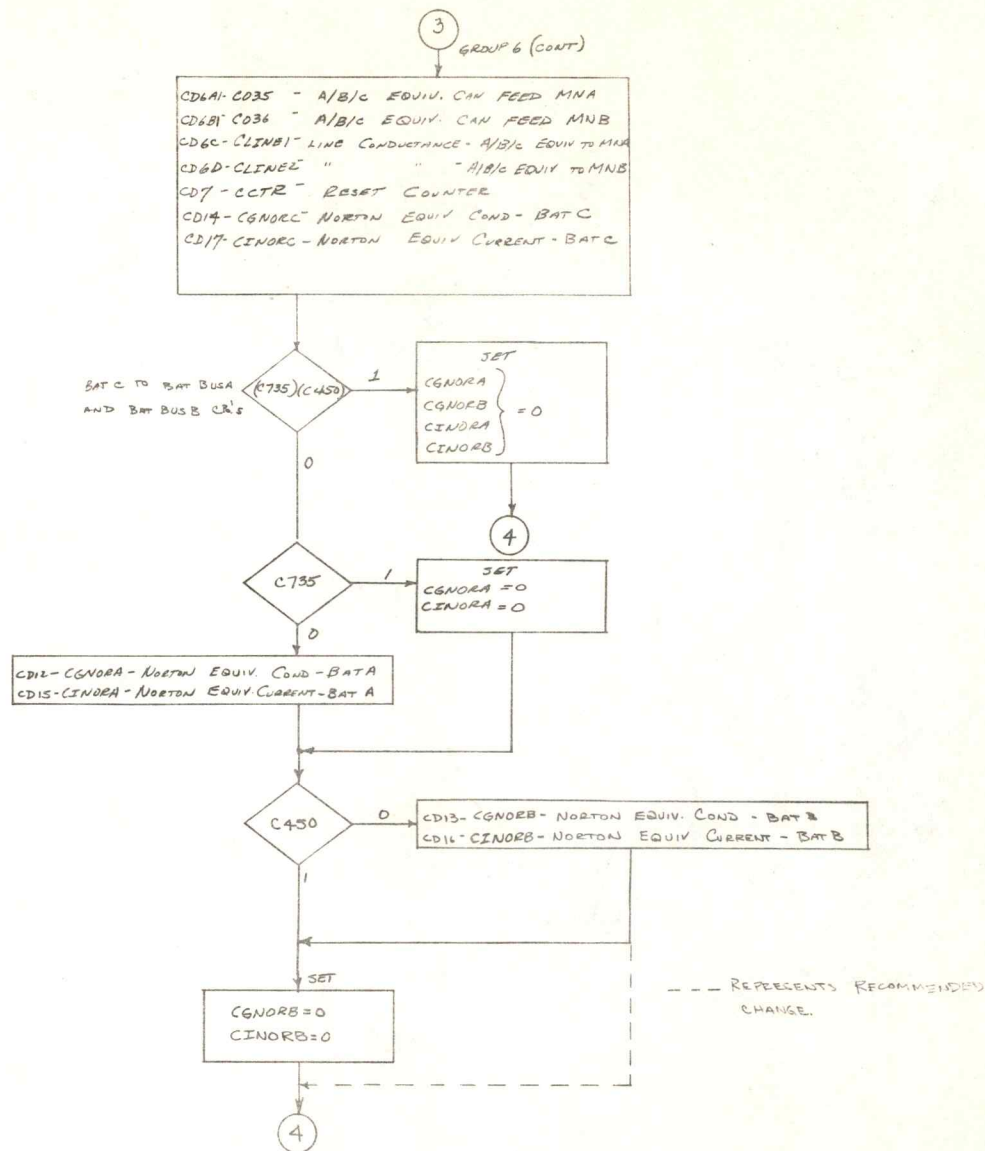
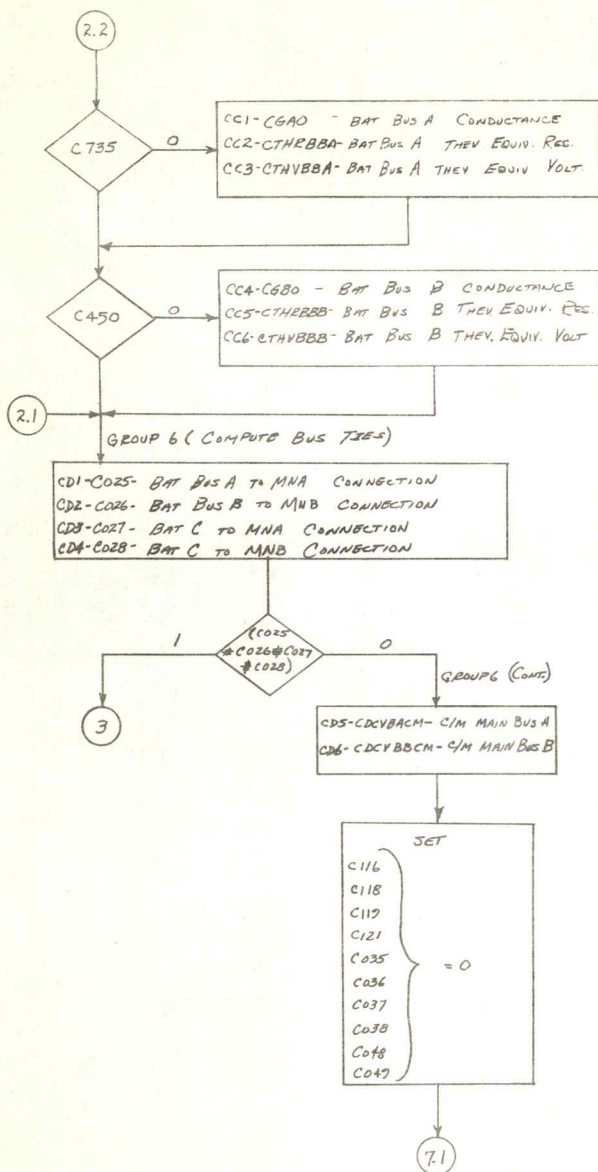
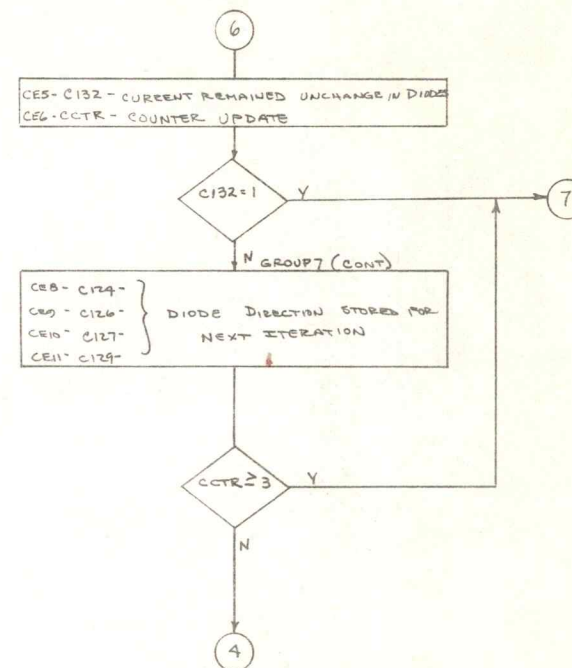
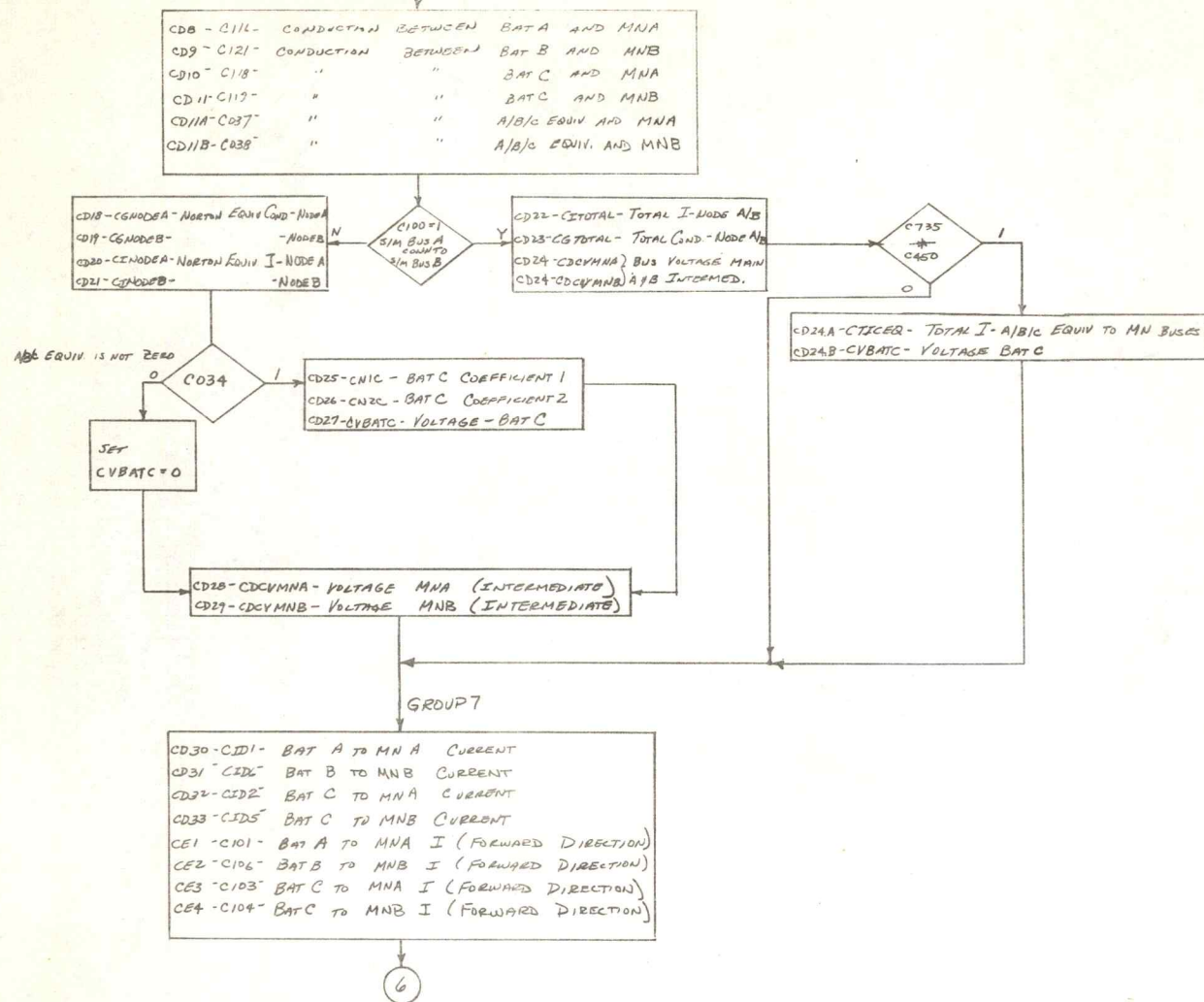
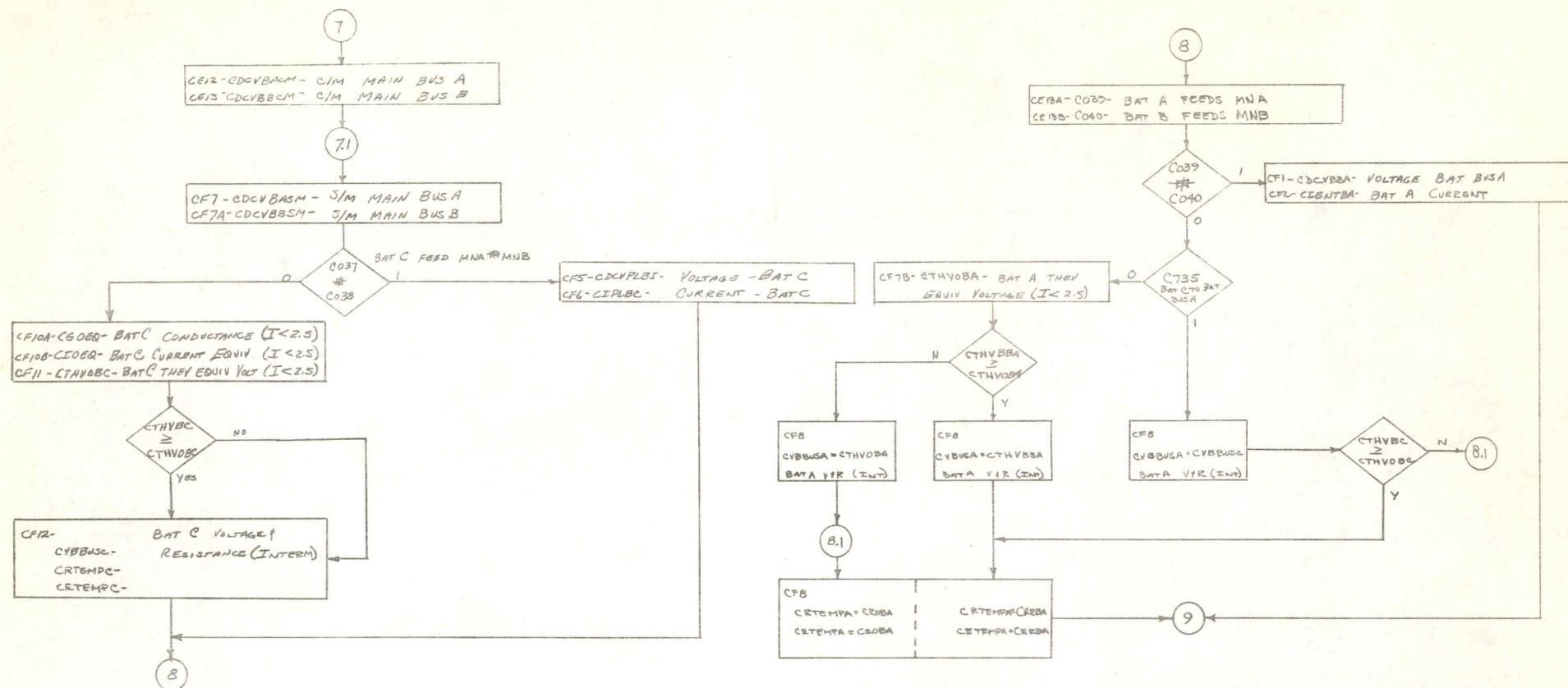


FIG A-7 PROGRAM SEQUENCE FOR CMS-MM-09C (CONT)



A-8



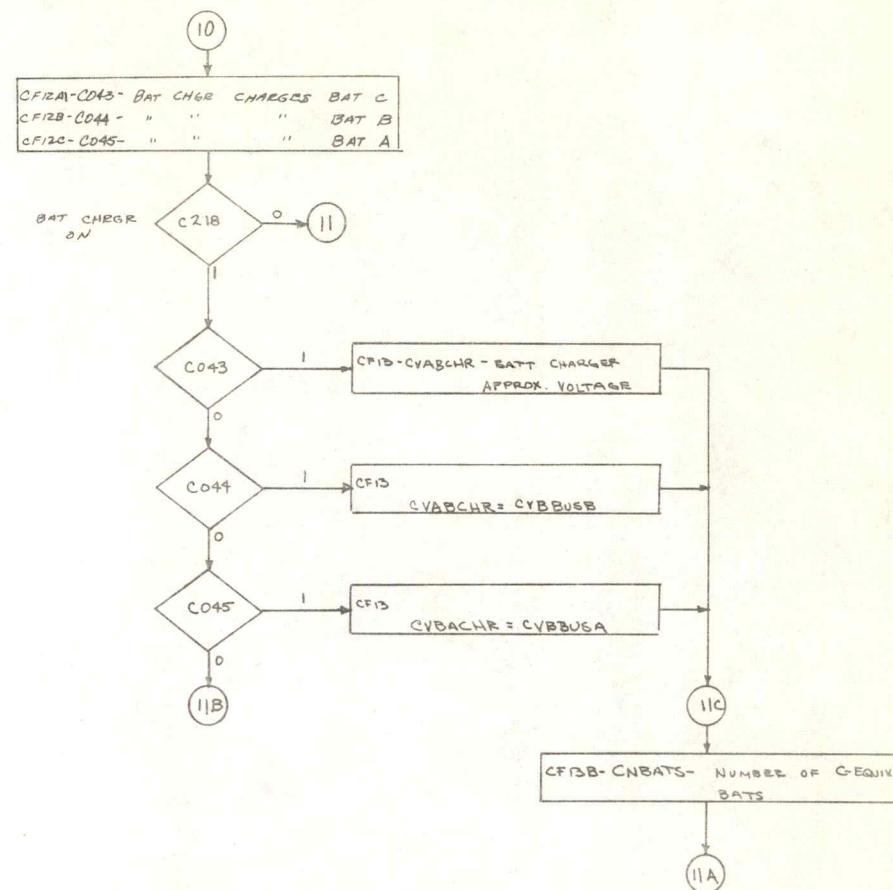
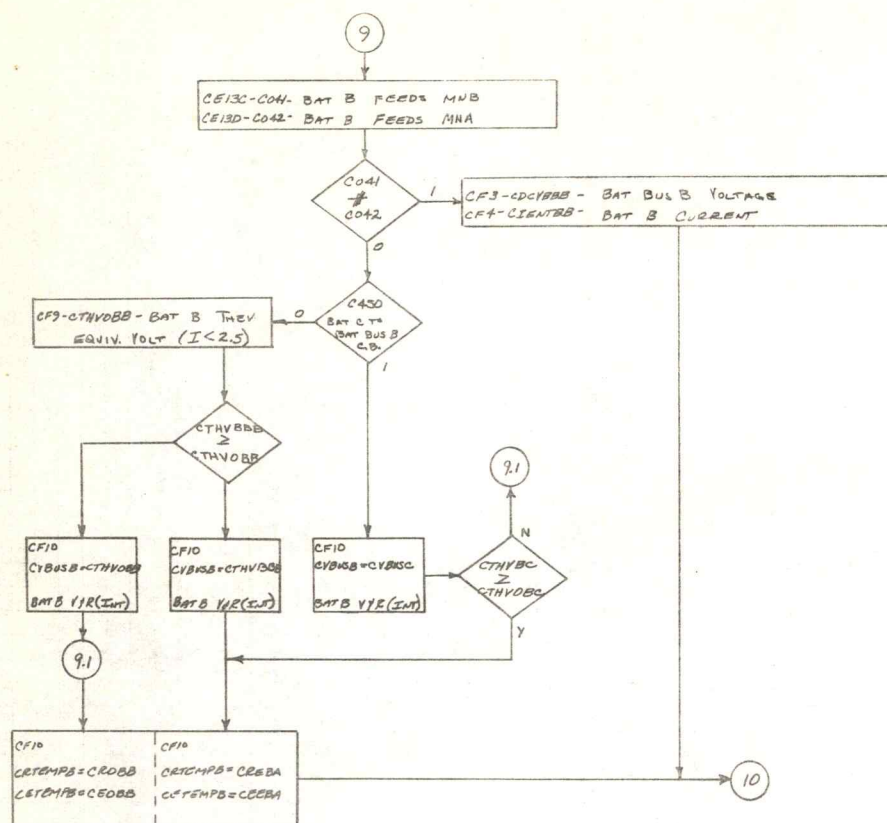


FIG. A-10 PROGRAM SEQUENCE FOR CMS-MM-09C (CONT.)

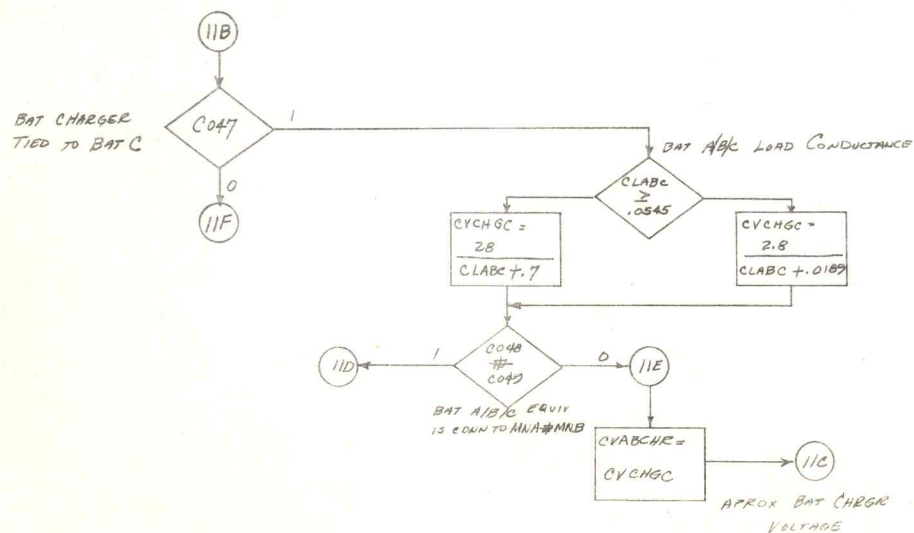
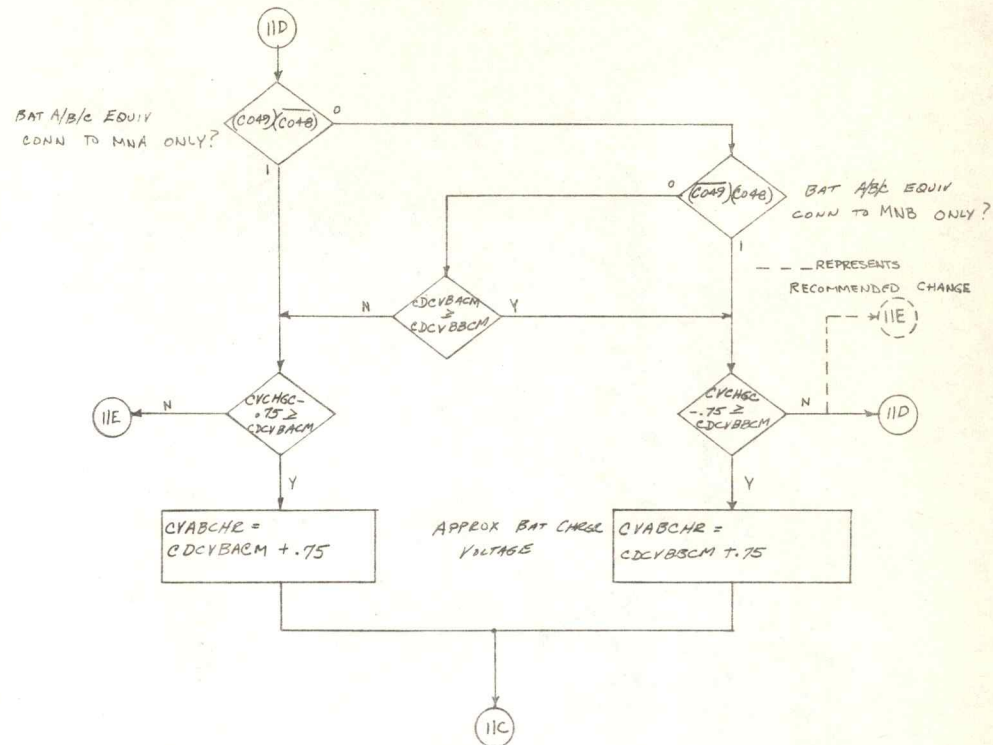
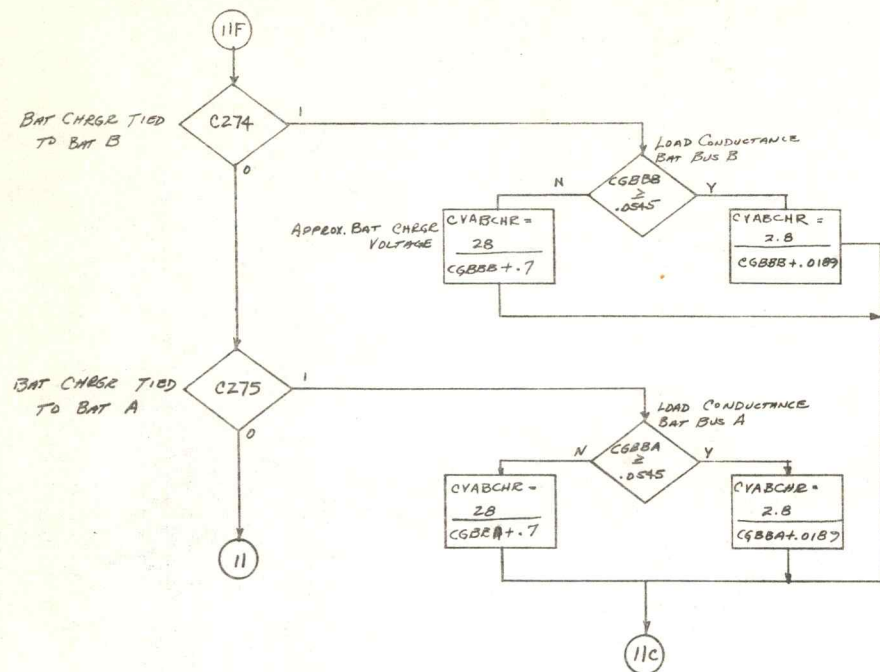


FIG.A-II PROGRAM SEQUENCE FOR CMS-MM-09C (CON'T)

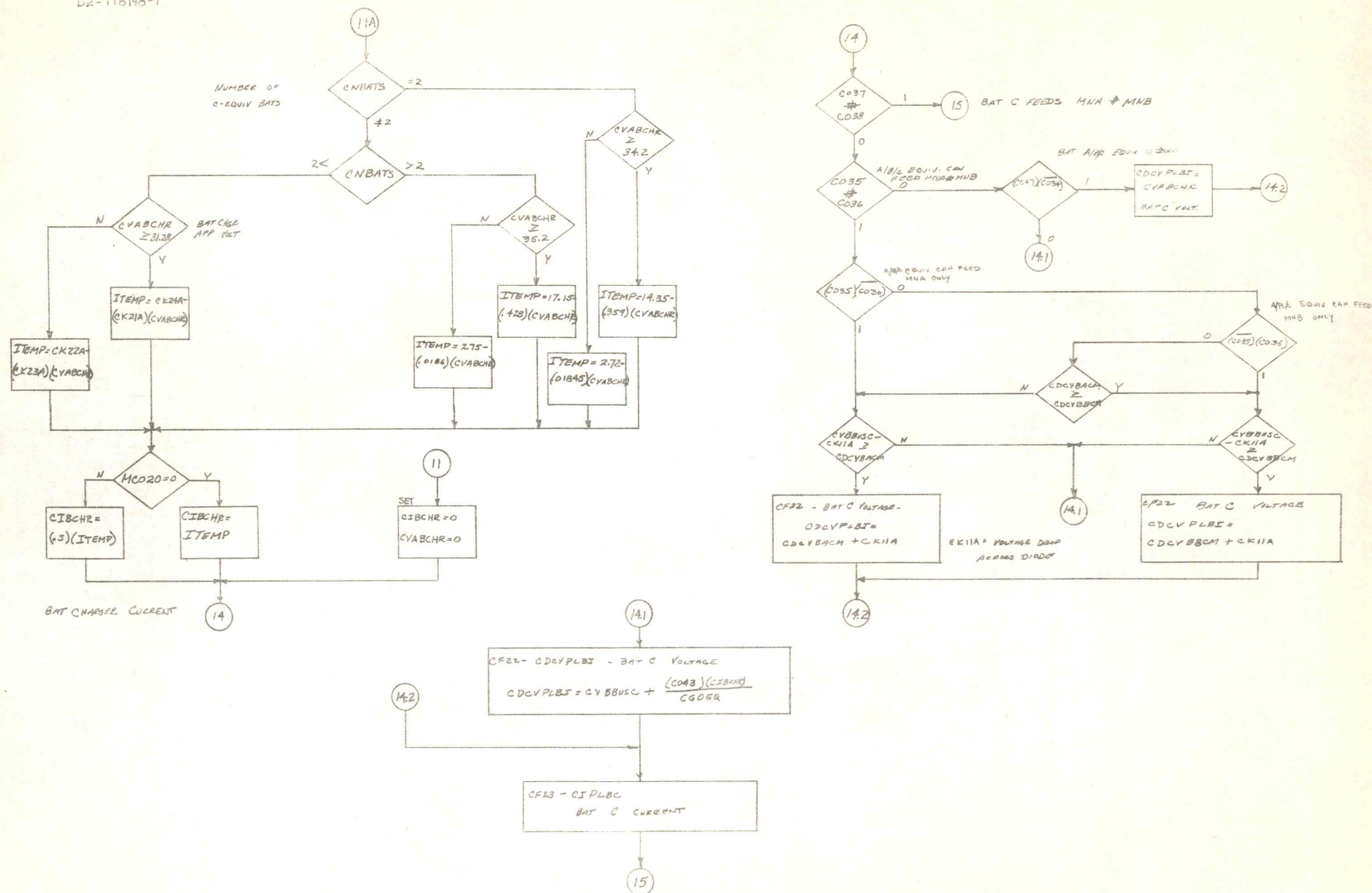


FIG A-12 PROGRAM SEQUENCE FOR CMS-MM-09C (CON'T.)

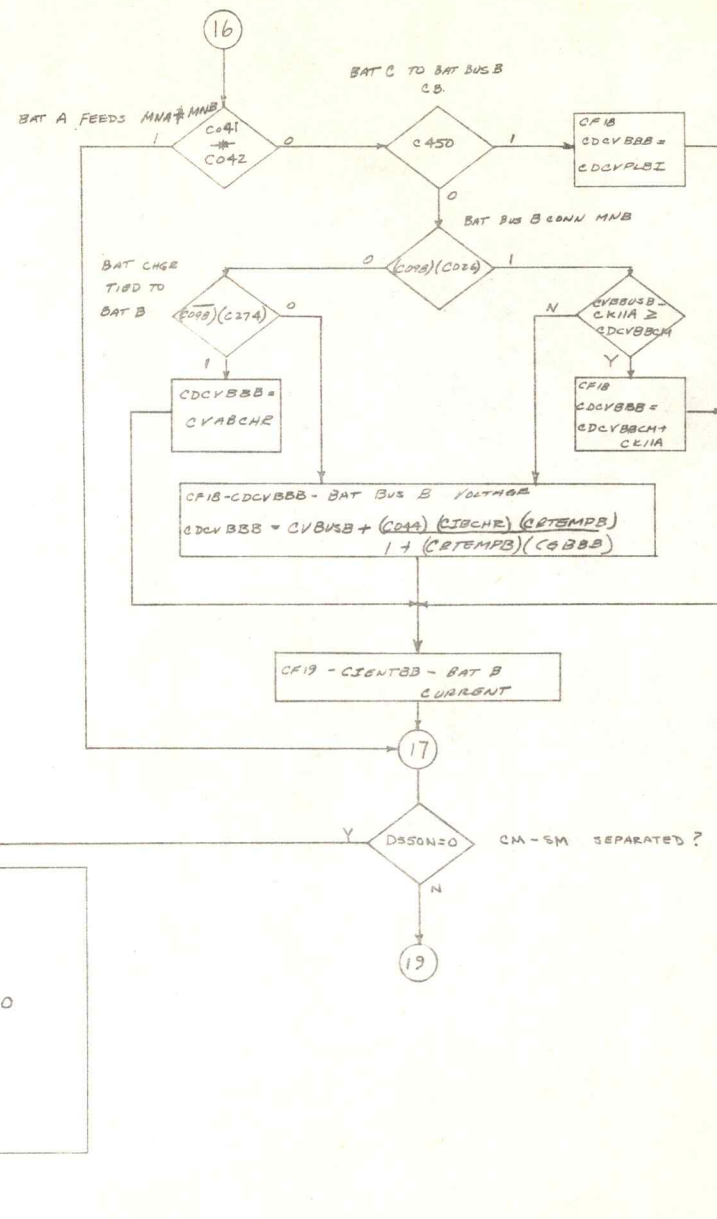
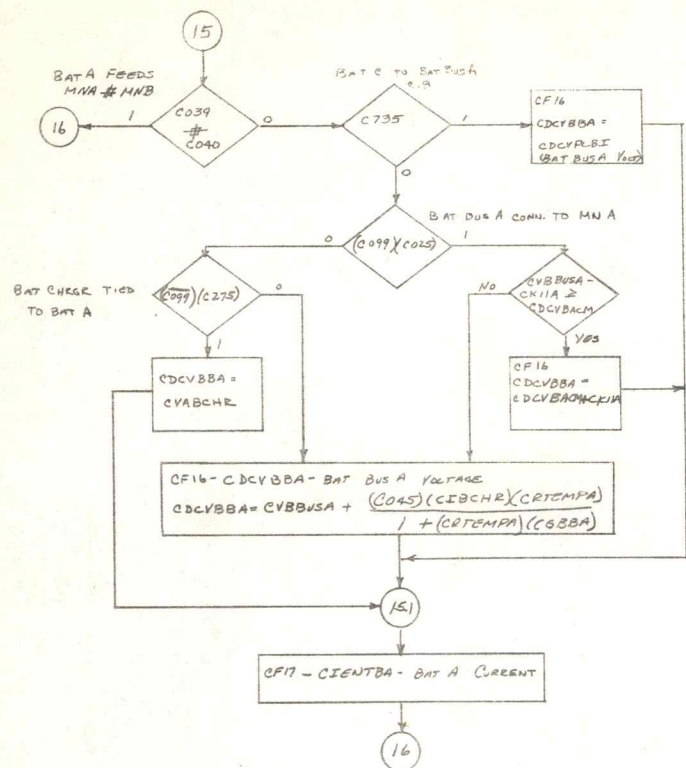


FIG. A-13 PROGRAM SEQUENCE FOR CMS-MM-09C (CON'T.)

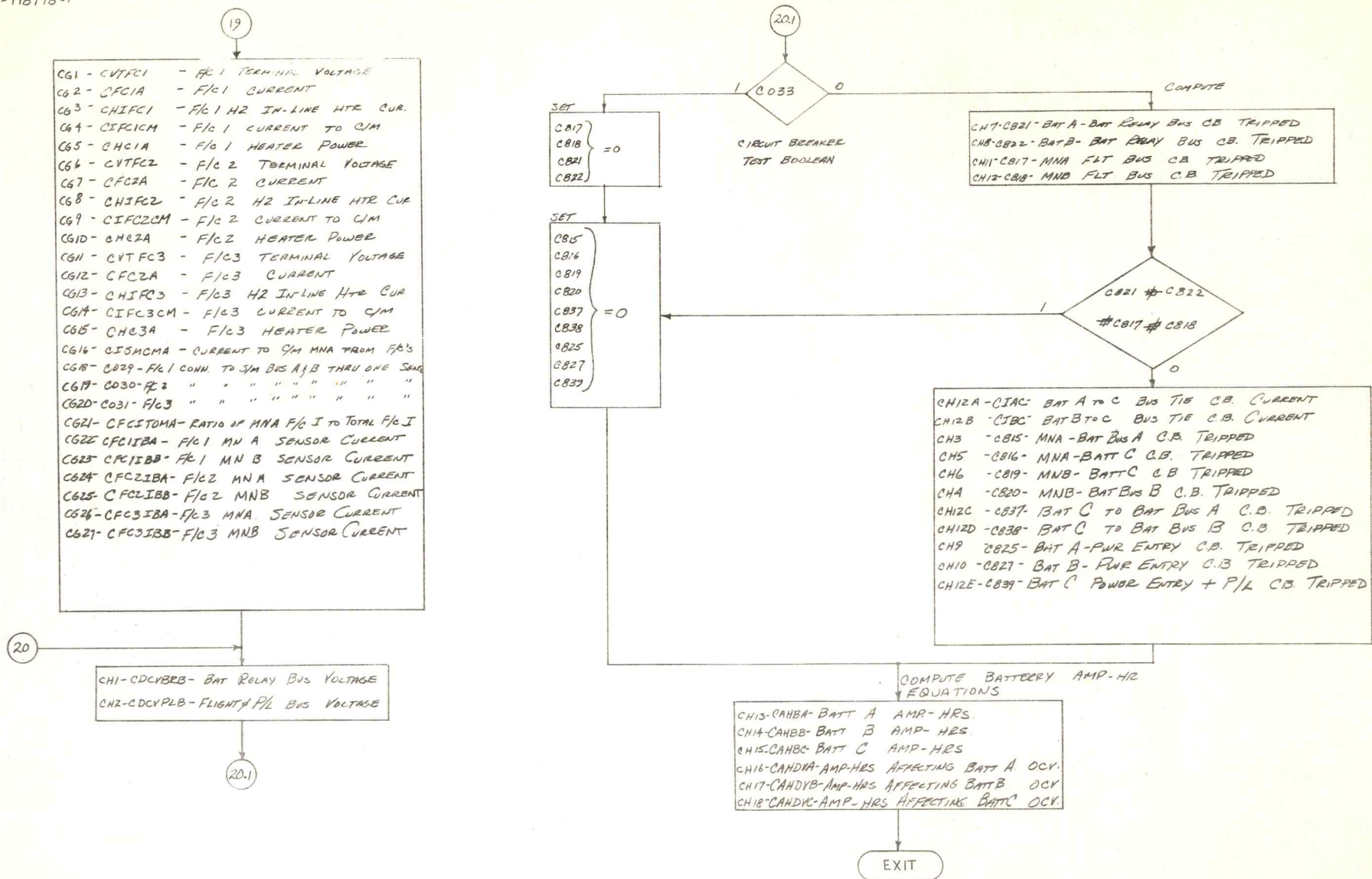
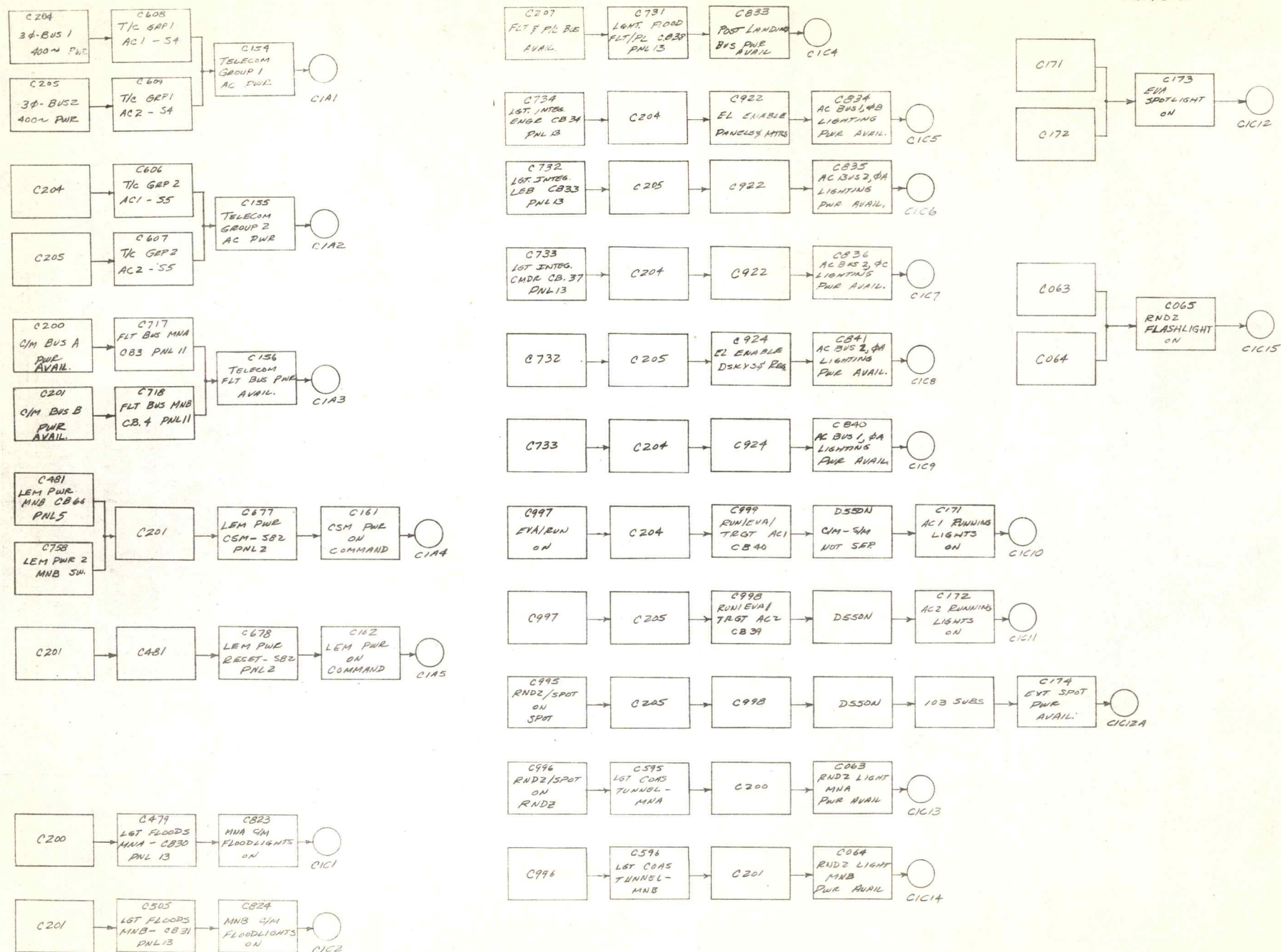


FIG A-14 PROGRAM SEQUENCE FOR CMS-MM-09C (CON'T.)

FIG. B-1A POWER AVAILABLE TO TELECOM, LEM, & LIGHTING
EQUATIONS C1A1 THRU C1C15

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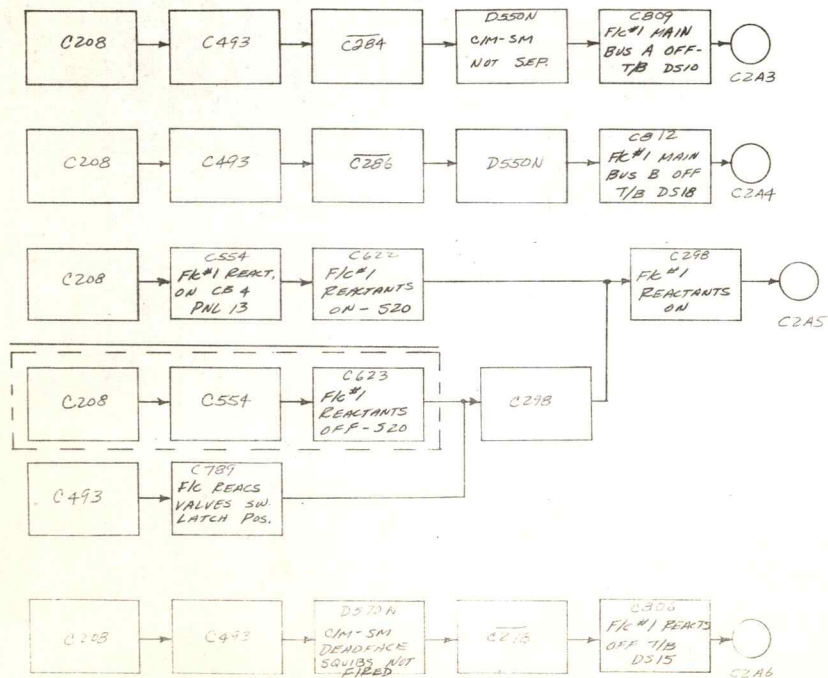
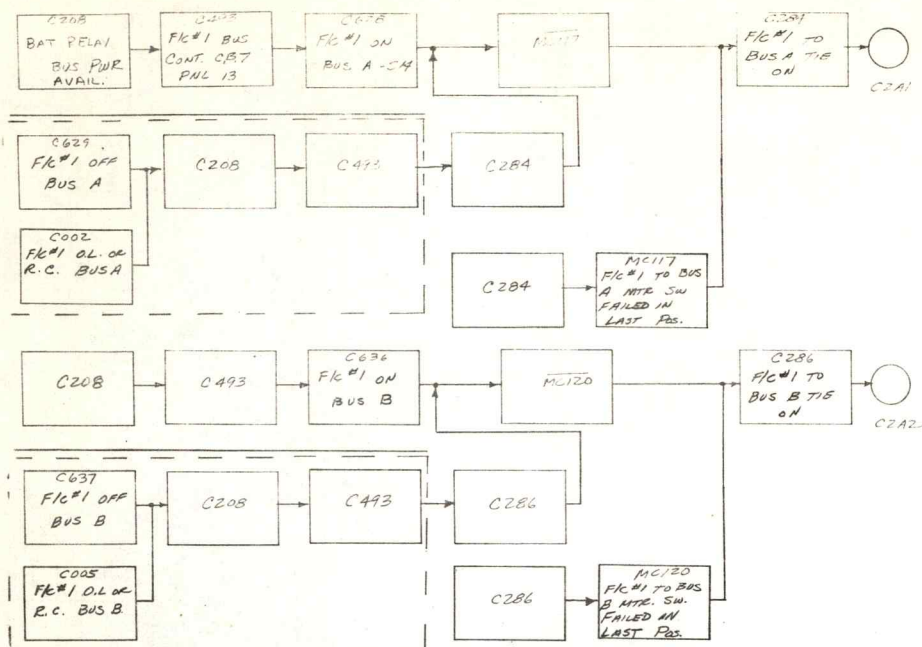


FIG B-2A FUEL CELL CONTROL EQUATIONS C2A1 THRU C2A12

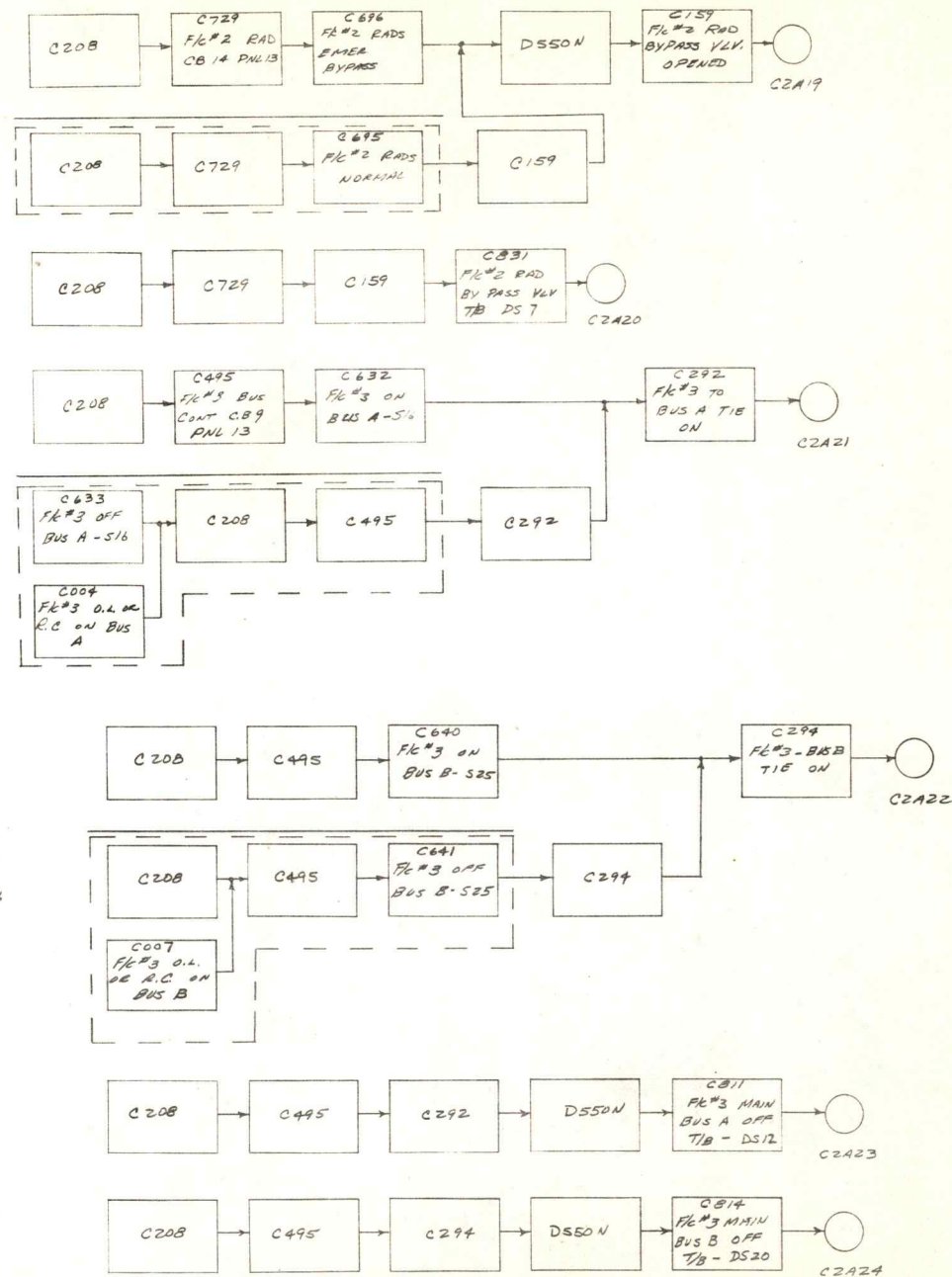
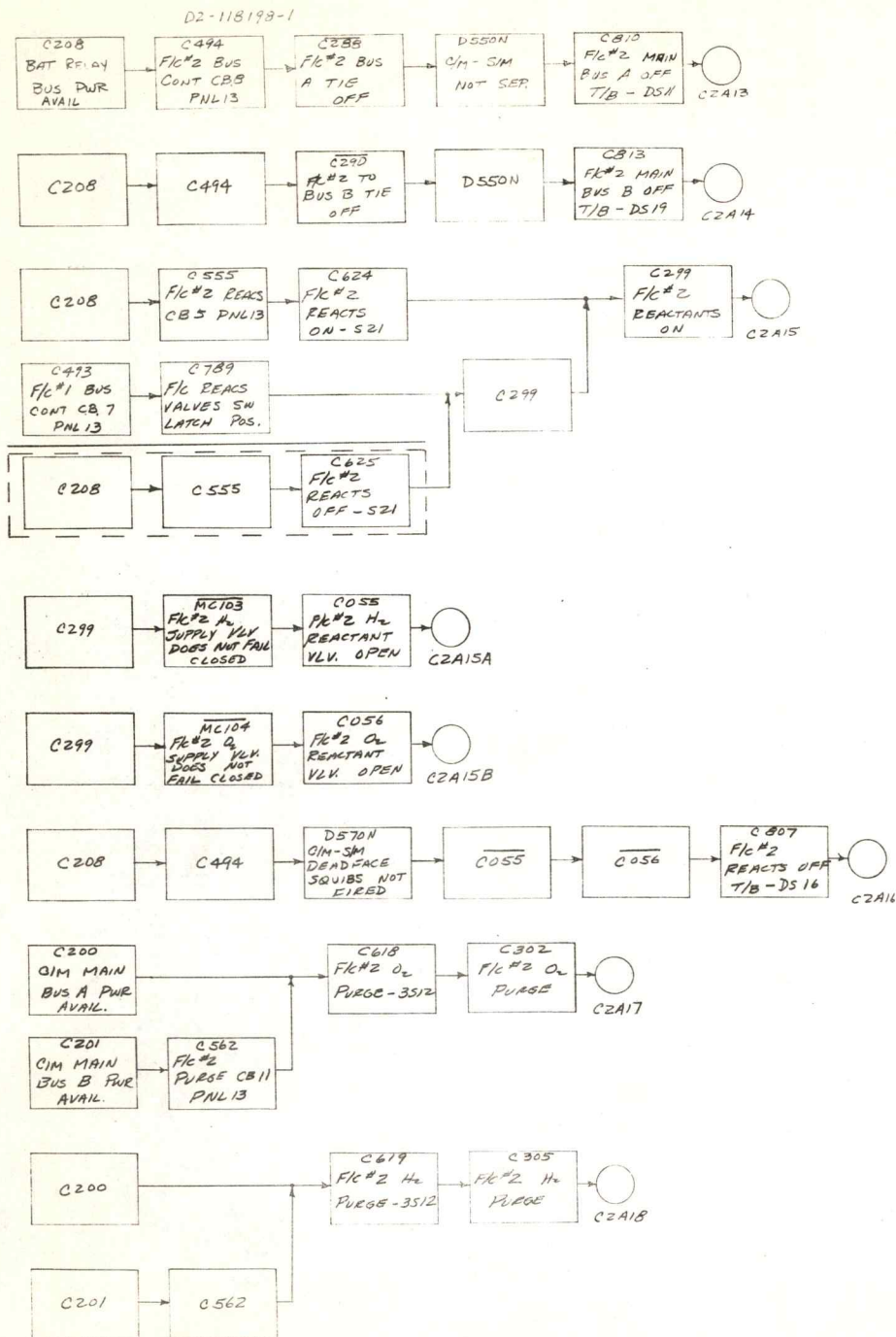


FIG. B-3A FUEL CELL CONTROL EQUATIONS C2A13 THRU C2A24

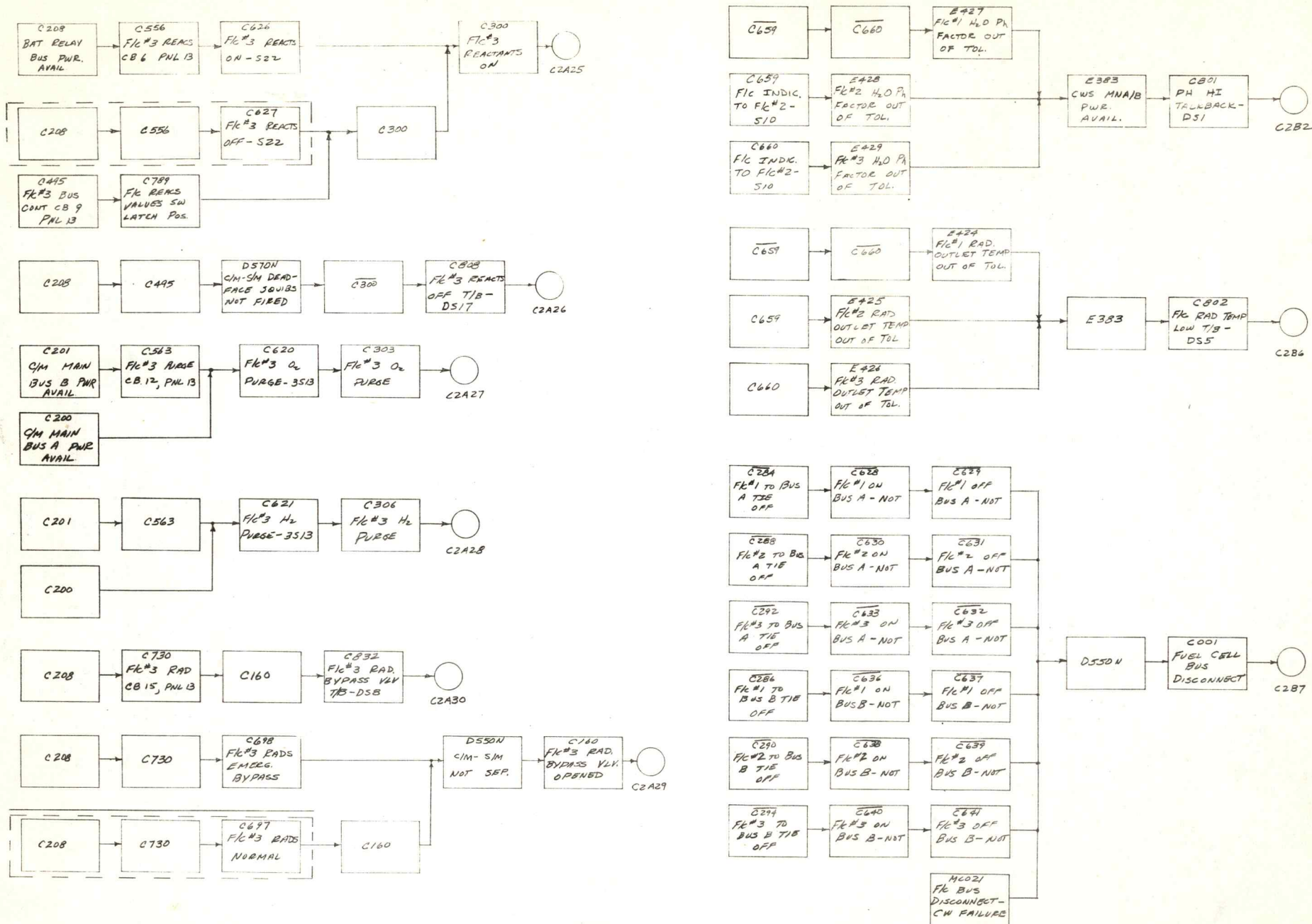


FIG. B-4A FUEL CELL CONTROL & CAUTION/WARNING INDICATIONS
EQUATIONS C2A25 THRU C2A29, C2B2, C2B6, AND C2B7

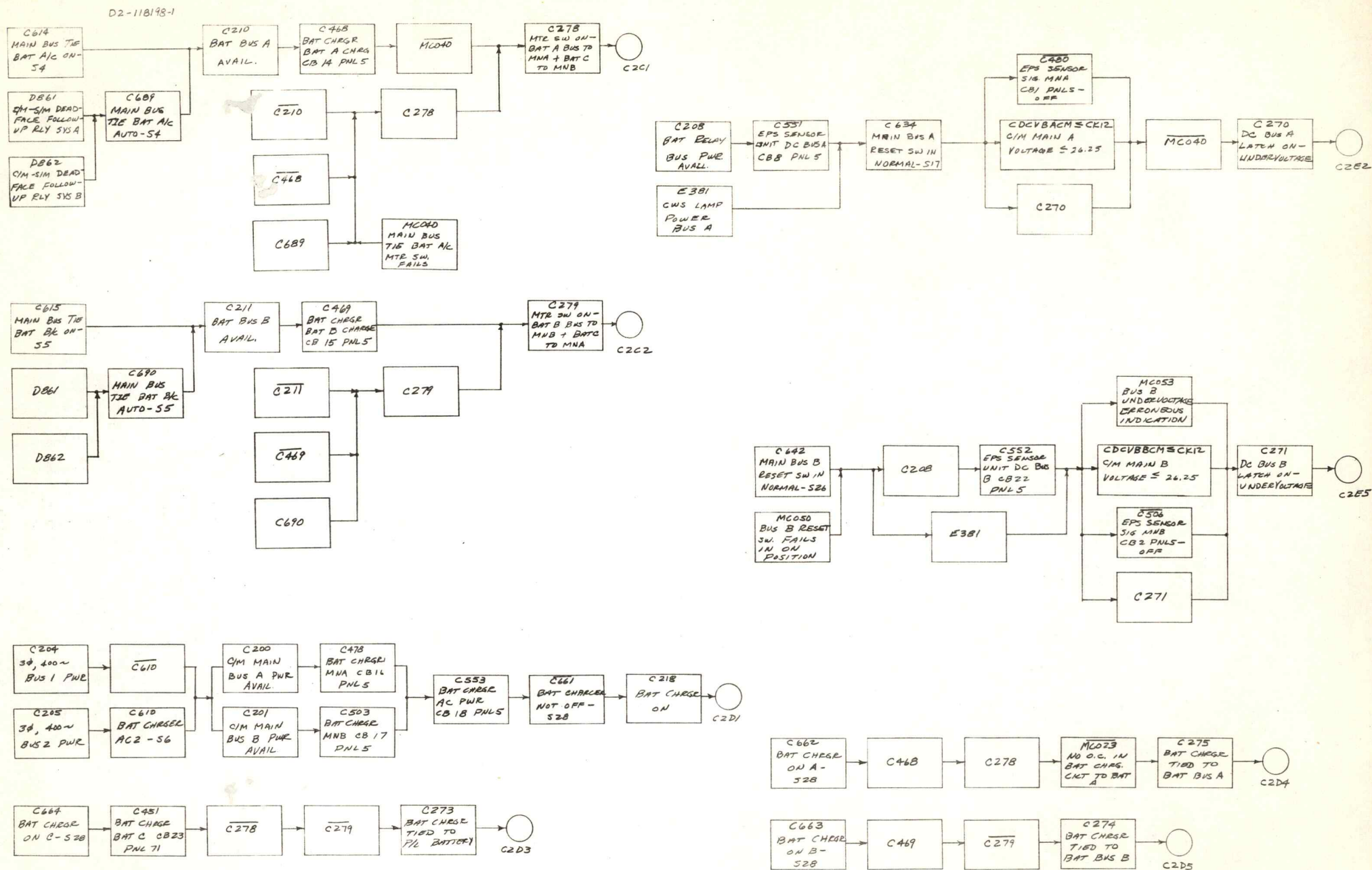


FIG. B-5A BATTERY TO BUS TIE & BATTERY CHARGER LOGIC EQUATIONS C2C1, C2C2, AND C2D1 THRU C2D5
MAIN BUS A OR B UNDERVOLTAGE SENSING EQUATIONS C2C2 AND C2C5

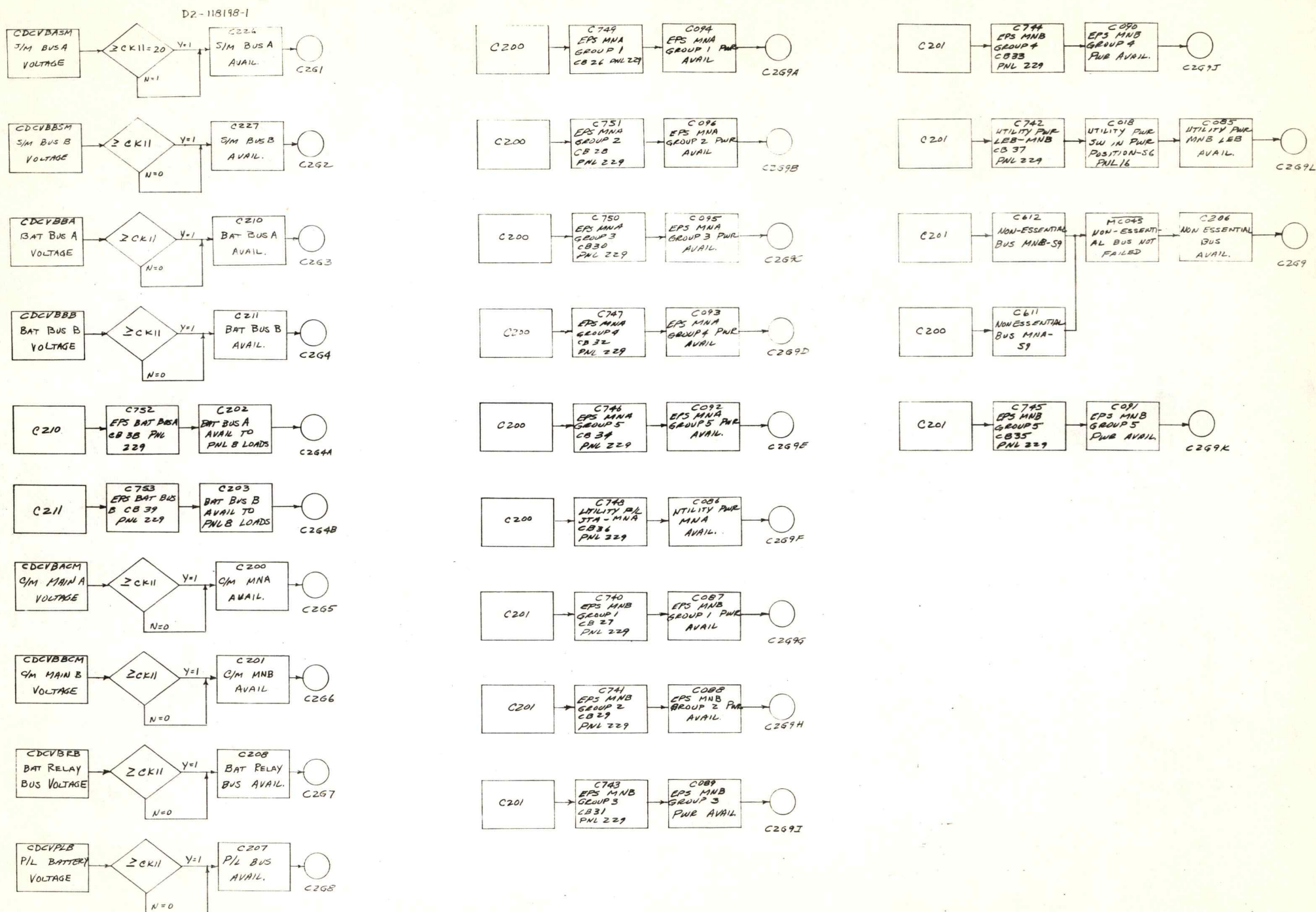


FIG. B-6A D.C. BUS POWER AVAILABLE EQUATIONS C2G1 THRU C2G9L


```

graph LR
    C208["C208  
BAT RELAY  
BUS AVAIL."] --> C443["C443  
JUV. CONT.1  
CBS PNL5"]
    C443 --> C646["C646  
AC INV 1-  
MNA 557"]
    C646 --> MC057["MC057  
INV 11 MTR  
SW DID NOT  
FAIL OK"]
    MC057 --> C280["C280  
MTR SW ON-  
INVERTER1"]
    C280 --> C341((C341))
  
```

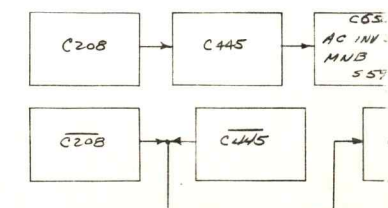
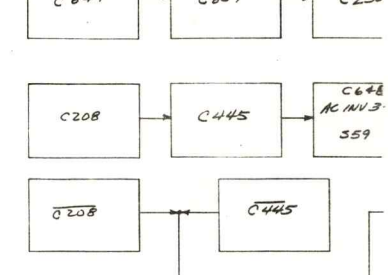
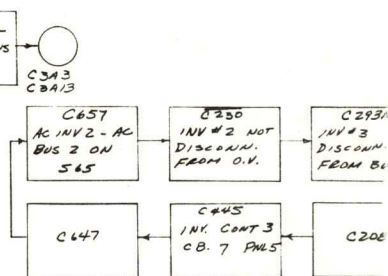
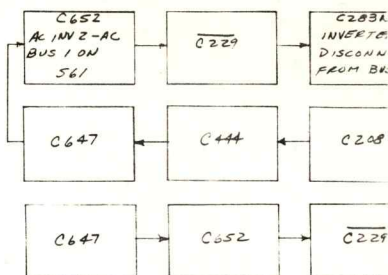
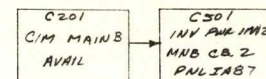
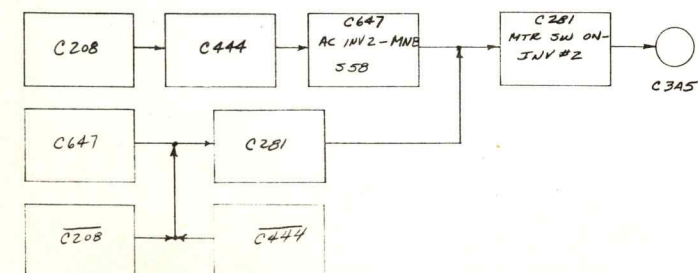
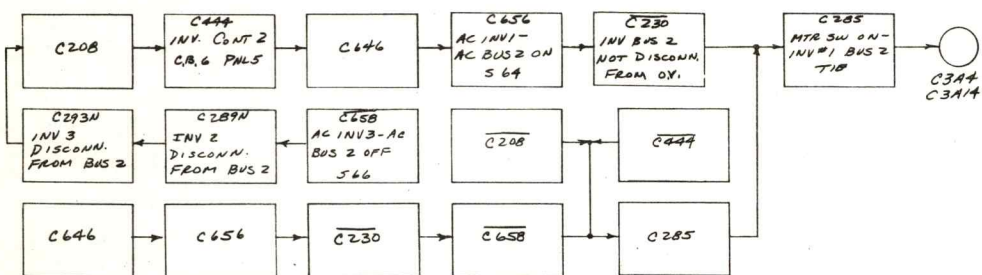
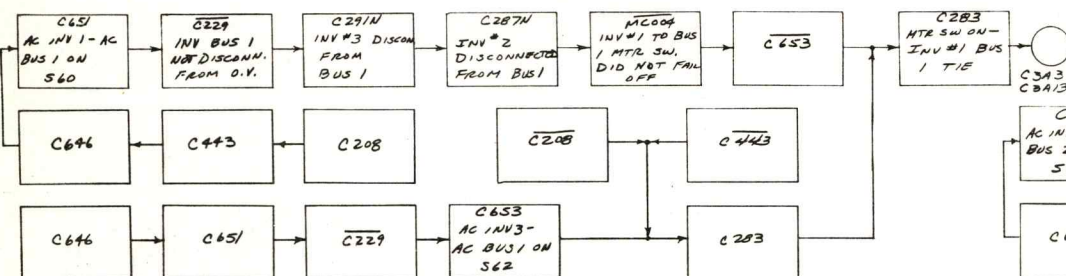
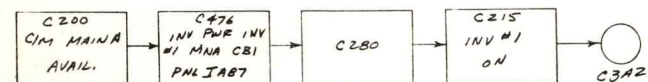
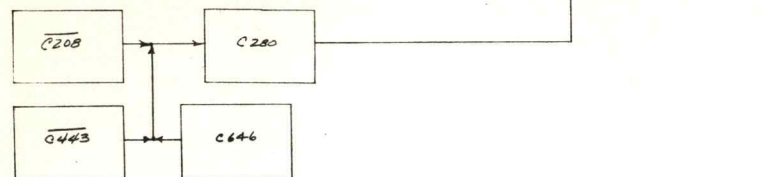


FIG. B-7A INVERTER CONTROL LOGIC
EQUATIONS C3A1 THRU C3A9C AND C3A13 THRU C3A16

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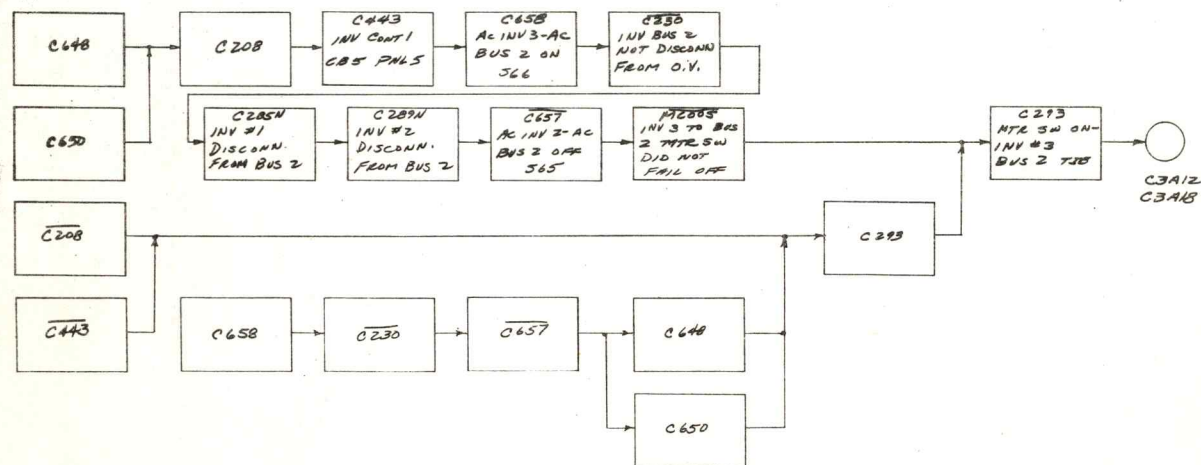
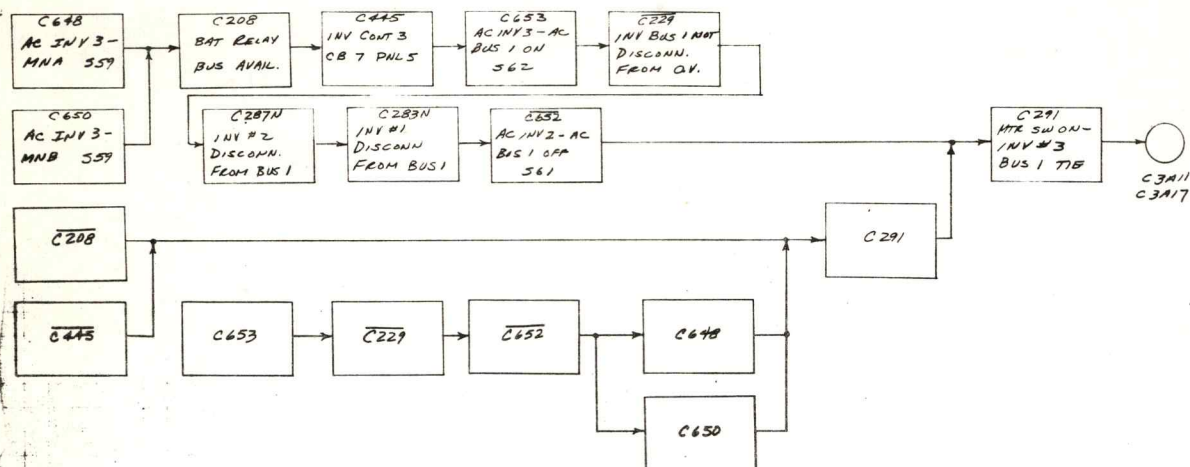
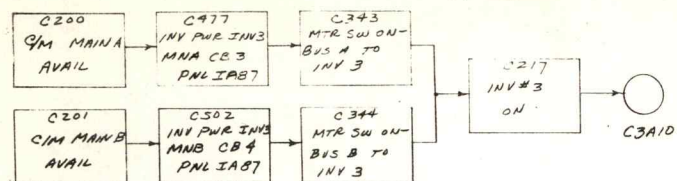


FIG. B-8A INVERTER CONTROL LOGIC
EQUATIONS C3A10, C3A11, C3A12, AND C3A18

D2-118198-1

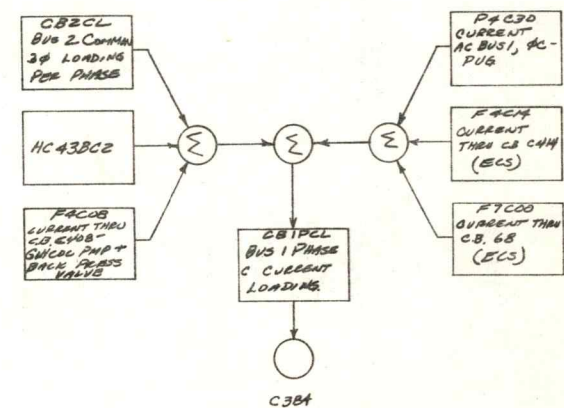
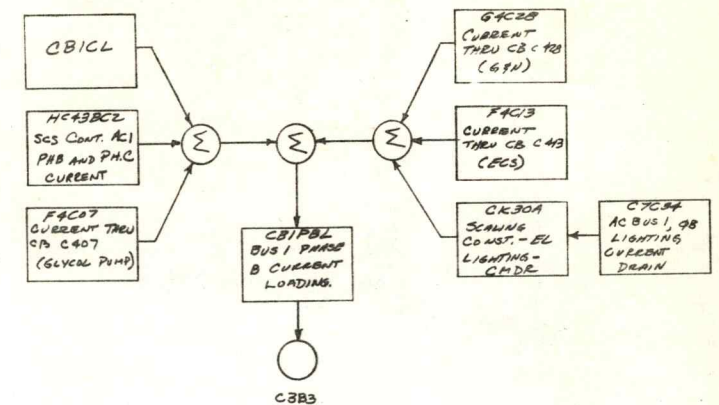
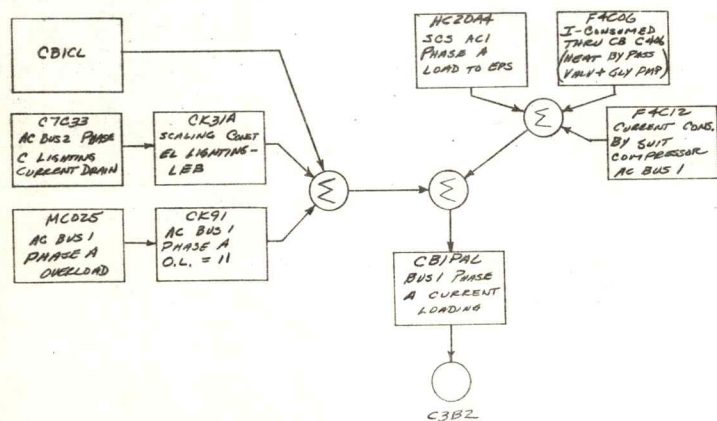
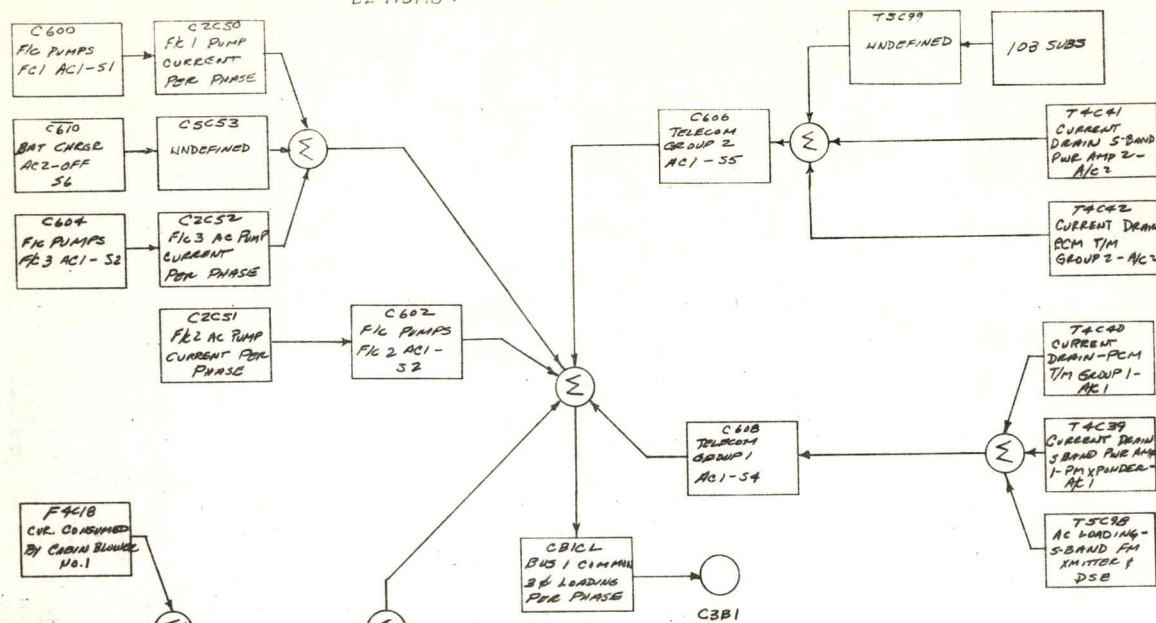


FIG B-9A A.C. BUS LOADING EQUATIONS C3B1, C3B2, C3B3, AND C3B4



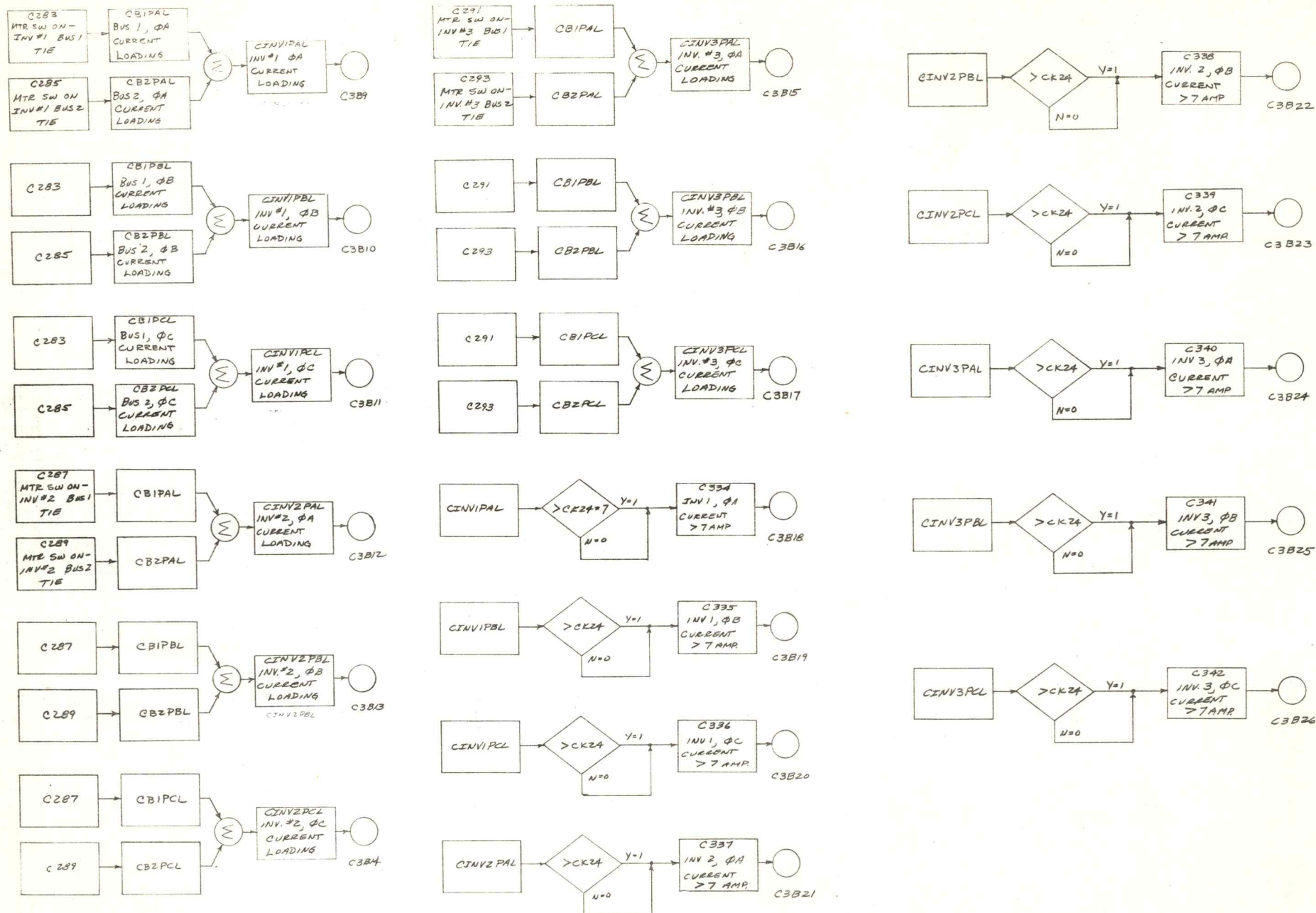


FIG. B-11A INVERTER LOAD CURRENT EQUATIONS C3B9 THRU C3B26

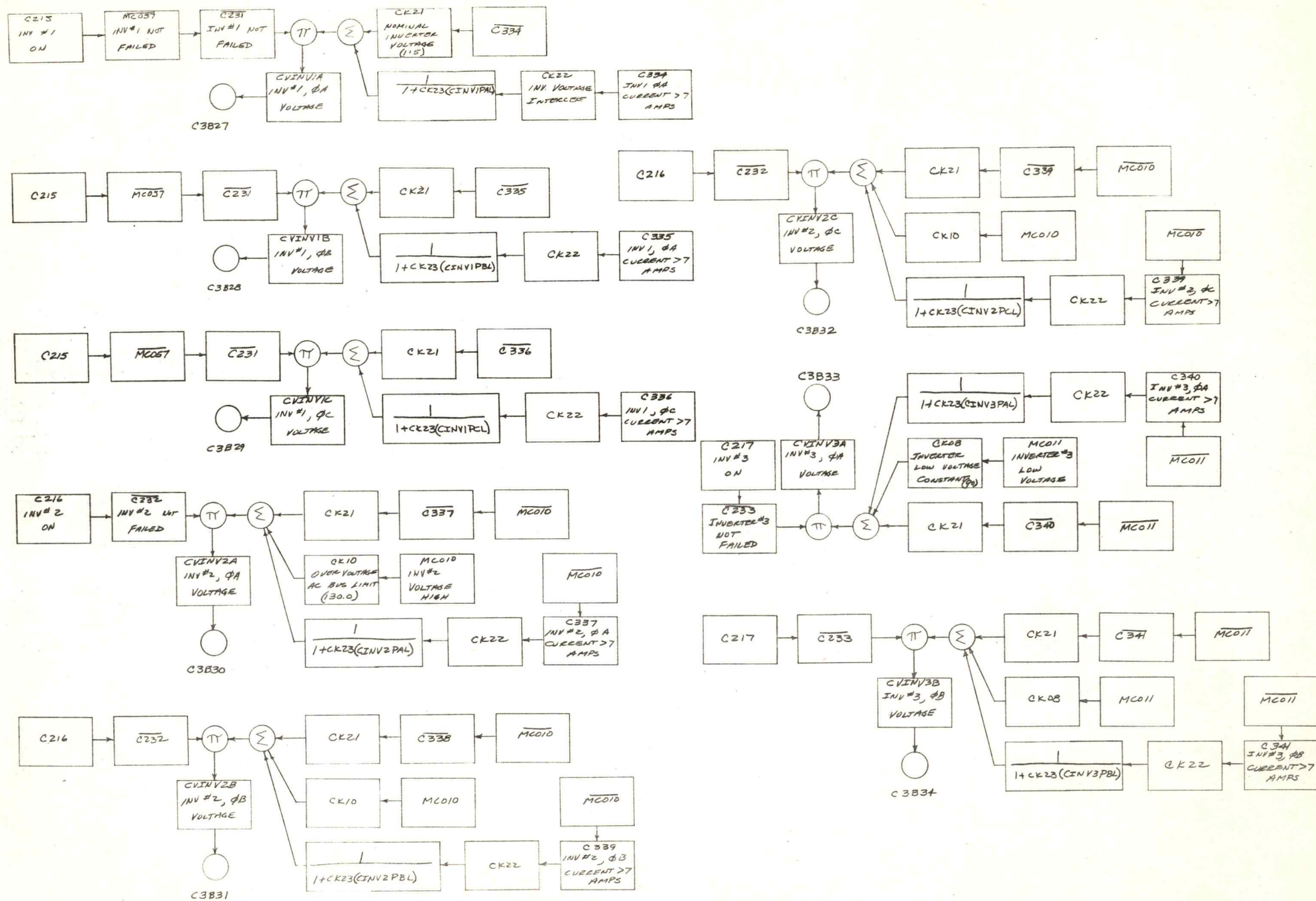
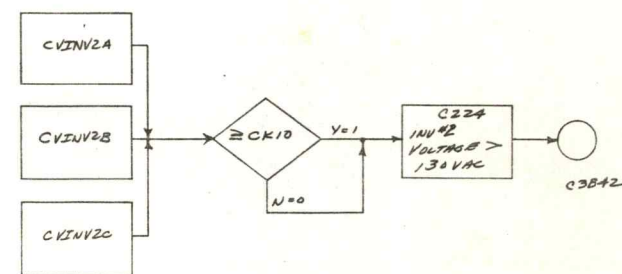
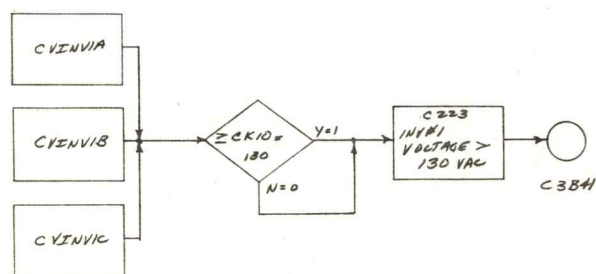
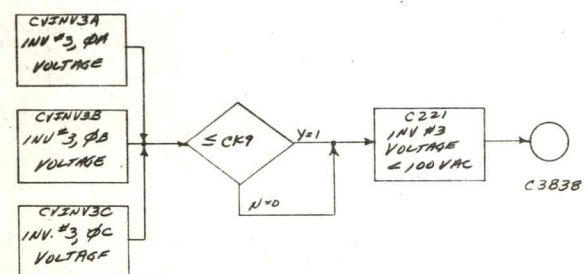
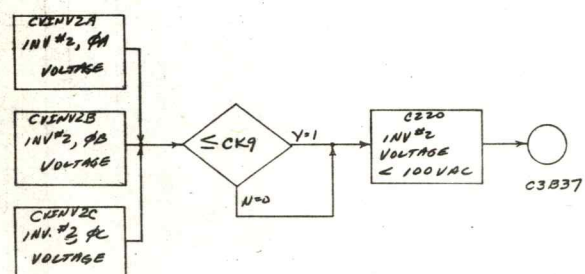
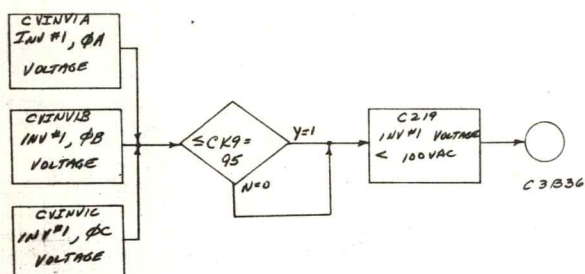
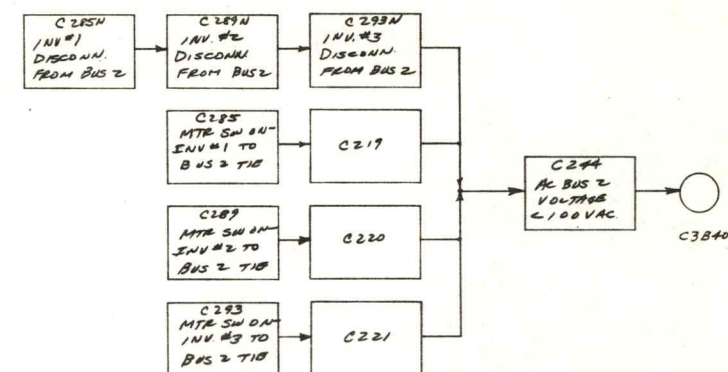
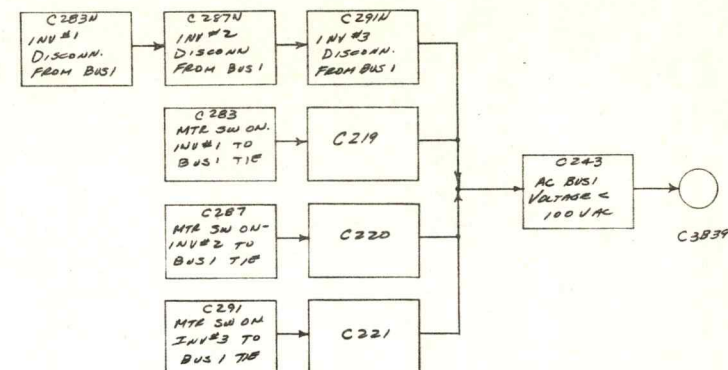


FIG. B-12A INVERTER VOLTAGE EQUATIONS C3B27 THRU C3B34



B-13

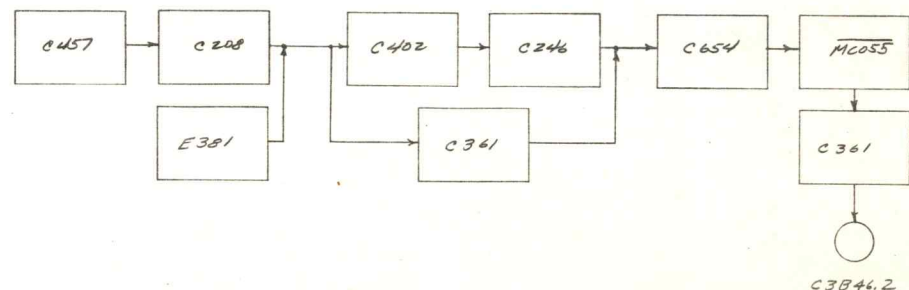
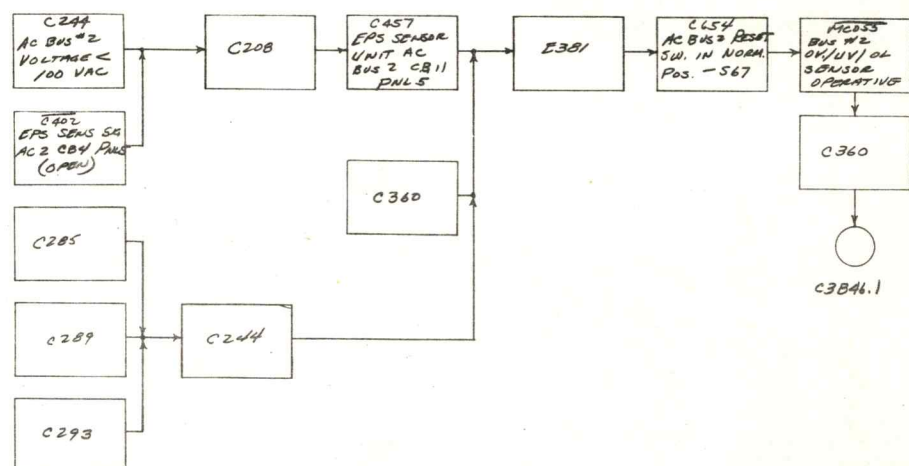
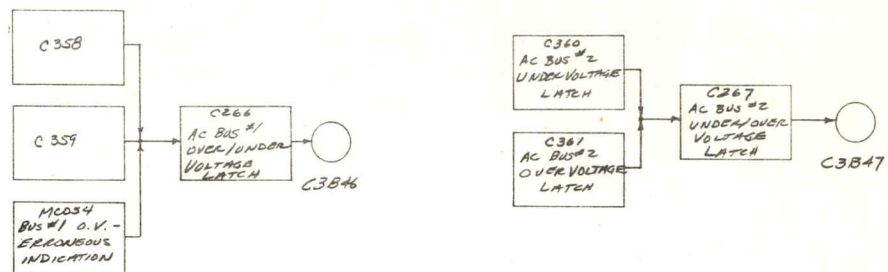
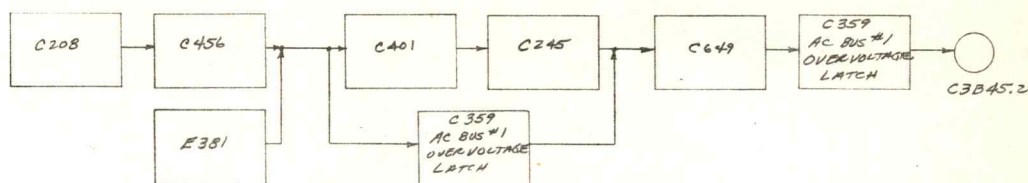
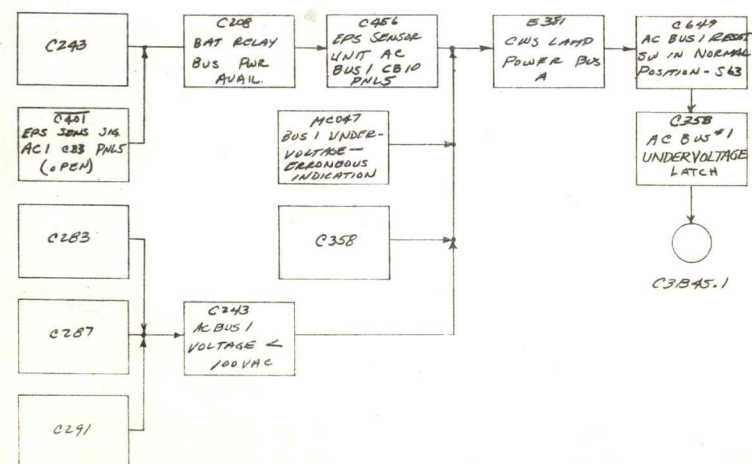
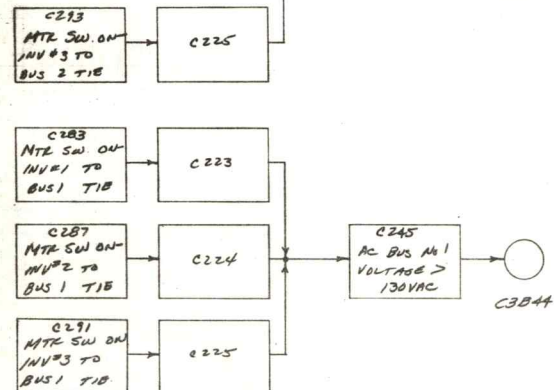
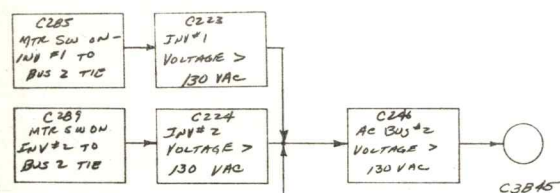
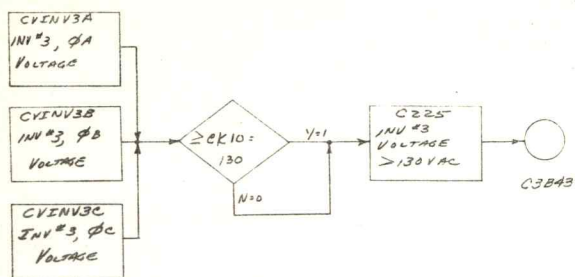


FIG B-14A INVERTER VOLTAGE AND AC BUS OVER/UNDER VOLTAGE EQUATIONS C3B43 THRU C3B47

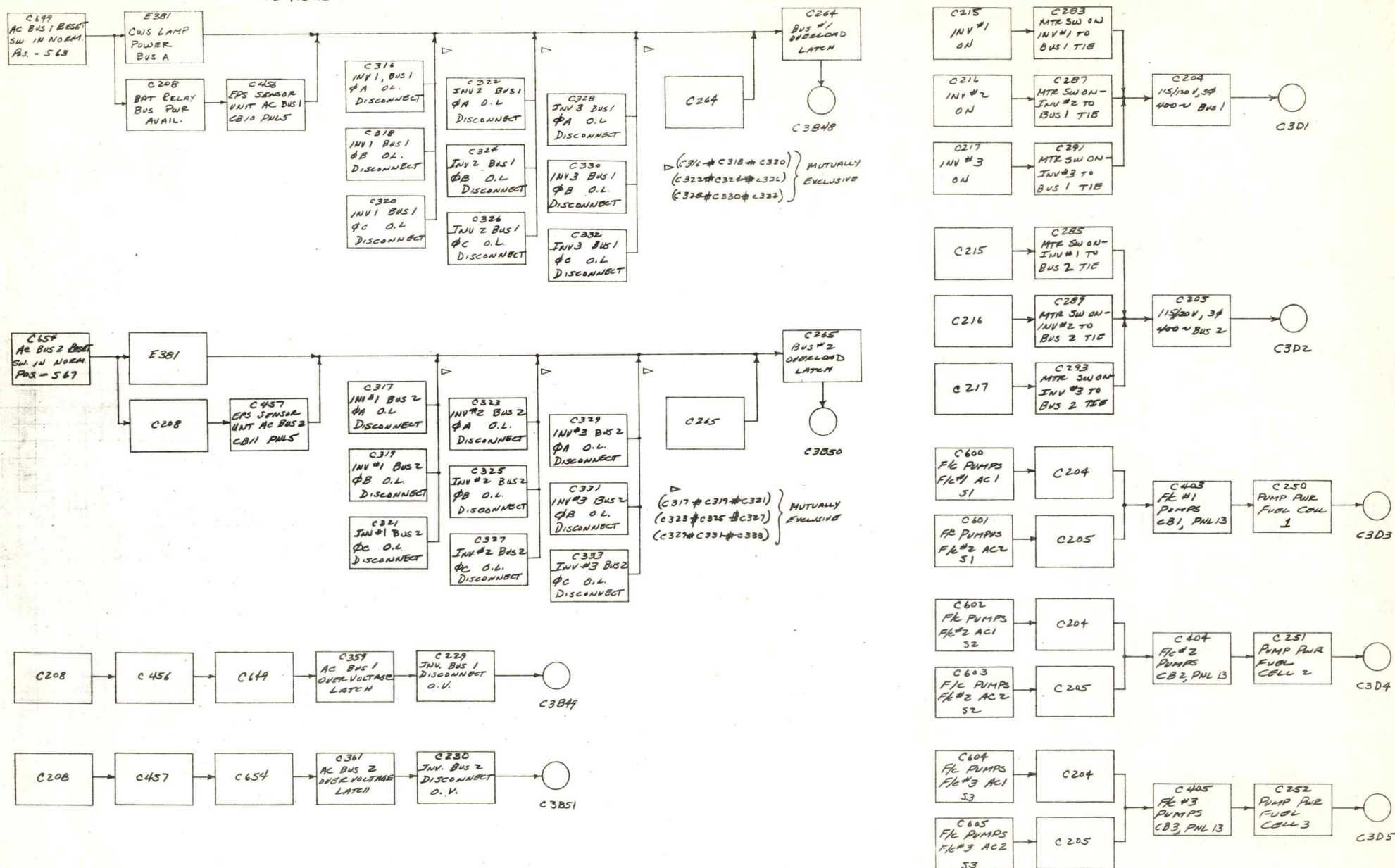


FIG B-15A AC BUS OVERLOAD AND DISCONNECT EQUATIONS C3B48 THRU C3B51
AC BUS POWER AVAILABLE EQUATIONS C3D1 THRU C3D5

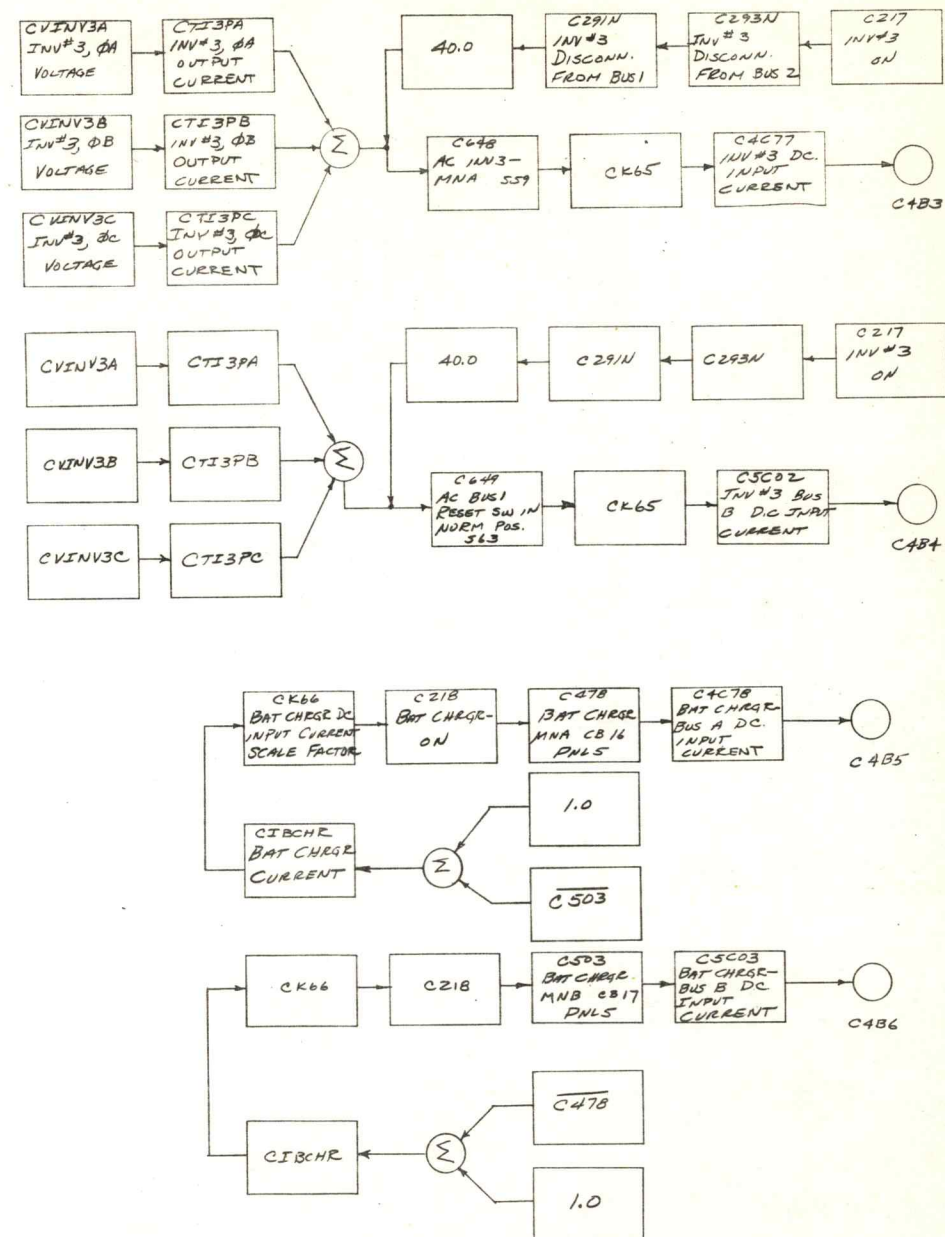
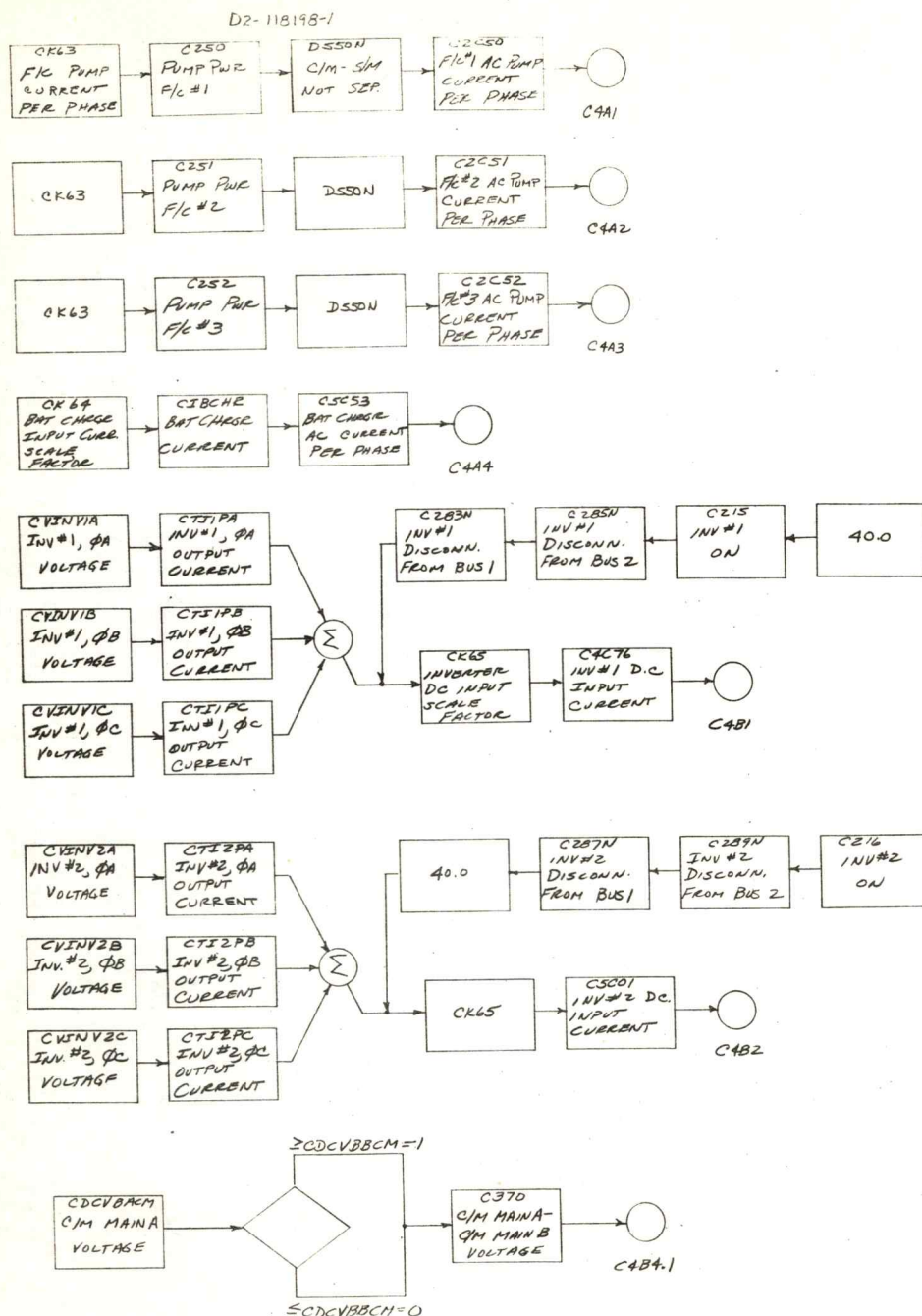


FIG B-16A AC/DC CURRENT DRAIN EQUATIONS C4A1 THRU C4B6

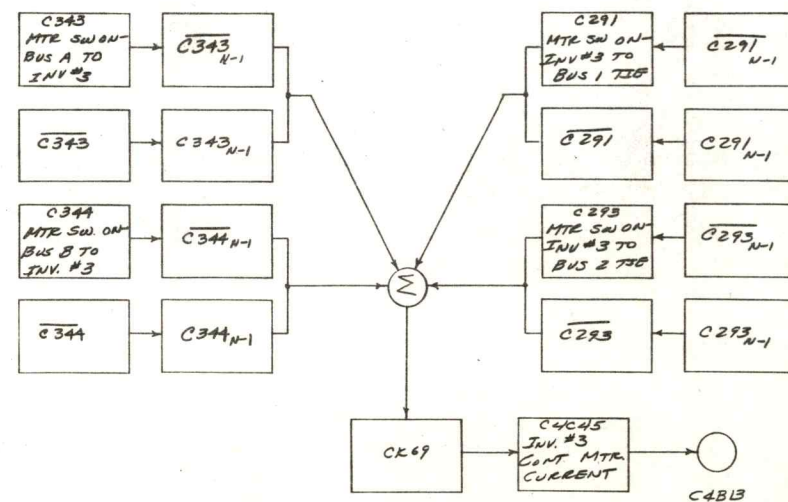
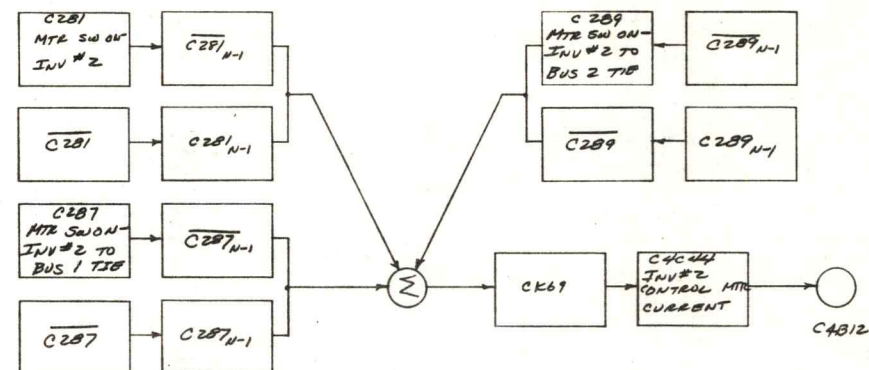
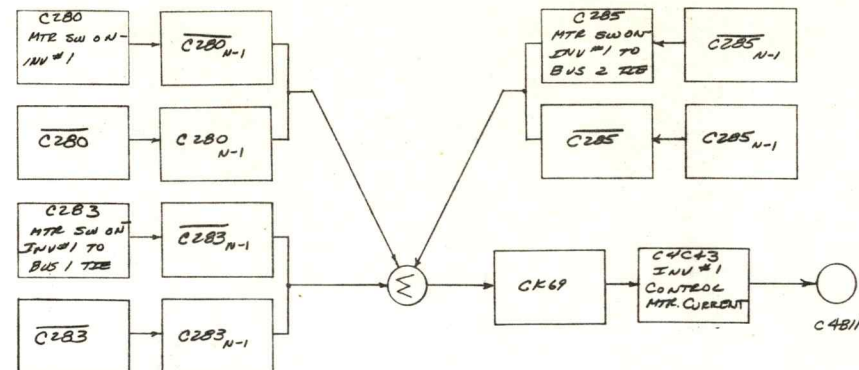
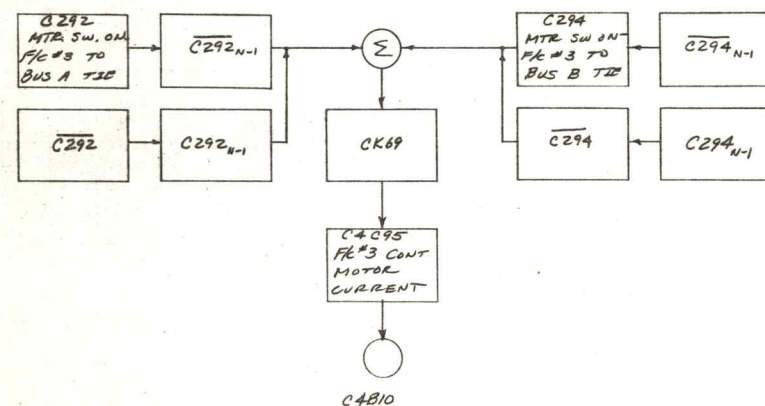
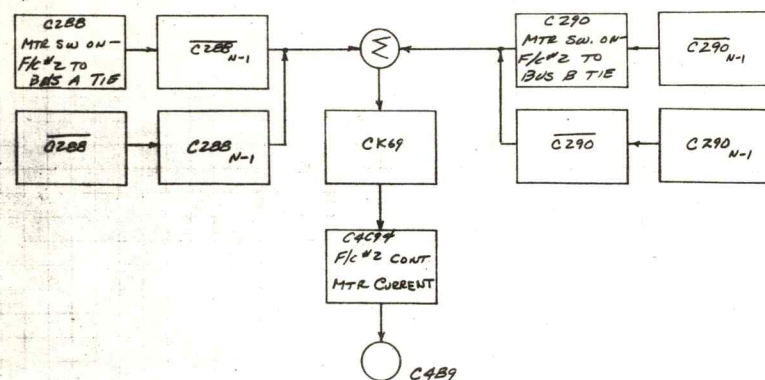
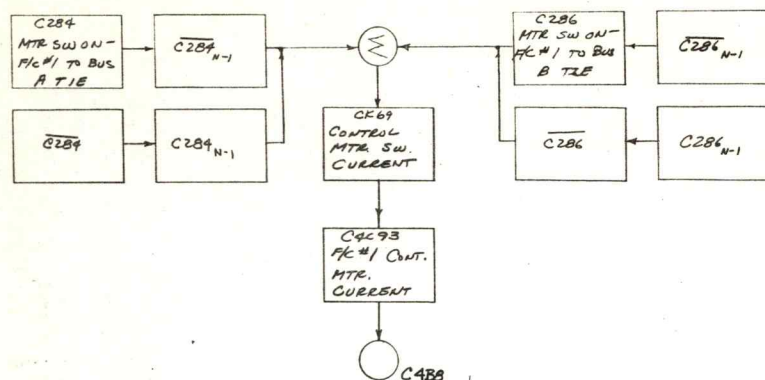
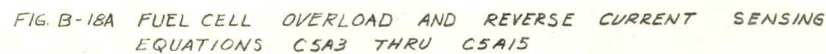


FIG. B-17A AC/DC INTERNAL CURRENT DRAIN EQUATIONS C4B8 THRU C4B13



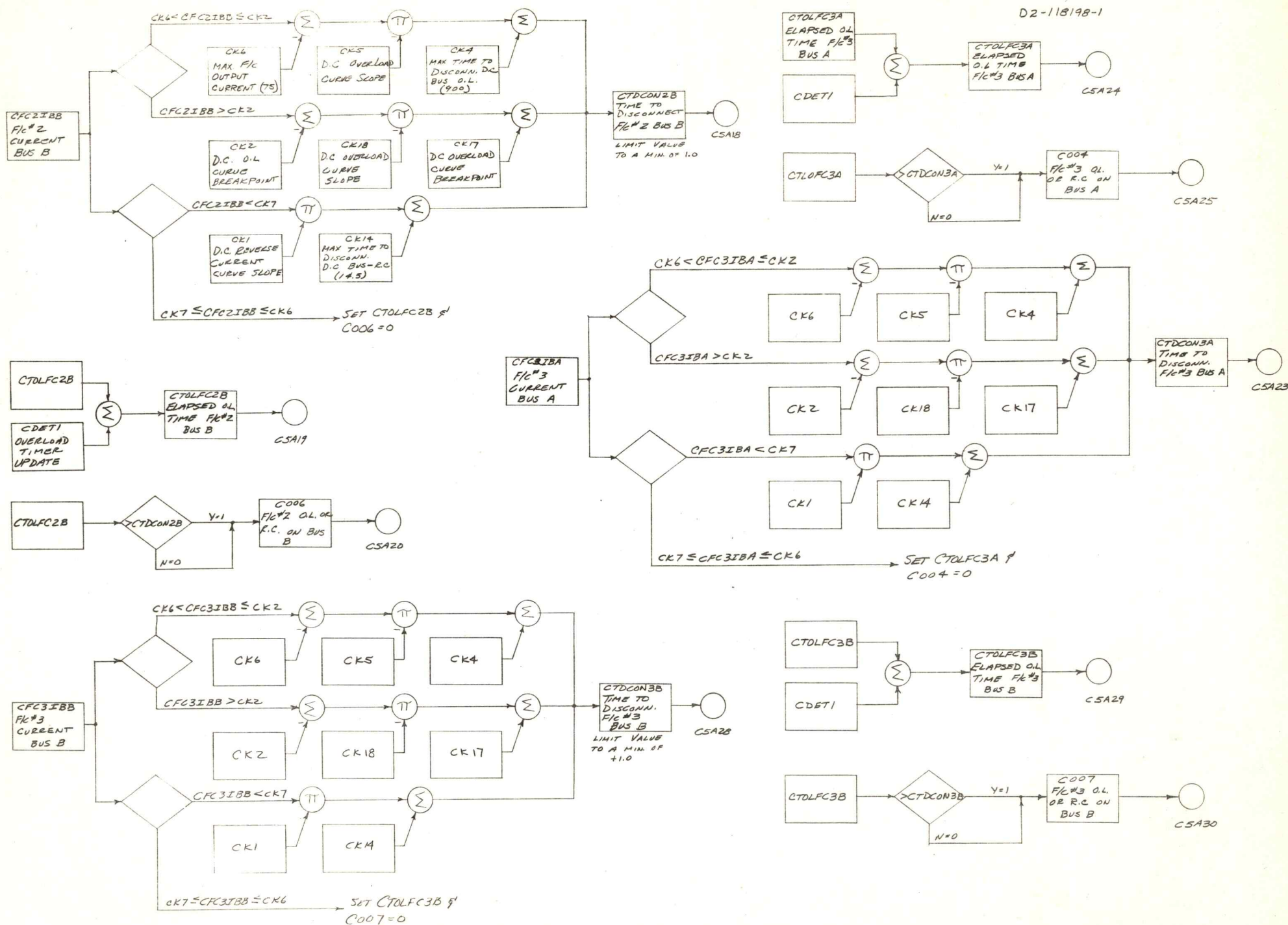


FIG. B-19A FUEL CELL OVERLOAD AND REVERSE CURRENT SENSING EQUATIONS CSA18 THRU CSA30

D2-118198-1

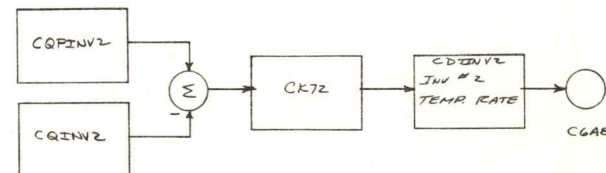
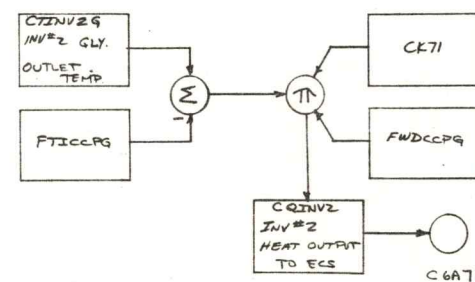
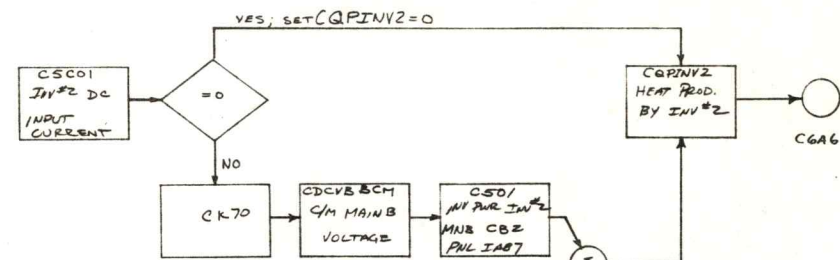
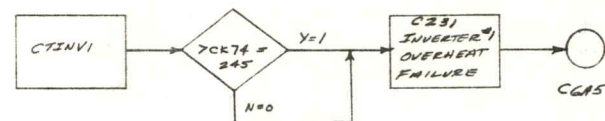
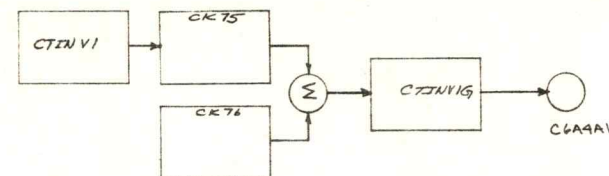
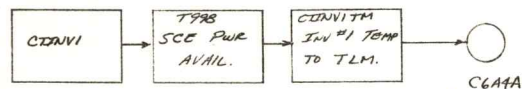
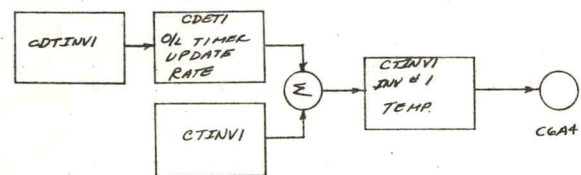
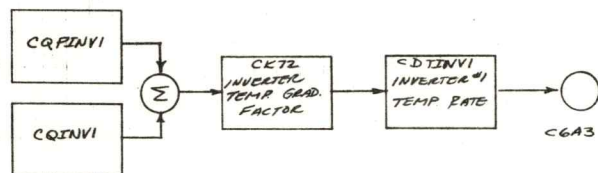
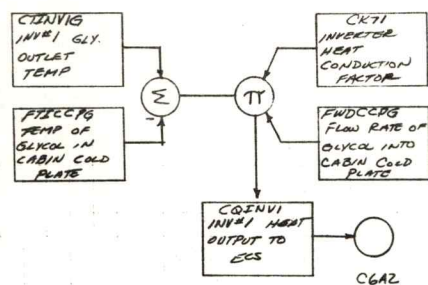
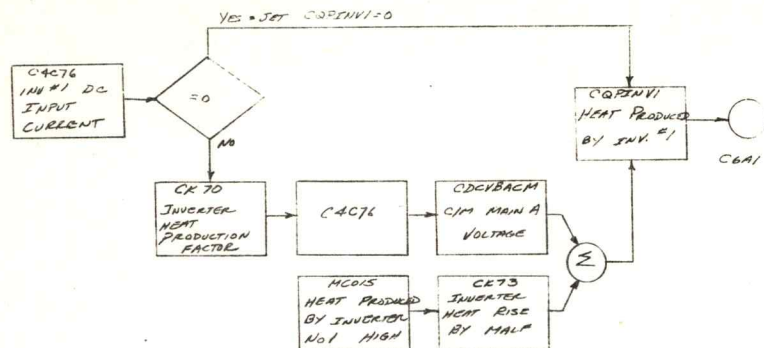


FIG. B-20A INVERTER TEMPERATURE EQUATIONS C6A1 THRU C6A8

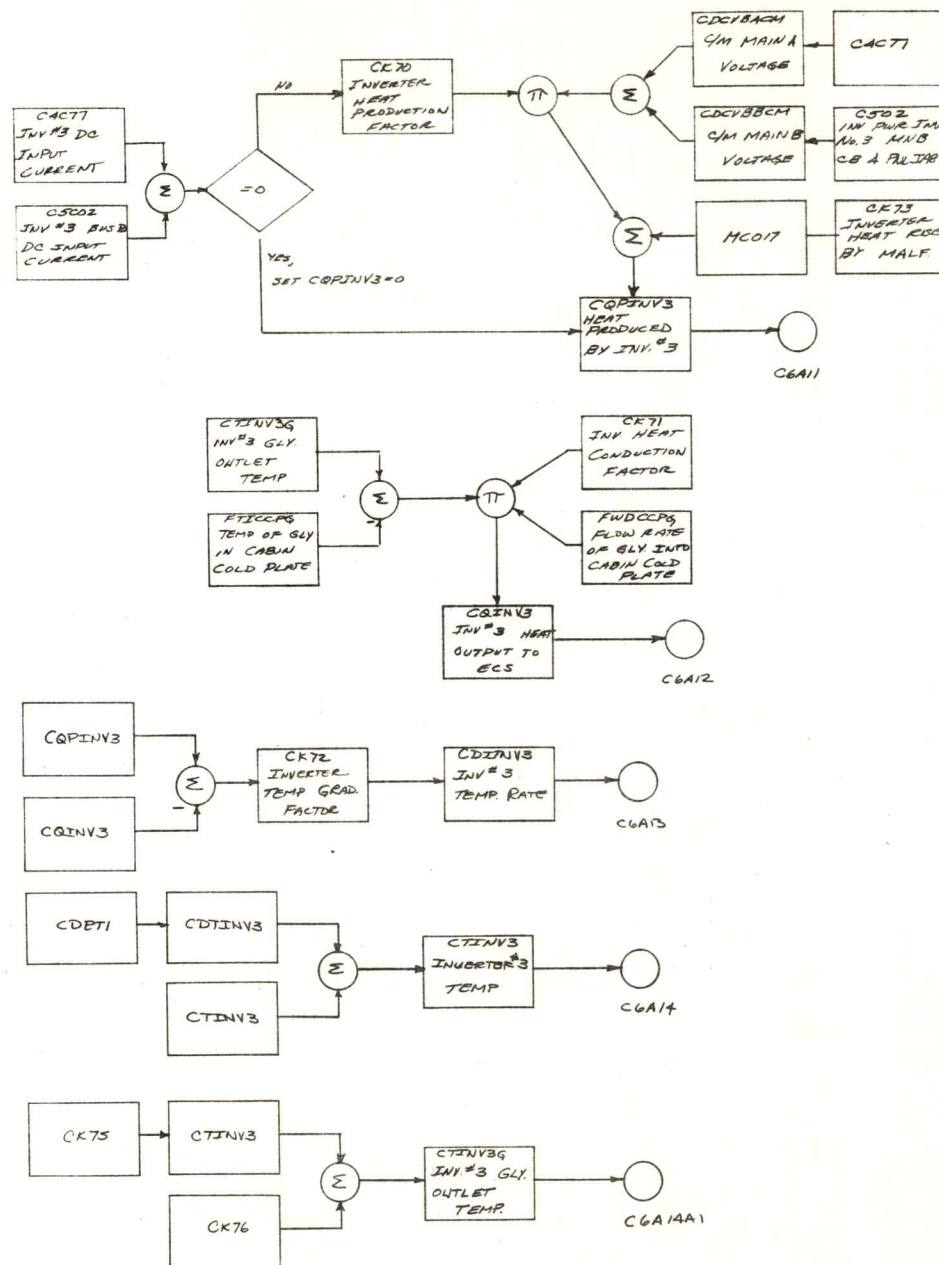
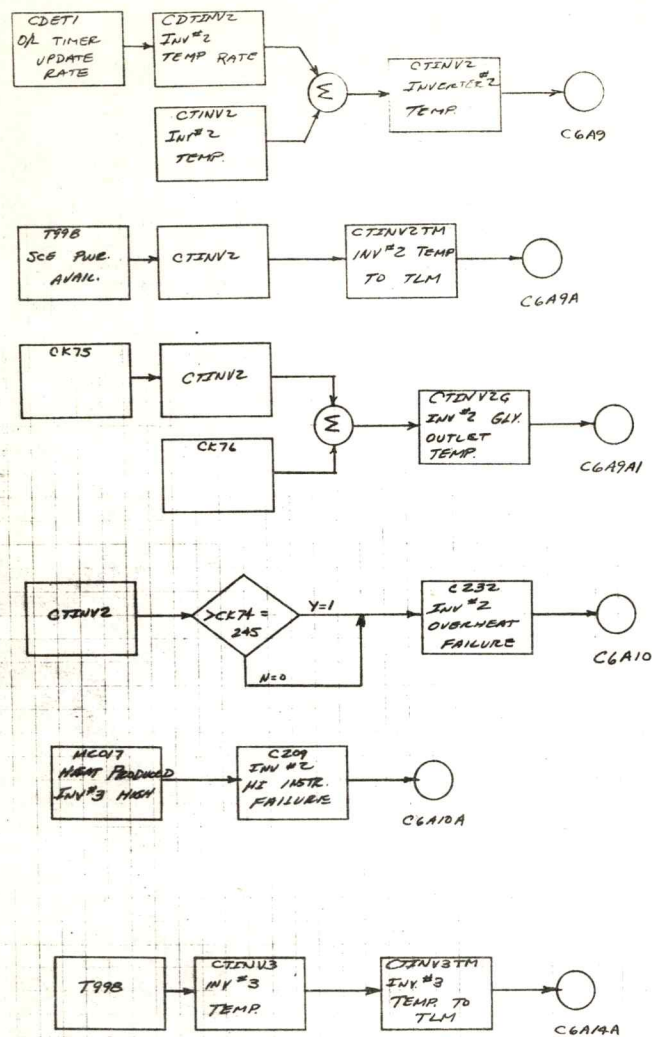


FIG. B-21A INVERTER TEMPERATURE EQUATIONS C6A9 THRU C6A14A1

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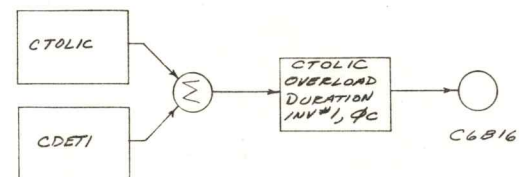
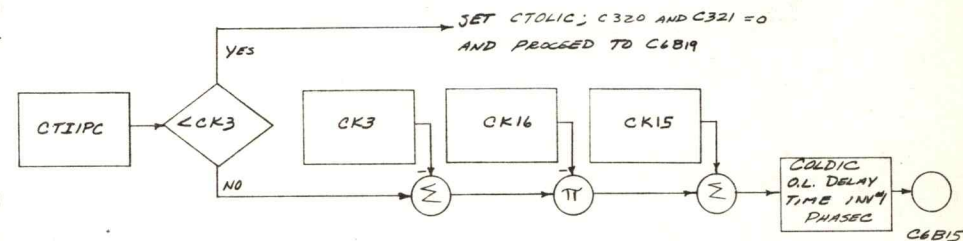
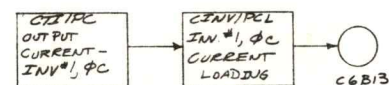
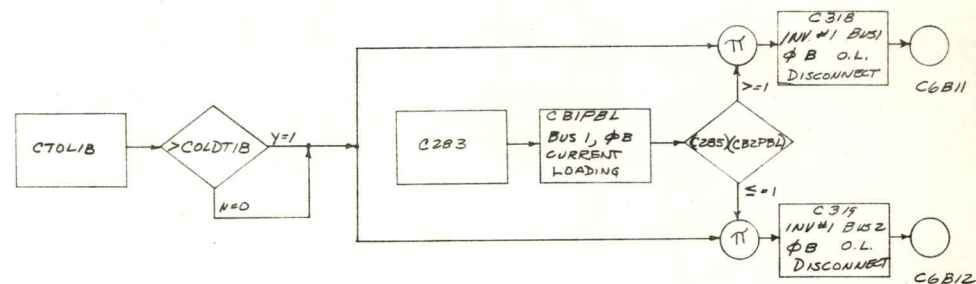
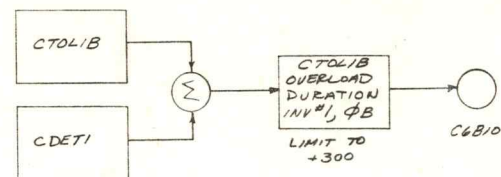
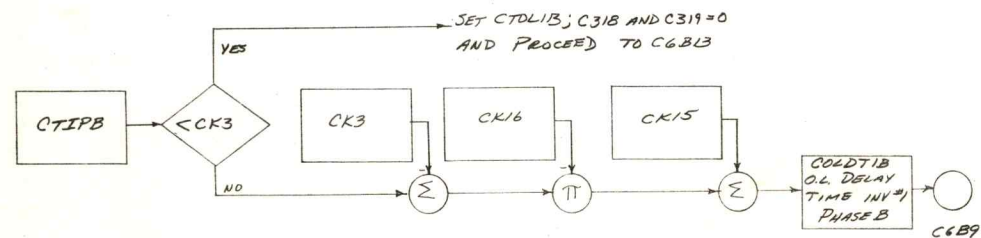
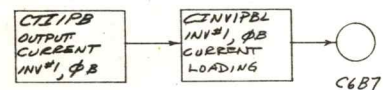
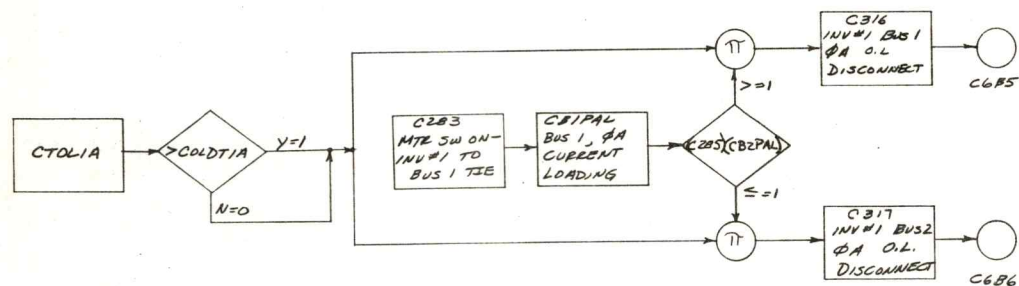
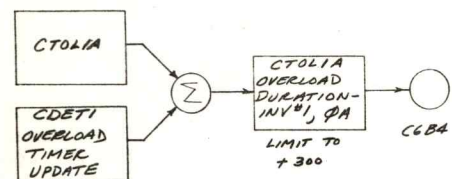
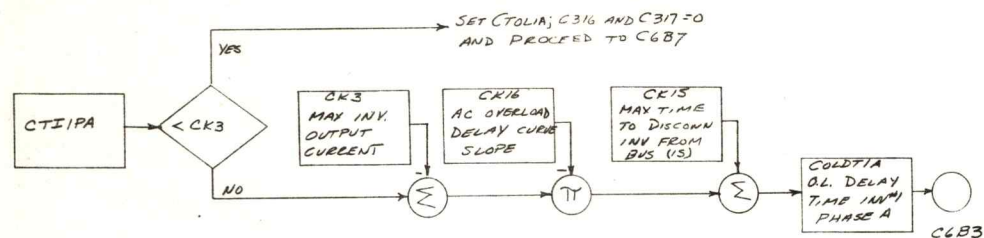
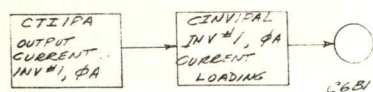


FIG B-22A INVERTER PHASE CURRENT AND OVERLOAD SENSING EQUATIONS C6B1 THRU C6B16

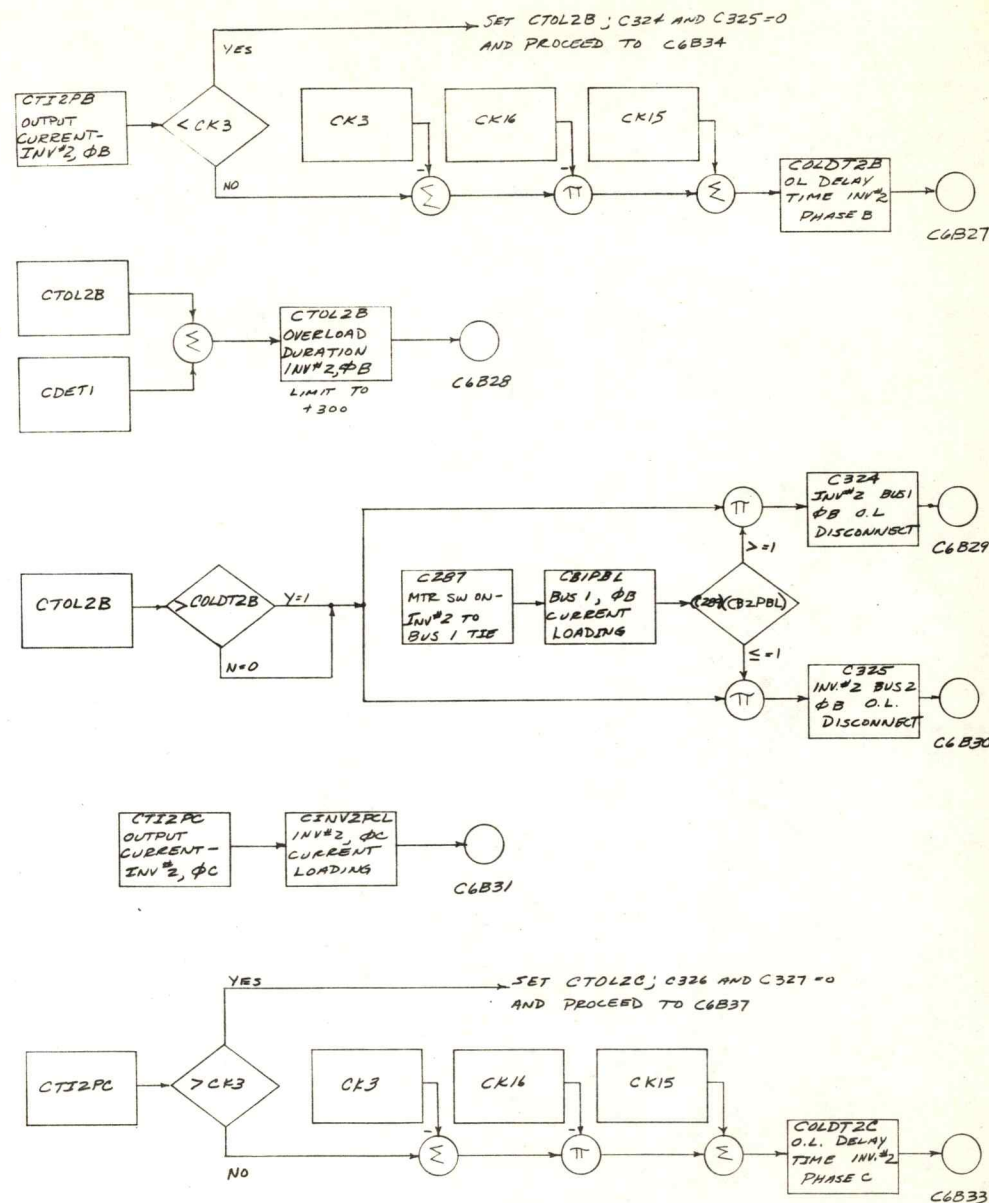
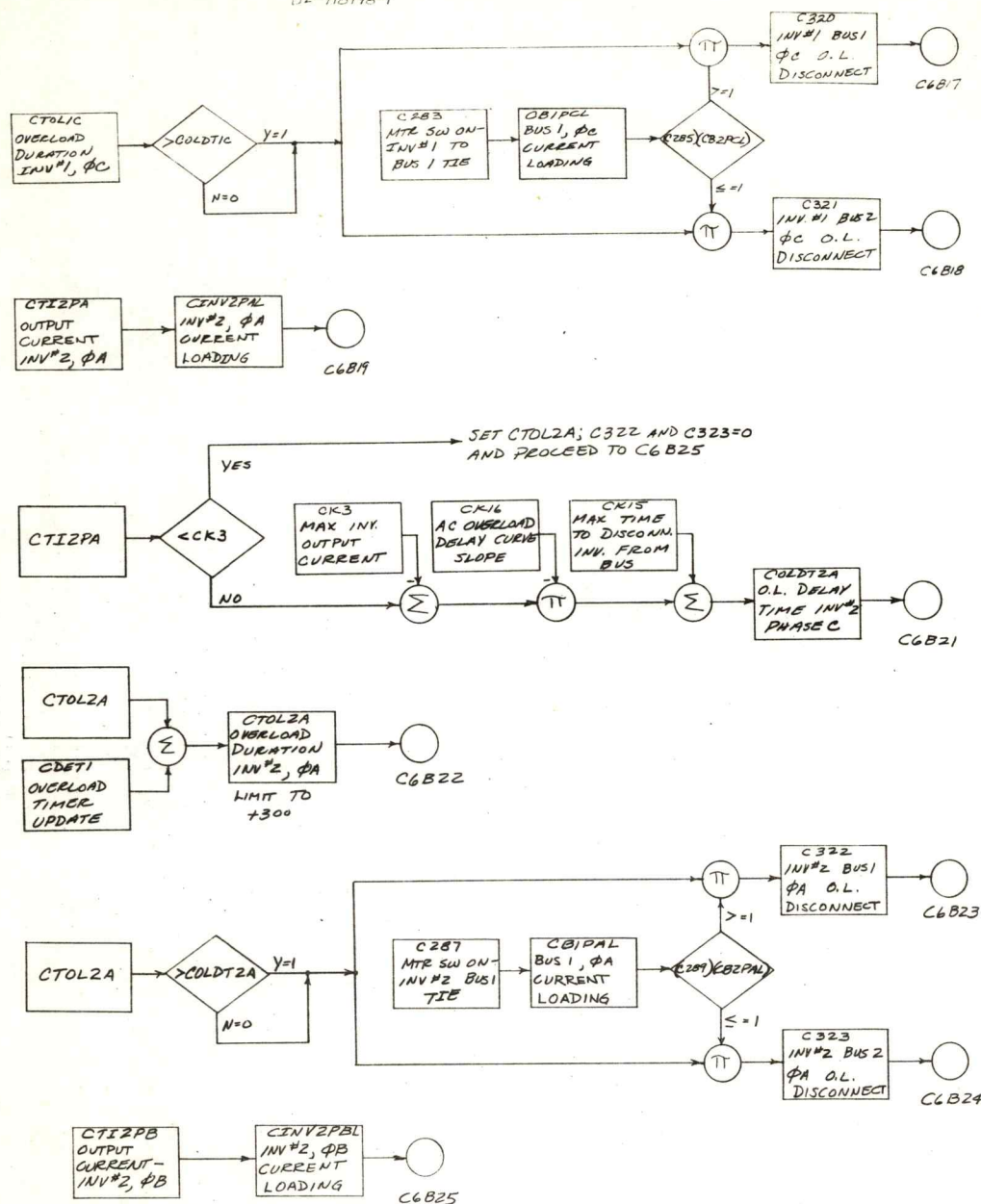


FIG. B-23A INVERTER PHASE CURRENT AND OVERLOAD SENSING EQUATIONS C6B17 THRU C6B34

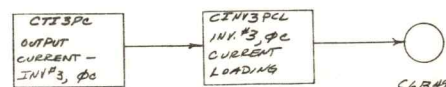
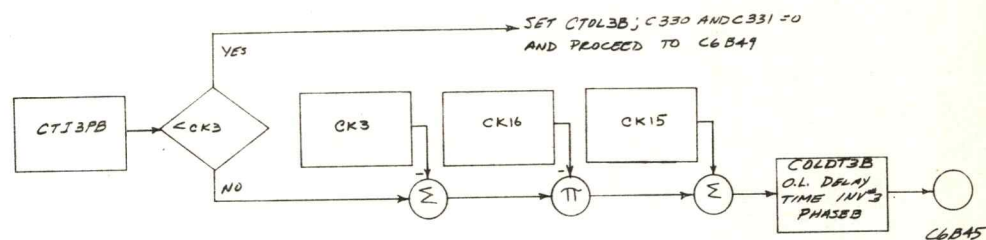
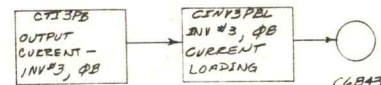
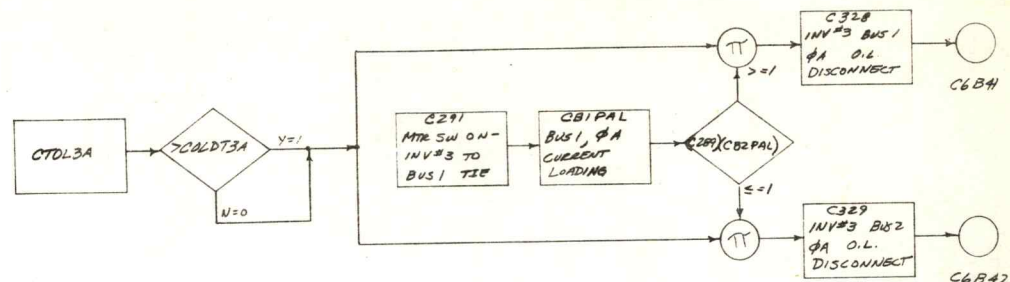
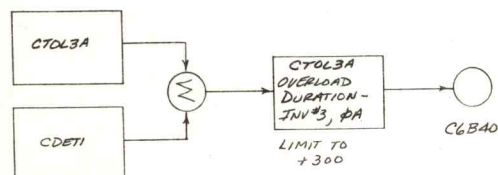
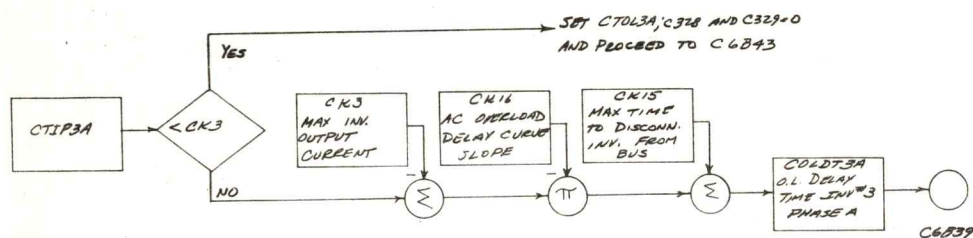
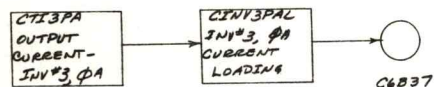
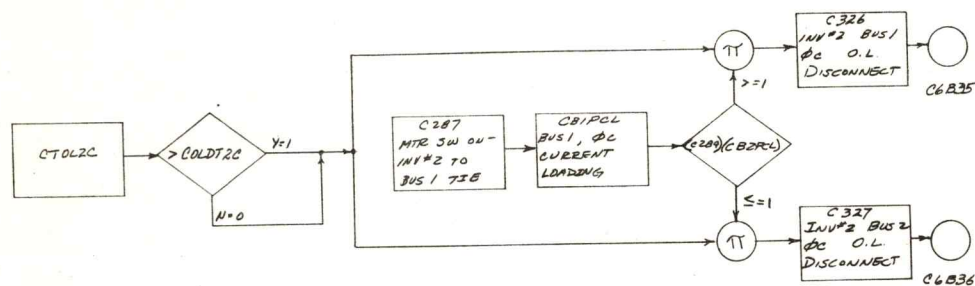
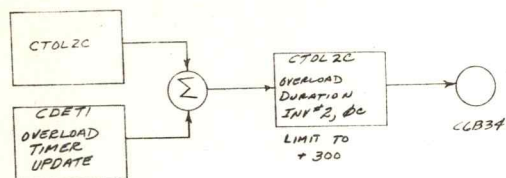


FIG. B-24A INVERTER PHASE CURRENT AND OVERLOAD SENSING EQUATIONS C6B34 THRU C6B49

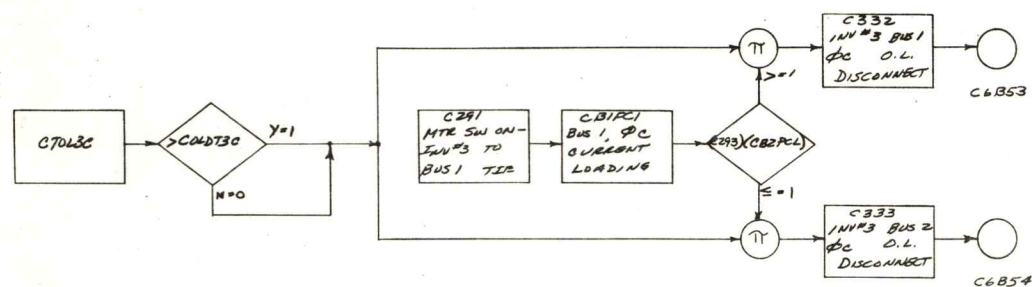
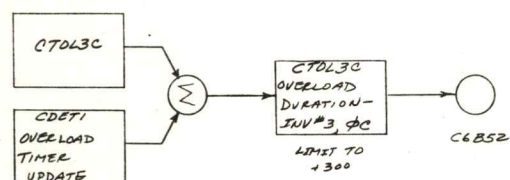
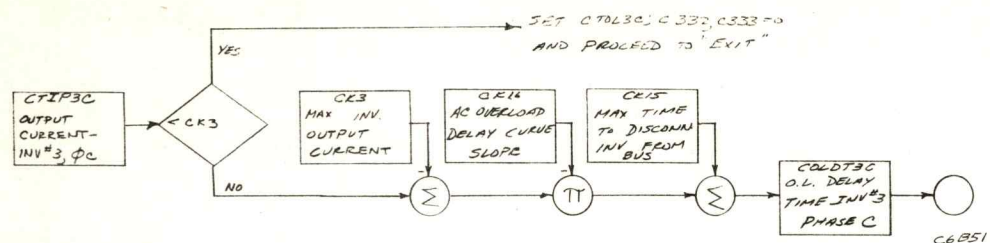


FIG. B-25A INVERTER PHASE CURRENT AND OVERLOAD SENSING
EQUATIONS C6B51 THRU C6B54

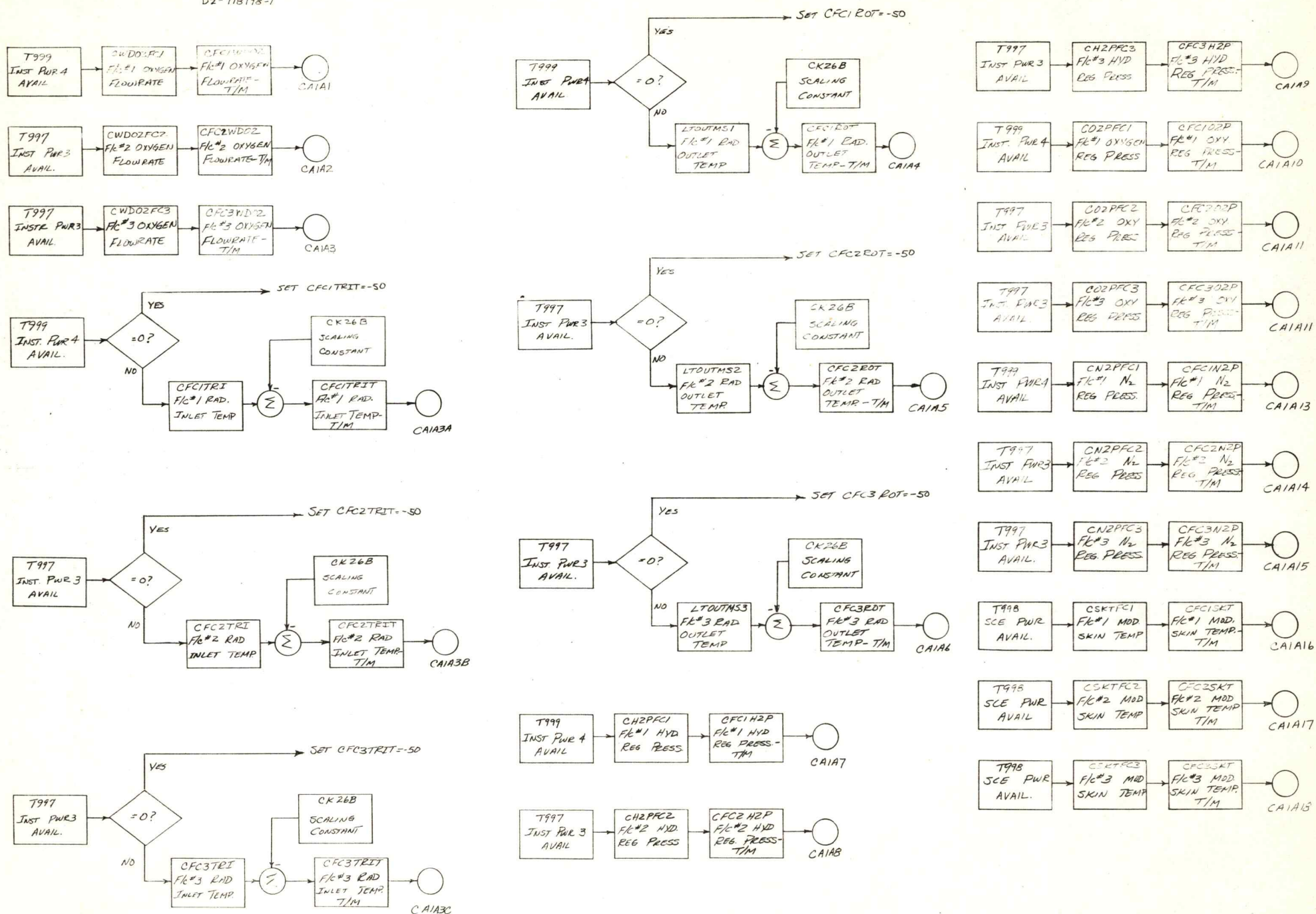


FIG.B-26B FUEL CELL VARIABLES AND DC CURRENTS - T/M SIGNAL
CONDITIONER EQ. CA1A1 THRU CA1A18

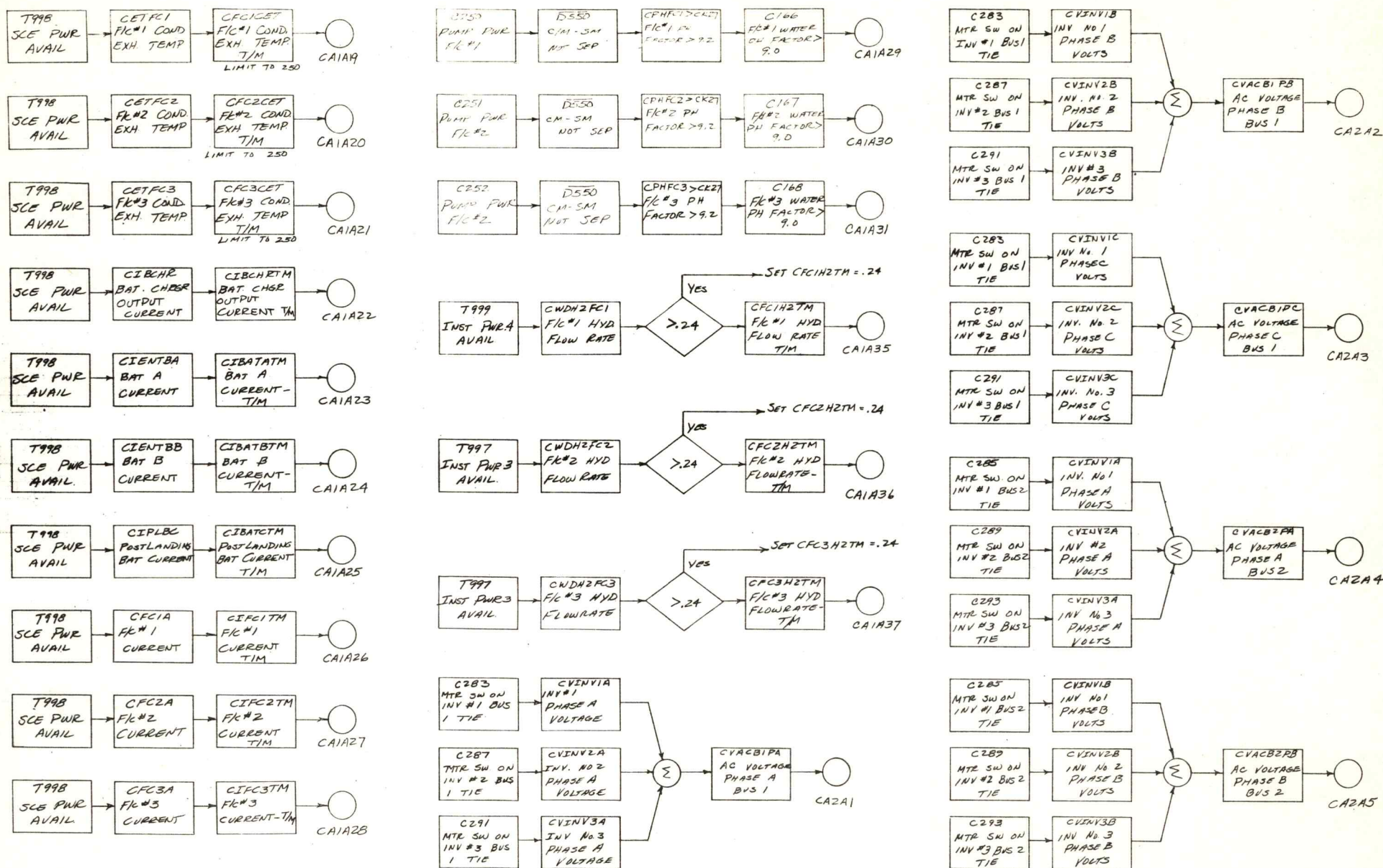


FIG B-27B FUEL CELL VARIABLE EQUATIONS CA1A19 THRU CA1A37
AC BUS VOLTAGE EQUATIONS CA2A1 THRU CA2A5

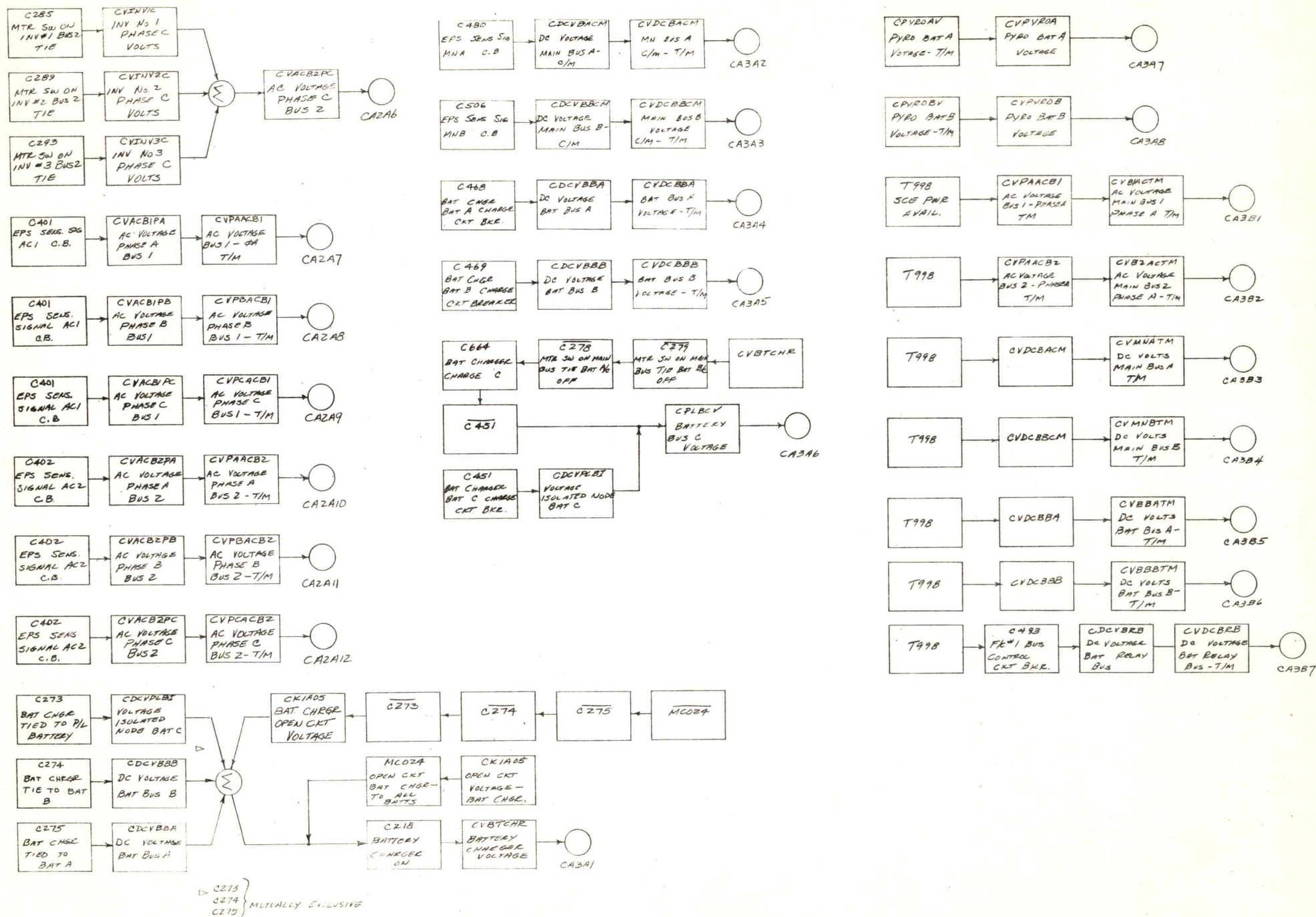
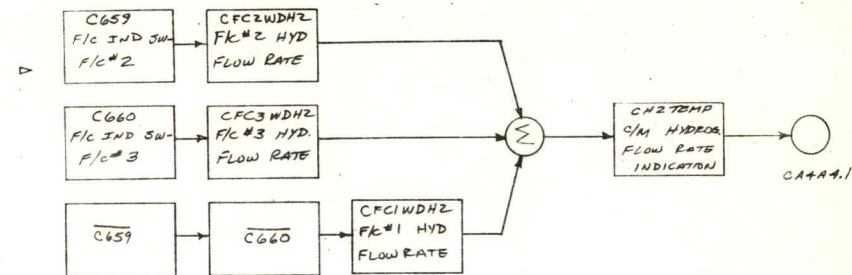
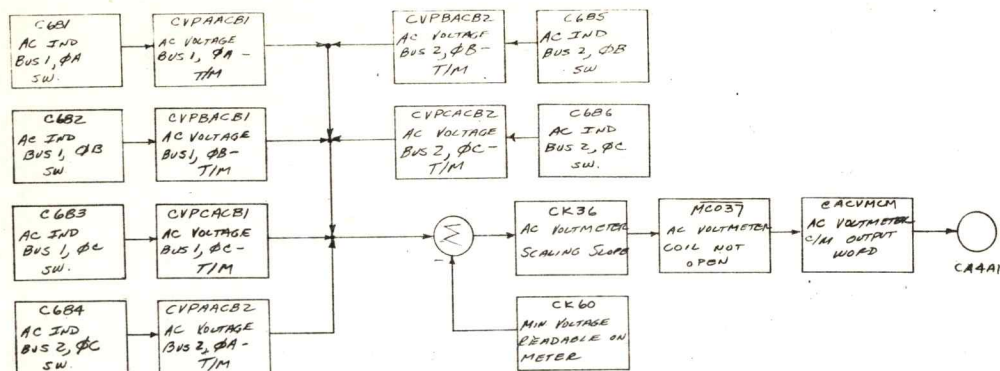


FIG. 13-25B AC BUS VOLTAGE EQUATIONS CA2A6 TO CA2A12
 DC DISPLAY VARIABLE EQUATIONS CA3A1 THRU CA3A8
 AC/DC VOLTAGES - T/M SIG. COND. EQUATIONS CA3B1 THRU CA3B7

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C659 } MUTUALLY EXCLUSIVE
C660 }

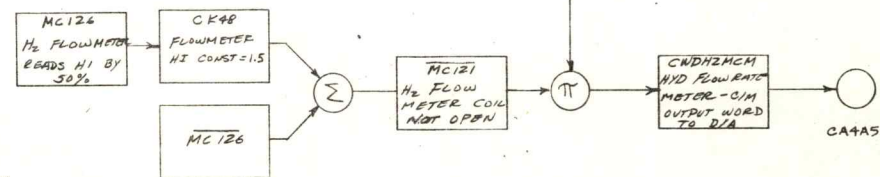
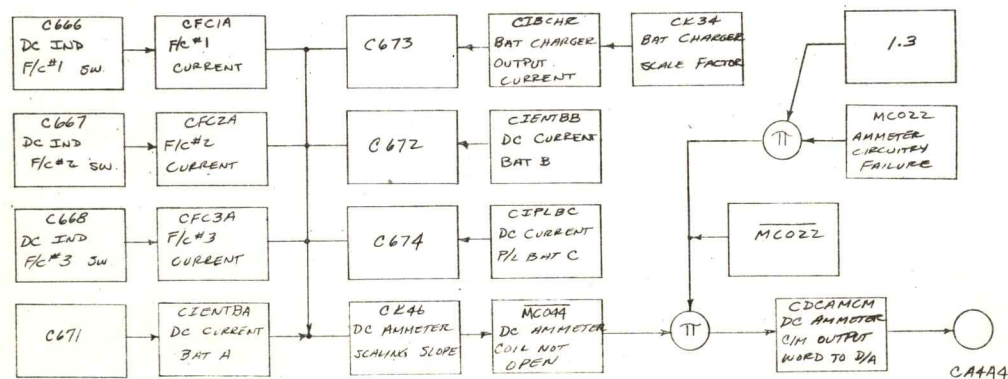
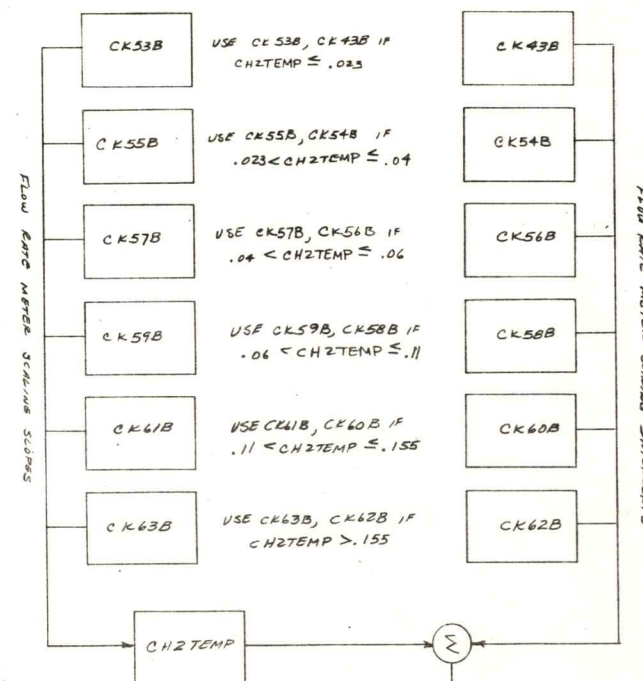
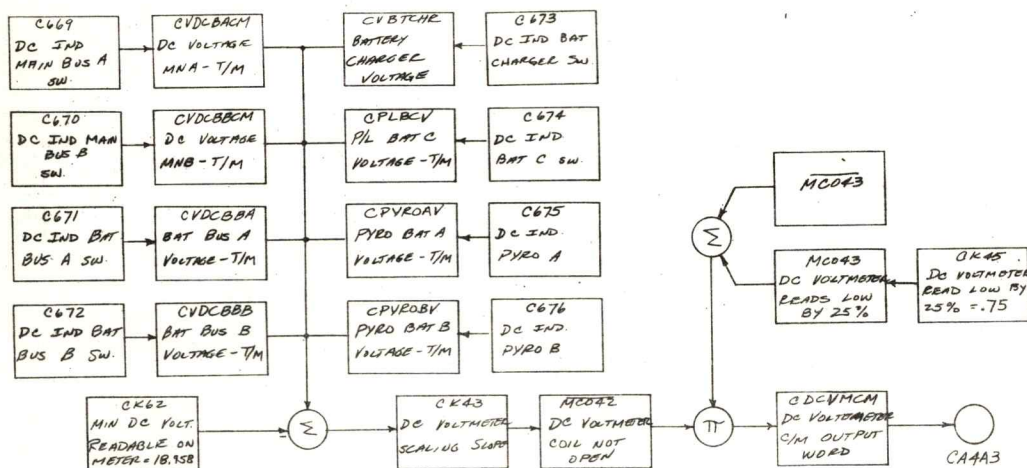
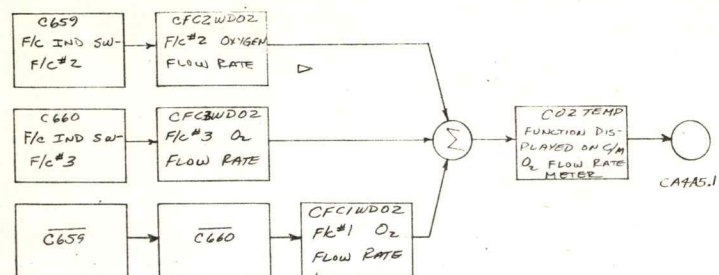


FIG B-29B C/M METER DISPLAYS - C/M OUTPUT TO D/A
EQUATIONS CA4A1 THRU CA4A5



Δ C659 } MUTUALLY EXCLUSIVE
C660 }

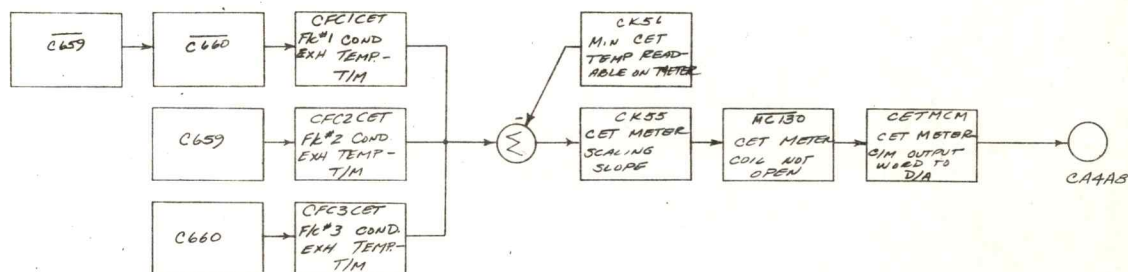
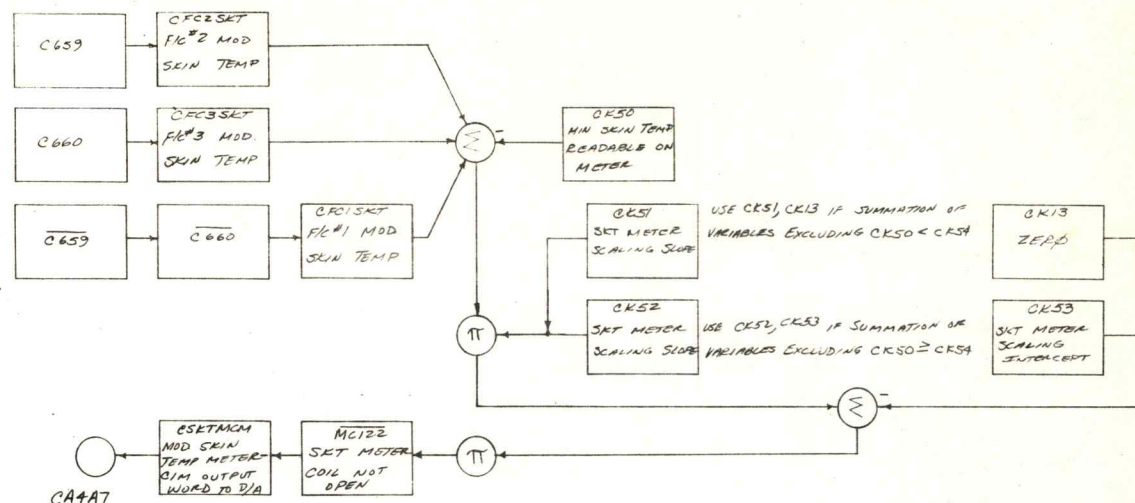
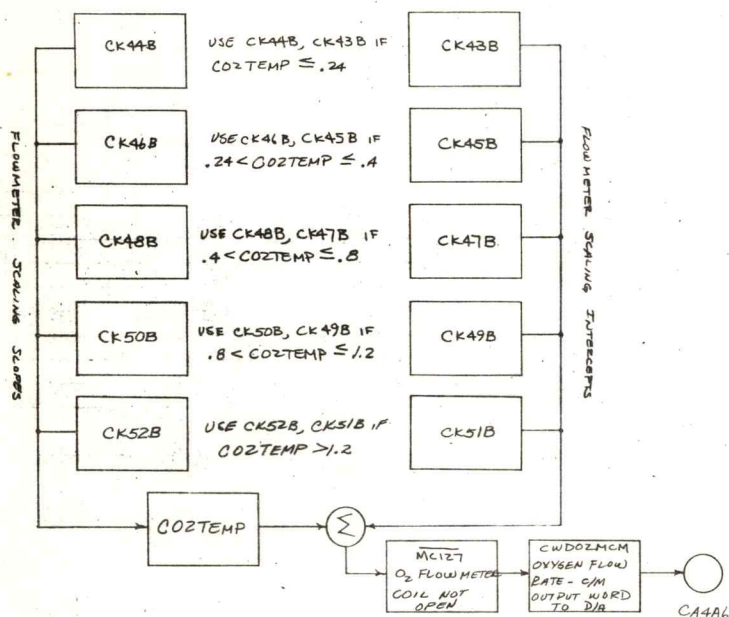


FIG B-30B C/M METER DISPLAYS - C/M OUTPUT WORD TO D/A
EQUATIONS CA4A5.1 THRU CA4A8

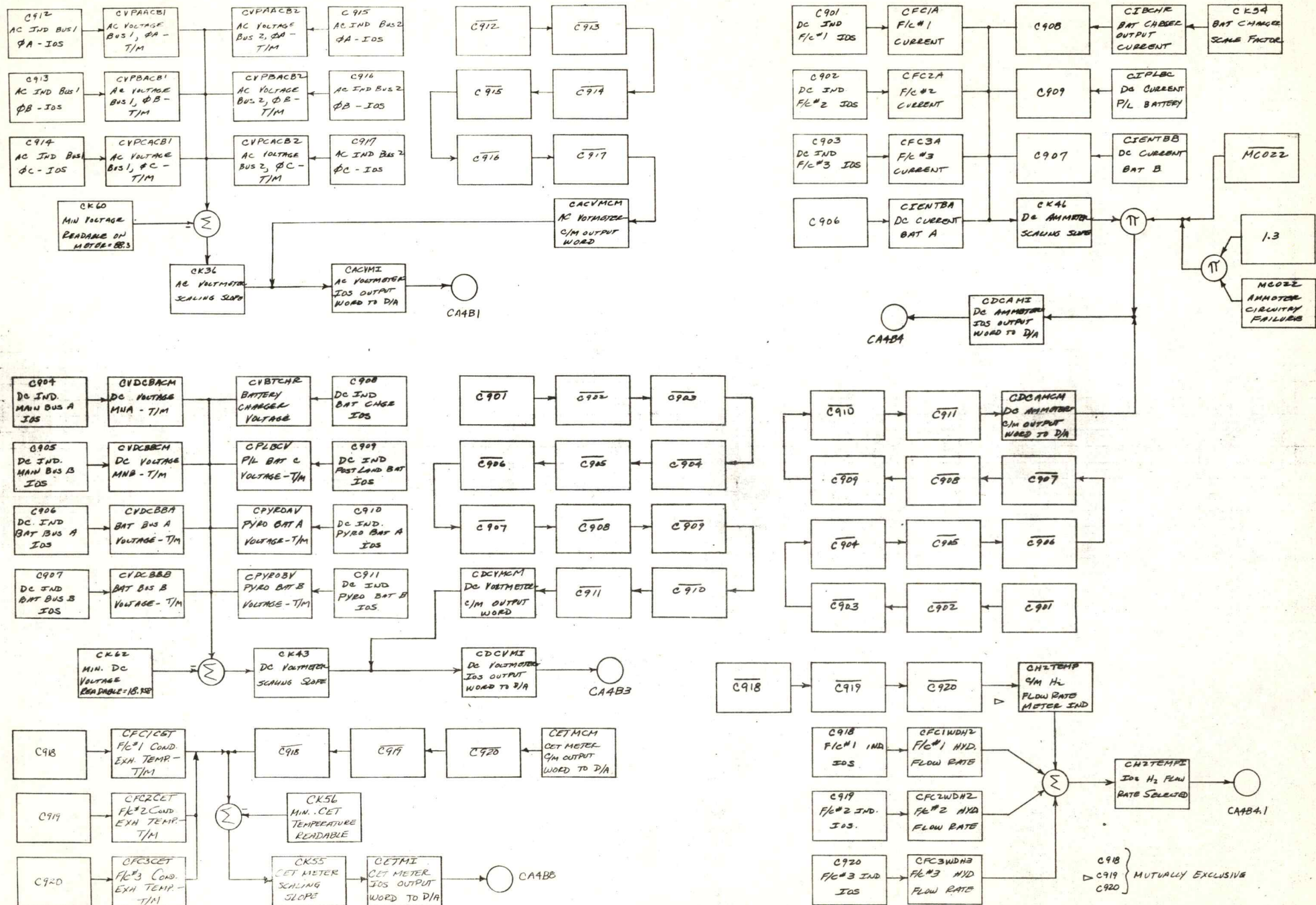


FIG B-31B IQS METER DISPLAYS- IQS OUTPUT WORD TO D/A
EQUATIONS CA4B1 THRU CA4B4.1 AND CA4B5

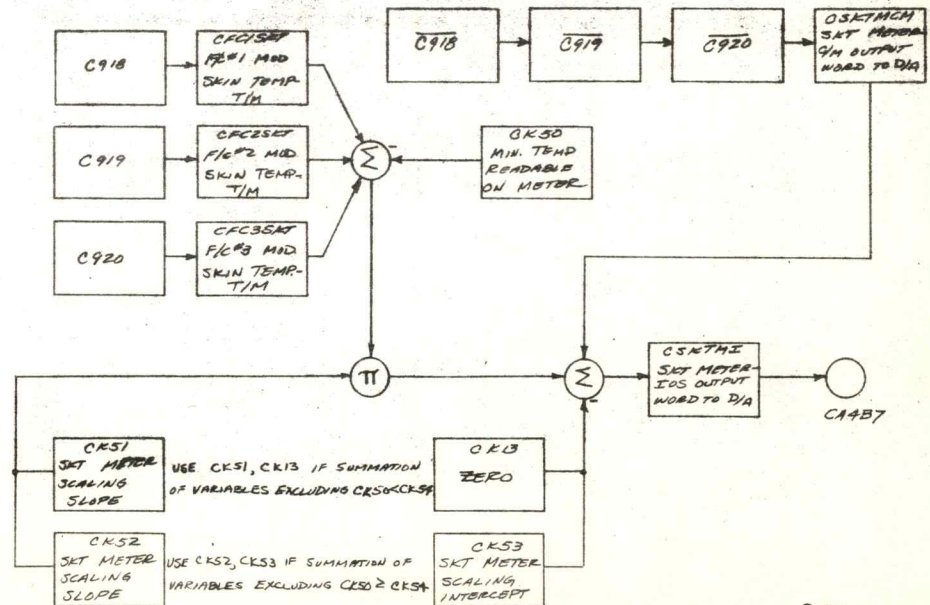
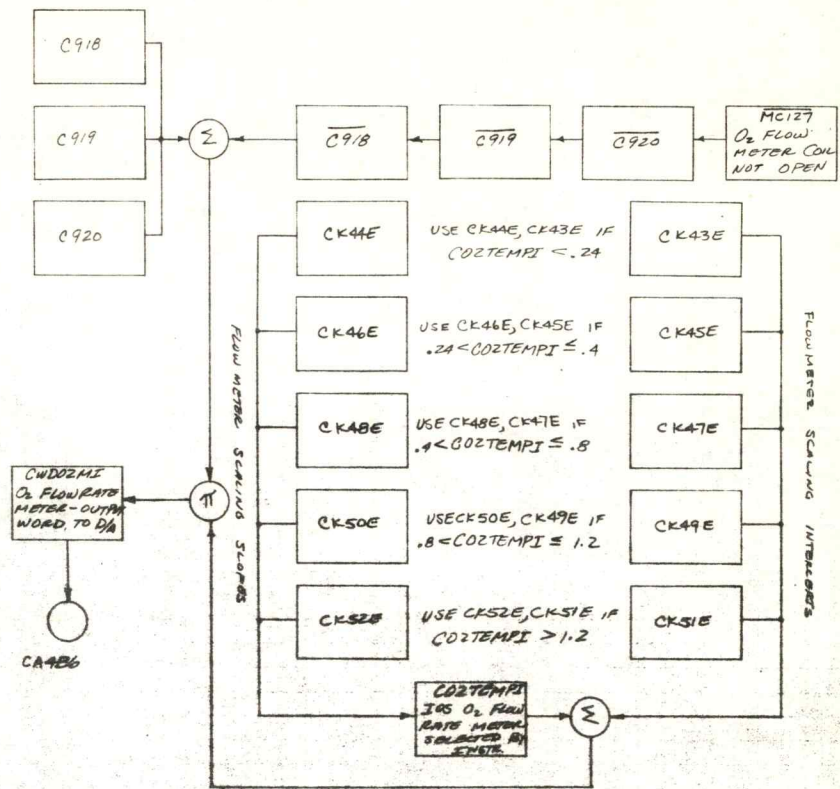
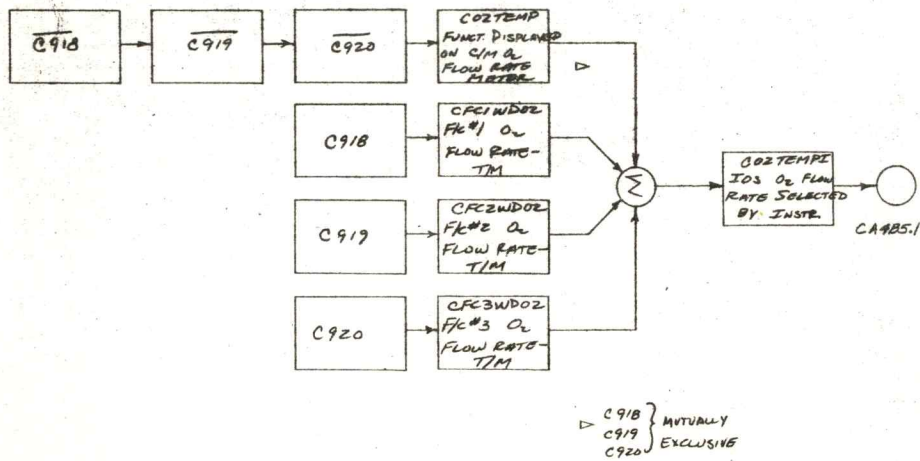
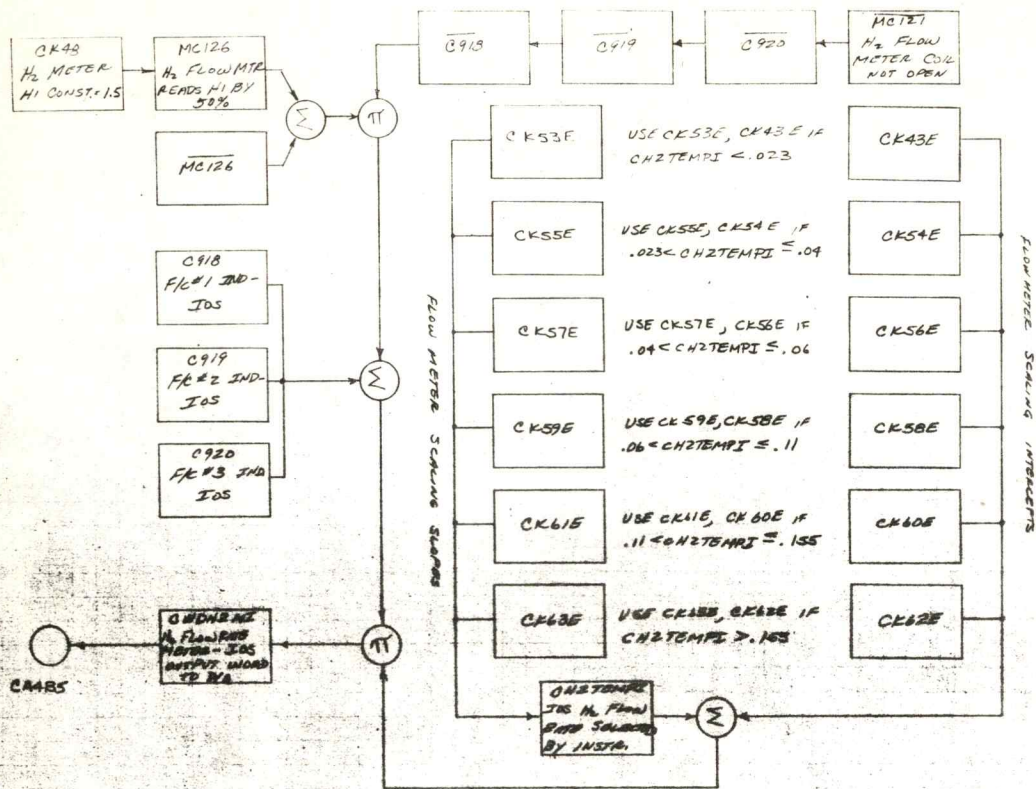


FIG. B-32B IOS METER DISPLAYS - IOS OUTPUT WORD TO D/A EQUATIONS CA4B5 THRU CA4B7

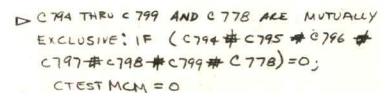


FIG B-34B SYSTEM TEST METER—C/M-105 OUTPUT WORD TO D/A, EQUATION CA4B9

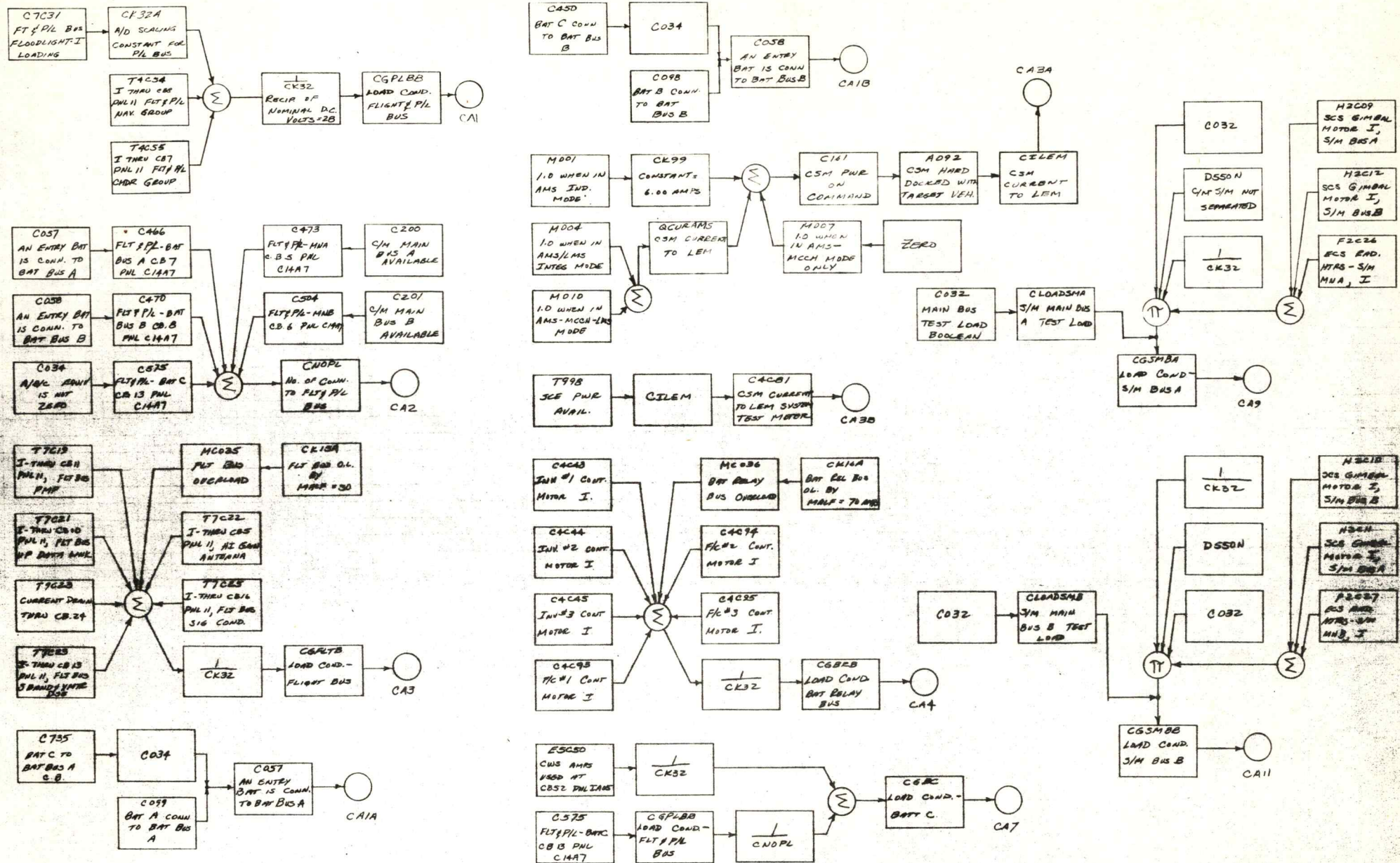


FIG B-35C BUS LOAD SUMMATION EQUATIONS CA1, CA2, CA3, CA1A, CA1B, CA3A, CA3B, CA4, CA7, CA9, AND CA11.

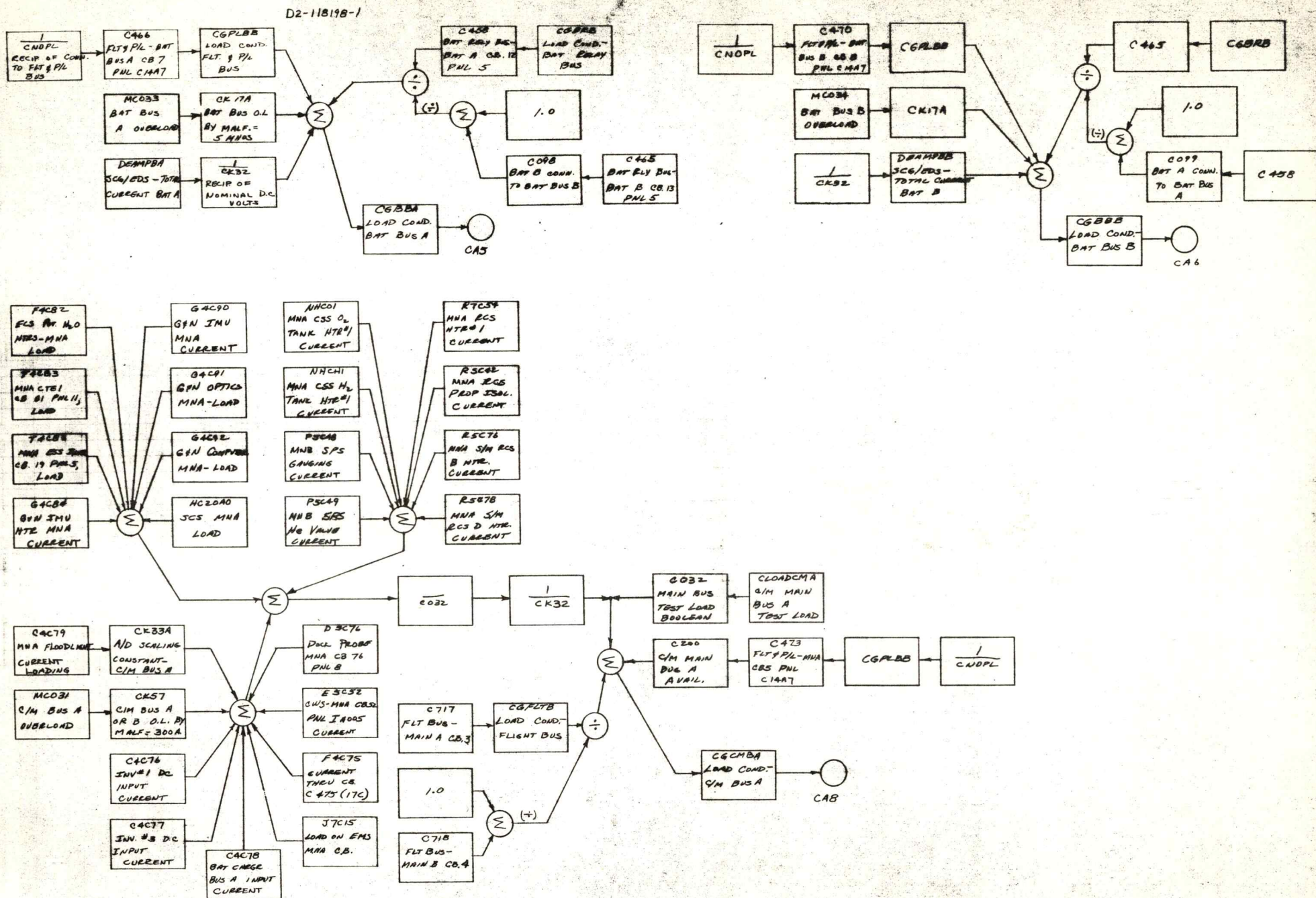


FIG B-36C BUS LOAD SUMMATION EQUATIONS CAB, CA6, AND CAB

B-37

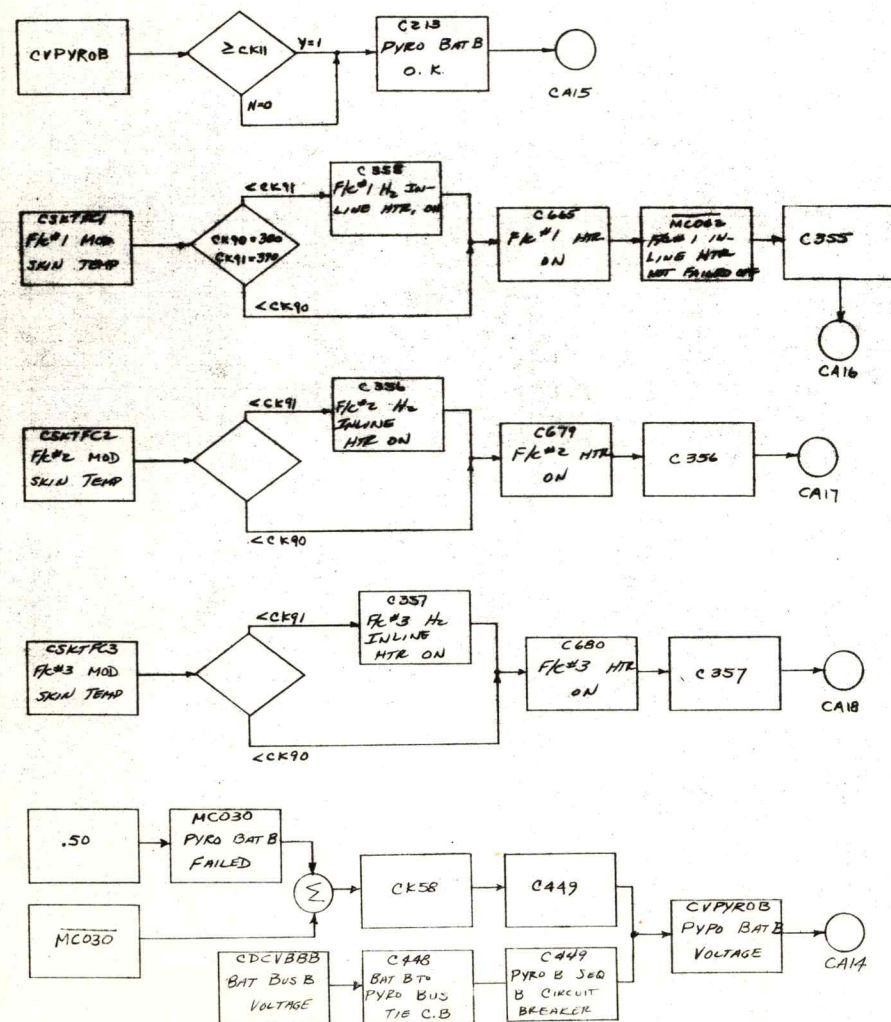
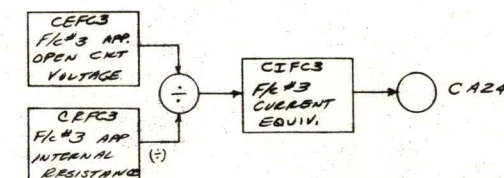
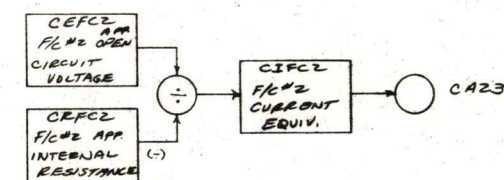
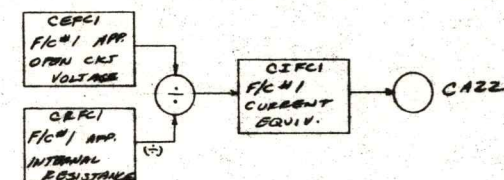
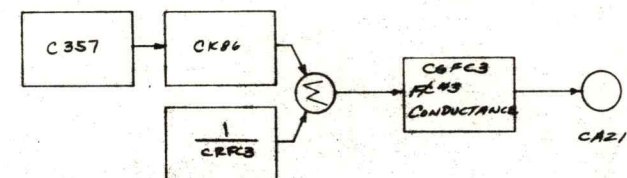
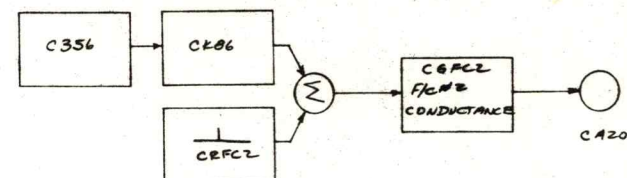
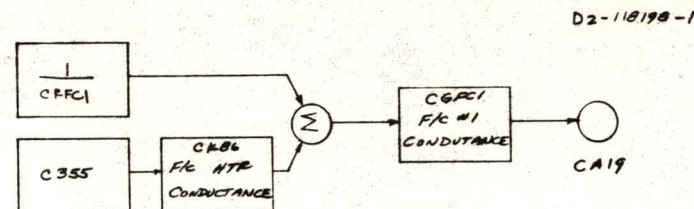
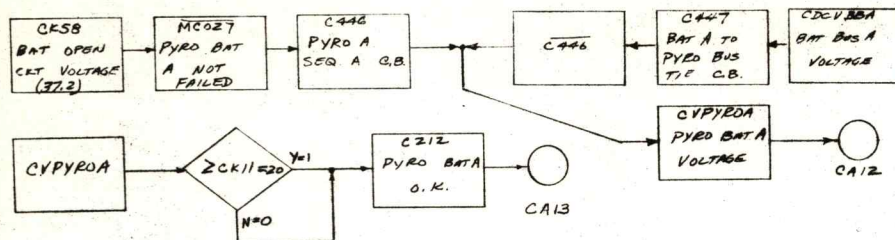


FIG. B-38C FUEL CELL CONDUCTANCE AND CURRENT EQUIVALENT EQUATIONS CA16 THRU CA24
PYRO BATTERY EQUATIONS CA12 THRU CA15

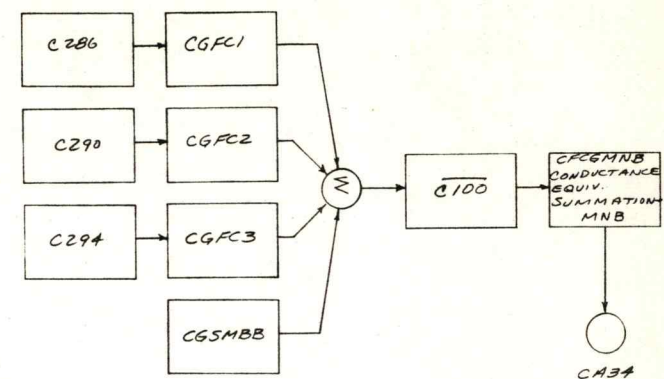
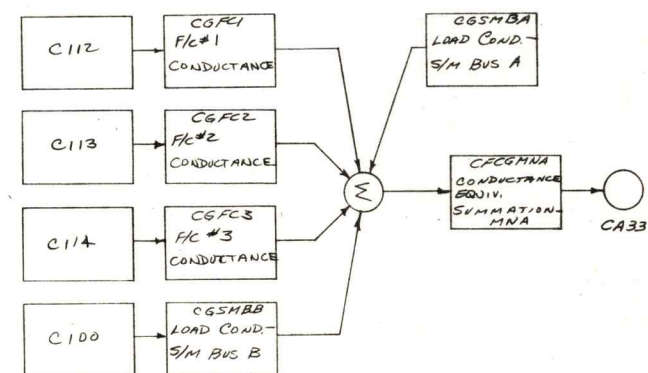
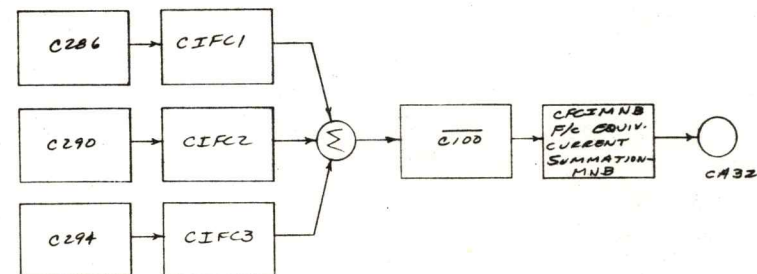
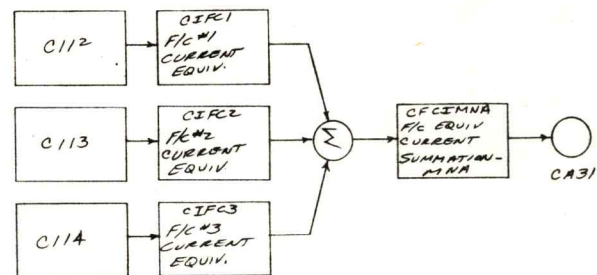
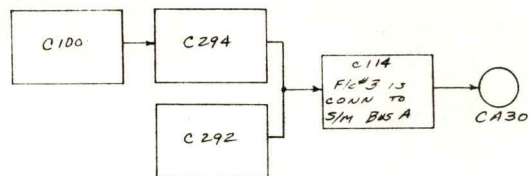
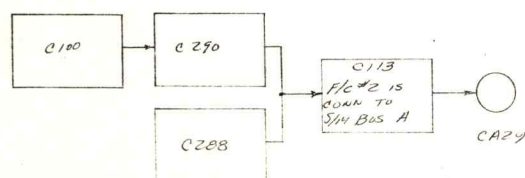
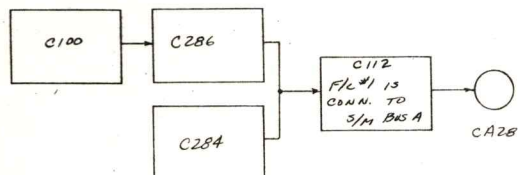
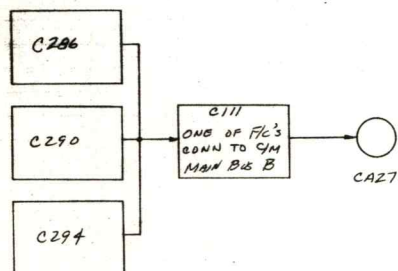
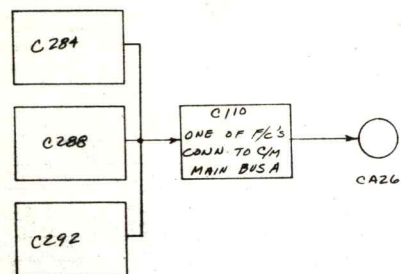
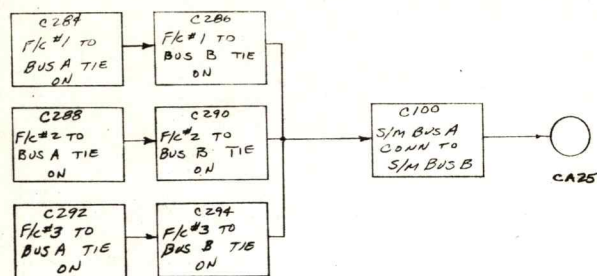


FIG B-39C FUEL CELL CONDUCTANCE AND CURRENT EQUIVALENT EQUATIONS CA25 THRU CA34

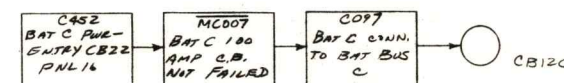
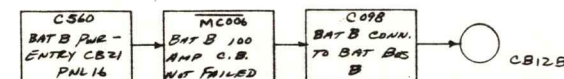
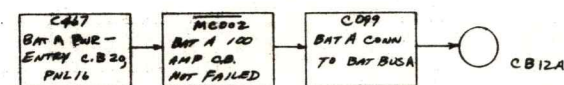
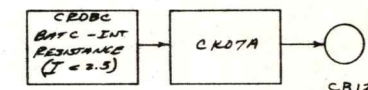
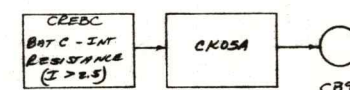
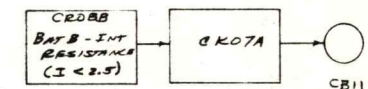
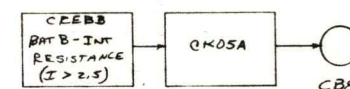
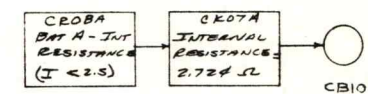
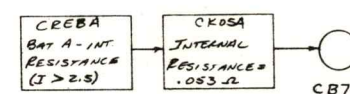
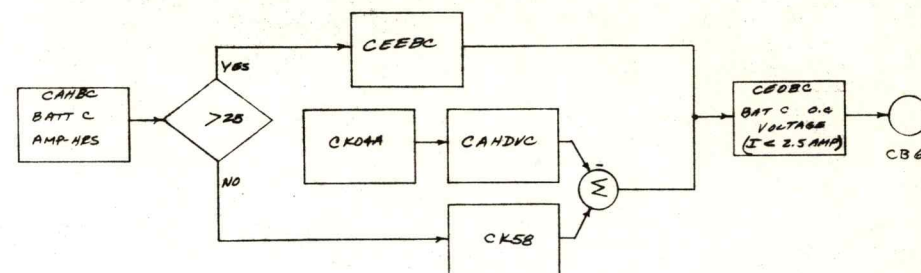
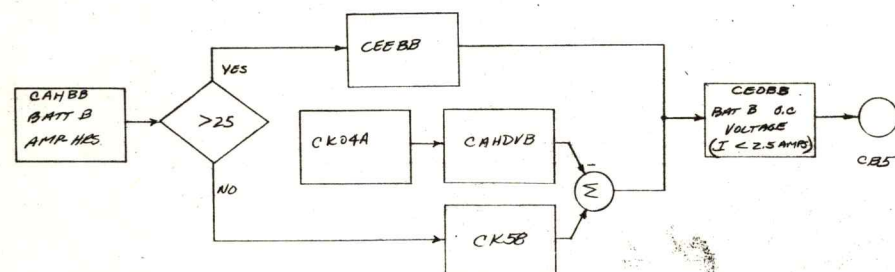
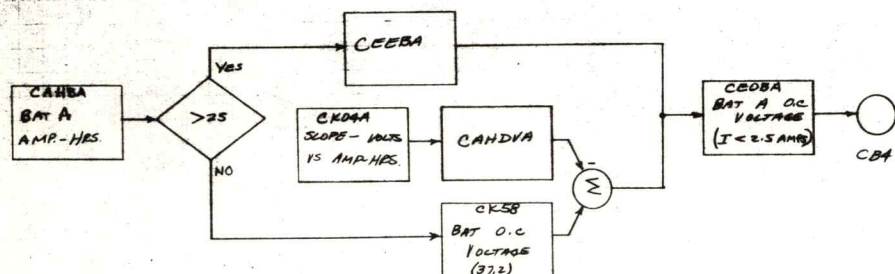
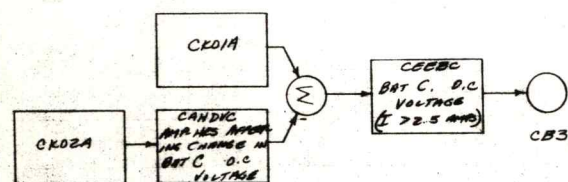
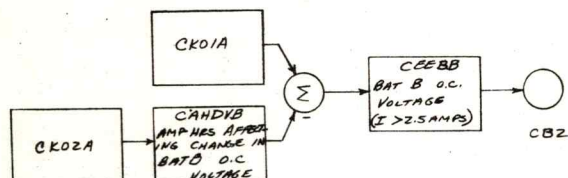
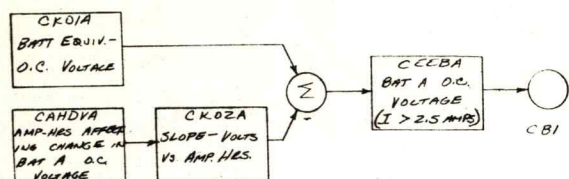


FIG-B-40C BATTERY OPEN CIRCUIT VOLTAGE AND RESISTANCE
EQUATIONS CB1 THRU CB12

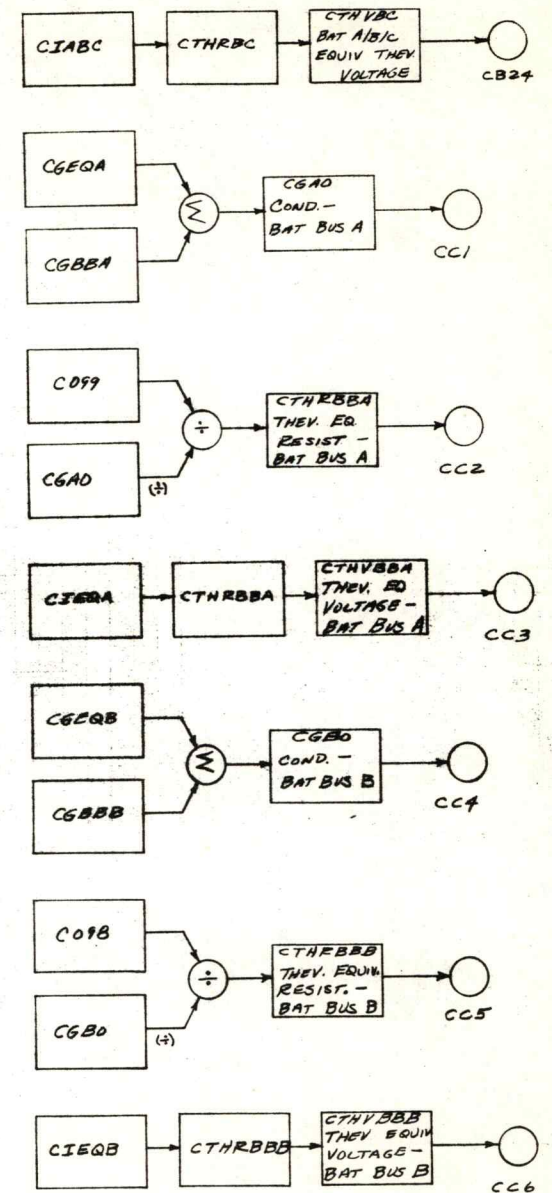
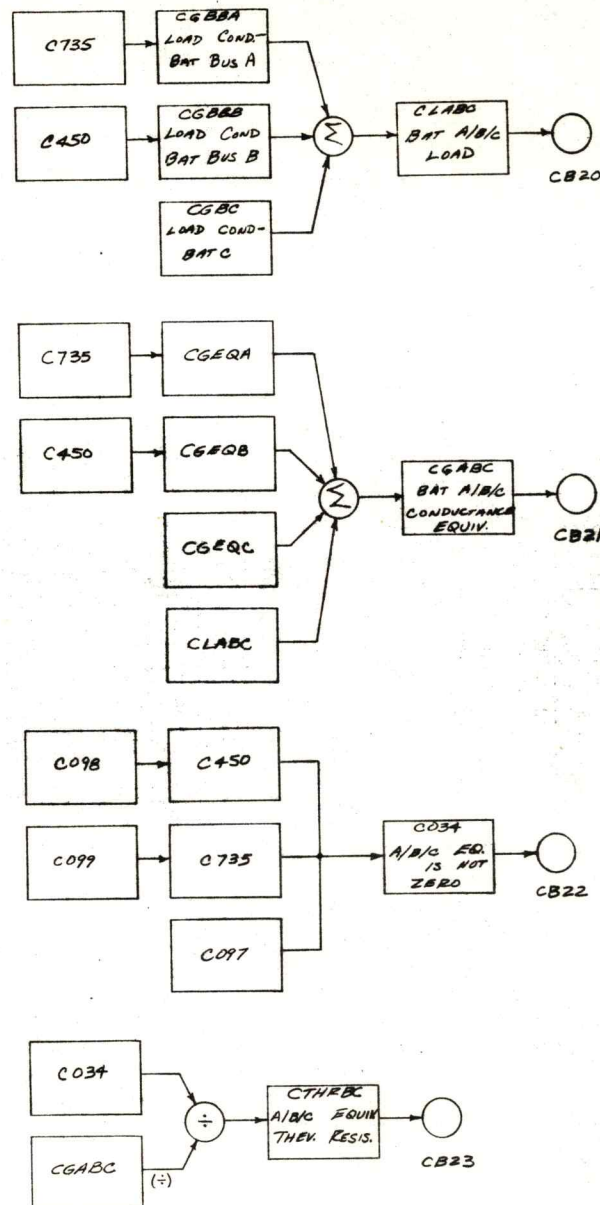
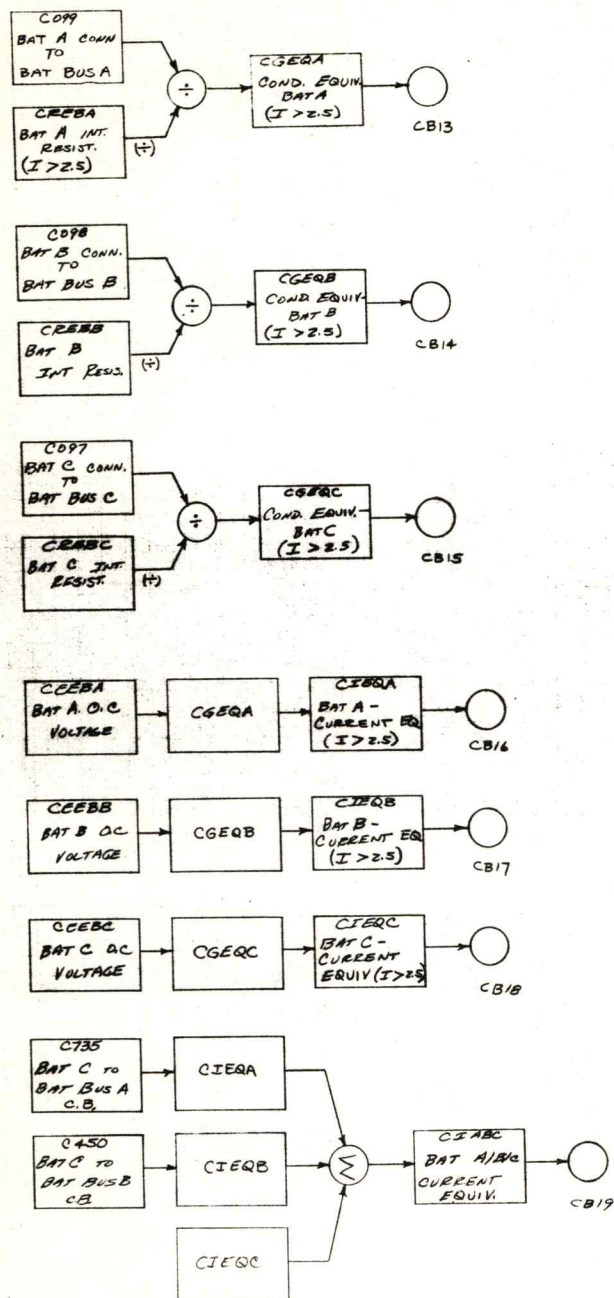


FIG B-41C BATTERY EQUIVALENT EQUATIONS CB13 THRU CC6

D2-118198-1

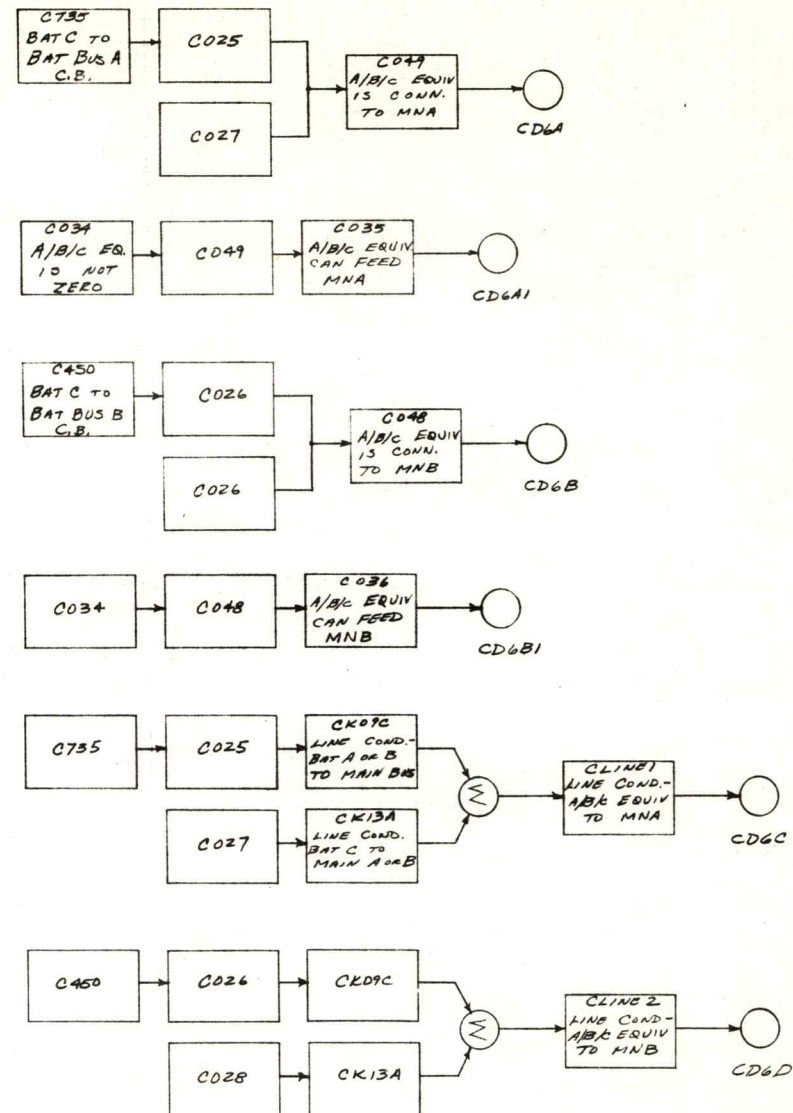
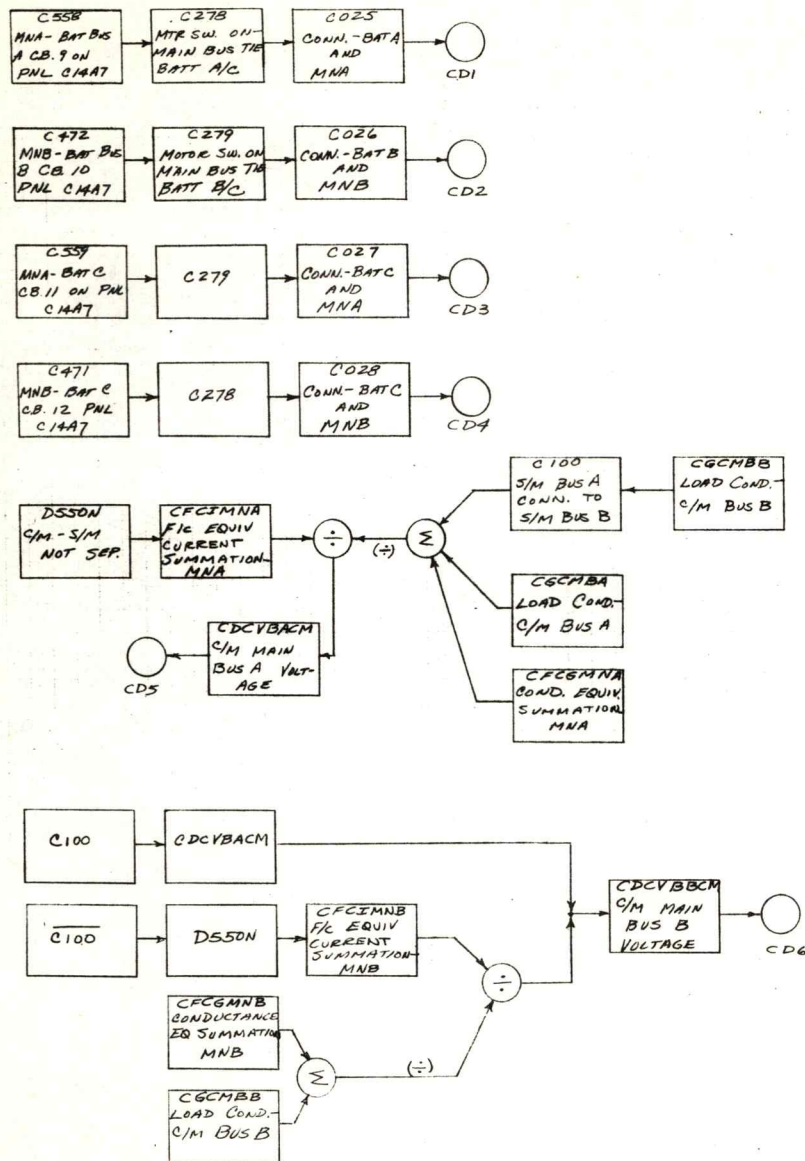


FIG B-42C MAIN BUS VOLTAGE COMPUTATION EQUATIONS CD1 THRU CD6D

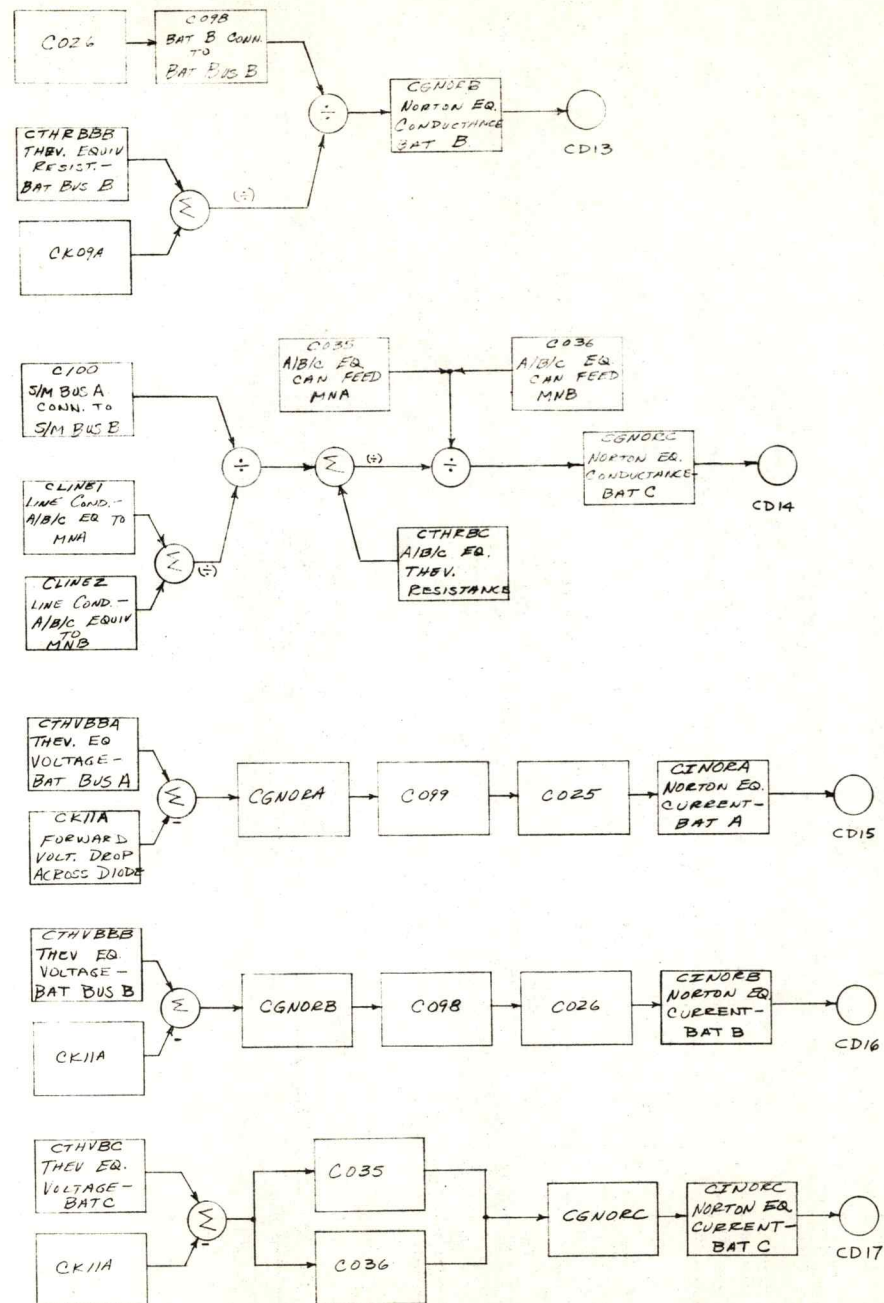
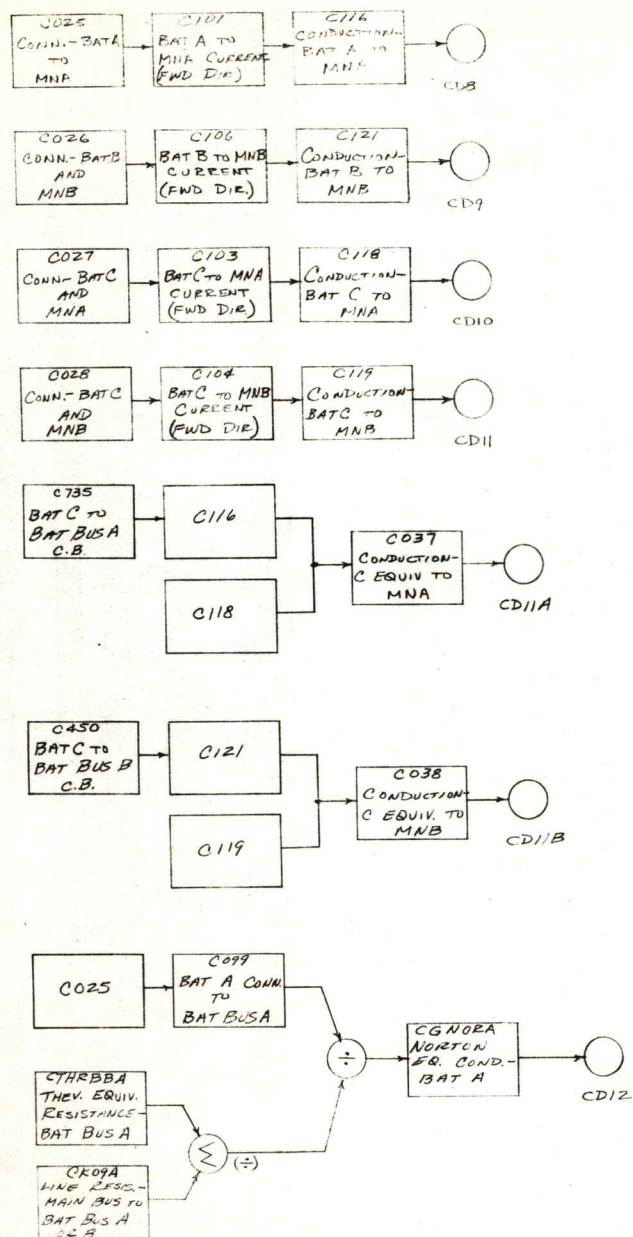


FIG. B-43C MAIN BUS VOLTAGE COMPUTATION EQUATIONS CD8 THRU CD17

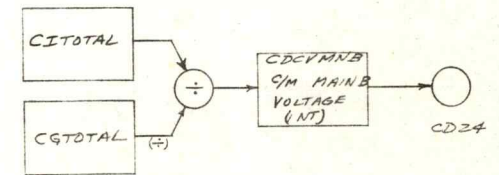
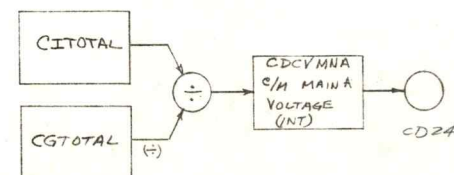
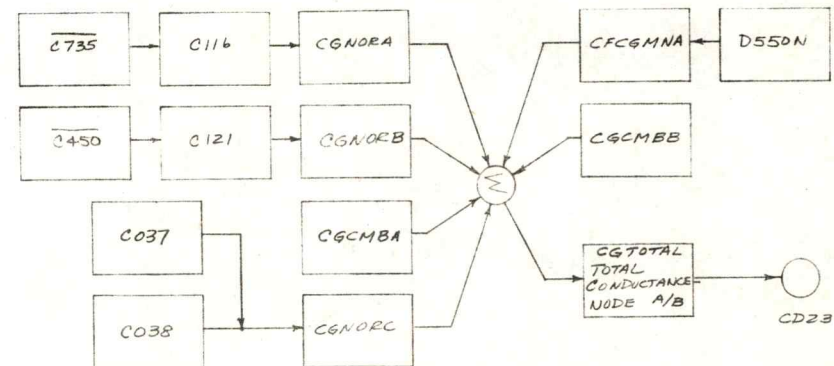
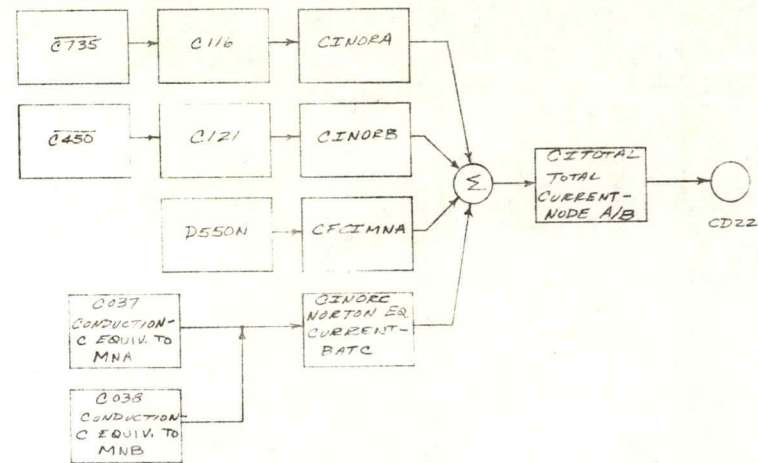
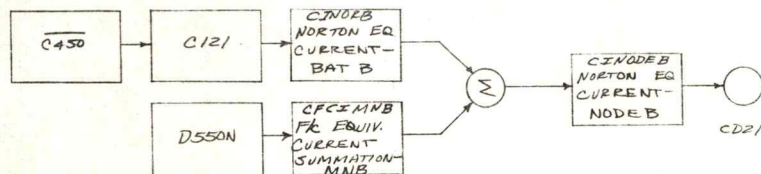
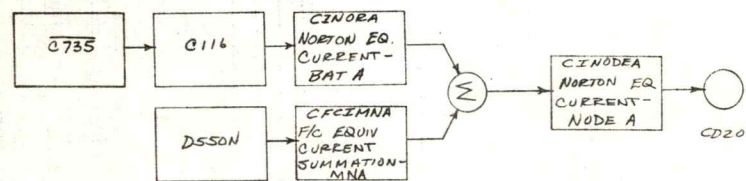
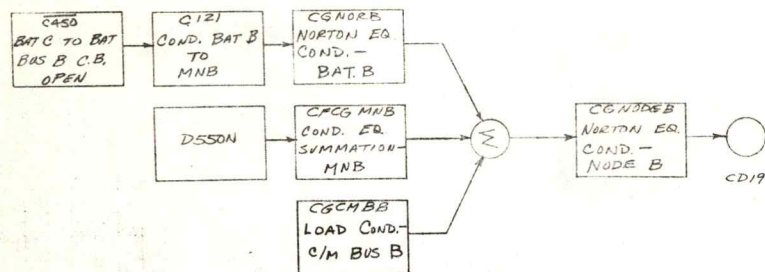
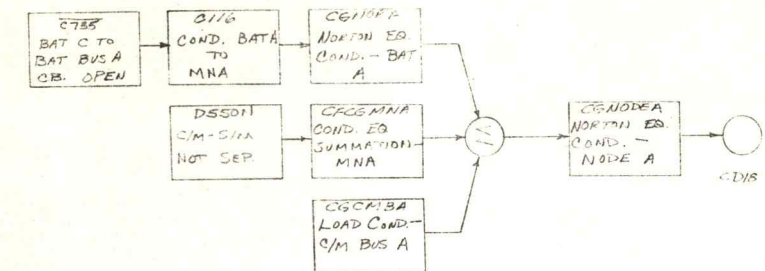


FIG B-44C MAIN BUS VOLTAGE COMPUTATION EQUATIONS CD18 THRU CD24

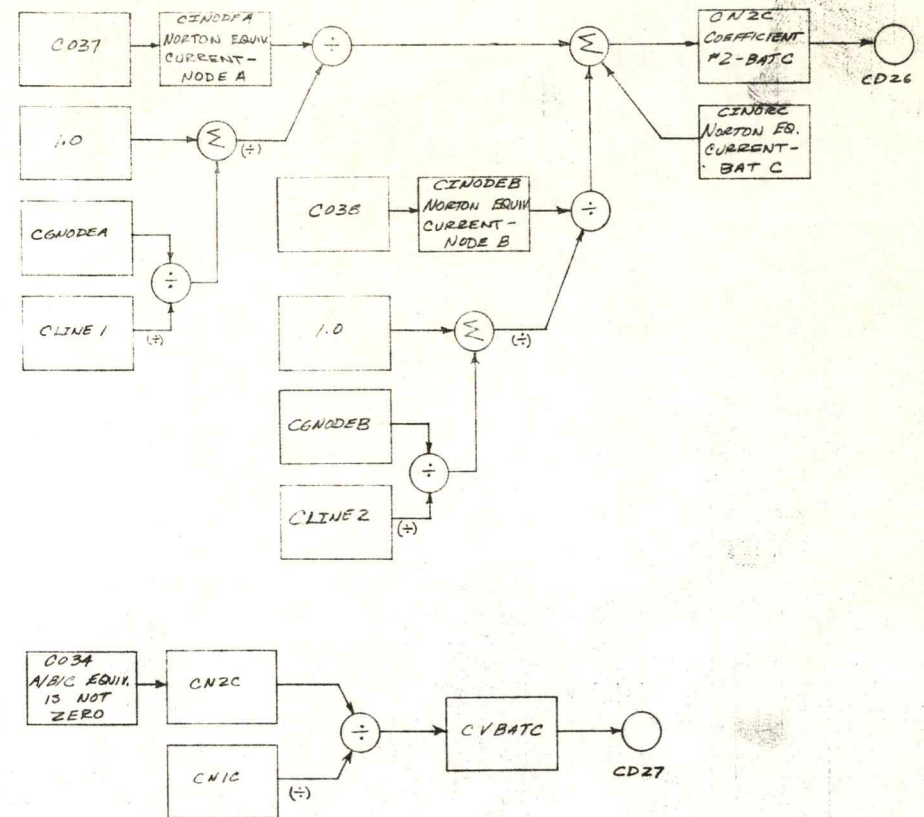
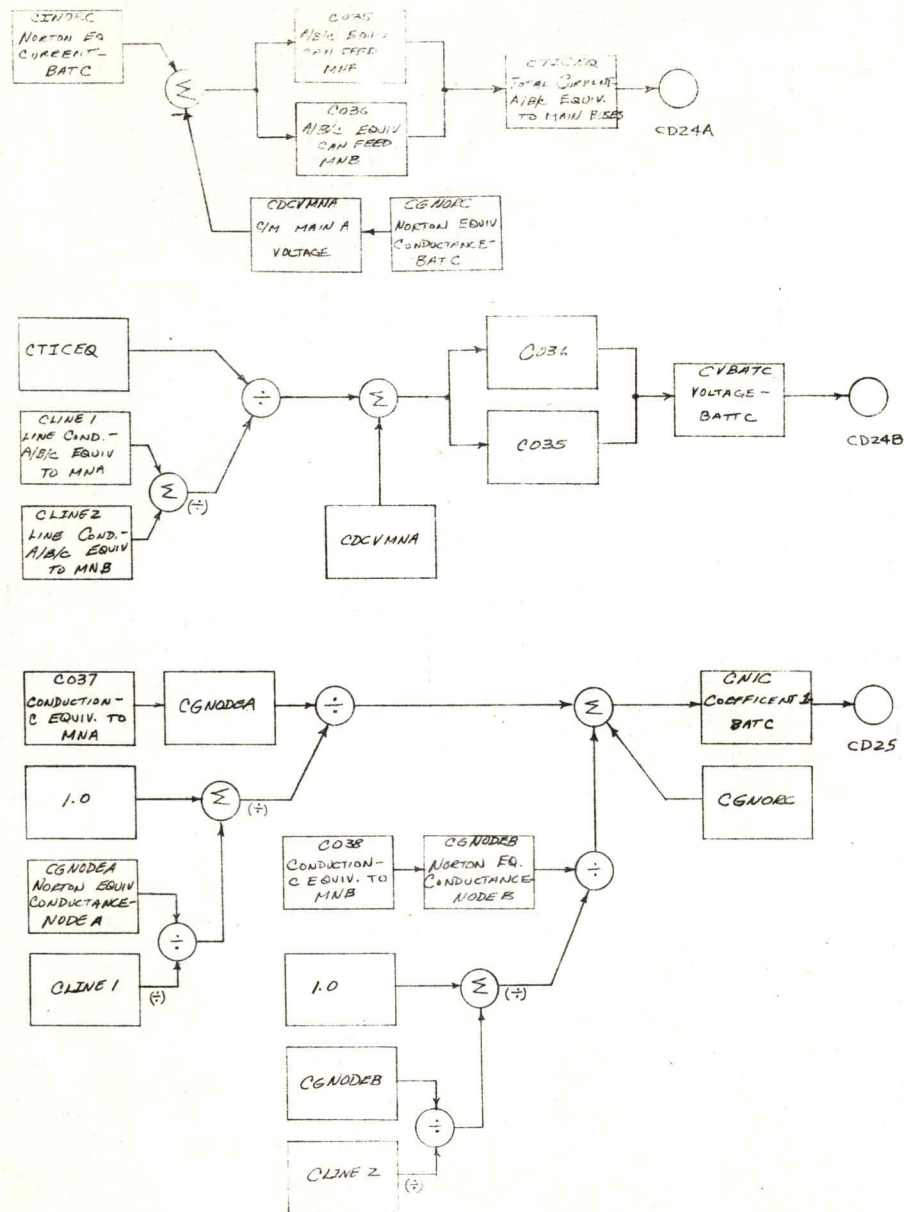
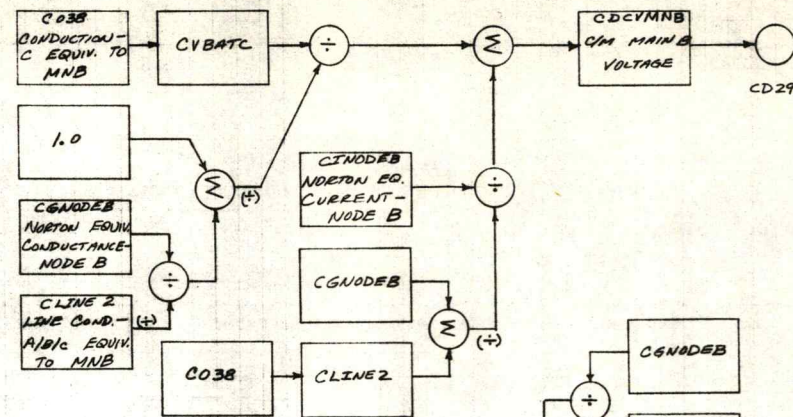
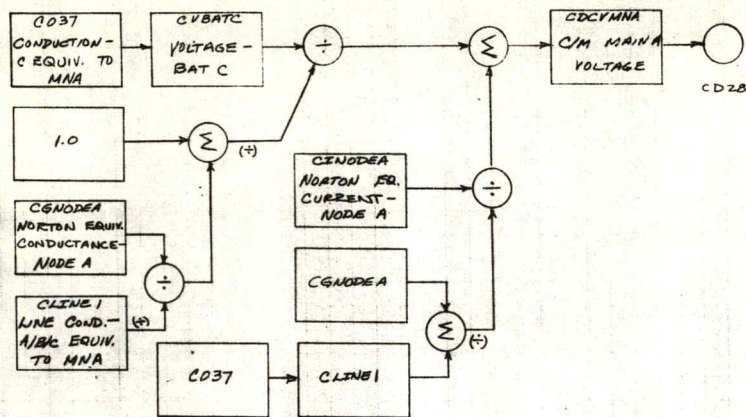
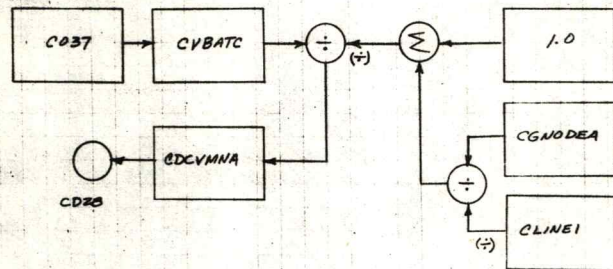


FIG. B-45C MAIN BUS VOLTAGE COMPUTATION EQUATIONS CD24A THRU CD27

D2-18198-1



IF CGNODEA = 0,



IF CGNODEB = 0,

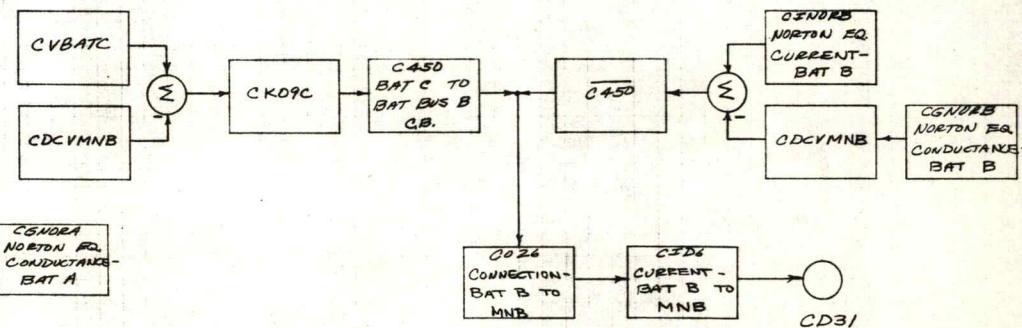
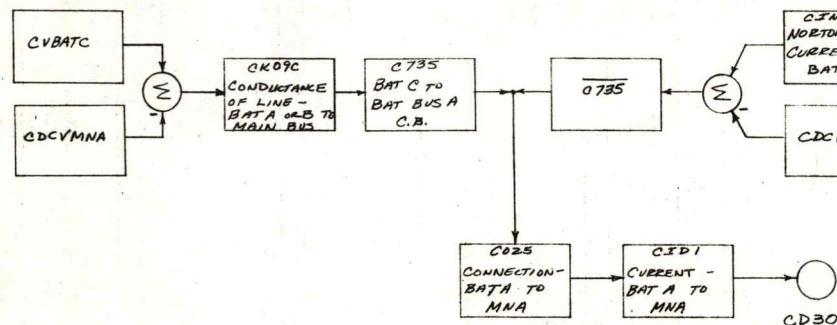
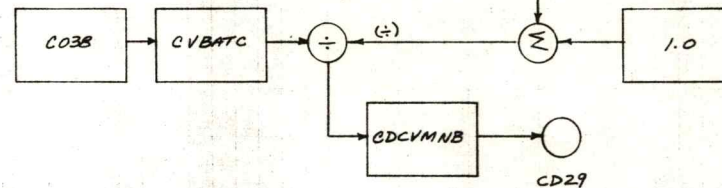


FIG B-46C MAIN BUS VOLTAGE COMPUTATION EQUATIONS CD28 THRU CD31

D2-118123-1

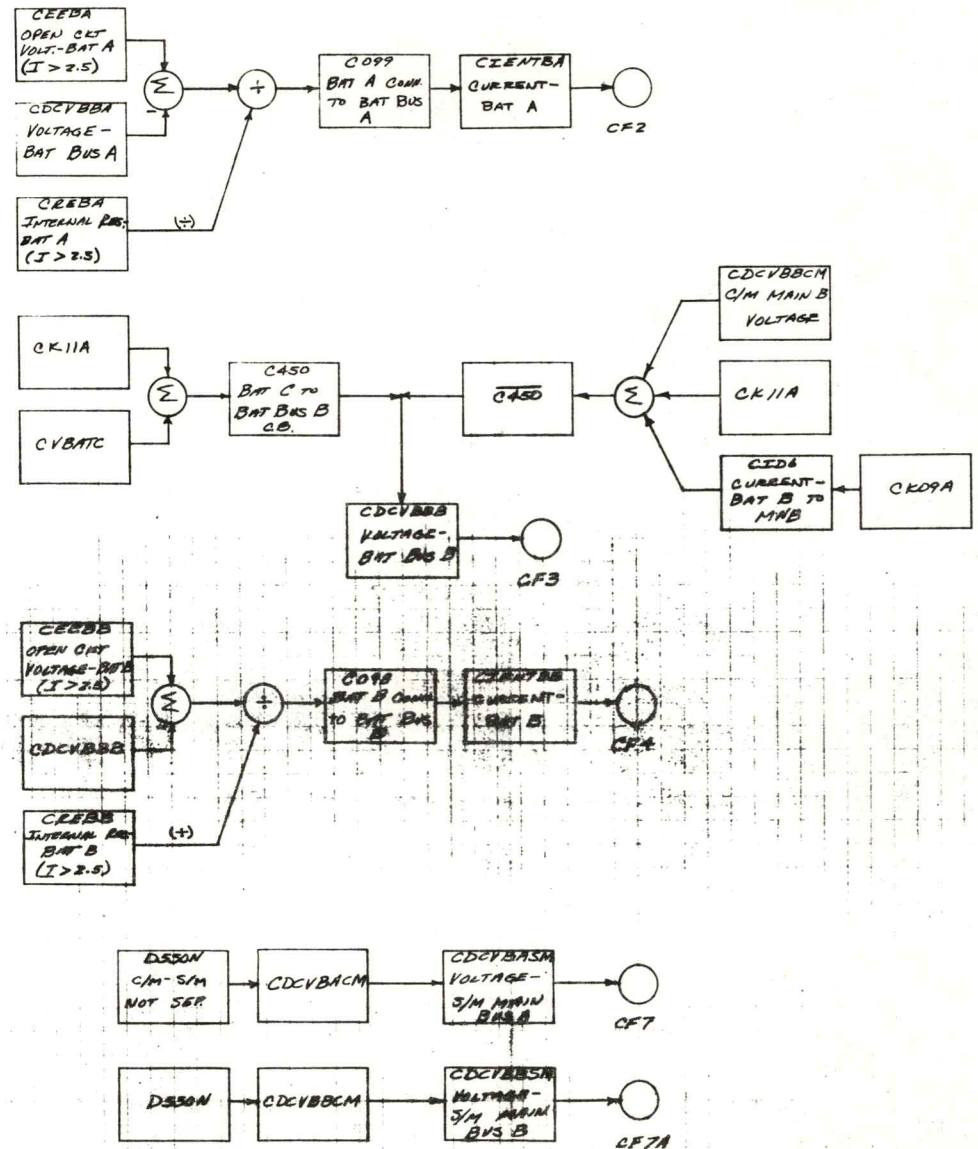
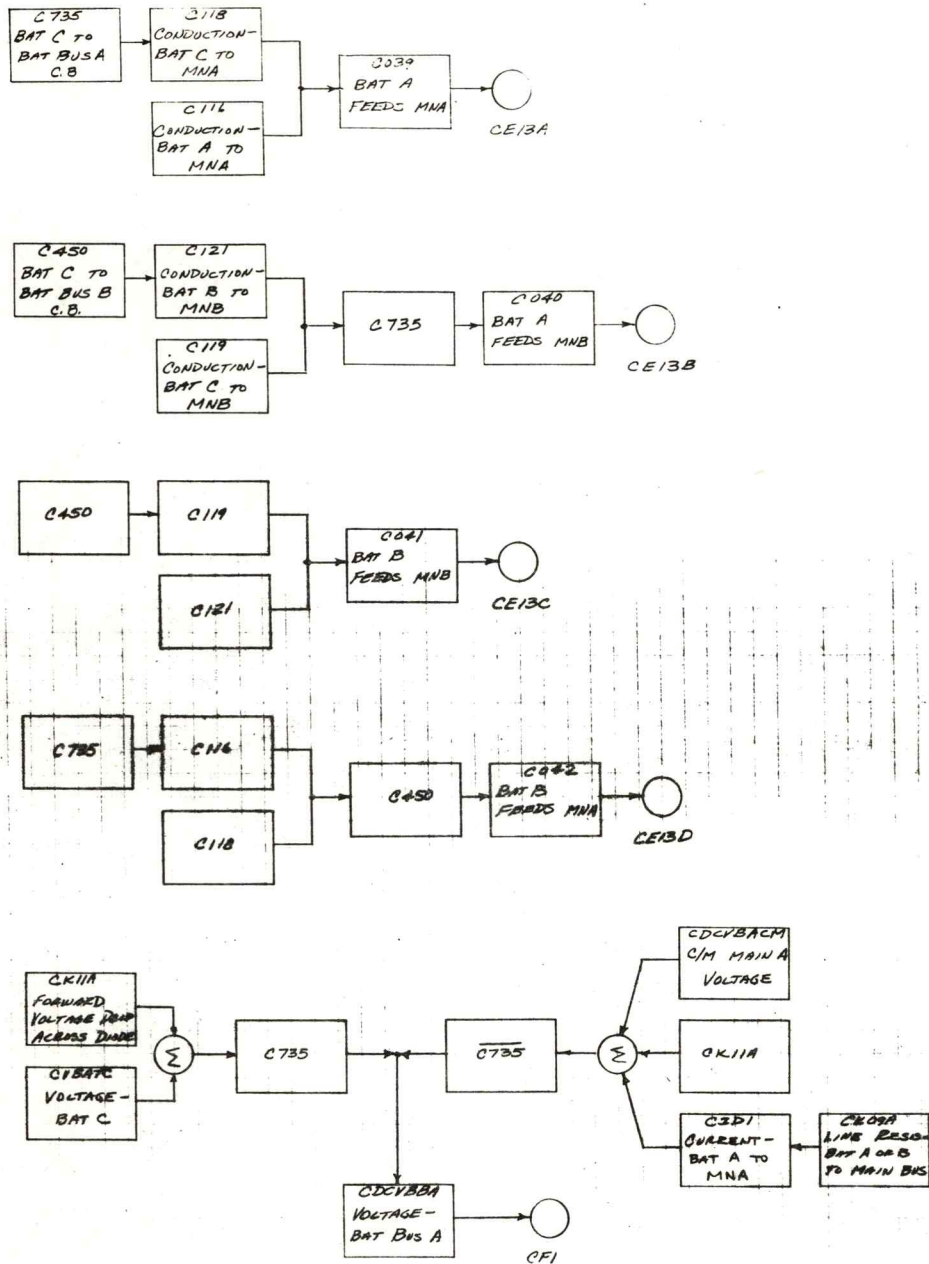


FIG B-48C DIODE CURRENT DIRECTION EQUATIONS CE13A THRU CE13D
BATTERY VOLTAGE AND CURRENT EQUATIONS CF1, CF2, CF3, CF4, CF7, AND CF7A

B-49

The flowchart is divided into three main sections, one for each battery (A, B, and C), and a final section for the current equivalent circuit.

Battery A Section:

- Starts with **C735** (BAT C TO BAT BUS A C.B.).
- Decision: $\geq CTHVBA$ (THEV. EQ. VOLTAGE BAT BUS A).
- If **YES**:
 - Calculate **CEBA** (BAT A INT. RESISTANCE (INT.)) and **CRTEMPA**.
 - Calculate **CEBA** (OPEN CIRCUIT VOLTAGE-BAT (I > 2.5)) and **CETEMPA**.
 - Calculate **CTHVBA** (BAT A VOLTAGE (INT.)) and **CVBBUSA** (BAT A THRU EQ. VOLTAGE (I < 2.5)).
 - Decision: $= 1$ (BAT C TO BAT BUS A C.B.).
 - If **YES**: Calculate **CVBBUSC** (BAT C VOLTAGE (INT.)).
- If **NO**:
 - Calculate **CRBA** (BAT A INT. RESISTANCE (I < 2.5)) and **CRTEMPA**.
 - Calculate **CEBA** (BAT B O.C. VOLTAGE (I < 2.5)) and **CETEMPA**.

Battery B Section:

- Starts with **C450** (BAT C TO BAT BUS B C.B.).
- Decision: $\geq CTHVBB$ (THEV. EQ. VOLTAGE BAT BUS B).
- If **YES**:
 - Calculate **CEBB** (BAT B INT. RESISTANCE (I > 2.5)) and **CRTEMPB**.
 - Calculate **CEBB** (OPEN CIRCUIT VOLTAGE-BAT (I > 2.5)) and **CETEMPB**.
 - Calculate **CTHVBB** (BAT B VOLTAGE (INT.)) and **CVBBUSB** (BAT B THRU EQ. VOLTAGE (I < 2.5)).
 - Decision: $= 1$ (BAT C TO BAT BUS B C.B.).
 - If **YES**: Calculate **CVBBUSC** (BAT C VOLTAGE (INT.)).
- If **NO**:
 - Calculate **CRBB** (BAT B INT. RESISTANCE (I < 2.5)) and **CRTEMPB**.
 - Calculate **CEBB** (BAT B O.C. VOLTAGE (I < 2.5)) and **CETEMPB**.

Battery C Section:

- Starts with **C735** (BAT C TO BAT BUS A C.B.).
- Decision: $\geq CTHVBC$ (THEV. EQ. VOLTAGE BAT C).
- If **YES**:
 - Calculate **CREBA** (BAT A INT. RESISTANCE (INT.)) and **CRTEMPA**.
 - Calculate **CEBA** (OPEN CIRCUIT VOLTAGE-BAT (I > 2.5)) and **CETEMPA**.
 - Calculate **CTHVBC** (BAT A VOLTAGE (INT.)) and **CVBBUSA** (BAT A THRU EQ. VOLTAGE (I < 2.5)).
 - Decision: $= 1$ (BAT C TO BAT BUS A C.B.).
 - If **YES**: Calculate **CVBBUSC** (BAT C VOLTAGE (INT.)).
- If **NO**:
 - Calculate **CRBA** (BAT A INT. RESISTANCE (I < 2.5)) and **CRTEMPA**.
 - Calculate **CEBA** (BAT B O.C. VOLTAGE (I < 2.5)) and **CETEMPA**.

Current Equivalent Circuit Section:

- Starts with **C034** (A/B/C EQUIV. IS NOT ZERO).
- Calculate **CE034** (CURRENT EQUIVALENT BAT C) and **CE054** (CONDUCTANCE EQUIVALENT BAT C).
- Calculate **CTHVBC** (BAT C THRU EQ. VOLTAGE (I < 2.5)).
- Calculate **CF11** (CURRENT EQUIVALENT BAT C).

B-50

D2-118193-1

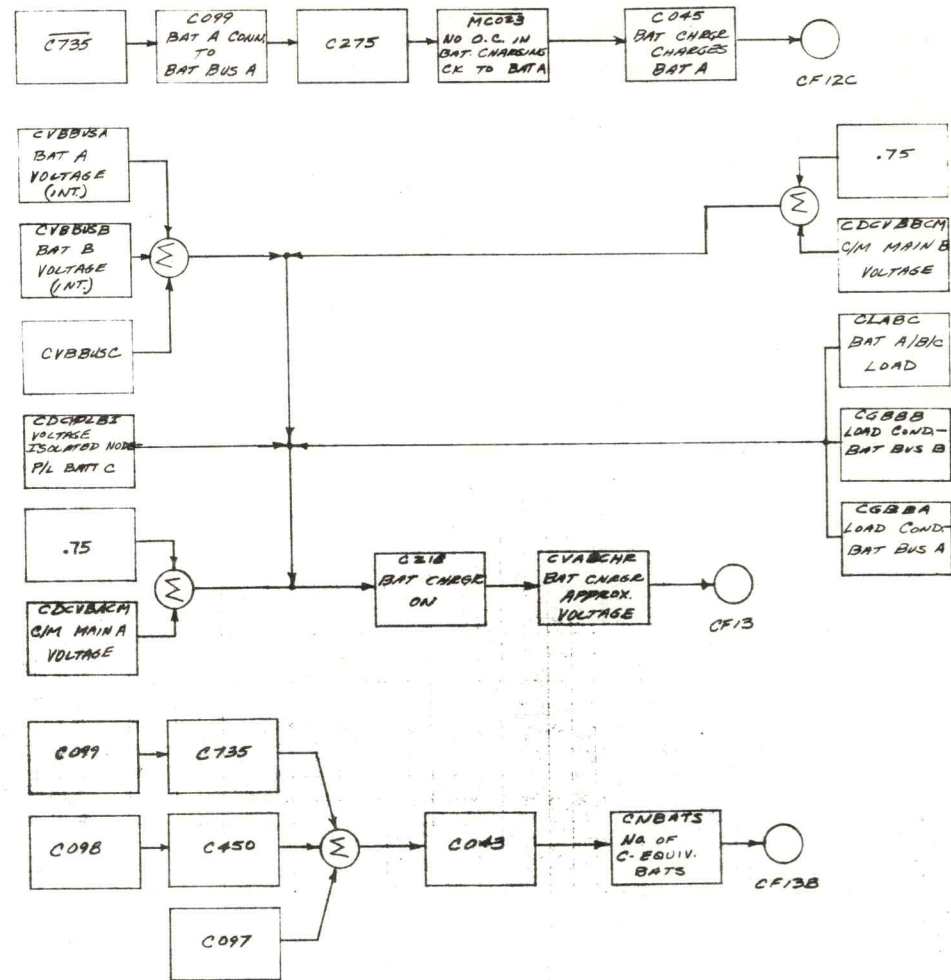
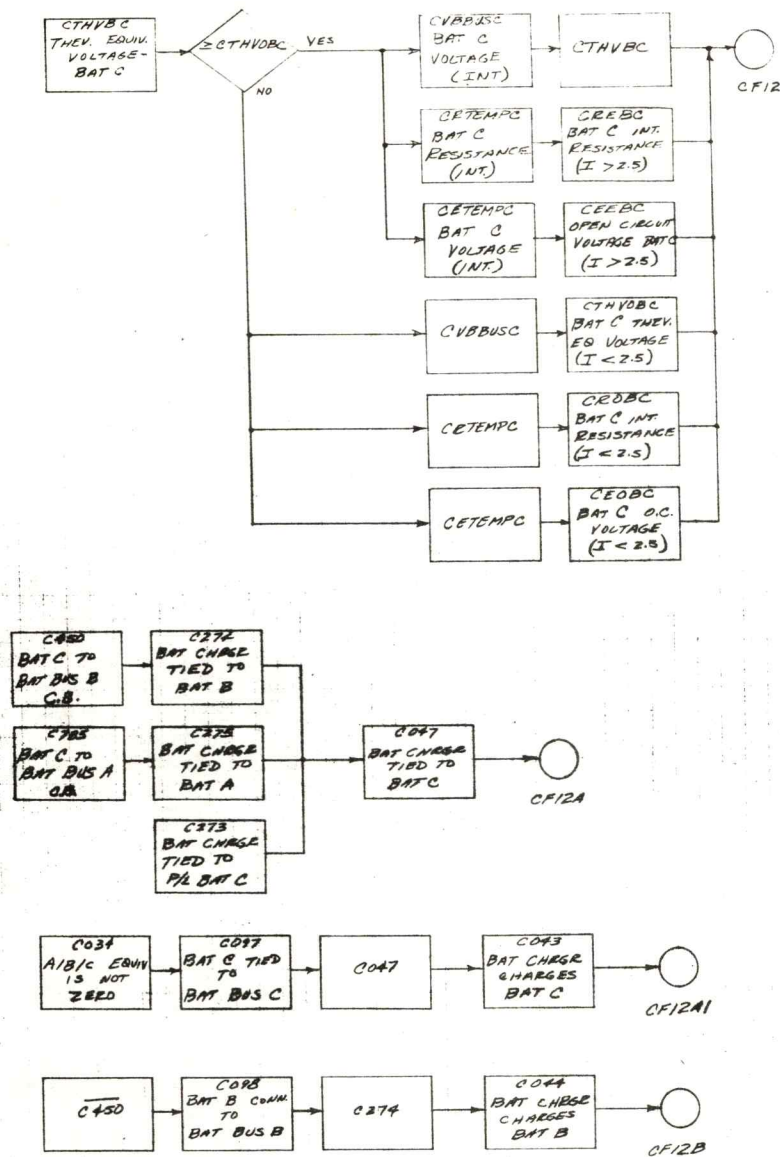


FIG B-51C BATTERY VOLTAGE AND CURRENT CALCULATION
EQUATIONS CF12 THRU CF13B

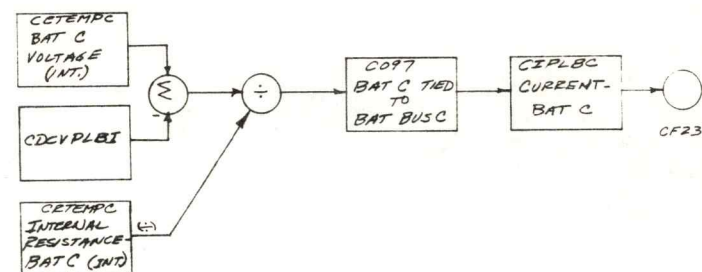
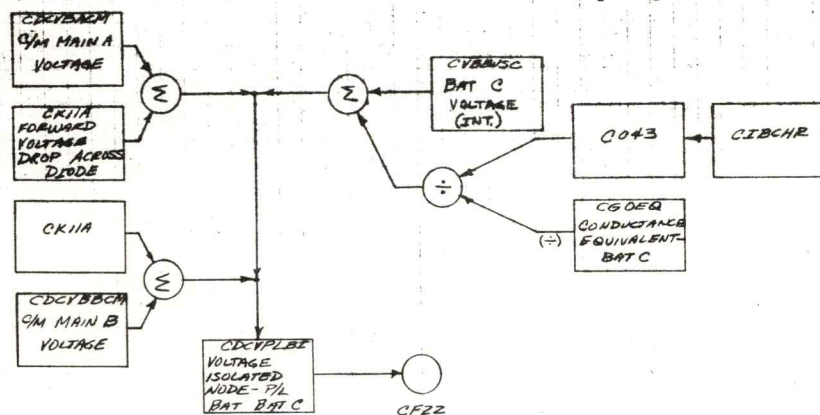
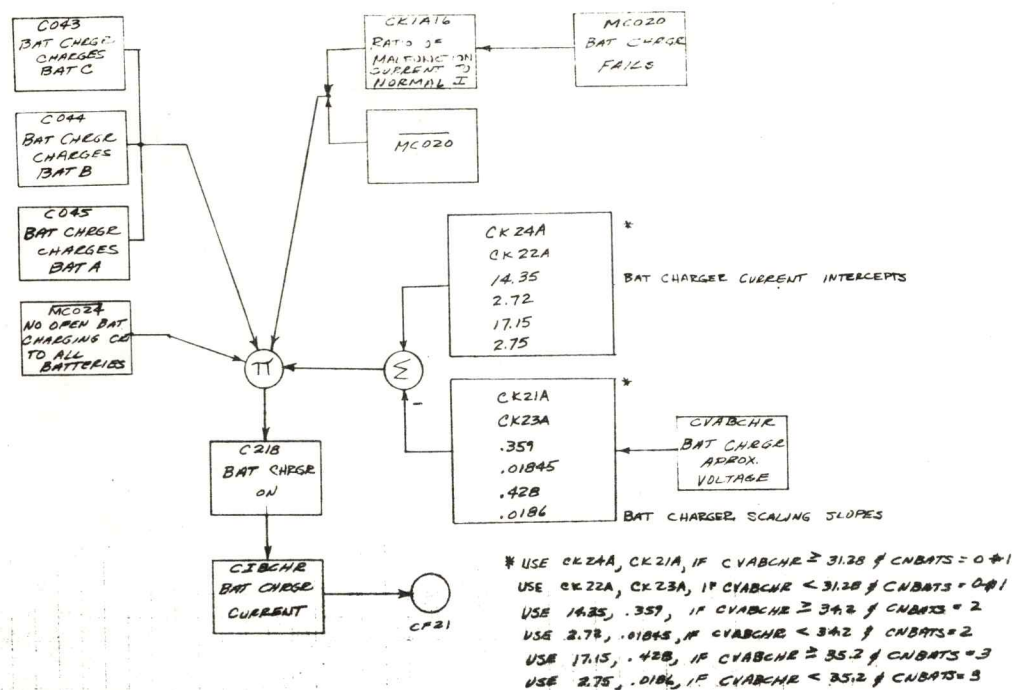
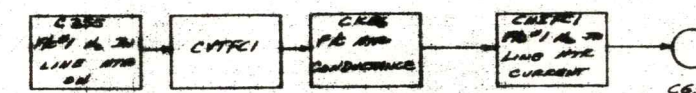
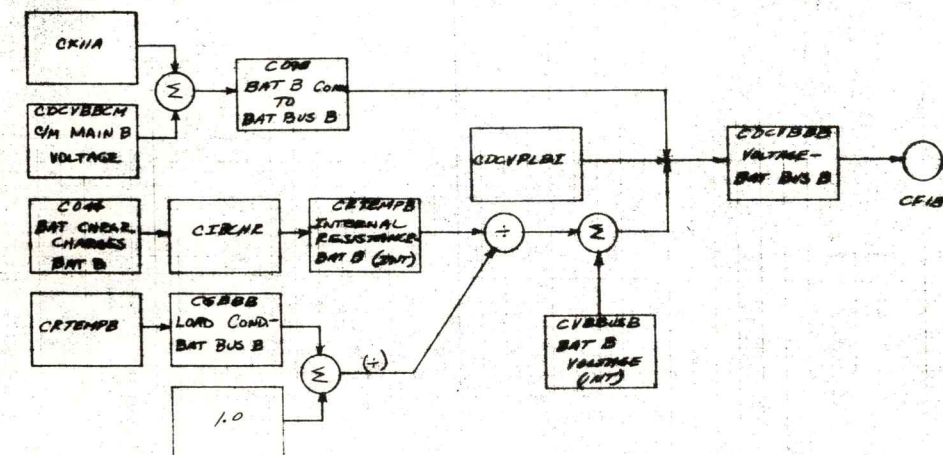


FIG B-52C BATTERY VOLTAGE AND CURRENT CALCULATION
EQUATIONS CF21, CF22, AND CF23



$\Delta \left. \begin{array}{l} C112 \\ C772 \\ C100 \\ C700 \\ C206 \end{array} \right\} \text{MUTUALLY EXCLUSIVE}$

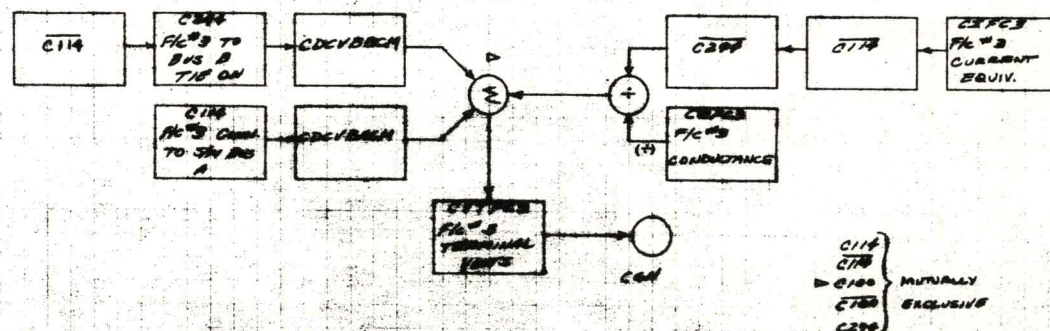
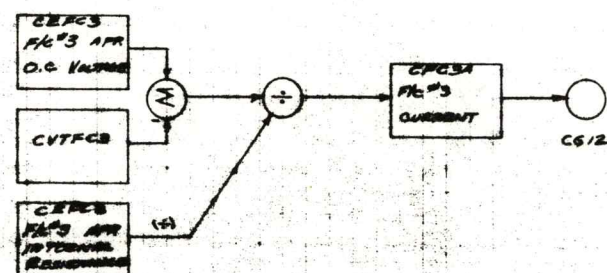
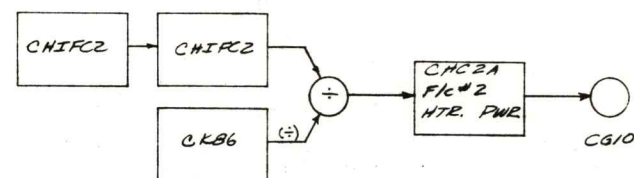
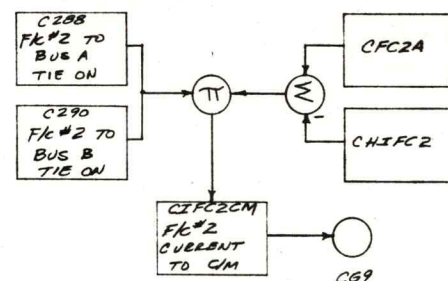
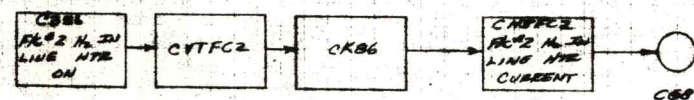
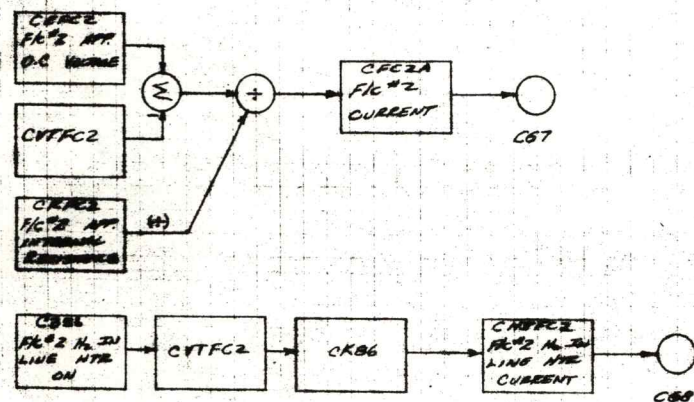
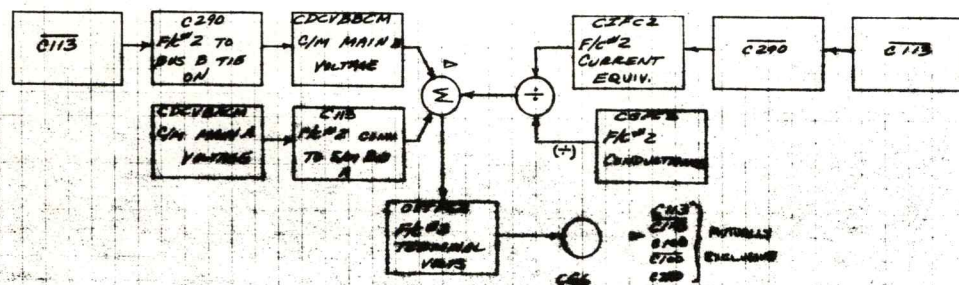
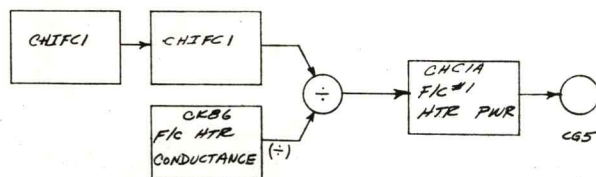
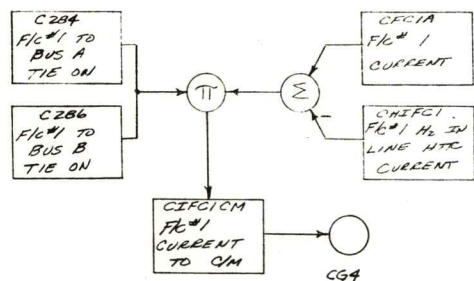


FIG. B-54C FUEL CELL VOLTAGE AND CURRENT EQUATIONS CG4 THRU CG12

D2-118,113-1

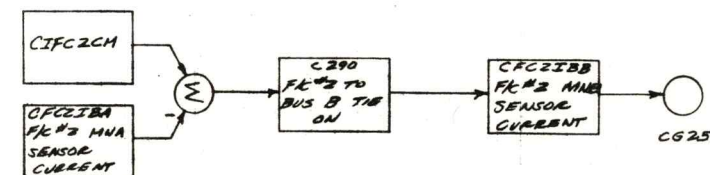
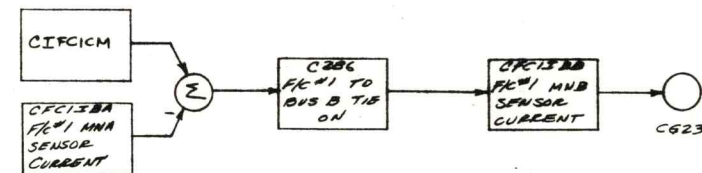
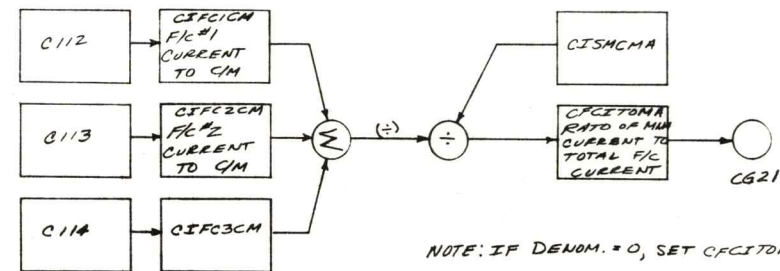
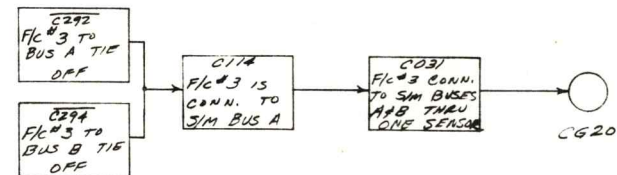
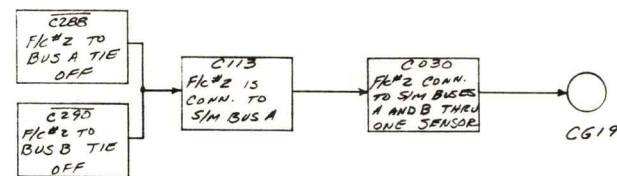
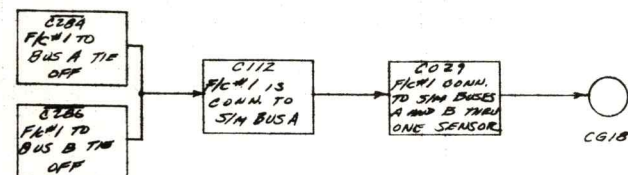
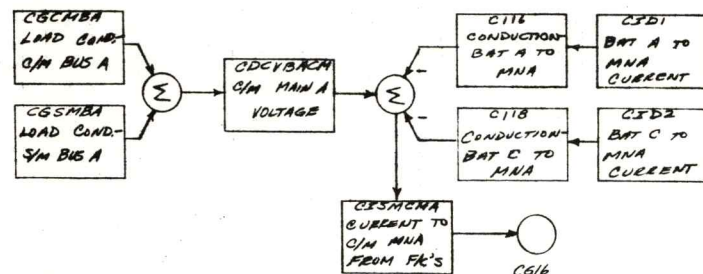
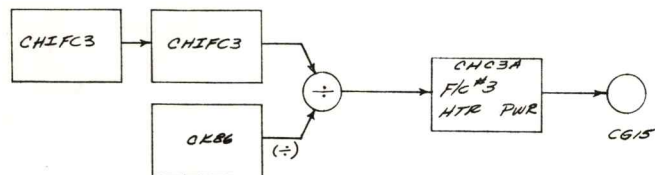
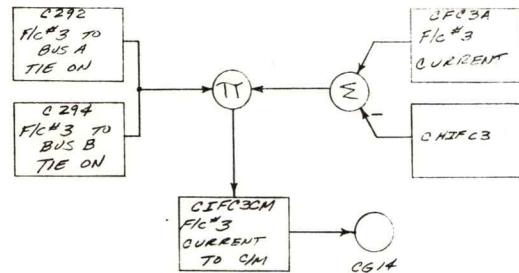
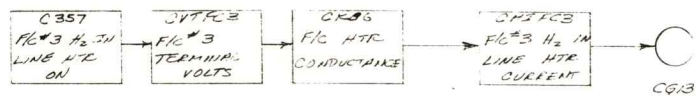


FIG B-55C FUEL CELL VOLTAGE AND CURRENT EQUATIONS CG13 THRU CG23

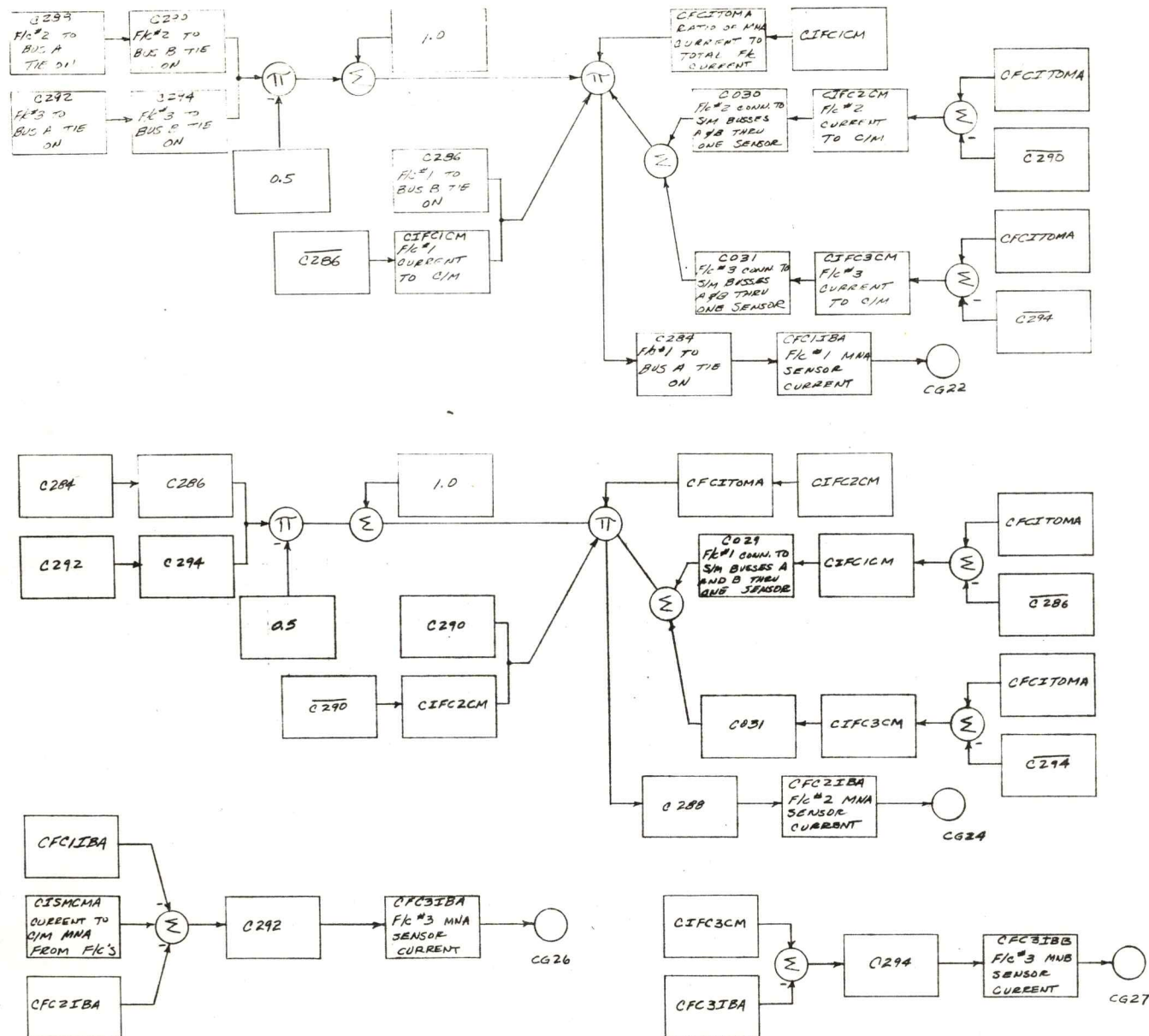


FIG B-56C FUEL CELL VOLTAGE AND CURRENT EQUATIONS CG24 THRU CG27

D2-11.9199-1

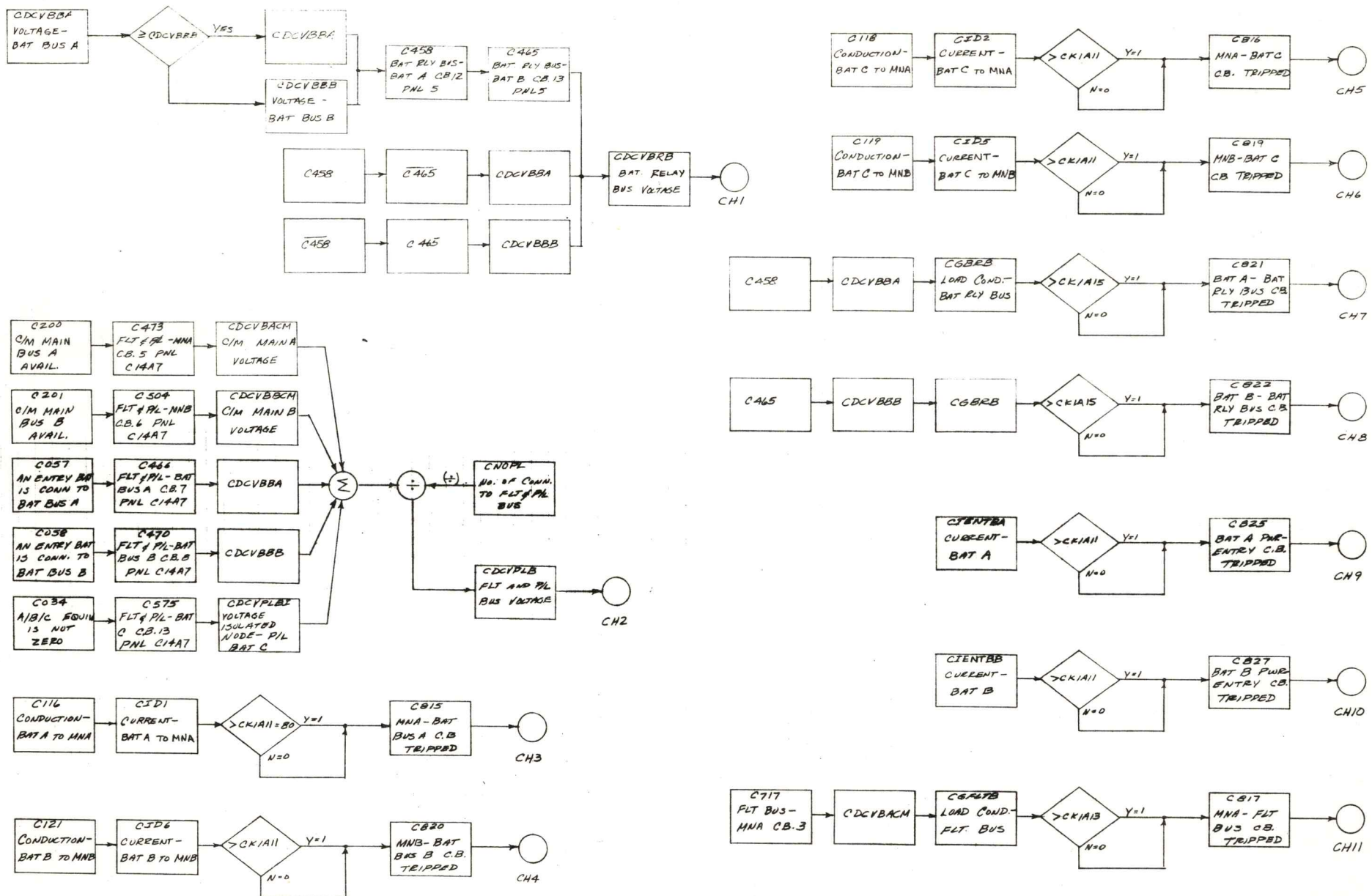


FIG B-57C BATTERY RELAY BUS VOLTAGE EQUATION CH1
 FLIGHT AND POST/LANDING BUS VOLTAGE EQUATION CH2.
 CIRCUIT BREAKER TRIP EQUATIONS CH3 THRU CH11

D2-118193-1

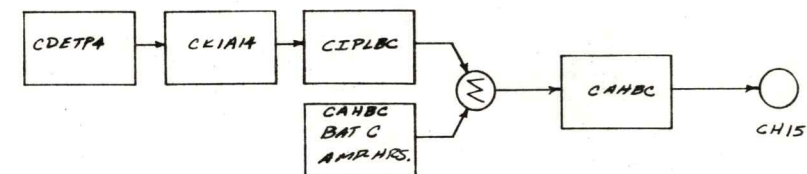
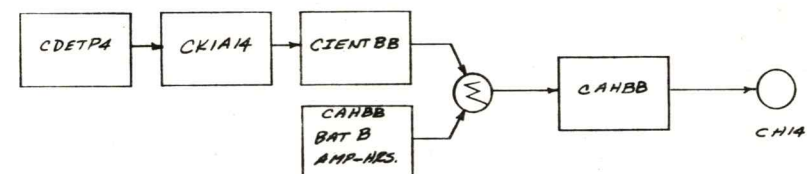
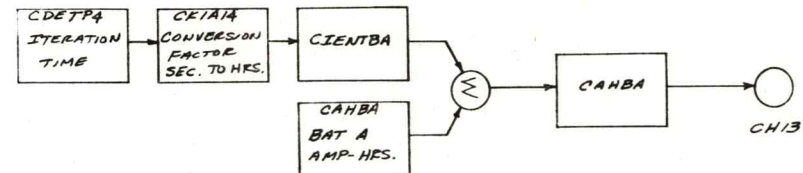
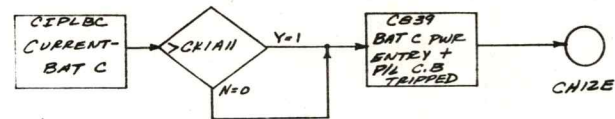
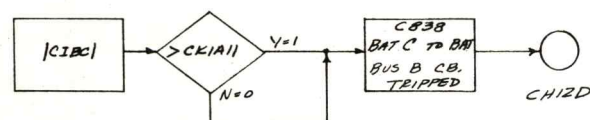
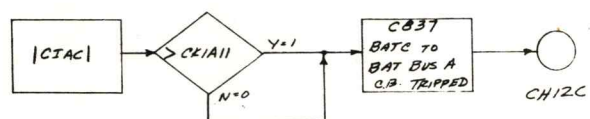
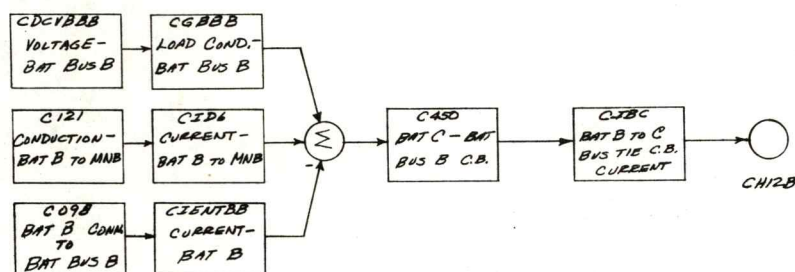
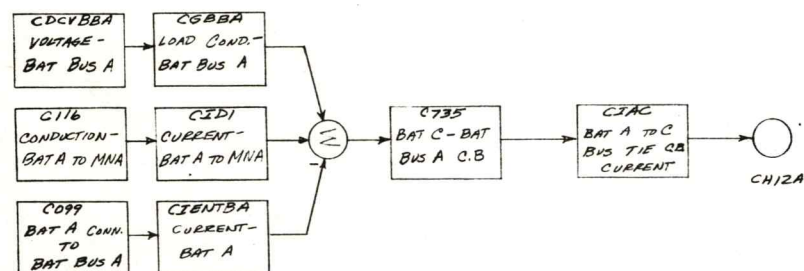
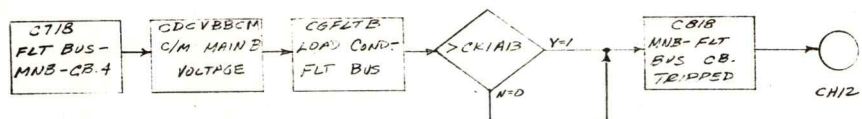


FIG. B-58C CIRCUIT BREAKER TRIP EQUATIONS CH12 THRU CH12E
BATTERY AMPERE-HOUR EQUATIONS CH13, CH14, AND CH15

D2-118198-1

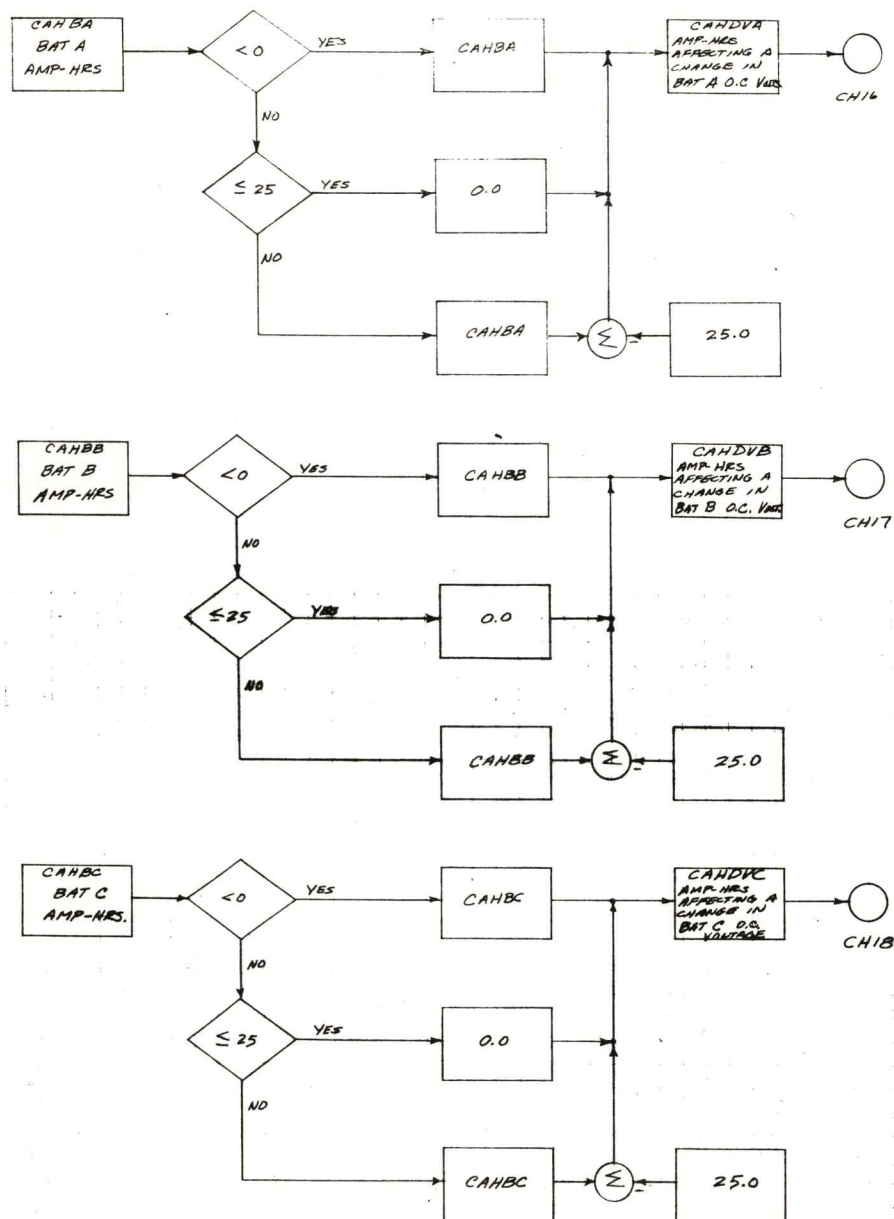


FIG. B-59C BATTERY AMPERE-HOUR EQUATIONS CH16, CH17, AND CH18