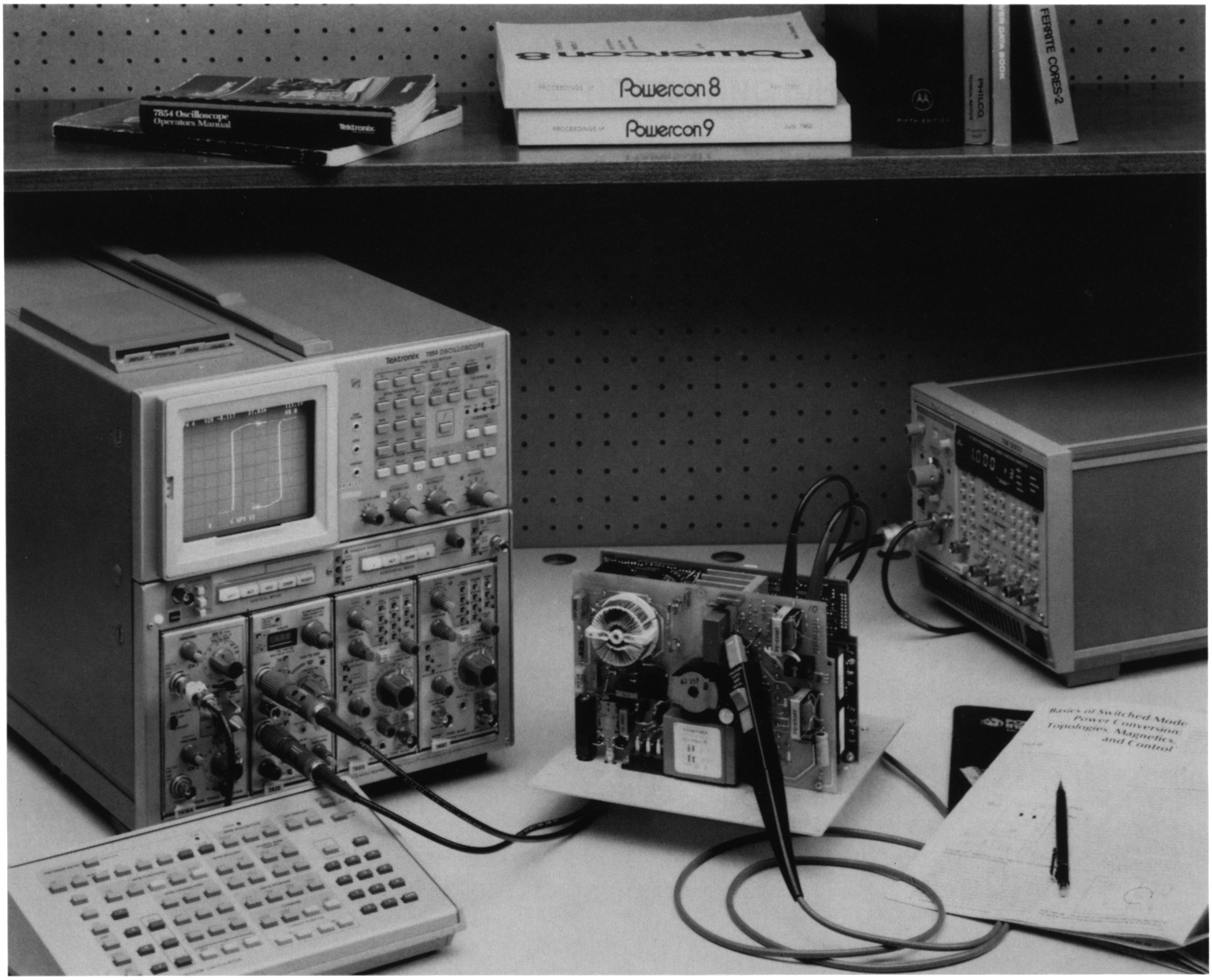
POWER SUPPLY/DEVICE TESTING



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SECTION 1

INTRODUCTION

This applications guide describes the use of the advanced waveform processing functions of the Tektronix 7854 Programmable Oscilloscope in a typical series of five power supply and power device test operations.

Stating the Problem

In designing switching power supplies, the two primary requirements are high efficiency and high reliability. These goals are within reach when, through careful design techniques, highly reliable components are included and operated within published specifications. The features of the 7854 can help the designer to significantly shorten and simplify this process.

7854 Features

The 7854, with its waveform calculator, combines the best features of a high-performance plug-in oscilloscope with the flexibility, speed and accuracy of a dedicated waveform-oriented digital processor. Single-key functions, equivalent-time-sampled digitization of waveforms to 400 MHz equivalent-time bandwidth, program storage for more than 2000 commands, and GPIB capability are just a few of the key features of the 7854.

Waveform Calculator Keyboard

The waveform calculator keyboard allows single-keystroke functions, many of which are particularly well suited to power supply testing. Differentiation (DIFF), integration (INTG), energy (ENERGY) and root-mean-square (RMS) are several of the more important of these functions that apply to such testing. The waveform averaging (AVG) mode is also very useful in reducing random noise. Cursors are available for quick and accurate time and amplitude measurements.

7854 Programing

Several operations may be programmed into the 7854 for later execution. The programs, consisting of a series of commands or functions, can be entered, edited and executed from either the waveform calculator or the GPIB port.

As the following five applications examples show, these features provide the power supply designer with a very powerful and useful tool.

The 7854 control settings and certain 7854 program entries apply to the particular power supply used in this guide. Your control settings and appropriate 7854 program lines may differ on the power supply you are testing.

In the illustrations and photos, units of measure are abbreviated which make the measurements more generally applicable to any power supply.

Test Instrument

A 7854 with maximum memory (Option 2D) was used for the tests in these application examples. An off-the-shelf switching power supply was modified to add the test points shown in test operations. All other test equipment, including probes and oscilloscope plug-ins, is as shown in the examples.

SPECIAL CONSIDERATIONS

It may be necessary, depending on the voltage and current probes used, to compensate for any probe signal delay. Although the technique for finding the delay is well known, a brief description is offered here. It includes a suggested method of incorporating this delay into the application programs in this guide.

Calculating Delay

The calibrator signal from the 7854 will be used to drive a resistive load. A 51 Ohm carbon resistor was used as the load resistor. Set the 7A13 to 10 mV/div., +input to DC, −input to GND, and the bandwidth limit switch to FULL. Connect the voltage probe from the calibrator output side of the resistor.

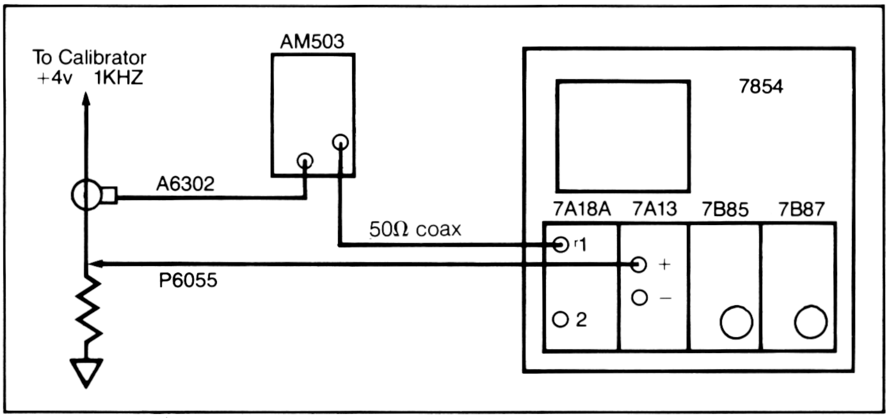


Figure 1 Test Set-Up

Set the 7A18A mode switch to CH1, channel 1 to 10 mV/div., and channel 1 to DC. Connect the AM503 through a 50 Ohm terminator to the channel 1 input. Set the 7854 trigger source switch to right vertical. Connect the current probe around the resistor lead. Set the "A" horizontal (7B85) to 50 ns/div. Figure 1 shows the proper test setup.

Figure 2 shows a 7854 program that will capture both waveforms and calculate the delay between waveforms. With the voltage and current probes used in this note, 16 nanoseconds was an average delay.

Implementing Delay

The 7854 has a command that adjusts the waveform in time. The HPLFT or HPRGT will shift the display left or right by the time specified in the argument. With a 16 nanosecond delay, the user simply calls up the current waveform,

```
000 VMDL HMDA
001 STORED AQR 2 >WFM
002 VMDR
003 AQR 3 >WFM
004 2 WFM CRS1 0 >HCRD
005 MID >VCRD HCRD 2 >CNS
006 3 WFM 0 >HCRD
007 MID >VCRD HCRD 3 >CNS
008 2 DSW
009 3 CNS 2 CNS -
```

Figure 2 Calculating Probe Delay

enters 16 nanosecond (16EEX 9CHS ENTER) and presses the HPLFT (f SMOOTH). This step can be added to any of the application programs that follow.

SECTION 2

INSTANTANEOUS POWER MEASUREMENT

In the design and evaluation of a switching power supply, the power dissipated in the switching transistor(s) is an important consideration. There are several methods for investigating dissipation. These range from monitoring the case temperature of the device to taking a picture of the waveforms for the voltage across and the current through the device and calculating the power at a specified point of interest.

7854 Power Dissipation Measurement

The capacity of the 7854 to capture both the voltage and current waveforms, multiply these waveforms, and display the power as a function of time, greatly increases measurement ease and accuracy. With a single cursor, the power dissipated at any point of the waveform can be read.

Inductive Loading

The typical load of switching transistors is inductive, generally transformer-type. This inductive load opposes any change in the current flowing through the inductor. As shown in Figure 3, this results in increased power dissipation.

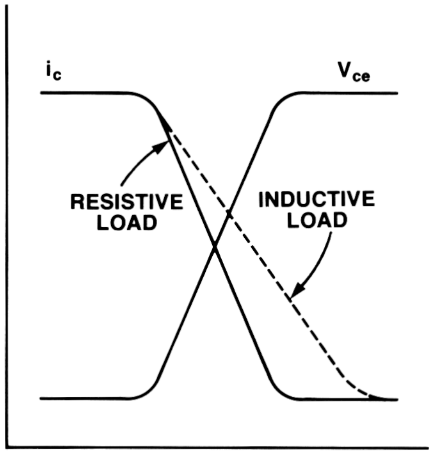


Figure 3. Current Lag With Inductive Loads

Measuring Power Dissipation

In this test, a Tektronix AM503 current amplifier and a Tektronix A6302 current probe are used to capture the current through a switching transistor. The amplifier is connected to the channel 1 input of a 7A18A vertical amplifier. Two P6055 10x voltage probes are connected, one to the emitter and one to the collector of the switching transistor. These probes are connected to the + and − input of a 7A13 differential amplifier. The set-up is shown in Figure 4.

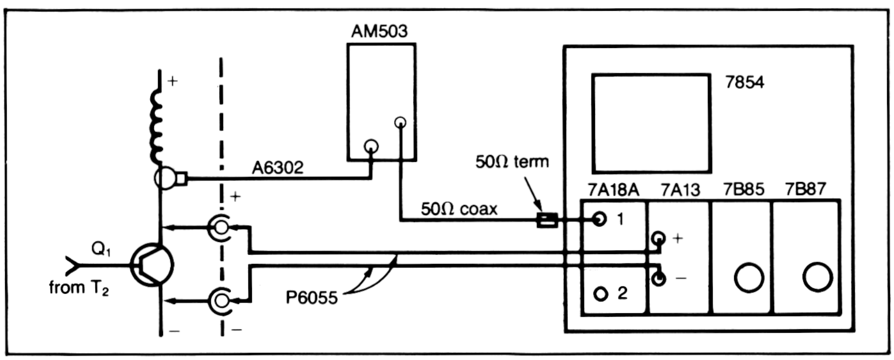


Figure 4. Instantaneous Power Measurement Test Set-up

Set-up

7A18A MODE to CH1
TRIGGER SOURCE to CH1
CH1 VOLTS/DIV. to
10 mV/div.
7A13 VOLTS/DIV. TO 5V/div.
7B85 MODE to B STARTS AFTER
DELAY
TIME/DIV. TO 10ms/div.
7B87 TIME/DIV. to 2μs/div.

Set 7854 trigger source to right vertical.

Enter the program shown in Figure 5 into the 7854 memory.

Using the Program

Ground the inputs to both vertical amplifiers and turn on the test power supply.

Press the 7854 START (f RUN) button. The program will acquire a ground reference for both vertical plug-ins and stop at line 004.

Set the 7A18A CH1 and the 7A13 + and − inputs to DC. Adjust the 7854 delay time on the 7B87 time/division if necessary to display only the overlapping positive current step and negative voltage step. Enter the AMPS/DIV. setting of the AM503 on the 7854 keyboard.

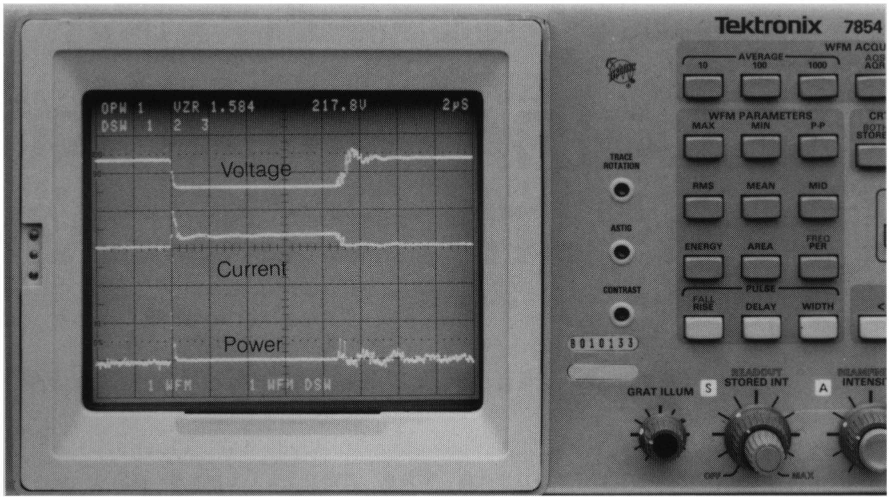


Figure 6. Instantaneous Power

Acquisition

Press the RUN button. The program will acquire the voltage and current waveforms, multiply the two and display all three (the original plus the resultant). The program will then stop at line 019.

Special Considerations

For the highest data accuracy, check the AM503 amplifier zero offset before running the program.

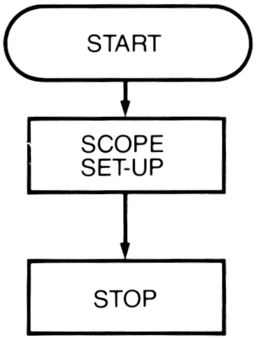
Conclusion

The 7854 is a valuable tool for looking at the power dissipated in power supply switching transistors. It removes the tedium of repetitive manual calculation.

As shown in Figures 6 and 7, the program is uncomplicated and the resultant waveforms are informative.

```
000 VMDALT HMDA CLD OFF
001 GND
002 SCOPE
003 HMDB
004 STOP
005 ENTER
006 1 >CNS
007 AQR STORED
008 1 CNS >VSCL
009 0 WFM 2 >WFM
010 1 WFM 2 WFM * 3 >WFM
011 1 WFM 1 P-P VSCL / / VXPD
012 2 >VZR
013 2 WFM 1 P-P VSCL / / VXPD
014 .5 >VZR
015 3 WFM 3 P-P VSCL / / VXPD
016 3CHS >VZR
017 1 DSW 2 DSW
018 CRS1 0 >HCRD MAX >VCRD
019 STOP
```

Figure 5. Power Measurement Program

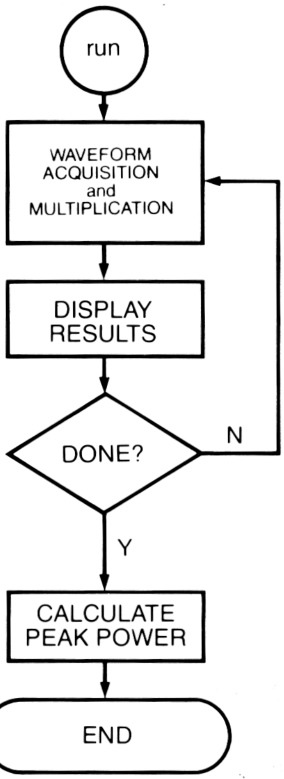


line 000-vertical mode to ALT, horizontal mode to A, turn off cursors.

line 001-Acquire ground reference.
002-7854 to scope mode.
003-Horizontal mode to B
User sets up the delayed/delaying time base to the area of interest.

line 004-stops the program

(User now ungrounds the amplifiers and enters the AMPS/DIV from the AM503)



When complete, press 'run'.
005-enter the amps/div
006-stored in 1 CNS
007-current and voltage waveform acquired
008-current vertical scale is adjusted
009-current wavefrom stored in 2 WFM
010-multiply current and voltage waveforms and store results in 3 WFM.

011-Adjust waveform size by taking the reciprocal of the peak to peak amplitude divided by the scale factor and vertically expanding the waveform by the results.
012-Adjust the position of the waveform.

lines 013 to 016 repeat lines 011 and 012 on the other waveform.

line 017-Display the three waveforms.

018-One cursor is turned on, the maximium point on the power waveform is found and the cursor is positioned to the maximium point.

019-program stops, peak power is displayed in the X register.

Figure 7. Instantaneous Power Program Flow Chart

SAFE OPERATING AREA MEASUREMENT

Most manufacturers publish safe operating area (SOA) curves and graphs for their products to provide to the circuit designer an easy method for specifying power transistors. An example of an SOA curve is shown in Figure 8. The information in these graphs, such as dissipation capabilities and current and voltage ratings, are important to the designer.

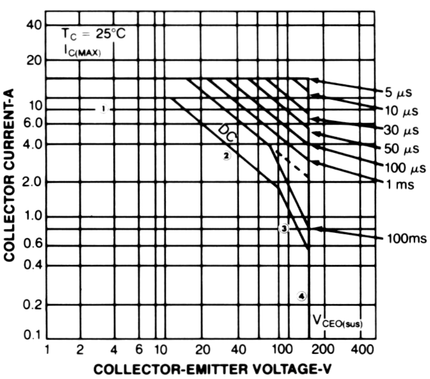


Figure 8. Typical SOA Graph

The ability of the 7854 to display power dissipation as a function of time, to join waveforms, to create waveforms and to display waveforms in an X versus Y mode is used in this application. The measurement of the power dissipation of a switching transistor under operating conditions can help the designer meet reliability goals.

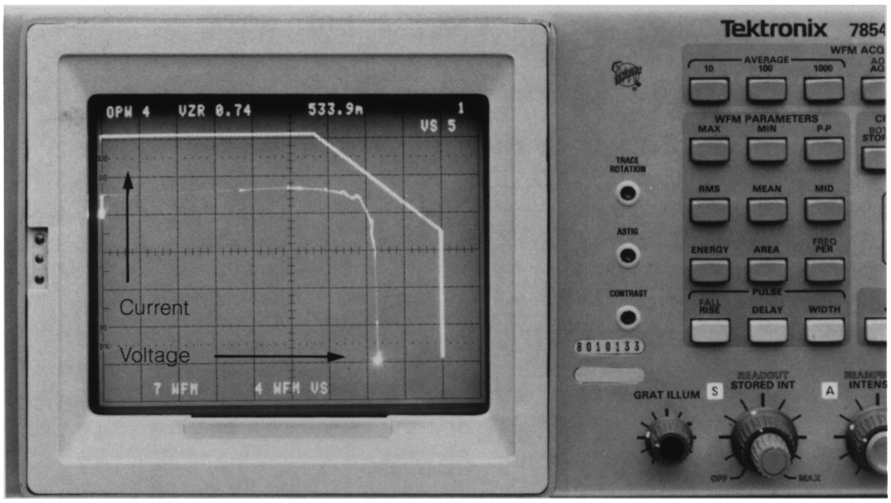


Figure 9 SOA Curve

Verifying Safe Operating Limits

The 7854 allows you to enter the SOA limit information from the manufacturer's data sheet, capture the Ic and Vce waveforms of the switching transistor, and display the resultant waveform in a log-log format just as in the data sheet. Figure 9 is an example of the SOA information of one of the switching transistors in the test power supply.

Set-up

The test set-up is similar to that for the instantaneous power measurement application example (see Figure 4).

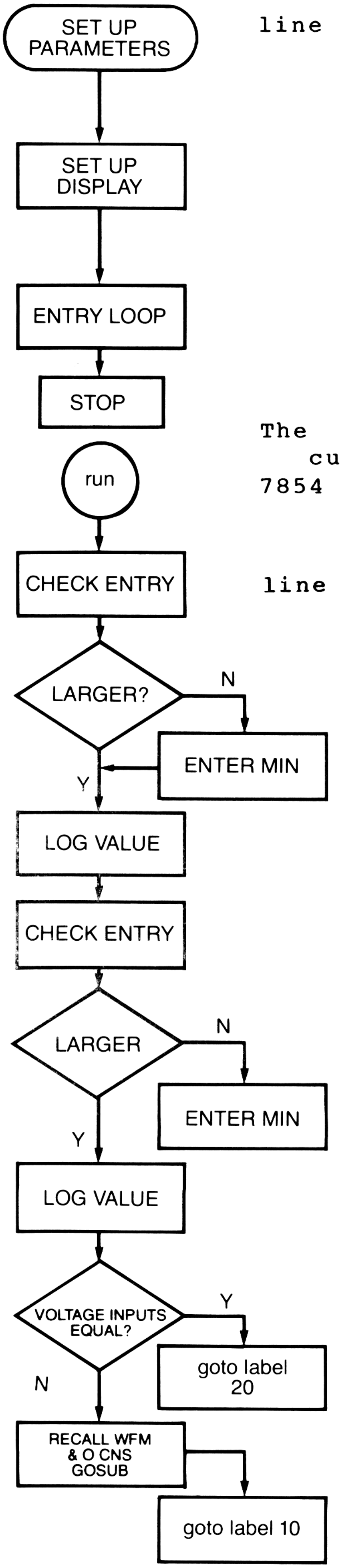
7A18	MODE to CH1 TRIGGER SOURCE to CH1 CH1 VOLTS/DIV. to 10 mV/div.
7A13	VOLTS/DIV. to 5V/div.
7B85	B DELAY MODE to independent, TIME/DIV. to 5μs/div., TRIGGERING MODE TO P-P AUTO or AUTO
7B87	TIME/DIV. to 2μs/div.
7854	A & B TRIGGER SOURCE to RIGHT

Enter the program into the 7854 memory as shown in the listing in Figure 10.

This program allows you to enter the manufacturer's SOA limits on a device and check the device against those limits under actual working conditions. The X-Y display is in a log scale just as in the manufacturer's data sheet. Cursor coordinates are logarithmic values. Linear values for time can be obtained by entering "HCRD .4343 / EXP". A program flow chart is shown in Figure 11.

```
000 10CHS ENTER 2 >CNS
001 0 ENTER 4 >CNS
002 1 ENTER 5 >CNS
003 .01 ENTER 6 >CNS
004 CLD OFF VECT TIME STORED
005 1 WFM 0 * 1 >WFM 2 >WFM
006 L00
007 STOP ENTER
008 6 CNS IFY>X CLX 01 LBL GOTO
009 CLX 6 CNS ENTER
010 L01
011 LN .4343 * 1 >CNS
012 CLX 5 CNS IFY>X CLX 02 LBL GOTO
013 CLX 5 CNS ENTER
014 L02
015 LN .4343 * 0 >CNS
016 0 CNS 2 CNS IFX=Y 20 LBL GOTO
017 1 WFM 0 CNS 10 LBL GSB
018 0 WFM 1 >WFM
019 2 WFM 1 CNS 10 LBL GSB
020 0 WFM 2 >WFM
021 4 CNS 2 + 4 >CNS 0 CNS 2 >CNS
022 10 ENTER 4 CNS IFX=Y 20 LBL GOTO
023 00 LBL GOTO
024 L10
025 HSCL 4 CNS * >ORD
026 4 CNS 0 IFX=Y 15 LBL GOTO
027 HSCL 4 CNS 2 - * HSCL 4 CNS *
028 0 WFM 5 >WFM CLX ITRP
029 L15
030 RTN
031 L20
032 1 WFM
033 HSCL 10 * P/W / P/W 1 - *
034 7 >CNS 0 CNS X<>Y >ORD
035 HSCL 4 CNS 2 - *
036 7 CNS ITRP
037 0 ENTER P/W 1 - >PNT 0 WFM 5 >WFM
038 .5 HXPD 5 HSCL * HPRGT
039 0 WFM 1 >WFM
040 2 WFM HSCL 10 * P/W / P/W 1 - *
041 7 >CNS 6 CNS LN .4343 * X<>Y >ORD
042 HSCL 4 CNS 2 - * 7 CNS ITRP
043 0 ENTER P/W 1 - >PNT 0 WFM 5 >WFM
044 .5 HXPD HSCL 5 * HPRGT
045 0 WFM 3 >WFM 1 WFM 2 >WFM
046 L31
047 STORED TIME BOTH
048 VMDR HMDA GND STOP
049 30 AVG CRS2-1 STOP
050 HXPD MIN - 8 >WFM
051 VMDL GND STOP
052 ENTER 10 >CNS
053 30 AVG HXPD OFF STORED
054 10 CNS >VSCL
055 6 CNS 11 >CNS 0 WFM
056 MIN - 40 LBL GSB
057 HSCL 3 WFM X<>Y >HSCL
058 CLX 0 WFM + 60 LBL GSB
059 6 X<>Y VSCL / / VXPD
060 3CHS MIN VSCL /
061 - >VZR
062 0 WFM 4 >WFM
063 5 CNS 11 >CNS 8 WFM
064 40 LBL GSB
065 HSCL 2 WFM X<>Y >HSCL
066 CLX 0 WFM + 60 LBL GSB
067 9 X<>Y VSCL / / VXPD
068 5CHS >VZR
069 1 >VSCL
070 0 WFM 5 >WFM
071 1 >VSCL
072 4 WFM 5 VS VECT
073 STOP
074 TIME 31 LBL GOTO
075 L40
076 6 >WFM CLX MIN X<>Y
077 IFY>X 50 LBL GOTO
078 6 WFM 11 CNS - SGN
079 1 + 2 / 6 WFM * 11 CNS +
080 0 WFM 6 >WFM
081 L50
082 6 WFM LN .4343 *
083 0 P/W 1 - >PNT
084 0 WFM 6 >WFM .5 HXPD
085 RTN
086 L60
087 CRS1 HSCL 5 * >HCRD
088 CRS2-1 0 >HCRD HSCL 10 *
089 P/W / HSCL 10 * X<>Y -
090 HSCL 5 * - >HCRD P-P
091 OFF RTN
```

Figure 10. SOA Program Listing



line 000-constant that checks for 2 equal voltage inputs
001-constant is total count register
002-constant is minimium voltage that can be input
003-constant is minimium current that can be input
004-turn off cursors, clear display, mode to vectors, mode to stored
005-multiply 0 waveform by 0, and store results in 1 and 2 waveform location

006-loop entry point

007- ready for entry

The user now enters each point on the soa curve, first the voltage, press ENTER on the 7854 keyboard, then the current, and press RUN

line 008-check X entry versus minimium (6 CNS) if larger goto label 01

009-if smaller, enter minimium

010-label 01

011-change into log value, store in 1 CNS (.4343 is natural log to base 10 log conversion)

012-clear register (brings Y entry into register) check Y entry vs minimium (5 CNS) if larger goto label 02
013-if smaller, enter minimium

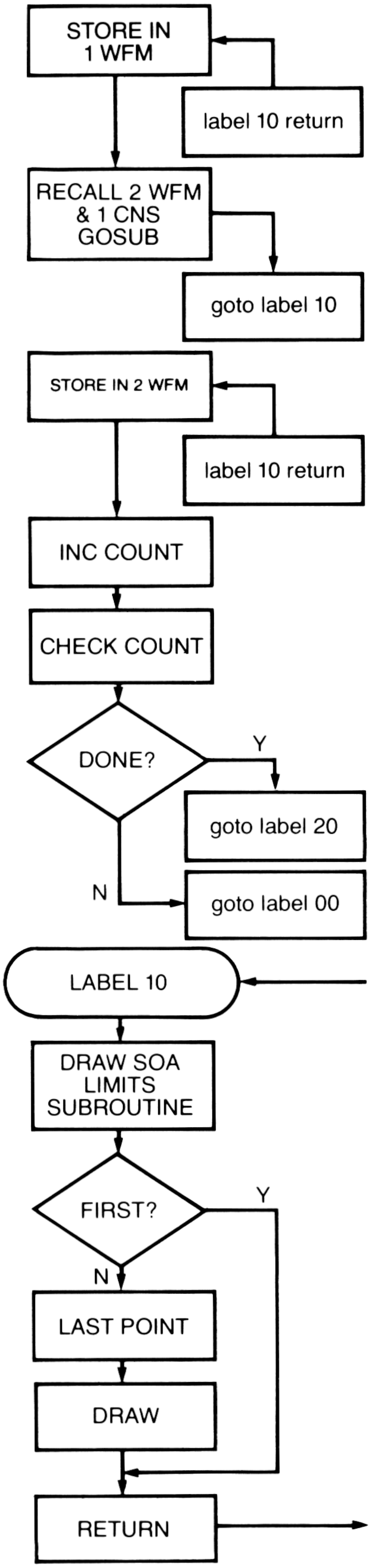
014-label 02

015-change into log value, store in 0 CNS

016-compare versus last voltage entry, if equal then leave loop

017-recall 1 WFM & 0 CNS, goto label 10 subroutine

Figure 11. SOA Program Flow Chart



018-store results in 1 WFM

019-recall 2 WFM & 1 CNS, goto label 10
subroutine

020-store results in 2 WFM

021-increment count by 2, store in 4 CNS,
store voltage entry in 2 CNS

022-check count, if count equals 5 goto
label 20

023-goto label 00 if done, restart loop

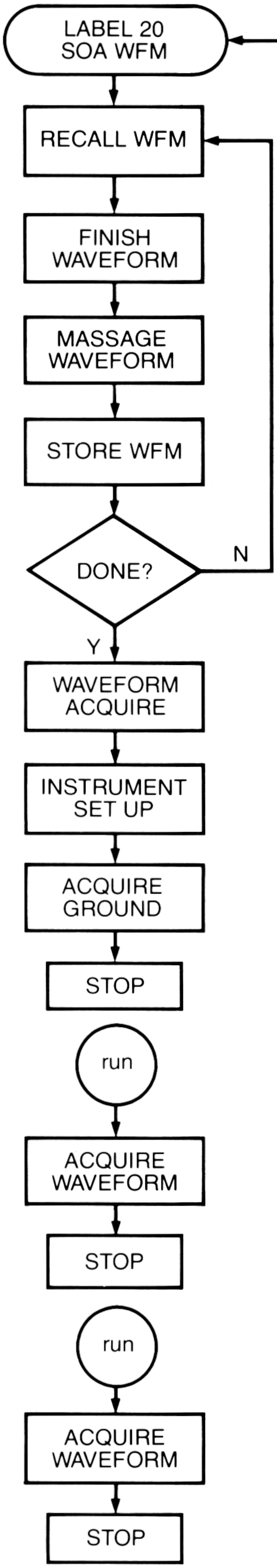
024-label 10
025-move to point at horizontal scale
factor times number of entries, create
point equal to entry

026-if first entry, then goto label 15

027-find previous entry

028-connect last 2 points with straight
line
029-label 15

030-return from subroutine



line 031-SOA waveform adjustment loop

032-recall 1 waveform

033-time window
034-repeat last entry
035-find previous point
036-draw between last 2 points
037-make last point equal 0
038-squish waveform into right half of waveform

039-store waveform in 1 WFM

040 to 45-lines 32 thru 39 are repeated for 2 WFM and results stored in 3 WFM

line 046-label 31

047-display both stored and scope mode to time
048-vertical mode to right, horiz to 'A', acquire ground reference, stop

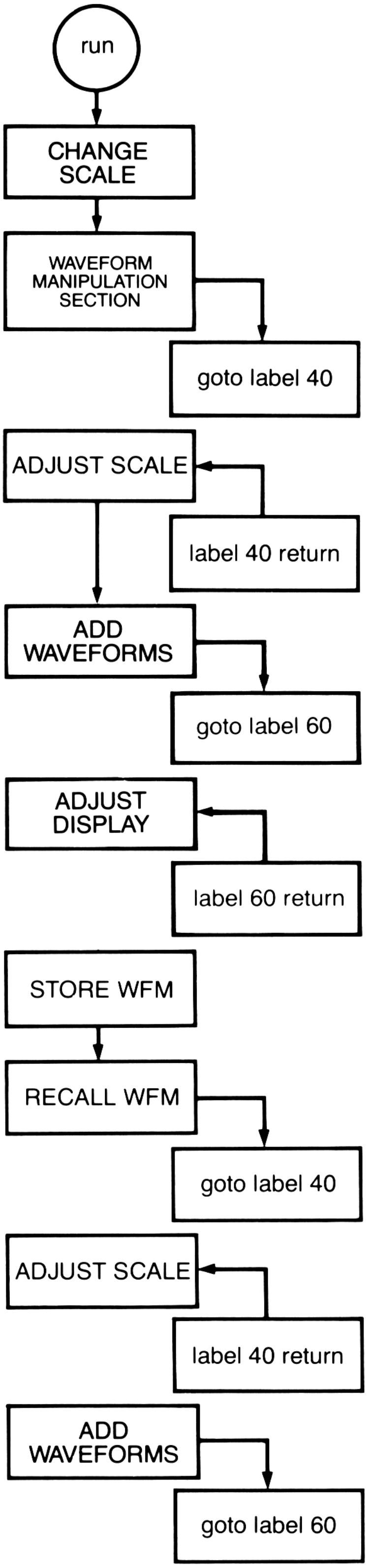
The user sets the right vertical input to DC and presses RUN on the 7854 key board

049-unground right plug-in, press 'RUN', average waveform 30 times & turn on 2 cursors, position cursors over area of interest

050-press 'RUN', waveform will be expanded & stored as 8 WFM

051-vertical mode to left, ground is acquired, stop

052-The user sets the left vertical input to DC, enters amps/div from AM503, and presses 'RUN'



053-waveform averaged 30 times & expanded over same area as previous, cursors are turned off, display is in stored mode
054-scale factor is in amps

055-recall minimium voltage level, 0 WFM
056-goto subroutine at label 40

057-get scale factor from current waveform, recall 3 WFM & add scale factor

058-combine current waveform with X part of limit curve & goto label 60 subroutine

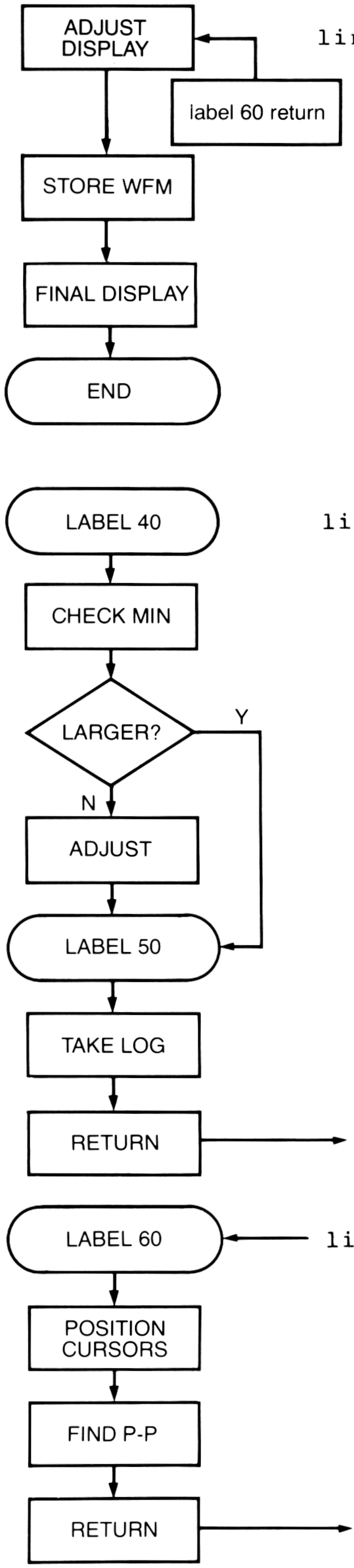
line 059 to 61- the waveform is adjusted in size and offset to the correct position on screen

062-current waveform is stored in location 4

063-recall voltage waveform & minimium voltage
064-goto label 40 subroutine

065-recall voltage scale factor, recall 2 WFM & add scale factor

066-add voltage waveform to Y part of SOA curve & goto label 60 subroutine



line 067 to 068-waveform is adjusted in size & position on screen

069-set scale factor
070-Y waveform is stored in 5 WFM
071-set scale factor

072-SOA waveform is now displayed

073-program is ended
074-to capture another waveform on the same SOA limits, ground both amplifiers and press 'RUN'

line 075 to 080-waveform is checked against minimium value, if smaller, then adjust to minimium (this is to match the SOA curve data), store resultant waveform in 6 waveform location.

081 to 084-waveform is transformed into log information & reduced by 1/2

085-subroutine return

line 086 to 090-find the peak to peak value of the last half of the waveform

091-subroutine return

Using the Program

Ground the inputs to both vertical amplifiers.

Initialization

Press the START (f RUN) button. This will initialize the program, which will stop at line 007 to wait for the first point of the SOA curve. The SOA curve points are entered as X-Y coordinates. For example, 1 Volt and 10 Amps would be entered as "1 ENTER 10 RUN)". Entry should begin with the minimum voltage/maximum current point (upper left corner) and proceed sequentially to the maximum voltage/minimum current point (lower right corner).

In lines 010 through 020, the voltage and current information are changed into log 10 and two waveforms are formed for an X-Y display (lines 021 through 023). Line 012 ends the input if the last two voltage points were equal. Line 022 ends the input if a total of five points were entered.

Program lines 031 through 045 compress the 2 waveforms by 1/2, put both in the right half of the waveform, and store both as waveforms 2 and 3. Later, these waveforms will be combined with the current and voltage acquisitions for X-Y display. Thus, each waveform will be one half acquired data and the other half SOA limit information. Lines 046 through 048 acquire a ground for the left vertical plug-in.

Turn on the device under test and set the right vertical inputs to DC.

Bracket the Waveform

Press the RUN button. The program will stop in line 049. You can now move the cursors to bracket the section of waveform that is of interest. Press the RUN button again and the waveform will be acquired and expanded horizontally (to the limits set by the cursors), then stored as waveform 8. A ground reference will also be acquired for the left vertical channel.

Waveform Combination

Set the left vertical input to DC, enter the AMPS/DIV. setting from the AM5O3 and press the RUN button again. The waveform will be acquired and expanded, then both waveforms changed to log 10 data and compressed by 1/2 (lines 075 through 085). The four waveforms are thus combined into two waveforms. Waveforms 2 and 8 are combined and stored as waveform 4. Waveforms 3 and 6 become waveform 5. Waveforms 4 and 5 are displayed in X versus Y mode.

Conclusion

Power supply device safe operating limit information is important to the power supply designer. The usual method of obtaining this information is to measure the device, then compare it to a manufacturer's data sheet. As shown, with the 7854 this measurement and comparison are made at the same time automatically.

SECTION 4

MAGNETIC TESTING B/H CURVE

Background

The following paragraph provides a brief review of magnetics in switching power supplies. It includes a brief discussion of magnetic design and power supplies, then B/H curves and applications, and finally, a chart that shows the units and terms used in magnetics. Material of this type can be found in a variety of sources; however, UNITRODE has summarized the subject in excellent fashion in their power supply design seminary workbook.*

Components

Magnetics must be considered in two very important components used in power supplies, the transformer and the inductor. These devices are somewhat similar, but are used quite differently. A transformer is used to couple energy and, therefore, any energy storage is undesirable. The inductor, however, is intended primarily to be an energy storage device. In designing a power supply, transformer energy storage results in inefficiencies and losses, decreasing the efficiency of the supply. Thus, an efficient inductor design must take into account the maximum energy storage, at the threshold of saturation, that will result in the desired ripple current.

Terms

Term	Parameter	SI Units	CGS Units
B	Magnetic flux density	Tesla	Gauss
H	Magnetic field intensity	A-T/m	Oersted
u_o	Permeability	4 × 10-7	1
Ae	Effective magnetic area	m2	cm2
le	Mean magnetic path length	m	cm
ϕ	Magnetic flux	Weber	Maxwell
mmf	Magnetic potential	amp-turns	Gilbert
N1	Number of turns on the core		
N2	Number of turns on pickoff winding		

H field = N1 × I/le
B field = 1/N2 × Vdt.

Energy Storage

By using a B/H curve from a magnetic core, the energy storage of that core can be determined. A B/H curve is the plot of the flux density against the magnetic field intensity of the core. A number of parameters must be known about a core in order to calculate the B/H curve, including the length of the magnetic path, the effective magnetic area, the number of turns in the winding, and others.

*Unitrode Power Supply Design Seminar, Copyright 1982 Unitrode Corp., Lexington, MA.

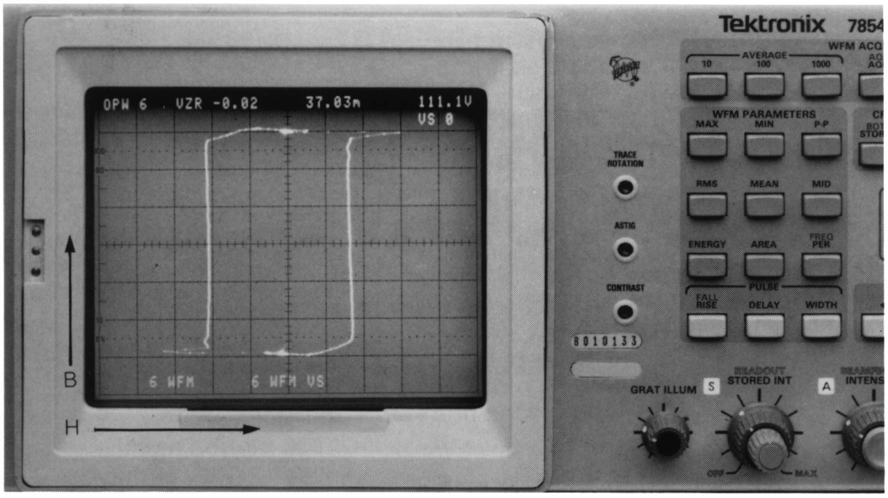


Figure 12. B/H Curve

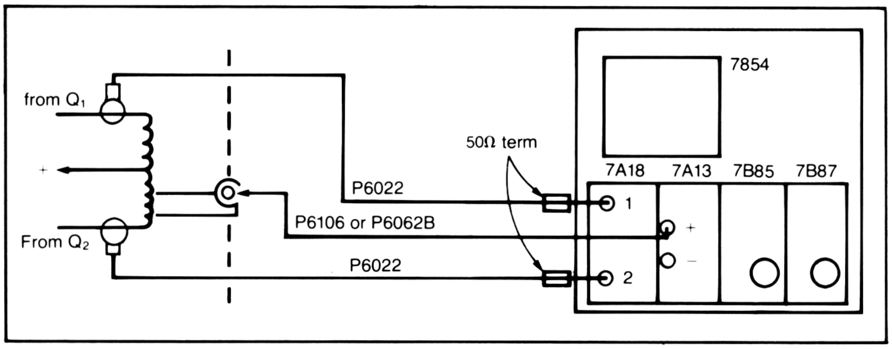


Figure 13. B/H Curve Test Set-up

B/H Measurements

The 7854 can provide a method for checking the losses in the transformer in a switching power supply under actual operating conditions. The program for such an application displays the B/H curve of a switching power transformer with the proper labels in SI units, which can be easily transformed into CGS units. The area of the B/H curve can be calculated and displayed. Figure 12 shows the B/H curve of the transformer in the test power supply. The set-up is shown in Figure 13.

Set-up

7A18A Display Mode to ADD, trigger source to CH2 POLARITY to INVERT, V/DIV to 50 mV/div (both).

7A13 V/DIV to 1 V/DIV. This setting depends on the turns ratio (primary to pickoff) times the voltage swing on the primary. Display to Center Screen

7B85 TIME/DIV to 10μs/div B DELAY MODE to INDEPENDENT

7854 A TRIGGER SOURCE to LEFT VERT.

Enter the program shown in Figure 14 into the 7854 memory.

```
000 L00
001 VMDL HMDA CLD TIME GND STOP
002 10 AVG CRS2-1
003 STORED STOP
004 0 WFM
005 HXPD 4 >WFM VMDR GND STOP
006 ENTER 3 >CNS
007 10 AVG HXPD 6 >WFM OFF
008 30 ENTER
009 10 ENTER
010 1 >CNS CLX 0 >CNS
011 100 ENTER 4 ENTER 3.14 * /
012 7 >CNS
013 1 ENTER 1 CNS / 4 >CNS
014 10EEXCHS4 ENTER 6 >CNS
015 .27 ENTER
016 .18 ENTER
017 30 >CNS CLX 20 >CNS
018 3 CNS 0 CNS * 30 CNS /
019 5 >CNS
020 L02
021 OFF
022 4 WFM 0 >WFM 3 CNS >VSCL
023 MEAN -
024 1.5 VXPD
025 0 WFM 4 >WFM
026 6 WFM MEAN - INTG
027 MEAN -
028 1.5 VXPD
029 0 WFM 5 >WFM
030 L05
031 4 WFM 0 >WFM
032 VSCL 5 CNS * 30 CNS / >VSCL
033 21 >CNS
034 0 WFM 2 >WFM
035 5 WFM 0 >WFM
036 VSCL 4 CNS * 20 CNS / >VSCL
037 31 >CNS
038 0 WFM 3 >WFM
039 2 WFM DIFF 3 WFM * AREA ABS
040 40 >CNS
041 3 WFM 2 VS 40 CNS
042 CLX
043 20 CNS 180EEX3CHS * 40 CNS *
044 20EEX3 * 40 CNS STOP
045 L06
046 2 WFM 21 CNS 7 CNS * >VSCL
047 3 WFM 31 CNS 6 CNS * >VSCL
048 2 WFM DIFF 3 WFM * AREA
049 3 WFM 2 VS
050 CLX
051 STOP
```

Figure 14. B/H Curve Program Listing

Using the Program

Set the input coupling to ground on both vertical amplifiers and turn on the test power supply.

Press the 7854 START (f RUN) button. The program will acquire a ground reference for the left-hand vertical plug-in and stop at line 002.

Set the 7A18A CH1 and CH2 inputs to DC.

Bracket the Waveform

Press the RUN button. The program will acquire the current waveform and turn on the cursors. You can then bracket the cycle or cycles of interest in the waveform with the cursors (one complete cycle is adequate for a good display).

Press the RUN button again. This causes the area bracketed by the cursors to fill the entire screen. Also, the program will acquire a ground reference for the right-hand vertical plug-in.

Set the 7A13 + input to DC. Enter the current/div setting (probe setting times 50mV/div) on the 7854 calculator keyboard.

Curve Calculation

Press the RUN button again. The program will acquire the voltage waveform and expand it as with the current waveform. Program lines 005 through 011 initialize the constants necessary to provide the proper units (see Figure 15).

In line 005, enter the AMPS/DIV setting (3 CNS is the proper setting of amps/div for the AM503).

Program Description

Program lines 017 through 020 accomplish positioning and vertical expansion. Line 021 integrates the voltage waveform. Line 032 re-labels the voltage waveform. Line 036 re-labels the current waveform. Line 039 calculates the area. Line 041 displays the B/H curve, and the area is displayed in the X register. The algorithm is defined as follows:

All values are expressed in SI units. The H field or magnetic field intensity is expressed in Amp Turns/Meter.

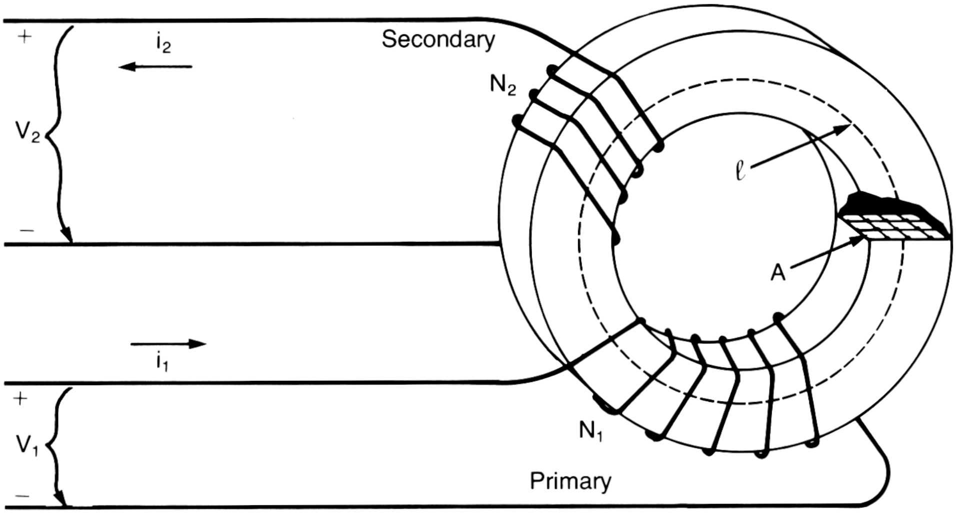


Figure 15. Transformer Core

Energy Algorithm

The following is a description of the energy loss in a transformer core:

N_1 = number of primary turns
N_2 = number of secondary turns
A = cross sectional area of core
ℓ = mean length of the core
μ = permeability of the core

To find the work (energy loss of the core):

$$W = \int H \cdot dB = \int H \left(\frac{dB}{dt}\right) dt$$

where:

$$B \text{ (magnetic flux density)} = \frac{\mu N_2 i_2}{\ell} = \frac{1}{N_2 A}\int v_2 dt$$

(2WFM in 7854)

$$H \text{ (magnetic field intensity)} = \frac{N_1 i_1}{\ell}$$

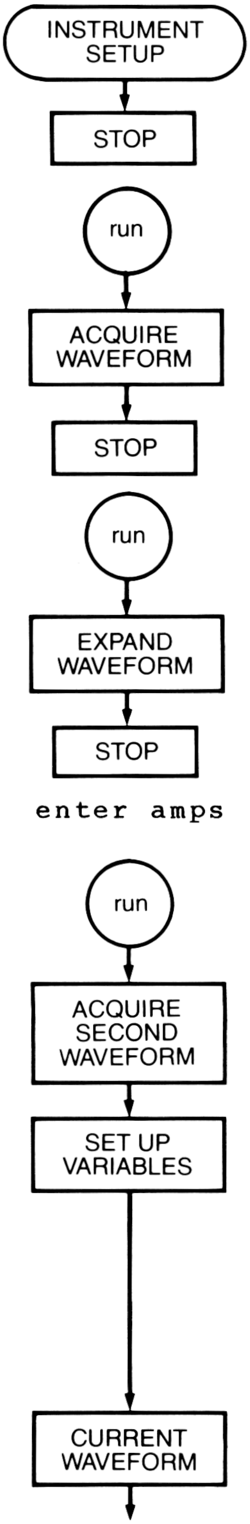
(3WFM in 7854)

7854 Implementation of Algorithm

To the 7854, this is

3WFM, 2WFM, DIFF ∗ AREA

As shown in Figure 16, the program is simple and efficient.



line 000-label 00
001-vertical mode to left, horizontal mode to A, clear display, reset mode to time, ground is acquired and program stops

The user now sets left vertical to DC, turns on the power supply and presses RUN on the 7854 keyboard

002-waveform is averaged 10 times, 2 cursors are turned on
003- 7854 mode to STORED and program stops

The user now brackets the section of waveform of interest with the cursors (for most pleasing results, bracket an integer number of cycles)
Now press RUN

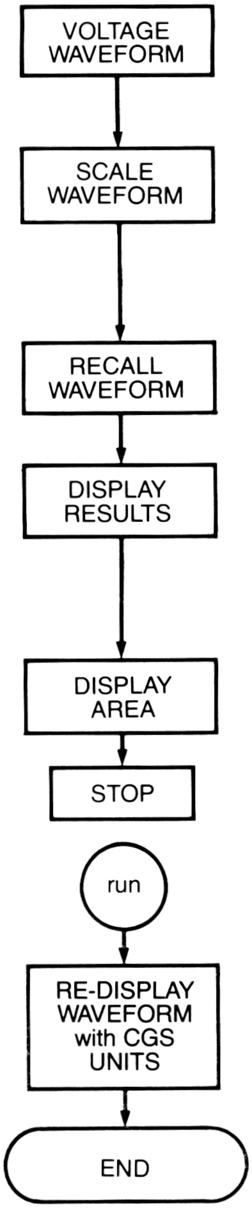
004-0 WFM is in X register
005-expand waveform, store in location 4 WFM, vertical mode to right, acquire ground reference and program stops

The user sets the right vertical to DC, enters the amps/div and presses RUN

006-amps/div stored in 3 CNS
007-waveform is averaged 10 times, expanded horizontally, stored in 6 WFM location and cursors turned off

008-010-number of turns into 0 CNS, number of pick off turns into 1 CNS
011-TESLA to GAUS conversion (7 CNS)
012-AMP-TURNS to OERSTADS conversion (4 CNS)
013-reciprocal of primary turns (6 CNS)
015-017-mean core length in meters (20 CNS) and core cross sectional area in meters (30 CNS)
018-019-AMP-TURNS/METER (5 CNS)
020-label 02
021-turn off cursors
022-recall 4 WFM, scale factor in amps
023-turn off cursors
024-subtract mean from waveform
025-expand waveform by 1.5 times
026-store waveform in 4 WFM

Figure 16. B/H Curve Program Flow Chart




```
027-recall voltage waveform, subtract
     the mean, and integrate the waveform
028-expand the waveform by 1.5
029-store waveform in 5 WFM
030-label 05
031-recall current waveform
032-recalculate scale factor in amp-turns
033-store scale factor in 21 CNS

034-store waveform in 2 WFM
035-recall current waveform
036-recalculate scale factor in Webers
037-store scale factor in 31 CNS
038-store waveform in 3 WFM
039-differentate 2 WFM, multiply 3 WFM
     times resultant waveform, find the
     absolute area
040-store area in 40 CNS
041-display 3 WFM versus 2 WFM, area is
     displayed in the X register
042-044-clear X, calculate area,
     and stop
```

```
The user may now redisplay the waveform with
units in CGS by pressing RUN
```

```
045-051-changes from SI to CGS units and
     displays waveform
```

Figure 16. B/H Curve Program Flow Chart

Conclusion

By using the B/H curve program, the 7854 can measure inductor energy storage under dynamic conditions. This allows the designer to optimize inductor designs for the most efficient power supply.

SECTION 5

OUTPUT IMPEDANCE MEASUREMENT

In power supply evaluation, it is often desirable or necessary to measure the output impedance versus frequency of a supply under operating conditions. This is because power supply stability is an important consideration, and a relatively simple way to check the stability of a supply under actual load conditions is to check the output impedance of the supply over a certain frequency range.

In using the 7854 in such applications, a capacitively coupled sinewave is applied to the output of the test power supply as shown in the test set-up of Figure 17. For best results, it is desirable that the signal-to-noise ratio be 30 dB. The amount of current and voltage induced in the output of the supply is used to calculate the output impedance (Zout=Epk-pk/Ipk-pk). Figure 18 shows an example of the test supply output impedance.

Note that the program listed in Figure 19 requires the user to input the next frequency into the sinewave generator before continuing the program. This is fine for checking a few points, however in Figure 18, 128 points were checked from 1000 Hz to 0.1 MHz. An automated version of this program was used to generate this waveform. A discussion of automating this program is on page 25.

Current versus voltage phase measurements over the frequency range can also be added easily to this program. This information can provide the designer with more information about the power supply.

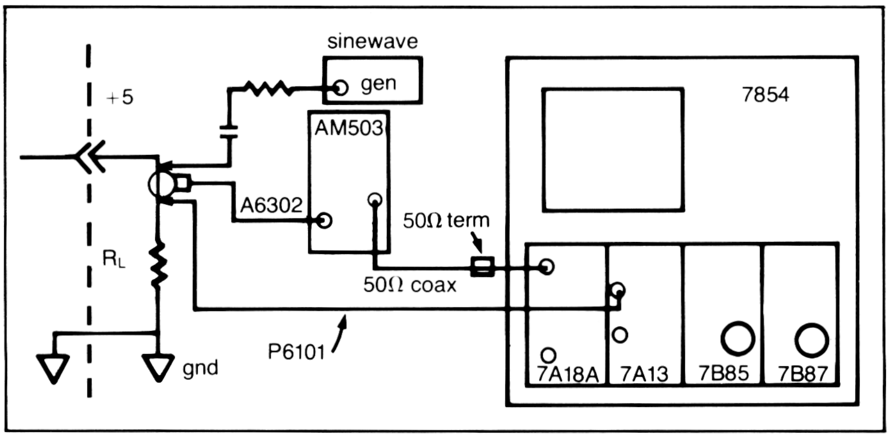


Figure 17. Output Impedance Measurement Test Set-up

Set-up

7A18A	MODE to CH1 CH1 to DC V/DIV to 10mV/div
7A13	BANDWIDTH to 5MHz AC/DC to AC VOLTS/DIV to 2mV/div
7B85	B DELAY to INDEPENDENT TIME/DIV to 10ms/div
Sinewave generator	Frequency to 1000Hz Output to 5 volts

Set A trigger mode to LEFT VERT.

Enter the program shown in Figure 19 into the 7854 memory.

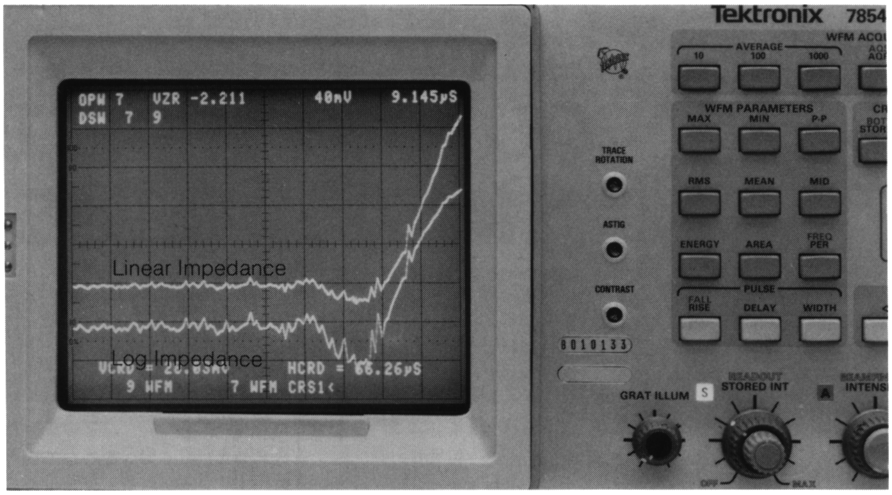


Figure 18. Output Impedance

```
000 LOO
001 TIME CLD SCOPE VMDR HMDA
002 0 WFM 0 * 4 >WFM
003 5 >WFM
004 0 ENTER
005 128 ENTER
006 1000 ENTER
007 0 > CNS CLX 7 >CNS CLX 8 >CNS
008 1EEX5 ENTER
009 LN 7 CNS 1 - /
010 17 >CNS STORED STOP
011 ENTER 9 >CNS
012 LO1
013 8 CNS 1 + 8 >CNS
014 7 CNS IFX=Y 6 LBL GOTO
015 2 LBL GSB
016 VMDR BOTH
017 17 CNS 8 CNS * EXP
018 0 CNS +
019 STOP
020 CLD
021 1 LBL GOTO
022 LO2
023 STORED
024 VMDR
025 50 AVG .2 SMOOTH P-P 2 >CNS
026 0 WFM 2 >WFM
027 VMDL 10 AVG P-P 3 >CNS
028 0 WFM 3 >WFM
029 4 WFM
030 HSCL 10 * P/W / 8 CNS * 10 >CNS
031 2 CNS 3 CNS /
032 10 CNS
033 >ORD
034 0 WFM 4 >WFM
035 RTN
036 LO6
037 4 WFM CRS1 0 >HCRD
038 HSCL 10 * 511 / 11 >CNS
039 7 CNS 11 CNS * 11 CNS -
040 >HCRD 10 >CNS
041 11 CNS >HCRD CRS2-1
042 10 CNS 11 CNS - >HCRD
043 4 WFM HXPD 7 >WFM
044 LN .4343 * 0 WFM 9 >WFM
045 7 DSW 9 DSW
```

Figure 19. Output Impedance Measurement Program

Using the Program

Turn on the test power supply.

Press the 7854 START (f RUN) button. Program lines 000 through 008 initialize the constants. Line 003 is the AMPS/DIV setting that is entered by the user. Line 004 zeroes the counter. Line 005 is the number of steps. Line 006 is the starting frequency. Line 008 is the ending (maximum) frequency. Lines 008, 009 and 010 together are the frequency per step. Line 011 is the amps/div.

Enter the AMPS/DIV setting from the AM503 and press the 7854 RUN button.

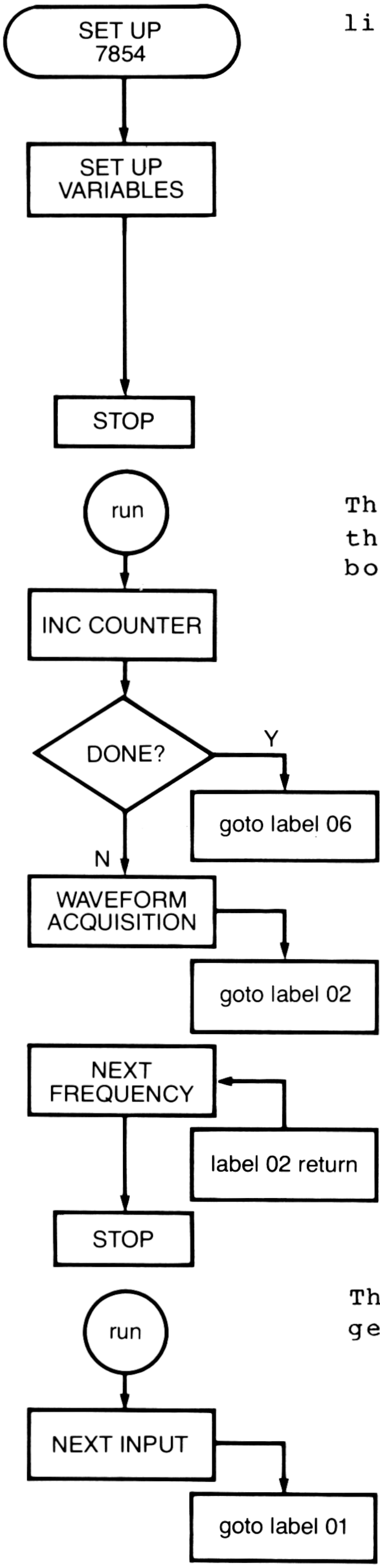
Acquisition

Line 012 steps to the acquisition subroutine. Lines 019 through 032 acquire the waveform, measure the peak-to-peak value, and place it into 3 CNS. The voltage (2 CNS) is divided by the current (3 CNS) to determine the resistance. This value is then used as the next data point in waveform 4.

Calculations

Lines 033 through 041 contain the display subroutine. The impedance waveform (waveform 7) is converted to log 10 and stored as waveform 9. The impedance waveform and the log impedance waveform are then displayed.

As shown in Figure 20, the program is uncomplicated and efficient. However, note the special considerations that follow the figure.




```
line 000-label 00
     001-mode to time, clear display, mode
         to scope, vertical mode to right
     002-multiply waveform times 0, store in 4 WFM
     003-store in 5 WFM
     004-step counter set to 0
     005-number of steps- 128 steps
     006-starting frequency of generator
     007-store number of steps in 7 CNS,
         store counter start in 8 CNS
     008-enter upper frequency limit
     009-take log of frequency, divide by steps,
         for frequency change per step
     010-store f/step in 17 CNS, stop program
```

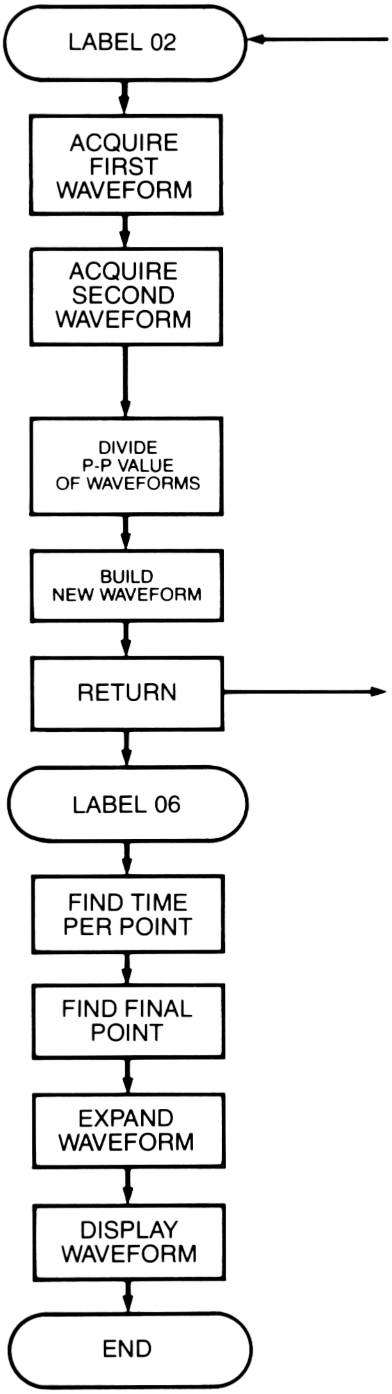
The user now enters the amps/div setting of the probes, then presses RUN on the 7854 key board

```
     011-store amps/div in 9 CNS
     012-label 01
     013-increment counter

     014-compare count to number of steps

     015-go to label 2 subroutine

     016-set vertical mode to right
     017-calculate next log frequency step
     018-add to base frequency (1000 Hz)

     019-next frequency is in X register
```

The user inputs the frequency to the generator and presses RUN

```
     020-clear display
     021-goto label 01
```

Figure 20. Output Impedance Measurement Program Flow Chart




```
022-label 02
023-mode to stored
024-vertical mode to right
025-average waveform 50 times, smooth
     waveform, find the p-p value and store in 2 CNS
026-store waveform in 2 WFM
027-vertical mode to left, average waveform
     10 times, find p-p value, and store
     in 3 CNS
028-store waveform in 3 WFM
029-recall 4 WFM
030-divide horizontal time by points per
     waveform and multiply by number of steps
     store in 10 CNS
031-divide  2 CNS by 3 CNS (peak to peak values)
032-recall 10 CNS
033-set horizontal point to this value
034-store waveform in 4 WFM

035-return

036-label 06
037-turn on 1 cursor, position to 0
     horizontal point
038-find the time per point for 512 point
   waveform, store in 11 CNS
039-multiply the time per point times
     number of points taken, subtract first point
040-move cursor to this point, store
   time in 10 CNS
041-move cursor to 1 point of waveform,
     turn on 2 cursors
042-subtract time of one point from time
   of final point, bracket this time with cursors
043-expand waveform between these points,
     store in 7 WFM
044-translate into log values, store in 9 WFM
045-display 7 WFM and 9 WFM
```

Special Considerations

If large frequency ranges are to be tested, the 7B85 time/division will require manual adjustment as the frequency increases. It is recommended that between 2 and 10 cycles be displayed during each measurement.

Automation

To further automate this test, one line can be added to the 7854 program and a short program can be generated on a GPIB controller (such as the Tektronix 4052A) to take the next frequency from the 7854 and set a programmable sinewave generator (such as the Tektronix FG5010) to this frequency.

Adding a "SENDX" to line 019 before the "STOP" will cause the 7854 to send the next frequency step to the controller. The controller will then send the frequency setting to the sinewave generator. An example program for the controller is shown in Figure 21.

```
100 PAGE
110 POLL D,S;24
120 PRINT @24:"FREQ 1000;AMPL 5;
    OUTPUT ON;FUNC SIN;MOD CONT"
130 POLL D,S;24
140 ON SRQ THEN 1000
150 S=0
160 PRINT @1:"0 GOTO"
170 PRINT @1:"RUN"
180 IF S<>2 AND S<>66 THEN 180
190 PRINT "ENTER AMP/DIV "
200 INPUT A
210 PRINT @1:"READX"
220 IF S<>147 AND S<>211 THEN 220
230 PRINT @1:A
240 IF S<>2 AND S<>66 THEN 240
250 FOR I=1 TO 127
260  S=0
270  PRINT @1:"RUN"
280  IF S<>146 AND S<>210 THEN 280
290  INPUT @1:F
300  S=0
310  PRINT @24:"FREQ ";F
320  CALL "WAIT",2
330 NEXT I
340 PRINT @1:"RUN"
350 END
1000 CALL "WAIT",.2
1010 POLL D,S;1
1020 CALL "WAIT",.2
1030 RETURN
```

Figure 21. 4052A Program

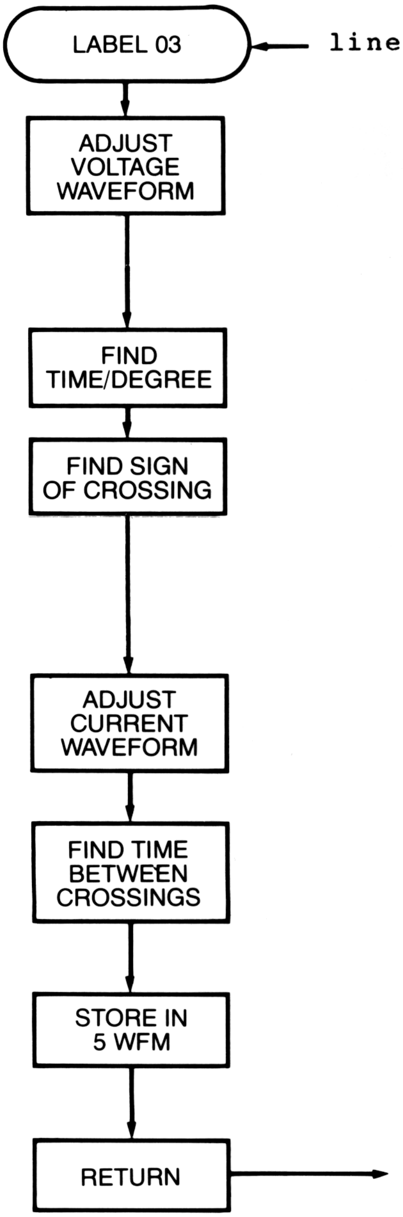
Phase Information

The 7854 can capture and display phase information with the addition of a subroutine to the program. The listing and flow chart for this subroutine are shown in Figures 22 and 23. In addition to the subroutine, the only program lines that must be added are a "3 LBL GSB" after line 014 and a line to display the waveform at the end of the program.

The results of the phase programs are shown in Figure 24.

```
046 LO3
047 2 WFM
048 1 SMOOTH
049 CRS1 HSCL .5 * >HCRD
050 CRS2-1 HSCL 9 * >HCRD
051 MID - 0 WFM HXPD OFF
052 MID 2 / PER 9 >CNS
053 360 / 2 >CNS
054 0 WFM CRS1 0 >HCRD
055 CRS2-1 9 CNS >HCRD
056 0 WFM HXPD
057 CRS1 0 >HCRD
058 SGN DIFF SGN
059 MAX >VCRD
060 HCRD 4 >CNS OFF
061 3 WFM 0 >WFM
062 CRS1 HSCL .5 * >HCRD
063 CRS2-1 HSCL 9 * >HCRD
064 0 WFM HXPD
065 CRS1 0 >HCRD
066 CRS2-1 9 CNS >HCRD
067 0 WFM HXPD CRS1
068 SGN DIFF SGN
069 MAX >VCRD HCRD 3 >CNS
070 4 CNS 3 CNS - 2 CNS /
071 12 >CNS OFF
072 5 WFM
073 12 CNS 10 CNS >ORD
074 0 WFM 5 >WFM
075 RTN
```

Figure 22. Phase Plot Subroutine




```
line 046-label 03

     047-recall voltage waveform (2 WFM)
     048-find  mid  point, center waveform by
             subtracting mid point from waveform,
             smooth the waveform
     049-turn on 1 cursor, set cursor to .5 division
     050-turn on 2 cursors, set second cursor to
              bracket 9 divisions
     051-horizontally expand waveform,turn off cursors
     052-divide mid value by 2, find the period,
             store in 9 CNS
     053-divide period by 360, store in 2 CNS

     054-058-turn on 1 cursor, set to 0 horizontal,
              turn on cursor 2, recall 9 CNS, expand
              waveform.
     059-find the signum of waveform, differentiate
              the result and find signum of results
     060-find first signum
     061-store signum of cursor location in 4 CNS
     062-recall current waveform
     063-65-steps 50 to 52 are repeated
     066-069-steps 54 to 60 are repeated for  the
              cursor waveform.

     070-find time between occurrence (line 66) and
              first occurrence (line 56), then divide
              by time per degree (line 54)
     071-store results in 12 CNS, turn off cursors
     072-recall 5 WFM
     073- phase is in Y register,  time of step is
              in  X  register
     074-modify waveform with phase information,
                   store in 5 WFM

     075-return from subroutine
```

Figure 23. Phase Plot Flow Chart

Conclusion

By using the 7854 with a controller such as the 4052A and a programmable generator such as the FG5010, dynamic power supply stability is checked automatically. This measurement would require a lot of "button pushing" and "babysitting" without the use of the 7854, 4052A and FG5010.

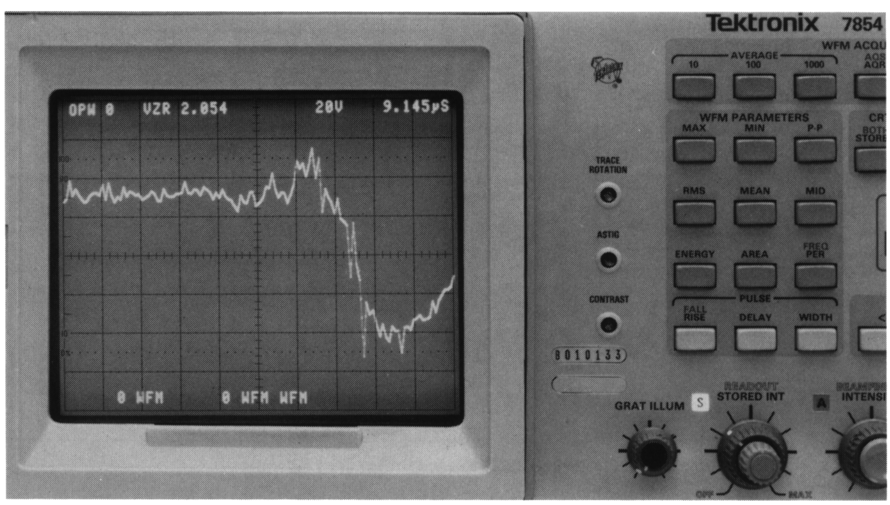


Figure 24. Phase of Current vs. Voltage Over Frequency Range

RIPPLE AND NOISE MEASUREMENT

Semi-automatic ripple and noise testing of power supplies is often desirable in production environments. Using the 7854, this can be done efficiently.

Ripple Measurement

Ripple of interest could be a multiple of the 6OHz input or the switching frequency of the power supply. This can be measured easily with the 7854, but a precaution must be mentioned. It may be necessary to use either line triggering for the 7B87 timebase or an external trigger from the switcher with 64 averages by the 7854 to examine the actual ripple signal.

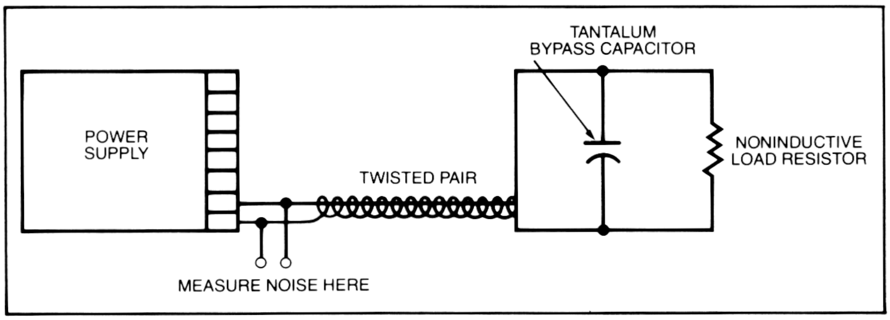


Figure 25. Example of Noise Measurement Technique

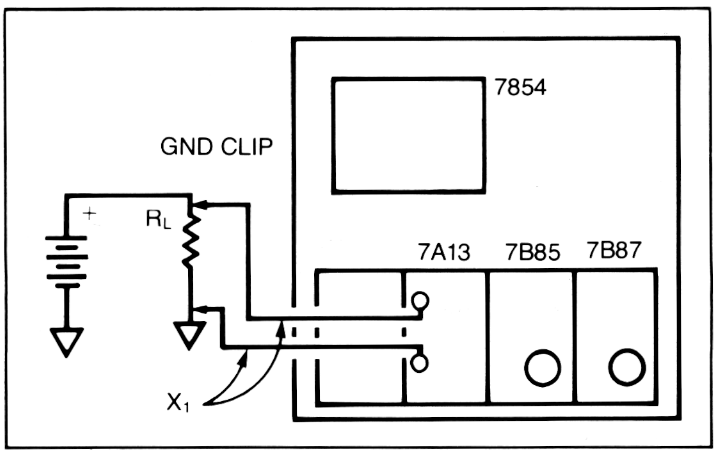


Figure 26. Ripple/Noise Measurement Test Set-up

Noise Measurement

There is no universally accepted measurement procedure or technique for measuring output noise of switching power supplies. Ground loops, lead lengths, inductive loading and other factors can drastically affect such measurements. One technique that is sometimes used is shown in Figure 25. This technique requires very careful set-up, however.

Another technique compares noise among several power supplies. This is done with the test setup shown in Figure 26 and with the procedure and program that follow.

Set-up

7A13 + and − inputs to AC VOLTS/DIV to 10mV/div.

7B85 B DELAY MODE to INDEPENDENT.

Enter the program shown in Figure 27 into the 7854 memory.

```
000 L00                                          014 2 CNS CHS HCRD >ORD
001 CLD VMDR HMDA OFF                            015 0 >HCRD CRS2-1 0 WFM ITRP
002 0 WFM 0 *                                    016 0 WFM 3 >WFM
003 10EEX3CHS ENTER                              017 L01
004 2.5 * 2 >CNS                                 018 2 DSW 3 DSW
005 CRS1 0 >HCRD                                 019 BOTH
006 2 CNS HCRD >ORD                              020 2 AVG P-P
007 HSCL 10 * >HCRD                              021 1 CNS 5 *
008 2 CNS HCRD >ORD                              022 X<>Y
009 0 >HCRD CRS2-1 0 WFM ITRP                    023 PAUSE
010 .5 VXPD 0 >VZR                               024 IFY>X 1 LBL GOTO
011 0 WFM 2 >WFM                                 025 STOP
012 CRS1 0 >HCRD 2 CNS CHS HCRD >ORD
013 HSCL 10 * >HCRD
```

Figure 27. Ripple/Noise Program

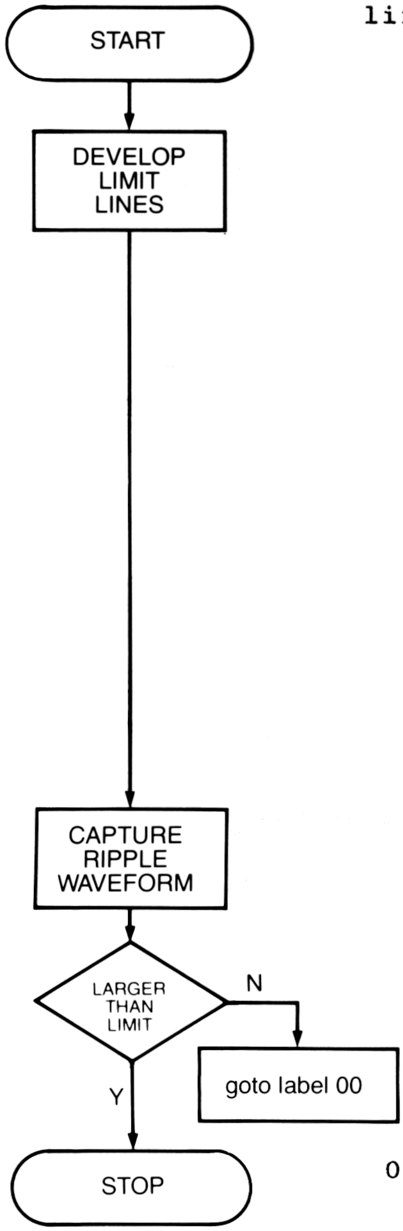


Figure 28. Ripple Flow Chart

```
line 000-label 00
     001-clear display, vertical mode right,
          horizontal mode A, cursors off.
     002-multiply 0 waveform by 0.
     003-store .01 into 1 CNS.
     004-muliply .01 by 2.5, store in 2 CNS.
     005-turn on 1 cursor, set to 0 horizontal
     006-set point to .025.
     007-move cursor to last point of waveform.
     008-set last point to .025.
     009-set cursor to 0 horizontal, turn on 2
          cursors and interpolate between points.
     010-expand waveform by .5, set vertical zero
          to center screen.
     011-store waveform in 2 waveform location.
     012-turn on 1 cursor, set to 0 horizontal,
          recall 2 CNS, change to minus and set
          point to -.025.
     013-move cursor to last point on waveform.
     014-recall 2 CNS, change to minus, and set
          last point to -.025.
     015-move cursor to first point, turn on 2
          cursors, and interpolate between points.
     016-store in 3 waveform location.
     017-label 01
     018-display both 2 and 3 waveform.
     019-set display mode to both.
     020-average waveform 2 times, find peak to
          peak value.
     021-multiply 1 CNS by 5.
     022-swap the x and y register.
     023-pause
     024-if ripple less than .05 volts, goto label 00

  025-stops if ripple exceeds 50 mv, total ripple
       is in the X register.
```

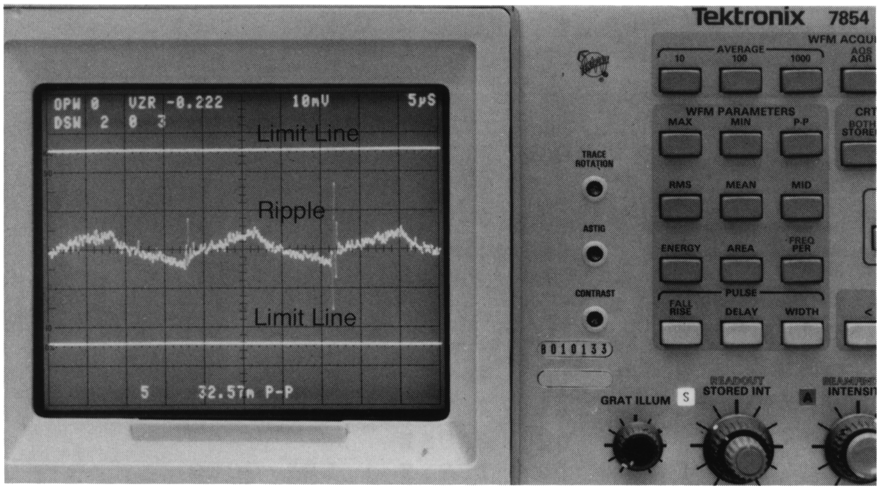


Figure 29. Ripple Measurement with Limit Lines

Using the Program

Press the START (f RUN) button. The program will produce a display (see Figure 29) and X register readout of the ripple and noise size. For this example, program lines 001 through 011 create two limit lines: waveform 2 is +25 millivolts from center screen, waveform 3 is −25 millivolts from center screen. Lines 012 to 017 acquire the waveform, compare the peak-to-peak voltage with 50 millivolts and stops if it is not within specifications.

A flow chart for this program is shown in Figure 28.

Ripple and noise measurements to desired specifications can be made using the listed program. The 7854 provides an efficient means of automatically rejecting any supply that does not meet requirements.

You may want your program to examine specific frequency components, several different frequency components, or total noise. The random noise generated by this test set-up is quite large. The two averages at line 013 reduce the random noise. However, you may want to change the test setup to reduce this noise further.

Summary

The 7854 Programmable Oscilloscope with its waveform processing capability is a powerful tool for power supply design. It helps the designer to provide reliable, properly specified power supply components. It can also help to shorten and simplify the design process.

The 7854 makes use of a waveform calculator for added flexibility. The 7854 is a high performance oscilloscope for general power supply measurements. It is also a digitizer for automation of key power supply design function.

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