Division 6 - Lincoln Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts

SUBJECT: DESIGN AND TESTS OF ELECTRONIC CIRCUITS FOR OPERATING SAFETY MARGINS

To: Norman H. Tayler

From: Jay W. Forrester

Date: January 27, 1953, Revised September 21, 1953

Abstract: A detailed laboratory test of circuits should be made to measure the operating margins and the sensitivity of the circuit to component changes. Also a measurement of marginal checking effectiveness in needed. A curve of component variation vs. marginal checking voltage (or other parameter) will reveal behavior of the circuit.

The testing of electronic circuits and the experimental demonstration of their performance, is one of the most important factors in the design of new equipment. Paper design may be used in arriving at the circuit constants, but the proof that these operate satisfactorily should be made on the basis of laboratory tests. I am listing below several groups of tests which I think should be made.

A. <u>Test for Input Signal Variations</u>

This test is to be made with all electronic components (including voltages) at their nominal center values. Input conditions are to be varied one at a time to upper and lower limits until the circuit fails to deliver its required output. Input quantities to be varied will include:

1. Rate of rise of pulse
2. Pulse length
3. Pulse height
4. Pulse frequency
5. Maximum noise level
6. Pulse grouping and transient response to pulse chain.

Limits in variation of each of the above quantities should be measured at the point where the output fails to meet performance specifications and the nature of the failure should be indicated.

B. Marginal Checking Effectiveness

It is presumed that one or more parameters have been chosen for preventive maintenance checking of circuit performance. The following tests are to demonstrate two things:

1. That the circuit as designed has adequate operating margins and

2. That the chosen marginal checking parameters are effective in measuring deterioration of circuit components.

In general, it is possible to plot a curve of component value (including supply voltages) vs. marginal checking parameter which shows the region of successful performance of the circuit. An example of such a curve is shown in Figure 1. The vertical scale is percentage of nominal value of the circuit component being studied. The horizontal scale is percentage of normal marginal checking parameter.

The inside of the enclosed figure shows the area in which the circuit meets its performance specifications.

The curve should be plotted in percentage of normal value (a log scale may be needed for values which can vary widely such as diode crystal resistance).

Range A shows the permissible variation in marginal checking parameter before circuit failure when all components are at nominal value. Range A is the same on all component test curves because all curves must go through points A' and A". (This represents the unperturbed circuit with all components at nominal value.)

Range B shows the permissible variation in component value before circuit failure when marginal checking parameter is fixed.

The curve should carry explanatory notes around the periphery to show the reason for circuit failure under the varying conditions.

Curves will not always be closed. Some component values have no limits in one direction (upper value of crystal back resistance in some circuits) leading to the general shape of Figure 2. Likewise it may not be possible to always test along the marginal checking parameter axis to circuit failure without physical destruction of the circuit by excessive voltage so a curve like Figure 3 may result.

Proper interpretation of these curves will divulge whether or not the marginal checking parameter provides an adequate test for variation in component value. Consider the idealized Figure 4. The normal operating point (N.O.P.) is aligned with the points A' and A" which are also the maximum and minimum points on the curve. The curve demonstrates a direct interrelationship between the two quantities and a change in the component value creates a progressive reduction of the operating margin test from the range A. This is a desirable condition. Consider, by contrast, the imaginary curve Figure 5. This curve shows complete independence of the component value and the marginal checking parameter. Variation of the component to either value B' or B" causes failure independent of the checking parameter value. There is no way of detecting the change in parameter value before the failure point is reached. For a circuit of this type a different form of marginal checking would be necessary.

A curve of the above sort should be plotted for each component of each final circuit. In preliminary design, points A', A", B' and B" should be measured to show that the circuit is apt to pass final approval.

The preceding curve also indicates the sensitivity of the circuit to changes in parameter value. All the preceding sketches have shown a good safety margin surrounding the normal operating point. Consider, however, Figure 6. A small change in either the component or the checking parameter will cause circuit failure and points out an undesirable condition.

Figure 7 shows a large enclosed area which is poorly placed with respect to the normal operating point. A revision of the circuit is indicated.

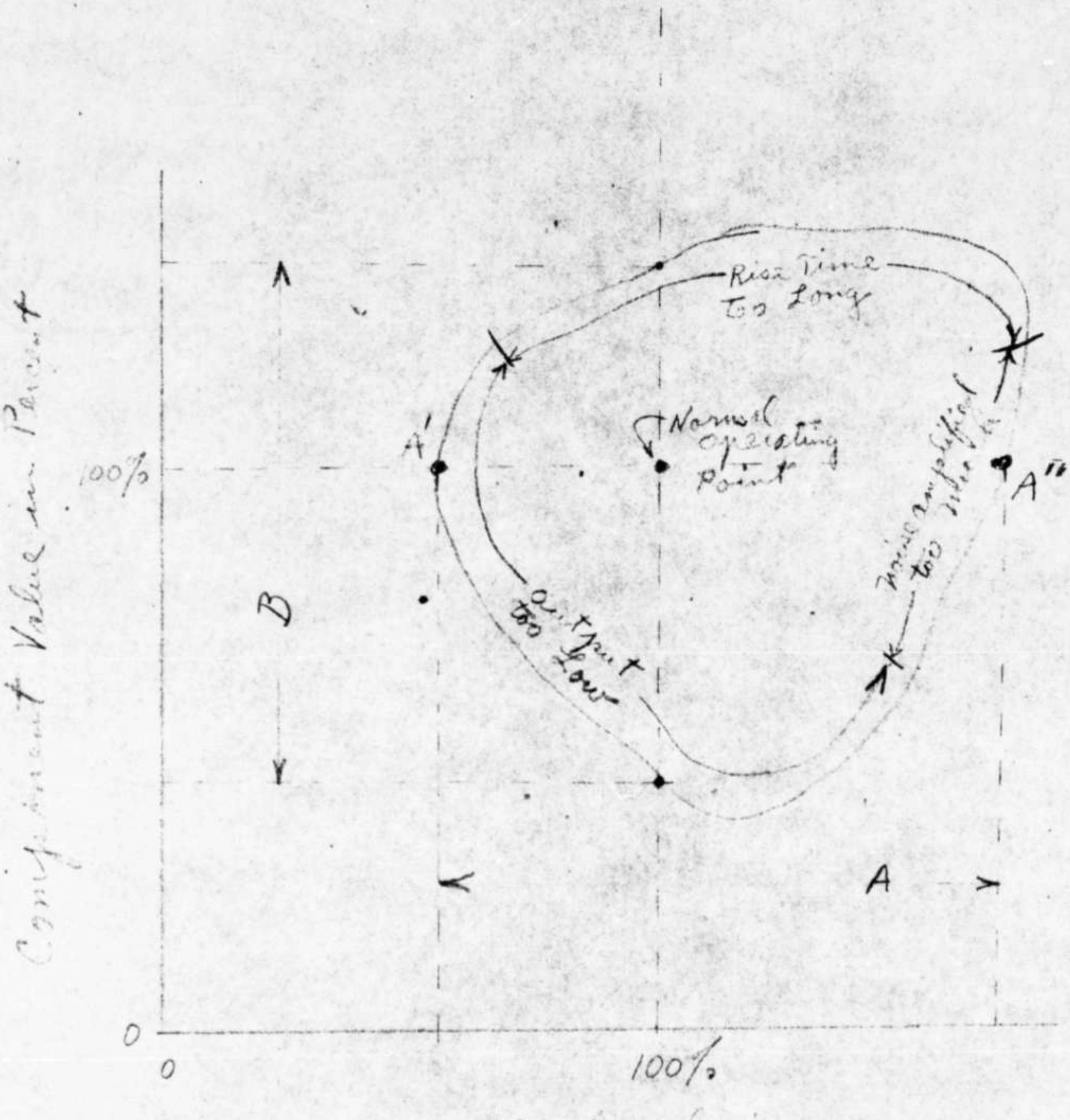
C. <u>Test for Combined Component Variation from Nominal Value</u>

The circuit is to be assembled with each component at the edge of the nominal tolerance range in the direction to give the worst combined detrimental effect. The tests of Section A should be repeated to find what ranges of input are necessary to give specified outputs. There may be several component combinations which give "worst" results with respect to the different specified values of performance, and, in some cases, the worst combination of tolerance may have to be discovered by some trial and error testing. The report of the test should explain what performance specifications were considered in determining worst operating conditions.

(Signed) ______________________
Jay W. Forrester

JWF:eg
Drawings attached:
SA-53821 SA-53823
SA-53822 SA-53824

SA-53821



SA-53821

Fig 1

Feb. 6, 1953
JF

SA-53822

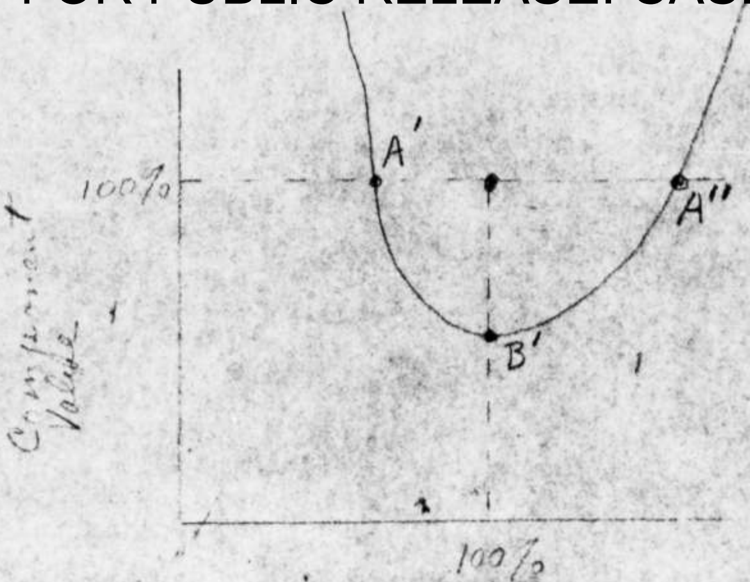


Fig. 2

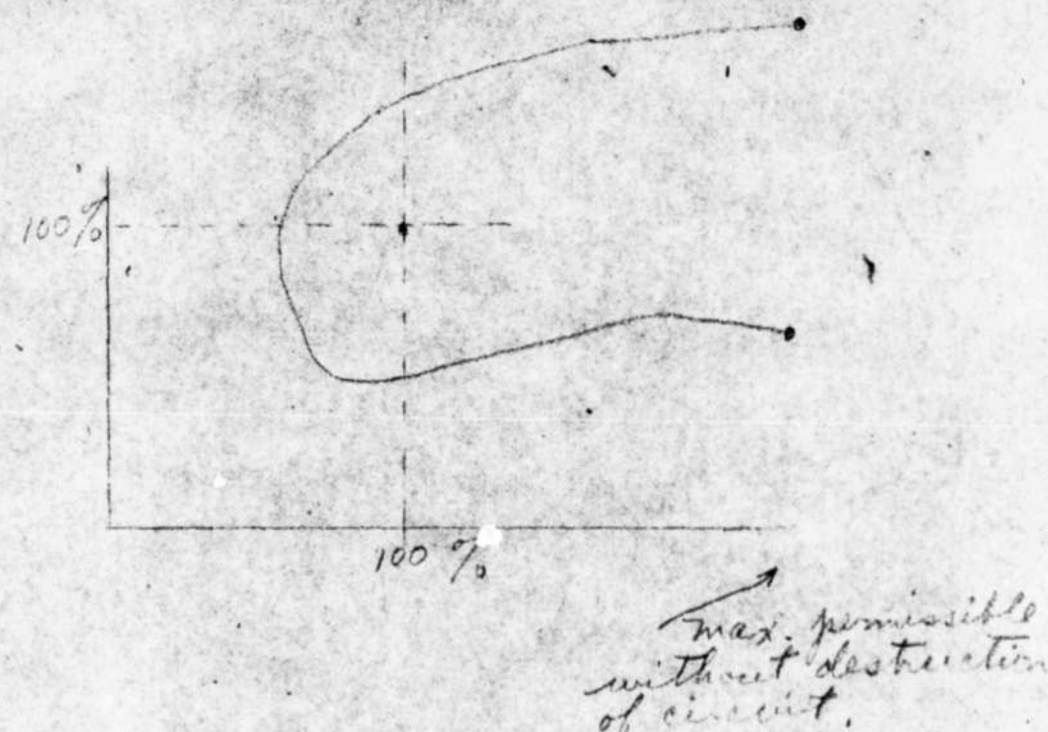


Fig 3

SA-53822

Feb. 6 1953

SA-53723

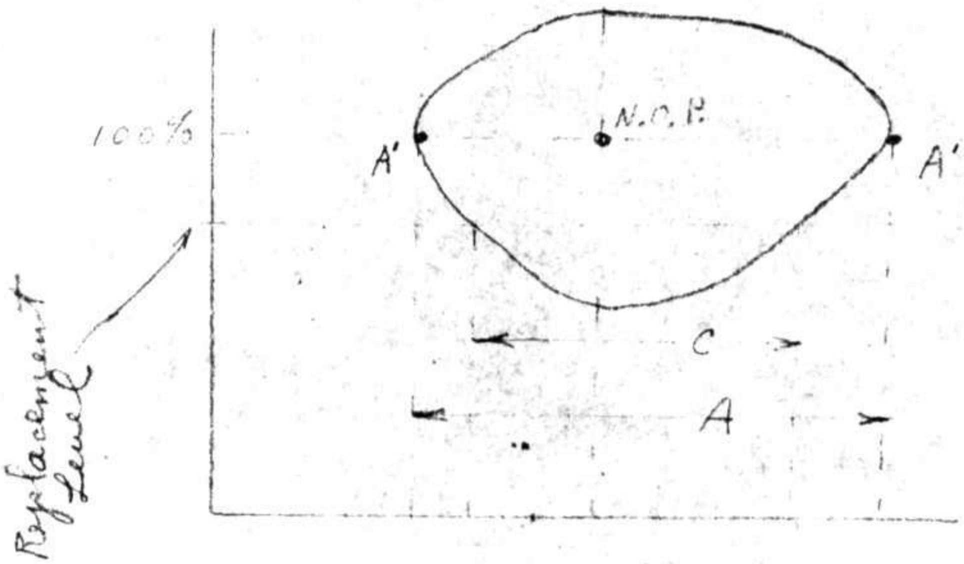


Fig 4

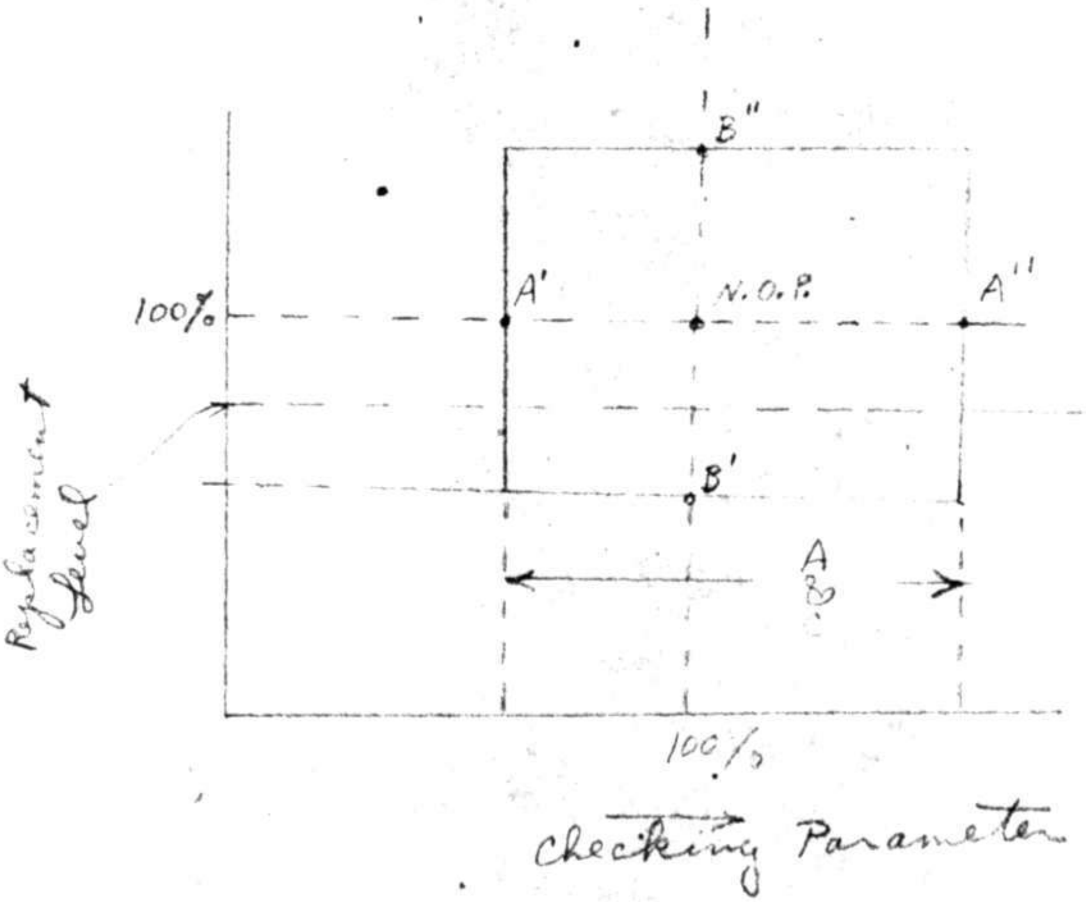


Fig 5

SA-53723