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Subject: RUDIMENTS OF GOOD CIRCUIT DESIGN

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To: Group 62

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Abstract: Circuits which depend on the absolute stability and reproducibility of components have proved to be unreliable and often impractical for field use. A study of the tolerances of a circuit to its component variations, when made a part of the design procedure, will lead to better equipment, producible and usable in the field. Such a study often leads to new circuits and new ways of obtaining results.

1. The Importance of Studying Tolerances

One of the most difficult concepts for the young circuit designer to appreciate is the importance of studying tolerances. These tolerances show up in many ways, but are most likely to come to his attention when a circuit that he has designed is duplicated by some other engineer, or when such a circuit is put into quantity production.

2. Present Dependence Upon Complete Stability of Components

The first approach to the problem of designing a circuit is usually to attempt to attain a result which has been specified by some systems group. A typical specification may call for a high-speed switch or flip-flop, with limits on rise time, voltage swing, and resolution time. Occasionally some mention of high reliability or long life will be made as an adjunct to the functional specification. Very often the designer will complete a circuit within a few days or weeks after he starts the development activity, and then, when asked if his circuit will be reliable, he will glibly say - "Certainly, it will be as reliable as the components." He will then turn to the component engineer and specify 1% resistors and tubes which must have closely held tolerances on plate current and transconductance; and he may go so far as to specify temperature and humidity stability. Seldom will he think of a way of designing the circuit in such a manner that the functions will not be dependent upon the complete stability of the components. And yet, when these requirements are part of his initial specification, he often finds that it is possible to design a circuit to do the job in which tight tolerances on components are not an important factor.

In the manufacture of components, two variables are always present:

The reproducibility of a given component is always in question; 1% resistors, for instance, are now quite commonly available, but even a variation of plus or minus 1% in a resistor is enough to throw some circuits into the marginal category. No one has yet been able to make vacuum tubes or crystal diodes to such close tolerances, yet many circuit designers feel quite indignant that this is not possible.

Stability is another factor which is an important consideration in components. The 1% resistor does not always stay within 1% under various conditions of temperature and humidity, and very often, after several thousand hours, these resistors change their values. The result can be catastrophic if one is dependent upon their being stable. The vacuum tube and crystal diode are also very vulnerable on this point of stability, and of course are seldom used in circuits where tolerances of more than 10% or 20% are expected.

The problem, therefore, becomes one of designing highly stable and reliable circuitry made up of components which are never really reproducible and stable. This is the problem of the production designer and very often taxes his ingenuity to a much greater degree than any other one problem.

In designing the circuitry to be used in a real-time control type of application, for example, it is very important that we consider this production designer's viewpoint. The components he will use will be neither really reproducible nor really stable, and it is up to the circuit designer to come up with circuits which are tolerant of these variables in the components.

3. Reasonable Specifications of Tolerances

It has been demonstrated in some circuitry that vacuum-tube transconductance can vary more than 50% before causing circuit failure and that such vulnerable points as diode reverse resistance can be allowed to change as much as an order of magnitude. These two parameters are very vulnerable ones, and liberal permissible variation should be specified in a design just as strongly as the actual performance characteristics of the circuit. For instance, when specifying that a flip-flop should run at 2 megacycles with a rise time of 0.2 microsecond and a voltage swing of 20 volts across an impedance level of 1,000 ohms, one should also specify that all resistors in the circuit should be able to vary between limits no tighter than plus or minus 5%, with the necessity for 1% resistors becoming a matter of serious concern requiring special approval. Large signal transconductance should probably be specified as having limits of 50% around the nominal specifications for tubes, and crystal diode back resistance should be allowed to decrease an order of magnitude below nominal before circuit failure occurs. The last three items in this specification are much more stringent than the actual functional specifications first noted, and they are much more important in determining the usefulness of the circuit in any large system such as we are contemplating. Most circuit designers can reproduce a high-speed flip-flop from their notebooks, but one that will perform under such stringent conditions of component variation would probably rule out the selection of any circuits used thus far and would make the designer think carefully about new ideas and new ways of doing the job.

4. Conclusion

It is important that all of the designers direct their thinking to the importance of changes in component tolerances. It is important to develop a philosophy of design in which one places the tolerance of the components at the head of the list instead of at the bottom.

The purpose of this memo is to emphasize the point that future circuits which are to be accepted in the framework of a real-time control system will not be considered good because they do unusual things, but will be considered good because they will perform their job with an exceptionally wide tolerance to component values. We should develop a method of describing a circuit in terms of its tolerance of these variables instead of only in terms of its actual function. Some of the experience on WWI has indicated that proper attention to this sort of detail can result in 10 to 100 times the improvement in the overall life of a given circuit, and certainly this kind of return is well worth the investment that goes into the original design.

An early task in the WWII program will be to reduce the above objectives to a carefully considered and detailed statement of circuit design standards and measurements.

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