Engineering the Schematic Diagram

Step-by-step procedure for preparing intricate diagrams so that major circuitry stands out clearly, with stages arranged according to mechanical groupings of equipment yet still in logical order. Diagrams for APS-3 radar serve as examples

By JAMES M. HENRY*

Radiotelephone Engineer
New England Telephone and Telegraph Co.
Boston, Mass.

and

MILLETT G. MORGAN*

Assistant Dean, Thayer School of Engineering, Dartmouth College
Hanover, New Hampshire

THE IDEAL schematic diagram should present the features of a circuit in a form which is suitable for ready analysis in the fashion of the flow-of-function outline, exemplified by the organization chart, the production-line flow, the chemical-process diagram and other systematized arrays of information.

Diagramming with lines which show only circuit components and their interconnecting copper wires, without a scheme, produces an impenetrable labyrinth when extended without refinement to modern complex electronic equipment. The scheme is the essence, and effective schematic diagrams should display clearly:

(1) A readily discernible pattern or general framework of the system that stands out boldly from a background of accurate but subordinate detail.

(2) The sequence of events or operations, such that cause is plainly related to effect, and the directions of flow of power, signals, impulses and functions.

(3) The relative importance of components or units.

(4) The roles that individual components play in circuit operation.

(5) Certain broad mechanical features of grouping of construction.

(6) The physical points of ready access to the circuits where tests may be applied, measurements made, or results obtained.

(7) The controls as to name, physical position, how the adjustment is made mechanically, how the controls are related to other controls and to the influences they exert.

(8) Copious annotations, including electrical values of components.

Careful planning of a clear, rich schematic calls for the expenditure of time, thought, and ingenuity to achieve clarity and smoothness. It must be sketched again and again, rearranged and sketched over. A good schematic cannot be drawn casually. It must be done by one who knows thoroughly the operation and purposes of the equipment.

FOR SIMPLIFIED MAINTENANCE

Increasing ingenuity in developing electronic devices today demands that a correspondingly high order of skill be devoted to lucid recording of their circuitry.

The techniques described here for enhancing the clarity and value of intricate schematic diagrams were successfully used during the War throughout the Massachusetts Institute of Technology Naval Radar School.

Extra time spent in planning and execution of diagrams for commercial radar, communication and industrial electronic control equipment will more than pay for itself in simplification and speedup of maintenance and servicing

The Block Diagram

The positions on the paper of all parts of the drawing should conform to a general framework or plan which shows the flow of function. This bare framework is called a block diagram. It should first be sketched out in as ideally simple and straightforward a manner as possible. The flow begins with the primary motivation of the equipment, generally at the left of the sheet. As the activating impulse or signal is carried through successive operations, such as amplification, reshaping, phasing, and the like, heavy black flow lines should be drawn toward the right, passing through these operators or modifiers sketched in as unit-function blocks without regard to their physical locations in the equipment.

By unit-function block is meant a whole circuit operating as a unit, such as an amplifier, multivibrator, or oscillator. The path may branch and proceed through parallel paths or it may be joined by paths of impulses coming in from blocks above or below the main flow. For eye appeal, consecutive order, and readability, the flow should be kept moving in smooth unbroken streams from the cause, on the left, to the effect on the right.

Having sketched an ideally smooth flow, as illustrated by the diagram of an APS-3 radar equipment shown in Fig. 1, it will be necessary to modify this to some

* Formerly with Massachusetts Institute of Technology Naval Radar School.

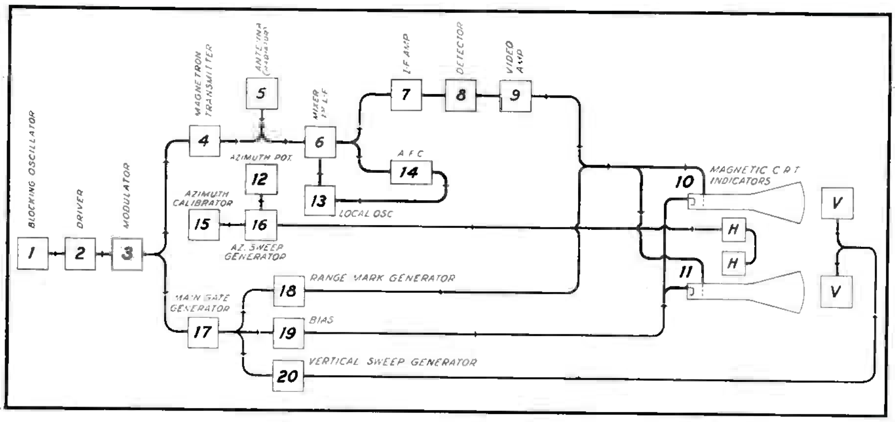

FIG. 1—First draft of block diagram, showing idealized flow of functions for APS-3 radar

extent to conform to the actual physical locations of the unit-function blocks in the equipment.

By moving these blocks up or down it will be possible to collect, in one general group on the sheet, those which are located in the same mechanical unit or box. Such a step is illustrated in Fig. 2. This will require the flow lines to dip downward or upward from the original ideal path. Any rearrangements which result in straighter flow lines or emphasis upon the relative importance of the paths should be used. This will often require related units to be above each other.

The blocks related by physical location are enclosed by a larger dashed outline, boldly drawn, designating the frame, unit, or box which contains them. Within this outline the blocks may be shifted about to preserve straight flow lines and to eliminate as many crossovers of paths as possible. From the schematic viewpoint these outlines may be rectangles, long, short, horizontal, vertical, notched, or otherwise shaped to accommodate blocks, without regard to similarity to the actual box shape in the equipment.

Frequently it is desirable to prepare the entire schematic so that it can be separated into individually complete numbered pages. This arrangement is particularly useful for instruction book or text book purposes. The appropriate section of the entire drawing may also be secured inside covers or doors of the individual apparatus boxes or cabinets. When the worker studies the overall system schematic drawing, he encounters the same familiar diagram patterns which he finds in the covers of the individual units. To provide this page sectionalization, additional rearrangements of the drawing may be required so that reasonable divisions can be made. In general this is not too difficult once the mechanical grouping of unit-function blocks has been determined.

Figure 3 illustrates a rearrangement of the material of Fig. 2 into four separate quadrants or pages. Helpful general details have been filled in to form the complete block diagram as finally developed. The quadrant or page numbers refer to detailed drawings, one of which is shown in Fig. 4. Note the very close correlation between the patterns of the heavy flow lines on Fig. 3 with their counterparts on the detailed drawings of Fig. 4. For the reader, this preservation of the pattern simplifies the mental transition from block diagram to individual page. It is also a powerful assistance to the memory.

The Detailed Sheet

The positions of the unit-function blocks having been roughly determined by the layout of the block diagram, it becomes necessary to develop the detail within each block. This detail comprises resistors, capacitors, coils, tubes, etc, whose wiring must fit into the general scheme.

To achieve smoothness, it may be necessary to draw and redraw the circuitry of blocks top for bottom or right for left to conform to the straightforward block diagram. It should always be kept in mind that each block is a subsidiary link in the branching chain-of-function flow.

The component resistors, capacitors, and tubes should be so disposed with respect to each other that the circuit behavior and purpose is made clear. This may require readjustment of the block diagram as space requirements become defined. Where voltage divider chains of resistors provide graduated voltages, they should be arranged in the simple straight line or row with the high voltage impressed across the ends. Successively lower-voltage taps come out from it like steps in a ladder. A convenient concept is a potential gradient of the tapping wires:

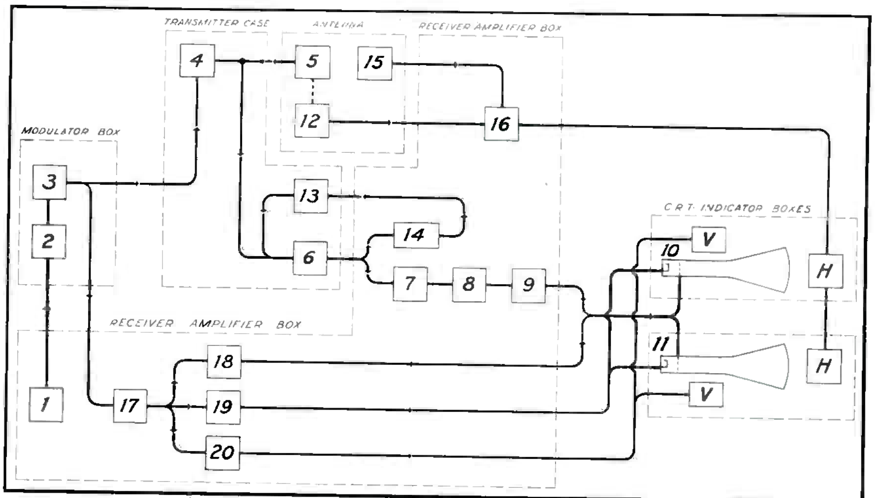

FIG. 2—Regrouping of unit-function blocks of APS-3 radar diagram to conform to mechanical divisions and minimize crossovers

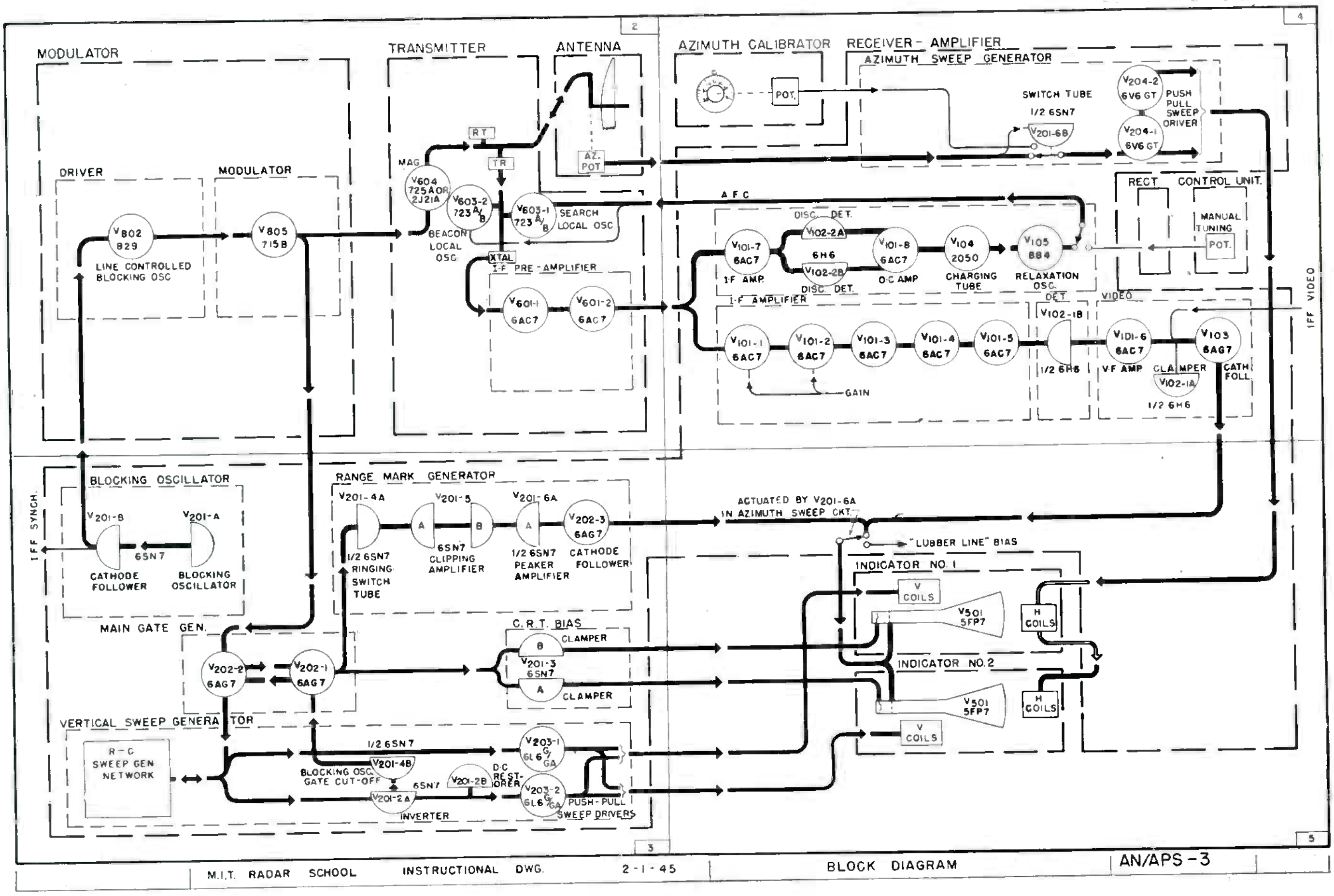

FIG. 3—Final block diagram of APS-3 radar, with helpful detail filled in. Arrangement in four quadrants permits comparison with the four schematic diagram sheets, one for each quadrant, that are drawn next

highest near the top, lowest toward the bottom.

Bridge circuits should be drawn to look like a bridge. If the plate impedance of a vacuum tube is part of an arm of the bridge, it should be drawn in one of the sides of the diamond and oriented to match. This will immediately assist the reader to understand what the designer expected the tube to do.

When networks might require the application of Thevenin's or Kirchhoff's principles for analysis, the link elements, meshes, and junctions should be drawn to stand slightly apart from other circuits and be arranged so that the appropriate principle is apparent.

Electrical symmetry as exemplified in balanced circuits should be expressed as graphical symmetry. Symmetry of general function should also be so shown where appropriate. It should be emphasized that graphical symmetry should not be employed for the sake of pictorial composition when no such real electrical symmetry exists.

Electrical similitude should be emphasized, when valid, by graphical similitude. A group of R-C chains, selectable by a switch, all similar in principle but differing only in time constant, should be grouped; all pairs of resistors should be placed at the same level and the attitudes of one R-C combination repeated for all. Once the reader has decided what one is for, he can plainly see that all fulfill the same purpose. Such an R-C group should stand apart from other similarly appearing R-C links whose function is not immediately related to them.

Where cables connect one outlined unit to another, the sides of such units should be arranged to be adjacent and the elements so arranged within that the cable can be shown as a family of straight wires, free of cross-overs, running between the units. Some cable wires will carry the chain-of-function flow, standing out boldly and becoming part of the general framework of the diagram.

Too often the simple circuitry of primary power distribution involving on-off switches, fuses, automatic overload cut-outs, interlocks, time delays, gate and battle switches, can become woven into a complex web of advanced wiremanship that would defy Maxwell himself, though he be armed with the finest of volt-ohmmeters. These primary circuits are usually set up sequentially: that is, the one most remote from the main fuses depends upon the functions of numerous devices preceding it. The diagram of this web should be drawn as branching chains of influence flowing across into rungs of a ladder whose rails are the two primary power leads. From the diagram it should be instantly apparent, without wire tracing, which units are controlled by a given switch and which chains of influence would be put out of commission by a blown fuse or open gate switch. The drawing should be deliberately set up so the man with the volt-ohmmeter can see immediately what

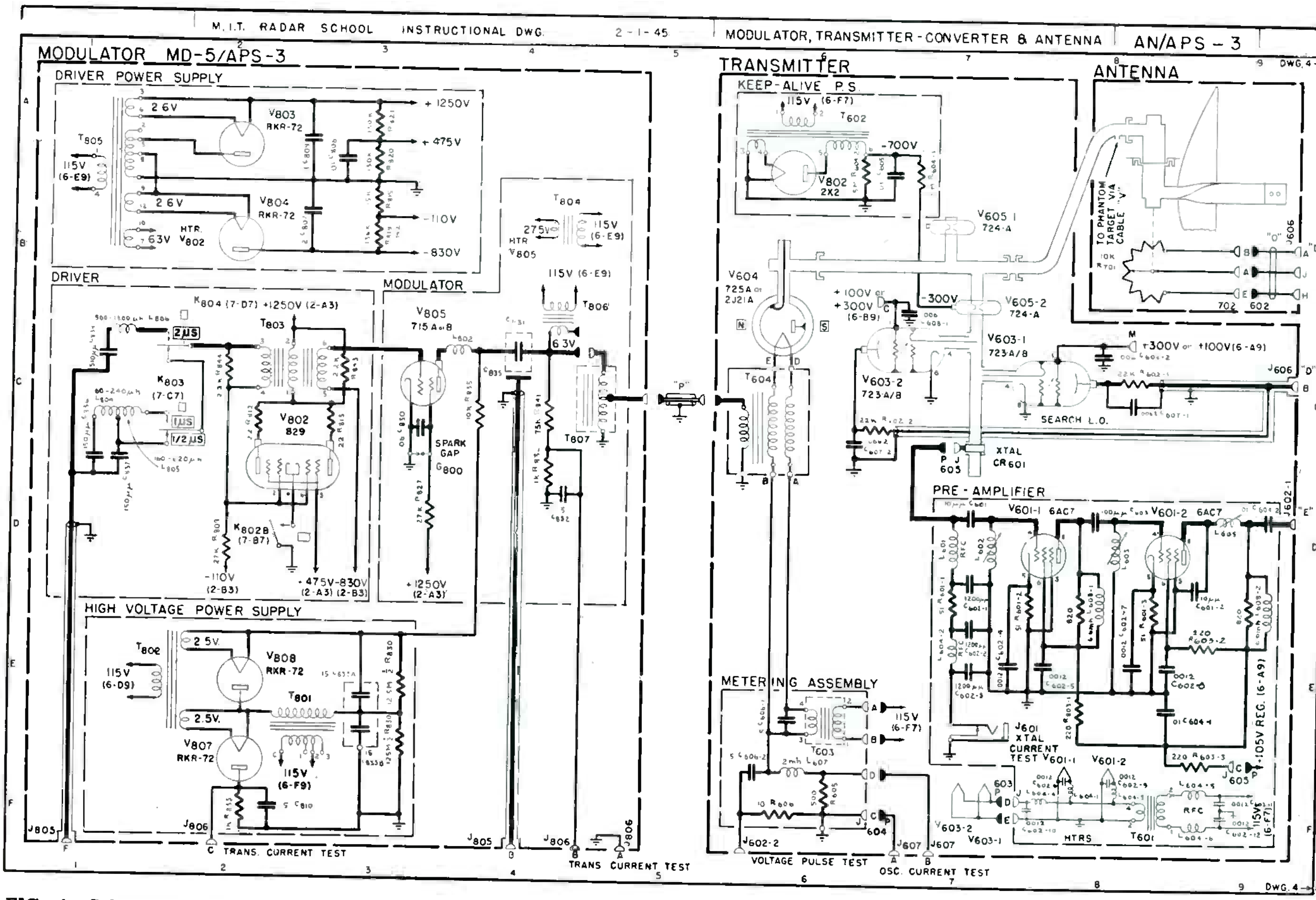

FIG. 4—Schematic diagram for upper left quadrant of Fig. 3, as drawn before standardization of symbols by ASA. Use of several weights of letters and lines improves effectiveness and eye appeal, but takes longer to draw

voltage or resistance he might normally expect to encounter in making a measurement at any point.

Designations and Markings

The schematic drawing should carry identification of every resistor, capacitor, tube, and switch. This means a designation (or part) number together with the circuit value or type number. It should make unnecessary the usual frequent and aggravating reference to the parts list.

All pin numbers on all tube sockets should be shown. All jacks, plugs, terminals, fanning strips and cables should carry their designations and actual numbers. All supply voltages should be shown where appropriate.

To eliminate many conventional leads from the drawing, a system of margin coordinates on each numbered page of the drawing makes it practical to show an arrow head on the end of a lead with a simple legend giving the drawing page number and coordinates where the other end of the lead may be picked up. This is used principally for plate supply voltage leads or similar common sources. Thus, in Fig. 4, drawing 2, the screen supply for the modulator tube has the legend + 1,250 V (2-A3). The 2 refers to the drawing sheet and A3 are the coordinates on drawing 2 where the screen supply source will be found.

Each control for adjustment, calibration or operation should be marked with the name it actually carries on the panel. This name (abbreviated) is usually enclosed in a box to designate that it is so marked.

It is desirable to designate by simple, appropriate symbols whether it is a screw-driver adjustment or a knob and whether it is accessible from the front panel or is within the chassis. Although the drawing examples printed herewith do not show the latter features, extensive and very helpful use was made of such designations in later drawings.

The several weights of letters and lines shown in the accompany-illustrations are the minimum found effective in providing the desired emphasis of flow and subordination of detail.

In the large amount of work done on drawings of this kind it has proved most satisfactory to standardize on 17" x 22" tracing cloth sheets for original ink drawings. This is a convenient scale for the draftsman and reduces to 8½" x 11" individual sheets in a 2 to 1 reduction. The examples shown here suffer unavoidably from a reduction somewhat more than this.

The authors wish to acknowledge the inestimable contributions of Richard L. Bliss of the MIT School of Architecture, who learned electronics for the sole purpose of producing the drawings described above and who wrestled with the fatiguing routines of countless redrawings to produce truly engineered schematics.