MEMO
COMMUNICATIONS
CONTROL - GUIDANCE - TELEMETRY

To provide the Astronuclear Laboratory personnel with a background for understanding the newer fields of digital systems, data-processing systems, pulse communications and telemetering, a brief lecture was given on March 30, 1962 and was supplemented by WANL-TR-156, R. A. Clark, et al. It was requested that the lecture notes also be published to be available as a reference.

The purpose of these notes is to provide a description of some basic type circuits and techniques which are common to the field. It begins with basic descriptions and works up to complete systems. The notes will be published in separate sections whenever time allows complete write-up.

The notes are a compilation of information and material gathered through contact with radio guidance systems, inertial guidance systems, and telemetry systems used for guided missiles plus information garnered from various texts.

L. B. Wilker

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

INTRODUCTION TO BINARY

VOLUME I, SECTION 1

INTRODUCTION

The following block diagram shows a simple method used for transmitting intelligence from the ground to a vehicle in space. Starting with the Binary system, we'll attempt to work our way up to the vehicle in space and then show how information is relayed back to the ground from the space vehicle.

The development of more elaborate command-signal techniques brought about the arrangement whereby the r-f carrier is modulated by pulsed signals. The bistable multivibrator finds extensive application in pulse circuitry as well as in the performance of digital operations.

A bistable multivibrator is a two tube (see figure 1) or transistor circuit which can exist indefinitely in either of two stable states and can be caused to make an abrupt transition from one state to the other. (For this discussion we will deal with tube circuitry except where otherwise noted. If enough requests for transistor circuitry are received and time allows, perhaps Volume II may be written using transistor circuitry.)

Fig. 1

Initially, tube V1 is conducting (on) and tube V2 is cutoff (off). While conducting, V1 has a low plate voltage (negative) and V2 being cutoff has a relatively high plate voltage (positive). A trigger input changes the state of the multivibrator. (The reverse could be true if initially V1 is cutoff and V2 is conducting.) This condition is easily applied to a Binary system and therefore the bistable multivibrator is known as a "binary or a "flip-flop" circuit.

BINARY MATHEMATICS

Volume I, Section 1, presents a brief discussion of binary mathematics before delving into binary applications in order to familiarize the readers with binary terminology and solutions used in communication networks.

The general formula for any number system is: $Z (S^n) + \dots + C (S^2) + B (S) + A (S^0)$ where S is equal to the base and $A, B, C, \dots, Z$ is equal to some constant (K) where (K) is less than (S). Thus in our decimal system - S is equal to 10 and (K) is less than 10. Therefore, when writing our decimal numbers, we use the formula as above, without realizing its meaning. Thus the number 1695 in reality has the meaning:

$$\begin{array}{rcccccl} 1 (10^3) & + & 6 (10^2) & + & 9 (10) & + & 5 (10^0) \\ 1000 & + & 600 & + & 90 & + & 5 & = & 1695 \end{array}$$

In the binary system - S is always equal to 2 and (K) is less than 2 so only two numerals 0 and 1 are required to represent a number.

$1(2^{10}) + 1(2^9) + 0(2^8) + 1(2^7) + 0(2^6) + 0(2^5) + 1(2^4) + 1(2^3) + 1(2^2) + 1(2^1) + 1(2^0)$
 $1024 + 512 + 0 + 128 + 0 + 0 + 16 + 8 + 4 + 2 + 1$
 is equal to ~~\$~~695 but represented in the binary system as 1 1 0 1 0 0 1 1 1 1 1.

In binary mathematics we apply the states of the multivibrator to mathematics. The various states that exist in the plates of the tubes of the multivibrator can be read and used in addition, subtraction, multiplication, division and square root.

Definitions (usual):

- Binary - characterized by two things or two parts
- Radix - the number of digit symbols employed in a number system (S)
- Digit - a single symbol representing an integral quantity.
- Number - a quantity represented by a group of digits
- Binary state (1) - Tube cutoff, plate voltage up (0 volts)
- Binary state (0) - Tube conducting, plate Voltage down (-30 volts)

CONVERSION

A. Binary to Decimal:

A binary number can be converted into decimal form by using the powers of two method. Therefore, for this conversion we merely add the powers of two for each binary digit from the least to the most significant figure.

Example: 1 0 0 1*

$$\text{Decimal} = 1 \times 2^0 + 0 \times 2^1 + 0 \times 2^2 + 1 \times 2^3 = 9$$

*Usually written as least significant digit (LSD) as in the decimal systems.

B. Decimal to Binary:

In order to convert a decimal to a binary we merely divide the decimal by the highest power of two which will not exceed its value.

Example: 182

$$\begin{array}{rcl}
 2^7 & = & 128 \\
 & & \underline{54} \\
 2^5 & = & 32 \\
 & & \underline{22} \\
 2^4 & = & 16 \\
 & & \underline{6} \\
 2^2 & = & 4 \\
 & & \underline{2} \\
 2^1 & = & 2 \\
 & & \underline{0}
 \end{array}
 \quad = 10110110$$

C. Becimal to Fractions:

What the decimal point is to the decimals the becimal is to binarys. The hyphen(-) is the commonly used symbol for the becimal. The numerator of the fraction is found with the same method as used above in (A). The denominator is equal to 2^n , where n is the number of binary digits. We convert the whole number first and then convert the fraction.

Examples:

$$-1011^* = \frac{11}{16} \quad -0101^* = \frac{5}{16} \quad 1-10101^*0 = 1\frac{21}{32}$$

One can see that to convert from fractions to becimal is just the reverse process. (*equals LSD)

D. Binary Algebra:

1) Binary Addition

$$1 + 1 = 0 \text{ and remainder of } 1 = 10$$

$$1 + 0 = 1 \text{ and remainder of } 0$$

$$0 + 0 = 0 \text{ and remainder of } 0$$

Examples:

1 1 0 1 (13)	(1) (1) (1) (1)	1 1 0 1 - 0 1 0 (13-1/4)
+ 0 1 1 0 (6)		+ 0 1 0 1 - 1 1 0 (5-3/4)
1 0 0 1 1 (19)		1 0 0 1 1 - 0 0 0 (19)

2) Binary Subtraction:

$$1 - 1 = 0 \text{ and borrow } 0$$

$$1 - 0 = 1 \text{ and borrow } 0$$

$$0 - 0 = 0 \text{ and borrow } 0$$

$$0 - 1 = 1 \text{ and borrow } 1$$

Examples:

1 1 0 1 (13)	1 1 0 1 - 0 1 0 (13-1/4)
(-) 0 0 1 0 (2)	(-) 0 1 0 1 - 1 1 0 (5-3/4)
1 0 1 1 (11)	0 1 1 1 - 1 0 0 (7-1/2)

Negative Balance:

When the subtrahend is larger than the minuend the difference will be negative. This process generates an "end-around-borrow". In end-around-borrow procedures, the answer will always be in ones (1's) complement which is analogous to 10's complement. To convert 1's complement to its true representation we simply invert 1's complement: for example:

$$1's \text{ complement} = 1 1 0 0 1 1 0 1$$

$$\text{True no.} = 0 0 1 1 0 0 1 0$$

(To convert to true number - change all 1's to 0's and all 0's to 1's.)

Example:

$$\begin{array}{r}
 \text{Minuend:} \quad 011101 \quad (29) \\
 \text{Subtrahend:} \quad (-) \underline{100101} \quad (37) \\
 \hline
 111000 \quad (-8) \\
 \\
 \text{End-around-borrow} \quad \underline{\quad (-) \quad 1 \quad} \\
 110111 \quad (1's \text{ complement})
 \end{array}$$

The answer obtained is 1's complement. Converting to true number =
 $001000 = -8$. When adding a negative balance to another number we generate an "end-around-carry".

Example:

$$\begin{array}{r}
 \text{Augend:} \quad -110111 \quad (1's \text{ complement of } -8) \\
 + \underline{100101} \quad (37) \\
 \hline
 011100 \\
 \\
 \text{End-around-carry} \quad \underline{\quad + \quad 1 \quad} \\
 011101 \quad (\text{true sum} \quad 29)
 \end{array}$$

3. Binary Multiplication:

$$1 \times 1 = 1$$

$$0 \times 1 = 0$$

$$0 \times 0 = 0$$

Examples:

$$\begin{array}{r}
 1111 \quad (15) \\
 \underline{1001 \quad (9)} \\
 1111 \\
 0000 \\
 0000 \\
 \underline{1111} \\
 10000111 \quad (135)
 \end{array}$$

4) Binary Division:

$$1 \div 1 = 1$$

$$1 \div 0 = 0$$

$$0 \div 1 = 0$$

Example:

$$\begin{array}{r} 101 \\ 101 \overline{) 11011} \\ \underline{101} \\ 00111 \\ \underline{101} \\ 10 \end{array}$$

$$\text{Ans. } 101 \frac{10}{101} \text{ (Binary)}$$

10 Remainder

5) Binary Square Roots:

The binary square root is very similar to decimal and an example of both is given for review:

$$\begin{array}{r} 396 \\ \sqrt{157524} \\ 9 \\ 69 \overline{) 675} \\ \underline{621} \\ 5424 \\ 786 \overline{) 5424} \\ \underline{4716} \\ 708 \text{ Rem.} \end{array}$$

The binarys are brought down in pairs both to the left and right of the bicimal.

The quotient can be doubled by merely adding a "0" to the least significant side.

$$\begin{array}{r} 11 \\ \sqrt{1001} \\ 1 \\ 101 \overline{) 0101} \\ \underline{101} \\ 000 \end{array}$$

Binary - Decimal Equivalents:

Decimal Binary No.	B ₀	B ₁	B ₂	B ₃	B ₄	B ₅	B ₆	B ₇	B ₈	B ₉	B ₁₀
Powers of (2)	2 ⁰	2 ¹	2 ²	2 ³	2 ⁴	2 ⁵	2 ⁶	2 ⁷	2 ⁸	2 ⁹	2 ¹⁰
Decimal Count	1	2	4	8	16	32	64	128	256	512	1024

The binary system is used in relation with multivibrators to form binary counters, dividers, subtractors and pulse gates for the indirect measurements of frequency, time, and speed. In the editions to come, we will look at basic binary circuits and see their application in the communication field.

References:

- 1) Millman-Taub, "Pulse and Digital Circuits", McGraw-Hill, 1956.
- 2) McCracken-Weiss-Lee, "Programming Business Computers", Wiley, 1959.
- 3) Richards, "Arithmetic Operations in Digital Computers".