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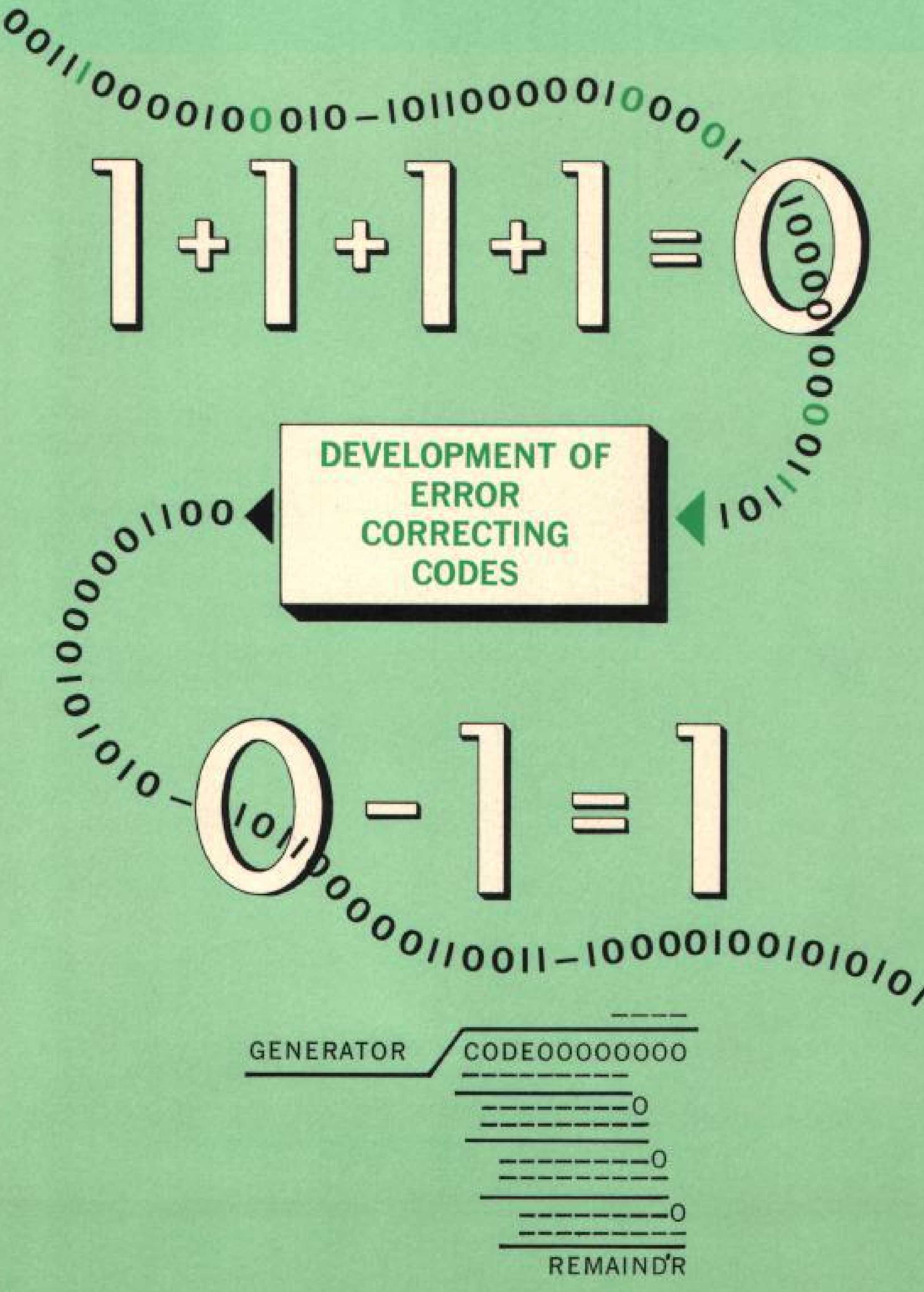
DEVELOPMENT OF ERROR CORRECTING CODES



THE WESTERN UNION TECHNICAL REVIEW

Cover: Patterns used in Error Detecting Codes

presents developments in Voice and Record Communications for the Western Union's Supervisory, Maintenance and Engineering Personnel.

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FOUNDATION for FUTURE

To the Readers of
The Western Union Technical Review

We have just completed a year in which the foundation has been provided for a great future.

The expansion of AUTODIN and Telex, the completion of the design and start of production and installation of equipment for the initial phases of the Advanced Record System for G.S.A., the first sales of commercial computerized switching and data processing systems, the introduction of our Broadband Exchange Service, the starting of our Private Message Service modernization program, along with the inauguration of our transcontinental Microwave System are testimony to the sound foundation laid this year in the telecommunications field.

The accomplishments have been documented, in part, in the Western Union TECHNICAL REVIEW. *Through our technical publication we share our technical knowledge with other companies and government agencies who buy and use our services.*

TELECOMMUNICATIONS

These milestones have been possible only because of the capabilities of our people and the engineering developments of our organization.

With creative, cooperative, diligent effort on the part of all of us we can take a great step forward in 1965.

Best wishes for a happy and prosperous New Year.

PRESIDENT

Steeneck, R., Data Systems Engineer—Data Sys. Div.—Plant and Engineering Dept.

Development of Error Correcting Codes

Part II—Multiple-Bit Error Correcting Codes

Although Modulo 2 arithmetic may appear to have few applications in everyday problems, it is considered a most useful tool in the development of codes which correct more than one-bit errors.[1]

Modulo 2 Division

Through the use of Modulo 2 division whole families of multiple-bit, error-correcting codes can be developed. The process of development is shown in Figure 8. In this illustration the code number to be protected is first written as a series of 1's and 0's, (CODE) followed by a number of zeros. The number of zeros is one less than the number of digits in a carefully preselected generator (GENERATOR) or divisor. The generator is then divided into the code number and its added zeros by means of Modulo 2 division.

The remainder (REMAIND'R) is the generated check information, and is in practice, transmitted as shown following the code bits. If the received combination of code and check bits is divided evenly (Modulo 2) by the generator, the remainder will indicate no errors are present, if there are no 1's in the remainder. However, the presence of a "1" in the remainder will indicate at least one bit is in error. If the code generator number has been properly selected the pattern of the 1's in the remainder can pinpoint the location of the bits which are in error.

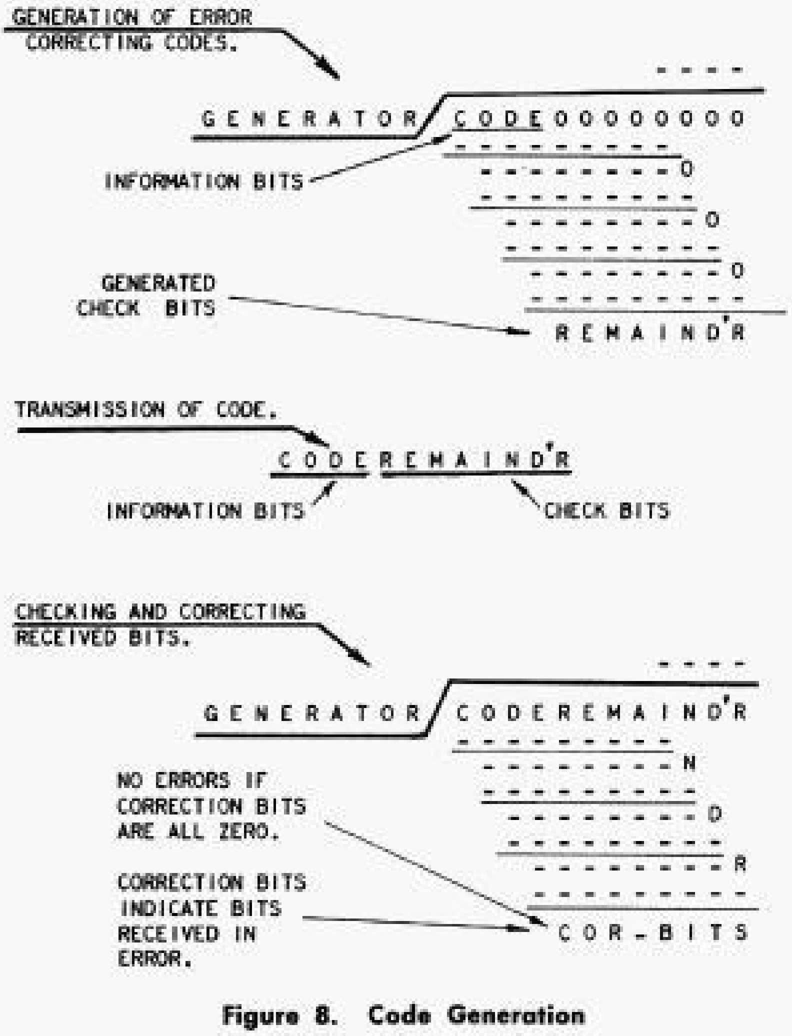

Figure 8. Code Generation

Generator Selection

In establishing a code of this type the first problem is to select a generator. It is quite obvious that a number, such as 1000 000, is not suitable, because this number will divide evenly into all numbers which end in 6 zeros and thus no check remainders can be obtained for any particular combination of code bits ahead of the 6 zeros.

The mathematical solution to the problem requires that "Irreducible Polynomials" be used as generators. Since the codes being considered are in binary form, an "irreducible polynomial" may be considered as a binary number which cannot be divided evenly by any number other than itself and one;[2] in other words —a binary prime number. However, the irreducible polynomials to be used, do not become the common prime numbers used in arithmetic; they are the numbers which are prime with respect to Modulo 2 arithmetic.

Modulo 2 Prime Numbers

"Modulo 2 prime" numbers may be derived by first writing all numbers in sequence and then crossing out those that can be evenly divided, (Modulo 2), by any smaller number. Those that remain are considered "Modulo 2 prime" numbers. A table containing all Modulo 2 prime numbers (Irreducible Polynomials), up to and including those 20 digits in length, may be obtained from the Department of Commerce.[2]

Figure 9 tabulates all Modulo 2 prime numbers up to 9 digits in length. In comparing Modulo 2 prime numbers with binary prime numbers in this table, it may be noted that many binary prime numbers are also prime in Modulo 2, as shown in the Columns 1 & 2 and Columns 3 and 4. However there are occasional deviations in both directions as may be seen by further examining this table.

Although ordinary prime numbers in general seem to resist attempts at mathematical proofs, this is not the case when working with Modulo 2 prime numbers. It is possible, for instance, to prove that each Modulo 2 prime number, when written in the reverse order of its digits, developes a Modulo 2 prime number. This is quite useful in checking the pattern of a Modulo 2 prime table, where every number must have a reverse-order twin.

BINARY PRIME	MOD.2 PRIME	BINARY PRIME	MOD.2 PRIME	MOD.2 PRIME	MOD.2 PRIME	MOD.2 PRIME
01	01	111011	111011	10000011	100011011	110100011
10	10	111101	111101	10001001	100011101	110101001
11	11	1000011	1000011	10001111	100101011	110110001
101	---	1000111	-------	10010001	100101101	110111101
111	111	1001001	1001001	10011101	100111001	111000011
1011	1011	1001111	-------	10100111	100111111	111001111
1101	1101	1010011	-------	10101011	101001101	111010111
10001	-----	-------	1010111	10111001	101011111	111011101
10011	10011	1111001	-------	10111111	101100011	111100111
10111	-----	-------	1011011	11000001	101100101	111110011
-----	11001	1100001	1100001	11001011	101101001	111110101
11101	-----	1100101	-------	11001111	101110001	111111001
11111	11111	1100111	1100111	11010011	101110111	
100101	100101	1101011	-------	11100101	101111011	
101001	101001	1101101	1101101	11101111	110000111	
101011	------	-------	1110011	11110001	110001011	
101111	101111	-------	1110101	11110111	110001101	
------	110111	1111111	-------	11111101	110011111	

Figure 9. Table of Binary Prime Numbers (7 Places) and Modulo 2 Prime Numbers (9 Places)

Remainder Analysis

The remainders in Modulo 2 division which provide the code protection bits, shown in Figure 8, can also be mathematically analysed to great advantage. In Figure 10 the problem in division, previously illustrated in Figure 7, in Part 1, of this article, has been restated and then broken down into 8 sub-problems in Modulo 2 division, each of which concerns one digit of the dividend. It will be noted that the final remainder, 1001, is equal to the Modulo 2 sum of all 8 sub-remainders. This breakdown is most useful in examining the error correcting possibilities of various generated codes.

It is quite obvious that the divisor, 11101, shown in Figure 10, would not serve as a generator of an error correcting code, because both sub-remainders of the first and eight digits are the same and therefore contribute the same numerical value to the final remainder. Thus, an error in either of these digits would alter the final remainder by the same amount and thus make the location of the error impossible to detect.

NUMBER				QUOTIENT	REMAINDER
11 011 011	DIVIDED BY →	11 101	EQUALS →	1 010	1 001
COMPONENTS OF NUMBER			COMPONENTS OF QUOTIENT		COMPONENTS OF REMAINDER
1	÷	11 101	=	0	1
10	÷	11 101	=	0	10
---		-- ---		-	-
1 000	÷	11 101	=	0	1 000
10 000	÷	11 101	=	1	1 101
--- ---		-- ---		-	-
1 000 000	÷	11 101	=	110	1 110
10 000 000	÷	11 101	=	1 101	1
11 011 011	← MODULO 2 SUMS OF COMPONENTS →			1 010	→ 1 001

Figure 10. Breakdown of Modulo 2 Division

MODULO 2 PRIME DIVISORS → 11 001 · 10 011 · 11 111

SUB - REMAINDERS

COMPONENTS OF ANY 15 DIGIT NUMBER	11 001	10 011	11 111
1	1	1	1
10	10	10	10
100	100	100	100
1 000	1 000	1 000	1 000
10 000	1 001	11	1 111
100 000	1 011	110	1
1 000 000	1 111	1 100	10
10 000 000	111	1 011	100
100 000 000	1 110	101	1 000
1 000 000 000	101	1 010	1 111
10 000 000 000	1 010	111	1
100 000 000 000	1 101	1 110	10
1 000 000 000 000	11	1 111	100
10 000 000 000 000	110	1 101	1 000
100 000 000 000 000	1 100	1 001	1 111

ALL BINARY NUMBERS FROM 0001 TO 1111

3 REPEAT CYCLES

Figure 11. Code Generation for 1-Bit Error Correction

Before considering multi-bit error correcting codes, however, it might be well to first show how a simple, one-bit error correcting code can be developed by using the Remainder Process. Both the Bosé-Chaudhuri solution and the Hamming solution indicate that four protection bits are needed to establish a one-bit error correcting code containing 11 information bits; a total of 15 bits, in the code block. This requires the use of a 5 digit generator. Figure 9 shows only three Modulo 2 prime numbers containing 5 digits. These are 11001, 10011, and 11111.

Figure 11 tabulates the sub-remainders that each of these Modulo 2 prime numbers generate from all possible components of any 15-digit number. From this table it is quite apparent that with the first two prime numbers, 11001 and 10011, each component digit of the 15 digits contributes a separate and distinctly individual remainder. All possible binary sub-remainders from 0001 to 1111 are present; there are no duplicates. Any single bit in error will thus produce a remainder that can be used to identify the location of the error. In effect this is essentially the Hamming Code, which was described in Part 1 of this article, but generated in an entirely different way.

The third Modulo 2 prime number, 11111, produces no such run of binary sub-remainders. The sub-remainders repeat themselves in three cycles of only 5 steps each. Therefore, this number cannot be used as a code generator. In fact all Modulo 2 prime numbers consisting of only 1's are unsatisfactory generators because they all end their cycle of remainders too soon to be useful for this purpose.

It will be noted that above the dotted line in Figure 11, the same pattern of sub-remainders appears regardless of the generator used. These identical patterns can be quite useful in correcting errors as will be shown later in this article.

Multi-Bit Error Correcting Codes

Codes that correct more than one errored bit, in a code block, can be generated in the same manner as illustrated in Figure 11. More protection bits will be needed, however, since more error combinations are possible.

Figure 12 lists the number of different error combinations that are possible in various code block lengths from one to 32 bits in length. The numbers shown are identical with those in Pascal's triangle of binomial coefficients often used in the solutions to probability problems. Figure 12, however, indicates the magnitude of the steps that must be taken in going from one-bit to two-bit error correcting codes. In a code block of 15 bits for instance, there are only 15 one-bit errors possible. If errors involving two bits are considered, there are 105 combinations possible. When longer code blocks are considered, the increases are even greater.

CODE BLOCK LENGTH (BITS)	POSSIBLE ERROR COMBINATIONS: 1 BIT ERRORS	2 BIT ERRORS	3 BIT ERRORS	CODE BLOCK LENGTH (BITS)	POSSIBLE ERROR COMBINATIONS: 1 BIT ERRORS	2 BIT ERRORS	3 BIT ERRORS
1	1	-	-	17	17	136	680
2	2	1	-	18	18	153	816
3	3	3	1	19	19	171	969
4	4	6	4	20	20	190	1140
5	5	10	10	21	21	210	1330
6	6	15	20	22	22	231	1540
7	7	21	35	23	23	253	1771
8	8	28	56	24	24	276	2024
9	9	36	84	25	25	300	2300
10	10	45	120	26	26	325	2600
11	11	55	165	27	27	351	2925
12	12	66	220	28	28	378	3276
13	13	78	286	29	29	406	3654
14	14	91	364	30	30	435	4060
15	15	105	455	31	31	465	4495
16	16	120	560	32	32	496	4960

Figure 12. Table of Possible Error Corrections for Code Blocks 1 to 32 Bits Long

To provide two-bit error correction according to the Bosé-Chaudhuri solution shown in Table 9.1 in "Error Correcting Codes" by W. W. Peterson, a block of 15 bits will require that 8 bits be assigned to protect the remaining 7 bits.[3] By referring to Figure 8 it is obvious that in order to generate 8-bit remainders, the generator has to be 9 bits in length. From Figure 9 it may be seen that 30 Modulo 2 primes, 9-bits long, are available. There are 28 reverse digit twins, such as 100011011 and 110110001, and 2 that are symmetrical, such as 100111001 which reads the same in both directions and is in effect its own reverse order twin.

In Figure 13, two non-symmetrical and one symmetrical 9-digit Modulo 2 prime numbers are analysed to determine their suitability for use as 2-bit error correcting code generators. The first two are not suited as generators because in each case, there are at least two pairs of sub-remainders generated whose Modulo 2 sums match each other. This means that with the use of each generator there are at least two possible two-bit error combinations that produce identical remainders which consequently are of no use as error correcting information.

This however, is not true of the third prime number, 100111001. In this case no one-bit error or two-bit error pattern will produce a check remainder that matches that of any other one or two-bit error. The Modulo 2 prime number, 100111001, is thus satisfactory for use as a generator for a 2-bit error correcting code, 15 bits in length.

It is interesting to note that the second symmetrical 9-digit Modulo 2 prime, 111010111, can also serve as a generator. Both symmetrical primes complete their cycle of sub-remainder components in 17 steps. All other 9-digit Modulo 2 primes require 255 steps.

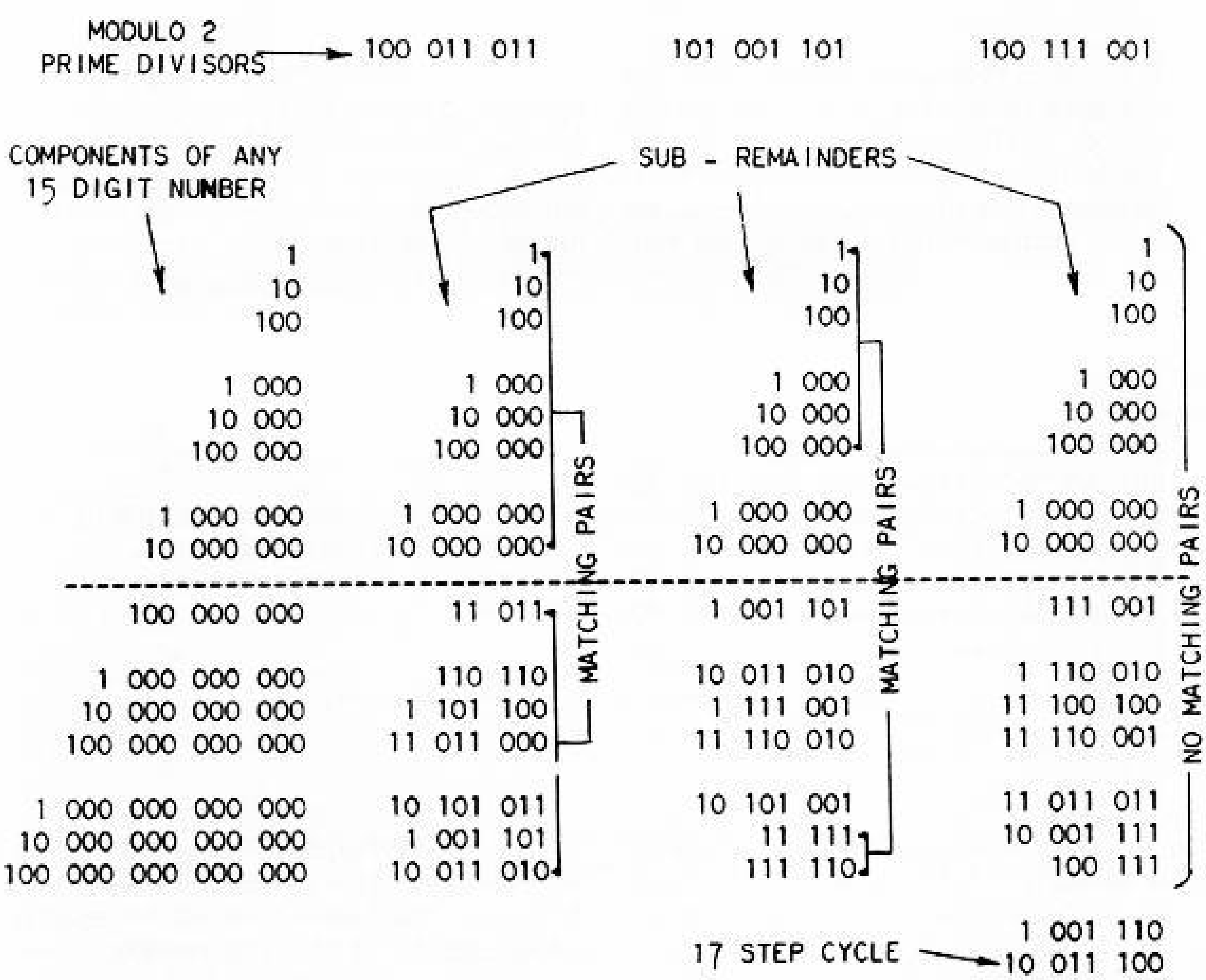

Figure 13. Code Generation for 2-Bit Correction

Error Detection and Correction

Errors are detected by dividing the code block by the generator (Modulo 2). If no errors are present, the remainder will be all zeros as shown in Figure 14. The presence of 1's in the remainder indicates that at least 1 bit is in error.

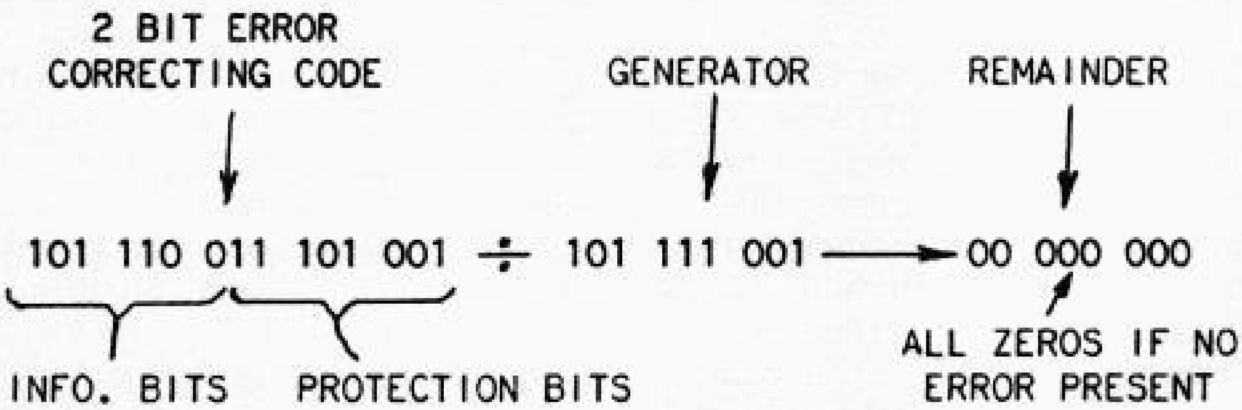

Figure 14. Method of Detecting Errors

If no more than 2 bits are in error, the errors may be located in at least one of two ways. In the first method a table may be made of the 120 different possible combinations of 1- and 2-bit error remainders and the locations of the faulty bits producing these remainders. Figure 15 shows part of such a table in which the locations of the errored bits, responsible for a particular remainder, are shown as a number with 1's marking their locations. If the error location number, as found from this table, be added (Modulo 2) to the original errored information, correct information will be obtained.

Whenever check remainders appear that are not listed in the table, the character is rejected as being beyond the correcting capabilities of the code.

In the second method, it is possible to find the errored bits by using one of the peculiar properties of Modulo 2 division. It can be proven that any binary number, which can divide evenly into a second number, will also divide evenly if the digits of both numbers are written in reverse order. Use of this can definitely determine the location of all 15 one-bit errors and 56 of the 105 two-bit errors possible in a 15-bit code block.

REMAINDERS		ERROR LOCATION NUMBERS
-- --- ---	--------	-- --- ---
10 000 111	--------	01 001 000
10 001 011	--------	01 000 100
10 001 101	--------	01 000 010
10 001 110	--------	01 000 001
10 001 111	--------	01 000 000
-- --- ---	--------	-- --- ---

TO CORRECT ERRORED BITS ADD ERROR LOCATION NUMBER TO ERRORED INFORMATION MOD.2

Figure 15. Error Correction Through Stored Remainders

Figure 16 shows that when both errors are located in either the first or the last 8 digits, and the check division is performed twice, (the second time with both digit orders reversed), one of the two check remainders will have a maximum of two 1's in its digital structure. The 1's will appear directly under the errored bits

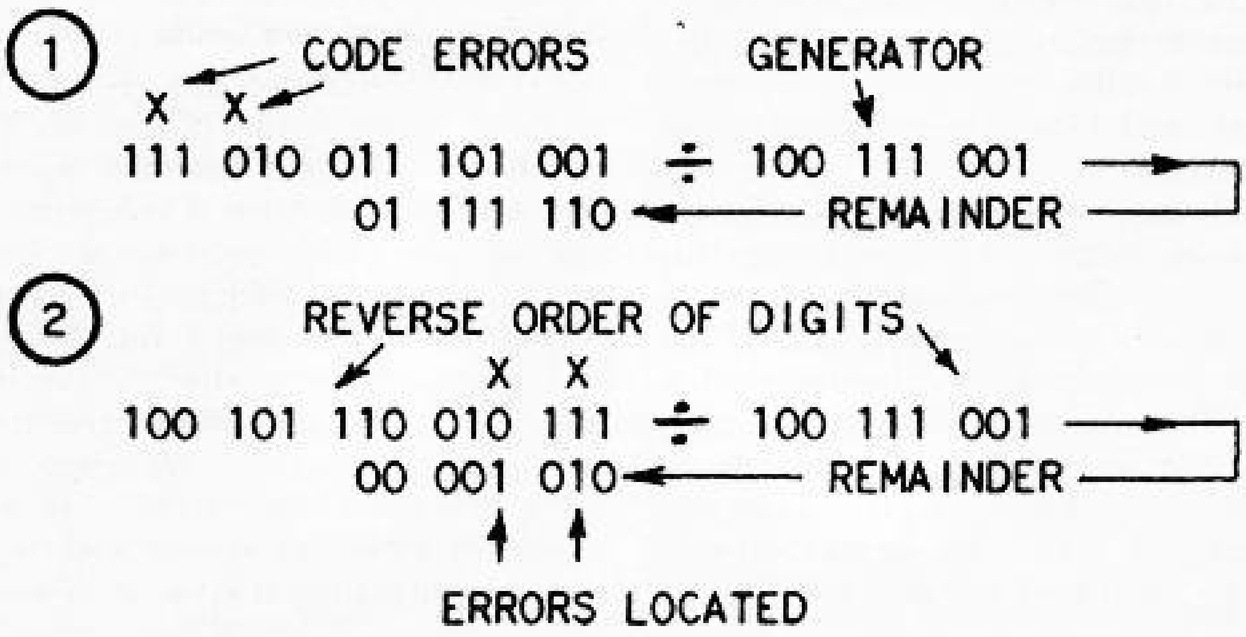

Figure 16. Two-Step Process of Check Division

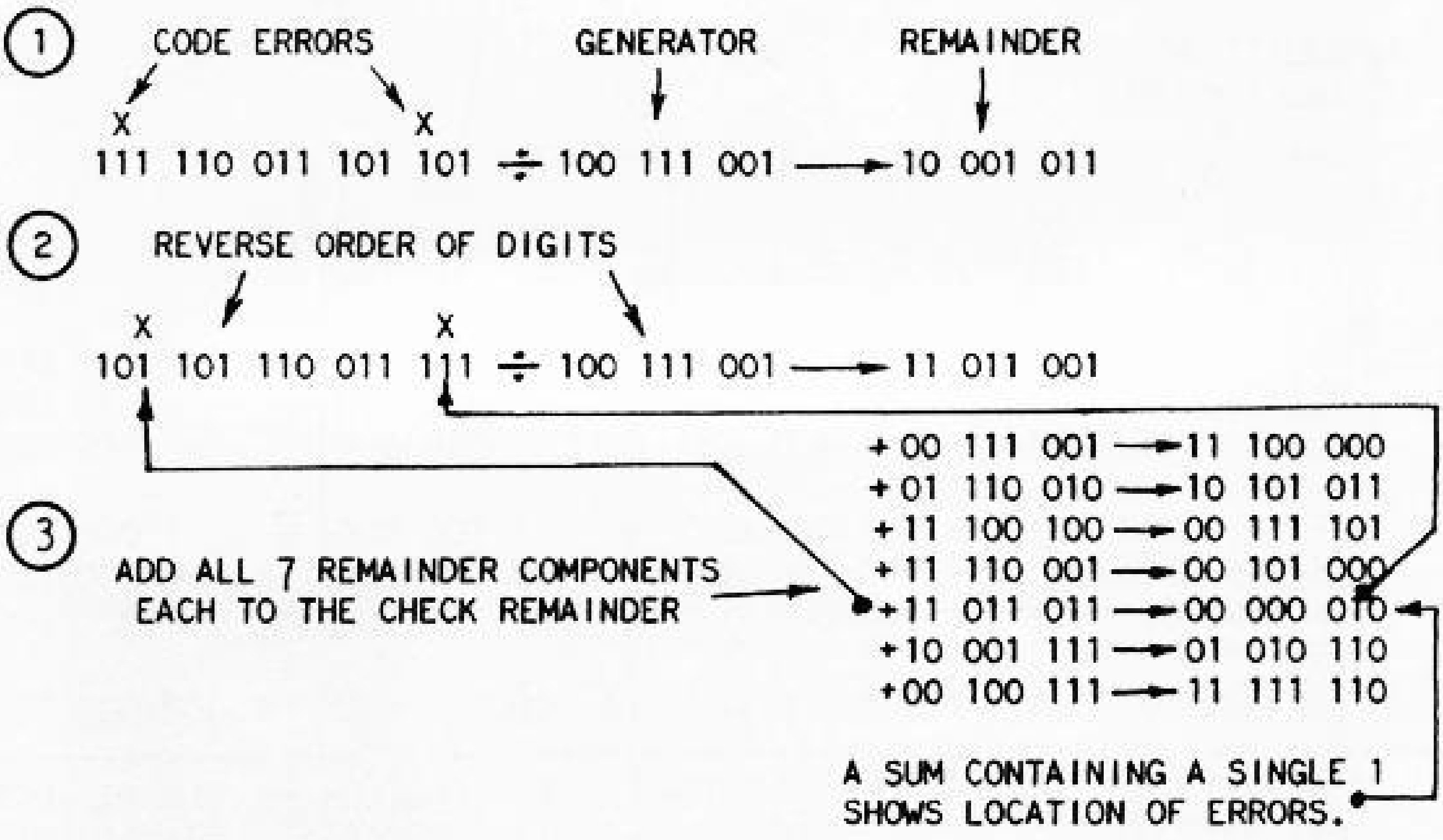

Figure 17. Three-Step Process of Check Division

so that a Modulo 2 addition can produce correction. If neither regular nor reverse order division produces a remainder having one or two 1's in its digital structure, one of two conditions may be present. Either the two errored bits may be located, one in the first 8 bits and the other in the last 8 bits—or there may be more than 2 errored bits present and no correction is possible.

A third step, shown in Figure 17, will indicate the condition present. In this step each of the last 7 sub-remainder components, shown in Figure 13, is individually added (Modulo 2) to the remainder. If one of these seven sums contains only a single "1" in its digital structure, it will appear in location directly under one of the errored bits. The second errored bit will be indicated by the level of the sub-remainder that produced the sum containing the single "1." If none of these additions produce such a sum, more than two bits are in error and no correction is possible.

3-Bit Error Correcting Codes

Error correcting codes are not limited to 2 bit errors alone but as each bit is added the problem becomes more complex and the need for a computer in designing such codes becomes obvious.

A 15-bit code block, for instance is capable of correcting 3 bit errors if 10 bits are used to protect 5 information bits. In such a code structure, however, it is now necessary to recognize 575 error patterns instead of 120, as was the case with a two-bit error correcting code. In designing such a code it is necessary

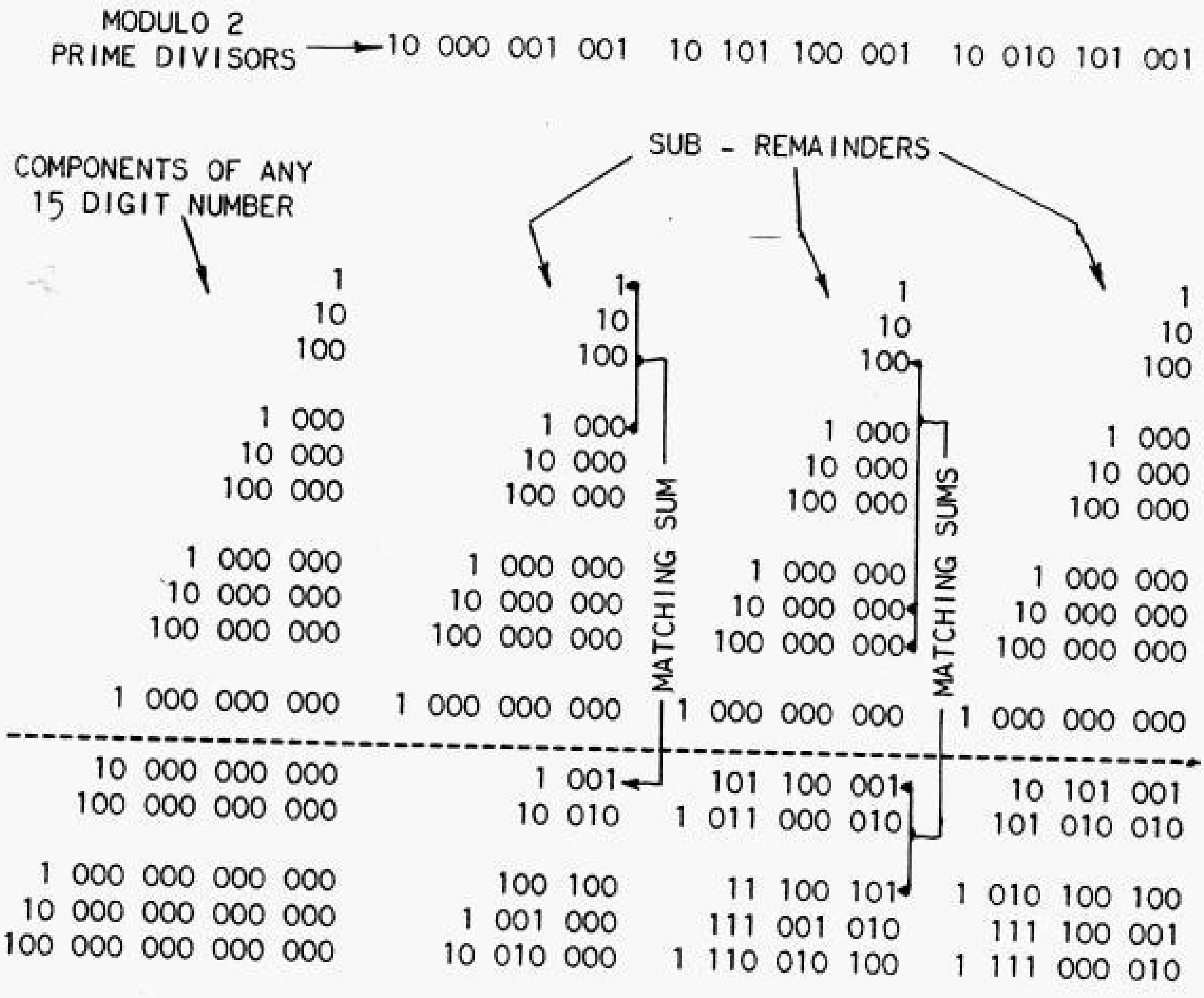

Figure 18. Code Generation for 3-Bit Correction

to use a Modulo 2 prime number containing 11 digits. There are 99 such Modulo 2 prime numbers available.

Figure 18 shows how three numbers function as generators. These numbers are 10,000,001,001 and 10,101,100,001 and 10,010,101,001. It is quite obvious that the first number 10,000,001,001 would not function at all because the subremainder components of every bit below the dotted line can be duplicated by two remainder components above the dotted line. It would thus be impossible to distinguish between a single-bit error in one end of the code block and a double-bit error at the other end.

The second Modulo 2 prime, 10101100001, when used as generator produces matching remainders between at least one three-bit error and a two-bit error, as can be seen in Figure 18.

The third Modulo 2 prime, 10010101001, seems to be clear of such matching remainders and if completely analysed, would probably produce a 3-bit error correcting code. This number is symmetrically constructed and reads the same in either direction. This, however, may not be a criterion for selecting a generator.

Limitation of Error-Correcting Codes

Error correcting codes are fascinating in their structure and have been put to excellent use in many applications. Unfortunately they all have their limitation and cannot do any code reconstruction whatsoever during total breaks in communication. Such a condition can only be corrected by a controlled retransmission such as used in EDAC.[4] The use of both systems on a data circuit provides the best possible combination available for efficiently transmitting error-free data.

* * * *

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2. Table of Irreducible Polynominals Over GF (2), Through Degree 19 by Department of Commerce, Office of Technical Service.
3. Error Correcting Codes, W. W. Peterson.
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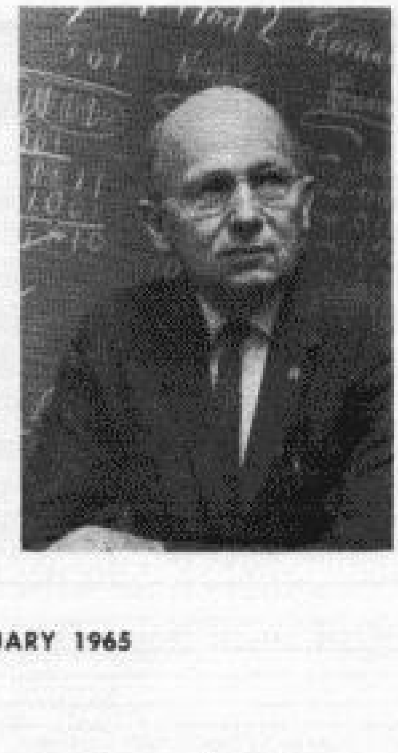


Mr. Robert Steeneck, Data Systems Engineer in the Plant and Engineering Department, has been responsible for the development of error detection and correction devices for data transmission. In his development of Error Detecting Codes he reveals a simple arithmetic method of analysis, design and function not previously disclosed in this complex field. He had a major role in the design of EDAC.

He received his M.E. degree from Stevens Institute of Technology in 1926 after which he joined Western Union as an apparatus engineer. He designed components for the Radar Contact Trainer, one of the first predecessors of analog computers. He later concentrated on the development of automatic switching systems.

Mr. Steeneck received the F.E. d'Humy Award for his achievements in electro-mechanical developments. He holds 22 patents and has written many articles for the Western Union TECHNICAL REVIEW.

G. H. Ridings, Facsimile Engineer—Facsimile Div.—Plant & Engineering Dept.

Facsimile Imaging Systems

Part II

Now to examine some of the optical configurations found in facsimile scanners and recorders. In one arrangement, previously illustrated in Figure 6, Part I, the incident light is perpendicular to the surface of the subject copy and the phototube views the copy at an angle of around 45°. Of course the phototube could view the copy perpendicularly with the incident light at another angle, but this would aggravate one weakness of spot projection, namely, the casting of a shadow at the edges of paste-ons. In any event it is of utmost importance to be sure the angles chosen are such that specular reflections of the incident light are outside the cone of light passed to the phototube. These reflections reduce the contrast between the characters and the background color of the sheet and under ideal light collecting conditions, i.e., where the angle of reflection is equal to the angle of incidence, would cause obliteration of glossy prints or text prepared on highly calendered paper stock.

In the design of spot-projecting lens assemblies passage of scatter light through the aperture is kept to a minimum by stops in the lens barrel and blackening of the walls. The aperture may be square, with one side equal to the width of the scanning line times the magnification of the system, or—it may be round. Occasionally a rectangular aperture with the dimension along the scanning line shorter than the scanning line width is employed but this and other unusual shape of apertures are generally chosen to compensate at least in part for electronic or mechanical deficiencies of the particular scanner. The exact choice of lenses to be used is determined largely by the physical specifications of the scanner but it is desirable to choose an objective with as long a focal length as practicable to avoid defocusing with different thicknesses of subject copy, mechanism eccentricities, etc. It is also desirable where possible to include some magnification so that the aperture will be large enough to fabricate easily.

In drum-type equipments the optical system may be mounted to the base of the machine and the drum which holds the subject copy rotated at a uniform rate while it is caused to slide along its rotating shaft at the same time, as illustrated in Figure 7. Or the drum can be rotated at a fixed position on its shaft and "line feed," as it is called, obtained by causing the optical system to move along tracks parallel to the drum axis. In another configuration, shown in Figure 8, the subject copy is mounted facing inward around a transparent cylinder which does not rotate. Inside the cylinder and on the same axis, a front surface mirror reflects the beam from a spot-projecting lens system so that it focuses on

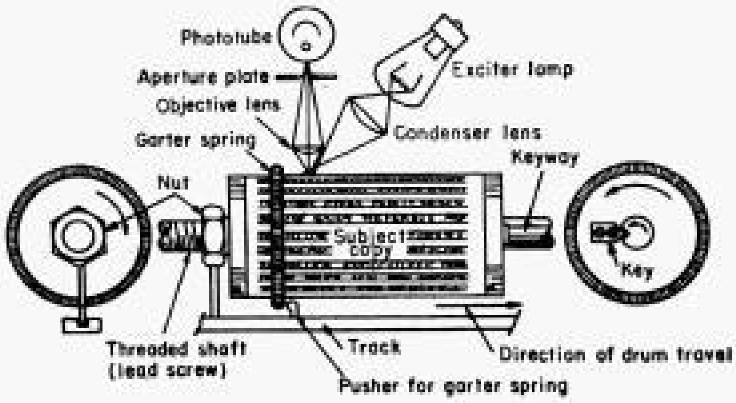


Figure 7. Optical System—Drum Scanner

This is Part II of a paper delivered to the New York Chapter of the Society of Photographic Scientists and Engineers on February 19, 1964 at the Chemist's Club in New York City. Part I appeared in the October 1964 issue of the Western Union TECHNICAL REVIEW.

the outer surface of the transparent cylinder (on the subject copy). The mirror rotates and causes the spot to sweep across the subject copy as the cylinder is caused to move at the line-feed rate along its axis. This same mirror collects the reflected light from the copy and passes it out the same end of the cylinder through a condensing lens to the phototube. Note that the rotary mirror angle is such that specular reflections from the surfaces of the cylinder and the copy are directed back into the cylinder so that they cannot reach the phototube. In this case, instead of a circle of light on the phototube cathode, there is a doughnut of light due to the 45° mirror in the light path.

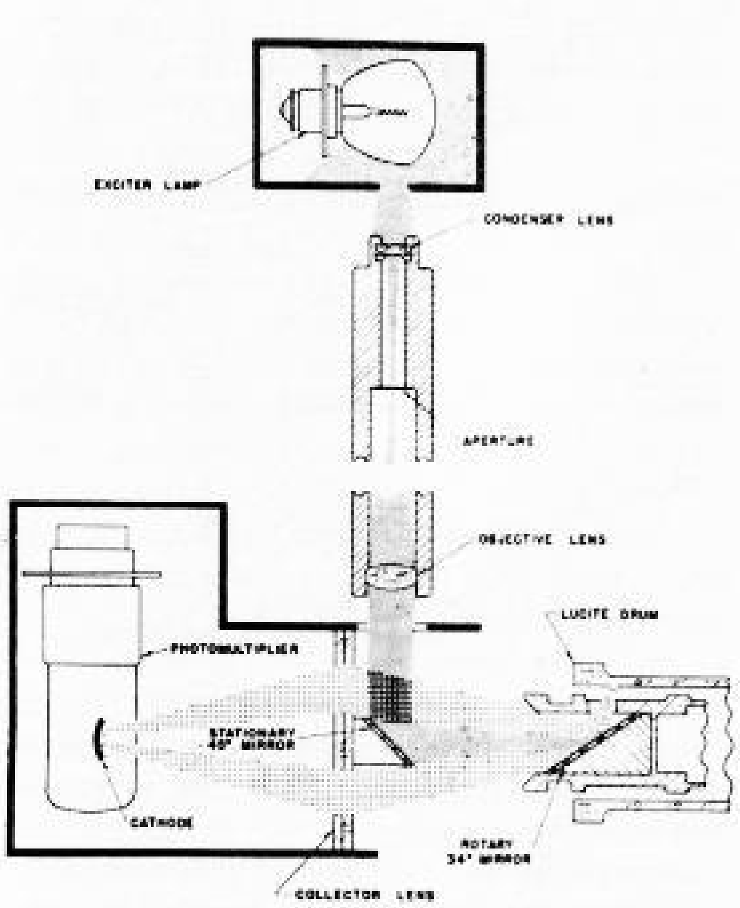


Figure 8. Internal Scanner

Mechanical Flying Spots

To avoid the necessity of manually mounting the subject copy and record sheet on drums or cylinders a number of so-called "flat-bed" scanners and continuous-roll recorders have been devised. The flat-bed scanners can be equipped with a stack-feed so that a large number of sheets of subject copy may be placed in the transmitter and it will transmit them in sequence, operating unattended for long periods. Some of the continuous recorders are arranged to automatically cut off each sheet from the roll as it is recorded and deposit it in a receptacle. In others the received copy is torn off manually or accumulated on a reel. Equipment having these features is usually more costly than simple drum-type equipment and there are inherent degradations in most of these scanning and recording mechanisms which render the quality of the reproduction somewhat inferior to that of drum-type machines. One of the simplest of these flat-bed scanners is the mechanical "flying spot," shown in Figure 9. In this type of scanner the copy lies flat and the light spot is caused to sweep across it from side to side while it is slowly advanced at the line-feed rate by rollers. A typical scanner configuration is seen here. In this arrangement, a front-surface spherical mirror is driven by a cam so that a spot of light from a concentrated arc lamp is caused to sweep at uniform rate across the subject copy. At the end of each sweep, the cam contour changes abruptly and the beam sweeps back across the sheet at a very rapid rate. During this "return-trace" interval the output of the phototube is "blanked." While there is a time loss here, the retrace time can be limited to 5 percent in equipments designed for operation over voice-band channels. Because the percent of lost time due to the retrace increases with speed, this type of scanner is not used at high speeds. A concentrated arc lamp is used in the application shown in Figure 9, but a more conventional spot-projection lens barrel can be used.

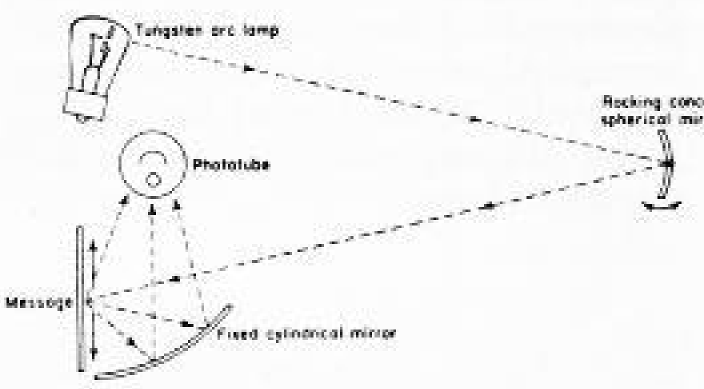


Figure 9. Flat-Bed Flying-Spot Scanner Using Oscillating Mirror

By proper design of the cam contour, uniform motion of the spot along the scanning line is achieved. However, there is a slight change in focus and spot size as it sweeps across the copy due to the longer light path at the edges compared with that in the center. The resulting degradation is minimized by making the light path as long as practicable and by focusing not in the center of the page but about ⅓ the way in from each edge. In one design of a transmitter for business documents, having an 8½ inch scanning line, the defocusing results in an increase in spot size of 5 percent at the center of the scanning line and about 15 percent at the ends. This is tolerable because most documents have borders containing no intelligence and the distortion an inch in from the edges of the document is not much greater than that in the center of the page.

This same scanning principle is used in a flying-spot recorder, shown in Figure 10, which was designed to record radar displays and satellite weather pictures on 3¼ x 4¼ Polaroid film. In this machine, because of the shorter (3¼ inch) scanning line, the sweep angle is smaller and the defocusing is less. Nevertheless, because the recording is on film the line pattern resulting from the varying width of scanning line would be noticeable and objectionable except for the fact that an odd-shaped aperture is used. Both ellipse and trapesoid shapes have been employed with the long dimension perpendicular to the scanning line and providing a tapered overlap or "feathering" of the edges of the scanning lines, thereby masking the line pattern satisfactorily.

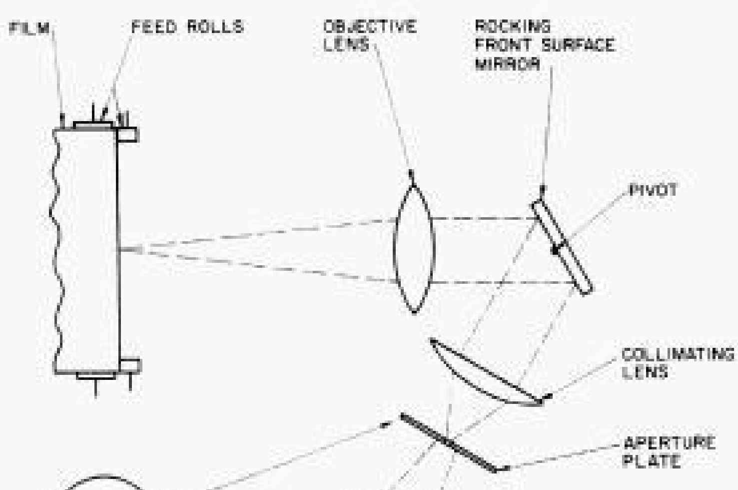


Figure 10. Flying Spot Recorder

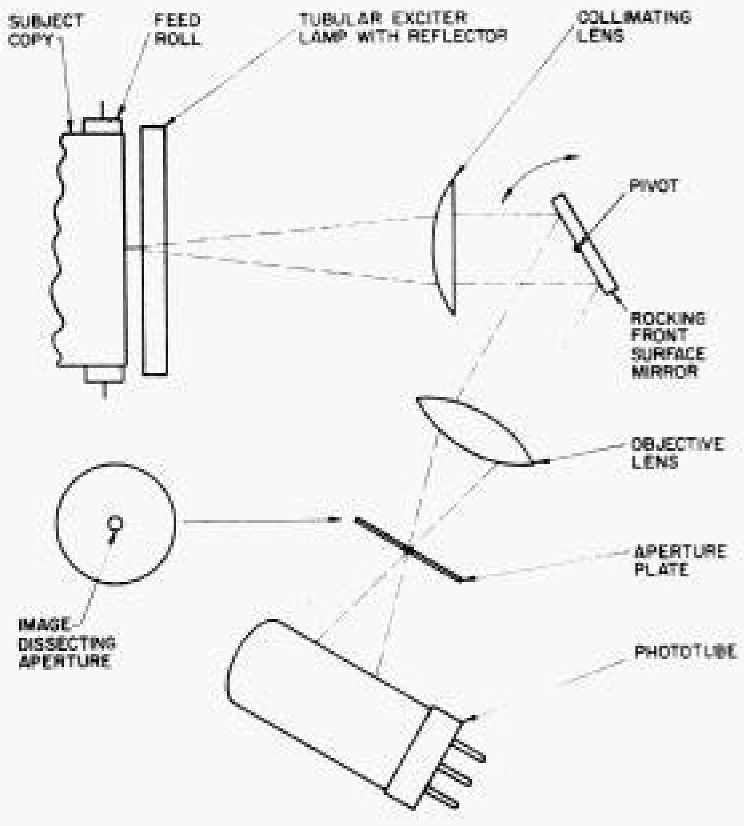


Figure 11. Image-Dissecting Transmitter Oscillating Mirror

This same type of mechanism is employed in an image-dissecting transmitter, shown in Figure 11. In this case, the floodlighted subject copy is fed at the line-feed rate by rollers. An image of the illuminated area of the copy is focused onto an aperture plate and the light passing through the aperture onto the cathode of a phototube. In this case the mirror serves to sweep the image across the aperture and since this is a transmitter, an ordinary square or round aperture is adequate.

Multifaced Mirror

In a typical flying-spot scanner arrangement, shown in Figure 12, a multifaced mirror is rotated to sweep the light spot across the subject copy. Since consecutive scanning lines are formed by different mirror faces, extreme precision is required in fabricating the mirror and its drive mechanism—particularly the gearing. Minute deviations, from absolute flatness of the mirror faces and in the angle each makes with adjoining faces, as well as any eccentricities in the drive, will cause the successive elements, comprising a character, to be displaced horizontally from their correct position. This produces a repetitive pattern of distortion, called "jitter," which shows in the formation of recorded characters.

Here again is a lost-time interval—an interval when the mirror is in such a position that the light beam impinges on two mirror surfaces at the same time. The optical configuration is arranged so that the two light spots so created lie beyond the edges of the subject copy and only one light spot is permitted to sweep across the copy at any one time. The lost-time interval in this case depends largely upon the number of mirror faces and the width of the light spot on these faces; and is not affected by speed. Therefore this arrangement can be used in very high speed systems. It should be noted, that for uniform increments of angular rotation of the mirror, the spot will move farther when it is near the ends of the scanning line than when it is in the center. This is compensated for by the use of a special objective lens having a controlled amount of lateral distortion. Non-linearity of the lens negates that of the mirror; and causes spot speed to be linear. Defocusing is present in this design also and its effects are minimized in the same manner as in the oscillating mirror arrangement.

A number of image-dissector transmitters have been developed utilizing this type of mechanism. In this type of transmitter, shown in Figure 13, a strip of the subject copy is illuminated usually by fluorescent lamps as it is advanced at the line-feed rate by rollers. The objective lens

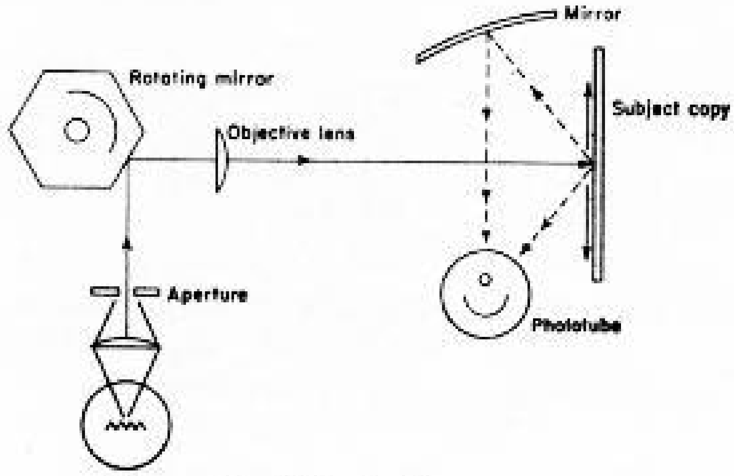


Figure 12. Flying-Spot Scanner with Rotating Multifaced Mirror

collimates the light before it strikes the mirror faces. The face of the mirror which makes an angle of approximately 45° with the optical axis of the lens, deflects the beam emerging from the objective lens 90° and through a scan-limiting slit to

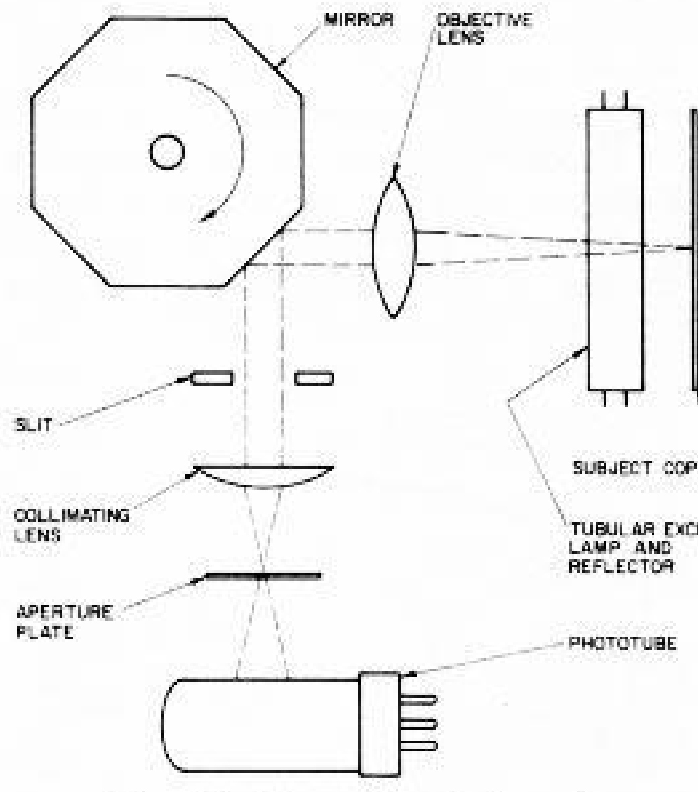


Figure 13. Image-Dissecting Transmitter with a Rotating Mirror

another lens, which focuses it upon the image-dissecting aperture. The scan-limiting slit prevents the phototube from seeing beyond the edges of the subject copy during the lost-time interval when two mirror faces are observing these areas. In these transmitters it is not necessary to compensate for the varying size of the subject copy area being viewed instantaneously so the usual round or square aperture may be used. However, it is necessary to employ the controlled lateral distortion in order to obtain uniform rate of sweep along the entire scanning line.

Image Dissecting Systems

"Flood projection" or image dissection, in which a relatively large area of the subject copy is floodlighted and the aperture which delineates the size of the area being viewed by the phototube is placed in the reflected beam, usually is arranged with the incident light applied from an angle and with the axis of the objective lens system perpendicular to the subject copy. Here again "paste-overs," creases and folds in the subject copy tend to cause shadow lines in the recorded copy. These are not as pronounced here as they are in spot-projection and can be minimized or eliminated by the use of a second exciter lamp on the opposite side or by the use of an ellipsoidal mirror instead of a condensing lens, as shown in Figure 14. These arrangements also have the advantage of creating a floodlighted area of more uniform illumination. This is particularly desirable where there are paste-overs or folds or creases in the subject copy because these areas, being slightly out of focus,

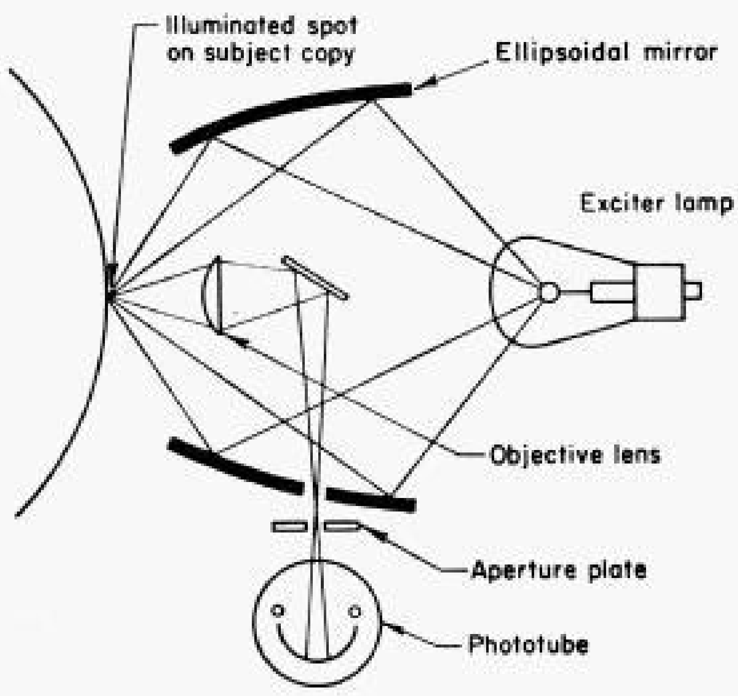


Figure 14. Image Dissecting Transmitter using Ellipsoidal Mirror

cause the image of the floodlighted area on the aperture plate to shift laterally. Inasmuch as the normal alignment provides that the aperture view the center or brightest portion of the floodlighted area, any shift to a less brightly lighted area causes a lower phototube output which is the equivalent of scanning a denser area; hence these areas will be recorded as grey instead of white.

Another arrangement to overcome this difficulty is shown in Figure 15. Since the axes of the incident light and the objective-lens system coincide, there is no lateral shift of the image of the lighted area on the aperture plate. Raised areas produce only the out-of-focus effects which are usually of small consequence in a well designed and constructed mechanism.

There are more variations of the image-dissection method of analyzing the subject copy than there are of the spot-projection method and all are designed to avoid the necessity of mounting the subject on a drum or cylinder. In one of these, shown in Figure 16, the copy is inserted into a curved funnel-like opening and the linefeed rolls carry it past the scanner optics while it is shaped in the form of a quarter-circle. The full scanning-line length is illuminated by a single straight fluorescent lamp. A disc is rotated on an axis, coinciding with that of the curved scanning line which has four objective lenses mounted on its periphery. At the center of the disc is the spot-delineating aperture and a mirror, located at an angle of 45°, to project the light passing through the aperture perpendicular to the disc through a condensing lens to the phototube. The aperture plate, mirror, condensing lens and phototube are all fixed in space; the aperture plate facing the center of the curved scanning line. Each objective lens is adjusted to focus an image of the subject copy on the aperture plate and as the disc rotates 90°, one line is scanned. As one objective lens passes over the right-hand edge of the subject copy, the next lens starts scanning at the left-hand edge. The subject copy is of course advanced one scanning-line width for each 90° rotation of the disc. Great precision is necessary in the construction of the disc and the mounting and adjustment of the objective lenses, so that they "track" properly in both the horizontal and vertical planes with respect to the subject copy. It will be

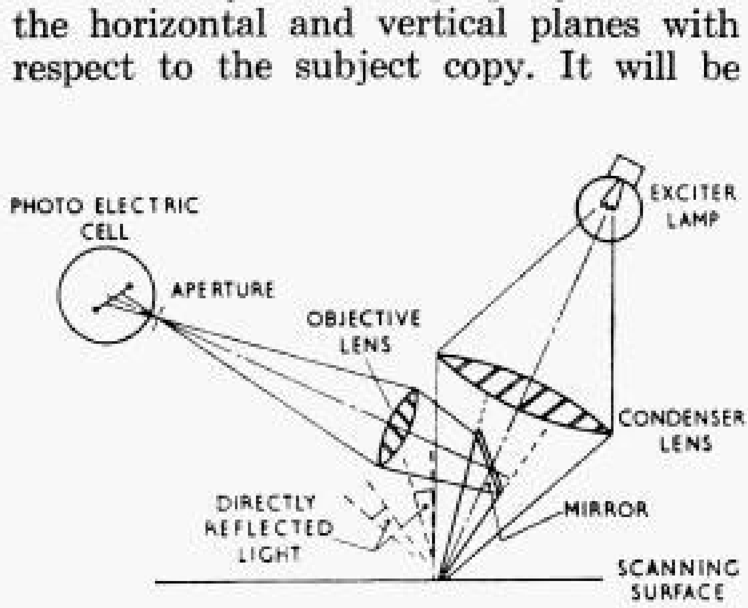


Figure 15. Image Dissecting Transmitter Optical System

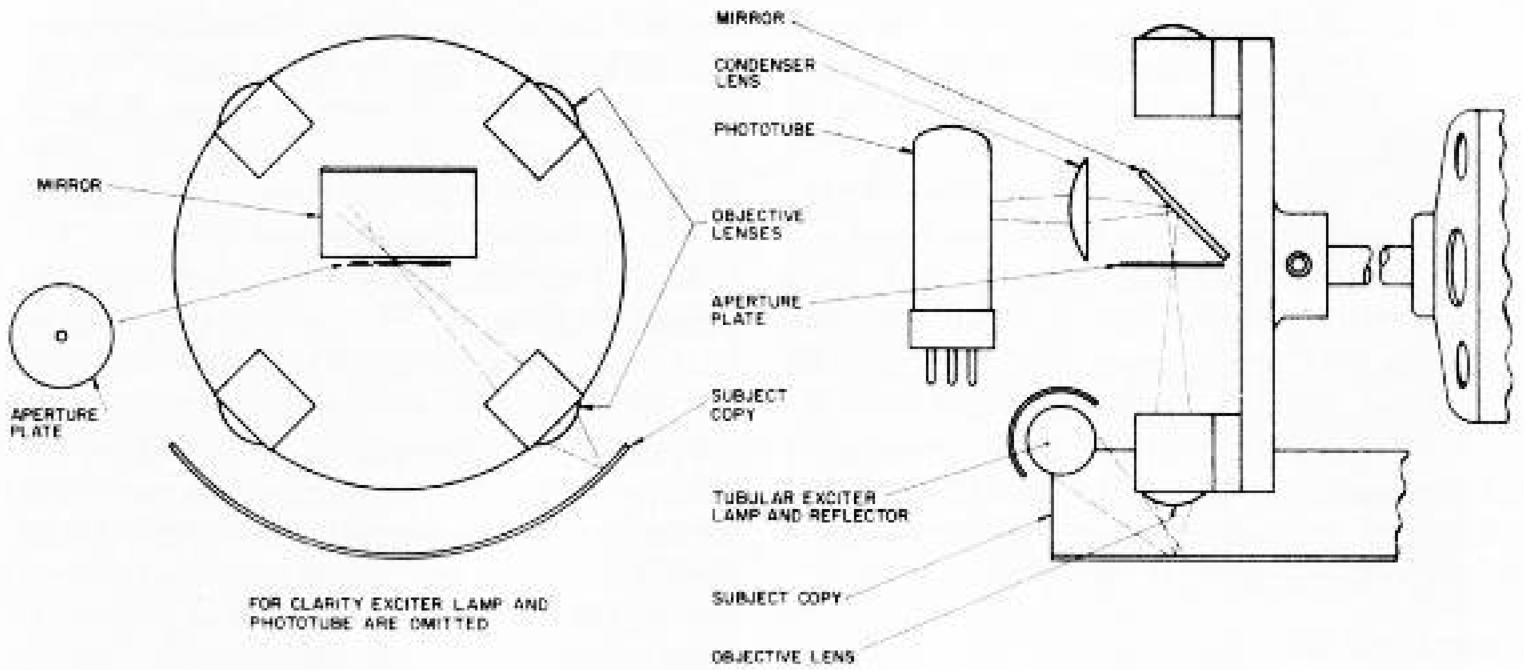


Figure 16. Image-Dissecting Transmitter Multiscan Head

noted that the angle between the aperture plate and the axis of the condenser lens system varies from 45° at the edges of the subject copy to 90° in the center whereas in most scanners it is fixed at 90°. This results in the effective size of the aperture being some 30 percent less at the edges of the subject copy than in the center. There is no corresponding reduction in light level to the phototube however, because the straight fluorescent lamp is in much closer proximity to the curved subject copy near the ends. The two variations tend to complement each other so that the light level at the photocell over the entire length of the scanning line is fairly uniform. A mirror properly placed near each end of the scanning line completes the necessary light equalization.

Helix and Slit

An optical configuration, which is especially suitable for the scanning of large charts, such as weather maps, 19 inches wide, employs a helix and slit arrangement, as shown in Figure 17. A narrow strip across the subject copy is illuminated by long fluorescent lamps and an image of the floodlighted strip is focused by means of the objective lens upon an aperture plate having a long narrow slit. Immediately behind this plate is an opaque cylinder which has a transparent helix of approximately the same width as the slit in the aperture plate. As the cylinder rotates, the intersection of the helix and slit becomes a moving aperture which dissects the image of the subject copy. The subject copy is of course transported at the line-feed rate so that the image is completely scanned line by line. Light from the aperture is directed by means of a curved mirror out one end of the cylinder to a phototube. A square aperture would be preferred to the parallelogram formed in this manner but the difference can be made relatively in-

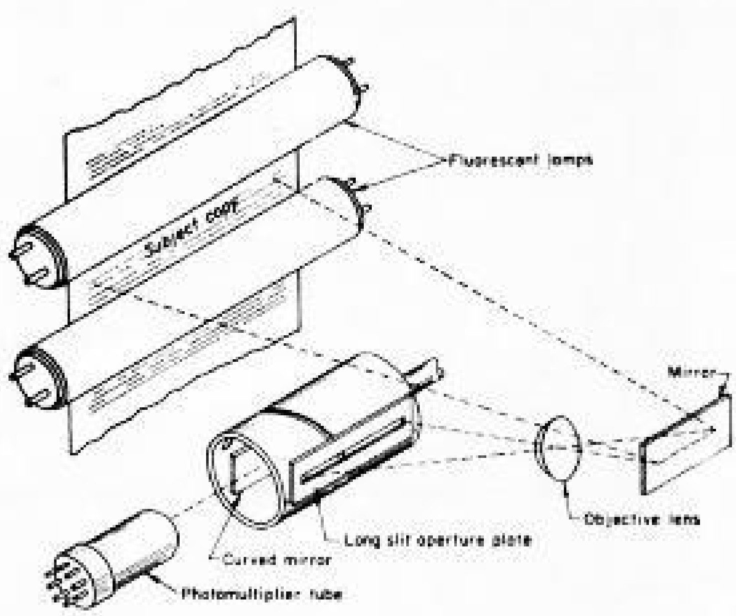


Figure 17. Helix and Slit Optical Configuration

significant by reducing the size of the image optically, so that the slit is short and by increasing the drum diameter. There is of course a practical limit on how much the image may be reduced. Factors involved are the mechanical precision with which the two elements of the moving aperture are fabricated, the very low light levels reaching the phototube which limit the signal-to-noise ratio at the phototube output, and to a lesser extent the effect of dust particles on the slit or transparent helix. The first two factors generally limit the dimensions of the aperture to something of the order of 0.002 inches and the moving aperture portion of the scanner is usually enclosed to seal out dust.

Spiral and Slit

Perhaps the most common of all the flat-bed scanner optical arrangements is the spiral-and-slit image dissector, shown in Figure 18. The image of the floodlighted area of the copy is dissected by the moving aperture created by the juncture of the transparent spiral and slit. Here again, the aperture is not square but a parallelogram and to minimize this distortion one design employs two spirals suitably geared together. The aperture-forming spiral is a five-turn spiral in order to make the intersection with the slit nearly 90°; whereas a wide single-turn spiral is used to blank out the other four intersections of the aperture-forming spiral and the slit. Another and much simpler arrangement for achieving the desired square aperture is to use an involute rather than an Archimedes' spiral. This is perhaps somewhat more difficult to generate but once the master is made, photographic reproductions are relatively inexpensive in quantity.

In the design, shown in Figure 19, the image of the subject copy is reduced by four-to-one in order to keep the size of the involute disc reasonably small. With a scanning line length of 8½ inches, the "throw" of the involute becomes 2⅛ inches and the overall diameter of the disc (allowing for mounting hub, etc.) about 7½ inches. To obtain the equivalent of a 0.010-inch elemental area on the subject copy, the width of the slit and involute must be 0.0025 inches. In the manufacturing, a tolerance of ±5 percent on this dimension was held to ±2 percent on variations in the width within each disc or slit plate. This is necessary because the combined variations of the two elements of the aperture result in ±4 percent variation in the level of light passed on to the phototube.

This precision was achieved in the following manner. First, an optically flat glass plate was coated on one side with soft silver using an aqueous silver solution. This plate was then placed on a Geneva rotary table with a traverse arm holding a diamond tool with chisel point, which removed the proper width of sil-

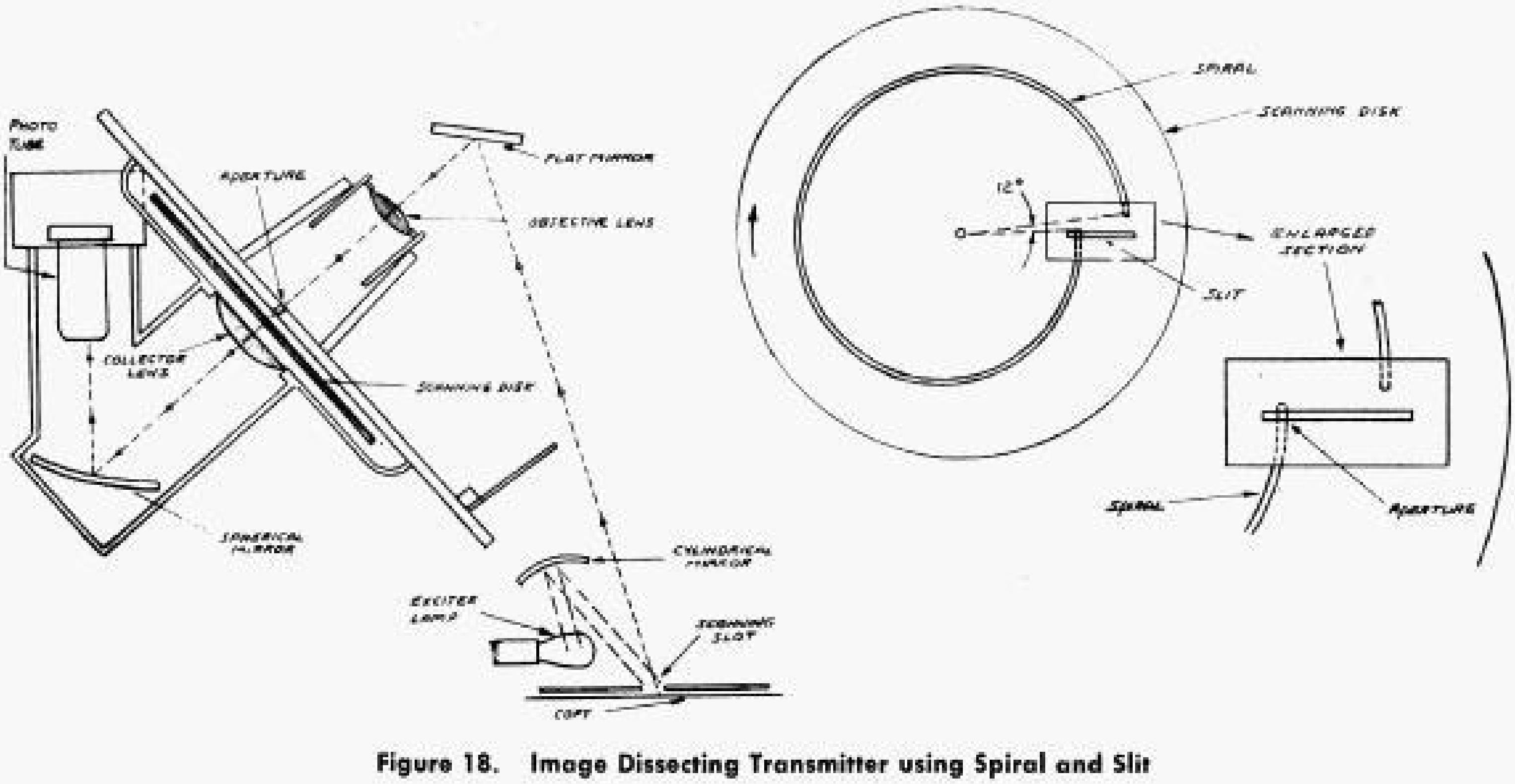


Figure 18. Image Dissecting Transmitter using Spiral and Slit

ver coating in the precise involute pattern. This plate now became the "master master" from which a contact print was made on a glass disc coated with a "glue silver" emulsion. This became the printing master from which successive prints were made on ¼ inch glass discs coated with a "glue silver" emulsion for the final involute discs. The slits were made by coating optically flat 1/16-inch glass strips with the aqueous soft silver solution and removing the proper width of coating by the chisel-pointed diamond tool in a shaper type of mechanism. Since this could be done rather quickly and easily once the machine was set up, these were used as the final slits omitting the two printing operations required in the case of the involutes. Because of the tolerances necessary in the disc mounting and drive and because some retouching was required on both the final involute and the slit, it was not possible to space them closer than about 0.004-0.005 inches. An objective lens with fairly long depth of focus permitted satisfactory operation under these conditions. A Wollensak Raptar (f-3.5) enlarging lens was used, and stopped down to f-8.0.

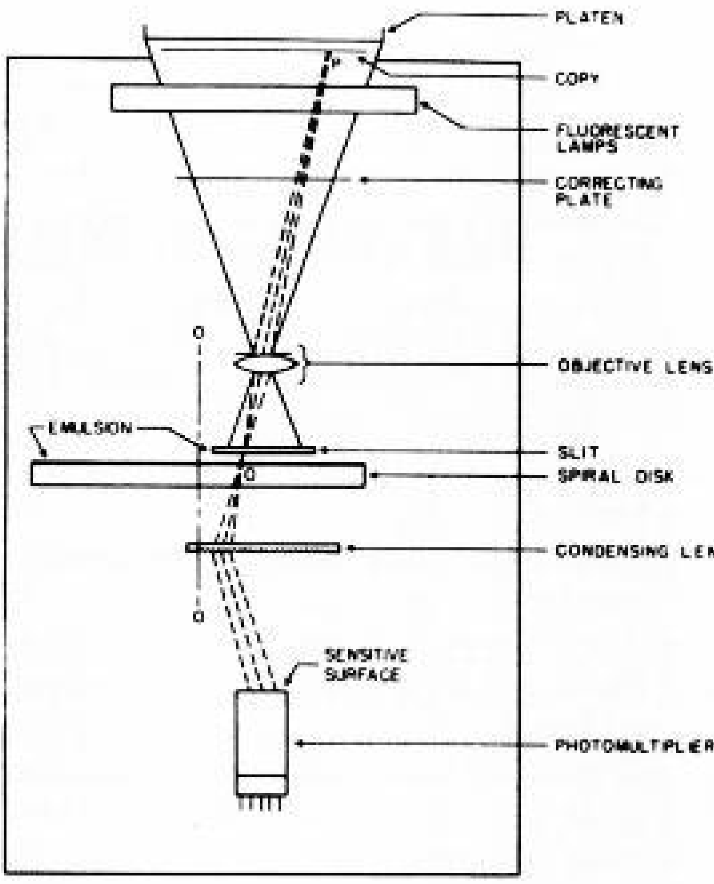


Figure 19. Image Dissecting Transmitter Involute and Slit

In order to equalize the light over the entire length of the scanning line a compensating bar is inserted in the light path between the subject copy and the objective lens. This bar incorporates a row of adjusting screws which make it possible to correct for both the normal cosine light pattern due to the varying length of the light path and also for the variations inherent in each individual fluorescent lamp.

Part III of this article will appear in the April 1965 issue.

Fred W. Smith, Senior Engineer—Telegraph Equipment Div.—P & E Dept.

NEW
8-LEVEL TELEPRINTERS AND ASR SETS

Part 1: Model 33

Introduction

In December 1964 Western Union began installation of a new line of 8-level teleprinters and automatic send-receive sets for use in outstations of the Advanced Record System now being built for the General Services Administration. This two-part article describes the Teletype Corporation's new 8-level Models 33 and 35 teleprinters and ASR sets to be used in this system.

The Models 33 and 35 sets are the first printing telegraph units designed for use with the new 7-bit American Standard Code for Information Interchange. (The ASCII code was described in the April, 1964 issue of the TECHNICAL REVIEW.) Teletype Corporation chose to use an 8-bit code for implementing ASCII. At present, the eighth bit can be used either as an even vertical parity check bit or can always be made a marking, or "one," bit. (In the GSA units, bit 8 will be an even vertical parity check bit.) Teletype also chose to use a unit-length start pulse and a two-unit-length rest pulse in the serial-by-bit transmission pattern in start-stop systems, thus it gives a modulation rate of 110 bauds at a transmission speed of 100 words per minute.

Two 8-Level Models

The Model 33 Teleprinters and ASR Sets are basically the same design as the Model 32[1] 5-level units and many of the parts used in the 8-level units are interchangeable with parts in the 5-level units. The Model 33, like the Model 32, is a low-cost line of equipment, with limited versatility, suitable for light-duty service. The Model 33 ASR set, shown in Figure 1, is very similar in appearance to the Model 32 ASR set and the overall dimensions of the two sets are identical. The most noticeable difference is in the 4-row keyboard used on the 8-level equipment. The same limitations apply to the Model 33 as to the Model 32. For example, a

Figure 1. Model 33 ASR Set

typing reperforator is not available for the Model 33 and it is not possible to simultaneously receive page copy on-line and prepare a tape off-line on the ASR set. A sprocket-feed typing unit with form feed-out is available as an optional feature, but horizontal and vertical tabulaton are not available. The light-weight construction of the Model 33 also prevents printing more than one legible carbon copy.

The Model 35 Teleprinters and ASR Sets, to be described in Part 2 of this article, are basically the same design as the 5-level Model 28 units. However, the Model 35 units are packaged in the more modern style of the Models 32 and 33 units. The Model 35 units are heavy-duty units, with all the versatility of the 5-level Model 28.[2] Features such as horizontal and vertical tabulation, multiple-copy printing, and printed and perforated tape, are available in the Model 35. Also, the Model 35 stunt box incorporates the versatility of the Model 28 stunt box.[3]

The ASCII Code

Certain characteristics of the ASCII code permit simplifying the design of printing apparatus for implementing the code in monocase teleprinters; that is, in printers which print either a lower case alphabet or an upper case alphabet, but not both. The 64-character graphic subset in the ASCII code is located in the middle four columns of the table shown as Table I. In each of these columns bit 7 differs from bit 6. Therefore, to determine whether a bit permutation, or "code," is a printing character or a control character, it is only necessary to compare these two bits. If either of them is a marking pulse, or "one" bit, and the other a spacing pulse, or "zero" bit, the character received is a graphic. If both bits 7 and 6 are zeros or if both are ones, the character is not a graphic. In a monocase printer, once a bit permutation has been identified as a graphic character, bit 6 can be ignored. Note that there are four discrete permutations of bits 7 and 5 in the four graphic columns of the table: 00, 01, 10, and 11. In both the Model 33 and the Model 35, bit 6 is not used in positioning the typing mechanism. If a lower case alphabet is eventually assigned to the 7th and 8th columns of ASCII and each lower case letter is so located that it differs from its corresponding upper case letter only in bit 6, as now seems likely, the Models 33 and 35 will simply convert all lower case letters to upper case letters, with no other resulting errors in printing.

In developing the ASCII code, an effort was made to place characters which are normally paired on a typewriter keytop so that they differed by only one bit. For example, the digit 4 differs from the dollar sign, with which it is normally paired on a typewriter keytop, only in bit 5. In this example, the dollar sign normally appears on the upper half of a keytop and the digit 4 on the lower half. In the code for the dollar sign, bit 5 is spacing and in the code for the digit 4, bit 5 is marking. The same relationship exists, of course, between all of the characters in the 3rd column of the ASCII table and the corresponding characters in the 4th column. By pairing the corresponding characters in these two columns on keytops, a keyboard could be designed to generate the "upper case" characters by using a shift key to delete bit 5; that is, to convert bit 5 from a "one" to a "zero." However, this would result in the question mark being made a "lower case" character and the diagonal sign, with which it is usually paired, being made an "upper case" character. This is the reverse of the conventional pairing on a typewriter keyboard. In order to permit the traditional pairing on the Models 33 and 35, a shift key is used to *invert* bit 5; that is, if bit 5 is a 0, the shift key converts it to a 1; and if bit 5 is a 1, the shift key converts it to a zero. This allows the period, comma, hyphen, and diagonal sign to be placed on lower halves of the keytops.

The 4-Row, 8-Level Keyboards

Most of the ASCII control characters are located in the first two columns of the code table. In both of these columns, bit 7 is a zero. In the Models 33 and 35 keyboards, most of the controls in these first two columns are generated by means of a control key which, when held depressed, deletes bit 7; that is, if bit 7 is

Table—1
ASCII Code

b_4	b_3	b_2	b_1								
b_7 →				0	0	0	0	1	1	1	1
b_6 →				0	0	1	1	0	0	1	1
b_5 →				0	1	0	1	0	1	0	1
0	0	0	0	NULL	DC_0	b̸	0	@	P	UNASSIGNED	UNASSIGNED
0	0	0	1	SOM	DC_1	!	1	A	Q		
0	0	1	0	EOA	DC_2	"	2	B	R		
0	0	1	1	EOM	DC_3	#	3	C	S		
0	1	0	0	EOT	DC_4 STOP	$	4	D	T		
0	1	0	1	WRU	ERR	%	5	E	U		
0	1	1	0	RU	SYNC	&	6	F	V		
0	1	1	1	BELL	LEM	' (APOS)	7	G	W		
1	0	0	0	FE_0	S_0	(	8	H	X		
1	0	0	1	HT/SK	S_1	)	9	I	Y		
1	0	1	0	LF	S_2	*	:	J	Z		
1	0	1	1	VTAB	S_3	+	;	K	[		
1	1	0	0	FF	S_4	, (COMMA)	<	L	\		ACK
1	1	0	1	CR	S_5	- (HYPHEN)	=	M	]		①
1	1	1	0	SO	S_6	. (PERIOD)	>	N	↑		ESC
1	1	1	1	SI	S_7	/	?	O	←		DEL

NULL—Null/Idle
SOM—Start of Message
EOA—End of Address
DC_1—Device Control
DC_2—Device Control
DC_3—Device Control
DC_4 (STOP)—Device Control (Stop)
ERR—Error
EOM—End of Message
EOT—End of Transmission
WRU—"Who are you?"
RU—"Are you . . .?"
BELL—Audible Signal
FE_0—Format Effector
HT—Horizontal Tabulation
SK—Skip (punched card)
LF—Line Feed
VTAB—Vertical Tabulation
FF—Form Feed
CR—Carriage Return
SO—Shift Out
SI—Shift In
DC_0—Device control reserved for Data Link Escape
SYNC—Synchronous Idle
LEM—Logical End of Media
S_0-S_7—Separator (information)
b̸—Space (Word separator, normally non-printing)
<—Less Than
>—Greater Than
↑—Up Arrow (Exponentiation)
←—Left Arrow (Implies/Replaced by)
\ —Reverse Slant
ACK—Acknowledge
①—Unassigned Control
ESC—Escape
DEL—Delete/Idle

a one, the control key converts it to a zero. For example, to generate the start-of-message (SOM) character, the control key is held down while the "A" key is being depressed. The carriage return, line feed, and escape characters are generated without using the control key, since separate keys are provided for these three controls.

The shift key on the 4-row keyboard serves the same purpose as the shift key on a typewriter. To print an "upper case" character, the shift key is held down while the selected character key is being depressed. Unlike a typewriter, however, there is no shift-lock key on the teleprinter keyboard.

are indicated in Figure 2 by the letters "SB" in the upper right quadrant of the key tops. These keys cannot be depressed while the shift key is held down. Similarly, the control key blocks keys not used to generate control characters. These keys are indicated by the letters "CB" in the upper left quadrants of the key tops. Control characters which must be generated by simultaneously depressing both the shift and control keys are shown in the lower right quadrants of the key tops.

In Figure 2, the control characters are labelled to correspond to the characters shown in Table I. Note that every assigned character in ASCII, except "ACK,"

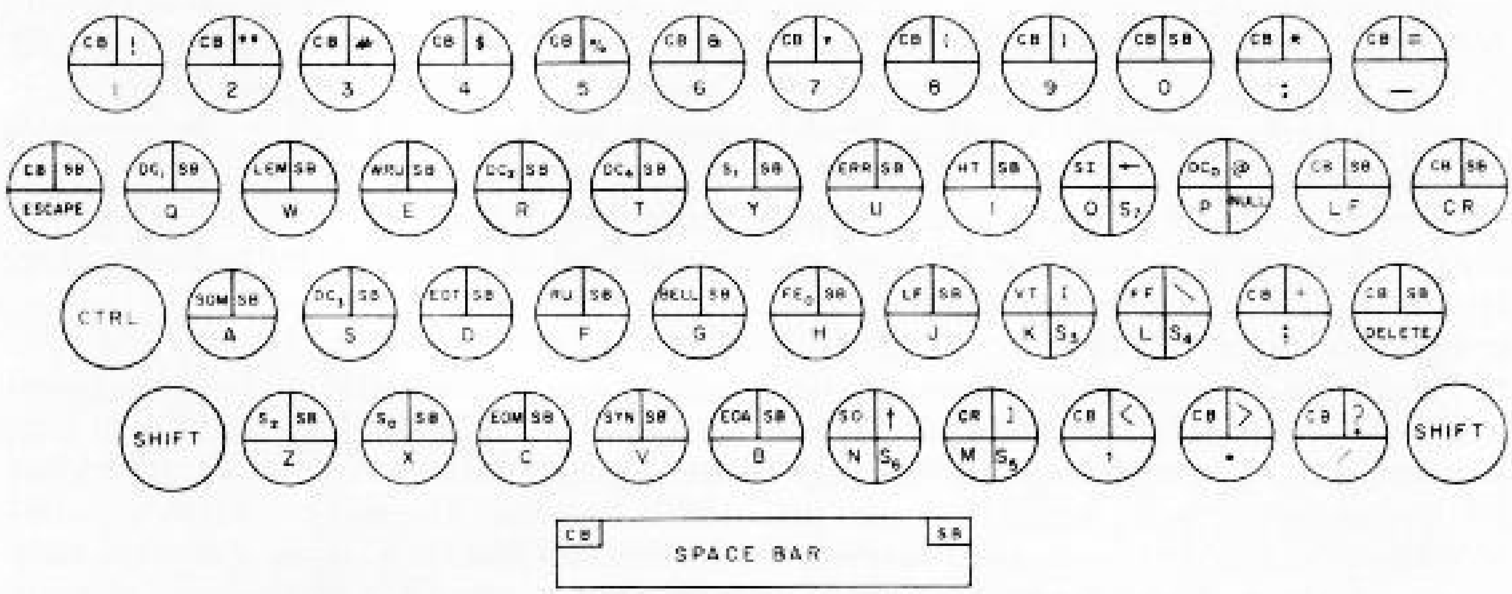


Figure 2. Shift and Control Characters Generated on the Models 33 and 35 Keyboards

Some of the control characters must be generated by simultaneously holding down the shift key and the control key, while depressing the appropriate character key. This deletes bit 7 and inverts bit 5. For example, the "null," or blank, character is generated by holding the shift and control keys down while depressing the "P" key. Information separators S-3 through S-7 are also generated in this manner. Figure 2 illustrates how the shift and control characters are generated on the Models 33 and 35 keyboards. On these keyboards, when the shift key is depressed, it blocks all keys not used to generate either a shift character, or a control character when used in combination with both the shift and control keys. Character keys so blocked can be generated on the Models 33 and 35. The "acknowledge" character was intended to be an automatically generated response character, somewhat like the single-character "V" answer-back used in some telegraph systems.

At present, the Models 33 and 35 do not include any means of checking the parity of received signals. In spite of this, it was decided to provide for generation of an even vertical parity check bit in the GSA keyboards. Each character generated (or perforated in tape) contains an even number of marking pulses. This feature can be obtained for very little additional cost and its inclusion in the GSA units will result in substantial cost savings, in the event that a vertical parity check at the receiving end is provided at some time in the future and the Models 33 and 35 are converted to provide an end-to-end parity check.

8-Level Tape

A drawing of the one-inch wide tape used in the 8-level equipment is shown in Figure 3. The dimensions and tolerances shown on this drawing are those included in the proposed American Standard for One Inch Perforated Paper Tape, expected to be approved in the near future. With a few minor exceptions in tolerances, the code and feed hole diameters and the spacing between holes are the same as the corresponding dimensions and tolerances in 5-level, 11/16-inch wide perforated tape.

Model 33 Teleprinters and ASR Sets

The Model 33 Teleprinter consists of the same basic components as the Model 32, its 5-level counterpart; namely, a keyboard, a typing unit, an answer-back unit, a distributor, a motor, a remote control unit, a cover with a copy holder, and a stand, or pedestal. The Model 33 ASR set includes, in addition to these components, a tape reperforator attachment and a tape transmitter attachment. An equipment mounting rack, which mounts inside the stand, is available as an optional accessory. In Figure 1, note that the remote control unit shown at the right side of the set is not equipped with a dial. In the GSA circuit switching network, keyboard dialing, or dialing from tape, is used.

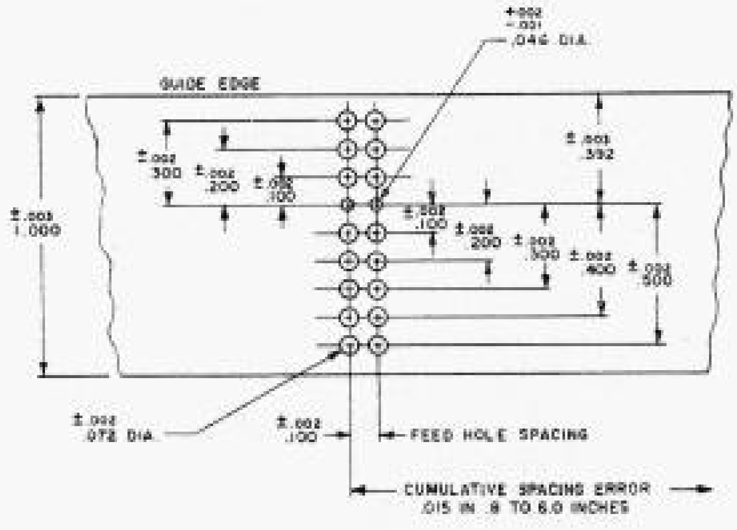


Figure 3. Dimensions and tolerances for 8-level Chad Tape

In the Model 33, unlike the 5-level Model 32, letters and figures shift characters are not used. When reference is made to an "upper case" character in the 8-level equipment, this means a character imprinted on the upper half of a key top.

Model 33 Keyboard

The layout of the Model 33 keyboard used in the GSA system is shown in Figure 4. Only those control characters actually used in the GSA system are imprinted on the key tops. As previously explained, however, any *assigned* character in ASCII, except "acknowledge," can be generated.

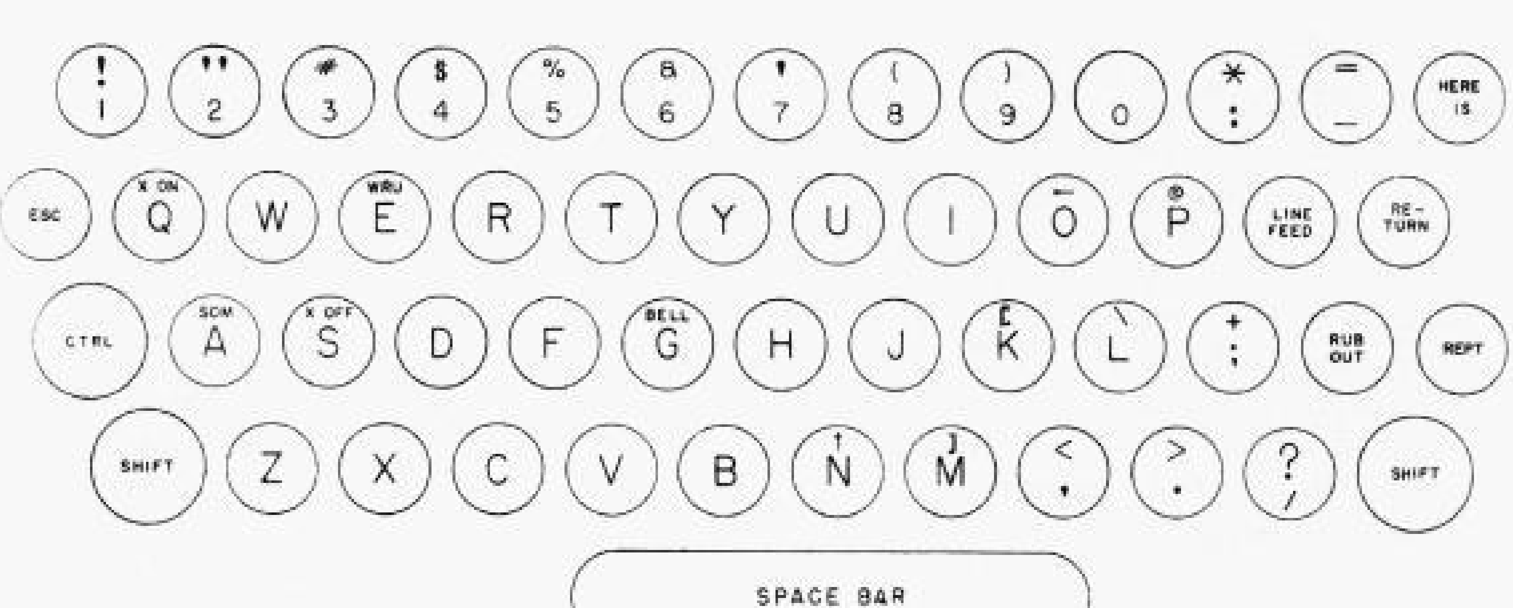


Figure 4. Model 33 Keyboard (GSA version)

Device Control 1 in the ASCII code (see Table I) is used in the GSA system as a "transmitter-on" control character and Device Control 3 is used as a "transmitter-off" control. These two controls, abbreviated "X ON" and "X OFF," are shown on the upper halves of the "Q" and "S" keytops, respectively. Although these two device controls have not been assigned specific functions in the ASCII code as yet, the GSA system requirements dictated the use of two control characters for automatically starting and stopping a tape transmitter. DC_1 and DC_3 were arbitrarily chosen for this purpose.

The escape (ESC) key shown in Figure 4 is not used at present in the GSA system. This key was included for possible future use in order to avoid the possibility of having to install this key later, at considerable cost, should it be required in the future. In the ASCII code, "ESC" is intended to signify an "escape" from the ASCII code in order to permit a broad expansion of the code for special uses.

In order to distinguish between control and shift characters, both of which appear on the upper halves of the keytops, the letters "CTRL" on the control key are imprinted in yellow. All control characters, such as "X ON" and "X OFF," are also imprinted on the keytops in yellow. All other lettering on the keytops is printed in white. (This feature was first adopted for the GSA units. Earlier models did not include the two-color printing on the keytops.)

Theory of Bit Inversion

When a keylever on the Model 33 keyboard is depressed, it operates eight pairs of code bars. Each pair of code bars positions two T-levers, one of which operates a contact, as on the Model 32 keyboard.[1] The positions of these T-levers subsequently determine whether a marking or spacing pulse will be transmitted. On the Model 33, six of these keyboard contacts operated by the T-levers are normally open single contacts and are allowed to close only when a marking pulse is to be transmitted. The No. 5 and No. 8 T-levers, however, each operates two contacts, as shown in Figure 5. In each case, one contact is normally open and the other is normally closed. These two contacts, or "double-headed" contacts, operate to the positions opposite to those shown in the figure, when the selected keylever is coded to cause the 5th and 8th pulses to be marking pulses. The 8th pulse is a vertical parity check pulse (even parity) and the No. 8 code bars are coded so that they will cause the 8th pulse to be a marking pulse when the depressed keylever represents an ASCII character with an odd number of bits. Conversely, if the selected character contains an even number of bits, the 8th pulse will be a spacing pulse.

The design of the Model 33 keyboard permitted bit 5 to be inverted by means of the shift key and bit 7 to be deleted by means of the control key, with very simple circuitry, as shown in Figure 5. The No. 7 segment on the distributor faceplate is connected to one side of a normally-open set of No. 7 contacts which are operated by the No. 7 T-lever when a character containing a No. 7 marking pulse is to be transmitted. The other side of this set of contacts is connected to a normally closed contact operated by the

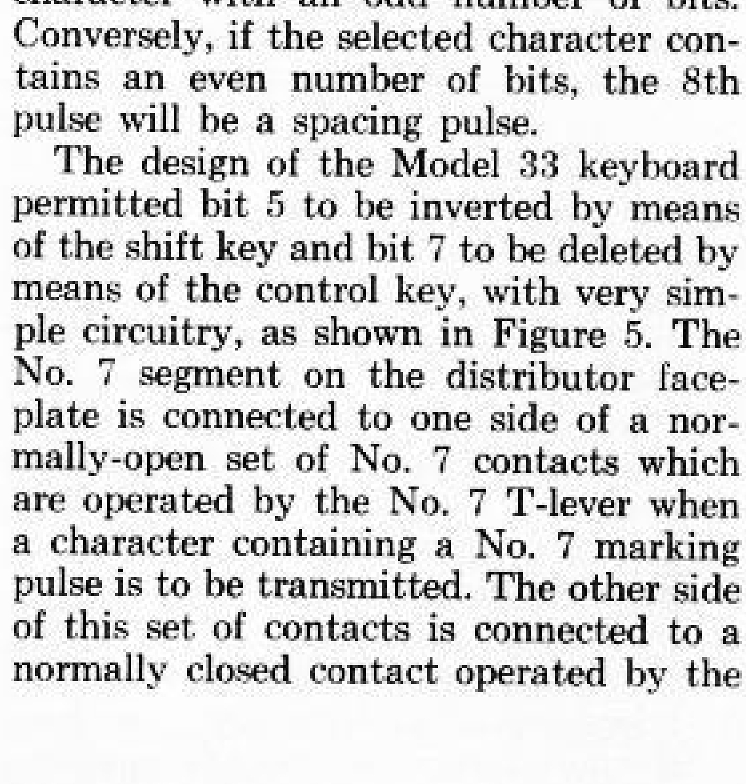


Figure 5. Partial Schematic Wiring Diagram of Model 33

control key. When the control key is held down, the circuit from the No. 7 distributor segment to the rest, or stop, segment will be opened at the NC control contact, regardless of the position of the No. 7 contact.

The shift key, which is used to invert bit 5, operates three pairs of "shift" contacts, as shown in Figure 5. One contact in each pair is normally open and the other is normally closed. When the shift key is held down, all three pairs of shift contacts operate to the reverse positions from those shown in the figure. The normally-closed (NC) No. 1 shift contact is connected to the normally-open (NO) No. 5 contact; the normally-open No. 1 shift contact is connected in series with the normally-closed No. 5 contact. If the shift key is held down and a keylever which normally causes the No. 5 pulse to be marking is simultaneously depressed, the 5th pulse will be converted to a spacing pulse; that is, when the distributor brush passes over the No. 5 segment on the faceplate, the NO contact of the No. 1 shift contacts will be closed, but the NC contact of the No. 5 pair will be open and thus the signal line circuit will be open. On the other hand, if the shift key is held down while a keylever which normally causes the 5th pulse to be spacing is depressed, the 5th pulse will be converted to a marking pulse. In this case, the normally-open No. 1 shift contact will be closed and the normally-closed No. 5 contact will remain closed. When the distributor brush passes over the No. 5 segment, the signal line will therefore be closed.

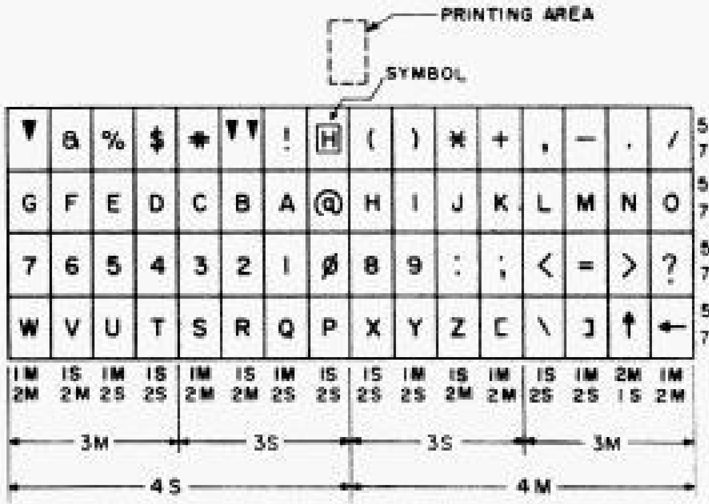
When bit 5 is inverted, bit 8 must also be inverted in order to maintain the even vertical parity. This is accomplished by means of the No. 3 shift contacts in conjunction with the two No. 8 contacts and the two control contacts.

When the 7th bit is deleted, bit 8 must be inverted to maintain the even parity. This is accomplished by means of the normally-open control contact and the No. 2 shift contacts.

As previously explained, some control characters can be generated only by simultaneously holding down both the shift and control keys while depressing a character key. This will invert bit 5 and delete bit 7. In this case, bit 8 must be inverted twice in order to maintain the even parity; in other words, bit 8 must remain a marking, or one, bit if the selected lower case character has a No. 8 marking pulse, and must remain spacing if the selected lower case character normally has a No. 8 spacing pulse. This is accomplished by means of the control contacts in conjunction with the Nos. 2 and 3 shift contacts.

Model 33 Typing Unit

The layout of the Model 33 type wheel is shown in Figure 6. The type wheel consists of 16 vertical columns, with four printing characters in each column. The character to be printed is moved to the printing position by rotating the type wheel to bring the vertical column containing this character to a position below the printing area, then raising the type wheel to bring the selected character to the printing area. Pulse 4 determines in which direction the type wheel will rotate. If the fourth pulse is marking, the type wheel will rotate counterclockwise; if the fourth pulse is spacing, the type wheel will rotate clockwise. Each half of the type wheel is divided into two "fields." The third pulse determines which of the two fields in the selected half of the type wheel will be posi-



S—spacing pulse

M—making pulse

Figure 6. Layout of Typewheel for Model 33 Teleprinter

tioned to the printing area. The first and second pulses determine which of the four vertical columns in the selected field will be moved to a position below the printing area and pulses 5 and 7 determine which of the four characters in the selected column will be raised to the printing area. As previously explained, the sixth pulse is not used in positioning the type wheel. However, ignoring bit 6 is purely mechanical. This bit, or pulse, is transmitted and received by the teleprinter. The No. 6 code bar in the teleprinter is moved to the marking or spacing position, depending upon whether the sixth pulse is marking or spacing, so that it can be used in performing stunt box functions.

Since the spacing character is a "non-printing graphic" in a page teleprinter, the type position for this character does not contain a raised printing character. The symbol corresponding to this position in Figure 6 is used only as an identification mark for the type wheel and is not printed.

Model 33 Stunt Box

The Model 33 typing unit is equipped with eight code bars and a print suppression bar. The code bars are positioned to marking or spacing, as in the Model 32, in response to the incoming signals. The stunt box function levers, which are coded to sense the character set up on the code bars, can therefore sense all seven of the ASCII code bits. (A function lever could be coded to detect a parity failure and thus fail to perform its required function if the No. 8 code bar were not positioned to indicate correct parity. However, the No. 8 code bar on current production units is not equipped with tines on its underside and parity failure cannot be detected at present.) A function lever can also be coded to block the print suppression bar and prevent it from moving to its print position, so that printing will be suppressed when the function lever is selected.

If pulses 6 and 7 are both spacing, the print suppression bar will be prevented from moving to its print position so that printing will be suppressed when one of the control characters in the first two columns of the ASCII code table is received. The print suppression bar is also blocked in its non-print position if pulses 3, 4, 5, 6, and 7 are all marking. This suppresses printing when one of the last four characters in the last column of the code table is received.

Tape Reperforator and Transmitter Attachments

The tape punch used on the Model 33 is basically the same design as the Model 32 punch. However, it punches the 1-inch wide, 8-level chad tape shown in Figure 3. It is equipped with the same four manual controls; i.e., on, off, backspace, and release control buttons. Unlike the Model 32, however, the Model 33 can punch the "who-are-you" character in the tape when this character is transmitted from its own keyboard. A non-contention feature prevents the answer-back unit from being actuated from its own keyboard or tape transmitter.

The tape reader attachment is also basically the same design as the Model 32 except that it "reads" 8-level chad tape. It contains the same manual and automatic controls as the Model 32; that is, a manual 4-position handle with neutral, start, stop and free-wheeling positions, as well as tape-out and tight-tape contacts. However, the start and stop contacts in the tape reader are different from the corresponding contacts used in the Model 32. On the Model 33, when the 4-position control handle is in the neutral position, the start contact is normally open. Moving the handle to the start position momentarily closes the start contact. Moving the handle to the stop position momentarily opens the normally-closed stop contact. When the handle is moved to the "free-wheel" position, it passes through the stop position, then opens the stop contact wider and keeps it open. This feature permits the use of an automatic transmitter-on and transmitter-off control feature as an optional accessory. When the tape reader reads an "X-ON" character in the tape, the transmitter is automatically started; when an "X-OFF" character is detected, the transmitter is automatically stopped.

A simplified schematic wiring diagram

of the automatic transmitter control circuit is shown in Figure 7. The clutch trip magnet shown is located in the distributor area. When this magnet is energized, it closes the transmitter step contacts in the teleprinter (not shown in Fig. 7) and releases the distributor clutch, allowing the distributor shaft to start rotating. Once during each revolution of this shaft, the transmitter step contacts are interrupted to pulse the transmitter step magnet (not shown) and step tape through the transmitter.

Relay R, which is located in the pedestal, controls the clutch trip magnet. When this relay is operated by closure of either the start contacts or the "X-ON" contacts in the stunt box, it locks up through its contacts R-2. Its contacts R-1 energize the clutch trip magnet. Relay R may be released to stop the transmitter by the tape-out or stop contacts in the tape reader or by the "X-OFF" or who-are-you contacts in the stunt box. (Automatic stopping of the tape transmitter on the "WRU" character was adopted for the GSA system to permit actuating the answer-back of the distant station from tape). The tight-tape contacts are wired in series with the clutch trip magnet and, therefore, can stop the transmitter without releasing Relay R. This permits the transmitter to restart automatically when the tight-tape condition is cleared.

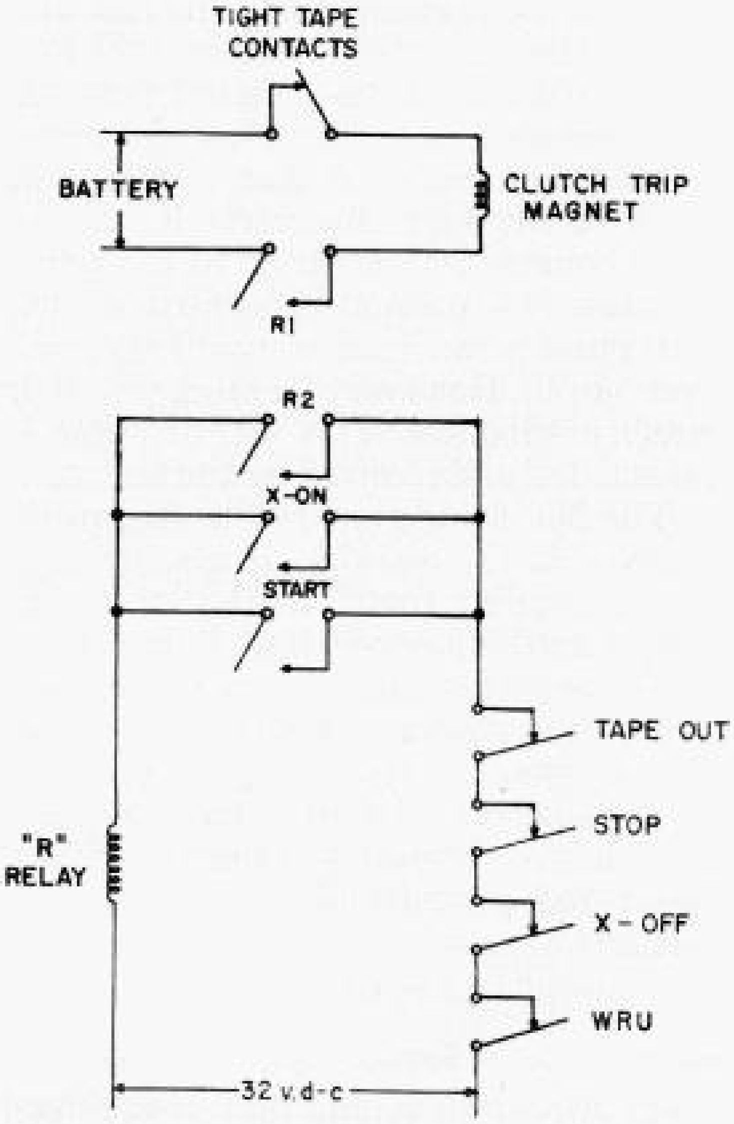


Figure 7. Model 33 ASR Set—Schematic Diagram of the Automatic Transmitter-off and Transmitter-on Circuit

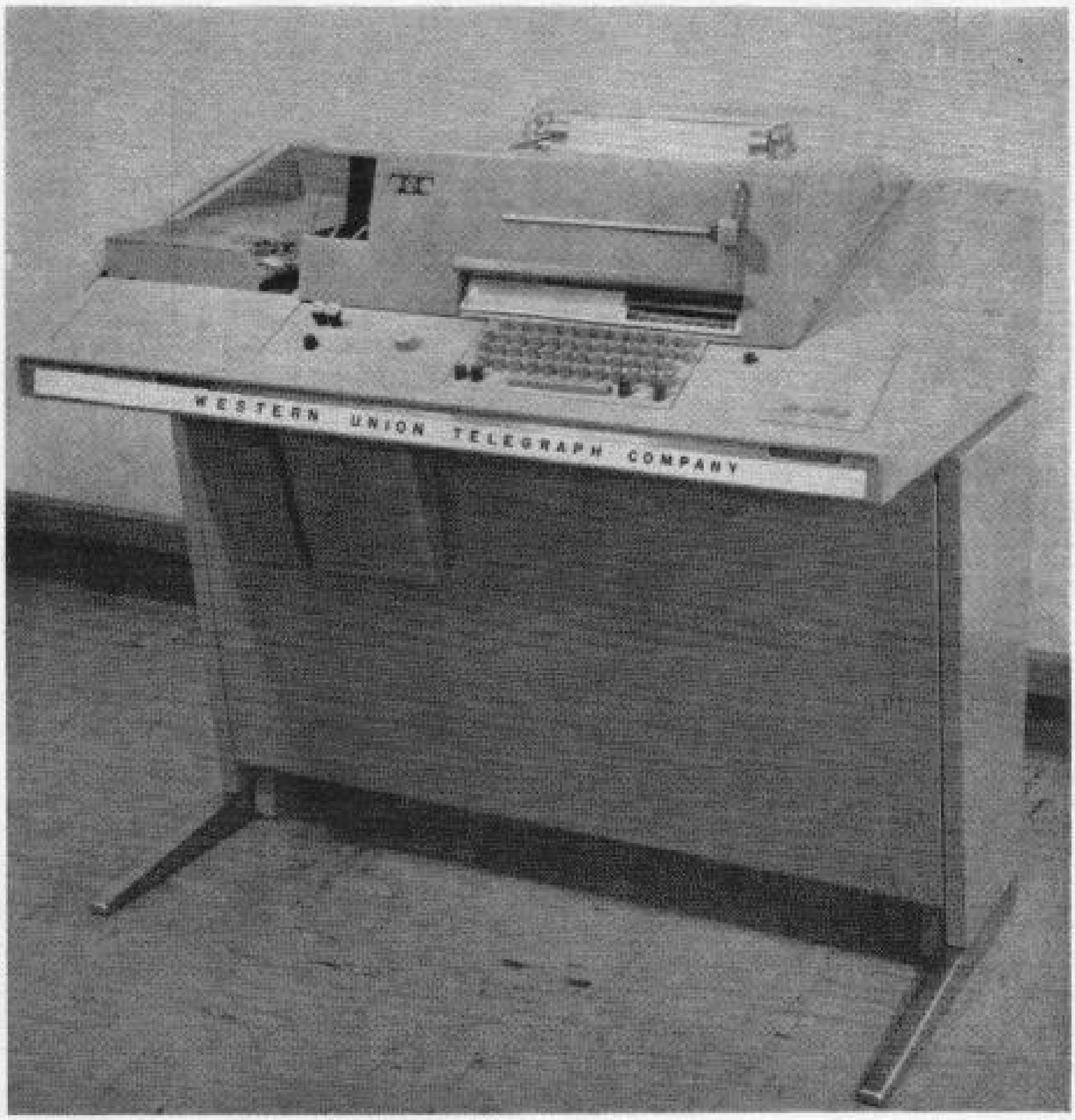
* * * *

Part II of this article will describe the Model 35 Teleprinter and ASR sets (heavy duty)

References:

1. A New Line of Light Duty Teleprinters and ASR Sets, Fred W. Smith Western Union TECHNICAL REVIEW Vol. 18, No. 1, Jan. 1964.
2. Modern High Speed Teleprinters, F. W. Smith Western Union TECHNICAL REVIEW Vol. 9, No. 3, July 1955.
3. Function Mechanisms of the Model 28 Teleprinter, E. Louis Parkington Western Union TECHNICAL REVIEW Vol. 10, No. 2, April 1956.

New Model 35 ASR Set



Model 35 ASR Set to be used in the Intercept positions in the GSA Advanced Record System

H. C. Likel, Senior Engineer—Transmission Div.—Plant & Engineering Dept.

Transistorized Modulator-Amplifier Group

For many years Western Union has provided vacuum tube frequency translation equipment, known as Modulator-Amplifier Groups, to subdivide a 300-3300 cycle voiceband into two 300-1800 cycle subbands used for telegraph and data channels. Recently a transistorized Mod-Amp Group of translation equipment was designed to complement the Type 60 terminal equipment and make up a solid-state twenty-channel carrier telegraph terminal.

The new Mod-Amp Group consists of a leveling amplifier, which is available in both self-powered and common power supply models; a carrier frequency supply; a tuned amplifier; a switching panel; a subband modulator; and two (one-ampere and three-ampere) power supplies suitable for powering the above equipment.

This group of equipments makes it possible to (1) modulate or translate the frequencies of ten channel terminals, designed to operate in the lower half of the frequency spectrum of a voiceband, to the upper half of the band at the transmitting end of a circuit, and (2) demodulate or retranslate these frequencies to their original position in the voiceband at the receiving end of the circuit. The lower half of the voiceband is occupied by ten additional channels which are transmitted without translation in the lower subband. Such a technique makes it possible to have a twenty-channel system using two each of only ten different frequency channel terminals. In addition, it provides half-bands or subbands which may be used for special services such as the transmission of data at intermediate speeds.

Leveling Amplifier

The Leveling Amplifier is used at the receiving end of a voiceband circuit to restore the level to the standard value for the system.

There are two models of this amplifier in the Mod-Amp Group. No. 8288 shown in Figure 1, has an integral power supply.

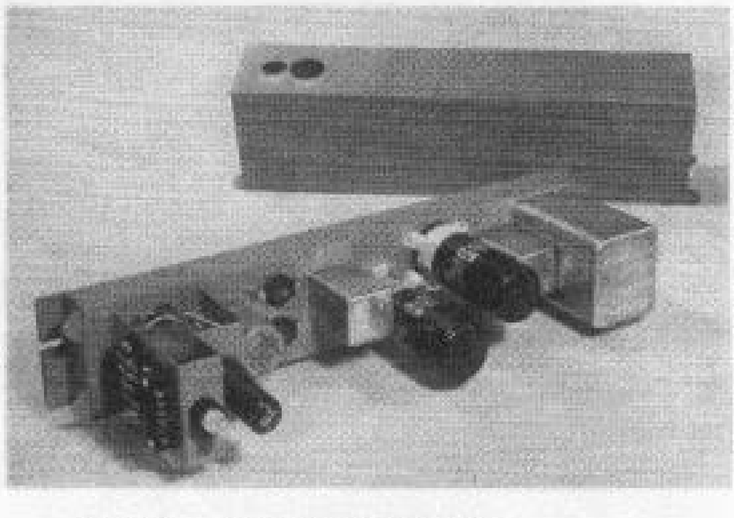


Figure 1. Leveling Amplifier with Integral Power Supply

The other, No. 10188, is shown in Figure 2, with a shelf which holds four amplifiers, and a common power supply. For large installations Shelf No. 10189, shown in Figure 3, was designed to hold eight amplifiers, which are served by Power Supply No. 10192 which mounts on Shelf No. 10493.

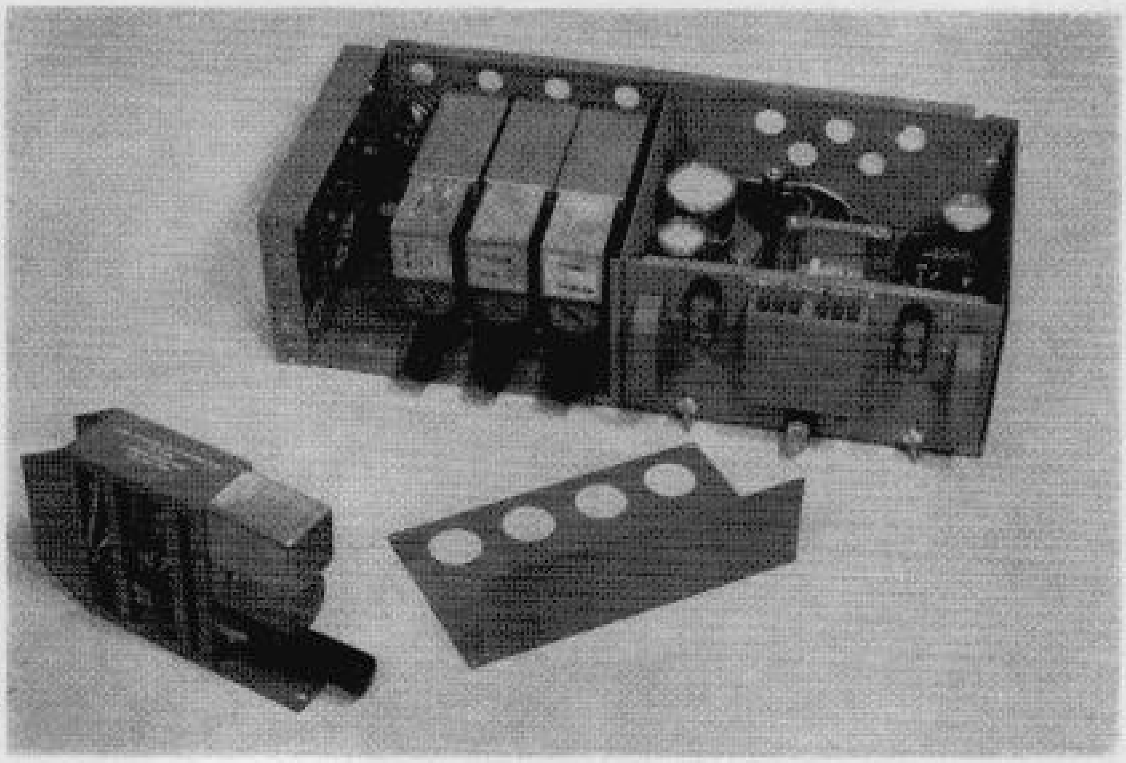


Figure 2. Four Leveling Amplifiers with a Common Power Supply

Amplifier No. 8288 is two rack-units high and may be mounted on a standard repeater rack. It is suitable for other than rack mounted applications since it is totally enclosed and may be operated in any position. Its nominal power consumption is 10 watts at 117 volts and 60 cycles.

The shelves used in conjunction with the No. 10188 Amplifiers and Power Supply No. 10192 are all three rack units high and suitable for mounting on standard Western Union Repeater racks. The equipment mounts on the shelves on a plug-in basis.

The circuitry for both amplifiers is identical; except for the power supply arrangements. They have a gain of 42db which may be adjusted to any lower value by using a 52-A, H pad in the socket provided in the input circuit. Western Union specifications require that the amplifiers do not produce harmonics greater than 45db below the single frequency test signal, at an output power level of +28dbm.

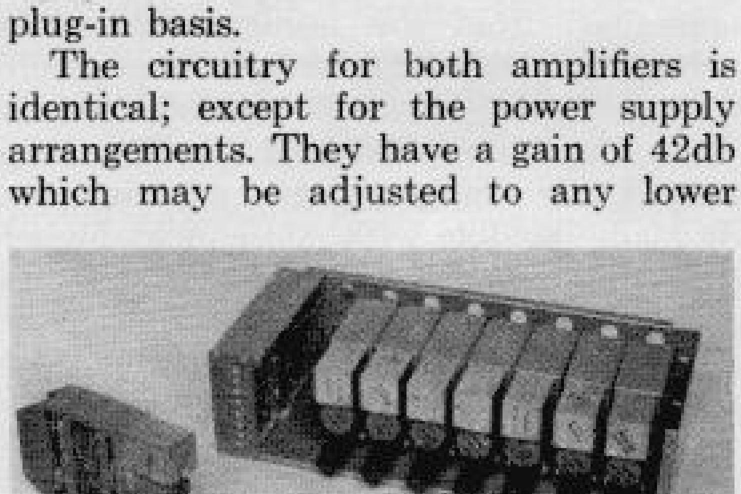


Figure 3. Amplifier Shelf for Eight Amplifiers

To allow for some in-service degradation of characteristics, these amplifiers are recommended for use at a maximum single frequency output level of only +24dbm or a multichannel output level of +14dbm. However, in services where higher distortion can be tolerated, a single frequency output of up to +30dbm may be used. The maximum satisfactory level depends upon the application.

Subband Carrier Oscillator

Subband Carrier Oscillator No. 10142, shown in Figure 4, has a self-contained power supply for operation from a 117 v. ac power line and draws approximately 10 watts. It is packaged to conform to the size and mounting arrangements adopted for the Type 60 channel terminals. Two Subband Carrier Oscillators mount side by side on a rack shelf which occupies three units of rack space.

This oscillator represents a radical change in concept as well as implementation from the old carrier supply system. The old system derived the 1,000 cycle

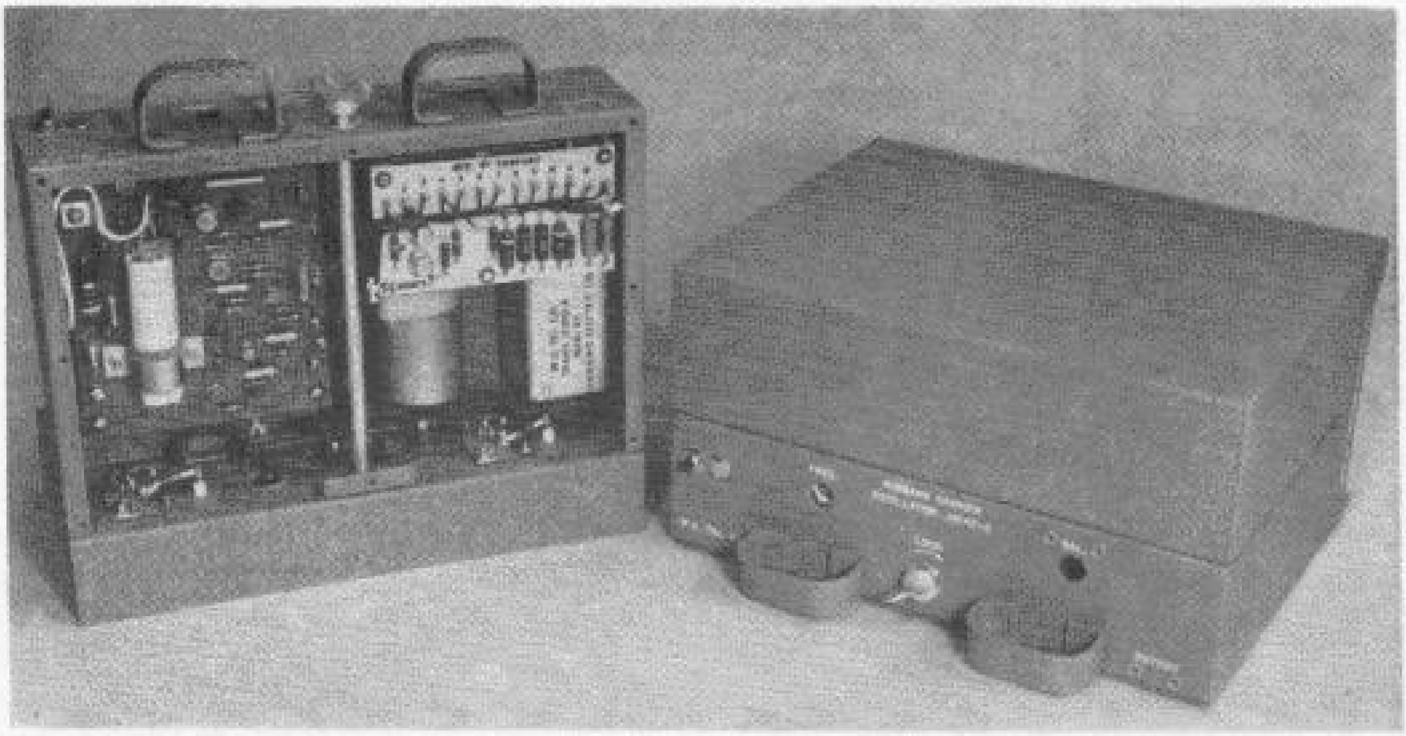


Figure 4. Subband Carrier Oscillator

test tone and the 3,600 cycle carrier frequency by selecting the 5th and 18th harmonics of a harmonic generator, driven by a 200 cycle fork oscillator. The new system derives these frequencies by subdivision of the output of a 36kc crystal oscillator. The subdividing process produces the required frequencies without the use of filters and delivers a 3,600 cps square wave, for driving the subband modulators. This square wave has a very low even harmonic content which is important, if signal leak through the modulators is to be kept to a minimum.

The 3,600 cycle output of the dividing chain is applied to what is essentially the same amplifier as the Model 8288 to obtain the required power level. The amplifier is incorporated in the oscillator package and its power supply energizes the crystal oscillator and dividing chains, as well as the amplifier itself. The differences between the amplifier in the Subband Carrier Oscillator and Amplifier No. 8288 are: the Subband Carrier Oscillator includes a control to make possible very close adjustment of the balance between the two sides of the push-pull circuit (so that even-harmonic generation may be kept to a minimum) and an output transformer, which presents a 5 ohm impedance, instead of 600 ohms, at the output.

In effect, as the amplifier merely switches the power supply potential from one end of the output transformer primary to the other, the amplititude of the square wave produced will vary directly with the power supply potential. Design of the system is such, however, that the variations in the carrier level due to changes in power supply potential caused by normal line voltage variations, will not affect the modulators. Each oscillator is capable of driving up to 140 pairs of modulators.

The crystal oscillator and dividing chains require a stabilized but lower voltage than the amplifier and so may be energized from the unregulated power supply of the amplifier, with a simple zenner diode circuit incorporated to fix the potential applied to them. Thus, the use of very simple power supply circuitry is made possible with consequent higher reliability for this key unit.

Tuned 1KC Amplifier

Tuned Amplifier No. 11403 converts the 1000 cps square wave output of the Subband Carrier Oscillator to a 1000 cps sine wave suitable for test purposes. Three semi-isolated 600 ohm equal outputs are available. The amplifier is provided with an adjustment for setting the output level at 0 dbm. A negative power supply of 25 to 29 volts is suitable for this amplifier. Since the current required is

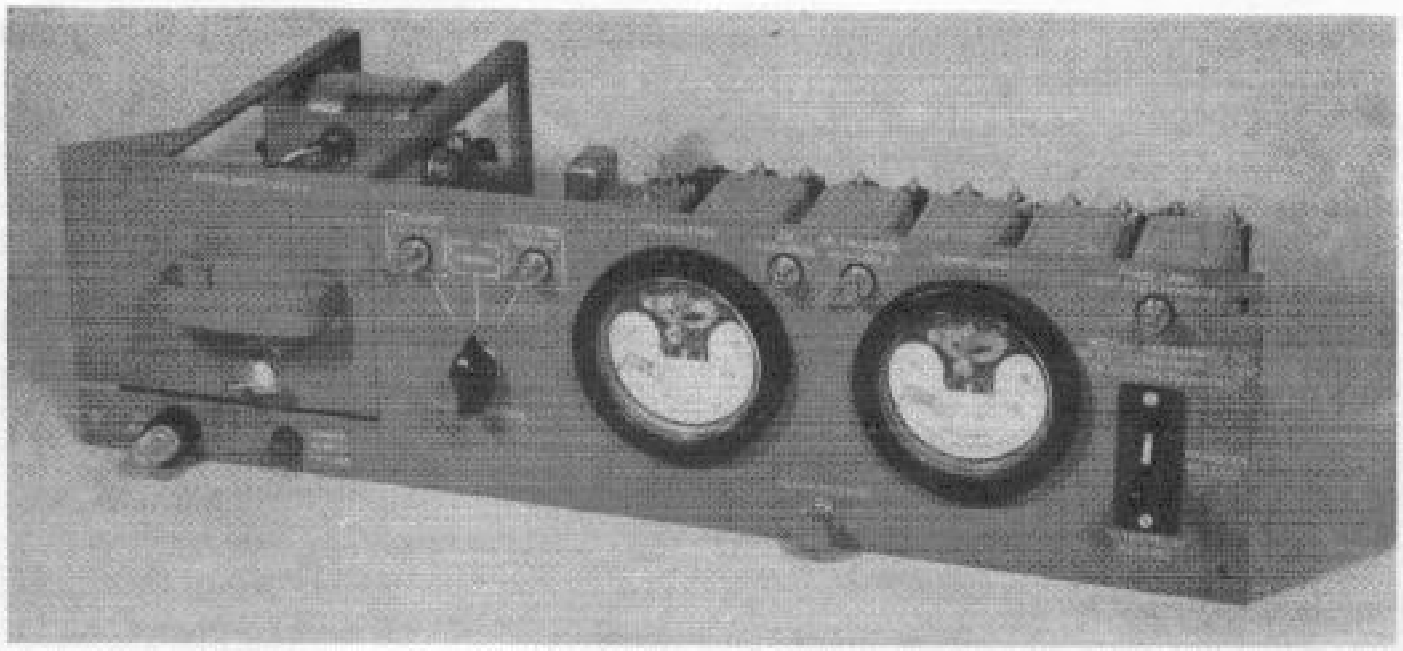


Figure 5. Oscillator Switching Panel

only approximately 20 milliamperes, the unit can be powered by connecting it to one of the outputs of Power Supply No. 10190 or No. 10192 in parallel with either an Amplifier No. 10188 or a Subband Modulator No. 10141.

Electrically the unit is a two-stage, two-transistor amplifier with tuned interstage coupling. It has an unbalanced input circuit and a metallic output circuit. It is a plug-in unit intended for mounting on Rack Shelf No. 11405. The level control is a screwdriver adjustment accessible through an opening in the front panel of the shelf.

This shelf also holds an adjustable resistor, connected in parallel with the modulators. Proper setting of this resistor results in matching the load resistance to the oscillator no matter how many modulators are on the circuit.

Oscillator Switching Panel

The Oscillator Switching Panel is intended for use with large installations of carrier equipment where the maximum reliability of the carrier supply is essential. It is shown with its own 120 v. power supply in place, in Figure 5.

When used with two Subband Carrier Oscillators, it does the following:

1. Monitors the output of each oscillator and activates an alarm circuit, when the output of either oscillator falls below a preset level.
2. Automatically switches to the fallback oscillator, if the regular oscillator's output falls below the preset level.
3. Senses the phase relationship between the regular and fallback oscillators, and indicates when they are in phase and the difference in frequency between them.
4. Under the control of an operator, switches the modulators from one oscillator to the other without interrupting the flow of carrier current.

The oscillators are monitored by meter-type relays connected so that a decrease of 3db in the level of either oscillator will cause contacts in the associated relay to close. A ground will then be connected to the alarm circuit which can be removed only by pressing the alarm-release button.

If the output of the regular oscillator decreases by 3db, the circuitry automatically connects it to the dummy load and connects the fallback oscillator to the modulators. As the switching must be done at the instant of failure, it is not possible to phase the oscillators or bridge the switching relay travel time. Thus complete continuity of the carrier current is not preserved, as with manual switching, and an error may appear in some or all of the dependent channels.

The switching panel occupies the full width of the rack and is 3 rack units high. The power supply mounts on the switching panel chassis as a plug-in unit. The switching panel assembly mounts on Rack Shelf No. 10696.

Subband Modulator

A Subband Modulator, shown in Figure 6, contains a modulator section, and an amplifier section, together with low-pass, band-pass and noise reduction filters. The first two of these set the frequency limits of the subbands, while the third reduces the level of any high frequency noise in the input to the modulator when used as a transmitting modulator, and eliminates the upper-sideband from the output of the mod-amp before it is applied to the channel terminals, when used as a receiving modulator. The characteristics of the three filters are shown in Figure 7A and 7B.

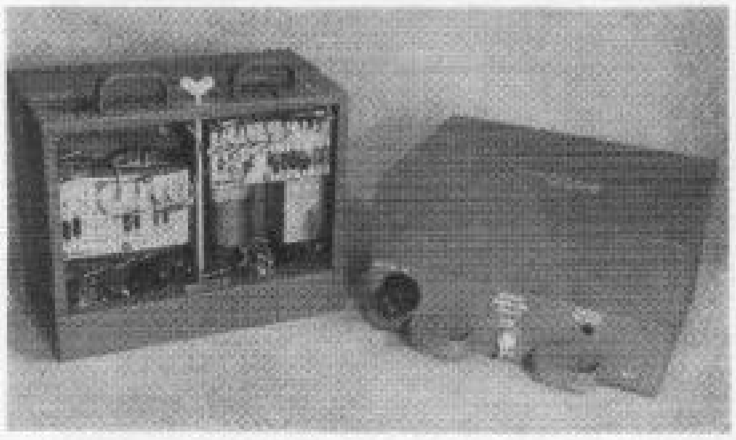


Figure 6. Subband Modulator

Whether the Subband Modulator operates as a transmitting modulator or receiving modulator depends only on the strapping of the receptacle on the shelf position where it is in use. Thus, any modulator may be plugged into any position, either transmitting or receiving without change or adjustment and it will operate in the way required by that position.

The balanced modulator circuit, familiar to Western Union personnel, has been used in this unit. Improved transformer materials and construction techniques make it possible to use but a single carrier balance control to obtain a carrier leak level of —45 DBM (max) at the submod send jack and —35 dbm (max) at the submod receive jack.

Part of the difference, between the 1-volt carrier supply potential used by the modulator and the nominally 4.5 volts available at the oscillator output, is lost in protective resistors at the carrier distribution point on the rack on which the

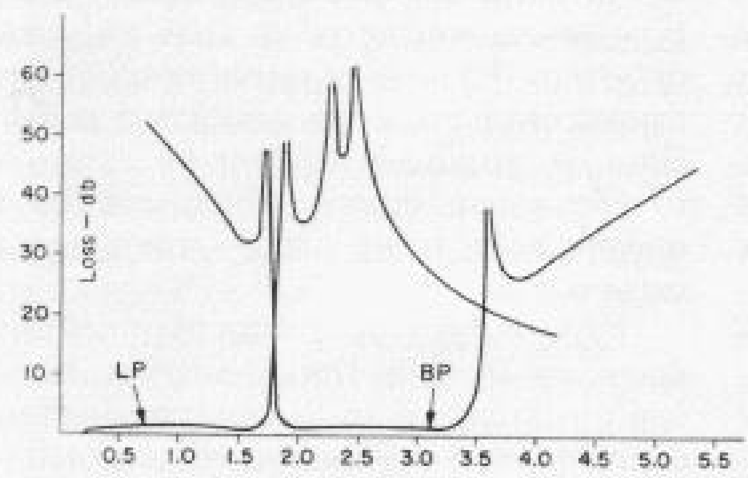


Figure 7a. Low Pass and Band Pass Filters

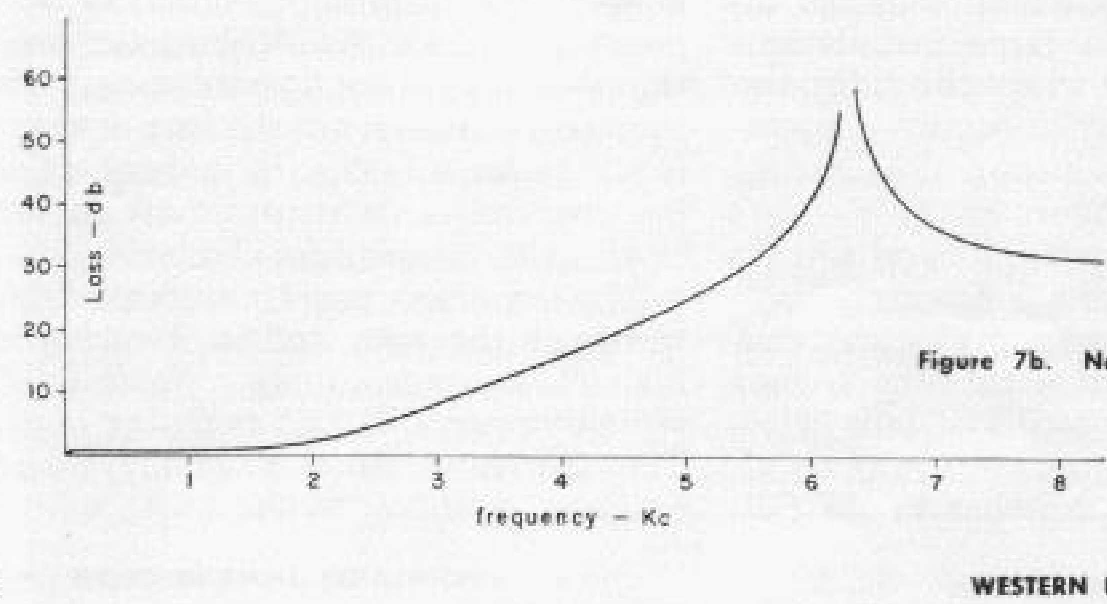


Figure 7b. Noise Reduction Filter

oscillator is mounted. Their resistance is high enough so that, should the distribution line fed through them become short circuited, the oscillator will not be overloaded. At the same time the value is low enough so that the distributed capacitance of the line will not seriously affect the wave shape of the carrier. The remainder and larger part of the voltage drop takes place in the protective resistors at the input of each modulator. These resistors are of such value that a short circuit of the carrier current in one modulator will not affect the operation of the other modulator on the same distribution line.

The high gain and low noise characteristics of the amplifier, following the modulator, makes it possible to operate the modulator at a very low level. The overall gain through the modulator and amplifier is nominally 35db. Since the standard level at the receiving bus is —4dbm per channel, it is necessary to use a 52-A H pad in the input circuit. This pad must reduce the level at the primary of the modulator input transformer (T1) to —39 dbm. A similar pad must be used with the transmitting modulator. The test points "IN" are connected ahead of the pad. This is done so that the signal level may be measured here on a terminating basis if the pad is removed, or on a shunt basis with a V.T.V.M. if the pad is in place. The low signal level permits a correspondingly low level of carrier to be used. The normal carrier level, indicated at the "LEVEL" test points on the modulator panel, is one volt although the modulator will operate satisfactorily with from one half to several times the normal value.

The amplifier circuit is the same as that used in the No. 10188 amplifier except for the input transformer, which is also the output transformer of the modulator section.

Two Subband Modulators mount side by side on a rack shelf and like the oscillators are of the same general size and shape as the Type 60 Channel Terminals.

Power Supplies

Since the one ampere power supply and the three ampere power supply may each have a rather wide range of connected loads, it was necessary to regulate their outputs to avoid too great a difference in output potential between the minimum load and full load conditions. Since the Mod-Amp equipment is not sensitive to moderate voltage changes in power supply it was possible to obtain the required regulation with a simple series—regulator, referenced directly to a zenner diode. Protection of the regulator transistor was obtained without recourse to complicated circuitry by fusing each load separately. This permits using small fuses which blow out without damage to the regulating transistor. The one ampere Power Supply No. 10190, is shown by Figure 8.

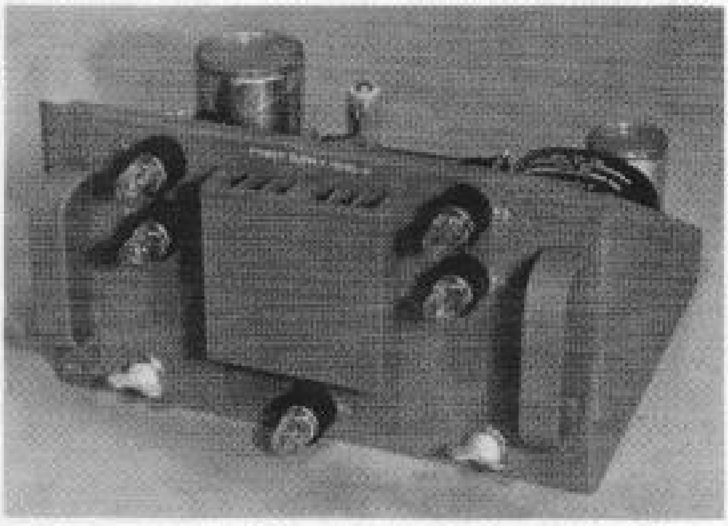


Figure 8. One-ampere Power Supply

Field Trial Equipment

Figure 9 shows a rack of equipment which was used for field trials at the New York Central Office. It operated throughout the tests without malfunction. During these tests it was shown that the output of the new Subband Carrier Oscillator could satisfactorily drive up to 44 pairs of (vacuum tube) Subband Modulators No. 4813-A.

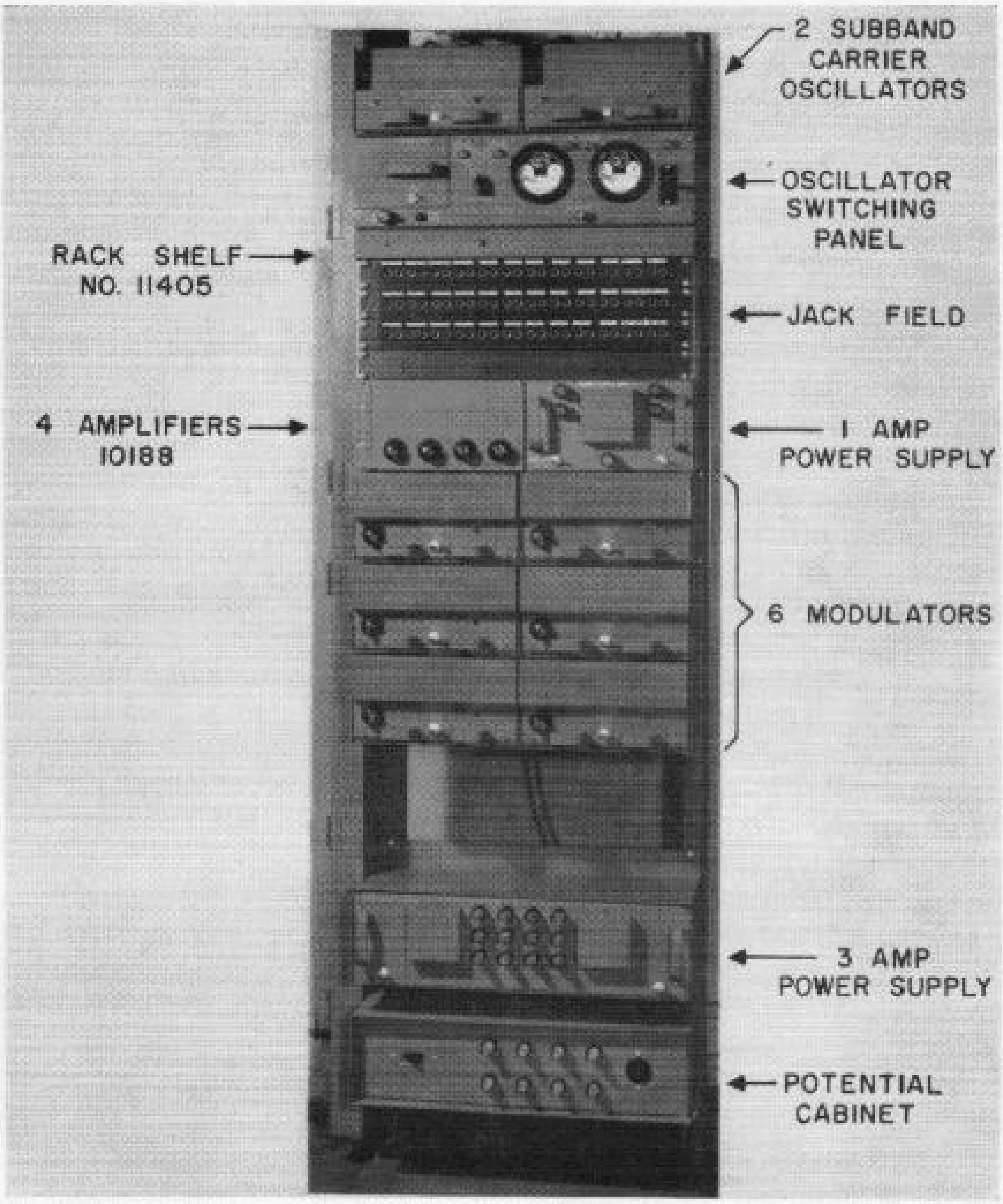


Figure 9. Test Rack

MR. H. C. LIKEL, senior engineer in the Transmission Division of the Plant and Engineering Department, has been responsible for such developments as the Mod-Amp Group, some units of which are in use in AUTODIN, the Network Repeaters No. 11622-A and No. 11724-A to be used in the Class "D" service and the Data Channel Combiner also used in the AUTODIN Switching System.

Mr. Likel received his degree in Electrical Engineering from the Polytechnic Institute of Brooklyn in 1930. He holds a registered New York State Professional Engineers License and is a senior member of the Institute of Electrical and Electronics Engineers.

He is a member of the Institute of Electrical and Electronics Engineers Committee on Data Communication and Telegraph Systems, the American Standards Association Committee on Data Transmission, the Electronics Industries Association Committee on Data Transmission Equipment and is a consulting member of the Association of American Railroads Committee on Transmission. He holds a number of issued patents and several pending applications.

Inauguration of Western Union's

Transcontinental Microwave System

Mr. Walter P. Marshall makes first transcontinental call during press conference.

Western Union's transcontinental Microwave System was put into service on November 17, 1964 when Mr. Walter P. Marshall, President at that time, made the first official cross-country call to San Francisco from the Company's New York Headquarters, using a special push-button telephone.

The new system can handle record and voice communications at high speeds and in large volume. It is capable of handling all forms of electronic communication including high-speed facsimile, data, voice, telegraph and Telex services. An important advantage of this new system is the dual transmission feature which assures maximum reliability and continuity of service. Signals travel simultaneously over separate operating frequencies, using separate radio beam equipment.

The new facility provides the nation with a second, separate transcontinental network of broadband facilities geared to modern, high-speed communication requirements and available for any emergency related to our national defense. The radio beam system's total capacity is designed about 7,000 voice channels, however initially it is equipped to provide 600 voice bands.

The microwave system is providing approximately 80 per cent of the circuitry for Western Union's new Broadband Exchange Service which permits subscribers to select various bandwidth connections by pushbutton telephone for the direct, two-way exchange of data, facsimile and voice communications. The system is also providing a substantial part of the circuitry required for the new AUTODIN system.

Codes
Error-Correcting Devices

Steeneck, R.: Development of Error Correcting Codes—Part II

Western Union TECHNICAL REVIEW, Vol. 19, No. 1 (Jan. 1965) pp. 4 to 13

Part II of this article covers the arithmetic methods of analysing, and designing block codes which correct one-bit, two-bit, and three-bit errors. Two methods of correcting errors are disclosed.

Part I of this article was published in the October 1964 issue of the Western Union TECHNICAL REVIEW.

Principles of Facsimile
Photographic Recordings
Facsimile Processes

Ridings, G. H.: Facsimile Imaging Systems—Part II

Western Union TECHNICAL REVIEW, Vol. 19, No. 1 (Jan. 1965) pp. 14 to 21

This is Part II of a series article on the fundamental principles of facsimile. It was extracted from a paper delivered to the Society of Photographic Scientists and Engineers in February 1964 at the Chemists Club in New York City. Part III will appear in the April 1965 issue of the Western Union TECHNICAL REVIEW.

Part I, which appeared in the October 1964 issue, covered the Principles of Facsimile, the Analogy of Reading, described signal Inversion, Framing, Phasing and compared various scanning and Recording mechanisms.

Teleprinters
Automatic Send-Receive Sets
Apparatus and Equipment

Smith, Fred W.: New 8-Level Teleprinters and ASR Sets—

Part I: Model 33

Western Union TECHNICAL REVIEW, Vol. 19, No. 1 (Jan. 1965) pp. 22 to 31

A new line of 8-level teleprinters and automatic send-receive sets was placed in service by Western Union in December, 1964. These units implement the new 7-bit American Standard Code for Information Interchange LASA X3.4 —1963, with an added 8th bit as a vertical parity check bit. Part I of this article describes the low-cost light-duty Model 33 line of equipment and its theory of operation.

Telegraph Equipment
Carrier Telegraph Terminals
Modulator-Amplifier Groups

Likel, Harry C.: Transistorized Modulator-Amplifier Group

Western Union TECHNICAL REVIEW, Vol. 19, No. 1 (Jan. 1965) pp. 32 to 38

This article describes the transistorized modulator-amplifier group which was developed to replace the older vacuum tube equipment. In conjunction with the Type 60 channel terminals it gives Western Union a completely transistorized carrier telegraph terminal. It, like the Type 60 terminals, is compatible with the old equipment and may be intermixed in an office or the system. This article describes the components: a leveling amplifier, a tuned amplifier, a switching panel, a subband modulator and a 1-ampere and 2-ampere power supply.

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