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The Inventors of this invention in the sense of being the actual devisers thereof within the meaning of Section 16 of the Patents Act 1949 are:— IVAR MO, of Sørliterrasse 36, Lørenskog, Norway, PER REIDAR ABRAHAMSEN, of Villvinveien 1D, Kjeller, Norway and KAARE RAGNAR MEISINGSET, of Ringsveien 16, Stabekk, Norway, all Norwegian Subjects.

COMPLETE SPECIFICATION

Key Material Generator for Cryptographic Equipment

We, INTERNATIONAL STANDARD ELECTRIC CORPORATION, a Corporation of the State of Delaware, United States of America, of 320 Park Avenue, New York 22, New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a key material generator for cryptographic telegraph equipment and in particular to a key material generator for producing psuedo-random sequences.

There are known many types of key material generator with mechanical rotors or with electrical ring counters. Such key material generators are, however, not considered suitable for giving sufficiently long sequence in all cases.

The object of the present invention is to provide a key material generator which with relatively simple circuits is capable of giving very long pseudo-random sequences.

According to the invention there is provided a key material generator for cryptographic telegraph equipment, which includes a plurality of shift registers, each said shift register having the outputs of a selection of its stages combined and the resultant signal fed back to its input, a modulo-2 adder the inputs of which are directly connected to the outputs of the last stages of each of said shift registers, so that when the contents of said shift registers are circulated the contents of said shift registers are combined by said modulo-2 adder, and an output register whose input is connected to the output of said modulo-2 adder so that when said shift registers are driven by the application thereto of a number of stepping pulses a key material combination is produced in said output register.

According to the invention there is also provided a key material generator for cryptographic telegraph equipment, which includes a plurality of shift registers, each said shift register having the outputs of a selection of its stages combined and the resultant signal fed to a modulo-2 adder, a connection from the last stage of each said shift register to its said modulo-2 adder so that for each said shift register the combined outputs from said selected stages and the last of said stages are added modulo-2, a connection from each said adder's output to the input of the corresponding one of said shift registers, a further modulo-2 adder to the inputs of which are directly connected to the outputs of the last stages of said shift registers, so that when the contents of said shift registers are circulated the contents of said shift register are combined by said further modulo-2 adder, an output register having the same number of bit places as the telegraph characters to be processed in accordance with the key material, and a connection from the output of said further modulo-2 adder to said output register, whereby when said shift registers are driven by the application thereto of a number of stepping pulses, a key material combination is produced in said output register.

Other features of the apparatus and the system described herein are claimed separately in our co-pending Applications No. 27791/67 and No. 27792/67 (Serial No's. 1178027 and 1178028).

A telegraph system in which the present invention is used will now be described in conjunction with the drawings, where

Fig. 1a shows functional block diagram

[Price 5s. 0d.]

of an embodiment of the invention,

Fig. 1b shows a block diagram showing the main interconnections between the blocks,

Fig. 1c—i and 2a—h show a detailed schematic of most of the blocks shown in Figs. 1a and 1b,

Fig. 3 shows a detailed schematic of the block 6 in Fig. 2a, a one-shot pulse generator (OS),

Fig. 4 shows a detailed schematic of the block 5 in Fig. 2a, a reset circuit (RES) and clock pulse generator (25kHz OSC),

Fig. 5 shows a detailed schematic of the block 14 in Fig. 2a, a teleprinter drive amplifier (DA) and a reading circuit (RC),

Fig. 6 shows the different logical symbols which are used in Fig. 1c—i and 2a—h, and

Fig. 7 shows how Figs. 1c—i and 2a—h should be arranged in order to constitute a complete circuit diagram.

Functional Block Diagram

In Fig. 1a is shown a function block diagram which has close connection with the detailed block schematic. Certain main parts of the block diagram will be explained in some detail below, whereafter the start procedure and the enciphering and deciphering procedures and telex operations are also explained in connection with the functional block diagram.

Generator of pseudo-random key bits

The key generator comprises two non-linear feed back shift registers called REG I and REG II respectively. Both registers have 15 stages, REG I has twelve of these situated in block 10 and three in block 12, and REG II has twelve stages in block 11, and three stages in block 12. The non-linear feed back logic for both registers is situated in block 12. It will be seen from the block diagram that the two outputs from the registers are added together modulo-2 and that the resulting sequence is stored in REG Z in block 9. During enciphering or deciphering the two registers are shifted, in order always to present a fresh key character in REG Z. All the outputs from the two registers are fed to separate columns on a pinboard. Which outputs to use for the non-linear feed back functions are chosen by means of pins on the pinboard. For register I rows F, G, H and K determine the non-linear feed back function, and for register II rows S, T, V, W.

Generator of 5-bit number "P"

"P" is a 5-bit pseudo-random number produced by the two main registers by means of 5 outputs from each register, selected by means of pins on the pinboard. It will be seen that pinboard rows A, B, C, D, E, M, N, P, Q and R are fed to block 8, i.e. into the set-circuits for the binary counter "C(P)". Each one of the five set input signals is a modulo-2 addition of one output signal from REG I and one output signal from REG II. Thus it will be understood that these combined signals also are pseudo-random.

Counter "C(P)"

The binary counter in block 7 will always count downwards. The function of this counter is to control the number of shift pulses fed to the input register REG X. During enciphering, the number "P" is initially set into the binary counter, which means that REG X is supplied with "P" shift pulses, but during deciphering the number 31—"P" is initially set into the counter. Also, during deciphering, the counter will stop when containing 1, instead of 0, which means that now it will count 31—"P"—1 counts, that is 30—"P" counts. The meaning of this will become clear when the ciphering procedures are described.

Input register REG X

REG X in block 2 consists of 5 equal stages, of which a typical one is shown in Fig. 1a. In addition it has a 6th stage which is a sort of buffer stage. REG X has two modes of operation.

a) It works as a normal 5-bit shift register receiving shift pulses from the input counter in block 4. The input to the first stage comes from the teleprinter through the reading circuit in block 14. (This connection is not shown in the functional block diagram.)

b) It works as a feed back shift register with each stage comprising a modulo-2 adder and a flip-flop, where any output can be connected to any input by means of solder connections on the code plug shown to the left, and these connections are made such as to result in a maximal length sequence $2^5-1=31$. This behaviour is symbolized in Fig. 1a by the X coming through plug A to the left through the modulo-2 adder in block 1 and through the input logic in block 2 up to the flip-flop.

It is also possible to set each bit of the 5-bit register REG X to the result of the modulo-2 addition of one bit in REG X itself, and one corresponding bit in REG Z. This is symbolized in Fig. 1a by the lower modulo-2 adder in block 1 with inputs X and Z.

Pinboard

The pinboard is a board with 10 horizontal terminal strips and 30 vertical terminal strips arranged in a matrix with 300 working positions (crosspoints). The vertical terminal strips are connected to the 30 outputs from the two main registers. Arbitrary outputs from these two registers can be connected to the horizontal rails by means of pins on this pinboard inserted in crosspoints. Then these arbitrary outputs will be led to

the non-linear feedback functions and to the set circuits for the number "P". Also, it is possible by means of row L on the pinboard to set the two registers initially with a starting content.

Plug A

When REG X works as a feedback shift register the five feedback signals are fed back to the five inputs through the plug A shown in the upper left corner of the functional block diagram. When the straps on this plug are made properly, REG X will cycle through a maximal length sequence, i.e. a cycle of 31.

Other parts shown in the functional diagram

It will be apparent from the functional block diagram that it is possible to set REG Z from a tape reader though the input logic in block 9. This mode of operation may be used by those users who require complete security for their messages. The main registers REG I and REG II do not function during this mode of operation, so the input to the left of REG Z is zero. In this case the key-sequence comes from a random tape inserted into the tape reader.

REG Y, also situated in block 9, is only used during the start phase as a buffer register on the enciphering unit. Block 3 contains three circuits which have not yet been mentioned.

1) The MEMO FF is a flip-flop which remembers whether a CARRIAGE RETURN character is detected or not.

2) The SET/RESET circuit is used during the start phase to reset the input register and two main registers.

3) The blocked K_1—K_5 is a normal shift register which is connected as a ring counter, and which is used to control the enciphering and deciphering processes. During enciphering the program counter functions as follows: In K_1 the teleprinter character is read into the register REG X. In K_2 the contents of this register is tested in order to find out whether it contains a FIGURE SHIFT or a CARRIAGE RETURN. If a FIGURE SHIFT is detected, this character is converted into a CARRIAGE RETURN. However, if a CARRIAGE RETURN is detected, it is converted into a LINE FEED. The reason for this will become clear when the telex operation is described. In K_3 the pseudo-random 5-bit number "P" is fed into the binary counter "C(P)". In K_4 the input register REG X is connected as a feedback shift register. The counter "C(P)" counts down to zero and the pulses from this are fed through FF_{S1} in block 4, to the input register in block 2. In K_5 the contents of REG X and REG Z are added modulo-2 and the result put into REG X again. Thereafter, the contents is tested in order to find out whether the resulting character is an allowed character for telex operation or not. If not, the modulo-2 addition is performed once more. The resulting character then is always an allowed character.

Block 7 contains two ring counters, called i_1—i_4 and j_1—j_3 respectively. The function of these two counters is to control the start phase. The two main registers should always start from a random starting point for each new message to be sent. This means that 6 characters have to be presented to them. The first three are directed to REG I and the next three to REG II by means of the two ring counters mentioned.

In block 5 there is an oscillator of about 25 kHz, which triggers a one shot, multivibrator in block 6, which in turn triggers the input counter in block 4. The one shot can be set to different time delays by means of a selector and the different possible teleprinter speeds can thus be realized.

The RESET CCT in block 5 is used in the clear mode or the tape reader mode to reset the two main registers in the key generator.

The TP logic shown in block 4 is a logic circuit which determines the signal delivered to the teleprinter receive coil. This signal consists of a start and a stop pulse supplied by the input counter, and five information bits delivered from the REG X. In the "CLEAR" mode this information comes from register stage number 1, and in "SEND" or "RECEIVE" mode from the buffer stage of REG X. These two inputs are symbolized by the letters X_1 and X_6 on the functional block diagram.

Enciphering process

The enciphering process starts when the reading circuit receives the stop pulse of some clear text character X on operation of the keyboard or automatic transmitter of the teleprinter. The reading circuit starts the input counter, which in turn gives shift pulses to REG X, REG I and II and REG Z through the flip-flop FF_{S2}. In this first phase of the enciphering process REG X is connected as a normal shift register with information input to the first stage, which means that the clear text character will enter REG X, while the preceding enciphered character is sent to the teleprinter from stage number X_6 through the teleprinter drive amplifier. When now REG X contains the five information bits, REG Z contains five new key bits, and "C(P)" is set to a fresh "P" number. Thereafter, REG X is connected as a maximal period feedback shift register of period 31, and pulses from the 25 kHz source are fed to "C(P)" and

REG X. The supply of these 25 kHz shift pulses is cut out when "C(P)"=0, i.e. after "P" pulses. REG X has then been stepped through "P" states and the present state is therefore a function of "P", which can be symbolized by the expression X(P). Finally therefore REG X is set to the result of the addition X(P)⊕Z, where Z is the stored output from the key generator. If the addition gives as result either of the two characters that are not allowed, the addition is performed once more, thus retrieving X(P) because X(P)⊕Z⊕Z=X(P). In this case X(P) is used as the enciphering character.

Deciphering process

The deciphering process starts when the reading circuit receives the start pulse of the enciphered character X(P)⊕Z, which is then shifted into REG X, while the preceding deciphered character is read by the teleprinter through the teleprinter drive amplifier. Then, the contents in REG X and REG Z are added modulo-2 and the result

—X(P)⊕Z⊕Z=X(P)—

is put back into REG X. Now, the clear text character X can theoretically be retrieved by shifting REG X "P" steps backwards in the cycle, or by shifting REG X 30—"P" steps in the forward direction. The last mentioned is carried out by setting C(P) to 31—"P" and counting down to 1. On the receiving station the addition REG X⊕ REG Z is of course also performed twice if an unallowed character is detected.

Start procedure

As explained earlier, 6 characters are needed for providing the main feedback shift registers with start information. These 6 characters are inserted in front of each message to be enciphered and are selected either at random or according to some list giving long cycles in the key generator. These characters are enciphered before transmission by using an initial setting of the main registers from the pinboard as mentioned earlier.

Telex operation

The cipher text should not contain characters which cannot be punched by a normal teleprinter in a TELEX installation, or characters that will disturb the transmission on a TELEX channel, such as letter D in upper case. Such characters are avoided by not using the characters ALL SPACE and FIGURE SHIFT as cipher text. The cipher text alphabet then consists of 30 characters, while there are 31 allowed clear text characters. Therefore, a unique transformation of these 31 characters is not possible. This problem is solved by putting a restriction on the use of CARRIAGE RETURN and LINE FEED. It is observed that on a teleprinter, the operation LINE FEED is nearly always preceded by a CARRIAGE RETURN. Hence if a LINE FEED is always preceded by CARRIAGE RETURN, the clear text alphabet has in fact only 30 characters, thus making unique transformation possible.

Unallowed characters are avoided very easily simply by avoiding the two critical characters in the input register REG X when this is working as a normal linear feedback shift register. Thus, REG X is being stepped along a 30-cycle which contains all possible 5 bit combinations except the two corresponding to the teleprinter characters ALL SPACE and FIGURE SHIFT.

Block Diagram

In Fig. 1b is shown a block diagram including the main control wires, for giving a better understanding of the detailed schematic.

General Description

In Fig. 1c—i and 2a—h are shown a detailed block schematic of an embodiment of the invention. The circuit shown represents an off-line tapeless cryptographic equipment capable of enciphering and deciphering normal teleprinter messages in a form compatible with standard telex procedures.

The main blocks are indicated by broken lines and the terminals of each main block are numbered by numbers individual for each main block. The terminals are furthermore provided with designations so that their interconnections should be readily understood.

In nearly all of the main blocks there are indicated suitable test points. These test points are designated TP1, TP2 . . . TP5 and will not be described further.

In the main blocks there are used logical symbols which are described in detail in connection with the symbol diagram, Fig. 6. All of the logic blocks are provided with codes which are individual for each main block. The flip-flops are in addition provided with functional designations in about the middle of the logical symbol.

Block 1, Fig. 1c, d contains five pairs of modulo-2 adders. All adders except the lowest one comprises one NAND-gate and one EXCLUSIVE-OR-gate. The lowest gate comprises three NAND-gates A1, A2, A3. The outputs of each pair of adders are connected to the inputs of an individual EXCLUSIVE-OR-gate. By means of two gating signals K'5 and K4 either the lower or the upper adder of each pair can have its output switched through to the outputs of the five EXCLUSIVE-OR-gates E1, E2, K1, K2, B2.

Block 2 in Fig. 1c, d contains six flip-flops, X_1—X_6, and associated circuits. The flip-flops X_1—X_5 constitute a feedback shift register (register X) which is used for storing and handling the information elements of teleprinter character. The flip-flop X_6 is used for delay purposes. In addition to the input circuits to the flip-flop X_1—X_6, block 2 also contains four NAND-gates A2, D2, A1, D1 for detecting when the content of the flip-flops X_1—X_5 correspond to the teleprinter characters FIGURE SHIFT (1 . . .), CARRIAGE RETURN (<), LINE FEED (≡) and ALL SPACE (BL), respectively.

Block 3 in Fig. 2d, f contains miscellaneous gating and flip-flop circuits, the most important of which are the MEMO flip-flop used for storing the character LINE FEED during deciphering, the SET flip-flop used for generating the necessary signals for initial setting of the key generator registers, and the main program counter (counter K) comprising five counting stages K1—K5.

Block 4 in Fig. 2c, b contains the input counter $\overline{FFo}$, FFe, FFa, FFb, FFd, FF_{S2}, and associated circuits. This is a binary counter used for governing the stepping of teleprinter characters into and out of the equipment.

Block 5, Fig. 2a which contains the 25 kHz OSC (Clock Pulse Generator) and RES (Reset Circuit) is shown in detail in Fig. 4. The reset circuit is used for supplying DC-signals to the main registers in the key material generator.

Block 6 in Fig. 2a which contains the block OS (One-Shot Circuit or Monostable Circuit with Short Recovery Time) is shown in detail in Fig. 3. This circuit is used for the timing of the input counter.

Block 7 in Fig. 2d, e, f, g, h, contains a ring counter (counter I) with three stages i_2—i_4 and another ring counter (counter J) also with three stages j_1—j_3. These two counters are used for governing the start procedure of the equipment. Block 7 also contains a binary counter (Counter P) with five stages C_1—C_5. The latter is a binary counter used for counting downwards from a setting point received as DC-signals from block 8.

Block 8 in Fig. 2e, g, h contains miscellaneous gating circuits. The gating circuits are used for supplying the counter C_1—C_5 in block 7 with appropriate information from the key material generator in the enciphering and deciphering mode respectively.

Block 9 in Fig. 1e, f contains a key character register (register Z) with five stages Z_1—Z_5. This register normally receives on terminals J, K of stage Z_1 its information in serial form from the key generator. However, information can also be supplied in parallel form from an external tape reader designated TR. Block 9 also contains the main shift pulse amplifier consisting of gates C2, C3, C4, and F, G, H1 and H2. It also contains a shift register (register Y) Y_1—Y_5 which is used as an intermediate storage register during the start procedure.

Blocks 10, 11 and 12 in Fig. 1e, f, g, h, i constitute the key generator, which comprises two 15 bit non-linear feedback shift registers, REG I_1—REG I_{15}, REG II_1—REG II_{15}, with trigger flip-flops and associated output and input gating circuits.

Block 14 in Fig. 2a contains the blocks RC (Reading Circuit) and DA (Driving Amplifier) which is shown in detail in Fig. 5.

PLUG A in Fig. 1c, d contains strapped interconnections between its terminals, which determine the feedback pattern on the feedback shift register X_1—X_5, Block 2, used in the enciphering and deciphering process.

Block TR in Fig. 1f is a tape reader. This device is normally not connected, but can be attached to make possible the use of one time key tape as key material.

The grids designated PB in Fig. 1g, h, i show the schematic of a pin board used for inserting key material information into the equipment. Circles around intersections between horizontal and vertical lines indicate that there is electric connection by means of a shorting pin.

In Fig. 1e, h, 2b are shown several changeover contacts designated either S or $\overline{S}$. These are contacts on a three position lever switch. The middle position of this switch corresponds to rest or clear mode of the equipment. The other two positions correspond to send and receive or enciphering and deciphering mode respectively.

Block TP in Fig. 2a indicates a teleprinter with its transmitting contact and receiving coil. This is also shown in Fig. 5.

Block TB1, Fig. 2a is a terminal strip. S4 in Fig. 2a is a toggle switch whose two positions correspond to single current and double current operation of the teleprinter. S3 in Fig. 2a is a toggle switch whose two positions correspond to twenty and thirty mA double current or forty and sixty mA single current to the teleprinter receiving magnet. The multiposition switch JB in Fig. 2a is used for selecting the proper time constant of the one-shot circuit in block 6, Fig. 2a.

Functional Description

Introduction

As mentioned, the cipher text must not contain characters which cannot be punched by a normal teleprinter in a telex installation, or characters that will disturb the transmission on a telex channel, such as letter D in upper case.

The enciphering process starts when the reading circuit receives the start pulse of a clear text character X_5 on operation of the key-board or automatic transmitter of a teleprinter. The reading circuit starts an oscillator, which in turn gives shift pulses to registers X, Fig. 2c, d, I, Fig. 1g, i, II Fig. 1h, i and Z, Fig. 1e. Thus, the preceding enciphered character is sent to the teleprinter from register X via the teleprinter drive amplifier. When register X contains the 5 information bits, register Z contains 5 "new" key bits and counter P, Fig. 2g, h is set to a fresh P-number. Now, register X is connected as a maximal length feedback shift register, and shift pulses are fed to counter P and register X. The supply of 25 kHz shift pulses is stopped when counter P=0; i.e. after P pulses. Thereafter, register X is connected as a normal shift register and is set to the information register X⊕ register Z. This is the enciphered form of the clear text, which is sent out when the next clear text character is shifted into register X.

This is the normal enciphering process. In order to avoid certain complications in connection with telex channels, the cipher text characters ALL SPACE and FIGURE SHIFT are not used. The first one because some teleprinters cannot perforate ALL SPACE. FIGURE SHIFT is avoided because disturbances of transmission can occur for certain characters in upper case.

Now, when one of these two combinations is detected in the enciphered text, the contents of register Z is added again to register X. Thus, the shifted version of the clear text in register X is sent out as cipher text.

It will be seen that this process is reversible, making deciphering possible.

Enciphering Mode

To begin with, it is assumed that a start procedure which will be explained later, has been completed and that normal enciphering is to take place. The character to be enciphered enters the equipment serially from the teleprinter transmitting contact TP, Fig. 2a which is energized from the reading circuit RC in block 14, Fig. 2a. In the reading circuit RC the current which flows, or not flows, to the transmitting contact is converted to suitable logical levels for the rest of the equipment. The output signal from the reading circuit is passed to block 4, (gate A1), Fig. 2c which contains the input counter FFo, FFe, FFa, FFb, FFc, FFd, Fig. 2c and associated circuits. Upon reception of the start pulse of the character to be enciphered, this input counter will pass through a complete cycle at a rate determined by the one-shot circuit OS in the block 6, Fig. 2a. Signals derived from the input counter are used to govern the stepping of the character into the input register X_1—X_5 in block 2, Fig. 1c, d, and also to step the key generator registers in blocks 10, 11 and 12. When the input counter has completed its cycle, the five information elements of the teleprinter character will be stored in the input register.

The enciphering process will then start. This process is governed by a ring counter k_1—k_6 in block 3, Fig. 2f, called the counter K. The counter K remains in its rest position K1 during the cycle of the input counter. At the end of the input counter cycle, i.e. when the last information element of teleprinter character has been stepped into register X_5 the counter K will step to position K2. In this position, K2, evaluation and possible modification of the plain text character in register X will take place. This is necessary because the cipher text which finally results from the enciphering process must not contain characters which cannot readily be transmitted on a telex channel. In this equipment the characters ALL SPACE and FIGURE SHIFT should not occur in the enciphered text. The former is not present in the plain text, but the latter is. To have a FIGURE SHIFT excluded from the enciphered text, this plain text character will be changed into CARRIAGE RETURN. To avoid confusion, CARRIAGE RETURN in the plain text must be converted into LINE FEED. This is possible because it is assumed that in plain text the two characters, CARRIAGE RETURN and LINE FEED, always occur in pairs, if necessary, the modifications of the plain text described above, are performed in program counter position K2, by applying a shift pulse to the input register stages X_1—X_5. The program counter K then steps to position K3.

In this position, K3, the first step of the enciphering process takes place. The input register X is now connected as a maximum length feedback register. It will receive a number of shift pulses determined by the content of the counter P, Fig. 2g, h, which is constituted by flip-flops C_1—C_6 in block 7, Fig. 2g, h. This counter is stepped downwards from its initial position to zero by the main clock signal. The initial position is determined by a pseudo-random number P transferred from the key generator REG I, REG II, Fig. 1g, h, i, to the counter P, Fig. 2g, h, in parallel form, when the main program counter K, Fig. 2f, is in position K2. When the counter P has reached the zero state, the program counter K will step from K3 to K4, and the second step of the enciphering procedure will take place.

This second enciphering step comprises modulo-2 addition, in block 1, of the content of the input register X with a random number supplied in parallel form from the register Z in block 9, Fig. 1e. As will be

seen from the schematic, the register Z comprises five stages, Z_1 to Z_5 connected as a normal straight shift register. The information passing into register Z is derived from the outputs of the two key generator registers, REG I, REG II, at gate D3 in block 12, Fig. 1i. Register Z is shifted together with the two generator registers REG I, REG II while the plain text character is being stepped in, during program counter position K1. The modulo-2 addition, mentioned above, of the contents of input register X and key character register Z is performed in parallel without any transfer of carry information from stage to stage. Before the program counter K is stepped to K5, the content of the register X is checked to determine whether it can be transmitted to the line. Gates D1 and A2, block 2, Fig. 1d, check whether the register contains the characters ALL SPACE or FIGURE SHIFT, respectively, and if it does the modulo-2 addition is repeated. The content of register X will then be as it was after step one of the enciphering process. Because ALL SPACE is never contained in the normal cycle of a maximum length feedback register and because the position FIGURE SHIFT is automatically bypassed in this equipment, the content of register X after step one of the enciphering process can always be transmitted to the line. As one can see, the results of the second step of the enciphering process is not used when it is a character which cannot be transmitted to the line.

The enciphered character now contained in the register X is transferred to the teleprinter receiving magnet TP, Fig. 2a, during the stepping in of the next plain text character into register X, whereupon the process described above is repeated.

The start procedure mentioned earlier is necessary to ensure different starting points of the key generator registers REG I, REG II from message to message. In the enciphering mode this start procedure comprises the stepping in of 6 teleprinter characters, i.e. 30 bits, into the key generator registers. Simultaneously these 6 characters are enciphered and transferred to the teleprinter receiving magnet TP (and later on to the line). At the receiving or deciphering end, the 6 characters will be deciphered and transferred into the key generator registers of the deciphering equipment. In this way the same starting point is ensured at both the enciphering and deciphering equipment. The 6 characters defining a start point are during normal operation taken from a start point table prepared in advance for a particular feedback pattern for the key generator registers. The sets of characters in this table are so chosen that the combination in Z to be added to X is never an "all zeros" code. During enciphering the start point characters are not transferred directly from the reading circuit to the key generator registers, but are passed through an intermediate storage register, register Y in block 9, Fig. 1e. Register Y receives shift pulses simultaneously with the key generator register REG I, REG II, and the key character register Z mentioned above.

The necessary gating functions during the start procedure are taken care of by means of two three-stage ring counters I and J in block 7, Fig. 2f, h. The counter I, comprising the stages i_2—i_4, is stepped once for each complete cycle of the counter K, Fig. 2f. The counter J, comprising the stages j_1—j_3, is stepped once for each complete cycle of the counter I.

The pinboard PB, Fig. 1g, h, i, stores information on how to set the registers REG I and REG II, Fig. 1e, f, g, h, i, initially. There are $2^{30} \approx 10^9$ possible settings. The initial settings are used for ciphering of the 6 characters which are selected to give adequate cycle lengths in said registers. The counters i_2—i_4 and j_1—j_3, block 7, keep record of the start procedure and determine when to feed the registers with the start information.

The main clock signal governing all the functions in the equipment is derived from a 25 kHz square wave oscillator in block 5, Fig. 2a. In block 5 is also contained a reset circuit which supplies the current needed to set all the flip-flops of the key generator registers to zero position when the equipment is in the plain or rest mode.

Deciphering mode

The deciphering of a character starts with a transfer of a character from the teleprinter transmitting contact TP into the equipment, as in the enciphering mode. The start pulse of the character to be deciphered will also in this case initiate a cycle of the input counter in block 4, Fig. 2c. Simultaneously the information elements of the cipher text character to be deciphered are stepped into the input register X. This happens with the program counter K in its rest position K1. The two steps of the enciphering process will now have to be performed in reverse order. Therefore, in position K2 of the program counter K, the modulo-2 addition of the content of register X and Z will be performed. If the content of register X after the modulo-2 addition is equal to ALL SPACE or FIGURE SHIFT, it is clear that the modulo-2 addition has been performed twice during enciphering. Therefore, it is also repeated here, and this means that only the opposite process of step 1 during enciphering will be performed. A

five stage maximal length feedback register has a cycle length of 31. In this equipment, the position corresponding to FIGURE SHIFT is automatically bypassed. Therefore, the effective length of this register is 30 positions. To reproduce the initial plain text during the deciphering process, it is now necessary to step the register X, 30—P steps. This is done by appropriate setting of the counter P mentioned during the explanation of the enciphering process. The shifting of register X during deciphering is performed in the program counter position K3. Finally, in program counter position K4 a possible opposite modification of the one performed at the enciphering end must be done. As explained above, the character FIGURE SHIFT was modified into CARRIAGE RETURN and the character CARRIAGE RETURN was modified into LINE FEED. Therefore, if the deciphered character contained in register X is equal to CARRIAGE RETURN it must be converted into FIGURE SHIFT. This is done by applying one shift pulse to the stages of register X in program counter position K4. If the content of register X after feedback is equal to LINE FEED, this may be due to either a LINE FEED character before enciphering or due to a converted CARRIAGE RETURN before enciphering. As mentioned above, it is assumed that the characters CARRIAGE RETURN and LINE FEED occur as pairs in the same order as just mentioned. Thus when the character LINE FEED from the feedback shift register operation is the first of a pair, it is unconditionally modified to CARRIAGE RETURN in the position K4 of the program counter. However, an isolated LINE FEED is not modified at this stage of the operation. This modification is also stored by setting the MEMO flip-flop in block 3, Fig. 2d. Provided CARRIAGE RETURN and LINE FEED are always transmitted in pairs, the next character resulting from the feedback shift register operation during deciphering will again be LINE FEED. Since the MEMO flip-flop now is set, the modification of the character LINE FEED will now be omitted in program counter position K4. This means that the deciphered character to be transferred to the teleprinter receiving magnet TP, Fig. 2a, during the next stepping in process, will be LINE FEED. As one will understand, the character CARRIAGE RETURN has in this way been made redundant, and the teleprinter combination normally used for transmitting this character is instead used for transmitting FIGURE SHIFT. The omission of the teleprinter combination FIGURE SHIFT from the enciphered text is introduced in order to avoid a figure case in the cipher text alphabet. This is necessary because it can not be allowed, when transmitting into an unattended telex terminal, to have the answer-back unit released when the cipher text is coming in. As will be known, the answer-back unit is released by the letter D in upper case. By omitting the character FIGURE SHIFT entirely in the cipher text, the teleprinter will never be set to upper case when receiving an enciphered message.

Description of the Main Functional Circuits

Key Generator

The key generator comprises two non-linear feedback shift registers, REG I and REG II (Blocks 10, 11, 12, Fig. 1g, h, i), each with 15 stages, REG I_{1-15} and REG II_{1-15} respectively and with a feedback signal

$$F(A_i,A_j,A_k,A_l)\oplus A_{15},$$

where $F(A_i,A_j,A_k,A_l)$ is a non-linear function, whose table of combinations of the binary variables A_i, A_j, A_k and A_l are the output signals from four of the register stages i, j, k and l are all different, and are otherwise randomly selected by means of pins on a pin board PB.

This is shown in Fig. 1g, h, i, where the feedback signal from REG I is taken from stages Nos. 4, 14, 10 and 9, so that i, j, k and l in this case are equal to 4, 14, 10 and 9 respectively. These four output signals are fed to the gates B4, C1, B3 and C2 in block 12, Fig. 1i, and the combined signal from the gate C2 is added modulo-2 in the gates E4, F1 to the output signal A_{15} from the last stage REG I_{15}. The feedback signal is applied to the register REG I at the gate D1, block 10, Fig. 1e, g.

The feedback signal for the register REG II is similarly taken from the stages Nos. 7, 10, 3 and 6, combined in the gates B1, A1, B2 and A2, block 12, Fig. 1i. This combined signal is added modulo-2 to the output signal A_{15} from the last register stage REG II_{15} in the gates E3, F2 and applied to the register input at the gate D2, block 11, Fig. 1f, h.

This is a type of register which is not yet fully explained mathematically in the literature, but it is evident that a long cycle from such a register will always present a pseudo-random pattern. Moreover, the sequences usually have different lengths, which means that the physical lengths of the key generator registers may be equal. However, there are certain chances that a sequence can be very short. Thus, in this system, the start points are not completely random, but are selected to give adequate cycle lengths. In the present equipment, which has two 15 bit registers, 6 characters must be selected for each message to be

sent. The output signals from the two registers are added modulo-2 in the gates D1, D2, D3 and D4, Fig. 1i, to give the desired sequence of pseudo-random key bits. Such sequences are stored in a 5-bit register Z_1—Z_5, block 9, Fig. 1e. The number of different connections is

$$\binom{15}{4}\times\left(\binom{15}{4}-1\right)\approx 1.86\times 10^6$$

In the two registers REG I and REG II there are used trigger flip-flops. In a trigger flip-flop the content after a clock pulse is dependent upon the input signal as well as upon the signal present in the flip-flop itself. Thus, the following set of equations describes the performance of a register:

$$A_1' = F(A_1, A_2, A_3, A_1) \oplus A_{15} \oplus A_1$$
$$A_2' = A_1 \oplus A_2$$
$$A_3' = A_2 \oplus A_3$$
$$\text{- - - - - - - - - - - - - -}$$
$$A_{15}' = A_{14} \oplus A_{15}$$

A_1 is the signal present in register stage No. 1 before a clock pulse and A_1' is the signal present in the same stage after the clock pulse. Similarly for the other stages, and the performance is identical for the two registers.

Generator for "P"

P is a 5-bit pseudo-random number, taken from the two registers REG I and REG II, Block 10, 11, 12, Fig. 1g, h, i, in the manner shown in block 8, Fig. 2e, g, h. Each bit is the result of a modulo-2 addition of output signals from randomly selected bits in both registers. Block 8, Fig. 2e, g, h, comprises 5 gate complexes to each of which there are applied two signals from the pin board PB. To the first gate complex comprising the gates C1, C2, C3, C4, B1, B2, B3 and D2, Block 8, Fig. 2e, are applied signals from the pin board multiples PB/A and PB/M. As will be seen from Fig. 1g, h, PB/A is associated with REG I, while PB/M is associated with REG II. A similar connection is assigned to the other four gate complexes. The number of different usable connections is

$$\binom{15}{5}\times\binom{15}{5}\approx 9\times 10^6$$

The output from each of the gate complexes which together constitute the number P is applied to a counter C_1—C_6, block 7, Fig. 2g, h.

During enciphering, number P is fed to the binary counter C_1—C_6, but during the deciphering, this counter receives the number 31—P. In both cases the counter counts down to zero, while counting pulses from the 25 kHz source.

Input Register

REG X (Block 2, Fig. 1c, d), consisting of stages X_1—X_5 has two modes of operation.

a) It works as a normal 5-bit shift register, receiving shift pulses at 50 Hz (for 50 Bauds teleprinter speed).

b) It works as a feedback shift register with each stage comprising a modulo-2 adder, e.g. the gate H1, and a flip-flop, e.g. X_1. Any output can be connected to any input by means of soldered connections on a plug, PLUG A, and these connections are made according to some polynominal, resulting in a maximal length sequence $2^5-1=31$. The 5-bit combination representing the character FIGURE SHIFT is removed from the cycle. Thus, REG X goes through a 30-cycle, which contains all possible 5-bit combinations except ALL SPACE and FIGURE SHIFT. There are approximately 15,000 different cycles, to choose between. The shift pulses in this case come from the 25 kHz source, and the number of pulses is equal to the number of steps the counter C_1—C_6, block 7, is counting.

Pin Board

The pin board (PB), Fig. 1g, h, i, is a board with "horizontal" and "vertical" terminal strips arranged in a matrix with approximately 300 cross-points (holes). A conducting pin inserted in a cross-point will connect the horizontal and vertical terminal strips at this particular cross-point. Pins on the pin board determine which outputs to use for the feedback functions, which outputs to use generating the number P and which flip-flops to set initially.

One-Shot Multivibrator

Fig. 3 shows the detailed schematic diagram of block 6 in Fig. 2a. This circuit, OS, gives the time reference for the teleprinter input and output signals. Defined time intervals are obtained by means of a monostable mutivibrator comprising transistors Ts1 and Ts2 and associated components. In the rest mode, transistor Ts1 is conducting, while Ts2 is cut off. A trigger pulse applied through a diode D3 will cut off transistor Ts1. Through the regenerative action of the circuit transistor Ts2 will now become conducting. This state will last until capacitor C1 has been discharged through resistor R3. The transistor Ts1 will start conducting again and Ts2 will be cut off. Transistor Ts4 becomes conducting for a short while, when the circuit flips back again to the rest mode. In this way the timing capacitor C1 will be quickly charged. Thereby, a very

short recovery time is obtained. The pulse length of the circuit will be unaffected by a high duty ratio. The transistor Ts3—4 and Ts5—6 constitute the input network. Triggering of the circuit occurs every time transistor Ts3 is switched on. The resistor R8 connected to the base of Ts3 is used to inhibit possible triggering pulses, when the circuit is in its quasi-stable position. The output signal is taken from the collector of transistor Ts7. In the rest mode, transistor Ts2 is as stated above, non-conducting. Then Ts7 will also be non-conducting and the output level will be high. When the circuit is trigged to its quasi-stable state, Ts2 becomes conducting, and so will also Ts7. The output signal will then be low, i.e. nearly ground potential. The timing capacitor C1 comprises four elements designated C1a—C1d. The purpose of this arrangement is by means of external strapping to obtain different pulse length to adapt the circuit to various teleprinter speeds. Interconnection of terminals 3—4 gives a speed of 75 Bauds, 6—4 corresponds to 50 Bauds, and 5—4 corresponds to 45 Bauds.

The transistors may be of the following types Ts1: 2S 301; Ts2—3: 2S 302; Ts4: 2N 1711; Ts5—7: BSY 95A or equivalent components and all diodes may be of the type 1S 920 or equivalent.

Clock Pulse Generator

Fig. 4 shows a detailed schematic of two different circuits in block 5, Fig. 2a. The upper one is the clock pulse generator, 25 kHz OSC. This is an astable multivibrator comprising transistors Ts1 and Ts2 and associated components. The transistors Ts3 and Ts4 are the output amplifiers of the circuit. The purpose of the diodes D1, D2 and the smoothing capacitor C3 is to avoid a stable state with both transistors conducting simultaneously, which can occur with a conventional astable multivibrator.

Reset Circuit

On the lower part of Fig. 4 is shown a reset circuit RES whose function is to supply a DC signal to the key generator feedback registers. When one of the input transistors Ts6 or Ts7 is conducting, the output transistor Ts5 will also conduct and supply current to the load. If both input transistors are in the cut off state, the output transistor Ts5 will also be non-conducting. The transistors may be of the following types: Ts5: 2S 302; Ts1—4, 6—7: BSY 27 or equivalent components, and the diodes D1—2 may be of the type 1S 920 or equivalent.

Reading Circuit

Fig. 5 shows the detailed schematic diagram of the circuits contained in block 14 in Fig. 2a. On the upper part of Fig. 5 is shown the reading circuit RC. A current of approximately 40 mA is fed from the +50V supply through the resistors R17 via terminals 6 and 3 through the teleprinter contact TP and back to the reading circuit RC. If the teleprinter contact is closed, the input transistor Ts9 will be conducting. If the teleprinter contact is open, Ts9 will be non-conducting. The output signal taken from the collector of Ts9 will be low when the teleprinter contact is closed, which corresponds to MARK, and high when the teleprinter contact is open, which corresponds to SPACE. To have the opposite phase of output signal available an inverting stage comprising Ts8 and associated components is added to the reading circuit.

Driving Amplifier

On the lower part of Fig. 5 is shown the detailed schematic of the teleprinter driving amplifier DA. This circuit comprises input transistors Ts1, Ts2 and Ts3 with associated components two constant current generators, Ts6 and Ts7 with associated components and two teleprinter current switching transistors Ts4, Ts5 with associated components. By means of external connections, S3, the circuit can be adapted to single or double current operation and to different current levels. In single current operation the two constant current generators are connected in parallel. In MARK condition transistor Ts5 will then be conducting and Ts4 non-conducting. The current from the constant current generators will then flow through the teleprinter receiving magnet M. In SPACE condition, the transistor Ts4 will be conducting and Ts5 non-conducting. No current will then flow through the teleprinter receiving magnet M. On the input side, MARK corresponds to high input signal and SPACE to low input signal. The transistors may be of the following types: Ts1, Ts2, Ts3, Ts8, Ts9: BSY 95A; Ts4, Ts5: 2N 1893; Ts6, Ts7: 2N 2904A or equivalent components, while the diodes D1, D2 may be of the type ZF 5.6 or equivalent.

Logical Symbols

On Fig. 6 is shown the different symbols representing the various logic functions in the main diagram. These are: Inverter, 2-input NAND-gate, 3-input NAND-gate, 5-input NAND-gate, JK-flip-flop with present and an EXCLUSIVE-OR-gate.

These logic symbols and their function are described in detail in the leaflet "Series 73 Solid Circuit Semi-conductor Networks", Bulletin No. DL-S 567650, July 1965, which is published by Texas Instruments Incorporated. The symbols shown from the top in Fig. 6, correspond to the following TI networks: 1/4 SN 7350, 1/4 SN 7360, 1/3

SN 7331, 1/2 SN 7311, 1/2 SN 7302 and 1/2 SN 7370. The symbols corresponding to 1/4 SN 7350, 1/2 SN 7302 and 1/2 SN 7370 are for simplification drawn somewhat differently.

WHAT WE CLAIM IS:—

1. Key material generator for cryptographic telegraph equipment, which includes a plurality of shift registers, each said shift register having the outputs of a selection of its stages combined and the resultant signal fed back to its input, a modulo-2 adder the inputs of which are directly connected to the outputs of the last stages of each of said shift registers, so that when the contents of said shift registers are circulated the contents of said shift registers are combined by said modulo-2 adder, and an output register whose input is connected to the output of said modulo-2 adder so that when said shift registers are driven by the application thereto of a number of stepping pulses a key material combination is produced in said output register.

2. Key material generator for cryptographic telegraph equipment, which includes a plurality of shift registers, each said shift register having the outputs of a selection of its stages combined and the resultant signal fed to a modulo-2 adder, a connection from the last stage of each said shift register to its said modulo-2 adder so that for each said shift register the combined outputs from said selected stages and the last of said stages are added modulo-2, a connection from each said adder's output to the input of the corresponding one of said shift registers, a further modulo-2 adder the inputs of which are directly connected to the outputs of the last stages of said shift registers, so that when the contents of said shift registers are circulated the contents of said shift register are combined by said further modulo-2 adder, an output register having the same number of bit places as the telegraph characters to be processed in accordance with the key material, and a connection from the output of said further modulo-2 adder to said output register, whereby when said shift registers are driven by the application thereto of a number of stepping pulses, a key material combination is produced in said output register.

3. Key material generator according to claim 2, in which each said register comprises a plurality of triggering flip-flop circuits, the control inputs to each of these circuits being connected to the output of the preceding circuit, so that the register operation is such that the next content of an arbitrary flip-flop is equal to the sum modulo-2 of the present contents of that flip-flop and the preceding flip-flop.

4. Key material generator according to claim 2 or 3, in which each said shift register has an individual feedback loop whereby outputs from two or more arbitrarily chosen register stages are combined in order to produce a non-linear feedback signal, and in which said outputs are chosen by inserting pins in a pin board on which the outputs from all registers stages are accessible.

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Reference has been directed in pursuance of Section 9, sub-section (1) of the Patents Act, 1949, to Patent No. 1,120,032.

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2. Key material generator for cryptographic telegraph equipment, which includes a plurality of shift registers, each said shift register having the outputs of a selection of its stages combined and the resultant signal fed to a modulo-2 adder, a connection from the last stage of each said shift register to its said modulo-2 adder so that for each said shift register the combined outputs from said selected stages and the last of said stages are added modulo-2, a connection from each said adder's output to the input of the corresponding one of said shift registers, a further modulo-2 adder the inputs of which are directly connected to the outputs of the last stages of said shift registers, so that when the contents of said shift registers are circulated the contents of said shift register are combined by said further modulo-2 adder, an output register having the same number of bit places as the telegraph characters to be processed in accordance with the key material, and a connection from the output of said further modulo-2 adder to said output register, whereby when said shift registers are driven by the application thereto of a number of stepping pulses, a key material combination is produced in said output register.

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