Description of Sturgeon (T52ca model) cipher machine

Introduction

The T52ca is a German teleprinter and a cipher machine. It emits or receive characters. If the Cipher mode is set, each character is ciphered before it is emitted or deciphered before is is received. If the sender and receiver have set their machine on the same way (they uses the same key), they exchange texts in clear text from their point of view. An other people who taps the dialogue views only gibberish (the cipher text).

Teleprinter

A teleprinter uses the Baudot code. This one codes letters, figures and some others characters ('+', '/', ...) with five bits for each character. Each five bits configuration correspond to two characters. The good interpretation is function of the present mode: letter or figure one. For exemple, in letter mode, the bits string 10000 means letter 'E', but it means the number '3' in the figure mode.

The are special characters with special meaning
(but with the same meaning in letter and figure mode):

00010	CR	(Carriage Return)
01000	NL	(New Line)
11111	LS	(Letter Switch: switchs from figure mode to letter mode)
11011	FS	(Figure Switch: switchs from to letter mode to figure mode)
00100	SP	(Space)
00000	BL	(Blank: Empty character)

Baudot Code

```
Letter mode (with Bletchley representation of the special characters)
    '/':'00000', 'E':'10000', '4':'01000', '9':'00100', '3':'00010',
    'T':'00001', 'A':'11000', 'S':'10100', 'D':'10010', 'Z':'10001',
    'I':'01100', 'R':'01010', 'L':'01001', 'N':'00110', 'H':'00101',
    'O':'00011', 'U':'11100', 'J':'11010', 'W':'11001', 'F':'10110',
    'Y':'10101', 'B':'10011', 'C':'01110', 'P':'01101', 'G':'01011',
    'M':'00111', 'K':'11110', 'Q':'11101', '+':'11011', 'X':'10111',
    'V':'01111', '8':'11111'
Figure mode
    '#':'00000', '3':'10000', '#':'01000', '#':'00100', '#':'00010',
    '5':'00001', '-':'11000', "'":'10100', '#':'10010', '+':'10001',
    '8':'01100', '4':'01010', ')':'01001', ',':'00110', '*':'00101',
    '9':'00011', '7':'11100', '#':'11010', '2':'11001', '*':'10110',
    '6':'10101', '?':'10011', ':':'01110', '0':'01101', '*':'01011',
    '.':'00111', '(':'11110', '1':'11101', '#':'11011', '/':'10111',
    '=':'01111', '@':'11111'
}
```

Remarks: Berkeley codification uses only the text part with a spcial representations of special characters (CR, LF, LS, FS, SP, BL).

Example of sentence:
- In German: "ES IST DER 4. FEBRUAR 1942 [LF] [CR]“
- In Baudot code (Bletchley representation): ES9IST9DER9+RM98FEBRUAR9+QORW43

Cipher mode – introduction

The bits of each character undergo an addition without carry (XOR) and a permutation.

Example:
- Plain character: 01001 (L)
- Addition character: 01110
- Result: 00111
- Permutation: 53241
- Crypto character: 11010 (J)

The addition character and the permutation change at each step (at each character). The Permutation consists of five permutations. A key character actives or does not actives each of theses five permutations. The permutation takes place if the correspond bit is zero.

Example
- Permutation circuit: (1-5), (4-5), (3-4), (2-3), (1-2)   [bit 1 is exchanged (or not) with bit 5, ...]
- Permutation character: 01101
- Effective permutation: (1-5), -, -, (2-3), -   : 53241

Cipher mode – generation of the bits stream

The ten bits keys (The Addition character and the Permutation character) come from ten wheels. They are named A from K (from right to left). At each step (at each character ciphered or deciphered), sensors read bits from the wheels and each wheel steps one sector. The wheels have a number of sectors first between them. As a result, we return to the starting position after several billion characters entered. Happily, the bit setting of each wheel is immutable (unlike the SZ40 cipher attachment).

```
Bit configuration of each wheel
            1         2         3         4         5         6         7
   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345
K="01011100101011100111011110001110100001111100010"
J="00111000111001011101000011110001011010110110011010110"
H="11110001101000110101100011111100110101101001111100011110100"
G="1111010010011101011010110100001101001011101111000110011000101"
F="10110111101100111000010000011101111110001010101011111000010111100"
E="11111001010011010000101111100111010101100010100010001011111110101"
D="0001001110011100101110001100100101111001000101101010001110000011010"
C="0100001111011101110001001001110000110000110001011111101011001011000011"
B="01101111110000001110001101110000001101010111000000101111001111110001000101 0"
A="0111010101110011001110110000011100011110100000010110111000100110010011110"
   1234567890123456789012345678901234567890123456789012345678901234567890123456789012345
```

Remark: For each Wheel, the sensor is before the benchmark which indicate the position of the wheel: K: 16 steps before position, J: 18 steps, H and G: 20 steps, F and E: 22 steps, D and C: 23 steps, B: 24 steps, A: 25 steps.

Exemple of bits stream for four characters ciphered (Position and sensor between parenthesis):

K	J	H	G	F	E	D	C	B	A	10 Bits
06(37)	16(51)	25(05)	31(11)	46(24)	36(14)	41(18)	06(52)	01(48)	09(57)	0 1 0 0 0 1 0 1 0 0
07(38)	17(52)	26(06)	32(12)	47(25)	37(15)	42(19)	07(53)	02(49)	10(58)	1 1 0 1 0 0 1 0 1 0
08(39)	18(53)	27(07)	33(13)	48(26)	38(16)	43(20)	08(54)	03(50)	11(59)	1 0 0 1 0 1 1 1 1 1
09(40)	19(01)	28(08)	34(14)	49(27)	39(17)	44(21)	09(55)	04(51)	12(60)	1 0 1 1 1 0 1 0 1 0

etc.

The main-key switches, the SR and the Inner-key

Output from the wheels (Output Channel)

The ten bits keys (The Addition character and the Permutation character) come from ten wheels... but not directly!
The sensors of wheels read bits. One sensor read one bit and there is one sensor by wheel. We obtain the ten bits output from the wheels.

The message key unit

The message key unit consists of 15 transposition units. It is connected between the code wheel sensors ans the main-key switches. The role of message key unit is to permute the order of the wheels before the main-key switchs mixes again the order of the wheels. But the message key unit modifies the wheel order at each message. It is part of the external key (with the starting position of the wheel). The main-key switchs fixes wheel order for the day. It is the Inner-key.

The setting of the machine is achieved thanks to 5 levers. For example, the setting UTPYW actvates the t1, t2, t3, t4 and T5 transpositions switches, then gives the BADCFEHGKJ transposition (the wheels are swappend two by two). The particular setting PZXUS corresponds to the identity transposition.

The main-key switches

Then the main-key switches mixes circuits. The input comes from the message key unit and then form the ten wheels (ABCDEFGHJK). These ten switchs (one switch by wheel) are labelled 1,3,5,7,9,I,II,III,IV,V. An electric circtuit forbides two wheels to occupe the same positions. For example wheels A and B cannot be associated to III position together. For each setting, the wheels operate on differents relays (SR1 to SR10).

Example of setting: 3, II, V, 1, 9, I, 7, III, 5, IV. If the message key unit is in nutral position (PZXUS), then wheel A is in 3 position, the wheel B in II position, on so on, until the wheel K is in IV position. The wheel A (3 position) operates on SR2, SR6, SR8 and SR10. The relay SR4 is the sum (modulo 2) of bits from positions 1, 9, II and IV.

The main-key switches

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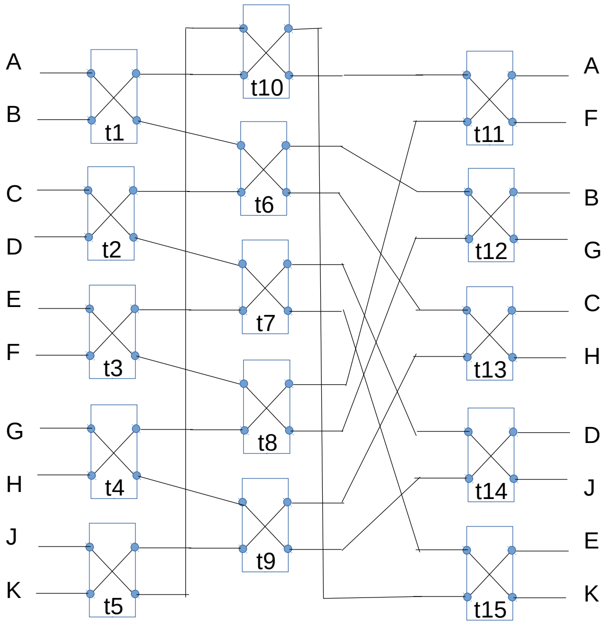
	1	3	5	7	9	I	II	III	IV	V
SR[1]:				X	X	X			X	
SR[2]:	X	X	X	X						
SR[3]:				X		X	X			X
SR[4]:	X				X		X		X	
SR[5]:	X				X			X		X
SR[6]:	X	X					X			X
SR[7]:						X	X	X	X	
SR[8]:		X	X		X				X	
SR[9]:			X	X		X		X		
SR[10]:		X	X					X		X

==

The message key unit (with its 5 levers [1,2,3,4,4] and its 15 transpositions units [t1, t2, ..., t15])

Lever		P	S	T	U	W	X	Y	Z
	t1				X	X	X		X
1	t6		X			X		X	X
	t11			X			X	X	X
	t2			X	X	X		X	
2	t7	X			X		X	X	
	t13		X			X	X	X	
	t3	X	X	X		X			
3	t8		X		X	X		X	
	t13			X	X	X			X
	t4	X		X				X	X
4	t9		X	X		X			X
	t14	X	X	X			X		
	t5	X				X	X	X	
5	t10	X		X			X		X
	t15	X			X			X	X



Key-Table and message key

Inner-Key

The Inner key is the setting of ten switchs (one switch by wheel) labelled 1,3,5,7,9,I,II,III,IV,V. An electric circtuit forbides two wheels to occupy the same positions. For example wheels A and B cannot be associated to III position together.

Example of an Inner-key:

3, II, V, 1, 9, I, 7, III, 5, IV.

If the message key unit is in nutral position (PZXUS), then wheel A is in 3 position, the wheel B in II position, on so on, until the wheel K is in IV position. .

The encipher-transmit / receive-decipher circuit

The encipher-transmit circuit is composed by two units each one consiting of five relays. In cipher mode, the first unit used is the subsitution's one then operates the transposition's one.

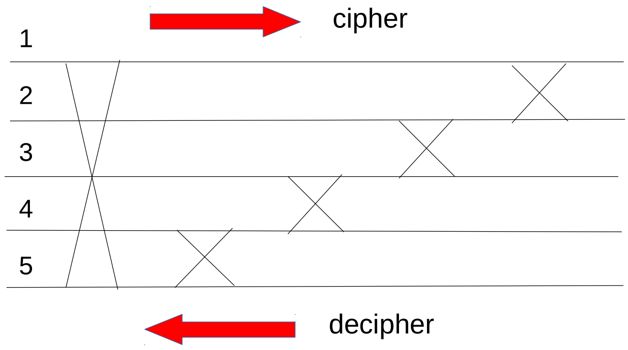
Conversely, in the receive-decipher circuit, the first unit used is the transposition unit and after the subtitution's one.

The substitution unit

The subsitution unit realises a XOR operation between the received signal (a plain or cipher character) and a key character produced by the keys wheels and the other stuffs (main-key switches and message key unit). It is composed by five relays: SR6 to SR10. Each relay operates on one bit of the signal. The SR6 operates on first signal bit, the SR7 on the second, on so on. Example:

Input signal	SR6->SR10 (XOR)	Output signal
00000	01011	01011
11111	01011	10100
01010	01011	00001

The transposition unit



The transposition unit can permute bit 1 and bit 5, bit 4 and bit 5, bit 3 and bit 4, bit 2 and bit 3, bit 1 and bit 2. We represent this by the formule (1-5), (4-5), (3-4), (2-3), (1-2)

Each transposition unit is materialized by a relay. The relay SR1 transposes bits (1-5), the relay SR2 transposes bits (4-5), the relay SR3 transposes bits (3-4), the relay SR4 transposes bits (2-3) and the relay SR5 transposes bits (1-2).

A key character actives or does not actives each of theses five permutations. The permutation takes place if the correspond bit is zero.

Examples

Key character	Permutation	Global
00000	(1-5), (4-5), (3-4), (2-3), (1-2)	15234
11111	nothing	12345
00101	(1-5), (4-5), - , (2-3), -	53214
10101	- , (4-5), - , (2-4), -	13254

External-Key

The External key is the setting of the Wheel start positions. A key-list specifies sets of wheel start positions, each one is indexed by a double letter, for example FF is for 53 for the first wheel K.

Example:

QEP FF OO PP AA ZZ VV CC MM HH UU

Then the start positions of the wheel are: 53,44,12,25,18,47,52,20,11,37 for the wheels from K to A.

Chat

The cipher clerks exchange information between messages sent or received. This may be unimportant conversation ("how are you Siegred?") or the indication of the new message key, and finally the indication that they are moving from the clear mode to the encrypted mode or vice versa.

Example of changing message key: "QEP 12 25 18 47 52"
Example of swiching from plain mode to cipher mode: sender: "UNUM", ACK of receiver: "VEVE"
Other examples: "QRV ?" meaning "understood ?", sender: "ALLES KLAR ?", receiver response: "JA, HIER ALLES KLAR" (is everything clear ?, yes, everything is clear).

Because the cipher clerks only see plain text (even they work in cipher mode), sometimes, they exchange important information (for example message key) in plain mode.

Cryptanalyse

Messages ciphered by the T52ca are very difficult to break. Happily, often cipher clerks reset their machine before exchange a new message. After this, the Wheel start position are reset to their initial position (corresponding to the start of the last message). A lever of the machine permits this operation: the wheels come back to an initial position. As a result, many messages are superimposable (they are "in depth").