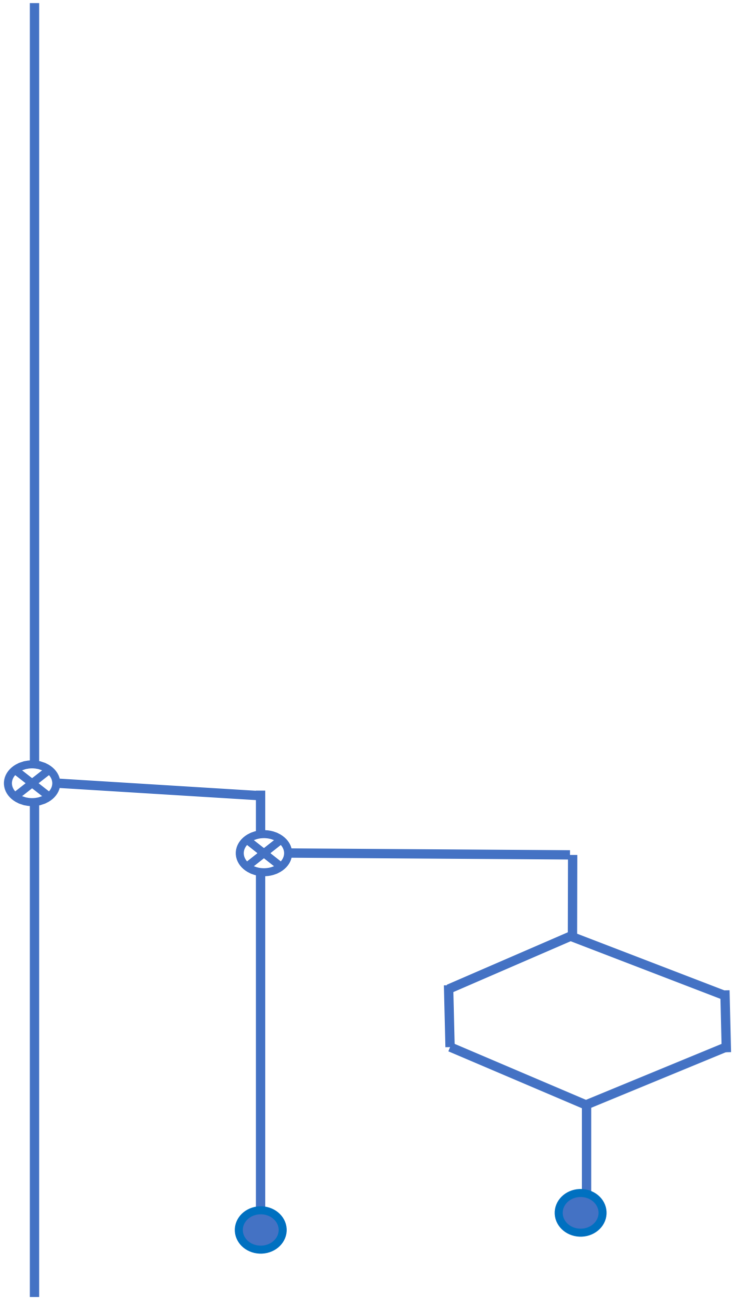

The Enigma of Forth

SVFIG
May 22, 2021
Bill Ragsdale

Today . . .

The Enigma cyphering machine was invented in 1920s with limited commercial acceptance.

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In the 1930s it was adopted by the German government for military communications.

Through the joint effort of Poland and England many/most of German radio communications were decoded.

Original Enigma, 3 rotors

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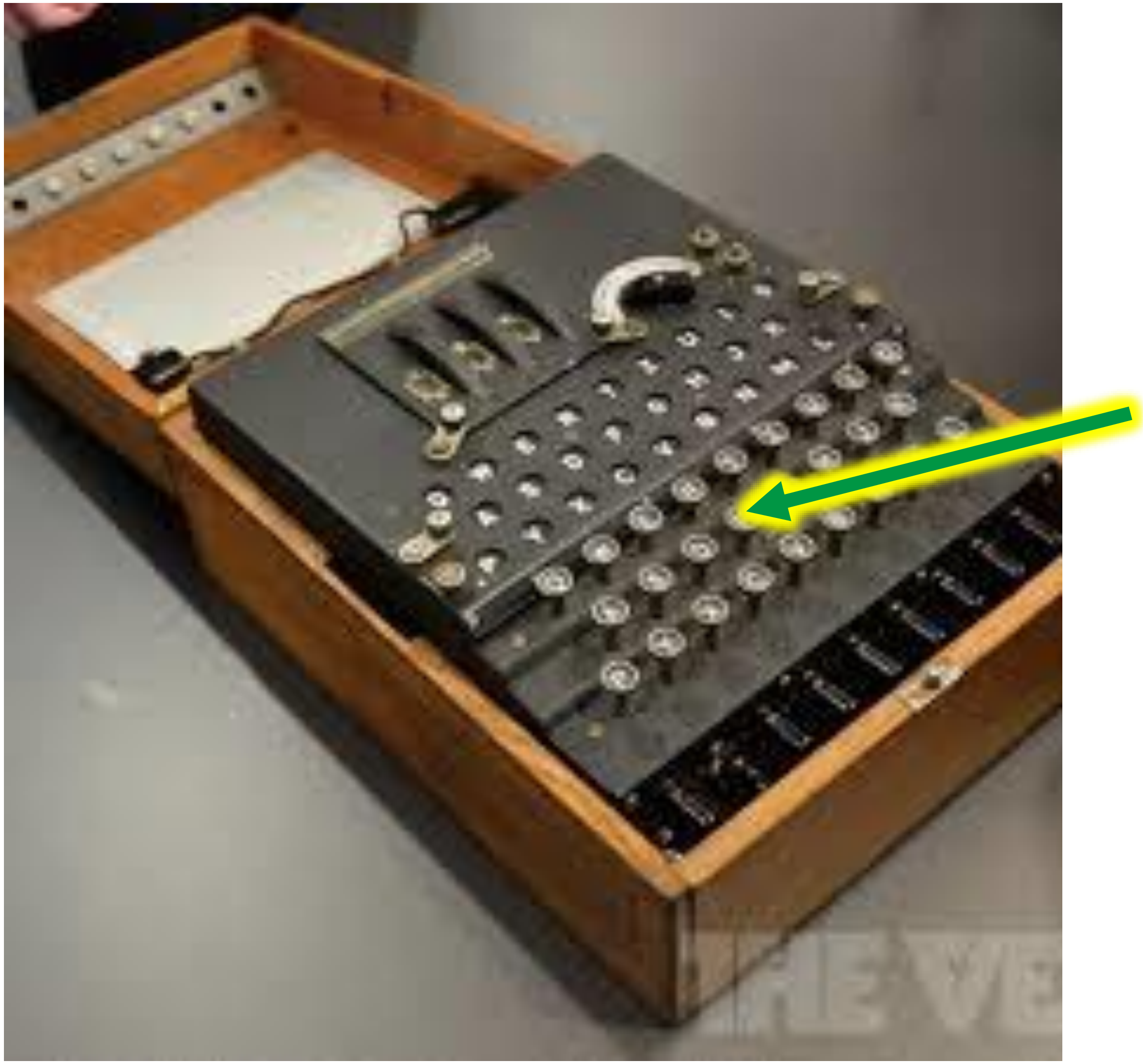
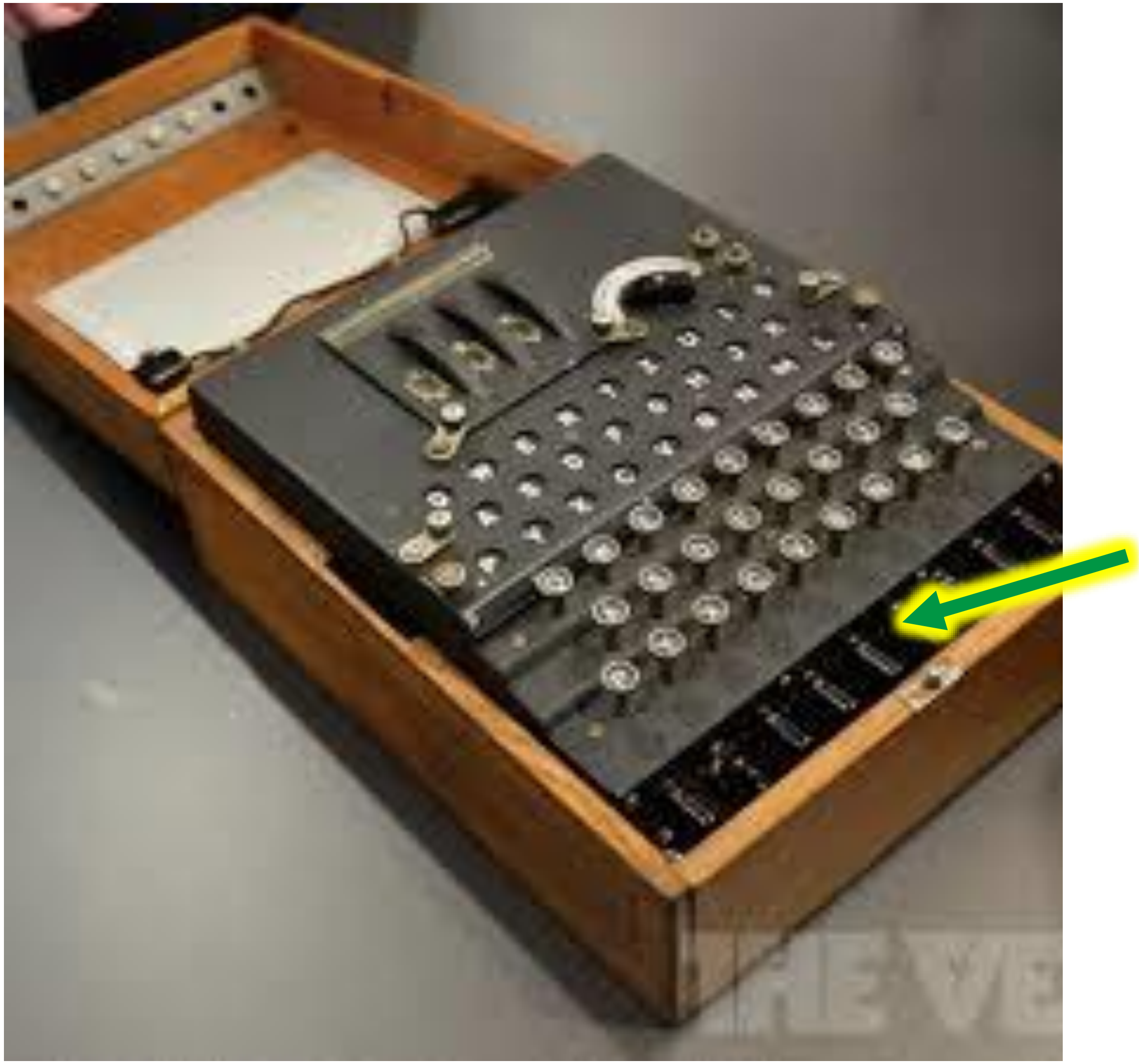


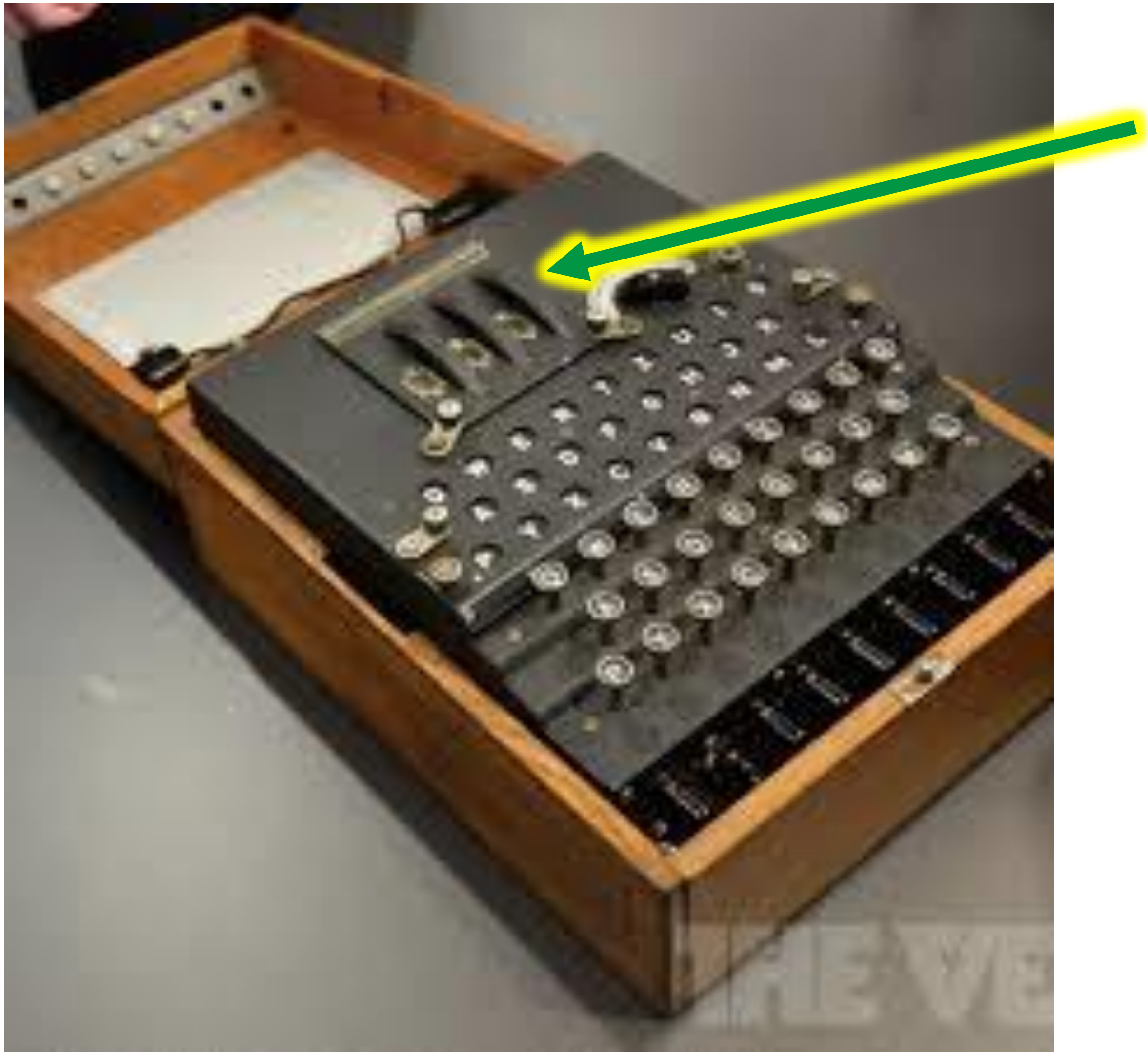
Keyboard

Original Enigma, 3 rotors



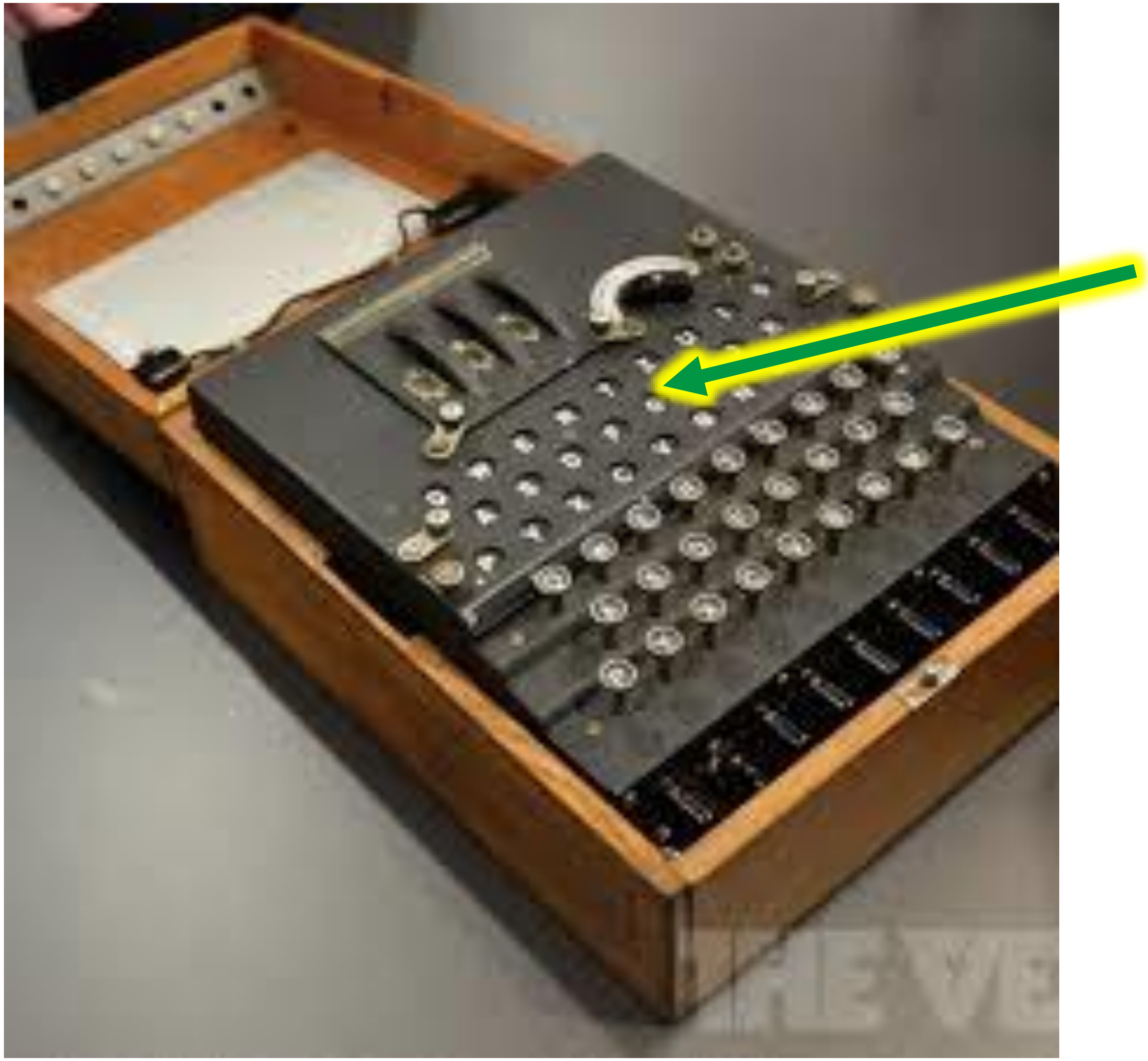
Plugboard

Original Enigma, 3 rotors



Rotors

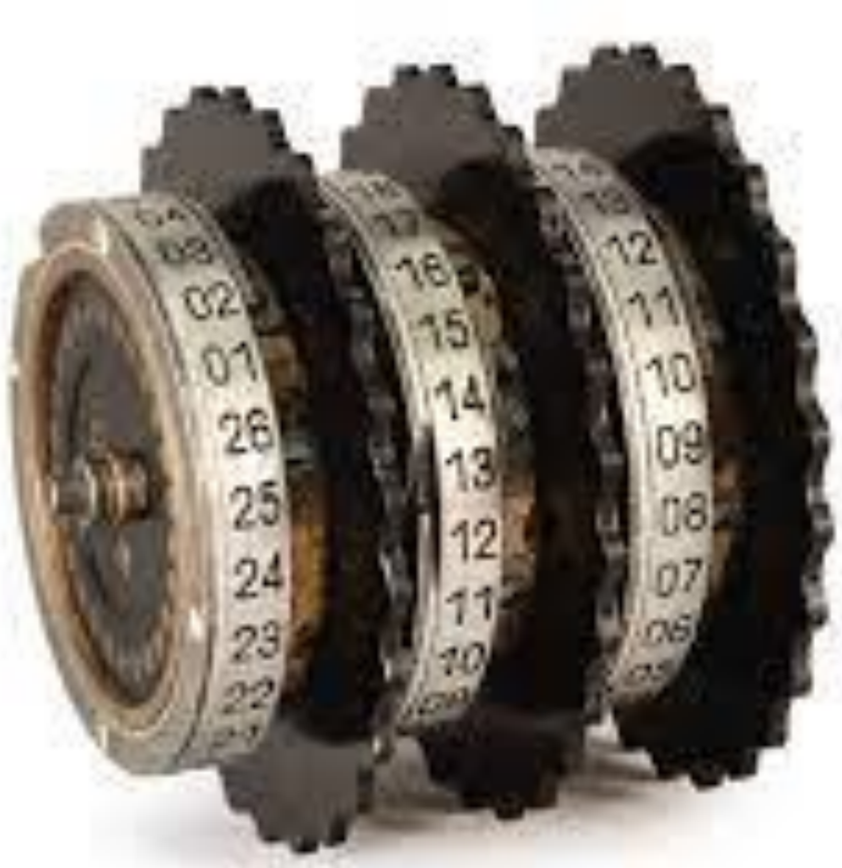
Original Enigma, 3 rotors



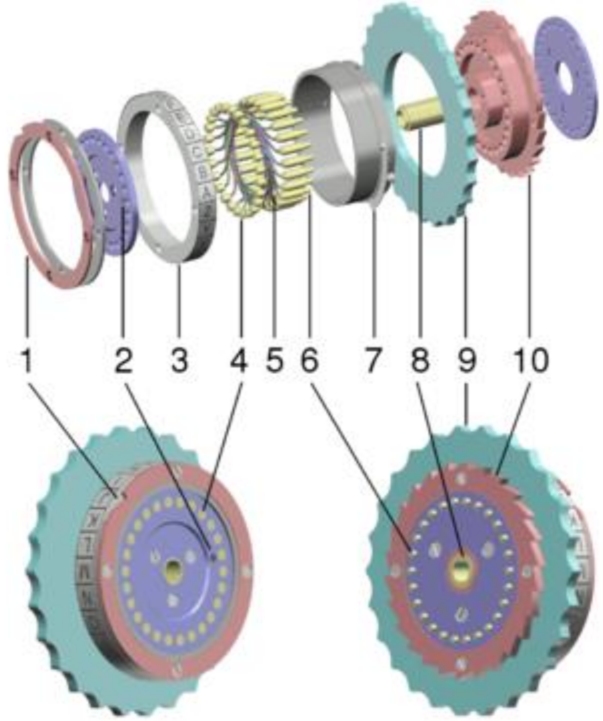
Lamps

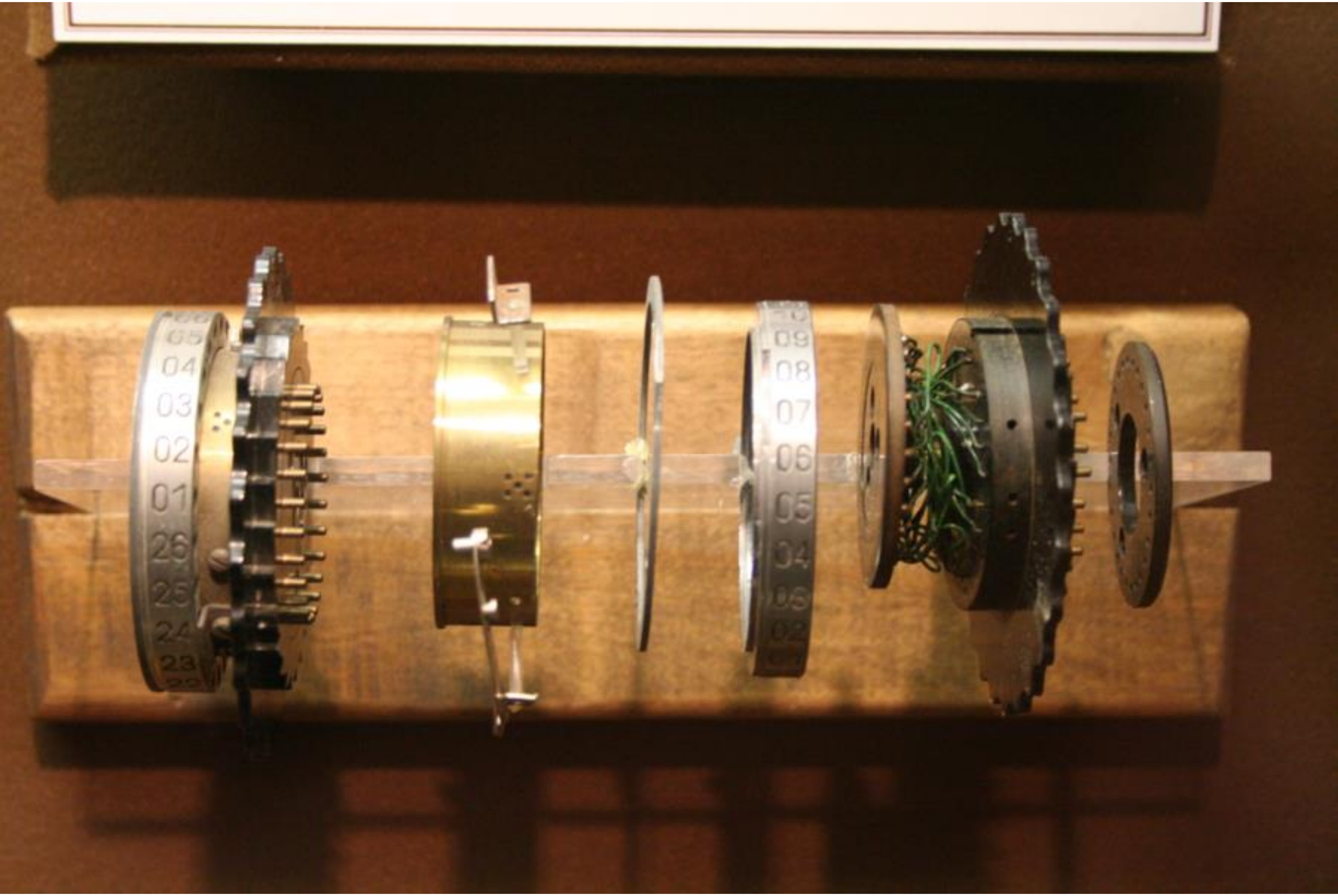
DOYLE

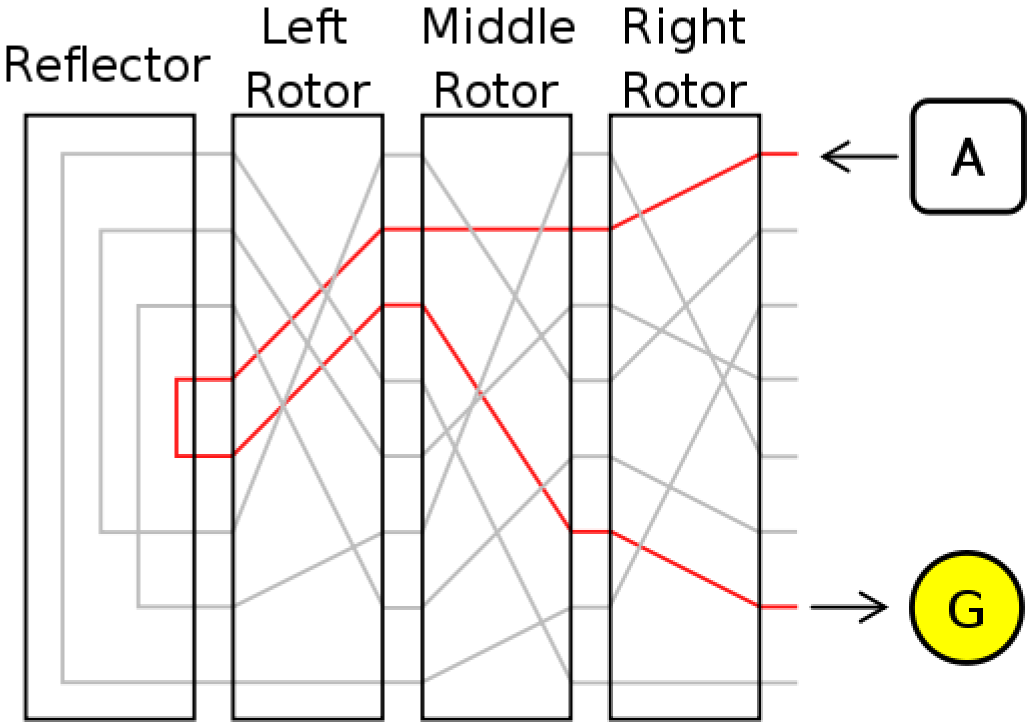
The Rotor Assembly



Rotor Exploded View

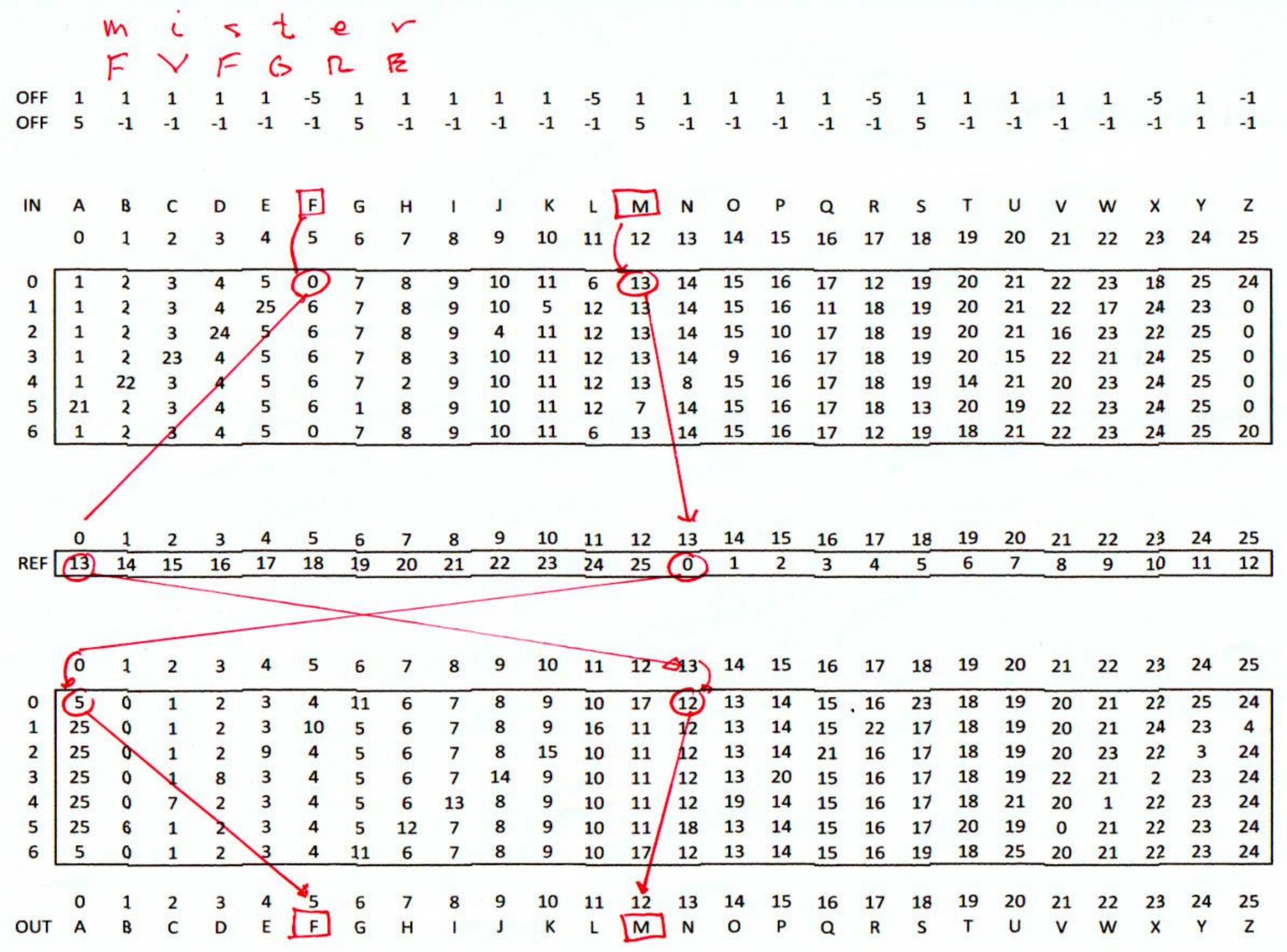



05
04
03
02
01
26
25
24
23
09
08
07
06
05
04
03
02



Letter A
Encrypts
To
Letter G

Manual Analysis, one rotor



m i s t e r

F V F G R E

OFF	1	1	1	1	1	-5	1	1	1	1	1	-5	1	1	1	1	1	-5	1	1	1	1	1	-5	1	-1
OFF	5	-1	-1	-1	-1	-1	5	-1	-1	-1	-1	-1	5	-1	-1	-1	-1	-1	5	-1	-1	-1	-1	-1	1	-1

IN	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0	1	2	3	4	5	0	7	8	9	10	11	6	13	14	15	16	17	12	19	20	21	22	23	18	25	24
1	1	2	3	4	25	6	7	8	9	10	5	12	13	14	15	16	11	18	19	20	21	22	17	24	23	0
2	1	2	3	24	5	6	7	8	9	4	11	12	13	14	15	10	17	18	19	20	21	16	23	22	25	0
3	1	2	23	4	5	6	7	8	3	10	11	12	13	14	9	16	17	18	19	20	15	22	21	24	25	0
4	1	22	3	4	5	6	7	2	9	10	11	12	13	8	15	16	17	18	19	14	21	20	23	24	25	0
5	21	2	3	4	5	6	1	8	9	10	11	12	7	14	15	16	17	18	13	20	19	22	23	24	25	0
6	1	2	3	4	5	0	7	8	9	10	11	6	13	14	15	16	17	12	19	18	21	22	23	24	25	20

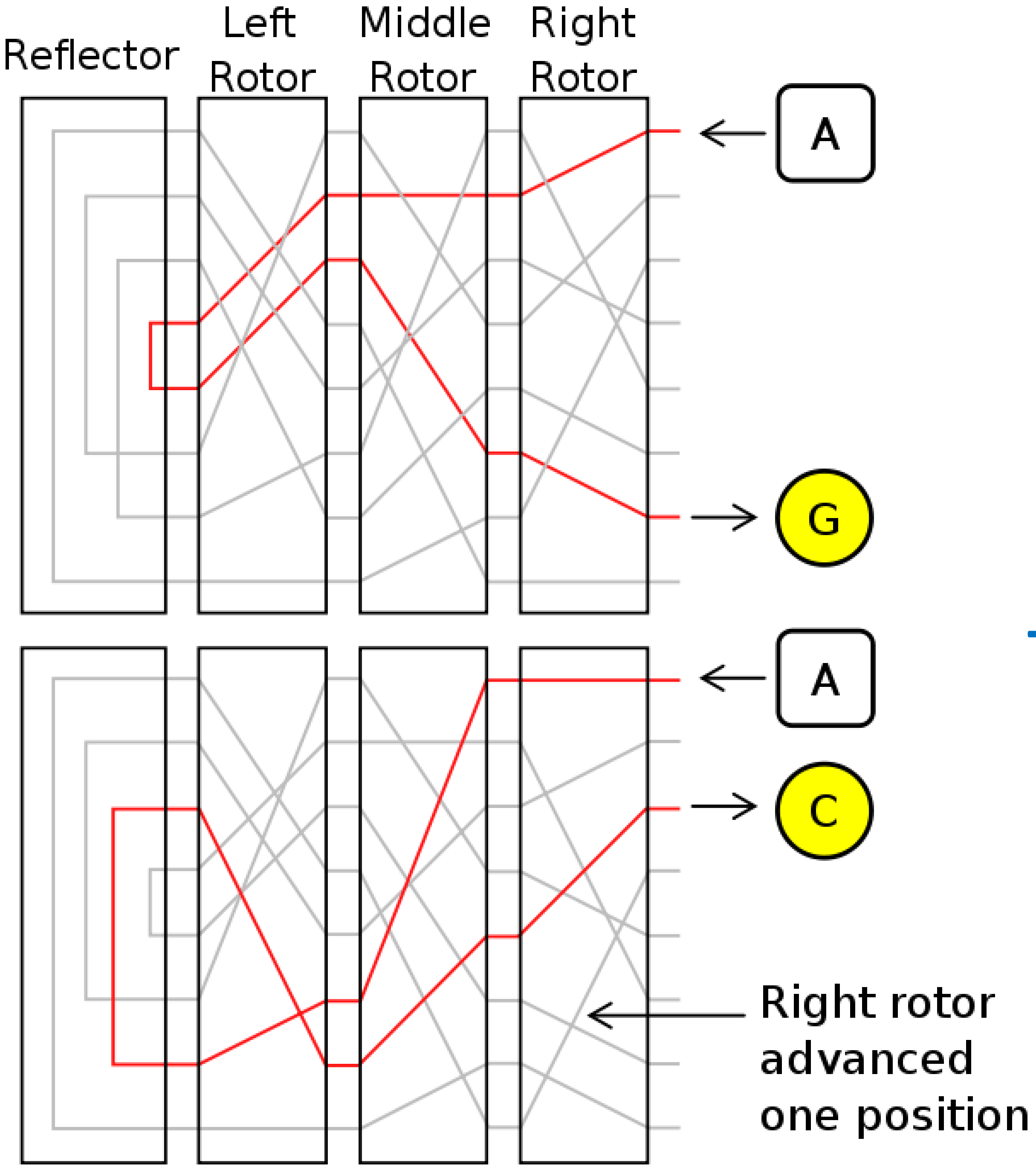
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
REF	13	14	15	16	17	18	19	20	21	22	23	24	25	0	1	2	3	4	5	6	7	8	9	10	11	12

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
0	5	0	1	2	3	4	11	6	7	8	9	10	17	12	13	14	15	16	23	18	19	20	21	22	25	24
1	25	0	1	2	3	10	5	6	7	8	9	16	11	12	13	14	15	22	17	18	19	20	21	24	23	4
2	25	0	1	2	9	4	5	6	7	8	15	10	11	12	13	14	21	16	17	18	19	20	23	22	3	24
3	25	0	1	8	3	4	5	6	7	14	9	10	11	12	13	20	15	16	17	18	19	22	21	2	23	24
4	25	0	7	2	3	4	5	6	13	8	9	10	11	12	19	14	15	16	17	18	21	20	1	22	23	24
5	25	6	1	2	3	4	5	12	7	8	9	10	11	18	13	14	15	16	17	20	19	0	21	22	23	24
6	5	0	1	2	3	4	11	6	7	8	9	10	17	12	13	14	15	16	19	18	25	20	21	22	23	24
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
OUT	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z

One Letter Through One Rotor

Output letter =
f(Rotor, Rotor Position, Input Letter, Transfer(+/-))

```
: Through-A-Rotor
RotorForward SlotIII   RotorPosition SlotIII
   @  2  pick  +  #letters  mod     ( position)
   swap  @     +  Sc@               ( transfer)
   +  #letters  mod    ;             ( output)
```



After Rotor Advance Letter A Encrypts To Letter C

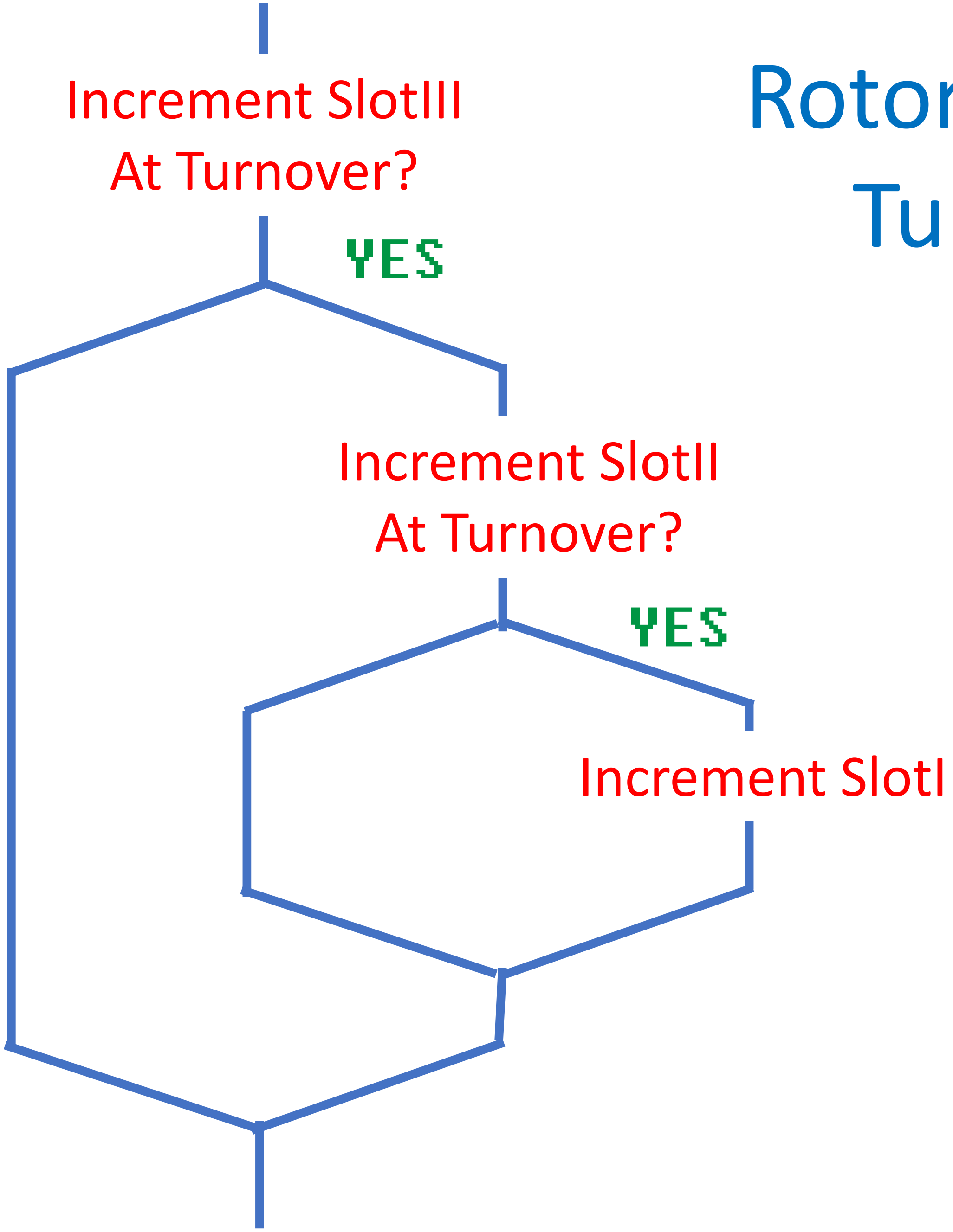
16
17
18
19
20
21
08
09
10
03

Turnover SlotIII to SlotII to SlotI

I	II	III
3	25	20
3	25	21
3	25	22
4	0	23
4	0	24
4	0	25
4	0	0
4	0	1
4	0	2

```
: EntryComplete \ Do turnover
  RotorPosition SlotIII @ >step dup
  RotorPosition SlotIII !
  RotorTurnover SlotIII @ =
   if   RotorPosition SlotII @ >step dup
       RotorPosition SlotII !
       RotorTurnover SlotII @ =
       if  RotorPosition SlotI @ >step
           RotorPosition SlotI  !
    then then ;
```

Rotor to Rotor Turnover



Increment SlotIII
At Turnover?

YES

Increment SlotII
At Turnover?

YES

Increment SlotI

Rotor A with +/- Offsets

```
CREATE RotorA-Forward  #letters  allot

\     0   1   2   3   4   5   6   7   8   9  10  11  12  letter in
      1   1   1   1   1  -5   1   1   1   1   1  -5   1

\    13  14  15  16  17  18  19  20  21  22  23  24  25  letter in
      1   1   1   1  -5   1   1   1   1   1  -5   1  -1


CREATE RotorA-Reverse  #letters  allot

\     0   1   2   3   4   5   6   7   8   9  10  11  12  letter in
      5  -1  -1  -1  -1  -1   5  -1  -1  -1  -1  -1   5

\    13  14  15  16  17  18  19  20  21  22  23  24  25  letter in
     -1  -1  -1  -1  -1   5  -1  -1  -1  -1  -1   1  -1
```

The Reflector with +/- Offsets

```
CREATE  Reflector #letters  allot

\   0   1   2   3   4   5   6   7   8   9  10  11  12
   13  13  13  13  13  13  13  13  13  13  13  13  13

\  13  14  15  16  17  18  19  20  21  22  23  24  25
  -13 -13 -13 -13 -13 -13 -13 -13 -13 -13 -13 -13 -13
```

A Slot Definer

```
: Define-Slot   ( RotorxFwd, RotorxRev, Its_Position, Its_Turnover )
 CREATE 4 cells allot
 DOES> + ;  \ Yield the field address within this array's data.

Define-Slot  SlotI
Define-Slot  SlotII
Define-Slot  SlotIII
Define-Slot  ReflectorI
Define-Slot  Plug Board (omitted)
Define-Slot  Keyboard   (omitted)

     0  CONSTANT  RotorForward
1 CELLS CONSTANT  RotorReverse
2 CELLS CONSTANT  RotorPosition
3 CELLS CONSTANT  RotorTurnover
```

Daily Setup By An Enigma Operator

Which rotor is in which slot.

Initial position of each rotor.

Turnover point of each rotor.

Plugboard settings. (omitted here)

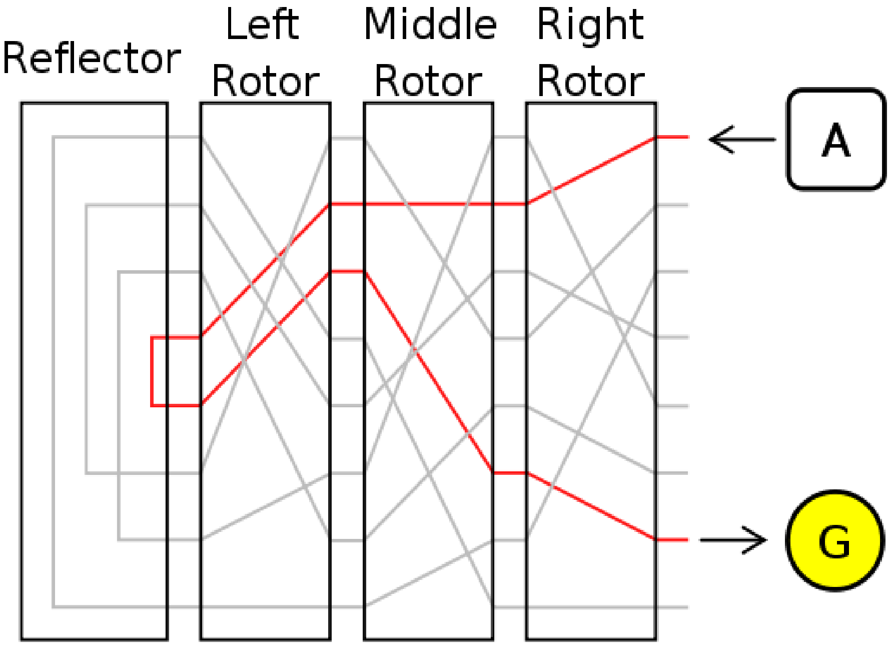
Assign Rotors to Slots and Reset

The daily setup by the Enigma operator.

```
: Start
     RotorA-Fwd  RotorForward  SlotI       !
     RotorA-Rev  RotorReverse  SlotI       !
              0  RotorPosition SlotI       !
              0  RotorTurnover SlotI       !
     RotorB-Fwd  RotorForward  SlotII      !
     RotorB-Rev  RotorReverse  SlotII      !
              0  RotorPosition SlotII      !
              0  RotorTurnover SlotII      !
     RotorC-Fwd  RotorForward  SlotIII     !
     RotorC-Rev  RotorReverse  SlotIII     !
              0  RotorPosition SlotIII     !
              0  RotorTurnover SlotIII     !
      Reflector  RotorForward  ReflectorI  !
      Reflector  RotorReverse  ReflectorI  !
              0  RotorPosition ReflectorI  !
              0  RotorTurnover ReflectorI  !   ;
```

Encrypting One Letter

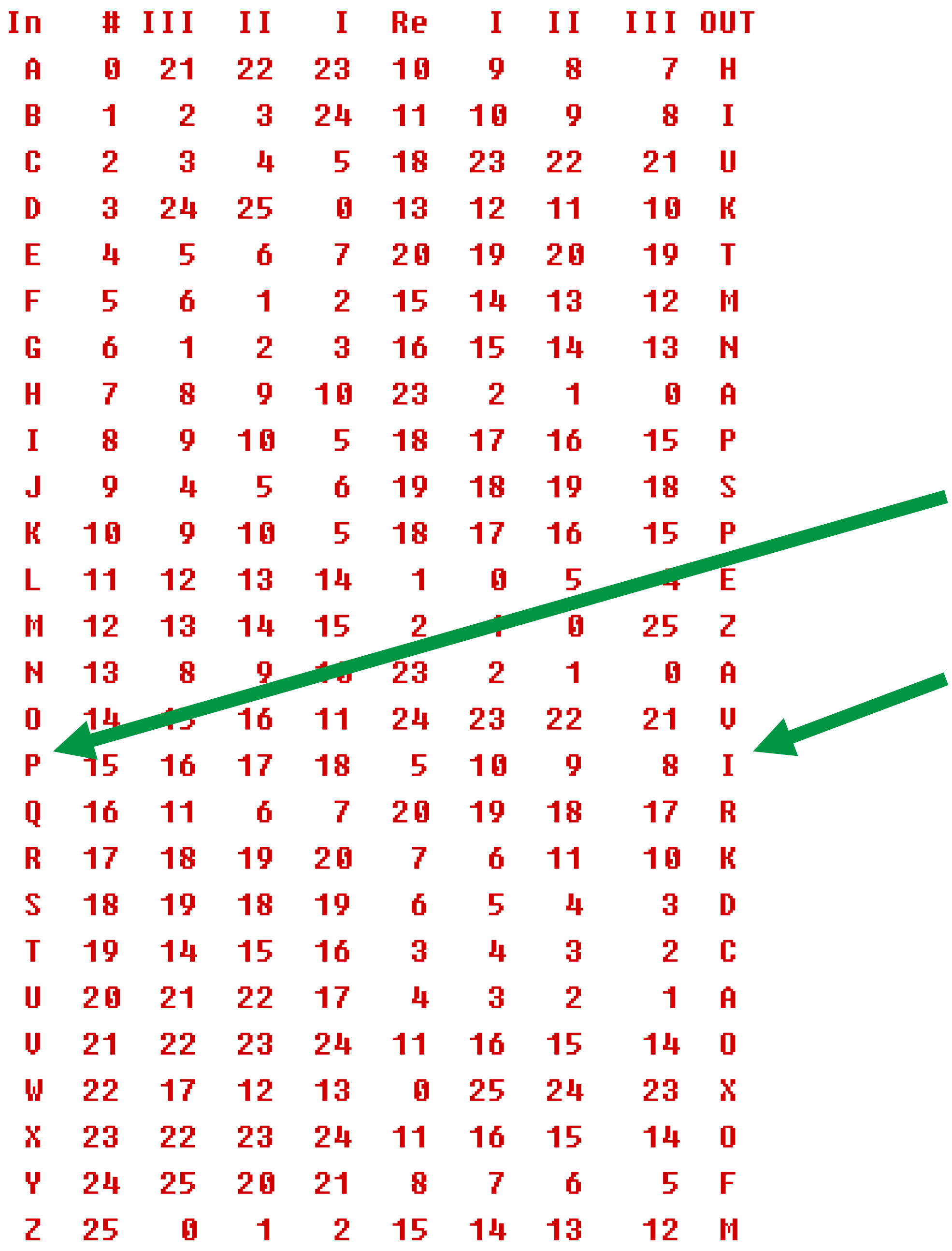
```
: A-letter  ( letter_in --- letter_out )
   RotorForward SlotIII     RotorPosition SlotIII     one-level
   RotorForward SlotII      RotorPosition SlotII      one-level
   RotorForward SlotI       RotorPosition SlotI       one-level
   RotorForward ReflectorI RotorPosition ReflectorI one-level
   RotorReverse SlotI       RotorPosition SlotI       one-level
   RotorReverse SlotII      RotorPosition SlotII      one-level
   RotorReverse SlotIII     RotorPosition SlotIII     one-level
   EntryComplete     ;
```



Setup For A Test

```
start
  5 RotorPosition SlotIII ! 12 RotorTurnover SlotIII !
  5 RotorPosition SlotII  !  6 RotorTurnover SlotII  !
 20 RotorPosition SlotI   ! 21 RotorTurnover SlotI   !
 Full-Alpha-Test
```

Encoding A 26 Letter Message “The Alphabet”

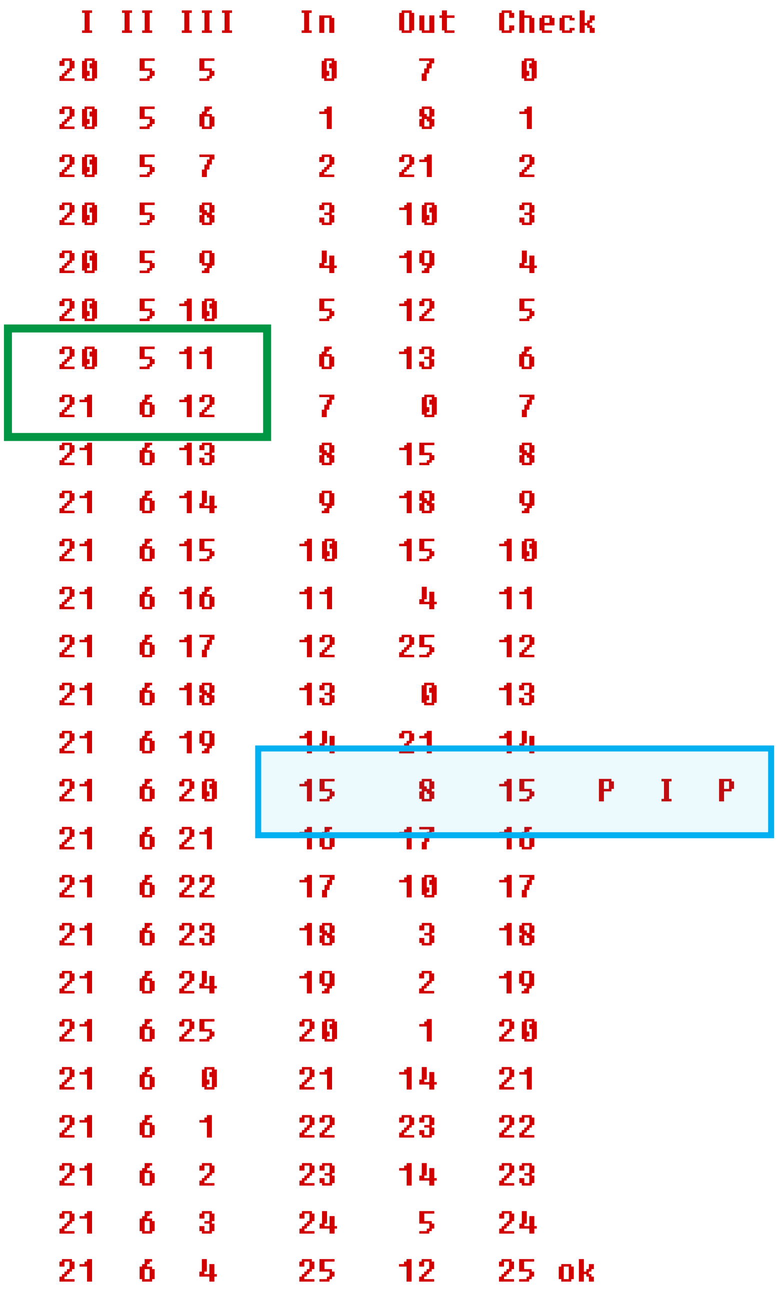


In	#	III	II	I	Re	I	II	III	OUT
A	0	21	22	23	10	9	8	7	H
B	1	2	3	24	11	10	9	8	I
C	2	3	4	5	18	23	22	21	U
D	3	24	25	0	13	12	11	10	K
E	4	5	6	7	20	19	20	19	T
F	5	6	1	2	15	14	13	12	M
G	6	1	2	3	16	15	14	13	N
H	7	8	9	10	23	2	1	0	A
I	8	9	10	5	18	17	16	15	P
J	9	4	5	6	19	18	19	18	S
K	10	9	10	5	18	17	16	15	P
L	11	12	13	14	1	0	5	4	E
M	12	13	14	15	2	1	0	25	Z
N	13	8	9	10	23	2	1	0	A
O	14	15	16	11	24	23	22	21	U
P	15	16	17	18	5	10	9	8	I
Q	16	11	6	7	20	19	18	17	R
R	17	18	19	20	7	6	11	10	K
S	18	19	18	19	6	5	4	3	D
T	19	14	15	16	3	4	3	2	C
U	20	21	22	17	4	3	2	1	A
V	21	22	23	24	11	16	15	14	O
W	22	17	12	13	0	25	24	23	X
X	23	22	23	24	11	16	15	14	O
Y	24	25	20	21	8	7	6	5	F
Z	25	0	1	2	15	14	13	12	M

IN = 15 = P

OUT = 8 = I

In Action Summary



```
 I  II  III    In    Out    Check
20   5   5      0     7      0
20   5   6      1     8      1
20   5   7      2    21      2
20   5   8      3    10      3
20   5   9      4    19      4
20   5  10      5    12      5
20   5  11      6    13      6
21   6  12      7     0      7
21   6  13      8    15      8
21   6  14      9    18      9
21   6  15     10    15     10
21   6  16     11     4     11
21   6  17     12    25     12
21   6  18     13     0     13
21   6  19     14    21     14
21   6  20     15     8     15    P   I   P
21   6  21     16    17     16
21   6  22     17    10     17
21   6  23     18     3     18
21   6  24     19     2     19
21   6  25     20     1     20
21   6   0     21    14     21
21   6   1     22    23     22
21   6   2     23    14     23
21   6   3     24     5     24
21   6   4     25    12     25  ok
```

Encrypting a 26 letter message:

00 = A

to

25 = Z

Small Words

```
: ASCII>Integer   ASCII A - ;

: Integer>ASCII   ASCII A + ;

: SignExtend    \ extend 8 bits to 32
    dup 128 and
    if -256 ( 0xFFFFFF00 ) or then ;

: bounded    \ keep in 0..25 range
   #letters mod ;
```

Forth Code

```
: encode
  sample-out 200 erase  start
  sample-out   sample-in count
  0 do  dup    i +    c@   A-letter
        2 pick i + 1+ c!
        i 1+ 2 pick   c!  loop   2drop ;

: decode
  sample-check 200 erase  start
  sample-check  sample-out count
  0  do  dup    i +    c@    A-letter
         2 pick i + 1+ c!
         i 1+ 2 pick   c!   loop   2drop ;
```

Encryption & Decryption

Plain Text

MISTER WATSON COME HERE I WANT TO SEE YOU

Encryption & Decryption

Plain Text

MISTER WATSON COME HERE I WANT TO SEE YOU

For Encryption, adding word separators “X”

MISTERXWATSONXCOMEXHEREXIXWANTXTOXSEEXYOUYXXX

Encryption & Decryption

Plain Text

MISTER WATSON COME HERE I WANT TO SEE YOU

For Encryption, adding X word separators

MISTERXWATSONXCOMEXHEREXIXWANTXTOXSEEXYOUYXXX

Encrypted

FXFGLKIJNGFZEIVBZLIURQLOXIVNAGCMBCFRRCNBHICCC

Encryption & Decryption

Plain Text

MISTER WATSON COME HERE I WANT TO SEE YOU

For Encryption, adding X word separators

MISTERXWATSONXCOMEXHEREXIXWANTXTOXSEEXYOUYXXX

Encrypted

FXFGLKIJNGFZEIVBZLIURQLOXIVNAGCMBCFRRCNBHICCC

As transmitted

FXFGL KIJNG FZEIV BZLIU RQLOX IVNAG CMBCF RRCNB HICCC

Encryption & Decryption

Plain Text

MISTER WATSON COME HERE I WANT TO SEE YOU

For Encryption, adding X word separators

MISTERXWATSONXCOMEXHEREXIXWANTXTOXSEEXYOUYXXX

Encrypted

FXFGLKIJNGFZEIVBZLIURQLOXIVNAGCMBCFRRCNBHICCC

As transmitted

FXFGL KIJNG FZEIV BZLIU RQLOX IVNAG CMBCF RRCNB HICCC

Decrypted

MISTERXWATSONXCOMEXHEREXIXWANTXTOXSEEXYOUYXXX

Performance

FXFGL KIJNG FZEIV BZLIU RQLOX IVNAG CMBCF RRCNB HICCC

= 62 microseconds

MISTERXWATSONXCOMEXHEREXIXWANTXTOXSEEXYOUYXXX

= 61 microseconds

Use In Attack

Time to decrypt all of the basic 3 rotor Enigma

1,054,450 combinations: 1 minute 34 seconds

Time to decrypt the 4 rotor Naval Enigma:

26^6 x 336 = 1.037 10^{11} combinations:

= 1.47 million minutes = 2.80 years

Use In Attack

Time to decrypt all of the basic 3 rotor Enigma
1,054,450 combinations: 1 minute 34 seconds

Time to decrypt the 4 rotor Naval Enigma:
26^6 x 336 = 1.037 10^{11} combinations

= 1.47 million minutes = 2.80 years

With analysis, lots of messages, electromechanical aids and German operator errors (most) messages were read through the entire war. Ultimately, about 30 cypher systems were in use.

Comments

The original Bletchley Park attack used sliding rods with inscribed alphabets. It depended on technical discoveries and German operator errors.

The expansion of Enigma to four slots and eight rotors blocked decryption for seven months (April, 1942 to October, 1942).

Development of the electromechanical ‘bombes’ led by Alan Turing delivered decryption ranging from one hour to 60 hours.

Summary

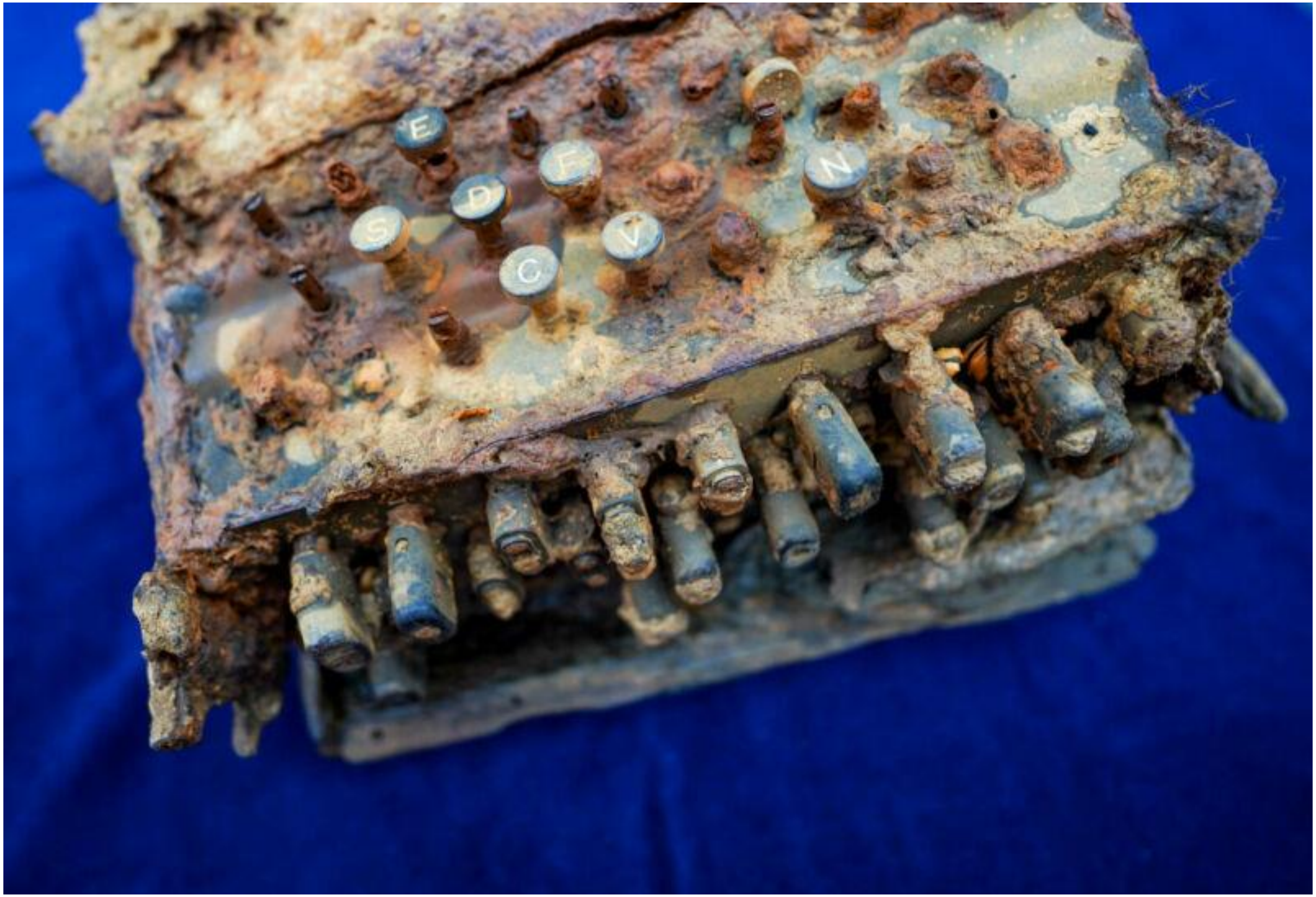
Enigma existed in about 20 production variations from 1923 to 1942.

Enigma encryption was in use until about 1960.

Its decryption was still a British Top Secret until 1974.

Many software implementations exist for personal use of this technology.

Recovered February, 2021



References

- https://github.com/BillRagsdale/Forth_Projects

- https://en.wikipedia.org/wiki/Enigma_machine

Questions?