**PLAYFAIR CRYPTANALYSIS**

Our preliminary step is to perform individual letter   
frequency and digraphic counts.  The former because high   
frequency ciphertext letters follow closely the high   
frequency letters they represent and will be located in   
the upper rows; similarly, low frequency letters follow   
their plain counterparts (UVWXYZ) and may be located at   
the last row of the square.  A digraph count is useful   
because cipher digraphs follow closely the frequency of   
their plaintext digraphs. i.e. TH = HM. The frequency of   
HM must be high for a normal length message. Also   
tetragraphs may be tested THAT, TION, THIS for   
corresponding their frequencies in the square.

All the authors agree that a probable word is need for   
entry into the Playfair. Due to its inherent   
characteristics, Playfair cipher words will follow the   
same pattern as their plaintext equivalents; they carry   
their pattern into the cipher.

Given:   Tip "er one day entere"     Hampian. 10/1952

EU  SM  FV  DO  VC  PB  FC  GX  DZ  SQ  DY  BA  AQ  OB   
ZD  AC  OC  ZD  ZC  UQ  HA  FK  MH  KC  WD  QC  MH  DZ   
BF  NT  BP  OF  HA  SI  KE  QA  KA  NH  EC  WN  HT  CX   
SU  HZ  CS  RF  QS  CX  DB  SF  SI  KE  FP  (106)

We set up a combined frequency tally with letters to the   
right and left of the reference letter shown:   
 

           K Q H H B   . A .   Q C   
               D O P   . B .   A F P   
     E Q K Z O A F V   . C .   X S X   
               W Z Z   . D .   O Z Y Z B   
                 K K   . E .   U C   
             S R O B   . F .   V C K P   
                       . G .   X   
               N M M   . H .   A A T Z   
                 S S   . IJ.   
                   F   . K .   C E A E   
                       . L .   
                   S   . M .   H H   
                   W   . N .   T H   
                   D   . O .   B C F   
                 F B   . P .   B   
               U A S   . Q .   C A S   
                       . R .   F   
                 Q C   . S .   M Q I U F I   
                 H N   . T .   
                 S E   . U .   Q   
                   F   . V .   C   
                       . W .   D N   
               C C G   . X .   
                   D   . Y .   
               H D D   . Z .   D D C

This particular message has no significant repeats.

Cipher  GX  DZ  SQ  DY  BA  AQ  OB  ZD  AC   
Plain   ..  ER  ON  ED  AY  EN  TE  RE  ..

Note the first and last pair reversal.

It is necessary to take each set of these pair   
equalities and establish the position of the four   
letters with respect to each other. They must conform to   
the above three rules for row, column, and rectangle.

The six different sets of pairs of know equalities are   
set up:

   1          2          3         4        5   
er = DZ    on = SQ    ed = DY   ay = BA   en = AQ   
------     -------    ------    -------   -------   
E D R Z    O S N Q    E D Y     Y A B     E A N Q   
D          S          D         A         A   
R   E D    N   O S    Y         B         N   E A   
Z   Z R    Q   Q N                        Q   Q N

   6   
te = OB   
-------   
T O E B   
O   
E   T O   
B   B E

The three possible relations of the letters are labeled   
Vertical (v), Horizontal (h), Diagonal (d).  Our object   
is to combine the letters in each of the set of pairs.

Combine 1 and 3:  E R D Z Y

      1/v - 3/v        1/h - 3/h        1/d - 3/h   
      ---------        ---------        ---------   
          E            E D Y R Z          E D Y   
          D                               Z R   
          Y   
          R   
          Z

Combine 2 and 5: O N S Q E A

      2/h - 5/d        2/d - 5/h         2/d - 5/d   
      ---------        ---------         ---------   
       O S N Q          E A N Q             S O   
           A E              S O             N Q   
                                            A E

Note that all the equalities hold for all letters.

Set number 6 combines only with the last combination: T   
E O B N S Q A

 2/d - 5/d - 6/v                2/d - 5/d - 6/d   
----------------                ---------------   
         T                          S O T   
       S O                          N Q   
       A E                          A E B   
         B   
       N Q

which we now combine with 4:

                 2/d - 5/d - 6/d - 4/h   
                 ---------------------   
                     S T O   
                   Y A E B           (rearranged and   
                     N   Q            equalities hold)

only one combination of 1 and 3 will combine with the   
above: S T O Y A B E D N Q Z R   
 

             1/d - 2/d - 3/h - 4/h - 5/d - 6/d   
             ---------------------------------   
                     S T O   
                   Y A E B D   
                     N   Q   
                         Z R

Arranged in a 5 X 5 square:

                    . . S T O   
                    D Y A B E   
                    . . . . .   
                    . . N . Q   
                    R . . . Z

We see that O is in the keyword, the sequence NPQ   
exists, the letters S T Y are in the keyword, and three   
of the letters U V W X  are in needed to fill the bottom   
row.

                   ----------   
                    . . S T O| C   
                    D Y A B E|   
                    . . . . .|   
                    . . N P Q|   
                    R . . . Z| U V W X

With the exception of F G H I K L M which must in order   
fill up the 3rd and 4th rows, the enciphering square is   
found as:

                     C U S T O   
                     D Y A B E   
                     F G H I K   
                     L M N P Q   
                     R V W X Z

Our plaintext message starts off: YOUNG RECRUIT DRIVER   
ONE DAY ENTERED STORE ROOM ....   
    
  Written by Alex Biryukov (Weizmann Institute of Science, Rehovot, Israel) in 2001 for a course taught there entitled Methods of Cryptanalysis

**Lecture 3**   
"Cryptanalysis of the Classical Ciphers"

A quick look forward for those, who want some reading before the lecture.   
Here are the [lecture notes](http://www.wisdom.weizmann.ac.il/%7Ealbi/cryptanalysis/lecture3.ps.gz)  (ps, gzipped) written by Ilya Safro.   
(Print with 600 or 1200 dpi to get better quality:  lpr -P12laser11 lecture3.ps)   
The 'after the lecture' notes are written in *light green italic.*

We will concentrate on the cryptanalysis of the classic schemes that we have described.   
(see [LANAKI's course](http://www.fortunecity.com/skyscraper/coding/379/lesson1.htm), lectures 1-4, 10-12, or the [Army Field Manual](http://www.und.nodak.edu/org/crypto/crypto/army.field.manual/), here is its   
[table of contents](http://www.wisdom.weizmann.ac.il/%7Ealbi/cryptanalysis/TOC.ps)). See also [extended lecture notes for lecture 1](http://www.wisdom.weizmann.ac.il/%7Ealbi/cryptanalysis/lecture1.ps) (sections 1.1, 1.2) for   
a classification of cryptanalytic attacks, and a sketch on methods of cryptanalysis.

We will try to cover the following attack methods   
*[we used D.Stinson's "Cryptography: Theory and Practice" book, pp.31-34, for the first two topics]:*

1. Frequency analysis, Index of Coincidence *[Chapter 2 of the Army Field Manual]*   
2. Kasiski's method (for example, for Carroll's Vigenere)   
3. Anagramming (for arbitrary transposition ciphers)   
4. Probable word method *(*[*Rosette stone*](http://www.wisdom.weizmann.ac.il/%7Ealbi/cryptanalysis/) *is an interesting historic example)*   
5. Vowel - consonants splitting *[see Chapter 4 of the Army Field manual]*   
6. Decimation   
7. Improbable word (for multi-letteral ciphers, *this is the way you solve puzzle 3 of Hw1)*

Meanwhile enjoy the following story (taken from LANAKI's course lecture 17,   
historic part of which is in turn taken from [Khan's book](http://www.wisdom.weizmann.ac.il/%7Ealbi/cryptanalysis/recread.htm).) Interestingly, here   
is the [same story](http://www.history.navy.mil/faqs/faq60-2.htm) from a totally different angle.

**DIGRAPHIC CIPHERS: PLAYFAIR**

Perhaps the most famous cipher of 1943 involved the   
**future president of U.S.**, **J. F. Kennedy,** Jr. [KAHN]   
On 2 August 1943, Australian Coastwatcher Lieutenant   
Arthur Reginald Evans of the Royal Australian Naval   
Volunteer Reserve saw a pinpoint of flame on the dark   
waters of Blackett Strait from his jungle ridge on   
[Kolombangara Island](http://www.wisdom.weizmann.ac.il/%7Ealbi/cryptanalysis/map.jpg), one of the Solomons. He did not   
know that the Japanese destroyer Amagiri had rammed and   
sliced in half an American patrol boat PT-109, under   
the command of Lieutenant John F. Kennedy, United States   
Naval Reserve.  Evans received the following message at   
0930 on the morning of the 2 of August 1943:

      29gps

     KXJEY  UREBE  ZWEHE  WRYTU  HEYFS   
     KREHE  GOYFI  WTTTU  OLKSY  CAJPO   
     BOTEI  ZONTX  BYBWT  GONEY  CUZWR   
     GDSON  SXBOU  YWRHE  BAAHY  USEDQ

                                  /0930/2

Translation:

     PT BOAT ONE OWE NINE LOST IN ACTION IN BLACKETT   
     STRAIT TWO MILES SW MERESU COVE X CREW OF TWELVE   
     X REQUEST ANY INFORMATION.

The coastwatchers regularly used the Playfair system.   
Evans deciphered it with the key ROYAL NEW ZEALAND NAVY   
and learned of Kennedy's fate. Evans reported back to   
the coastwatcher near Munda, call sign PWD, that Object   
still floating between Merusu and Gizo, and at 1:12 pm,   
Evans was told by Coastwatcher KEN on Guadalcanal that   
there was a possibility of survivors landing either on   
Vangavanga or near islands.  That is what Kennedy and   
his crew had done. They had swum to Plum Pudding Island   
on the Southeastern tip of Gizo Island.

Several messages passed between PWD, KEN and GSE   
(Evans). The Japanese made no attempt to capture Kennedy   
even though they had access to the various messages. The   
importance to the crew was missed even though many P-40's   
could have been spotted in the Search and Rescue (SAR) attempt.   
Maybe the Japanese didn't want to waste the time or men   
because the exact location of the crew was not   
specified. A Japanese barge chugged past Kennedy's   
hideout. On 09:20 a.m. on Saturday morning 7 August 1943,   
two natives found the sailors, who had moved to Gross   
Island, and had reported the find to Evans. He wrote a brief   
message: *Eleven survivors PT boat on Gross Is X Have*   
*sent food and letter advising senior come here without*   
*delay X Warn aviation of canoes crossing Ferguson RE.*   
The square Evans used was based on the key PHYSICAL   
EXAMINATION :   
               P H Y S I   
               C A L E X   
               M N T O B   
               D F G K Q   
               R U V W Z

The encipherment did not split the doubled letters (*Gross* and   
*crossing*) as is the rule:

     XELWA  OHWUW  YZMWI  HOMNE  OBTFW   
     MSSPI  AJLUO  EAONG  OOFCM  FEXTT   
     CWCFZ  YIPTF  EOBHM  WEMOC  SAWCZ   
     SNYNW  MGXEL  HEZCU  FNZYL  NSBTB   
     DANFK  OPEWM  SSHBK  GCWFV  EKMUE

**A message of this length alone suffices for the solution of**   
**Playfair.**There were four more messages in the same key,   
including one of 335 letters, beginning:

XYAWO  GAOOA  GPEMO  HPQCW  IPNLG  RPIXL   
TXLOA  NNYCS  YXBOY  MNBIN  YOBTY  QYNAI ...,

for

*Lieut. Kennedy considers it advisable that he pilot PT*   
*boat tonight X ...*

These five messages detailed the rescue arrangements, which   
offered the Japanese a chance to not only to get the crew (and   
change all history!) but also the force coming out to save it.   
**All of the messages could have been solved within an hour by**   
**even a moderately experienced cryptanalyst.**Yet some ten hours   
later, at 10:00 p.m. Kennedy and his crew was rescued.

Digraphic substitution refers to the use of pairs of   
letters to substitute for other pairs of letters. The   
Playfair system was originated by the noted British   
scientist, Sir Charles Wheatstone (1802 - 1875) but, as   
far as known, it was not employed for military  or   
diplomatic use during his lifetime. About 1890 it was   
adopted for use by the British Foreign Office on the   
recommendation of Lord Lyon Playfair (1818-1898) and   
thereafter by mistake identified with its sponsor.

**Encipherment**

The Playfair is based on a 25 letter alphabet (omit J)   
set up in a 5 X 5 square.  A keyword is written in   
horizontally into the top rows of the square and the   
remaining letters follow in regular order.  So for the   
key = LOGARITHM, we have:   
                L O G A R   
               I T H M B   
               C D E F K   
               N P Q S U   
               V W X Y Z

In preparation for encipherment, the plaintext is   
separated into pairs. Doubled letters such as SS or NN   
are separated by a null.

For example, "COME QUICKLY WE NEED HELP"  we have

       CO ME QU IC KL YW EN EX ED HE LP

There are three rules governing encipherment:

1.   When the two letters of a plain text pair are in   
     the same column of the square, each is enciphered   
     by the letter directly below it in that column. The   
     letter at the bottom is enciphered by the letter at   
     the top of the same column.

                  Plain       Cipher   
                   OP           TW   
                   IC           CN   
                   EX           QG   
    
    
 

2.   When the two letters of a plain text pair are in   
     the same row of the square, each is enciphered by   
     the letter directly to its right in that row.  The   
     letter at the extreme right of the row is enciph-   
     ered by the letter at the extreme left of the same   
     row.   
                       Plain       Cipher   
                      YW           ZX   
                      ED           FE   
                      QU           SN

3.   When two letters are located in different rows and   
     columns, they are enciphered by the two letters   
     which form a rectangle with them, beginning with   
     the letter in the SAME ROW with the first letter of   
     the plaintext pair. (This occurs about 2/3 of the   
     time.)

                     Plain       Cipher   
                      CO           DL   
                      ME           HF   
                      KL           CR   
                      LP           ON

Decipherment, when the keyword is known, is accomplished   
by using the rules in reverse.

**Identification Of The Playfair**

The following features apply to the Playfair:

1. It is a substitution cipher.

2. The cipher message contains an even number of   
   letters.

3. A frequency count will show no more than 25 letters.   
   (The letter J is not found.)

4. If long repeats occur, they will be at regular (even)   
   intervals.  In most cases, repeated sequences will be   
   an even number of letters.

5. Many reversals of digraphs.

**Peculiarities**

1. No plaintext letter can be represented in the cipher   
   by itself.

2. Any given letter can be represented by 5 other   
   letters.

3. Any given letter can represent 5 other letters.

4. Any given letter cannot represent a letter that it   
   combines with diagonally.

5. It is twice as probable that the two letters of any   
   pair are at the corners of a rectangle, than as in   
   the same row or column.

6. When a cipher letter has once been identified as a   
   substitute for a plaintext letter, their is a 20%   
   chance that it represents the same plaintext letter   
   in each other appearance.

The goal of recovery of the 5 X 5 square and various   
techniques for accomplishing this are the focus for   
solving the Playfair.   Colonel Parker Hitt describes   
Lieutenant Frank Moorman's approach to solving the   
Playfair which addresses the keyword recovery logically.   
[HITT].  Other writers [ELCY], [BOW2], [FRE4], and   
[MAST] do an admirable job of discussing the process.   
However, W. M. Bowers Volume I on Digraphic Substitution   
presents the easiest protocol for students. [BOWE]

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HM must be high for a normal length message. Also   
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All the authors agree that a probable word is need for   
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Given:   Tip "er one day entere"     Hampian. 10/1952

EU  SM  FV  DO  VC  PB  FC  GX  DZ  SQ  DY  BA  AQ  OB   
ZD  AC  OC  ZD  ZC  UQ  HA  FK  MH  KC  WD  QC  MH  DZ   
BF  NT  BP  OF  HA  SI  KE  QA  KA  NH  EC  WN  HT  CX   
SU  HZ  CS  RF  QS  CX  DB  SF  SI  KE  FP  (106)

We set up a combined frequency tally with letters to the   
right and left of the reference letter shown:   
 

           K Q H H B   . A .   Q C   
               D O P   . B .   A F P   
     E Q K Z O A F V   . C .   X S X   
               W Z Z   . D .   O Z Y Z B   
                 K K   . E .   U C   
             S R O B   . F .   V C K P   
                       . G .   X   
               N M M   . H .   A A T Z   
                 S S   . IJ.   
                   F   . K .   C E A E   
                       . L .   
                   S   . M .   H H   
                   W   . N .   T H   
                   D   . O .   B C F   
                 F B   . P .   B   
               U A S   . Q .   C A S   
                       . R .   F   
                 Q C   . S .   M Q I U F I   
                 H N   . T .   
                 S E   . U .   Q   
                   F   . V .   C   
                       . W .   D N   
               C C G   . X .   
                   D   . Y .   
               H D D   . Z .   D D C

This particular message has no significant repeats.

Cipher  GX  DZ  SQ  DY  BA  AQ  OB  ZD  AC   
Plain   ..  ER  ON  ED  AY  EN  TE  RE  ..

Note the first and last pair reversal.

It is necessary to take each set of these pair   
equalities and establish the position of the four   
letters with respect to each other. They must conform to   
the above three rules for row, column, and rectangle.

The six different sets of pairs of know equalities are   
set up:

   1          2          3         4        5   
er = DZ    on = SQ    ed = DY   ay = BA   en = AQ   
------     -------    ------    -------   -------   
E D R Z    O S N Q    E D Y     Y A B     E A N Q   
D          S          D         A         A   
R   E D    N   O S    Y         B         N   E A   
Z   Z R    Q   Q N                        Q   Q N

   6   
te = OB   
-------   
T O E B   
O   
E   T O   
B   B E

The three possible relations of the letters are labeled   
Vertical (v), Horizontal (h), Diagonal (d).  Our object   
is to combine the letters in each of the set of pairs.

Combine 1 and 3:  E R D Z Y

      1/v - 3/v        1/h - 3/h        1/d - 3/h   
      ---------        ---------        ---------   
          E            E D Y R Z          E D Y   
          D                               Z R   
          Y   
          R   
          Z

Combine 2 and 5: O N S Q E A

      2/h - 5/d        2/d - 5/h         2/d - 5/d   
      ---------        ---------         ---------   
       O S N Q          E A N Q             S O   
           A E              S O             N Q   
                                            A E

Note that all the equalities hold for all letters.

Set number 6 combines only with the last combination: T   
E O B N S Q A

 2/d - 5/d - 6/v                2/d - 5/d - 6/d   
----------------                ---------------   
         T                          S O T   
       S O                          N Q   
       A E                          A E B   
         B   
       N Q

which we now combine with 4:

                 2/d - 5/d - 6/d - 4/h   
                 ---------------------   
                     S T O   
                   Y A E B           (rearranged and   
                     N   Q            equalities hold)

only one combination of 1 and 3 will combine with the   
above: S T O Y A B E D N Q Z R   
 

             1/d - 2/d - 3/h - 4/h - 5/d - 6/d   
             ---------------------------------   
                     S T O   
                   Y A E B D   
                     N   Q   
                         Z R

Arranged in a 5 X 5 square:

                    . . S T O   
                    D Y A B E   
                    . . . . .   
                    . . N . Q   
                    R . . . Z

We see that O is in the keyword, the sequence NPQ   
exists, the letters S T Y are in the keyword, and three   
of the letters U V W X  are in needed to fill the bottom   
row.

                   ----------   
                    . . S T O| C   
                    D Y A B E|   
                    . . . . .|   
                    . . N P Q|   
                    R . . . Z| U V W X

With the exception of F G H I K L M which must in order   
fill up the 3rd and 4th rows, the enciphering square is   
found as:

                     C U S T O   
                     D Y A B E   
                     F G H I K   
                     L M N P Q   
                     R V W X Z

Our plaintext message starts off: YOUNG RECRUIT DRIVER   
ONE DAY ENTERED STORE ROOM ....

**SERIATED PLAYFAIR**

Perhaps the best known variation of the Playfair system,   
and one which adds greatly to its security, is called   
the Seriated Playfair.

The plain text is written horizontally in two line   
periodic groups as shown below in period six

       C O M E Q U    E N E E D H    M E D I A T   
       I C K L Y W   (X)E L P I M    E L Y T O M

The vertical pairs are formed and enciphered by the   
regular Playfair rules. Based on the keyword LOGARITHM,   
the above message is enciphered:   
    
    
 

 L O G A R                  Cipher:   
 I T H M B    N L B C S P   Q Q C D C M   H C F T R H   
 C D E F K    C D F G X Z   G C G Q T B   F G W H G B   
 N P Q S U   
 V W X Y Z

we take the ciphertext off horizontally by the same   
route by which the plain text was written in for   
encipherment:

NLBCS  PCDFG  XZQQC  DCMGC  GQTBH  CFTRH  FGWHG  B.

**Solution of Seriated Playfair:**

We assume a period of 4 - 10 which fits most of the   
cases encountered.  Of prime importance is determination   
of the period. We test the various periods and eliminate   
any test where we find a vertical pair consisting of two   
appearances of the same letter.

If the message enciphered above is tested this way, in   
all periods from 4 - 10, it will be found that period 6   
is correct. All others will show a doubled vertical   
pair.

Charles A. Leonard [PLAf] detailed a method to determine   
impossible periods mathematically:

              S2   
           -------    = Q & R   
           S2 - S1

 where: S2 - S1 = Period, Q = quotient, R = remainder

 Substituting known S values in this formula and solving   
for Q and R, a doubled vertical pair will occur in   
period S2 - S1 in the following cases:

     1.  When Q is an odd number and R is greater than   
         zero;   
     2.  When Q is an even number and R is zero.

Cipher letter position numbers in our message are:

 A   B   C   D   E   F   G   H   I   K   L    etc.   
     3   4   8       9  10  25           2   
    24   7  16      27  19  30   
    36  15          31  21  34   
        17              32   
        20              35   
        26   
 

Period  Letter  S2 - S1     Q   R   Result   
  4       F     31 - 27     7   3   Eliminated-Case 1   
  5       C     20 - 15     4   0   Case 2   
  6       C     26 - 20     4   2   possible   
  7       H     34 - 30             Eliminate-last gp   
  8       D     16 - 8      2   0   Case 2   
  9       C     26 - 17     2   8   possible   
          G     19 - 10     2   1   possible   
          H     34 - 25     3   7   Case 1   
  10      C     17 - 7      1   7   Case 1

When a periodic group S2 - S1 does not occur in message   
the last group is inspected. If it is shorter than the   
regular groups of the period being tested, a double   
vertical pair may show at S2- S1 value equal to the   
length of this final group. If so, eliminate.

The mono and digraphic frequency counts are made.   
Plaintext high frequency digraphs and tetragraphs do not   
carry their identity over into the cipher and are not   
recognizable. Entry must be made with a probable word.   
Patterns do carry over to the two line groups and will   
repeat.

The placing of the probable word is important. Given a   
cipher text slice with period 6 found using the Leonard   
procedure:

   HKILVP   PBVBAA   BHRPOU   TBITFE   UCEVZK   
   RNFTZU   HZWVFR   UDTKBD   UIBYNS   EXBZAR

and the probable phrase "is destined to", the word   
destined could be in any of the following positions when   
enciphered in period 6:

DESTIN  .DESTI   ..DEST   ...DES    ....DE   
ED....  NED...   INED..   TINED.    STINED

The DE = ED reversal in all arrangements is noted and   
found in the cipher text portion:

            BHRPOU   TBITFE   UCEVZK   
            UDTKBD   UIBYNS   EXBZAR   
                     .desti   
                     ned..

adding the additional information:

            BHRPOU   TBITFE   UCEVZK   
            UDTKBD   UIBYNS   EXBZAR   
                 .   sdesti   
                 i   nedto.

we develop several equations:

                   ed = IB   
 -I = UD, sn = TU, de = BI, ST = TY, to =FN, I- =ES

these translate to the following equalities:

   1          2          3         4        5   
SN = TU    DE = BI    ST = TY   TO = FN   I- = ES   
-------    -------    ------    -------   -------   
S T N U    D B E I    S T Y     T F O N   I E - S   
T          B          T         F         E   
N   S T    E   D B    Y         O   T F   -   I E   
U   U N    I   I E              N   N O   S   S -

   6         7   
-I = UD    ED = IB   
-------    -------   
- U I D    E I D B   
U          I   
I   - U    D   E I   
D   D I    B   B D

After some work (and with some assumptions to be tested   
we develop a tentative square for the system:

              1/d-2/d -3/h-4/v- 5/h -6/h   
              --------------------------   
                      -   
                    O U N   
                      I E   
                      D B   
                    F S T Y

check:   
TO=FN+   + = yes   
SN=TU+   
ST=TY+                        letters left: A C E G H K   
I-=ES -=t  IT =ES                           L M P Q R V   
DE=BI+                                      W X Z   
ED=IB+   
-I=UD+

from here we need to expand on the cipher text or choose   
another probable word.