

PAGES - A Family of Block Ciphers

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Abstract

PAGES is block cipher family based on the design of Speck, see [1]. However, some intriguing design details of Speck were not used in the design of PAGES. PAGES has block size of 256 bit and comes in three version: PAGES-512, PAGES-768, and PAGES-1024, where the number denotes the key length. The number of rounds is 64, 96, or 128, respectively. PAGES uses variables of 128 bit, that is half the block size.

1 Introduction

The Simon and Speck Block Cipher Families, see [1], have an impressive performance and are easy to program on modern CPU's. In particular, the SSE performance, where eight encryptions are done in parallel (Speck128), outperforms other existing block ciphers. The SSE register in my laptop has a width of 128 bit. It sprang into my mind, that an implementation which uses the register at full size, could have an increased security. Since gcc version 4.8.2 supports the variables with 128 bit (unsigned `_int128`), it was easy to design a block cipher similar to Speck128, which utilizes 128 bit variables. Since the days of register poor CPU's are over, both AMD and Intel microprocessors have enough registers to put 128 bit integers into them, as far as PAGES is concerned. The 128 bit variable is stored into two 64 bit general purpose registers. The cipher is called PAGES and its reference implementation can be found in the appendix A. As NSA nor its employees claim intellectual property for its block ciphers, PAGES is also free of charge and I claim no intellectual property for this cipher. While it was straightforward to implement PAGES, some intriguing

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details in the Speck128 cipher were not used. In particular the eight bit rotation of the lefthand side were not increased by the factor of two. Instead the rotation amount was set to 19. The reason for that and the other changes can be found in the Section 4. The block cipher comes in three versions, PAGES-512, PAGES-768, and PAGES-1024, where the number denotes the key size.

This paper is organized as follows: Section 2 contains the preliminaries like definitions and so on. Section 3 comprises the assembly of PAGES. The design rationale is given in Section 4. We conclude in Section 5.

2 Preliminaries

The following symbols are used to build the block cipher PAGES: \boxplus denotes addition modulo 2^{128} , \boxminus denotes subtraction modulo 2^{128} , \oplus denotes addition modulo 2 in \mathbb{F}_2^{128} (XOR), $\lll m$ denotes the left circular shift of m positions, $\ggg m$ denotes the right circular shift of m positions, GCD denotes the greatest common divisor, and LCM denotes the least common multiple. PAGES has a block length of 256 bits and is divided into two halves of equal length (128 bit).

3 Assembly of PAGES

3.1 Encryption

The left half of PAGES is circular shifted by 19 position to the right, see figure 1a and the function encrypt of the reference implementation in the appendix A. Then the right half is XORed to the left half. The right half is then circular shifted by 7 bits to left. The round key is added modulo 2^{128} to the left half. Then the left is added modulo 2^{128} to the right half. That concludes one round of encryption. The number of rounds can be 64, 96, or 128. The respective key sizes are 512 bit, 768 bit, or 1024 bit.

3.2 Decryption

The left half is subtracted from the right half modulo 2^{128} , see figure 1b and the function decrypt of the reference implementation in the appendix A. Then the round key is subtracted modulo 2^{128} from the left half. The right half is circular shifted to the right by 7 bits. The right half is XORed to the left half. The left half is then circular shifted to the left by 19 positions. That concludes one round of decryption.

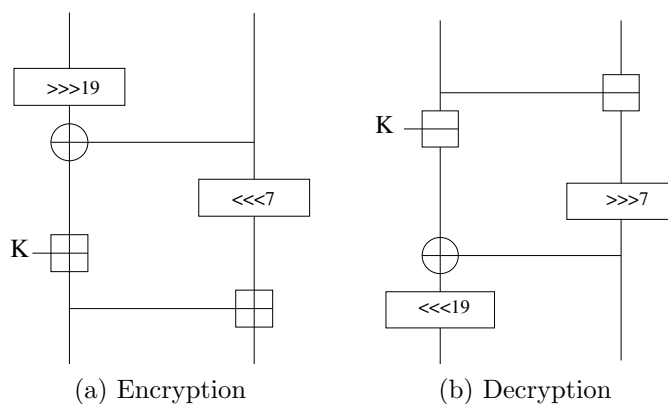


Figure 1: A round of PAGES

3.3 Key Schedule

The key schedule of PAGES resemble the key schedule of the block cipher 1024, 1024XKS, 2048XKS-F, and 4096XKS-F, see [4, 5, 6]. The number of rounds can be 64, 96, or 128. Divide the round number by 16 and you will get the size of the array the userkey is saved in (i.e. 4, 6, or 8), see the reference implementation in appendix A. Since the type of variable is `_int128` the size of the key is 512 bit, 768 bit, and 1024 bit, respectively. The userkey is stored in the first 4, 6, or 8 round keys, see the function `expand_key` in the reference implementation in appendix A. The userkey is circular shifted by 61 bits to the left and stored in the next round keys. This is repeated 15 times until all the round keys have received their values. Then two 128 bit variables are set to 0 and encrypted. The output is stored in first two round keys or in the last round keys, depending on whether the macro `FORWARD` is defined. The block cipher is employed in Output Feedback Mode until all the round keys have received their values. The block cipher is now ready for encryption or decryption.

4 Design Rationale

The round key in Speck is added modulo 2 (XOR) to left half of the block cipher and the right half is XORed with left half. However, when it comes to linear cryptanalysis (see [2]) addition modulo 2^n is more secure. The bias or effectiveness $\epsilon = |p - 1/2| = \frac{1}{2^{i+1}}$, where p denotes the probability of the linear approximation and i is the bit position (lsb=0). This was presented by [8] and with a different proof

by [3]. Since addition in PAGES is modulo 2^{128} and the plaintext requirement for success is roughly $1/\epsilon^2$, the key is added modulo 2^{128} to the left half of the block cipher and then the left half is added modulo 2^{128} to right half. The equation for the bias holds also for the right half, since the addition of the left half can be separated in the addition of the left half without the key and the addition of the key itself (i.e. addition is associative). To have three different operation, namely addition modulo 2^{128} , XOR, and rotation, the addition of the right half to the left half of block cipher was replaced by XOR.

The concept of diffusion in cryptography is known since Claude E. Shannon, see [7]. If one looks at Speck and PAGES, diffusion means in that case, that every plaintext bit is rotated to every bit position, provided that the number of rounds is sufficient. In Speck128, the left half of the block cipher is rotated by 8 bits to the right. Since $\text{GCD}(8,64)=8$, where 64 denotes half the block length and the bit length, a possible bit flip in the left half of the plaintext is after eight rounds in the same position as it was in the plaintext. Since carry propagation, the only non linear operation in \mathbb{F}_2^{128} , is essentially local, this might be a security issue. Carry propagation comes to a halt, when both bits at the same position of the addends are zero. Since two bits can have four values (00, 01, 10, 11), the probability for random and pseudorandom numbers for two zeros is 1/4. Thus the average length of carry propagation is four, that is a halfbyte. Consequently, the amount of rotation of the left half was not doubled to 16, but was set to 19. Since 19 and 128 are coprime, i.e. $\text{GCD}(19,128)=1$, a possible bit flip in the left half of the plaintext is rotated to all the position in left half of the block cipher, if the number of rounds is 128. For the same reason, the amount of circular shift to the left of the right half was not doubled to 6, but was set to 7.

Since the circular shifts are opposed to each other, one also has the sum taken into account. If the rotations are in the same direction, one has to take the difference into account. The sum is $19+7=26$. Since $\text{GCD}(26,128)=2$, a possible bit flip in the left half is rotated to 64 positions to the right half and vice versa (we did not consider the addition). If we take 17 instead of 19, the sum is $17+7=24$ and $\text{GCD}(24,128)=8$. Then the bit flip would have been rotated to 16 positions from the right half to the left half and vice versa. Since $\text{odd}+\text{odd}=\text{even}$ (or $\text{odd}-\text{odd}=\text{even}$), one must take even values where power of 2 is one. When we come back to Speck128, we can see that the right rotation of the left half would be better with 10 positions, since $\text{GCD}(10,64)=2$.

5 Conclusion

We have presented the block cipher PAGES, which comes in three version PAGES-512, PAGES-768, and PAGES-1024. The number denotes the key length, while the block size is 256 bit. The cryptographic community is invited to determine the security of the block cipher, and, if need be, make the necessary amendments. PAGES comes with no intellectual property claim.

References

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A Reference Implementation

```
/*
```

```
The C reference implementation of the  
block ciphers PAGES with 256 bit blocksize  
for gcc compatible compilers.
```

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See <http://www.gnu.org/licenses/gpl.txt> for details.*/*

```
#include<stdio.h>
```

```
#define INTLENGTH 128  
#define NUMROUNDS 128 // 64 and 96 also possible  
#define ROL(x,a) (((x)<<(a))|((x)>>(INTLENGTH-(a))))  
#define ROR(x,a) (((x)>>(a))|((x)<<(INTLENGTH-(a))))  
#define KEYLENGTH NUMROUNDS/16  
#define ROTROUNDKEY 61  
#define ROTROUNDDATA1 7  
#define ROTROUNDDATA0 19
```

```
#define FORWARD
```

```
void encrypt(unsigned __int128 data[2],\
```

```

unsigned __int128 keys[NUMROUNDS]){

    unsigned long i;

    for(i=0;i<NUMROUNDS;i++){
        data[0]=ROR(data[0],ROTROUNDDATA0);
        data[0]^=data[1];
        data[1]=ROL(data[1],ROTROUNDDATA1);
        data[0]+=keys[i];
        data[1]+=data[0];
    }
    return;
}

void decrypt(unsigned __int128 data[2],\
unsigned __int128 keys[NUMROUNDS]){

    unsigned long i;

    for(i=0;i<NUMROUNDS;i++){
        data[1]-=data[0];
        data[0]-=keys[NUMROUNDS-i-1];
        data[1]=ROR(data[1],ROTROUNDDATA1);
        data[0]^=data[1];
        data[0]=ROL(data[0],ROTROUNDDATA0);
    }
    return;
}

void expand_key(unsigned __int128 userkey[KEYLENGTH],\
unsigned __int128 keys[NUMROUNDS]){

    unsigned long i,j;
    unsigned __int128 data[2],a;

    for(i=0;i<KEYLENGTH;i++) keys[i]=userkey[i];
    for(i=1;i<16;i++){
        a=keys[(i-1)*KEYLENGTH];
        a>>=(INTLENGTH-ROTROUNDDATA0);
        for(j=0;j<(KEYLENGTH-1);j++){
            keys[i*KEYLENGTH+j]=(keys[(i-1)*KEYLENGTH+j]\
<<ROTROUNDDATA0)|(keys[(i-1)*KEYLENGTH+j+1]\
>>(INTLENGTH-ROTROUNDDATA0));
        }
    }
}

```

```

    }
    keys[i*KEYLENGTH+KEYLENGTH-1]=\
    (keys[(i-1)*KEYLENGTH+KEYLENGTH-1]\
    <<ROTROUNDKEY)|a;
}
data[0]=0;data[1]=0;
for(i=0;i<(NUMROUNDS/2);i++){
    encrypt(data,keys);
    #ifdef FORWARD
        keys[2*i]=data[1];
        keys[2*i+1]=data[0];
    #else
        keys[NUMROUNDS-2-2*i]=data[1];
        keys[NUMROUNDS-2*i-1]=data[0];
    #endif
}
return;
}

int main(){

    unsigned __int128 data[2],userkey[KEYLENGTH],keys[NUMROUNDS];
    unsigned long i,j;

    data[0]=0;data[1]=1;
    for(i=0;i<KEYLENGTH;i++) userkey[i]=i;
    expand_key(userkey,keys);
    encrypt(data,keys);
    decrypt(data,keys);
    i=(long) data[0];
    j=(long) data[1];
    printf("%20lx%20lx\n",i,j);
    return(0);
}

```