OCB : Parallelizable Authenticated Encryption

PMAC : Parallelizable Message Authentication Code

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What I'm doing

OCB - Refining a parallelizable scheme recently suggested by [Jutla] for authenticated encryption (privacy+authenticity)

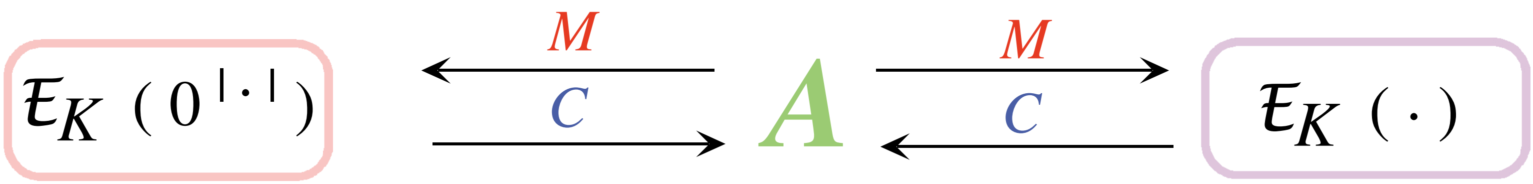
PMAC - Improving on [Bellare, Guerin, Rogaway], [Bernstein], [Gligor, Donescu] for a parallelizable MAC.

OCB (Offset CodeBook) Mode

Security Goals

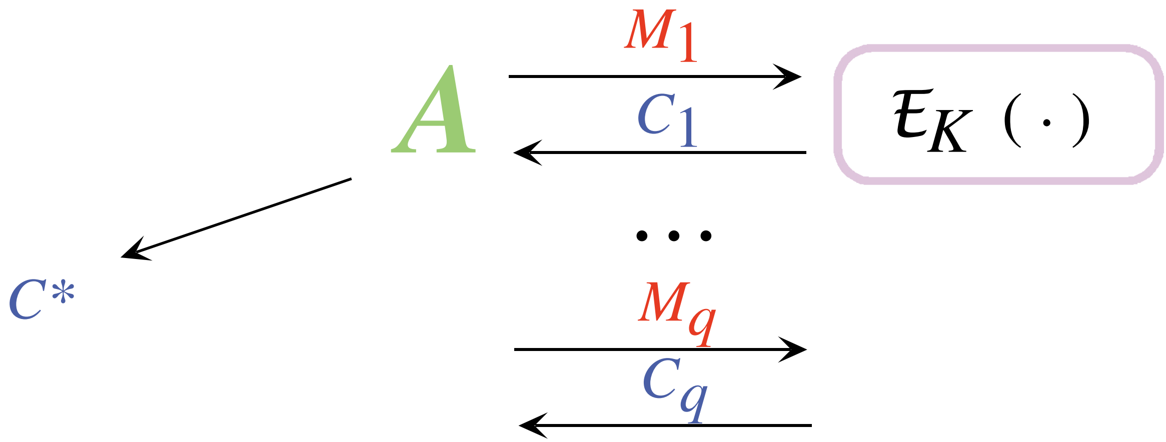
(1) The adversary can't understand anything about plaintexts

Formalized as *IND - CPA* [GM, BDJR]



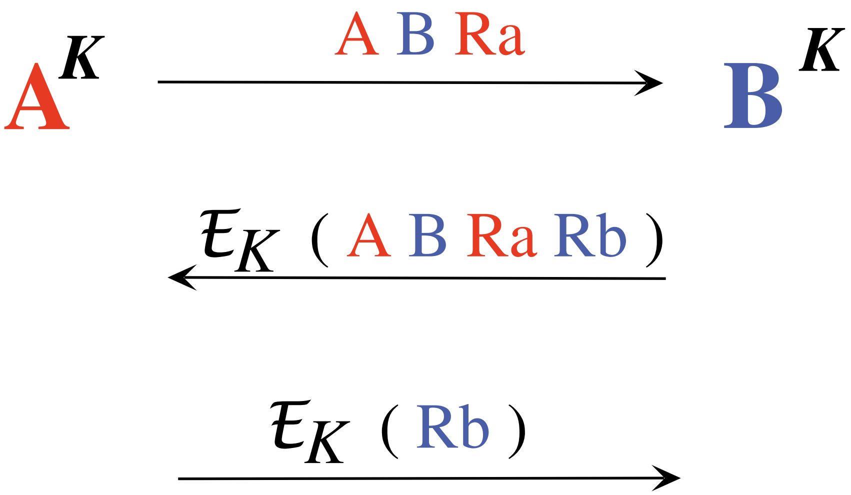
(2) The adversary can't produce valid ciphertexts

Formalized as *Integrity of Ciphertexts* [KY, BR, BN]



Why is Integrity-of-Ciphertexts important?

Because users of encryption **often** assume, wrongly, that they have it! Achieving IND-CPA + integrity-of-ciphertexts implies IND-CCA [BN] and non-malleablity-CCA, so an encryption scheme with Integrity-of-Ciphertexts is **far less likely** to be misused.



$\mathbf{A}^{K}$

A B Ra

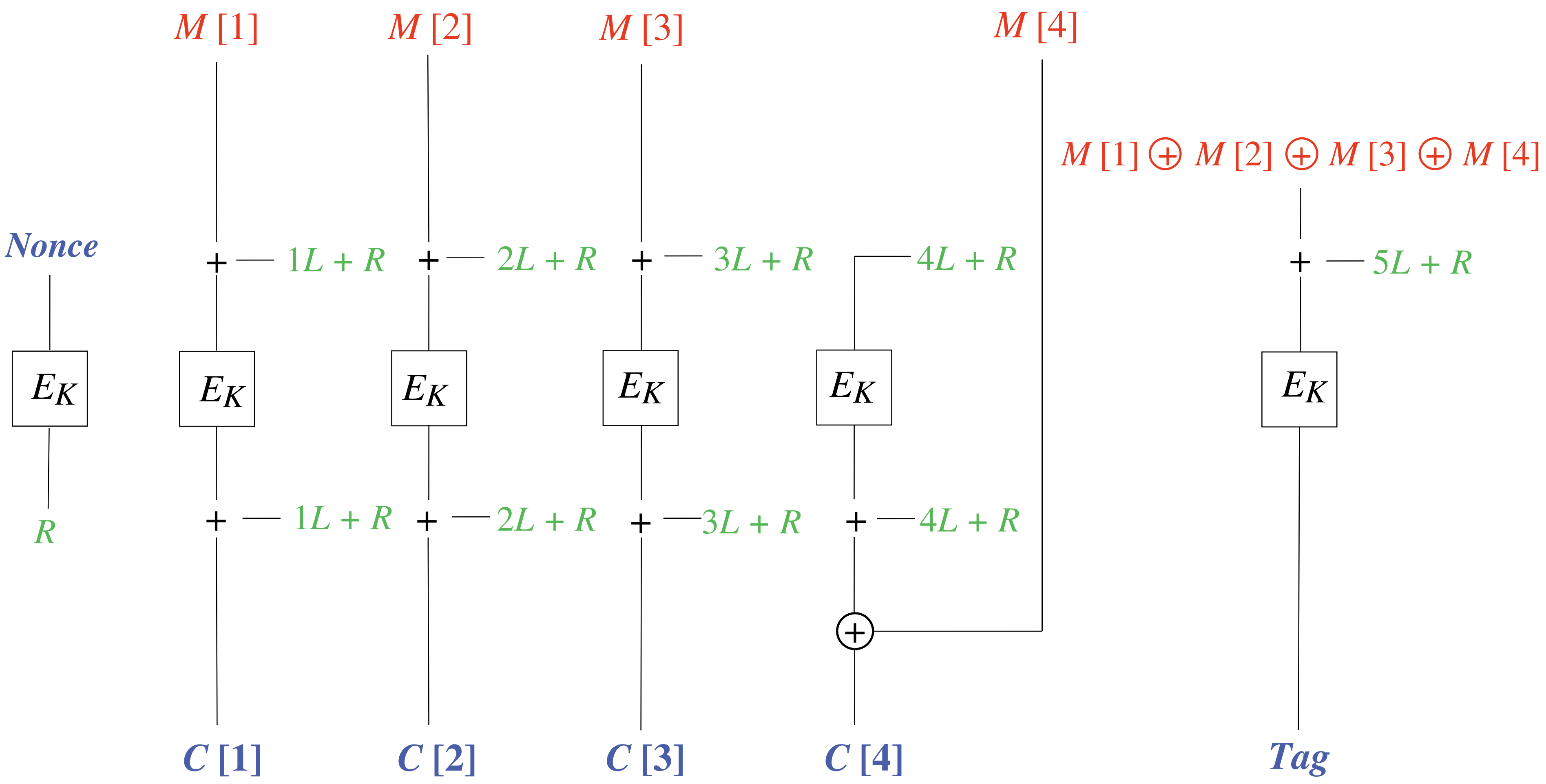
$\mathbf{B}^{K}$

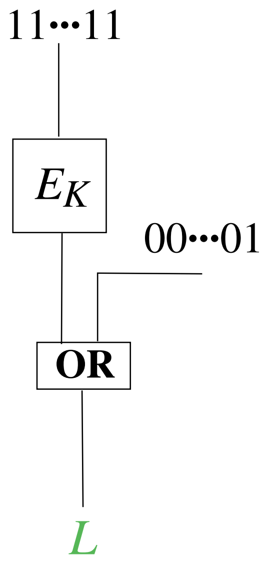
$\mathcal{E}_K$ (A B Ra Rb)

$\mathcal{E}_K$ (Rb)

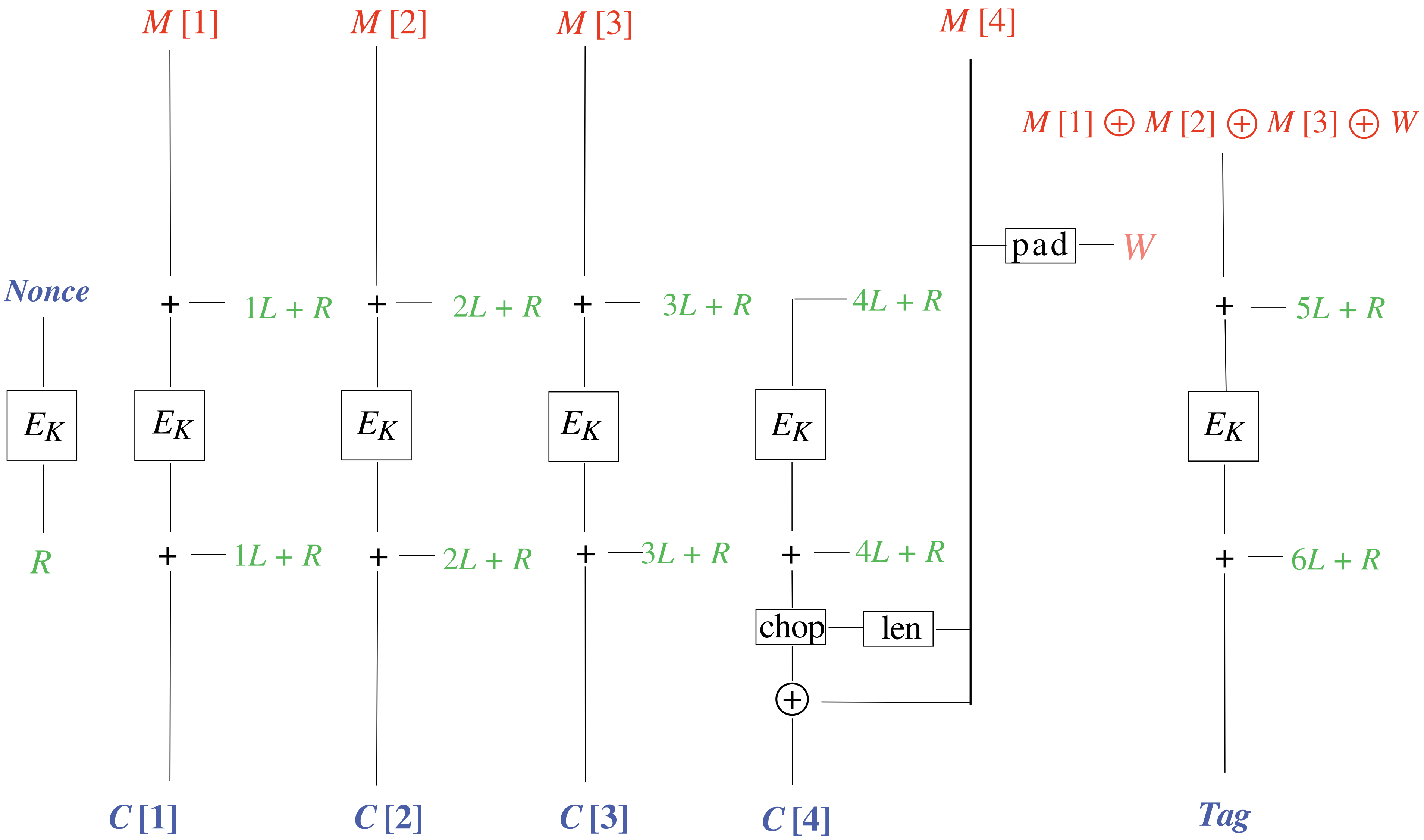
This sort of encryption-scheme usage, to **bind** together a private message, is very common in the literature and in practice. But is **completely bogus** when using IND-CPA encryption.

OCB (full final block)




11•••11
E_K
00•••01
OR
L

OCB (short final block)



```
procedure Encrypt ($K, Nonce, M$)

$L = E_K(1^{128}) \vee 0^{127}1$          // Do during key-setup
$R = E_K(Nonce)$

Let $m = \max\{1, \lceil |M|/128 \rceil\}$
Let $M[1], \ldots, M[m]$ be strings s.t. $M[1] \cdots M[m] = M$ and $|M[i]| = 128$ for $1 \le i < m$

$\mathrm{Offset} = L + R$
for $i = 1$ to $m - 1$ do
                $C[i] = E_K(M[i] + \mathrm{Offset}) + \mathrm{Offset}$
                $\mathrm{Offset} = \mathrm{Offset} + L$

if $|M[m]| = 128$ then $\mathrm{Mask} = E_K(\mathrm{Offset}) + \mathrm{Offset}$
                    $C[m] = M[m] \oplus \mathrm{Mask}$
                    $\mathrm{Offset} = \mathrm{Offset} + L$
                    $\mathrm{PreTag} = M[1] \oplus \cdots \oplus M[m-1] \oplus M[m] + \mathrm{Offset}$
                    $\mathrm{Tag} = E_K(\mathrm{PreTag})$
                else $W = \mathrm{pad}(M[m])$
                    $\mathrm{Mask} = E_K(\mathrm{Offset}) + \mathrm{Offset}$
                    $C[m] = M[m] \oplus$ ( last $|M[m]|$ bits of $\mathrm{Mask}$)
                    $\mathrm{Offset} = \mathrm{Offset} + L$
                    $\mathrm{PreTag} = M[1] \oplus \cdots \oplus M[m-1] \oplus W + \mathrm{Offset}$
                    $\mathrm{Offset} = \mathrm{Offset} + L$
                    $\mathrm{Tag} = E_K(\mathrm{PreTag}) + \mathrm{Offset}$

return ( $Nonce,\ C[1] \cdots C[m],\ T[1..tagLen]$ )
```

OCB Advantages

(1) Fully parallelizable - important for HW and SW

(2) Arbitrary domain - any bitstring can be encrypted

(3) Short ciphertexts - $|M| + |Nonce| + |T|$

(4) Fewer block-cipher calls - ceiling$\{\ |M| / n\ \} + 2$

(5) Nonces - counter is fine - needn't be unpredictable

(6) Short key - OCB defined as using one AES key

(7) Fast key setup - one AES invocation to make L

(8) Addition version - three 128-bit adds per block
one 128-bit xor per block

(9) XOR version - four 128-bit xors per block,
some shifting/xoring or table-lookups
to make the offsets

OCB/xor

Gray codes and GF(2^{128})

Addition is less pleasant than you might think

- Add-with-carry unavailable from C
- Dependency among instructions slows things down

```
L1: add ecx, edi
    adc edx, ebp
    adc edx, ebp
    dec eax
    jne L1
```

4.1 cycles

```
L1: xor ecx, edi
    xor edx, ebp
    xor eax, ebp
    dec eax
    jne L1
```

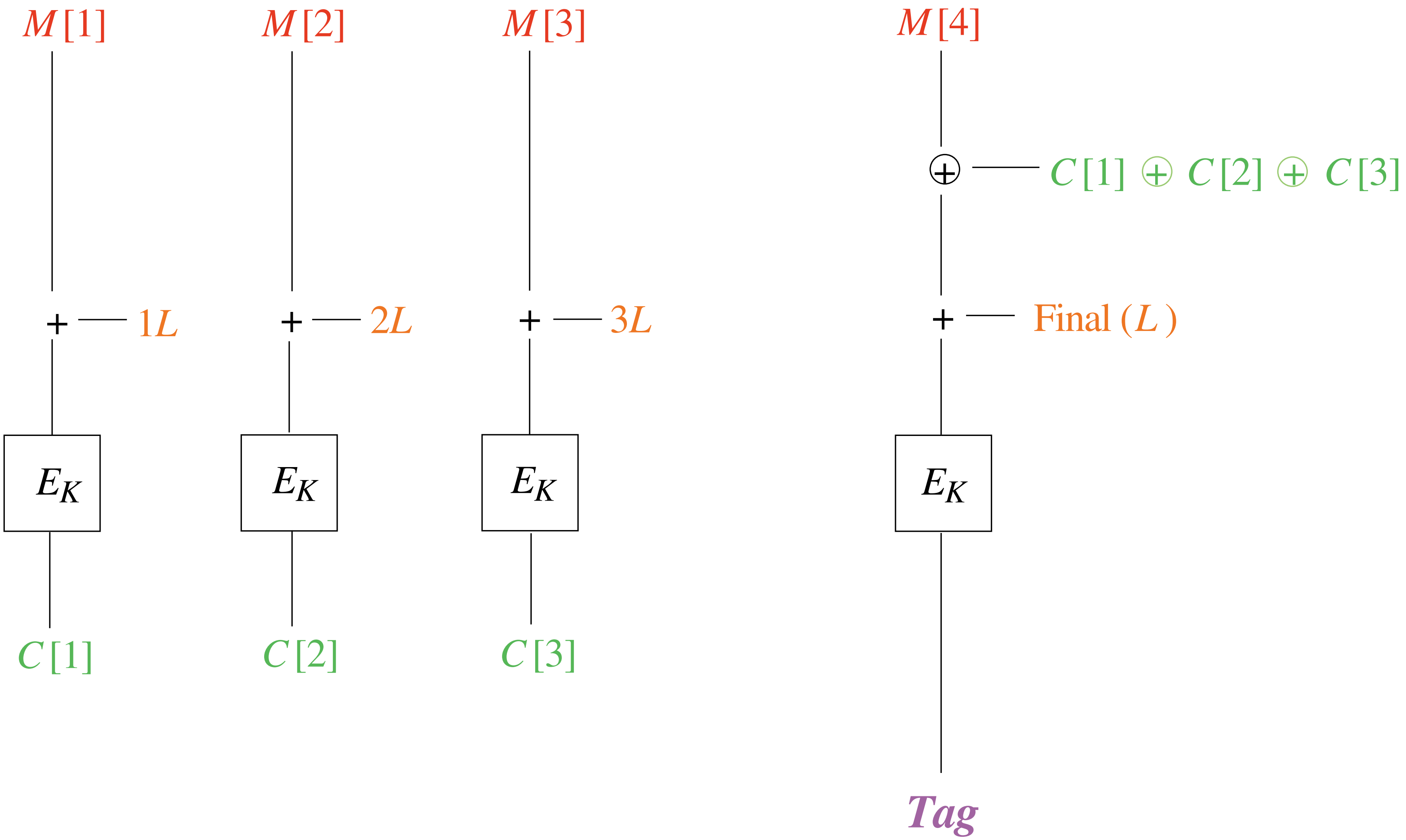
2.5 cycles

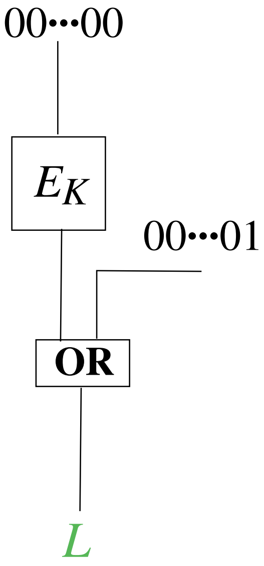
$$\mathrm{Offset}(i+1) = \mathrm{Offset}(i)\ \texttt{xor}\ L(\texttt{ntz}(i))$$

where $L(0) = L$ and

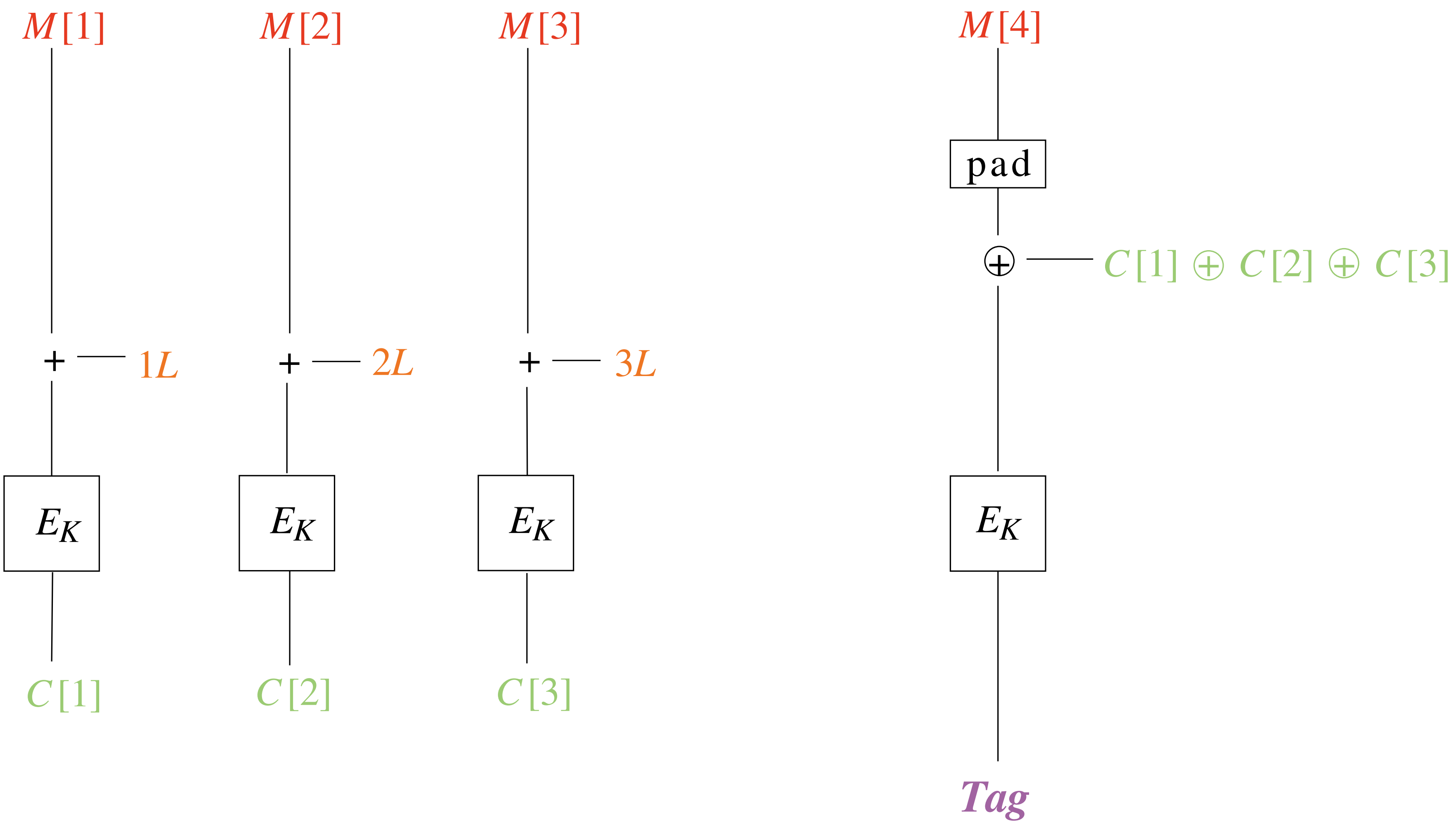
$$L(j+1) = \begin{cases} L(j) \ll 1 & \text{if } \texttt{lsb}(L(j)) = 0 \\ L(j) \ll 1\ \texttt{xor}\ \texttt{CONST} & \text{otherwise} \end{cases}$$

PMAC (full final block)




00•••00
E_K
00•••01
OR
L

PMAC (short final block)



PMAC Advantages

(1) Fully parallelizable - important for HW and SW
(2) Arbitrary domain - any bitstring can be MACed
(3) Deterministic - uses no nonces or random values
(4) Short MACs - up to 128 bits, but 64 bits is enough
(5) Fewer block-cipher calls - ceiling{ $| M | / n$ }
(6) Short key - PMAC defined as using one AES key
(7) Fast key setup - one AES invocation to make L
(8) Addition version - two 128-bit adds per block
one 128-bit xor per block
(9) XOR version - three 128-bit xors per block,
some shifting/xoring or table-lookups
to make the offsets