Cyclic Redundancy Check and Modulo-2 Division

CRC or Cyclic Redundancy Check is a method of detecting accidental changes/errors in the communication channel.

CRC uses **Generator Polynomial** which is available on both sender and receiver side. An example generator polynomial is of the form like $x^3 + x + 1$. This generator polynomial represents key 1011. Another example is $x^2 + 1$ that represents key 101.

```
n : Number of bits in data to be sent
    from sender side.
k : Number of bits in the key obtained
    from generator polynomial.
```

Sender Side (Generation of Encoded Data from Data and Generator Polynomial (or Key)):

1. The binary data is first augmented by adding k-1 zeros in the end of the data
2. Use ***modulo-2 binary division*** to divide binary data by the key and store remainder of division.
3. Append the remainder at the end of the data to form the encoded data and send the same

Receiver Side (Check if there are errors introduced in transmission)

Perform modulo-2 division again and if the remainder is 0, then there are no errors.

In this article we will focus only on finding the remainder i.e. check word and the code word.

Modulo 2 Division:

The process of modulo-2 binary division is the same as the familiar division process we use for decimal numbers. Just that instead of subtraction, we use XOR here.

- In each step, a copy of the divisor (or data) is XORed with the k bits of the dividend (or key).
- The result of the XOR operation (remainder) is (n-1) bits, which is used for the next step after 1 extra bit is pulled down to make it n bits long.
- When there are no bits left to pull down, we have a result. The (n-1)-bit remainder which is appended at the sender side.

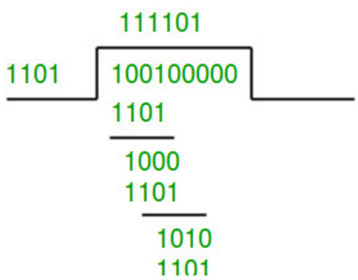
Illustration:

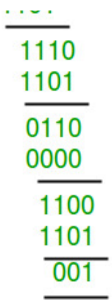
Example 1 (No error in transmission):

Data word to be sent - 100100

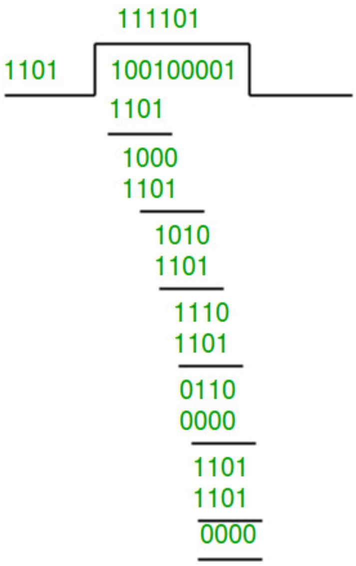
Key - 1101 [Or generator polynomial $x^3 + x^2 + 1$]

Sender Side:





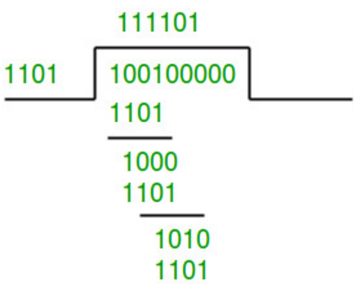

```
Therefore, the remainder is 001 and hence the encoded
data sent is 100100001.

Receiver Side:
Code word received at the receiver side  100100001
```

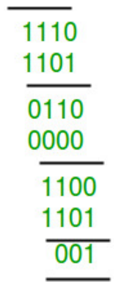



```
Therefore, the remainder is all zeros. Hence, the
data received has no error.
```

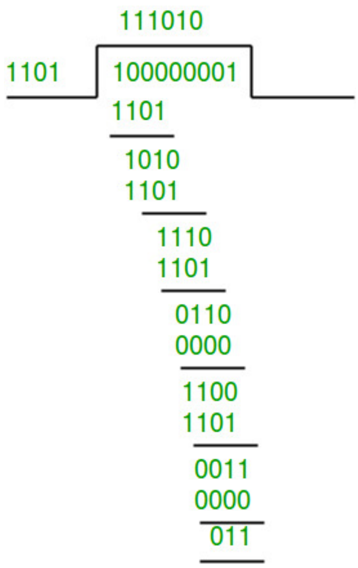
Example 2: (Error in transmission)

```
Data word to be sent - 100100
Key - 1101

Sender Side:
```






```
Therefore, the remainder is 001 and hence the
code word sent is 100100001.

Receiver Side
Let there be an error in transmission media
Code word received at the receiver side - 100000001
```



Since the remainder is not all zeroes, the error
is detected at the receiver side.

Implementation:

Below implementation for generating code word from given binary data and key.

C++

```
#include <bits/stdc++.h>
using namespace std;

// Returns XOR of 'a' and 'b'
// (both of same length)
string xor1(string a, string b)
{
```

```
    // Initialize result
    string result = "";

    int n = b.length();

    // Traverse all bits, if bits are
    // same, then XOR is 0, else 1
    for (int i = 1; i < n; i++) {
        if (a[i] == b[i])
            result += "0";
        else
            result += "1";
    }
    return result;
}

// Performs Modulo-2 division
string mod2div(string dividend, string divisor)
{

    // Number of bits to be XORed at a time.
    int pick = divisor.length();

    // Slicing the dividend to appropriate
    // length for particular step
    string tmp = dividend.substr(0, pick);

    int n = dividend.length();

    while (pick < n) {
        if (tmp[0] == '1')

            // Replace the dividend by the result
            // of XOR and pull 1 bit down
            tmp = xor1(divisor, tmp) + dividend[pick];
        else

            // If leftmost bit is '0'.
            // If the leftmost bit of the dividend (or the
            // part used in each step) is 0, the step cannot
            // use the regular divisor; we need to use an
            // all-0s divisor.
            tmp = xor1(std::string(pick, '0'), tmp)
                  + dividend[pick];

        // Increment pick to move further
        pick += 1;
    }

    // For the last n bits, we have to carry it out
    // normally as increased value of pick will cause
```

```
    // Index Out of Bounds.
    if (tmp[0] == '1')
        tmp = xor1(divisor, tmp);
    else
        tmp = xor1(std::string(pick, '0'), tmp);

    return tmp;
}

// Function used at the sender side to encode
// data by appending remainder of modular division
// at the end of data.
void encodeData(string data, string key)
{
    int l_key = key.length();

    // Appends n-1 zeroes at end of data
    string appended_data
        = (data + std::string(l_key - 1, '0'));

    string remainder = mod2div(appended_data, key);

    // Append remainder in the original data
    string codeword = data + remainder;
    cout << "Remainder : " << remainder << "\n";
    cout << "Encoded Data (Data + Remainder) :" << codeword
         << "\n";
}
// checking if the message received by receiver is correct
// or not. If the remainder is all 0 then it is correct,
// else wrong.
void receiver(string data, string key)
{
    string currxor
        = mod2div(data.substr(0, key.size()), key);
    int curr = key.size();
    while (curr != data.size()) {
        if (currxor.size() != key.size()) {
            currxor.push_back(data[curr++]);
        }
        else {
            currxor = mod2div(currxor, key);
        }
    }
    if (currxor.size() == key.size()) {
        currxor = mod2div(currxor, key);
    }
    if (currxor.find('1') != string::npos) {
        cout << "there is some error in data" << endl;
    }
    else {
        cout << "correct message received" << endl;
```

```
        }
    }
    // Driver code
    int main()
    {
        string data = "100100";
        string key = "1101";
        cout << "Sender side..." << endl;
        encodeData(data, key);

        cout << "\nReceiver side..." << endl;
        receiver(data+mod2div(data+std::string(key.size() - 1, '0'),key), |

        return 0;
    }

    // This code is contributed by MuskanKalra1 , Mayank Sharma
```

Java

```
// Java code to implement the approach
import java.util.Arrays;
class Program {

    // Returns XOR of 'a' and 'b'
    // (both of same length)
    static String Xor(String a, String b)
    {

        // Initialize result
        String result = "";
        int n = b.length();

        // Traverse all bits, if bits are
        // same, then XOR is 0, else 1
        for (int i = 1; i < n; i++) {
            if (a.charAt(i) == b.charAt(i))
                result += "0";
            else
                result += "1";
        }
        return result;
    }

    // Performs Modulo-2 division
    static String Mod2Div(String dividend, String divisor)
    {

        // Number of bits to be XORed at a time.
        int pick = divisor.length();
```

```
        // Slicing the dividend to appropriate
        // length for particular step
        String tmp = dividend.substring(0, pick);

        int n = dividend.length();

        while (pick < n) {
            if (tmp.charAt(0) == '1')

                // Replace the dividend by the result
                // of XOR and pull 1 bit down
                tmp = Xor(divisor, tmp)
                      + dividend.charAt(pick);
            else

                // If leftmost bit is '0'.
                // If the leftmost bit of the dividend (or
                // the part used in each step) is 0, the
                // step cannot use the regular divisor; we
                // need to use an all-0s divisor.
                tmp = Xor(new String(new char[pick])
                              .replace("\0", "0"),
                          tmp)
                      + dividend.charAt(pick);

            // Increment pick to move further
            pick += 1;
        }

        // For the last n bits, we have to carry it out
        // normally as increased value of pick will cause
        // Index Out of Bounds.
        if (tmp.charAt(0) == '1')
            tmp = Xor(divisor, tmp);
        else
            tmp = Xor(new String(new char[pick])
                          .replace("\0", "0"),
                      tmp);

        return tmp;
    }

    // Function used at the sender side to encode
    // data by appending remainder of modular division
    // at the end of data.
    static void EncodeData(String data, String key)
    {
        int l_key = key.length();

        // Appends n-1 zeroes at end of data
        String appended_data
```

```
            = (data
               + new String(new char[l_key - 1])
                     .replace("\0", "0"));

        String remainder = Mod2Div(appended_data, key);

        // Append remainder in the original data
        String codeword = data + remainder;
        System.out.println("Remainder : " + remainder);
        System.out.println(
            "Encoded Data (Data + Remainder) :" + codeword
            + "\n");
    }

    // checking if the message received by receiver is
    // correct or not. If the remainder is all 0 then it is
    // correct, else wrong.
    static void Receiver(String data, String key)
    {
        String currxor
            = Mod2Div(data.substring(0, key.length()), key);
        int curr = key.length();
        while (curr != data.length()) {
            if (currxor.length() != key.length()) {
                currxor += data.charAt(curr++);
            }
            else {
                currxor = Mod2Div(currxor, key);
            }
        }
        if (currxor.length() == key.length()) {
            currxor = Mod2Div(currxor, key);
        }
        if (currxor.contains("1")) {
            System.out.println(
                "there is some error in data");
        }
        else {
            System.out.println("correct message received");
        }
    }

    // Driver code
    public static void main(String[] args)
    {
        String data = "100100";
        String key = "1101";
        System.out.println("\nSender side...");
        EncodeData(data, key);

        System.out.println("Receiver side...");
        Receiver(data+Mod2Div(data+new String(new char[key.length() -
```

```
                              .replace("\0", "0"),key),key);
    }
}

// This code is contributed by phasing17
```

Python3

```python
# Returns XOR of 'a' and 'b'
# (both of same length)


def xor(a, b):

    # initialize result
    result = []

    # Traverse all bits, if bits are
    # same, then XOR is 0, else 1
    for i in range(1, len(b)):
        if a[i] == b[i]:
            result.append('0')
        else:
            result.append('1')

    return ''.join(result)


# Performs Modulo-2 division
def mod2div(dividend, divisor):

    # Number of bits to be XORed at a time.
    pick = len(divisor)

    # Slicing the dividend to appropriate
    # length for particular step
    tmp = dividend[0: pick]

    while pick < len(dividend):

        if tmp[0] == '1':

            # replace the dividend by the result
            # of XOR and pull 1 bit down
            tmp = xor(divisor, tmp) + dividend[pick]

        else:   # If leftmost bit is '0'
            # If the leftmost bit of the dividend (or the
            # part used in each step) is 0, the step cannot
            # use the regular divisor; we need to use an
```

```
            # all-0s divisor.
            tmp = xor('0'*pick, tmp) + dividend[pick]

        # increment pick to move further
        pick += 1

    # For the last n bits, we have to carry it out
    # normally as increased value of pick will cause
    # Index Out of Bounds.
    if tmp[0] == '1':
        tmp = xor(divisor, tmp)
    else:
        tmp = xor('0'*pick, tmp)

    checkword = tmp
    return checkword

# Function used at the sender side to encode
# data by appending remainder of modular division
# at the end of data.


def encodeData(data, key):

    l_key = len(key)

    # Appends n-1 zeroes at end of data
    appended_data = data + '0'*(l_key-1)
    remainder = mod2div(appended_data, key)

    # Append remainder in the original data
    codeword = data + remainder
    print("Remainder : ", remainder)
    print("Encoded Data (Data + Remainder) : ",
          codeword)


# Driver code
data = "100100"
key = "1101"
encodeData(data, key)
```

C#

```
using System;
using System.Linq;

class Program {

    // Returns XOR of 'a' and 'b'
```

```
    // (both of same length)
    static string Xor(string a, string b)
    {

        // Initialize result
        string result = "";
        int n = b.Length;

        // Traverse all bits, if bits are
        // same, then XOR is 0, else 1
        for (int i = 1; i < n; i++) {
            if (a[i] == b[i])
                result += "0";
            else
                result += "1";
        }
        return result;
    }

    // Performs Modulo-2 division
    static string Mod2Div(string dividend, string divisor)
    {

        // Number of bits to be XORed at a time.
        int pick = divisor.Length;

        // Slicing the dividend to appropriate
        // length for particular step
        string tmp = dividend.Substring(0, pick);

        int n = dividend.Length;

        while (pick < n) {
            if (tmp[0] == '1')

                // Replace the dividend by the result
                // of XOR and pull 1 bit down
                tmp = Xor(divisor, tmp) + dividend[pick];
            else

                // If leftmost bit is '0'.
                // If the leftmost bit of the dividend (or
                // the part used in each step) is 0, the
                // step cannot use the regular divisor; we
                // need to use an all-0s divisor.
                tmp = Xor(new string('0', pick), tmp)
                      + dividend[pick];

            // Increment pick to move further
            pick += 1;
        }
```

```
        // For the last n bits, we have to carry it out
        // normally as increased value of pick will cause
        // Index Out of Bounds.
        if (tmp[0] == '1')
            tmp = Xor(divisor, tmp);
        else
            tmp = Xor(new string('0', pick), tmp);

        return tmp;
    }

    // Function used at the sender side to encode
    // data by appending remainder of modular division
    // at the end of data.
    static string EncodeData(string data, string key)
    {
        int l_key = key.Length;

        // Appends n-1 zeroes at end of data
        string appended_data
            = (data + new string('0', l_key - 1));

        string remainder = Mod2Div(appended_data, key);

        // Append remainder in the original data
        string codeword = data + remainder;
        Console.WriteLine("Remainder : " + remainder);
        Console.WriteLine(
            "Encoded Data (Data + Remainder) :" + codeword
            + "\n");
        return codeword;
    }

    // checking if the message received by receiver is
    // correct or not. If the remainder is all 0 then it is
    // correct, else wrong.
    static void Receiver(string data, string key)
    {
        string currxor
            = Mod2Div(data.Substring(0, key.Length), key);
        int curr = key.Length;
        while (curr != data.Length) {
            if (currxor.Length != key.Length) {
                currxor += data[curr++];
            }
            else {
                currxor = Mod2Div(currxor, key);
            }
        }
        if (currxor.Length == key.Length) {
            currxor = Mod2Div(currxor, key);
        }
```

```
        if (currxor.Contains('1')) {
            Console.WriteLine(
                "there is some error in data");
        }
        else {
            Console.WriteLine("correct message received");
        }
    }

    // Driver code
    static void Main(string[] args)
    {
        string data = "100100";
        string key = "1101";
        Console.WriteLine("Sender side...");
        EncodeData(data, key);
        Console.WriteLine("Receiver side...");
        Receiver(data+Mod2Div(data + new string('0', key.Length - 1),k
    }
}

// This code is contributed by phasing17.
```

Javascript

```
// A JavaScript program for generating code
// word from given binary data and key.

// Returns XOR of 'a' and 'b'
// (both of same length)
function xor1(a, b)
{

        // Initialize result
        let result = "";

        let n = b.length;

        // Traverse all bits, if bits are
        // same, then XOR is 0, else 1
        for (let i = 1; i < n; i++) {
                if (a[i] == b[i]) {
                        result += "0";
                }
                else {
                        result += "1";
                }
        }
        return result;
}
```

```
    // Performs Modulo-2 division
    function mod2div(dividend, divisor) {

            // Number of bits to be XORed at a time.
            let pick = divisor.length;

            // Slicing the dividend to appropriate
            // length for particular step
            let tmp = dividend.substr(0, pick);

            let n = dividend.length;

            while (pick < n)
            {
                    if (tmp[0] == '1')
                    {

                            // Replace the dividend by the result
                            // of XOR and pull 1 bit down
                            tmp = xor1(divisor, tmp) + dividend[pick];
                    }
                    else
                    {
                            // If leftmost bit is '0'.
                            // If the leftmost bit of the dividend (or the
                            // part used in each step) is 0, the step cann
                            // use the regular divisor; we need to use an
                            // all-0s divisor.
                            let str = "";
                            for (let i = 0; i < pick; i++) {
                                    str = str.concat('0');
                            }
                            tmp = xor1(str, tmp) + dividend[pick];
                    }

                    // Increment pick to move further
                    pick += 1;
            }

            // For the last n bits, we have to carry it out
            // normally as increased value of pick will cause
            // Index Out of Bounds.
            if (tmp[0] == '1') {
                    tmp = xor1(divisor, tmp);
            }
            else {
                    tmp = xor1(string(pick, '0'), tmp);
            }
            return tmp;
    }
```

```
// Function used at the sender side to encode
// data by appending remainder of modular division
// at the end of data.
function encodeData(data, key) {
        let l_key = key.length;

        // Appends n-1 zeroes at end of data
        let str = "";
        for (let i = 0; i < l_key - 1; i++) {
                str = str.concat('0');
        }
        console.log(str);
        let appended_data = data.concat(str);

        let remainder = mod2div(appended_data, key);

        // Append remainder in the original data
        let codeword = data + remainder;

        // Adding the print statements
        document.write("Remainder : ", remainder);
        document.write("Encoded Data (Data + Remainder) :", codeword);
}

// Driver code
{
        let data = "100100";
        let key = "1101";

        encodeData(data, key);
}

// This code is contributed by Gautam goel (gautamgoel962)
```


Output

```
Sender side...
Remainder : 001
Encoded Data (Data + Remainder) :100100001

Receiver side...
correct message received
```

Output:

Time Complexity: O(n)

Auxiliary Space: O(n)

Note that CRC is mainly designed and used to protect against common of errors on communication channels and NOT suitable protection against intentional alteration of data (See reasons here)

Implementation using Bit Manipulation:

CRC codeword generation can also be done using bit manipulation methods as follows:

C++

```
// C++ Program to generate CRC codeword
#include <iostream>
#include <math.h>
#include <stdio.h>

using namespace std;

// function to convert integer to binary string
string toBin(long long int num)
{
    string bin = "";
    while (num) {
        if (num & 1)
            bin = "1" + bin;
        else
            bin = "0" + bin;
        num = num >> 1;
    }
    return bin;
}

// function to convert binary string to decimal
long long int toDec(string bin)
{
    long long int num = 0;
    for (int i = 0; i < bin.length(); i++) {
        if (bin.at(i) == '1')
            num += 1 << (bin.length() - i - 1);
    }
    return num;
}

// function to compute CRC and codeword
void CRC(string dataword, string generator)
{
    int l_gen = generator.length();
    long long int gen = toDec(generator);

    long long int dword = toDec(dataword);
```

```
    // append 0s to dividend
    long long int dividend = dword << (l_gen - 1);

    // shft specifies the no. of least
    // significant bits not being XORed
    int shft = (int)ceill(log2l(dividend + 1)) - l_gen;
    long long int rem;

    while ((dividend >= gen) || (shft >= 0)) {

        // bitwise XOR the MSBs of dividend with generator
        // replace the operated MSBs from the dividend with
        // remainder generated
        rem = (dividend >> shft) ^ gen;
        dividend = (dividend & ((1 << shft) - 1))
                   | (rem << shft);

        // change shft variable
        shft = (int)ceill(log2l(dividend + 1)) - l_gen;
    }

    // finally, AND the initial dividend with the remainder
    // (=dividend)
    long long int codeword
        = (dword << (l_gen - 1)) | dividend;
    cout << "Remainder: " << toBin(dividend) << endl;
    cout << "Codeword : " << toBin(codeword) << endl;
}

int main()
{
    string dataword, generator;
    dataword = "10011101";
    generator = "1001";
    CRC(dataword, generator);
    return 0;
}
```

Java

```
// Java Program to generate CRC codeword
class GFG {

    // function to convert integer to binary string
    static String toBin(int num)
    {
        String bin = "";
        while (num > 0) {
            if ((num & 1) != 0)
```

```
                bin = "1" + bin;
            else
                bin = "0" + bin;
            num = num >> 1;
        }
        return bin;
    }

    // function to convert binary string to decimal
    static int toDec(String bin)
    {
        int num = 0;
        for (int i = 0; i < bin.length(); i++) {
            if (bin.charAt(i) == '1')
                num += 1 << (bin.length() - i - 1);
        }
        return num;
    }

    // function to compute CRC and codeword
    static void CRC(String dataword, String generator)
    {
        int l_gen = generator.length();
        int gen = toDec(generator);

        int dword = toDec(dataword);

        // append 0s to dividend
        int dividend = dword << (l_gen - 1);

        // shft specifies the no. of least
        // significant bits not being XORed
        int shft = (int)Math.ceil(Math.log(dividend + 1)
                                  / Math.log(2))
                   - l_gen;
        int rem;

        while ((dividend >= gen) || (shft >= 0)) {

            // bitwise XOR the MSBs of dividend with
            // generator replace the operated MSBs from the
            // dividend with remainder generated
            rem = (dividend >> shft) ^ gen;
            dividend = (dividend & ((1 << shft) - 1))
                       | (rem << shft);

            // change shft variable
            shft = (int)Math.ceil(Math.log(dividend + 1)
                                  / Math.log(2))
                   - l_gen;
        }
```

```
        // finally, AND the initial dividend with the
        // remainder (=dividend)
        int codeword = (dword << (l_gen - 1)) | dividend;
        System.out.println("Remainder: " + toBin(dividend));
        System.out.println("Codeword : " + toBin(codeword));
    }

    // Driver Code
    public static void main(String[] args)
    {
        String dataword, generator;
        dataword = "10011101";
        generator = "1001";
        CRC(dataword, generator);
    }
}

// This code is contributed by phasing17
```

Python3

```
# Python3 program to generate CRC codeword
from math import log, ceil


def CRC(dataword, generator):
    dword = int(dataword, 2)
    l_gen = len(generator)

    # append 0s to dividend
    dividend = dword << (l_gen - 1)

    # shft specifies the no. of least significant
    # bits not being XORed
    shft = ceil(log(dividend + 1, 2)) - l_gen

    # ceil(log(dividend+1 , 2)) is the no. of binary
    # digits in dividend
    generator = int(generator, 2)

    while dividend >= generator or shft >= 0:

        # bitwise XOR the MSBs of dividend with generator
        # replace the operated MSBs from the dividend with
        # remainder generated
        rem = (dividend >> shft) ^ generator
        dividend = (dividend & ((1 << shft) - 1)) | (rem << shft)

        # change shft variable
        shft = ceil(log(dividend+1, 2)) - l_gen
```

```
    # finally, AND the initial dividend with the remainder (=dividend)
    codeword = dword << (l_gen-1) | dividend
    print("Remainder:", bin(dividend).lstrip("-0b"))
    print("Codeword :", bin(codeword).lstrip("-0b"))


# Driver code
dataword = "10011101"
generator = "1001"
CRC(dataword, generator)
```

C#

```
// C# Program to generate CRC codeword
using System;

class GFG {

    // function to convert integer to binary string
    static string toBin(int num)
    {
        string bin = "";
        while (num > 0) {
            if ((num & 1) != 0)
                bin = "1" + bin;
            else
                bin = "0" + bin;
            num = num >> 1;
        }
        return bin;
    }

    // function to convert binary string to decimal
    static int toDec(string bin)
    {
        int num = 0;
        for (int i = 0; i < bin.Length; i++) {
            if (bin[i] == '1')
                num += 1 << (bin.Length - i - 1);
        }
        return num;
    }

    // function to compute CRC and codeword
    static void CRC(string dataword, string generator)
    {
        int l_gen = generator.Length;
        int gen = toDec(generator);
```

```
        int dword = toDec(dataword);

        // append 0s to dividend
        int dividend = dword << (l_gen - 1);

        // shft specifies the no. of least
        // significant bits not being XORed
        int shft = (int)Math.Ceiling(Math.Log(dividend + 1)
                                     / Math.Log(2))
                   - l_gen;
        int rem = (dividend >> shft) ^ gen;

        while ((dividend >= gen) || (shft >= 0)) {

            // bitwise XOR the MSBs of dividend with
            // generator replace the operated MSBs from the
            // dividend with remainder generated
            rem = (dividend >> shft) ^ gen;
            dividend = (dividend & ((1 << shft) - 1))
                       | (rem << shft);

            // change shft variable
            shft = (int)Math.Ceiling(Math.Log(dividend + 1)
                                     / Math.Log(2))
                   - l_gen;
        }

        // finally, AND the initial dividend with the
        // remainder (=dividend)
        int codeword = (dword << (l_gen - 1)) | dividend;
        Console.WriteLine("Remainder: " + toBin(dividend));
        Console.WriteLine("Codeword : " + toBin(codeword));
    }

    // Driver Code
    public static void Main(string[] args)
    {
        string dataword, generator;
        dataword = "10011101";
        generator = "1001";
        CRC(dataword, generator);
    }
}

// This code is contributed by phasing17
```

Javascript

```
// JavaScript Program to generate CRC codeword
```

```
// function to convert integer to binary string
function toBin(num){
    var bin = "";
    while (num){
        if (num & 1)
            bin = "1" + bin;
        else
            bin = "0" + bin;
        num = num>>1;
    }
    return bin;
}

// function to convert binary string to decimal
function toDec(bin){
    var num = 0;
    for (var i=0; i<bin.length; i++){
        if (bin[i]=='1')
            num += 1 << (bin.length - i - 1);
    }
    return num;
}

// function to compute CRC and codeword
function CRC(dataword, generator){
    var l_gen = generator.length;
    var gen = toDec(generator);

    var dword = toDec(dataword);

     // append 0s to dividend
    var dividend = dword << (l_gen-1);

    // shft specifies the no. of least
    // significant bits not being XORed
    var shft = Math.ceil(Math.log2(dividend+1)) - l_gen;
    var rem;

    while ((dividend >= gen) || (shft >= 0)){

        // bitwise XOR the MSBs of dividend with generator
        // replace the operated MSBs from the dividend with
        // remainder generated
        rem = (dividend >> shft) ^ gen;
        dividend = (dividend & ((1 << shft) - 1)) | (rem << shft);

        // change shft variable
        shft = Math.ceil(Math.log2(dividend + 1)) - l_gen;
    }

    // finally, AND the initial dividend with the remainder (=dividend
    var codeword = (dword << (l_gen - 1)) | dividend;
```

```
    console.log( "Remainder:", toBin(dividend));
    console.log("Codeword :", toBin(codeword));
}

//Driver code
var dataword = "10011101";
var generator = "1001";
CRC(dataword, generator);


//This code is contributed by phasing17
```


Output

```
Remainder: 100
Codeword : 10011101100
```

Time Complexity: O(n)

Auxiliary Space: O(n)

References:

https://en.wikipedia.org/wiki/Cyclic_redundancy_check

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J

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