A New Algorithm to Search for Irreducible Polynomials Using Decimal Equivalents of Polynomials over Galois Field GF(p^q)

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Abstract. In this paper a new algorithm to find the decimal equivalents of all monic irreducible polynomials (IPs) over Galois Field GF(p^q) has been introduced. This algorithm is effective to find the decimal equivalents of monic IPs over Galois Field with a large value of prime modulus and also with a large extension of the prime modulus. The algorithm introduced in this paper is much more time effective with less complexity. It is able to find monic irreducible polynomials for a large value of prime modulus and also with large extension of the prime modulus in few seconds.

Introduction. From the last few decades, efficient implementation of cryptographic algorithms has been in the focal point of major research efforts in cryptography. Cryptography is one of the most dominant application areas of the finite field arithmetic [1]. Almost all symmetric-key cryptographic algorithms, including recent algorithms such as elliptic curve and pairing-based cryptography depends heavily on finite field arithmetic. Majority of cryptographic algorithms utilize arithmetic in finite mathematical structures such as finite multiplicative groups, rings, polynomials and finite fields [2]. The use of basic arithmetic operations (i.e. addition, multiplication, and inversion) over finite fields, GF(p^q), where p is prime modulus and q is extension of the prime modulii, are dominant in many cryptographic algorithms such as RSA algorithm [3], Diffie-Hellman key exchange algorithm [4], the US federal Digital Signature Standard [5], elliptic curve cryptography [6][7], and also recently pairing-based cryptography [8][9]. Due to elliptic curve based schemes, most efficient finite fields that are commonly used in cryptographic applications are prime fields GF(p) and binary extension fields GF(2^n). The standard 8-bit S-Box of Advance Encryption Standard is usually generated by using a monic irreducible polynomial {11B} as the modulus in extended binary Galois Field GF(2^8) and a particular additive constant {63} in Binary Galois Field GF(2). Rijndael used this particular modulus and the additive constant in the original proposal of Advance Encryption Standard . It has also been discovered that the other moduli and constants can also be used to make the generation of 8-bit S-Boxes more dynamic [10][11][12]. Recently, pairing-based cryptography based on bilinear pairings over elliptic curve points stimulated a significant level of interest in the arithmetic of ternary extension fields GF(3^n) [13].

Polynomials over finite fields have been studied since the time of Gauss and Galois [14][15]. The determination of special types of polynomials such as irreducible, primitive, and permutation polynomials, is a long standing and well studied problem in the theory and application of finite fields [16][17][18][19]. On the other hand, in recent years there has been intensive use of special polynomials in many areas including algebraic coding theory for the error-free transmission of information [20], cryptography for the secure transmission of information [10][11][12], and polynomials over finite fields appear very naturally in several areas of combinatorics. First, due to the finite number of elements, the enumeration of various special kinds of polynomials over finite fields is an interesting and extremely important research area in combinatorics, especially in design theory, polynomials are used to construct and describe cyclic difference sets and special types of designs such as group divisible designs [21]. Divisibility conditions on trinomials over finite fields have been shown to produce orthogonal arrays with certain strengths [22], and bivariate and multivariate polynomials can be used to represent and study latin squares and sets of orthogonal latin squares and hypercubes of prime power orders [23][24]. Polynomials over finite fields are the key ingredient in the construction of error-correcting codes such as BCH [25], Goppa [25], Reed-Solomon [25], and Reed-Muller codes [25], among others. Moreover, polynomials also play a key role in other areas of coding theory such as the determination of weight enumerators [26], the study of distance distributions [27], and decoding algorithms [28]. Large extensions of finite fields (especially over the two-element field) are important in cryptography . Elements in these extension fields can be represented by polynomials over the prime subfield [29]. Thus, constructions of extension fields and fast arithmetic of polynomials are important practical questions . In addition, polynomials over finite fields are important in engineering applications. Linear recurrence relations over finite fields produce sequences of field elements [30]. Linear feedback shift registers are used to implement these recurrences. Characteristic polynomials over finite fields are one of the main tools when dealing with shift registers [31]. In particular, primitive characteristic polynomials produce sequences with large periods, and thus have found many applications in areas such as random number generation [32].

In past decades many results towards the enumeration of classes of univariate irreducible polynomials over finite field or Galois Field with certain characteristics have appeared in the literature. Such polynomials are used to implement arithmetic in extension fields found in many applications, including coding theory [33][34], cryptography [35][36], multivariate polynomial factoring [37] parallel polynomial arithmetic [38]. Many algorithms had also been introduced along with to determine irreducible polynomials over finite fields, including a composite polynomial method to find monic irreducible polynomials by a hand on calculation over Galois field with prime modulus 2 to 7 with for extensions 1 to 11 [39], Rabin's algorithm to find monic irreducible polynomials over Galois Field GF(p) where p is a prime integer, An improvement of Rabin's algorithm with less complexity [40], an algorithm that constructs a degree d irreducible polynomial over finite fields proved that under the generalized Riemann hypothesis by Adleman and Lenstra [41], a deterministic algorithm that runs in polynomial time for fields of small characteristic [42], and recently a method that uses the concept of p-nary equivalent of multiplicative inverses of the elemental polynomials (ep) of a basic monic irreducible polynomial to determine a basic monic polynomial to be irreducible [43].

A basic polynomial BP(x) over finite field or Galois Field GF(p^q) is expressed as,

$$BP(x) = a_q x^q + a_{q-1}x^{q-1} + - - - + a_1x + a_0.$$

B(x) has (q+1) terms, where a_q is non-zero and is termed as the leading coefficient [44]. A polynomial is monic if a_q is unity, else it is non-monic. The GF(p^q) have (p^q – p) elemental polynomials ep(x) ranging from p to (p^q -1) each of whose representation involves q terms with leading coefficient a_{q-1}. The expression of ep(x) is written as,

$$ep(x) = a_{q-1}x^{q-1} + - - - + a_1x + a_0 \text{, where } a_1 \text{ to } a_{q-1} \text{ are not simultaneously zero.}$$

Many of BP(x), which has an elemental polynomial as a factor under GF(p^q), are termed as reducible. Those of the BP(x) that have no factors are termed as irreducible polynomials IP(x) [45][46] and is expressed as,

$$IP(x) = a_q x^q + a_{q-1}x^{q-1} + - - - + a_1x + a_0 \text{, where } a_q \neq 0.$$

In Galois field GF(p^q), the decimal equivalents of the basic polynomials of extension q vary from p^q to (p^{q+1} - 1) while the elemental polynomials are those with decimal equivalents varying from p to (p^q – 1). Some of the monic basic polynomials are irreducible, since it has no monic elemental polynomials as a factor.

In this paper a new algorithm to determine the decimal equivalents of monic irreducible polynomials over extended Galois fields, also for large value of prime modulus and its large extensions is demonstrated with example. In this algorithm the decimal equivalents of each of two monic elemental polynomials at a time with highest degree d and (q-d) where d = 0 to (q-1)/2, are split into the p-nary coefficients of each term of those two monic elemental polynomials. The coefficients of each term in each two monic elemental polynomials are multiplied, added with each other and modulated to obtain the p-nary coefficients of each term of the monic basic polynomial. The decimal equivalent of the resultant monic basic polynomial is termed as the decimal equivalent of a reducible monic basic polynomial. The decimal equivalents of polynomials belonging to the list of reducible polynomials are cancelled leaving behind the monic irreducible polynomials.

For convenient understanding, the proposed algorithm is presented in Sec.2 for Galois Field GF(p^q) and for clarity of understanding the algorithm is described with example of Galois Field GF(7^7), where p=7 and q=7 has also been demonstrated in the same section . The method is able to find all monic irreducible polynomials IP(x) over any Galois Field GF(p^q), also for large value of prime modulus and its large extension. Sec. 3 demonstrates the obtained results to show that the proposed searching algorithm is actually able to search over any Galois field GF(p^q) with any value of prime modulus and its extension, such as, p €{ 3, 5, 7,....,101,..,p} and q € { 2, 3, 5, 7,…,101,….q}. In Sec.4 and 5, the conclusion of the paper and the references are illustrated. A list of decimal equivalents of all the monic irreducible polynomials over Galois Field GF(7^5) is given in Appendix-1. Initial part of the list of decimal equivalents of all the monic irreducible polynomials over Galois Field GF(101^3) is given in Appendix-2.

2. Algorithm to find Decimal Equivalents of Irreducible Polynomials over Galois Field GF(p^q).

In this section the new algorithm to search for Decimal equivalents of all monic Irreducible polynomials over Galois Field GF(p^q) has been described with example. The detailed structural description of the algorithm is given in sub sec.2.1. The detailed mathematical description of the algorithm is given in sub sec.2.2. The

Computational Algorithm is demonstrated in sec.2.3.The example of the said algorithm for Galois Field GF(7^7) is given in sub sec 2.4. The analysis of time complexity is illustrated in sub sec.2.5.

2.1. Structural Description of the Algorithm.

In this algorithm the decimal equivalents of each of two monic elemental polynomials at a time with highest degree d and (q-d) where d € {0,..,(q-1)/2}, are split into the p-nary coefficients of each term of those two monic elemental polynomials. The coefficients of each term in each two monic elemental polynomials are multiplied, added respectively with each other and modulated to obtain the p-nary coefficients of each term of the monic basic polynomial. The decimal equivalent of the resultant monic basic polynomial is termed as the decimal equivalent of a reducible monic basic polynomial. The decimal equivalents of polynomials belonging to the list of reducible polynomials are cancelled leaving behind the monic irreducible polynomials. For Galois Field GF(p^q), where p is prime modulus and q is the extension of the field, the algorithm is given as follows,

Step 1. Generate Decimal Equivalents of all Monic Elemental Polynomials dec(ep(x)) over Galois Field GF(p^q).
Step 2. Split dec(ep(x_1)), dec(ep(x_2)) with highest degree d and (q-d) respectively where d = 1 to ((q-1)/2), are split into p-nary coefficients of each term of each monic elemental polynomial ep(x).
Step 3. Multiply and add terms with degree d to 0 and (q-d) to 0 to obtain the decimal coefficients of each term of the Basic Polynomial BP(x).
Step 4. Split coefficient of each term of BP(x) into p-nary coefficients.
Step 5. Obtain the decimal equivalent of the Basic Polynomial BP(x) or dec(BP(x)) as Decimal equivalent of Reducible Polynomial.
Step 6. The decimal equivalents of polynomials belonging to the list of monic reducible polynomials are cancelled leaving behind the monic irreducible polynomials.
Step 7. Stop.

2.2 Mathematical Structure of the Algorithm.

Here the interest is to find the monic irreducible polynomials over Galois Field GF(p^q), where p is the prime modulus and q is the extension of the prime modulus and p must be a prime integer. Since the indices of multiplicand and multiplier are added to obtain the product. The extension q can be demonstrated as a sum of two integers, d_1 and d_2, The degree of highest degree term present in elemental polynomials of GF(p^q) is (q-1) to 1, since the polynomials with highest degree of term 0, are constant polynomials and they do not play any significant role here, so they are neglected. Hence the two set of monic elemental polynomials for which the multiplication is a monic basic polynomial, have the degree of highest degree terms d_1, d_2 where, d_1 € {1,2,3,..,((q-1)/2)}, and the corresponding values of d_2 € {(q-1), (q-2), (q-3).,...,q-((q-1)/2)}. Number of coefficients in the monic basic polynomial BP(x) = (q+1); they are defined as BP_0, BP_1, BP_2, BP_3, BP_4, BP_5, BP_6, BP_7……., BP_q, the value of the suffix also indicates the degree of the term of the monic basic polynomial. For monic polynomials BP_q= 1.

Coefficients of each term in the 1st monic elemental polynomial EP^0, where, d_1 € {1,2,…..,((q-1)/2)}; are defined as EP_0^0, EP_1^0,……., $EP_{((q-1)/2-1)}^0$. Coefficients of each term in the 2nd monic elemental polynomial EP^1 where d_2 € {(q-1), (q-2), (q-3).,...,q-((q-1)/2-1)}; are defined as EP_0^1, EP_1^1, EP_2^1, EP_3^1, EP_4^1, … , $EP_{q-((q-1)/2-1)}^1$. The value in suffix also gives the degree of the term of the monic elemental polynomials. Total number of blocks is the number of integers in d_1 or d_2, i.e. (q-1)/2 .
Now, the Mathematical Structure of (q-1)/2th block for the algorithm is as follows,

(q-1)/2th block:

$\mathbf{BP_0}$= ($EP_0^0 \times EP_0^1$) mod p.
$\mathbf{BP_1}$= ($EP_0^0 \times EP_1^1 + EP_1^0 \times EP_0^1$) mod p.
$\mathbf{BP_2}$= ($EP_0^0 \times EP_2^1 + EP_1^0 \times EP_1^1 + EP_2^0 \times EP_0^1$) mod p.
$\mathbf{BP_3}$= ($EP_0^0 \times EP_3^1 + EP_1^0 \times EP_2^1 + EP_2^0 \times EP_1^1 + EP_3^0 \times EP_0^1$) mod p.
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$\mathbf{BP_{q-1}}$= ($EP_0^0 \times EP_{(q-1)}^1 + EP_1^0 * EP_{(q-2)}^1 + \ldots\ldots + EP_{(q/2-1)}^0 * EP_{(q-1)-(q-1)/2}^1$) mod p.
$\mathbf{BP_q}$= ($EP_{(q-1)/2}^0 * EP_{q-(q-1)/2}^1$) mod p.

Now the given basic monic polynomial is illustrated in Eq.1. and its decimal equivalent is calculated as in eq.2,

$\mathbf{BP(x)} = BP_q x^q + BP_{q-1} x^{q-1} + \ldots + BP_5 x^5 + BP_4 x^4 + BP_3 x^3 + BP_2 x^2 + BP_1 x^1 + BP_0 x^0$………………………..(1)

Decm_eqv(BP(x))= $BP_q \times p^q + BP_{q-1} \times p^{q-1} + \ldots + BP_5 \times p^5 + BP_4 \times p^4 + BP_3 \times p^3 + BP \times p^2 + BP_1 \times p^1 + BP_0 \times p^0$……(2)

Similarly all the decimal equivalents of all the resultant basic polynomials or reducible polynomials for all a and its corresponding b values are calculated. The polynomials belonging to the list of reducible polynomials are cancelled leaving behind the irreducible polynomials.

2.3. Description of the Computational Algorithm.

Here the Basic polynomials over Galois Field overGalois Field GF(p^q) is presented as BP(x) and Elemental polynomials over the same Galois field is presented as ep(x). For Galois Field GF(p^q) the prime modulus = p and the extension of the prime modulus = q. Highest degree term of the 1st elemental polynomial ep(x_1) is d_1 € {1,2,3,…………,(q-1)/2} and second elemental polynomial ep(x_2) is d_2 € { (q-1), (q-2), (q-3),...,q-(q-1)/2}. Number of terms in 1st elemental polynomial € {N(d_1)} and number of terms in 2nd elemental polynomial € {N(d_2)}. Coefficients of each ep(x) are demonstrated as $EPep_{\_indx\_i}$, where $1\leq i \leq 2$.

Here Number of terms in Basic Polynomial = p+1. Coefficients of BP(x) = BP_{bp_indx}, where $0\leq$ bp_indx $\leq$ q, The said Computational Algorithm is as follows,

Step 1. for block = 1 to (N(d_1) or N(d_2)) do the following steps.
Step 2. for ep_index_1 =1 to (q-1)/2 do the following steps.
Step 3. for ep_index_2 =(q-1) to (q-((q-1)/2)) do the following steps.
Step 4. for bp_index = 0 to q do the following steps.
Step 5. for P_1 = 1 to N(d_1) and P_2 = 1 to N(d_2) do the following steps.
Step 6. $BP_{bp\_indx} = (\Sigma(EP_{ep\_indx\_1}{}^{p1}\times EP_{ep\_indx\_2}{}^{p2}))$ mod p;
Step 7. Stop.

2.4 Time Complexity of the New Algorithm.

This Algorithm have a time complexity of O(n^5). Means it is much faster as Rabin's algorithm [40] for larger value of prime modulus and its modification [40]. Since the time complexity of the both Rabin's algorithm and its modification depends upon the value of prime modulus so it becomes a slow algorithm for large value of the prime modulus. But the new algorithm is much effective and works better as the value of prime modulus and the extension of prime modulus grows larger since time complexity depends only on the value of the extension of the Galois field. So this algorithm is suitable to find monic Irreducible polynomials of higher value of prime modulus and the extension of prime modulus .Comparison of time complexity of the new algorithm with other Algorithms is given below,

Algorithms	New Algorithm	Rabin's Algorithm	Rabin's Algorithm(mod)
Time Complexity	O(n^5)	O($n^4(\log P)^3$)	0($n^4(\log p)^2 + n^3(\log P)^3$)

2.5. Description of the Computational Algorithm for Galois Field GF(7^7).

Here the Basic polynomials over Galois Field overGalois Field GF(7^7) is presented as BP(x) and Elemental polynomials over the same Galois field is presented as ep(x). For Galois Field GF(7^7) the prime modulus = 7 and the extension of the prime modulus = 7. Highest degree term of the 1st elemental polynomial ep(x_1) are d_1 € {1, 2, 3} and second elemental polynomial ep(x_2) are d_2 € {6, 5, 4}. Number of terms in 1st elemental polynomial: N(d_1) € {2,3,4} and number of terms in 2nd elemental polynomial: N(d_2) € {7,6,5} respectively. Coefficients of each ep(x) are demonstrated as $EPep_{\_indx\_i}$, where $1\leq i \leq 2$.

Here Number of terms in Basic Polynomial = 8. Coefficients of BP(x) = BP_{bp_indx}, where $1\leq$ bp_indx ≤ 8, The said Computational Algorithm is as follows,

Step 1. for block = 1 to 3 do the following steps.
Step 2. for bp_index = 1 to 8 do the following steps.

Step 3. for ep_index_1 = 1 to 3 do the following steps.
Step 4. for ep_index_2 = 6 to4 do the following steps.
Step 5. for P_1 = 2 to 4 and P_2 = 7 to 5 do the following steps.
Step 6. $BP_{bp\_indx} = (\Sigma(EP_{ep\_indx\_1}{}^{p1} \times EP_{ep\_indx\_2}{}^{p2}))$ mod p;
Step 7. Stop.

3. Results.

The algebraic method or the above pseudo code has been tested on $GF(3^3)$,$GF(7^3)$,$GF(11^3)$, $GF(101^3)$, $GF(3^5)$, $GF(7^5)$, $GF(3^7)$, $GF(7^7)$,. Numbers of monic Irreducible polynomials given by this algorithm are same as in hands on calculation by the theorem to count monic irreducible polynomials over Galois Field $GF(p^q)$ [46]. The list of Numbers of monic irreducible polynomials for a particular Galois Field are given below for all of the above ten Extended Galois Fields. The list of all Irreducible monic basic polynomials of ten extended Galois fields are available in reference [47][48][49][50][51][52][53][54]. A part of the list of monic Irreducible Polynomial over $GF(7^7)$ is given in Appendix and also available in the link given in [54].

Ex.GF.	**$GF(3^3)$**	**$GF(7^3)$**	**$GF(11^3)$**	**$GF(101^3)$**
Number of IPs.	8	112	440	343400
Ex.GF.	**$GF(3^5)$**	**$GF(7^5)$**	**$GF(3^7)$**	**$GF(7^7)$**
Number of IPs.	50	2157	312	117648

4. Conclusion.

To the best knowledge of the present authors, there is no mention of a paper in which the composite polynomial method is translated into an algorithm and turn into a computer program. The new algorithm is a much simpler to find monic irreducible polynomials over Galois Field $GF(p^q)$. It is able to determine decimal equivalents of the monic irreducible polynomials over Galois Field with a large value of prime modulus, also with large extensions of the prime modulii. So this method can reduce the time complexity to find monic Irreducible Polynomials over Galois Field with large value of prime modulii and also with large extensions of the prime modulii. So this would help the crypto community to build S-Boxes or ciphers using irreducible polynomials over Galois Fields with a large value of prime modulii, also with the large extensions of the prime modulii.

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Appendix-1.

The list of decimal equivalents of Monic Irreducible Polynomials over Galois Field $GF(7^5)$ has been given below.

List.

16818	16823	16829	16833	16834	16836	16844	16845	16847	16852	16853	16855
16866	16875	16878	16890	16893	16902	16913	16923	16935	17006	17008	17009
17013	17022	17029	17037	17041	17051	17074	17075	17076	17089	17091	17093
17095	17098	17099	17104	17106	17107	17110	17116	17133	17162	17163	17170
17188	17189	17194	17205	17207	17212	17225	17228	17243	17250	17253	17279
17286	17287	17291	17298	17309	17314	17329	17334	17340	17343	17350	17352
17357	17365	17370	17373	17377	17379	17383	17391	17405	17411	17418	17428
17439	17443	17445	17459	17461	17469	17470	17473	17485	17505	17518	17524
17526	17536	17541	17547	17558	17567	17572	17575	17580	17594	17595	17611
17614	17634	17639	17642	17653	17655	17662	17663	17671	17686	17690	17694
17699	17706	17709	17716	17718	17729	17730	17735	17749	17755	17763	17764
17772	17777	17789	17796	17800	17803	17823	17825	17834	17844	17846	17859
17862	17868	17886	17890	17891	17898	17902	17914	17916	17919	17925	17938
17947	17953	17956	17964	17970	17974	17987	17988	17991	17995	18015	18041
18058	18073	18089	18097	18108	18122	18127	18132	18133	18149	18150	18155
18159	18196	18199	18202	18205	18210	18215	18231	18239	18245	18246	18264
18276	18278	18283	18289	18300	18303	18316	18330	18335	18346	18348	18359
18363	18365	18377	18378	18387	18388	18391	18397	18409	18415	18420	18422
18437	18443	18453	18460	18462	18467	18477	18484	18497	18505	18506	18517
18521	18531	18540	18541	18565	18570	18574	18575	18577	18581	18582	18583
18588	18598	18604	18622	18628	18637	18645	18647	18654	18666	18671	18675
18678	18687	18689	18733	18742	18766	18785	18791	18796	18804	18812	18817
18821	18827	18847	18850	18860	18880	18895	18899	18903	18904	18916	18917
18919	18927	18930	18933	18934	18947	18959	18964	18973	18981	18996	19000
19007	19008	19013	19015	19027	19042	19043	19093	19099	19108	19121	19132
19140	19150	19157	19163	19165	19169	19171	19175	19195	19211	19212	19223
19235	19241	19244	19246	19249	19254	19259	19265	19269	19270	19274	19277
19287	19317	19326	19331	19339	19351	19356	19360	19366	19372	19373	19374
19378	19381	19389	19406	19417	19426	19434	19441	19445	19454	19459	19462
19464	19473	19483	19492	19493	19506	19522	19546	19549	19556	19559	19566
19578	19589	19602	19611	19613	19622	19636	19639	19645	19650	19654	19658
19668	19674	19683	19695	19704	19706	19707	19708	19710	19721	19725	19731
19738	19749	19773	19787	19791	19793	19794	19798	19804	19825	19827	19835
19853	19869	19882	19886	19889	19890	19911	19923	19955	19965	19966	19969
19974	19975	19980	19998	20005	20009	20011	20022	20023	20031	20038	20039
20044	20063	20065	20070	20075	20085	20107	20117	20124	20129	20135	20137
20141	20148	20149	20154	20157	20163	20171	20172	20179	20186	20194	20197
20211	20219	20221	20261	20266	20267	20280	20295	20298	20308	20310	20322
20323	20332	20333	20341	20347	20355	20357	20362	20365	20375	20387	20399
20407	20421	20425	20427	20443	20446	20449	20452	20471	20483	20509	20514
20518	20532	20544	20558	20563	20575	20595	20596	20604	20621	20630	20634
20637	20639	20645	20647	20652	20653	20658	20691	20695	20716	20718	20719
20726	20731	20740	20754	20761	20767	20773	20781	20787	20813	20827	20833
20837	20838	20842	20855	20858	20861	20885	20894	20900	20910	20921	20924
20925	20935	20940	20946	20959	20964	20968	20980	20982	20991	20997	21011
21020	21025	21037	21039	21041	21055	21059	21068	21071	21083	21095	21103
21109	21114	21115	21118	21125	21127	21141	21143	21145	21146	21149	21150
21158	21162	21163	21171	21173	21174	21181	21185	21186	21193	21220	21227
21236	21246	21247	21263	21279	21293	21311	21316	21318	21324	21327	21331

21333	21341	21346	21356	21383	21397	21403	21412	21414	21415	21421	21435
21458	21471	21477	21478	21481	21482	21494	21498	21500	21502	21526	21545
21550	21554	21562	21563	21569	21575	21583	21599	21606	21611	21614	21622
21633	21634	21635	21641	21646	21654	21659	21666	21675	21676	21678	21689
21691	21720	21723	21738	21747	21751	21760	21762	21766	21772	21786	21789
21790	21799	21804	21806	21813	21822	21827	21829	21851	21857	21858	21862
21869	21870	21877	21881	21885	21905	21934	21939	21944	21963	21985	22010
22013	22021	22023	22044	22047	22049	22053	22058	22062	22067	22073	22083
22084	22087	22091	22104	22109	22110	22135	22145	22146	22158	22171	22181
22188	22189	22193	22198	22206	22210	22212	22216	22224	22227	22229	22238
22244	22249	22258	22259	22261	22289	22319	22324	22327	22342	22348	22350
22355	22362	22363	22373	22374	22387	22391	22410	22417	22419	22420	22426
22431	22444	22452	22459	22469	22479	22487	22497	22507	22513	22541	22548
22553	22557	22558	22560	22565	22573	22605	22614	22620	22630	22637	22655
22678	22683	22691	22692	22699	22702	22707	22711	22716	22717	22735	22749
22759	22770	22774	22786	22789	22803	22825	22831	22843	22849	22859	22860
22861	22863	22865	22866	22868	22893	22906	22915	22922	22933	22937	22947
22955	22964	22969	22975	22987	22999	23007	23013	23026	23031	23046	23047
23053	23055	23070	23076	23083	23085	23089	23094	23113	23116	23123	23131
23141	23143	23146	23147	23148	23155	23171	23173	23178	23204	23213	23214
23218	23225	23227	23237	23238	23244	23249	23293	23297	23299	23311	23315
23322	23332	23335	23363	23371	23388	23393	23395	23398	23410	23414	23419
23420	23425	23430	23442	23449	23453	23467	23468	23476	23493	23495	23503
23510	23514	23537	23539	23546	23549	23554	23573	23578	23594	23614	23622
23627	23635	23654	23663	23668	23671	23687	23691	23692	23700	23707	23710
23734	23735	23739	23750	23754	23760	23767	23775	23791	23794	23795	23796
23806	23818	23827	23831	23837	23850	23852	23854	23858	23866	23871	23875
23881	23886	23899	23902	23908	23909	23910	23911	23915	23917	23918	23929
23942	23945	23956	23966	23969	23972	23980	23995	23998	24012	24016	24027
24028	24042	24049	24051	24054	24062	24068	24070	24074	24075	24084	24099
24110	24114	24117	24125	24131	24142	24145	24151	24160	24165	24172	24187
24193	24197	24198	24203	24205	24210	24214	24216	24237	24246	24253	24264
24274	24275	24280	24293	24299	24309	24328	24338	24369	24382	24391	24401
24412	24421	24427	24438	24449	24459	24461	24474	24477	24483	24484	24495
24502	24504	24508	24509	24531	24534	24547	24555	24558	24571	24576	24581
24586	24596	24617	24622	24632	24641	24642	24644	24653	24657	24665	24667
24685	24699	24713	24719	24730	24732	24733	24735	24765	24767	24769	24775
24778	24785	24790	24791	24798	24809	24813	24823	24827	24835	24838	24844
24861	24868	24882	24887	24889	24915	24938	24940	24946	24954	24957	24965
24977	24985	24986	24993	25009	25019	25022	25045	25051	25059	25073	25077
25091	25115	25129	25134	25135	25139	25162	25163	25169	25180	25195	25197
25205	25215	25220	25223	25226	25231	25234	25240	25259	25262	25267	25271
25293	25294	25297	25299	25300	25327	25337	25345	25356	25364	25366	25374
25381	25390	25397	25419	25420	25423	25427	25429	25430	25435	25446	25450
25457	25463	25470	25498	25506	25526	25537	25539	25540	25547	25549	25579
25581	25597	25635	25638	25643	25646	25652	25658	25678	25688	25691	25692
25700	25705	25710	25715	25735	25743	25751	25755	25756	25759	25775	25777
25779	25799	25805	25806	25814	25827	25829	25839	25846	25849	25868	25882
25883	25884	25889	25891	25910	25913	25916	25918	25919	25923	25939	25943
25954	25961	25972	25973	25978	25981	25993	26006	26011	26017	26021	26035
26041	26060	26065	26067	26070	26074	26077	26098	26099	26111	26125	26142
26143	26147	26156	26160	26167	26171	26182	26186	26203	26212	26213	26226
26231	26242	26245	26246	26258	26260	26262	26269	26273	26279	26293	26309
26315	26317	26332	26335	26340	26361	26366	26374	26380	26389	26396	26407

26409	26412	26417	26420	26428	26433	26451	26455	26458	26459	26464	26472
26473	26478	26490	26491	26493	26521	26526	26536	26538	26545	26560	26561
26566	26568	26571	26577	26587	26596	26597	26611	26625	26640	26644	26653
26654	26658	26661	26668	26674	26685	26688	26699	26701	26706	26717	26729
26730	26763	26765	26795	26801	26805	26806	26811	26814	26819	26833	26837
26842	26844	26865	26878	26885	26897	26899	26900	26902	26920	26923	26934
26941	26946	26953	26979	26996	27003	27012	27016	27017	27029	27030	27032
27043	27060	27072	27077	27086	27092	27100	27106	27127	27137	27145	27150
27173	27175	27179	27183	27189	27190	27197	27198	27205	27214	27217	27227
27231	27249	27261	27274	27275	27276	27278	27283	27284	27289	27297	27315
27317	27318	27331	27338	27346	27358	27362	27372	27385	27416	27418	27421
27432	27437	27438	27442	27444	27453	27467	27471	27479	27484	27487	27499
27515	27519	27523	27525	27532	27539	27546	27549	27550	27557	27562	27586
27589	27604	27612	27613	27614	27620	27623	27630	27641	27654	27656	27659
27661	27666	27673	27674	27676	27677	27679	27688	27690	27691	27693	27698
27718	27721	27740	27744	27750	27752	27756	27768	27796	27799	27847	27852
27863	27869	27870	27871	27878	27886	27891	27894	27899	27901	27903	27905
27914	27924	27936	27946	27949	27955	27967	27971	27992	27998	28003	28006
28019	28022	28032	28036	28037	28043	28045	28052	28060	28062	28069	28073
28082	28094	28097	28109	28116	28153	28159	28166	28177	28181	28183	28186
28195	28206	28207	28213	28222	28234	28241	28250	28267	28275	28277	28300
28303	28310	28331	28332	28333	28334	28337	28354	28366	28367	28370	28380
28390	28394	28414	28424	28426	28429	28442	28452	28459	28463	28485	28487
28492	28510	28540	28542	28549	28550	28555	28559	28562	28564	28572	28579
28585	28598	28604	28607	28612	28622	28625	28639	28655	28662	28663	28675
28676	28698	28699	28713	28716	28729	28754	28758	28765	28778	28788	28796
28803	28816	28817	28820	28825	28827	28837	28855	28859	28867	28870	28872
28890	28893	28897	28906	28914	28915	28923	28929	28933	28942	28949	28956
28965	28968	28977	28981	28985	28989	29003	29004	29006	29009	29028	29032
29038	29042	29053	29067	29069	29082	29089	29093	29105	29109	29125	29147
29164	29179	29181	29182	29185	29201	29202	29203	29205	29213	29214	29219
29242	29247	29261	29275	29291	29310	29314	29331	29332	29336	29353	29357
29361	29410	29411	29420	29429	29430	29436	29453	29458	29460	29465	29468
29480	29490	29492	29509	29514	29524	29546	29557	29571	29581	29583	29591
29611	29613	29621	29626	29630	29634	29635	29646	29649	29664	29665	29669
29675	29677	29699	29709	29718	29726	29731	29734	29740	29753	29762	29765
29766	29768	29784	29797	29800	29804	29826	29840	29849	29859	29860	29861
29875	29879	29892	29893	29896	29905	29910	29926	29935	29940	29944	29950
29966	29977	29978	29998	30001	30010	30012	30013	30017	30019	30022	30035
30036	30041	30045	30054	30074	30082	30090	30092	30110	30115	30116	30125
30130	30133	30139	30146	30157	30161	30172	30182	30190	30197	30203	30223
30227	30228	30230	30245	30250	30251	30255	30260	30270	30274	30278	30283
30291	30292	30298	30299	30307	30329	30333	30339	30353	30356	30367	30374
30402	30406	30419	30432	30440	30454	30456	30462	30470	30473	30484	30488
30493	30494	30531	30532	30545	30547	30550	30559	30594	30599	30606	30612
30614	30619	30627	30628	30636	30637	30647	30649	30671	30685	30692	30694
30697	30698	30701	30703	30714	30726	30732	30739	30750	30755	30773	30776
30782	30798	30809	30812	30822	30829	30840	30845	30848	30852	30861	30875
30882	30889	30901	30918	30925	30941	30943	30959	30966	30972	30983	30991
31004	31006	31027	31033	31036	31043	31044	31046	31049	31062	31063	31069
31081	31106	31107	31110	31124	31126	31138	31147	31148	31149	31165	31181
31184	31190	31195	31203	31211	31214	31216	31222	31236	31237	31243	31246
31249	31267	31277	31278	31289	31291	31294	31306	31312	31314	31321	31326
31333	31344	31350	31354	31365	31368	31378	31384	31385	31387	31392	31397

31398 31411 31421 31427 31428 31436 31450 31473 31484 31489 31492 31494
31502 31513 31517 31554 31561 31566 31578 31579 31581 31589 31599 31613
31618 31632 31636 31642 31645 31651 31652 31656 31665 31667 31678 31686
31688 31690 31707 31726 31733 31739 31740 31747 31789 31790 31795 31807
31818 31826 31830 31837 31841 31848 31855 31859 31861 31884 31917 31921
31923 31925 31931 31937 31939 31940 31950 31957 31971 31980 31982 31996
32027 32034 32045 32062 32064 32065 32076 32077 32099 32100 32129 32156
32160 32162 32173 32178 32188 32194 32203 32204 32213 32216 32222 32225
32240 32243 32245 32250 32254 32257 32281 32299 32309 32314 32330 32335
32339 32344 32346 32362 32369 32371 32377 32381 32397 32401 32405 32418
32428 32429 32430 32434 32444 32449 32453 32470 32478 32488 32489 32521
32525 32532 32533 32538 32546 32556 32566 32576 32577 32581 32596 32611
32614 32623 32653 32659 32668 32675 32678 32692 32696 32701 32702 32719
32726 32731 32733 32734 32742 32744 32747 32750 32773 32784 32790 32796
32803 32822 32826 32827 32840 32864 32866 32867 32869 32877 32882 32898
32905 32909 32910 32931 32938 32948 32954 32959 32982 33001 33014 33018
33022 33027 33035 33065 33070 33074 33085 33086 33090 33091 33097 33102
33109 33113 33115 33130 33133 33149 33169 33171 33188 33190 33192 33202
33205 33212 33224 33234 33235 33242 33246 33260 33265 33279 33281 33283
33290 33301 33319 33324 33325 33326 33329 33332 33347 33364 33371 33372
33398 33409 33412 33417 33434 33437 33438 33442 33444 33451 33452 33454
33455 33459 33468 33480 33494 33497 33513 33517 33521 33532 33534 33540
33541 33557 33559 33566 33589 33594 33602 33603 33611

Appendix-2.

Initial part of the list of decimal equivalents of Monic Irreducible Polynomials over Galois Field GF(101^3) has been given below.

1030403	1030405	1030409	1030411	1030415	1030419	1030424	1030428
1030434	1030437	1030439	1030441	1030442	1030445	1030448	1030450
1030452	1030453	1030455	1030457	1030460	1030463	1030464	1030466
1030468	1030471	1030477	1030481	1030486	1030490	1030494	1030496
1030500	1030502	1030509	1030518	1030519	1030520	1030524	1030525
1030527	1030530	1030533	1030534	1030535	1030539	1030544	1030547
1030551	1030552	1030553	1030554	1030555	1030556	1030560	1030563
1030568	1030572	1030573	1030574	1030577	1030580	1030582	1030583
1030587	1030588	1030589	1030598	1030606	1030609	1030610	1030611
1030614	1030617	1030621	1030623	1030627	1030628	1030630	1030631
1030637	1030641	1030642	1030645	1030647	1030662	1030664	1030667
1030668	1030672	1030678	1030679	1030681	1030682	1030686	1030688
1030692	1030695	1030698	1030699	1030700	1030703	1030708	1030709
1030711	1030712	1030713	1030714	1030722	1030725	1030728	1030729
1030731	1030734	1030740	1030741	1030746	1030750	1030752	1030759
1030761	1030765	1030770	1030771	1030777	1030780	1030782	1030783
1030786	1030789	1030797	1030798	1030799	1030800	1030802	1030803
1030807	1030809	1030810	1030811	1030813	1030814	1030817	1030818
1030819	1030827	1030829	1030835	1030838	1030845	1030847	1030849
1030854	1030859	1030864	1030866	1030868	1030875	1030878	1030884
1030886	1030894	1030895	1030896	1030899	1030900	1030902	1030903
1030904	1030906	1030910	1030912	1030916	1030919	1030921	1030922
1030923	1030928	1030929	1030931	1030935	1030939	1030940	1030943
1030945	1030946	1030950	1030965	1030969	1030970	1030972	1030975
1030976	1030980	1030984	1030986	1030987	1030992	1030993	1030994
1030996	1030999	1031003	1031005	1031011	1031012	1031021	1031025
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