Josyula R. Rao
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7th International Workshop
Edinburgh, UK, August/September 2005
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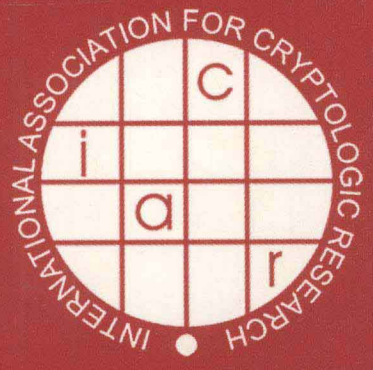

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Preface

These are the proceedings of the 7th Workshop on Cryptographic Hardware and Embedded Systems (CHES 2005) held in Edinburgh, Scotland from August 29 to September 1, 2005. The CHES workshop has been sponsored by the International Association for Cryptologic Research (IACR) for the last two years.

We received a total of 108 paper submissions for CHES 2005. The double-blind review process involved a 27-member program committee and a large number of external sub-referees. The review process concluded with a two week discussion process which resulted in 32 papers being selected for presentation. We are grateful to the program committee members and the external sub-referees for carrying out such an enormous task. Unfortunately, there were many strong papers that could not be included in the program due to a lack of space. We would like to thank all our colleagues who submitted papers to CHES 2005.

In addition to regular presentations, there were three excellent invited talks given by Ross Anderson (University of Cambridge) on "What Identity Systems Can and Cannot Do", by Thomas Wille (Philips Semiconductors Inc) on "Security of Identification Products: How to Manage", and by Jim Ward (Trusted Computing Group and IBM) on "Trusted Computing in Embedded Systems". It also included a rump session, chaired by Christof Paar, featuring informal talks on recent results.

The focus of CHES 2005 was similar to that of the earlier CHES workshops with the addition of a few new topics of emerging interest among which were smart card attacks and architectures, tamper resistance on the chip and board level, true and pseudo random number generators, special-purpose hardware for cryptanalysis, embedded security, cryptography for pervasive computing (e.g., RFID, sensor networks), device identification, non-classical cryptographic technologies, and side channel cryptanalysis. Special attention was paid to trusted computing platforms.

Special compliments go out to Colin D. Walter, the general chair and local organizer of CHES 2005, who brought the workshop to the beautiful historic town of Edinburgh, Scotland making it as much of a cultural event as a stimulating technical gathering. Christof Paar held the publicity Chair of CHES and was helpful at all stages of the organization. We would like to thank our corporate sponsors Cryptography Research Inc., escrypt GmbH, Gemplus, IBM, and RSA Security, who made it possible to have a lively event with their generous contributions. We would like to thank our dedicated webmaster Jens-Peter Kaps for maintaining the CHES website and review system even when he was travelling. Finally, we would like to thank the CHES steering committee members for giving us the honor of being part of such an influential conference.

August 2005 Josyula R. Rao and Berk Sunar

7th Workshop on Cryptographic Hardware and Embedded Systems

August 29 – September 1, 2005, Edinburgh, Scotland
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Resistance of Randomized Projective Coordinates Against Power Analysis

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Abstract. Embedded devices implementing cryptographic services are the result of a trade-off between cost, performance and security. Aside from flaws in the protocols and the algorithms used, one of the most serious threats against secret data stored in such devices is Side Channel Analysis.

Implementing Public Key Cryptography in low-profile devices such as smart cards is particularly challenging given the computational complexity of the operations involved. In the area of elliptic curve cryptography, some choices of curves and coefficient fields are known to speed up computations, like scalar multiplication. From a theoretical standpoint, the use of optimized structures does not seem to weaken the cryptosystems which use them. Therefore several standardization bodies, such as the NIST, recommend such choices of parameters. However, the study of their impact on practical security of implementations may have been underestimated.

In this paper, we present a new chosen-ciphertext Side-Channel Attack on scalar multiplication that applies when optimized parameters, like NIST curves, are used together with some classical anti-SPA and anti-DPA techniques. For a typical exponent size, the attack allows to recover a secret exponent by performing only a few hundred adaptive power measurements.

1 Introduction

The use of elliptic curves for cryptographic purposes was proposed by Miller [10] in 1985 and Koblitz [8] in 1987. Since then, it became an essential part of public key cryptography. In particular, many cryptosystems rely on the intractability of the discrete logarithm problem (DLP) on elliptic curves. The main advantage of this problem is that it is believed to be harder to solve than other number-theoretic problems. As a consequence, for a similar security level, it is possible to use smaller objects than with integer factorization for example. This property is especially attractive for embedded systems, where storage requirements and computation times are critical.

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Cryptosystems relying on DLP on elliptic curves use the *scalar multiplication* operation in some large elliptic curve group $(G, +)$

$$P \in G \rightarrow kP \tag{1}$$

where k is a secret data. Because of DLP hardness, it is believed to be infeasible to compute k from the knowledge of one or several pairs (P, kP).

In a situation where no reasonable attack on a cryptographic algorithm is known, Kocher first observed in 1996 [9] that the measurement of the algorithm computation time could still reveal secret information. This paved the way to Side Channel Attacks that take advantage of the measurement of physical signals emitted by a cryptographic device during a computation to gain access to secret data.

Since then, several examples of Side Channel Attacks led to various countermeasures being developed. Concerning scalar multiplication in EC groups, the use of scalar multiplication algorithms with a regular computation flow like *double-and-add always* or *Montgomery Ladder* is an answer to Simple Power Analysis (SPA), while randomized projective coordinates, first proposed by [4], are used to counter Differential Power Analysis (DPA).

In this paper, we present a new side-channel attack against scalar multiplication implementing these countermeasures, when the EC group used is chosen among the NIST [12], ANSI [1] or SEC [13] recommended curves. It is a Goubin-style attack [6] that uses distinguished points whose presence can be detected along the computation by an observation of power traces despite the randomization countermeasure. It leverages the particular shape of the underlying coefficient fields.

The paper is organized as follows. We first briefly review some facts about elliptic curves in section 2. Then section 3 presents some classical Side Channel Attacks and common countermeasures to prevent them. Finally, sections 4 and 5 present the details of our attack.

2 Elliptic Curves

2.1 Elliptic Curve Equation

Let $\mathbb{K}$ be a finite field of characteristic p. Over this field, we set the equation (E)

$$y^2 + a_1xy = x^3 + a_2x^2 + a_4x + a_6$$

The elliptic curve (C) associated to (E) is the set of all points of $\mathbb{K}^2$ satisfying (E), together with a particular point $\mathcal{O}$ called *point at infinity*. $\mathbb{K}$ is the *coefficient field* of the curve.

Up to an affine change of variables, if $p = 2$, we can set $a_1 = 1$ and $a_4 = 0$. The equation can then be rewritten $y^2 + xy = x^3 + a_2x^2 + a_6$. If $p \geq 3$, we can set $a_1 = a_2 = 0$ and then (E) becomes $y^2 = x^3 + a_4x + a_6$.

Together with an addition law, this set forms a commutative group. We do not describe the group law here since it does not play any role in the attack we present.

2.2 Affine and Projective Representation

A point on a curve of equation (E) is a solution of (E). Therefore the simplest representation of a point on a curve of equation (E) is the corresponding solution of (E) in $\mathbb{K}^2$. This is the *affine* representation.

Nevertheless, other representations can be preferred. We are mainly interested in *projective coordinates*. Given $P = (x, y)$ in affine coordinates, its representation in projective coordinates is $P = (xZ, yZ, Z)$ for any $Z \in \mathbb{K}^*$. If a finite solution of (E) is represented by (α, β, γ), then $\gamma \neq 0$. The point at infinity $\mathcal{O}$ is represented by $(0, \beta, 0)$ for any $\beta \neq 0$.

The projective representation is not unique. In fact, for some finite solution (x, y) of (E) with $x \neq 0$ and $y \neq 0$, any of the three projective coordinates can take an arbitrary value in $\mathbb{K}^*$. This observation is the basis of the randomized projective coordinates countermeasure, which we will describe in section 3.2. Projective representation is also used to increase the efficiency of point addition computations since for example, it allows to compute the group law without having to perform modular inversion in the coefficient field.

2.3 Recommended Coefficient Fields for NIST Elliptic Curves

Curves recommended by standardization bodies such as NIST, ANSI, or SEC are usually defined over $\mathbb{F}_p$, or $\mathbb{F}_2[x]/(P)$ where P a primitive polynomial. We focus on NIST recommended curves from now on. Other standardized curves present similar properties as the ones of the NIST.

Curves Defined on Binary Fields. The coefficient field is here of the form $\mathbb{F}_2[x]/(P)$. The primitive polynomials standardized by the NIST are:

$$P_{233}(x) = x^{233} + x^{74} + 1$$
$$P_{283}(x) = x^{283} + x^{12} + x^7 + x^5 + 1$$
$$P_{409}(x) = x^{409} + x^{87} + 1$$
$$P_{571}(x) = x^{571} + x^{10} + x^5 + x^2 + 1$$

We can notice that these polynomials are very sparse. This has to do with hardware efficiency.

Curves Defined on Prime Order Fields. For these curves, the coefficient field is $\mathbb{F}_p$, with p among

$$p_{192} = 2^{192} - 2^{64} - 1$$
$$p_{224} = 2^{224} - 2^{96} + 1$$
$$p_{256} = 2^{256} - 2^{224} + 2^{192} + 2^{96} - 1$$
$$p_{384} = 2^{384} - 2^{128} - 2^{96} + 2^{32} - 1$$
$$p_{521} = 2^{521} - 1$$

As in the binary case, the sparse form of these primes simplifies and speeds up operations in the coefficient field.