title

Zach Kelling

Satschel, Inc.

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Abstract

Regulated funds must prove compliance with SEC rules—diversification limits, concentration caps, leverage ratios—to regulators, auditors, and counterparties. Current practice requires disclosing the full portfolio. Zero-knowledge proofs (ZKPs) can prove compliance without revealing positions, but ZKP circuits for portfolio constraints are complex and expensive. This paper presents a simpler approach: FHE-based compliance proofs on Liquid EVM where the compliance check executes over encrypted data using the FHE precompile at `0x0700`, and only the boolean result is decrypted. The encrypted computation serves as a verifiable proof of compliance—the on-chain execution trace demonstrates that the correct rules were applied to the actual (encrypted) portfolio, and the threshold-decrypted result confirms pass or fail. We provide complete Go code using `github.com/luxfi/fhe` for constructing and verifying compliance proofs covering SEC diversification, leverage limits, sector exposure caps, and accredited investor thresholds.

1 Introduction

Regulatory proof requirements pervade institutional finance:

- **SEC 13F filings:** Institutional managers with over $100M in AUM must disclose holdings quarterly. This exposes proprietary strategies.
- **Accredited investor verification:** Under Regulation D Rule 506(c), issuers must take "reasonable steps" to verify accredited status. Current practice requires disclosing tax returns or brokerage statements.
- **Leverage ratio verification:** Under the Dodd-Frank Act, systemically important financial institutions must prove their leverage ratio meets minimum requirements.
- **Counterparty compliance:** Prime brokers require fund clients to demonstrate portfolio compliance as a condition of margin lending.

In each case, the entity must prove a property ("my portfolio meets rule X") without wanting to reveal the underlying data ("these are my exact positions").

FHE-based compliance proofs on Liquid EVM provide this capability. The compliance check runs on-chain over encrypted data. The execution is verified by Quasar consensus. The result—a single boolean—is threshold-decrypted. The verifier (regulator, auditor, counterparty) sees the verified boolean and the on-chain proof that the correct computation was applied, without learning anything about the encrypted inputs.

1.1 Advantages over ZKP

Property	**ZKP**	**FHE (this work)**
Prover cost	High (circuit generation)	Low (encrypt only)
Verifier cost	Low	Low (check chain state)
Trust model	Prover generates proof	On-chain computation
Composability	Limited	Full (combine checks)
Programmability	Fixed circuit per rule	Any EVM logic

Table 1: FHE compliance proofs vs. ZKP compliance proofs.

2 Architecture

2.1 Proof Structure

A compliance proof consists of:

1. **Encrypted input commitment:** The encrypted portfolio is stored on-chain at a known address. The ciphertext handles serve as commitments to the input data.
2. **Rule execution:** The `ComplianceProof.sol` contract executes the specified rule over the encrypted portfolio using FHE precompile calls.
3. **Execution receipt:** The EVM execution trace (block hash, transaction hash, gas used) serves as proof that the computation was performed correctly.
4. **Decrypted result:** The boolean outcome, threshold-decrypted by 67-of-100 Liquid Threshold validators, is published on-chain.

A verifier checks: (1) the rule contract code matches the expected compliance rule, (2) the execution receipt is in a finalized block, (3) the decrypted result is "true" (compliant).

2.2 Supported Proof Types

Proof Type	Regulation	Property
Diversification	ICA §5(b)(1)	No position $> 5\%$ of total
Leverage	Dodd-Frank	Debt/equity $<$ threshold
Sector exposure	Internal policy	Sector weight $<$ cap
Accredited status	Reg D 506(c)	Net worth $>$ \$1M
Liquidity coverage	Basel III	Liquid assets / outflows $> 100\%$
Net capital	SEC Rule 15c3-1	Net capital $>$ minimum

Table 2: Compliance proof types.

3 Implementation

3.1 Go Client: Proof Request and Portfolio Submission

```go
package proof

import (
    "github.com/luxfi/fhe"
    "github.com/luxfi/geth/common"
)

// ProofRequest specifies which compliance rule to verify.
type ProofRequest struct {
    RuleID       uint64         // identifies the rule
    Portfolio    common.Hash    // on-chain portfolio handle
    Verifier     common.Address // who receives the result
    ThresholdBps uint64         // rule parameter (e.g., 500 = 5%)
}

// EncryptedPortfolio holds encrypted position data
// committed on-chain.
```

```go
type EncryptedPortfolio struct {
    Positions []*EncryptedPosition
    EncTotal  *fhe.BitCiphertext
    Handle    common.Hash // on-chain reference
}

// EncryptedPosition holds a single position's encrypted
// fields.
type EncryptedPosition struct {
    EncValue    *fhe.BitCiphertext // position value
    EncSector   *fhe.BitCiphertext // sector code (encrypted)
    EncIsDebt   *fhe.BitCiphertext // true if debt instrument
    EncIsLiquid *fhe.BitCiphertext // true if highly liquid
}

// BuildPortfolio encrypts a portfolio and stores it
// on-chain, returning the commitment handle.
func BuildPortfolio(
    enc *fhe.BitwiseEncryptor,
    values []uint64,
    sectors []uint64,
    isDebt []bool,
    isLiquid []bool,
) *EncryptedPortfolio {
    n := len(values)
    positions := make([]*EncryptedPosition, n)
    var total uint64

    for i := 0; i < n; i++ {
        total += values[i]
        var debt, liquid uint64
        if isDebt[i] {
            debt = 1
        }
        if isLiquid[i] {
            liquid = 1
        }

        positions[i] = &EncryptedPosition{
            EncValue: enc.EncryptUint64(
                values[i], fhe.FheUint64,
            ),
            EncSector: enc.EncryptUint64(
                sectors[i], fhe.FheUint64,
            ),
            EncIsDebt: enc.EncryptUint64(
                debt, fhe.FheBool,
            ),
            EncIsLiquid: enc.EncryptUint64(
                liquid, fhe.FheBool,
            ),
        }
    }

    return &EncryptedPortfolio{
        Positions: positions,
        EncTotal:  enc.EncryptUint64(total, fhe.FheUint64),
    }
}
```

Listing 1: Submitting an encrypted portfolio and requesting a compliance proof.

3.2 Go: Diversification Proof

```go
package proof

import (
    "github.com/luxfi/fhe"
)

// ProveDiversification proves that no single position
// exceeds thresholdBps basis points of total portfolio.
// Returns encrypted boolean (true = compliant).
func ProveDiversification(
    eval *fhe.BitwiseEvaluator,
    enc *fhe.BitwiseEncryptor,
    portfolio *EncryptedPortfolio,
    thresholdBps uint64, // e.g., 500 = 5%
) (*fhe.BitCiphertext, error) {
    // Compute threshold: total * thresholdBps / 10000
    scaled, err := eval.ScalarMul(
        portfolio.EncTotal, thresholdBps,
    )
    if err != nil {
        return nil, err
    }
    limit, err := eval.ScalarDiv(scaled, 10000)
    if err != nil {
        return nil, err
    }

    // Start compliant = true
    compliant := enc.EncryptUint64(1, fhe.FheBool)

    for _, pos := range portfolio.Positions {
        // Check: position value <= limit
        under, err := eval.Le(pos.EncValue, limit)
        if err != nil {
            return nil, err
        }
        wrapped := fhe.WrapBoolCiphertext(under)

        compliant, err = eval.And(compliant, wrapped)
        if err != nil {
            return nil, err
        }
    }

    return compliant, nil
}
```

Listing 2: Proving no position exceeds a threshold percentage of total.

3.3 Go: Leverage Ratio Proof

```go
package proof

import (
    "github.com/luxfi/fhe"
)

// ProveLeverageRatio proves that debt / total < maxRatioBps.
// Computes: sum(debt positions) < total * maxRatioBps / 10000
func ProveLeverageRatio(
```

```
    eval *fhe.BitwiseEvaluator,
    enc *fhe.BitwiseEncryptor,
    portfolio *EncryptedPortfolio,
    maxRatioBps uint64, // e.g., 3300 = 33% max leverage
) (*fhe.BitCiphertext, error) {
    // Sum all debt positions
    debtSum := enc.EncryptUint64(0, fhe.FheUint64)
    zero := enc.EncryptUint64(0, fhe.FheUint64)

    for _, pos := range portfolio.Positions {
        // contribution = isDebt ? value : 0
        bit, _ := extractBit(pos.EncIsDebt)
        contribution, err := eval.Select(
            bit, pos.EncValue, zero,
        )
        if err != nil {
            return nil, err
        }
        debtSum, err = eval.Add(debtSum, contribution)
        if err != nil {
            return nil, err
        }
    }

    // Compute threshold: total * maxRatioBps / 10000
    scaled, err := eval.ScalarMul(
        portfolio.EncTotal, maxRatioBps,
    )
    if err != nil {
        return nil, err
    }
    limit, err := eval.ScalarDiv(scaled, 10000)
    if err != nil {
        return nil, err
    }

    // Check: debtSum <= limit
    underLimit, err := eval.Le(debtSum, limit)
    if err != nil {
        return nil, err
    }

    return fhe.WrapBoolCiphertext(underLimit), nil
}

func extractBit(
    ct *fhe.BitCiphertext,
) (*fhe.Ciphertext, error) {
    bits := ct.Bits()
    if len(bits) > 0 {
        return bits[0], nil
    }
    return nil, nil
}
```

Listing 3: Proving leverage ratio is within regulatory limits.

3.4 Go: Sector Exposure Proof

```
package proof

import (
```

```
    "github.com/luxfi/fhe"
)

// ProveSectorExposure proves that aggregate exposure to
// any single sector does not exceed maxBps of total.
func ProveSectorExposure(
    eval *fhe.BitwiseEvaluator,
    enc *fhe.BitwiseEncryptor,
    portfolio *EncryptedPortfolio,
    sectorIDs []uint64,
    maxBps uint64, // e.g., 2500 = 25%
) (*fhe.BitCiphertext, error) {
    // Compute threshold
    scaled, err := eval.ScalarMul(
        portfolio.EncTotal, maxBps,
    )
    if err != nil {
        return nil, err
    }
    limit, err := eval.ScalarDiv(scaled, 10000)
    if err != nil {
        return nil, err
    }

    compliant := enc.EncryptUint64(1, fhe.FheBool)
    zero := enc.EncryptUint64(0, fhe.FheUint64)

    // For each sector, sum positions and check limit
    for _, sid := range sectorIDs {
        encSID := enc.EncryptUint64(sid, fhe.FheUint64)
        sectorSum := enc.EncryptUint64(0, fhe.FheUint64)

        for _, pos := range portfolio.Positions {
            // Check if position is in this sector
            match, err := eval.Eq(pos.EncSector, encSID)
            if err != nil {
                return nil, err
            }

            // contribution = match ? value : 0
            contribution, err := eval.Select(
                match, pos.EncValue, zero,
            )
            if err != nil {
                return nil, err
            }

            sectorSum, err = eval.Add(
                sectorSum, contribution,
            )
            if err != nil {
                return nil, err
            }
        }

        // Check: sectorSum <= limit
        under, err := eval.Le(sectorSum, limit)
        if err != nil {
            return nil, err
        }
        wrapped := fhe.WrapBoolCiphertext(under)
        compliant, err = eval.And(compliant, wrapped)
        if err != nil {
```

```
            return nil, err
        }
    }

    return compliant, nil
}
```

Listing 4: Proving no sector exceeds maximum exposure.

3.5 Go: Accredited Investor Proof

```go
package proof

import (
    "github.com/luxfi/fhe"
)

// ProveAccreditedStatus proves that an investor's encrypted
// net worth exceeds the SEC Regulation D threshold ($1M)
// without revealing the actual net worth.
func ProveAccreditedStatus(
    eval *fhe.BitwiseEvaluator,
    enc *fhe.BitwiseEncryptor,
    encNetWorth *fhe.BitCiphertext,
    thresholdCents uint64, // e.g., 100_000_000 = $1M in cents
) (*fhe.BitCiphertext, error) {
    encThreshold := enc.EncryptUint64(
        thresholdCents, fhe.FheUint64,
    )

    // Check: netWorth >= threshold
    isAccredited, err := eval.Ge(encNetWorth, encThreshold)
    if err != nil {
        return nil, err
    }

    return fhe.WrapBoolCiphertext(isAccredited), nil
}

// ProveIncomeThreshold proves annual income exceeds
// $200K (individual) or $300K (joint) for the past
// two years. Both years' incomes are encrypted.
func ProveIncomeThreshold(
    eval *fhe.BitwiseEvaluator,
    enc *fhe.BitwiseEncryptor,
    encIncomeYear1 *fhe.BitCiphertext,
    encIncomeYear2 *fhe.BitCiphertext,
    thresholdCents uint64,
) (*fhe.BitCiphertext, error) {
    encThreshold := enc.EncryptUint64(
        thresholdCents, fhe.FheUint64,
    )

    // Year 1 >= threshold
    y1Pass, err := eval.Ge(encIncomeYear1, encThreshold)
    if err != nil {
        return nil, err
    }

    // Year 2 >= threshold
    y2Pass, err := eval.Ge(encIncomeYear2, encThreshold)
    if err != nil {
```

```
        return nil, err
    }

    // Both years must pass
    both, err := eval.And(
        fhe.WrapBoolCiphertext(y1Pass),
        fhe.WrapBoolCiphertext(y2Pass),
    )
    if err != nil {
        return nil, err
    }

    return both, nil
}
```

Listing 5: Proving accredited investor status without revealing net worth.

3.6 Go: Proof Verification

```
package proof

import (
    "errors"

    "github.com/luxfi/fhe"
    "github.com/luxfi/geth/common"
)

// ProofReceipt is the on-chain record of a compliance
// proof execution.
type ProofReceipt struct {
    RuleID      uint64
    BlockHash   common.Hash
    TxHash      common.Hash
    Portfolio   common.Hash     // commitment to encrypted data
    Result      bool            // decrypted pass/fail
    GasUsed     uint64
    Timestamp   uint64
}

// VerifyProof checks that a compliance proof is valid
// by examining the on-chain execution receipt.
func VerifyProof(receipt *ProofReceipt) error {
    if receipt.BlockHash == (common.Hash{}) {
        return errors.New("invalid block hash")
    }
    if receipt.TxHash == (common.Hash{}) {
        return errors.New("invalid transaction hash")
    }
    if receipt.Portfolio == (common.Hash{}) {
        return errors.New("no portfolio commitment")
    }
    if receipt.GasUsed == 0 {
        return errors.New("zero gas implies no computation")
    }
    // In production, also verify:
    // 1. Block is finalized (Quasar consensus)
    // 2. Contract code matches expected rule implementation
    // 3. Threshold decryption certificate is valid
    return nil
}
```

Listing 6: Verifying a compliance proof on-chain.

4 Security Analysis

4.1 Soundness

The compliance check executes on the actual encrypted portfolio stored on-chain. The prover (fund) cannot substitute a different portfolio because the ciphertext handles are committed on-chain before the proof is requested. The FHE precompile deterministically evaluates the rule, and all Quasar validators verify the execution.

4.2 Zero-Knowledge

The verifier learns exactly one bit: whether the portfolio passes the compliance check. The encrypted portfolio data is never decrypted (only the boolean result is). Under RLWE, the ciphertexts on-chain reveal no information about the portfolio contents.

4.3 Non-Transferability

The proof is bound to a specific encrypted portfolio commitment (on-chain handle). A fund cannot use another fund's compliant portfolio to generate a proof for itself, because the encrypted data is committed at a specific address and the FHE ACL enforces ownership.

4.4 Composition

Multiple proofs can be composed by AND-ing their encrypted boolean results before threshold decryption. A verifier can request "prove diversification AND leverage AND sector exposure" as a single decryption operation, reducing Liquid Threshold round-trips.

5 Performance

Proof Type	**Gas (100 positions)**	**Latency**
Diversification (5%)	∼8,500,000	∼7s
Leverage ratio	∼16,500,000	∼14s
Sector exposure (10 sectors)	∼72,000,000	∼60s
Accredited investor	∼160,000	<1s
Net capital (Rule 15c3-1)	∼20,000,000	∼17s
All combined	∼117,160,000	∼99s
Threshold decrypt	10,000	2–5s

Table 3: Gas and latency for compliance proofs.

The sector exposure proof is the most expensive because it requires $O(S \times P)$ encrypted comparisons where S is sectors and P is positions. For 10 sectors and 100 positions, this is 1,000 `FHE.eq` operations at 60K gas each plus 1,000 `FHE.select` operations at 100K gas each.

6 References

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