Bit flip error

→ Definition:- Bit flip error occurs when Qbit changes from $|0\rangle$ to $|1\rangle$ or viceversa

$\boxed{\text{Pauli X operator}}$ – Bit flip error operator

→ Steps:- Transformation – Encoding
Syndrome – Detection measurement done by parity check
Correction – Use Quantum gates which do not disturb original gates.

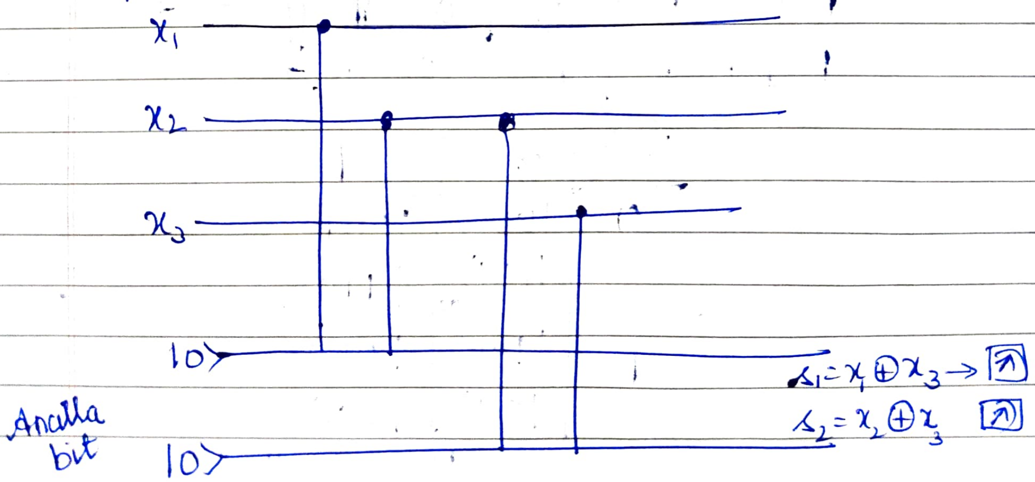
→ For state $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$
$X|\psi\rangle = \alpha|1\rangle + \beta|0\rangle$] Bit flip swaps the amplitudes of $|0\rangle$ and $|1\rangle$ states

1] $\boxed{\text{Transformation}}$ - Encoding → Q bit Encoding
$X = \alpha|0\rangle + \beta|1\rangle$

Logical $|0\rangle \to |000\rangle$
Logical $|1\rangle \to |111\rangle$
$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle = \alpha|000\rangle + \beta|111\rangle$

One logical bit is encoded into three physical qubits using redundancy.

2] $\boxed{\text{Syndrome measurement}}$ -
Two-syndrome bits uniquely identify which Qbit has the error without collapsing the quantum state



Ancilla bit – Direct measurement of data Qubits would collapse the quantum superposition;

Ancilla bits - Direct measurement of data qubits would collapse the quantum superposition destroying the quantum information.
Ancila qubits allow us to extract error information (syndrome) while preserving the quantum state of the data qubits.

Data qubits : $\alpha|000\rangle + \beta|111\rangle$

Ancilla qubits : $|s_1 s_2\rangle$ (measured gives classical qubits)

s_1	s_2	error
0	0	no error
0	1	3^{rd} bit
1	0	1^{st} bit
1	1	2^{nd} bit

x_1	x_2	x_3	s_1	s_2
0	0	0	0	0
0	0	1	0	1
0	1	0	1	1
0	1	1	1	0
1	0	0	1	0
1	0	1	1	1
1	1	0	0	1
1	1	1	0	0

→ no error

→ 3^{rd} bit error

→ 2^{nd} bit

1^{st} bit

$s_1 \backslash s_2$	0	1
0	$\|000\rangle$ $\|111\rangle$ (00)	$\|001\rangle$ $\|110\rangle$ (01)
1	$\|100\rangle$ $\|011\rangle$ (10)	$\|010\rangle$ $\|101\rangle$ (11)

write

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Stabalizers

Hermiton operator $= A^2 = I$

Eigen values $\lambda = \pm 1$

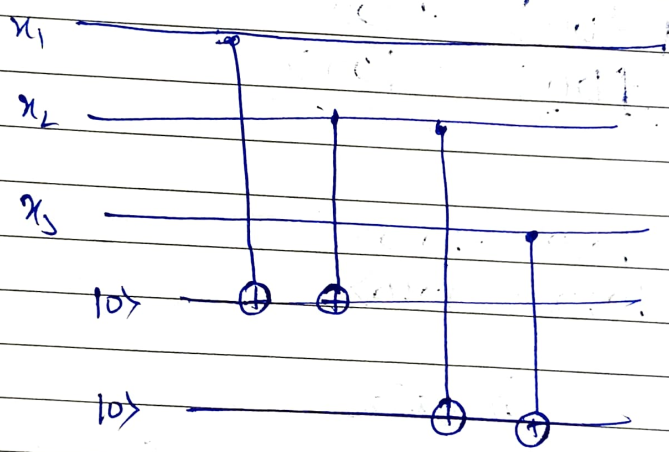
Eigen values are equal to ± 1

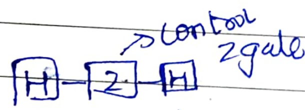
$\hat{S}|\psi\rangle = \pm|\psi\rangle$

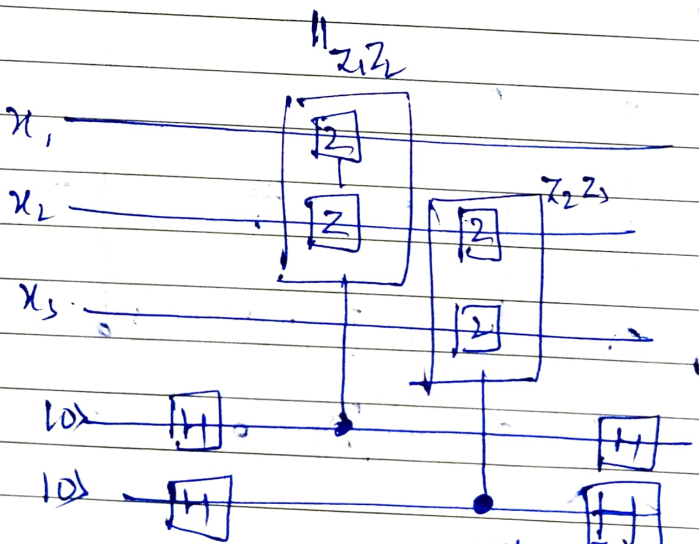
stabalize

Syndrome state

[Eigen value equation]







Stabalizers

syndrome state

$Z_1Z_2|\psi\rangle = (-1)^{S_1}|\psi\rangle$ S_i

$Z_2Z_3|\psi\rangle = (-1)^{S_2}|\psi\rangle$

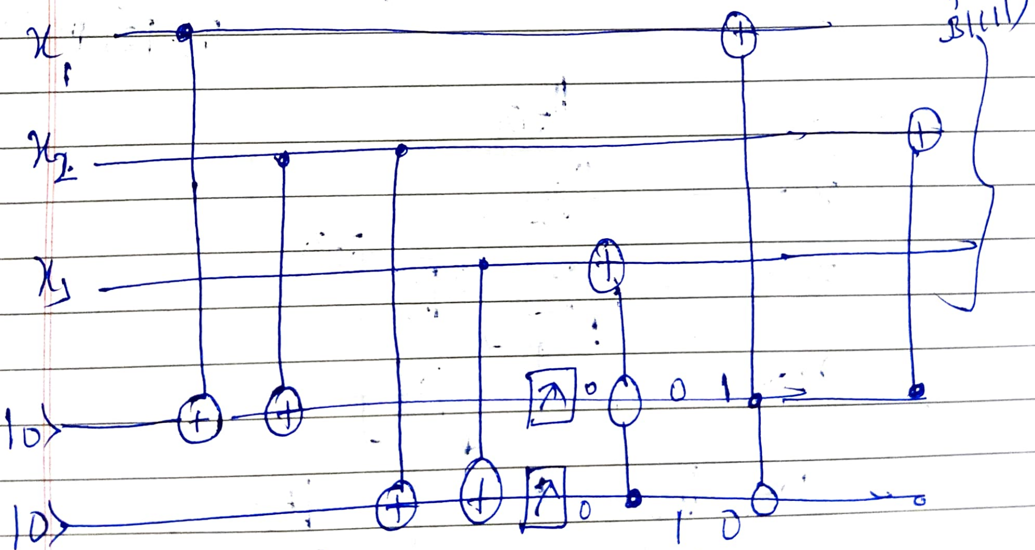
Z_1Z_2 \ Z_2Z_3 (s_1 \ s_2)	0 (+)	1 (−)
+ (0)	000 111	001 110
− (1)	100 111	010 101

$Z_1Z_2|\psi\rangle = (-1)^{s_1}|\psi\rangle$
$Z_2Z_3|\psi\rangle = (-1)^{s_2}|\psi\rangle$

① $Z_1Z_2I_3|001\rangle = +|001\rangle$
$IZ_2Z_3|001\rangle = -|001\rangle$

② $Z_1Z_2I_3|010\rangle = -|010\rangle$
$IZ_2Z_3|010\rangle = -|010\rangle$

Correction



Phase flip error

↳ No classical analogy

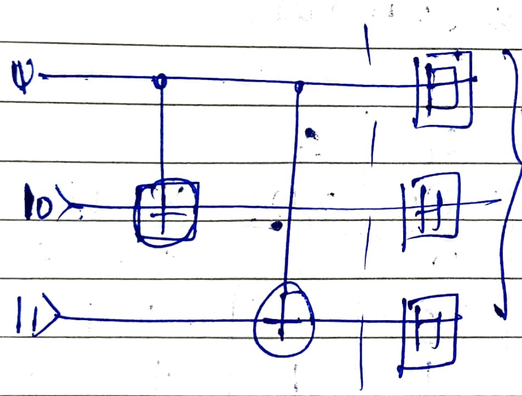
→ Convert phase flip model to bit flip model by transforming the basis

$$\{|0\rangle, |1\rangle\} \xrightarrow{\boxed{H}} \{|+\rangle, |-\rangle\}$$

$$H|0\rangle = \frac{1}{\sqrt{2}}[|0\rangle + |1\rangle] = |+\rangle$$

$$H|1\rangle = \frac{1}{\sqrt{2}}[|0\rangle - |1\rangle] = |-\rangle$$

Encoded circuit:-



$$\alpha|{+}{+}{+}\rangle + \beta|{-}{-}{-}\rangle$$

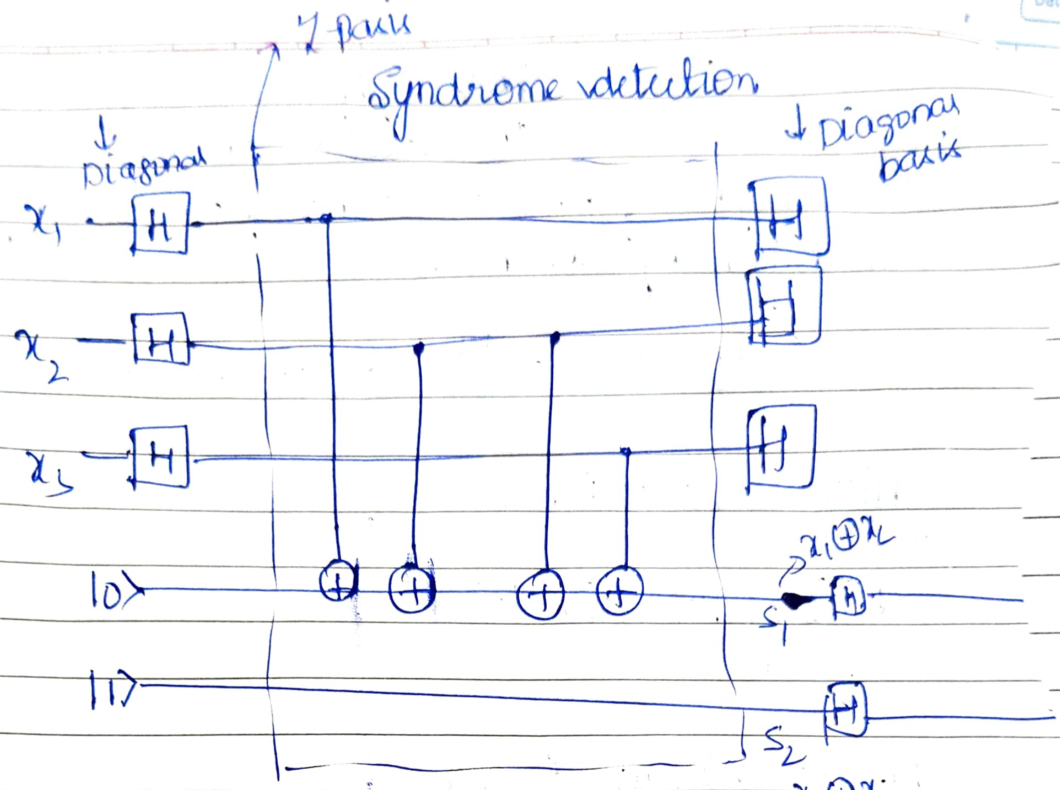
Noise

$I \otimes I \otimes I$ → no error

$Z \otimes I \otimes I$ → 1st qubit

$I \otimes Z \otimes I$ → 2nd qubit

$I \otimes I \otimes Z$ → 3rd qubit



Bit flip model.

$x_1\ x_2\ x_3$ X Basis	Z basis	s_1 $x_1 \oplus x_2$	s_2 $x_2 \oplus x_3$	X Basis
+ + +	0 0 0	0	0	+ + +
+ + −	0 0 1	0	1	+ + −
+ − +	0 1 0	1	1	+ − +
+ − −	0 1 1	1	0	+ − −
− + +	1 0 0	1	0	− + +
− + −	1 0 1	1	1	− + −
− − +	1 1 0	0	1	− − +
− − −	1 1 1	0	0	− − −

No error

No error

$S_1 \backslash S_2$	0	1
0	$+++$ $---$	$++-$ $--+$
1	$-++$ $+--$	$+-+$ $-+-$

Stabalizers:-

$x_1 x_2 |\psi\rangle = \pm |\psi\rangle$

$x_2 x_3 |\psi\rangle = \pm |\psi\rangle$

x_1x_2	$S_1 \backslash S_2$	x_2x_3: + 0	x_2x_3: − 1
+	0	$+++$ $---$	$++-$ $--+$
−	1	$-++$ $+--$	$+-+$ $-+-$

$x_1 x_2 |\psi\rangle = (-1)^{s_1} |\psi\rangle$

$x_2 x_3 |\psi\rangle = (-1)^{s_2} |\psi\rangle$

$x_1 x_2 |+++\rangle = +|+++\rangle$

$x_2 x_3 |---\rangle = +|---\rangle$

$x_1 x_2 |+-+\rangle = -|+-+\rangle$

$x_2 x_3 |+-+\rangle \quad -|+-+\rangle$

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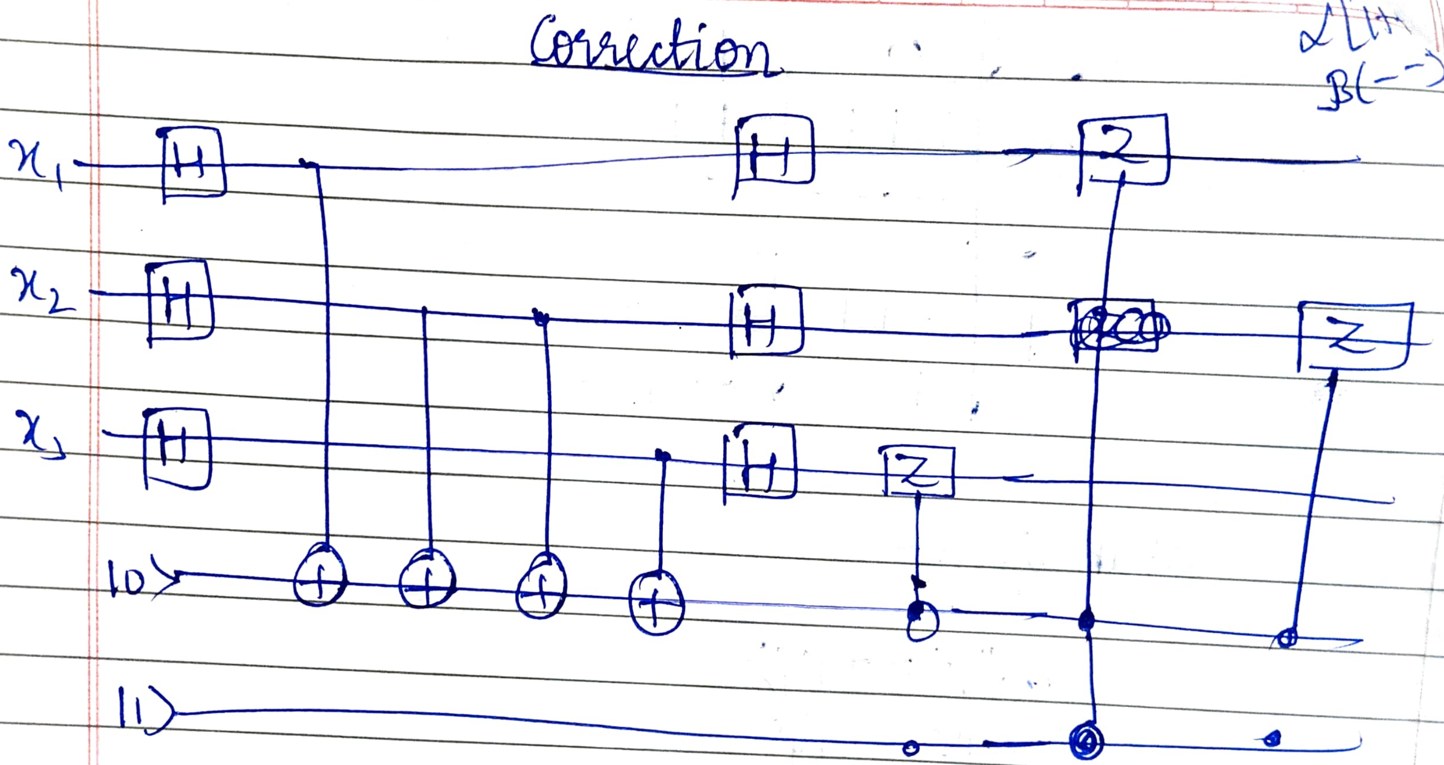
Correction



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QKD

QKD is based on 2 key concepts
- Superposition
- Measurement disturbance

↓ Measuring the quantum state disturbs it revealing the presence of an eavesdropper [Eve]

↓ eves dropper measure

Alice ———————————— Bob

two basis
rectilinear / diagonal

→ Preparation
→ Transmission
→ Measurement
→ Basis Reconciliation
→ Key sifting & error check.

Explain with App
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