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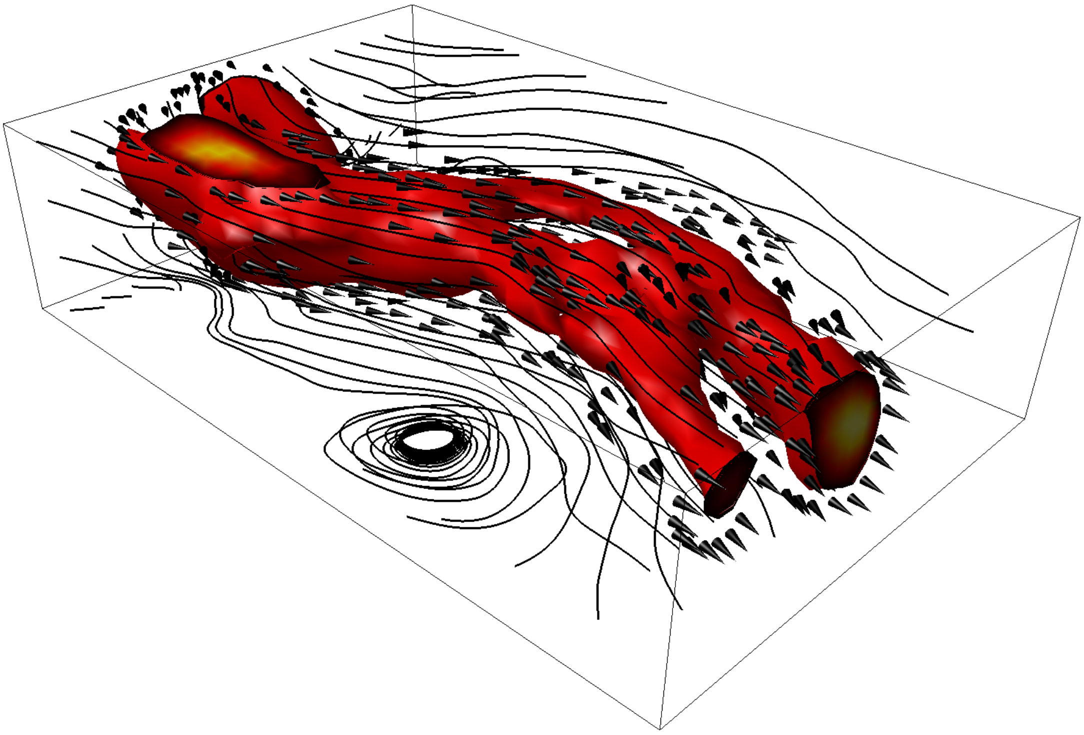

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Master's thesis in Master Programme Name

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
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Master's thesis 2023

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## Abstract

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# Acknowledgements

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Name Familyname, Gothenburg, Month Year

# List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

| | |
|---|---|
| BES | Battery Energy Storage |
| DER | Distributed Energy Resource |
| MILP | Mixed-Integer Linear Programming |
| MG | Microgrid |
| PV | Photovoltaic |
| RES | Renewable-based Energy Sources |

# Nomenclature

Below is the nomenclature of indices, sets, parameters, and variables that have been used throughout this thesis.

## Indices

| | |
|---|---|
| $i$,$j$ | Indices for distribution network buses |
| $t$ | Index for time step |

## Sets

| | |
|---|---|
| $\mathcal{D}$ | Set of distribution network buses |
| $\mathcal{D}_s$ | Set of substation buses |
| $\mathcal{H}$ | Set of time steps (simulation/scheduling horizon) |
| $\mathcal{N}$ | Set of buses |

## Parameters

| | |
|---|---|
| $\gamma$ | Penalty coefficient |
| $\Delta t$ | Time discretization step (time interval) |
| $\eta_j^{ch}$ | Charging efficiency of BES |
| $\eta_j^{dis}$ | Discharging efficiency of BES |
| $\boldsymbol{H}$ | Adjacency matrix |
| $N$ | Number of iterations |
| $P_{j,t}^{L}$ | Active power of load demand |
| $P_{j,t}^{PV}$ | Active power from solar generation |

# Variables

| | |
|---|---|
| $p_j$ | Active power injection at bus $j$ |
| $p_{ji}$ | Active power flow from bus $j$ to bus $i$ |
| $v_i$ | Square of voltage magnitude at bus $i$ |

# Contents

# List of Figures

# List of Tables

# 1
# Introduction

This chapter presents the section levels that can be used in the template.

## 1.1 Section levels

The following table presents an overview of the section levels that are used in this document. The number of levels that are numbered and included in the table of contents is set in the settings file `Settings.tex`. The levels are shown in Section 1.2.

| Name | Command |
|---|---|
| Chapter | `\chapter{`*Chapter name*`}` |
| Section | `\section{`*Section name*`}` |
| Subsection | `\subsection{`*Subsection name*`}` |
| Subsubsection | `\subsubsection{`*Subsubsection name*`}` |
| Paragraph | `\paragraph{`*Paragraph name*`}` |
| Subparagraph | `\paragraph{`*Subparagraph name*`}` |

## 1.2 Section

### 1.2.1 Subsection

#### 1.2.1.1 Subsubsection

##### 1.2.1.1.1 Paragraph

###### 1.2.1.1.1.1 Subparagraph

# 2

# Transmission Concept

A super block is one symbol, which contains a number of blocks. Each block contains a number of time slots. For each super block length in blocks, we calculate
1. Number of ways to organize the blocks in a super block

$$n!$$

2. Number of Bits / Symbol

$$log_2(n!)$$

3. Number of Bits / Photon

$$\frac{log_2(n!)}{n}$$

4. Number of Bits / Time Slot

$$\frac{log_2(n!)}{n} \times \frac{n}{T}$$

For example, we have [1,2,3,4], there are 4! = 24 permutation of ways to organize the blocks to generate different super blocks representing the corresponding symbols as follow:

$[1,2,3,4] \rightarrow A, [1,2,4,3] \rightarrow B, [1,3,2,4] \rightarrow C, [1,3,4,2] \rightarrow D, [1,4,2,3] \rightarrow E, [1,4,3,2] \rightarrow F$

$[2,1,3,4] \rightarrow G, [2,1,4,3] \rightarrow H, [2,3,1,4] \rightarrow I, [2,3,4,1] \rightarrow J, [2,4,1,3] \rightarrow K, [2,4,3,1] \rightarrow L$

$[3,1,2,4] \rightarrow M, [3,1,4,2] \rightarrow N, [3,2,1,4] \rightarrow O, [3,2,4,1] \rightarrow P, [3,4,1,2] \rightarrow Q, [3,4,2,1] \rightarrow R$

$[4,1,2,3] \rightarrow S, [4,1,3,2] \rightarrow T, [4,2,1,3] \rightarrow U, [4,2,3,1] \rightarrow V, [4,3,1,2] \rightarrow W, [4,3,2,1] \rightarrow X$

The information content of the super block is

$$log_2(4!) = 4.6 \quad \text{bits/symbol}$$

For each photon, it contains

$$1.15 \quad \text{bits/photon}$$

For each time slot, it has

$$0.33 bits/timeslot$$

# 3

# Our Method

We define a block as an integral number of time bins ( or time slots, or other encoding sources that are orthogonal, i.e., that can be perfectly discriminated).

Our method uses 4 photons in 14 time slots
It means that our method has:
1. $4! = 24$ ways to order them
2. 4.6 bits/symbol
3. 1.15 bits/photon
4. 0.33 bits / time slot

| | Number of Photon | Number of Permutation | Number of Bits per Symbol | Number of Bits per Photon | Number of Bits per Time Slots |
|---|---|---|---|---|---|
| 0 | 1.000000 | 1.000000 | 0.000000 | 0.000000 | 0.000000 |
| 1 | 2.000000 | 2.000000 | 1.000000 | 0.500000 | 0.000000 |
| 2 | 3.000000 | 6.000000 | 2.584963 | 0.861654 | 0.000000 |
| 3 | 4.000000 | 24.000000 | 4.584963 | 1.146241 | 0.000000 |
| 4 | 5.000000 | 120.000000 | 6.906891 | 1.381378 | 0.000000 |
| 5 | 6.000000 | 720.000000 | 9.491853 | 1.581976 | 0.000000 |
| 6 | 7.000000 | 5040.000000 | 12.299208 | 1.757030 | 0.000000 |
| 7 | 8.000000 | 40320.000000 | 15.299208 | 1.912401 | 0.000000 |
| 8 | 9.000000 | 362880.000000 | 18.469133 | 2.052126 | 0.000000 |
| 9 | 10.000000 | 3628800.000000 | 21.791061 | 2.179106 | 0.000000 |
| 10 | 11.000000 | 39916800.000000 | 25.250493 | 2.295499 | 0.000000 |
| 11 | 12.000000 | 479001600.000000 | 28.835455 | 2.402955 | 0.000000 |
| 12 | 13.000000 | 6227020800.000000 | 32.535895 | 2.502761 | 0.000000 |
| 13 | 14.000000 | 87178291200.000000 | 36.343250 | 2.595946 | 2.596000 |
| 14 | 15.000000 | 1307674368000.000000 | 40.250140 | 2.683343 | 2.683000 |
| 15 | 16.000000 | 20922789888000.000000 | 44.250140 | 2.765634 | 2.766000 |
| 16 | 17.000000 | 355687428096000.000000 | 48.337603 | 2.843388 | 2.843000 |
| 17 | 18.000000 | 6402373705728000.000000 | 52.507528 | 2.917085 | 2.917000 |
| 18 | 19.000000 | 121645100408832000.000000 | 56.755456 | 2.987129 | 2.987000 |
| 19 | 20.000000 | 2432902008176640000.000000 | 61.077384 | 3.053869 | 3.054000 |

**Figure 3.1:** Table

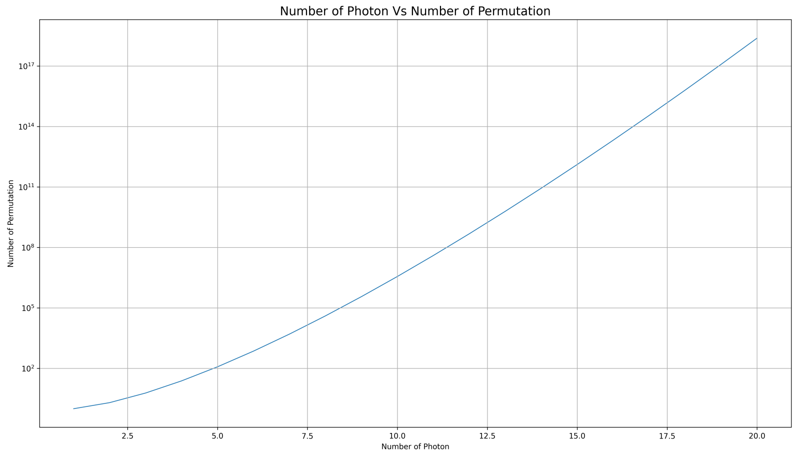



**Figure 3.2:** Number of Photons Vs Number of Permutation

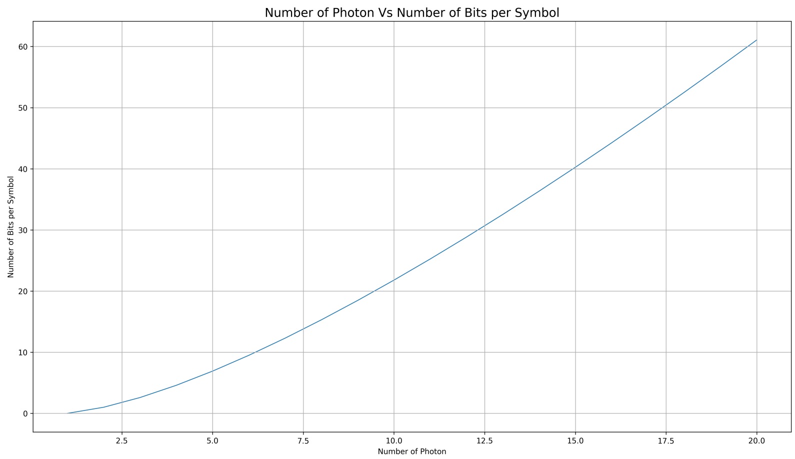



**Figure 3.3:** Number of Photons Vs Number of Bits per Symbol

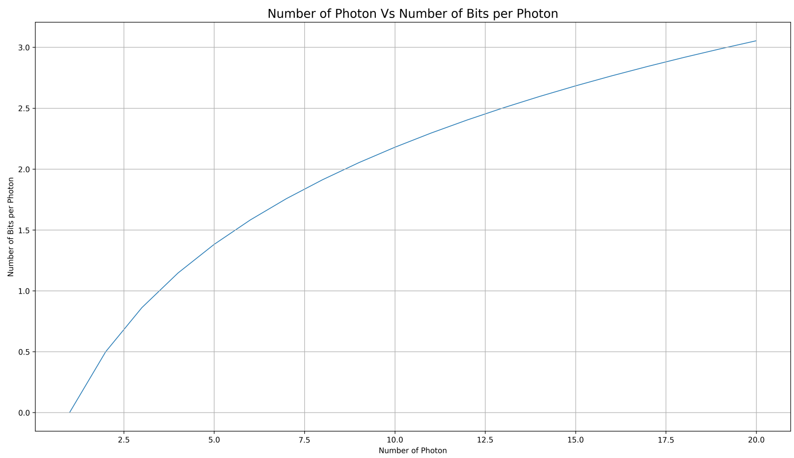



**Figure 3.4:** Number of Photons Vs Number of Bits per Photon

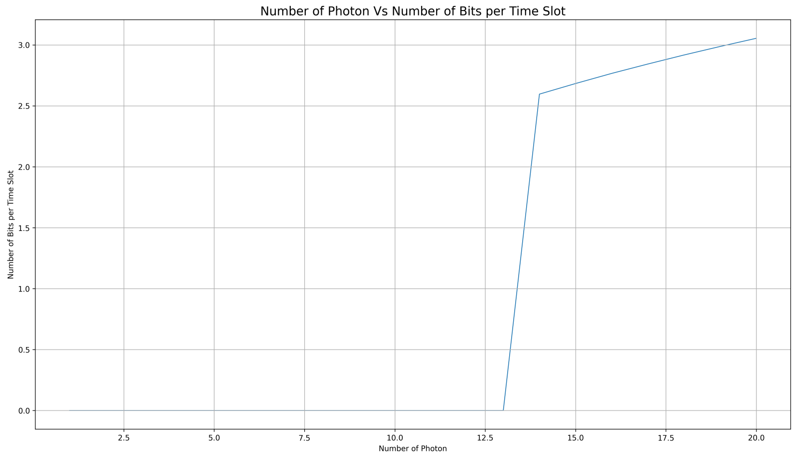



**Figure 3.5:** Number of Photons Vs Number of Bits per Time Slot

# 4
# PPM

The representation of bits to symbol is as follow:
100000 $\rightarrow A$
010000 $\rightarrow B$
001000 $\rightarrow C$
000100 $\rightarrow D$
000010 $\rightarrow E$
000001 $\rightarrow F$

PPM uses 1 photon in 14 time slots
It means that PPM has:
1. 14 ways to order them
2. 3.8 bits/symbol
3. 3.8 bits/photon
4. 0.27 bits / time slot

[?]

| | Number of Photon | Number of Permutation | Number of Bits per Symbol | Number of Bits per Photon | Number of Bits per Time Slots |
|---|---|---|---|---|---|
| 0 | 1.000000 | 14.000000 | 3.807355 | 3.807355 | 0.000000 |
| 1 | 2.000000 | 14.000000 | 3.807355 | 1.903677 | 0.000000 |
| 2 | 3.000000 | 14.000000 | 3.807355 | 1.269118 | 0.000000 |
| 3 | 4.000000 | 14.000000 | 3.807355 | 0.951839 | 0.000000 |
| 4 | 5.000000 | 14.000000 | 3.807355 | 0.761471 | 0.000000 |
| 5 | 6.000000 | 14.000000 | 3.807355 | 0.634559 | 0.000000 |
| 6 | 7.000000 | 14.000000 | 3.807355 | 0.543908 | 0.000000 |
| 7 | 8.000000 | 14.000000 | 3.807355 | 0.475919 | 0.000000 |
| 8 | 9.000000 | 14.000000 | 3.807355 | 0.423039 | 0.000000 |
| 9 | 10.000000 | 14.000000 | 3.807355 | 0.380735 | 0.000000 |
| 10 | 11.000000 | 14.000000 | 3.807355 | 0.346123 | 0.000000 |
| 11 | 12.000000 | 14.000000 | 3.807355 | 0.317280 | 0.000000 |
| 12 | 13.000000 | 14.000000 | 3.807355 | 0.292873 | 0.000000 |
| 13 | 14.000000 | 14.000000 | 3.807355 | 0.271954 | 0.272000 |
| 14 | 15.000000 | 14.000000 | 3.807355 | 0.253824 | 0.254000 |
| 15 | 16.000000 | 14.000000 | 3.807355 | 0.237960 | 0.238000 |
| 16 | 17.000000 | 14.000000 | 3.807355 | 0.223962 | 0.224000 |
| 17 | 18.000000 | 14.000000 | 3.807355 | 0.211520 | 0.212000 |
| 18 | 19.000000 | 14.000000 | 3.807355 | 0.200387 | 0.200000 |
| 19 | 20.000000 | 14.000000 | 3.807355 | 0.190368 | 0.190000 |

**Figure 4.1:** Table

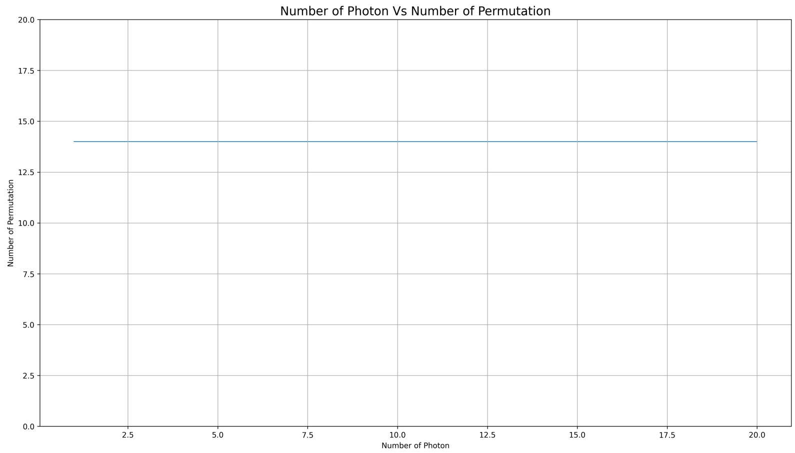



**Figure 4.2:** Number of Photons Vs Number of Permutation

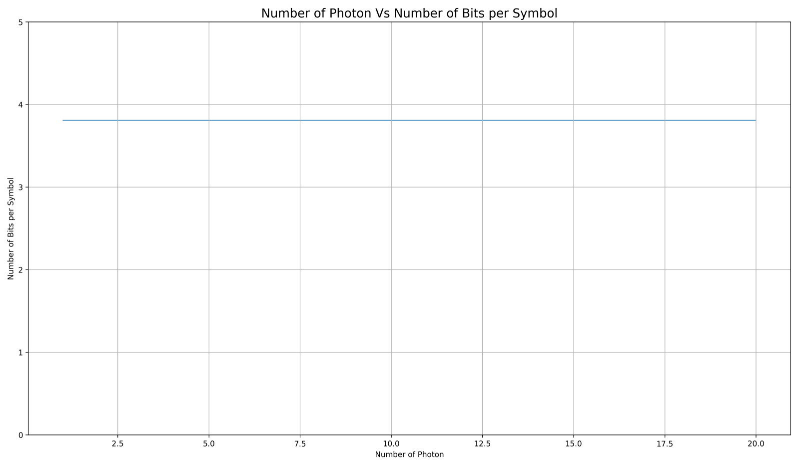



**Figure 4.3:** Number of Photons Vs Number of Bits per Symbol

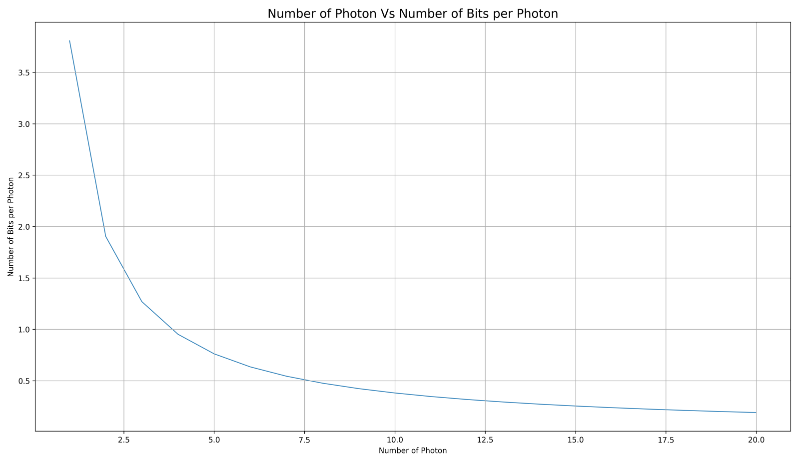



**Figure 4.4:** Number of Photons Vs Number of Bits per Photon

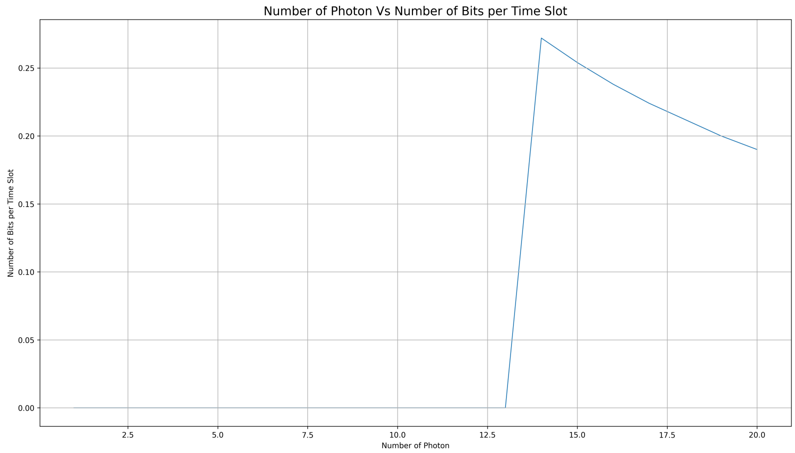



**Figure 4.5:** Number of Photons Vs Number of Bits per Time Slot

# 5

# On-Off Key (OOK)

OOK uses 7 photons in average in 14 time slots
It means that PPM has:
1. $2^{14} = 16,384$ ways to order them
2. 14 bits/symbol
3. 2 bits/photon
4. 1 bits / time slot

| | Number of Photon | Number of Permutation | Number of Bits per Symbol | Number of Bits per Photon | Number of Bits per Time Slots |
|---|---|---|---|---|---|
| 0 | 1.000000 | 16384.000000 | 14.000000 | 14.000000 | 0.000000 |
| 1 | 2.000000 | 16384.000000 | 14.000000 | 7.000000 | 0.000000 |
| 2 | 3.000000 | 16384.000000 | 14.000000 | 4.666667 | 0.000000 |
| 3 | 4.000000 | 16384.000000 | 14.000000 | 3.500000 | 0.000000 |
| 4 | 5.000000 | 16384.000000 | 14.000000 | 2.800000 | 0.000000 |
| 5 | 6.000000 | 16384.000000 | 14.000000 | 2.333333 | 0.000000 |
| 6 | 7.000000 | 16384.000000 | 14.000000 | 2.000000 | 0.000000 |
| 7 | 8.000000 | 16384.000000 | 14.000000 | 1.750000 | 0.000000 |
| 8 | 9.000000 | 16384.000000 | 14.000000 | 1.555556 | 0.000000 |
| 9 | 10.000000 | 16384.000000 | 14.000000 | 1.400000 | 0.000000 |
| 10 | 11.000000 | 16384.000000 | 14.000000 | 1.272727 | 0.000000 |
| 11 | 12.000000 | 16384.000000 | 14.000000 | 1.166667 | 0.000000 |
| 12 | 13.000000 | 16384.000000 | 14.000000 | 1.076923 | 0.000000 |
| 13 | 14.000000 | 16384.000000 | 14.000000 | 1.000000 | 1.000000 |
| 14 | 15.000000 | 16384.000000 | 14.000000 | 0.933333 | 0.933000 |
| 15 | 16.000000 | 16384.000000 | 14.000000 | 0.875000 | 0.875000 |
| 16 | 17.000000 | 16384.000000 | 14.000000 | 0.823529 | 0.824000 |
| 17 | 18.000000 | 16384.000000 | 14.000000 | 0.777778 | 0.778000 |
| 18 | 19.000000 | 16384.000000 | 14.000000 | 0.736842 | 0.737000 |
| 19 | 20.000000 | 16384.000000 | 14.000000 | 0.700000 | 0.700000 |

**Figure 5.1:** Table

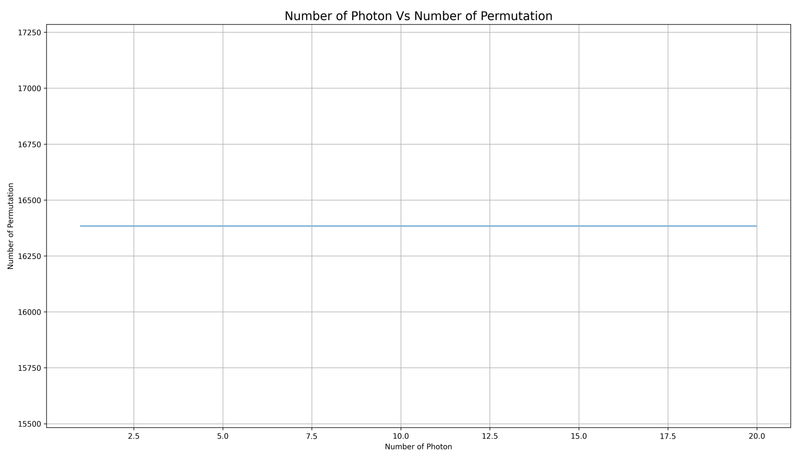



**Figure 5.2:** Number of Photons Vs Number of Permutation

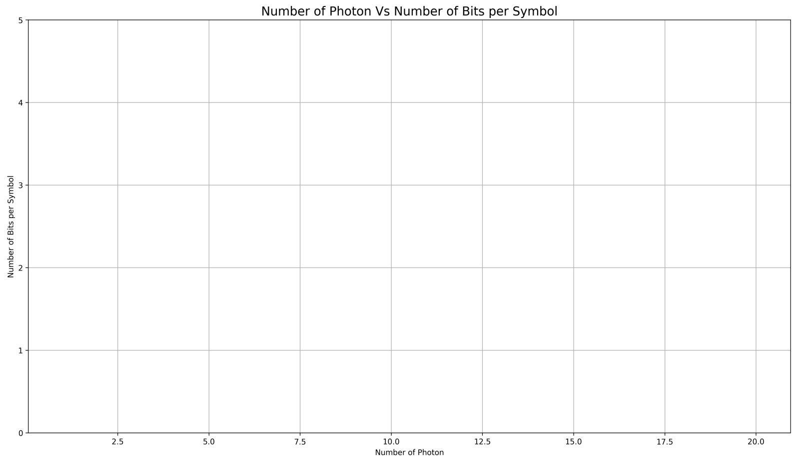



**Figure 5.3:** Number of Photons Vs Number of Bits per Symbol

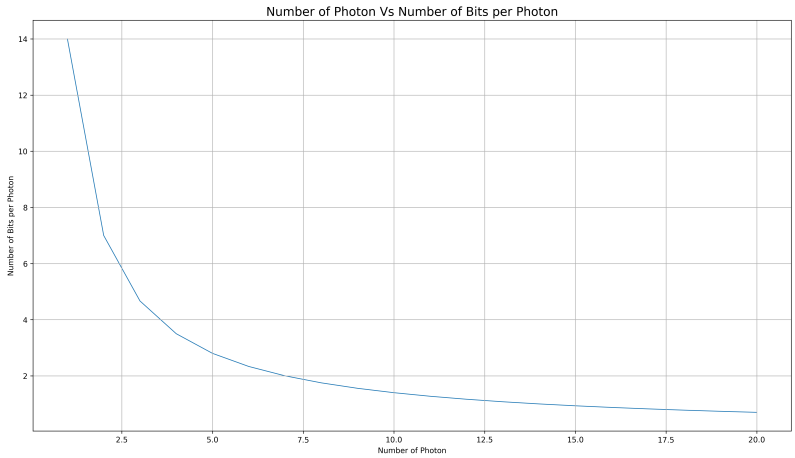



**Figure 5.4:** Number of Photons Vs Number of Bits per Photon

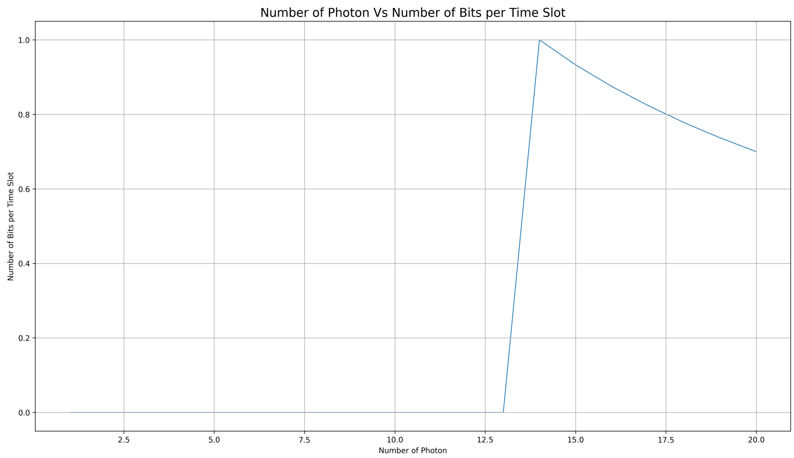



**Figure 5.5:** Number of Photons Vs Number of Bits per Time Slot

# 6

# In General

In general, it takes 4 photons in 14 time slots
It means that it has:

1. 1,001 ways to order them
2. 10 bits/symbol
3. 2.5 bits/photon
4. 0.71 bits / time slot

# 7
# Reed-Solomon Codes

The Reed-Solomon (RS) codes are the non-binary codes, they are important for the use in communication systems where errors appear in bursts rather than independent random errors.

RS codes were discovered by Reed and Solomon in 1960. The non-binary BCH block codes have $2^m(\{0, 1, 2, \ldots, 2^m - 1\})$ symbols with block length $n = 2^m - 1$, which can be extended to $n = 2^m$ or $m = 2^m + 1$. RS codes can correct up to $e_0$ errors within a block of n symbols by using $n - k = n - 2e_0 = 2^m - 1 - 2e_0$ parity symbols.

RS code can aciheve the maximum number of error correction by finding the largest possible $d_{min} = 2e_0 + 1$

# 8

# Theory

In the following sections, examples of a figure, an equation, a table, a chemical structure, a list, a listing and a to-do note are shown.

## 8.1 Figure

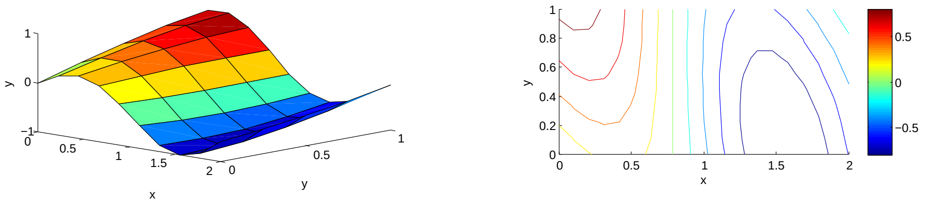



**Figure 8.1:** Surface and contour plots showing the two dimensional function $z(x,y) = \sin(x+y)\cos(2x)$.

## 8.2 Equation

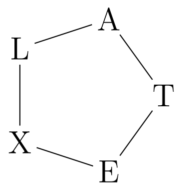
$$f(t) = \begin{cases} 1, & t < 1 \\ t^2 & t \geq 1 \end{cases} \tag{8.1}$$

## 8.3 Table

**Table 8.1:** Values of $f(t)$ for $t = 0, 1, \ldots 5$.

| $t$ | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| $f(t)$ | 1 | 1 | 4 | 9 | 16 | 25 |

## 8.4 Chemical structure




## 8.5 List

1. The first item
   (a) Nested item 1
   (b) Nested item 2
2. The second item
3. The third item
4. . . .

## 8.6 Source code listing

```
% Generate x- and y-nodes
x=linspace(0,1); y=linspace(0,1);

% Calculate z=f(x,y)
for i=1:length(x)
 for j=1:length(y)
  z(i,j)=x(i)+2*y(j);
 end
end
```

## 8.7 To-do note

The `todo` package enables to-do notes to be added in the page margin. This can be a very convenient way of making notes in the document during the process of writing. All notes can be hidden by using the option *disable* when loading the package in the settings.

Example of a to-do note.

# 9
# Methods

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# 10
# Results

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# 11

# Conclusion

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# Bibliography

[1] Gustaver, M. (2020) A Chalmers University of Technology Master's thesis template for LaTeX. Unpublished.
[2] Ziemer, R., Tranter, W. H. (2006). Principles of communications: system modulation and noise. John Wiley Sons.

# A

# Appendix 1

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