RF Topologies

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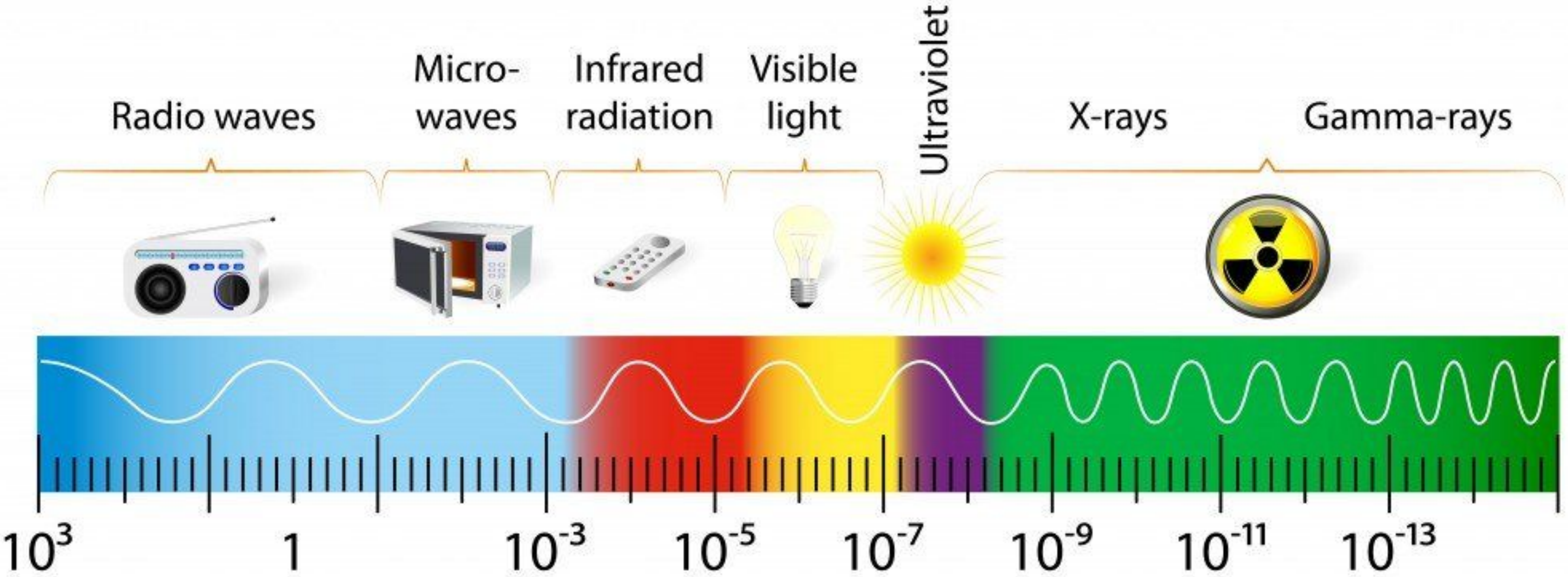
Goals

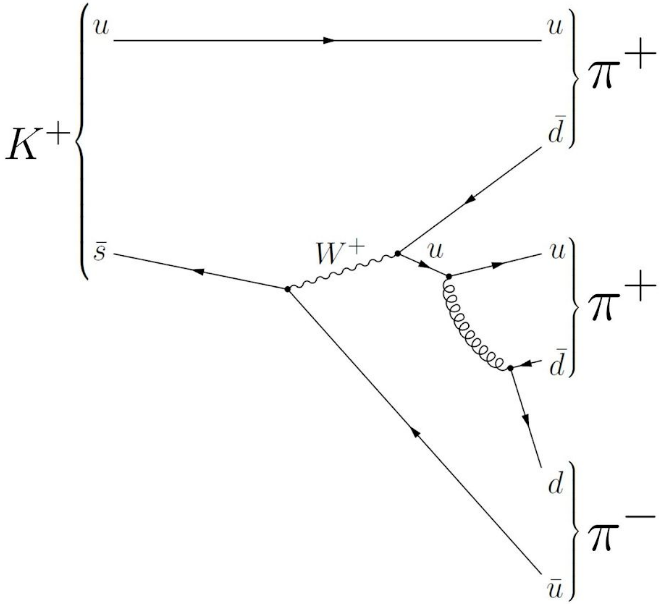
- Apply generalized topology diagrams towards standardizing WiFi test rig designs
- Better emulate over the air (OTA) scenarios when using “conducted equipment”
- Frequency band is 2.4-6 GHz
- Use “low cost” conducted equipment sold by outside vendors
- Automate with python

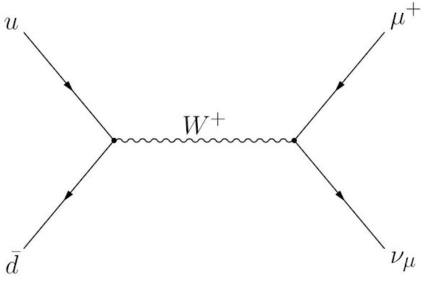
Theory

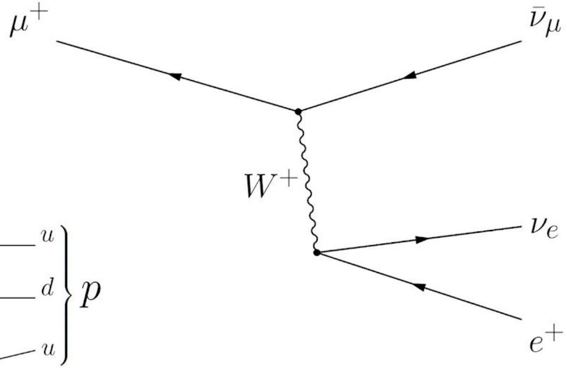
THE ELECTROMAGNETIC SPECTRUM

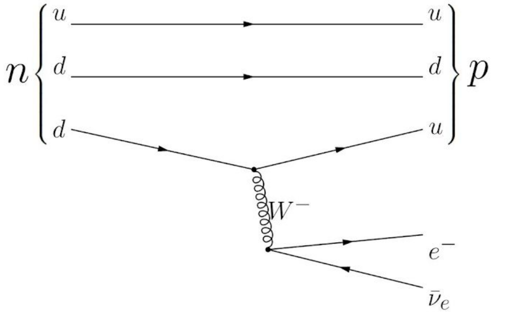


An introduction to:





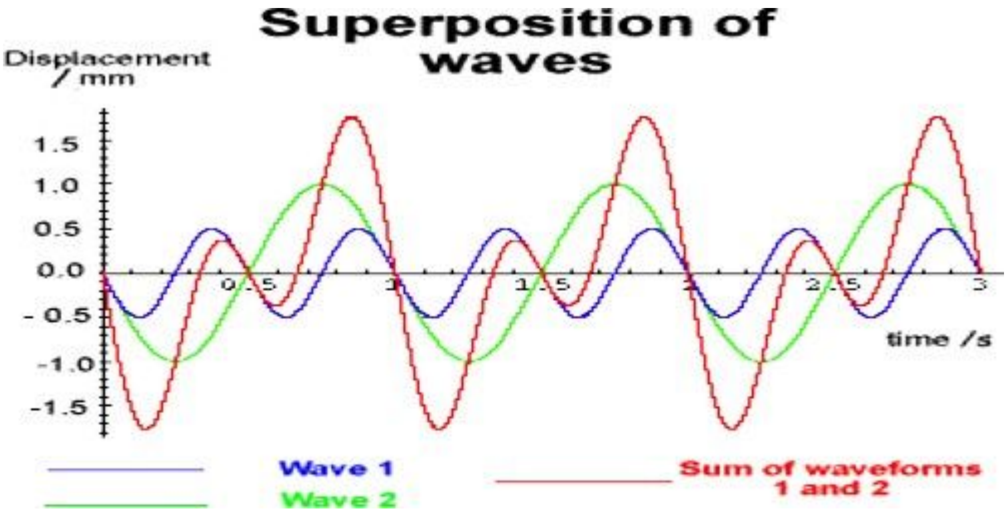




Feynman Diagrams

astronomy2GCSE

Superposition



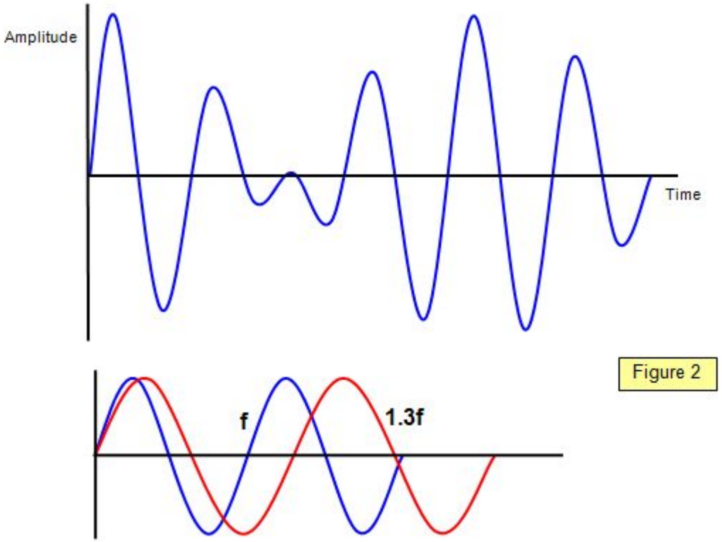
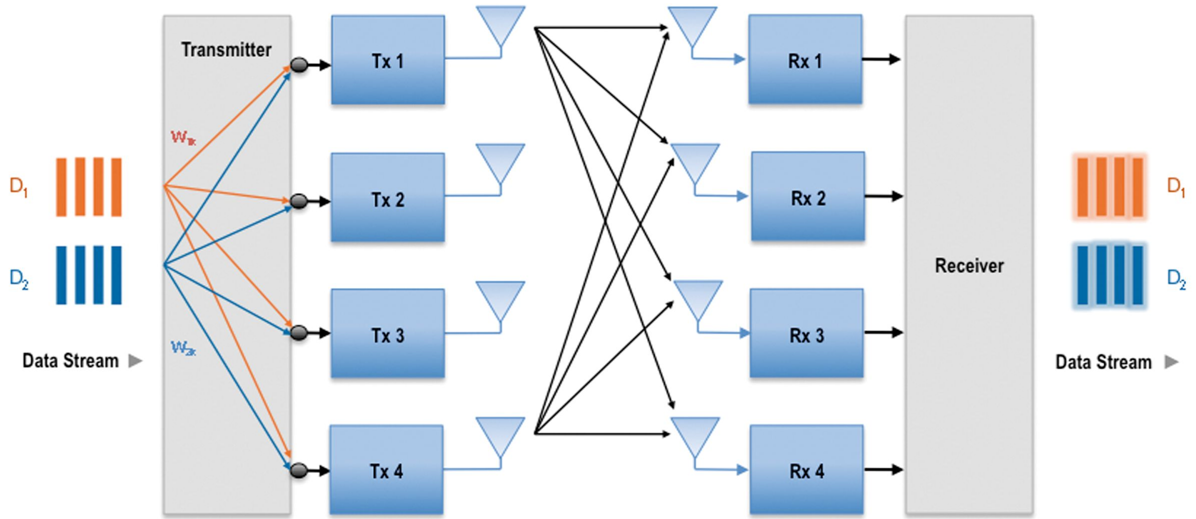


Figure 2

Mathematical Models

A Basic MiMo Model

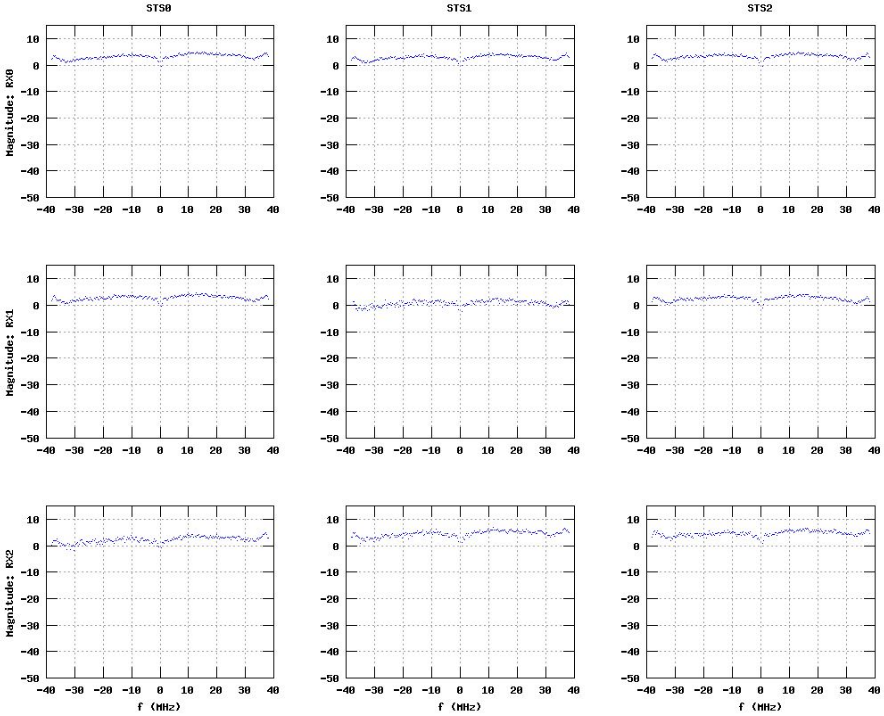


Transfer Matrix

$$\begin{bmatrix} R1 \\ R2 \\ R3 \\ R4 \end{bmatrix} = \begin{bmatrix} D1 & 0 & 0 & 0 \\ 0 & D2 & 0 & 0 \\ 0 & 0 & D3 & 0 \\ 0 & 0 & 0 & D4 \end{bmatrix} \times \begin{bmatrix} h11 & h12 & h13 & h14 \\ h21 & h22 & h23 & h24 \\ h31 & h32 & h33 & h34 \\ h41 & h34 & h43 & h44 \end{bmatrix} \times \begin{bmatrix} D1' & 0 & 0 & 0 \\ 0 & D2' & 0 & 0 \\ 0 & 0 & D3' & 0 \\ 0 & 0 & & D4' \end{bmatrix} \times \begin{bmatrix} S1 \\ S2 \\ S3 \\ S4 \end{bmatrix}$$

- S-Matrix is the transmitted signal (or energy) per antenna
- R-Matrix is the received signal
- D-Matrices are the cables and attenuators between the antenna and the H-Matrix (one for source and one for sink)
- H-Matrix is the MiMO “channel” (signal mixing, e.g butler matrix, splitter/combiner, power divider, MuMimo midbox)

Phychanest



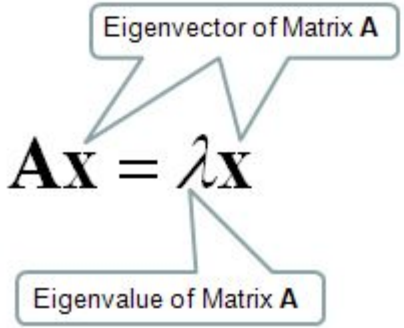
STS0
STS1
STS2
Magnitude: RX0
Magnitude: RX1
Magnitude: RX2
f (MHz)

Hermitian

Diagonalizing Hermitian Matrices

- **The eigenvalues of a Hermitian Matrix are always real**
- **For a Hermitian matrix the eigenvectors corresponding to two different eigenvalues are orthogonal**
- **A matrix has real eigenvalues and can be diagonolized by a unitary similarity transformation if and only if it is Hermitian**
- **A matrix has real eigenvalues and can be diagonolized by an orthogonal similarity transformation if and only if it is symmetric**

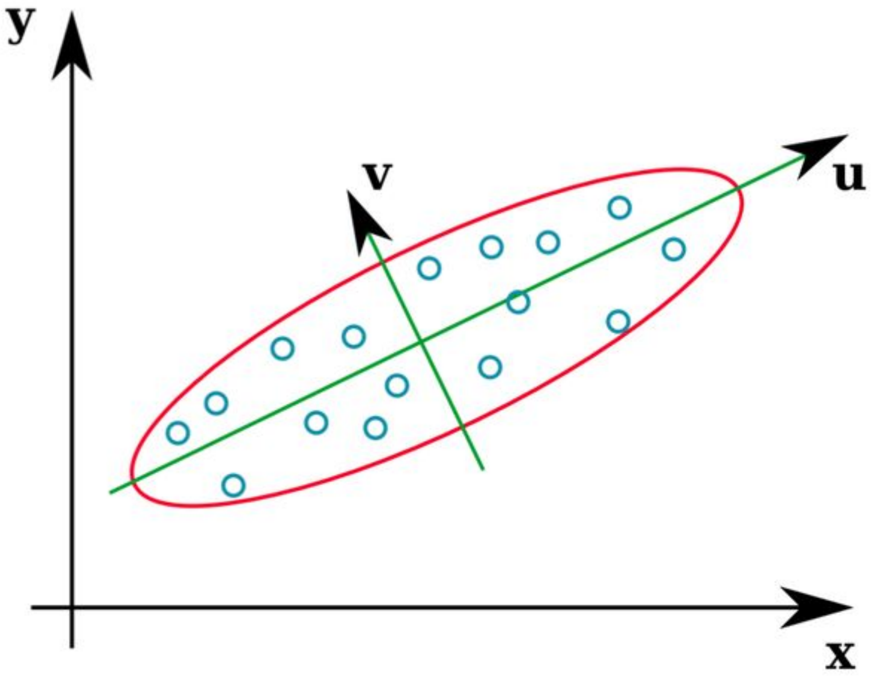
"Eigens"

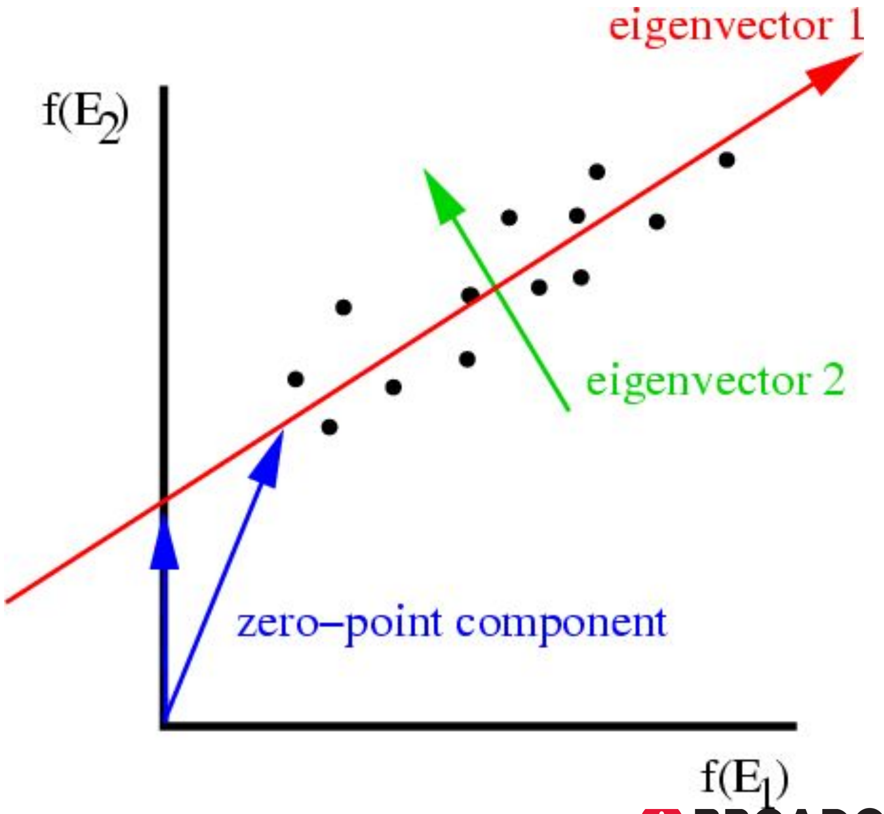


Eigen 'in Germany' means 'Characteristics' in English. So you may guess, 'Eigen vector' would be a special vector that represents a specific characteristics of a Matrix (a Square Matrix) and 'Eigen value' would be a special value that represents a specific characteristics of a Matrix (a Square Matrix)

If you think of a Matrix as a geometric transformer, the Matrix usually perform two types of transformational action. One is 'scaling(extend/shrink)' and the other one is 'rotation'.

Eigenvalues, Eigenvectors





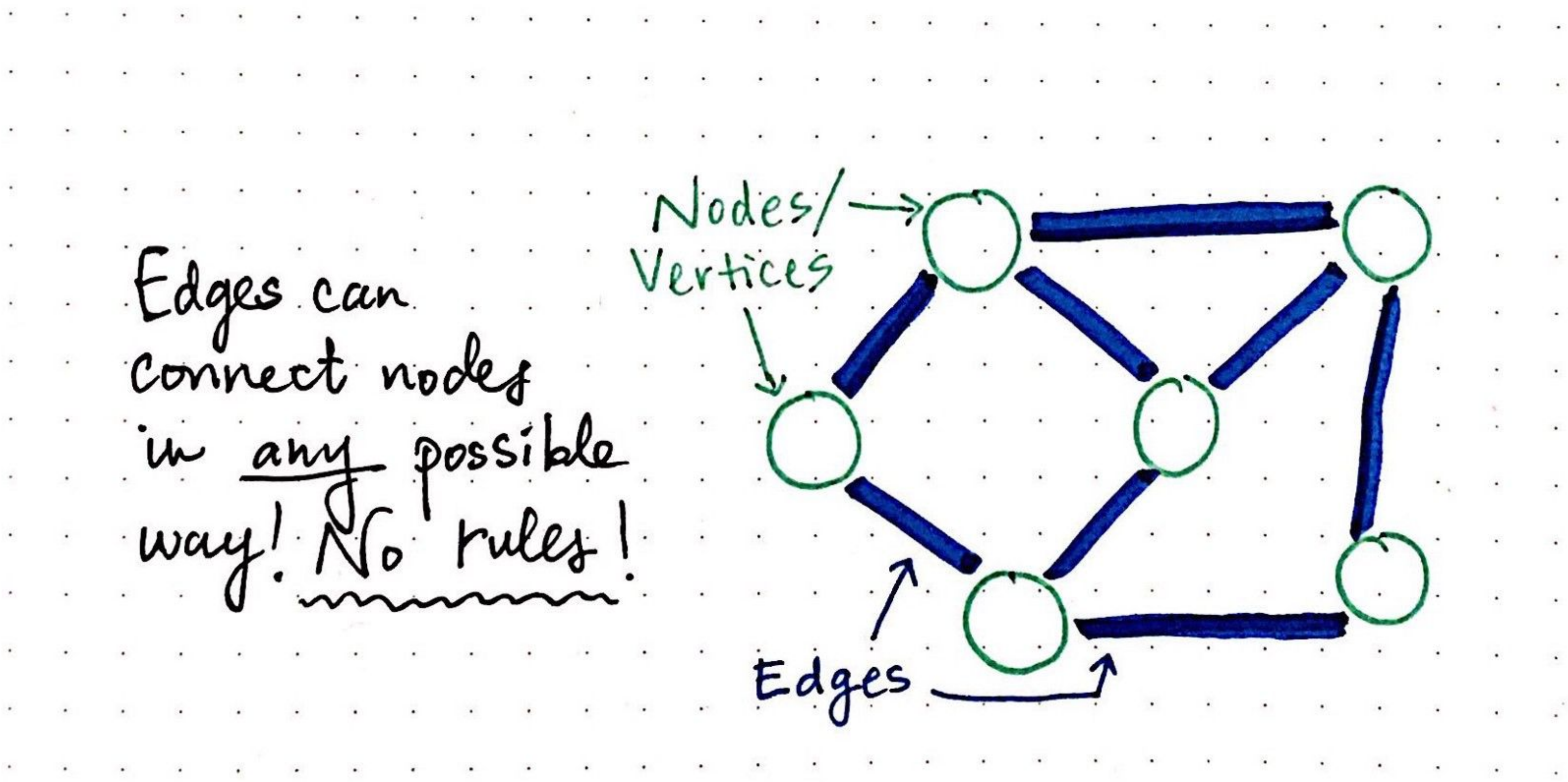
Graph Theory

In mathematics, graphs are a way to formally represent a network, which is basically just a collection of objects that are all interconnected.

Applied to MiMO

- The eigenvalues are the ones that characterize the MIMO channel capacity, while the eigenvector does not affect it (for a single-user point-point MIMO channel).
- The capacity-achieving transmission strategy is to send one data signal in each of the eigendirections. Hence, the eigenvalues tell us how strong these parallel channels are.

Gentle Introduction



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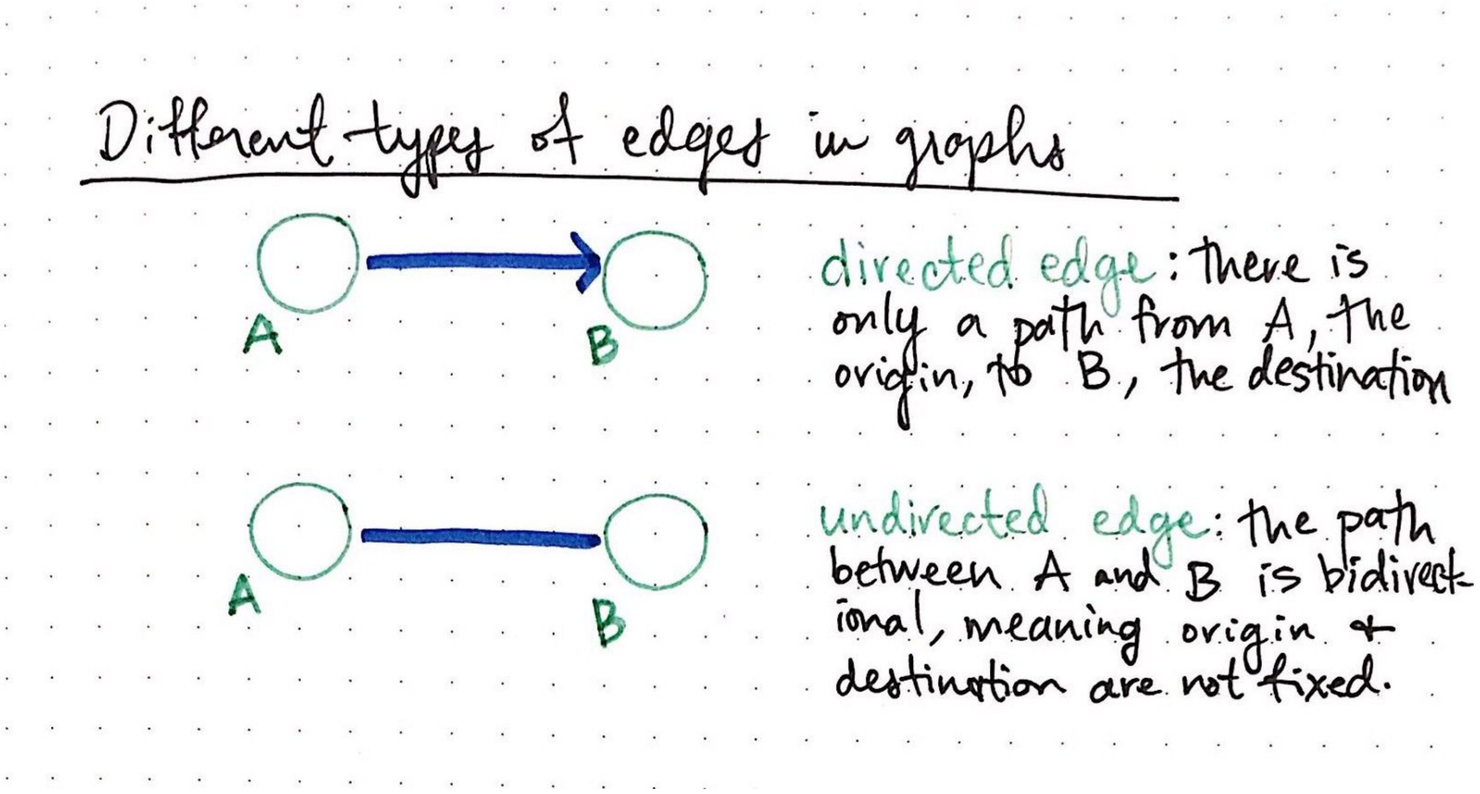
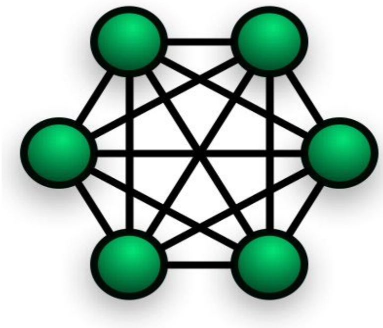
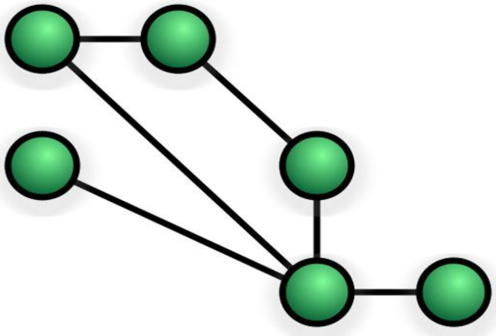
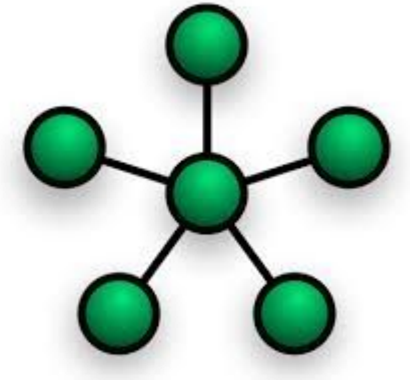
Edge types

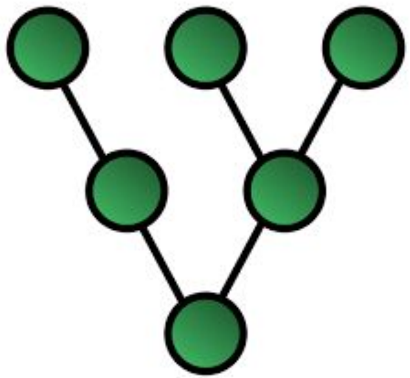

Different types of edges in graphs
A
B
directed edge: there is only a path from A, the origin, to B, the destination
A
B
undirected edge: the path between A and B is bidirectional, meaning origin + destination are not fixed.

Graph examples

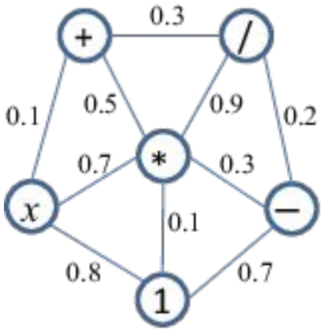




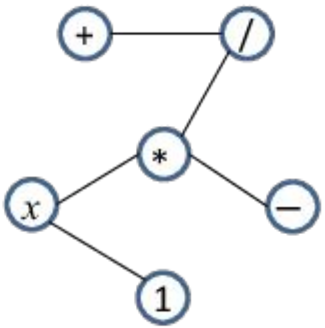




Graph->Tree->Distance Matrix



Weighted graph

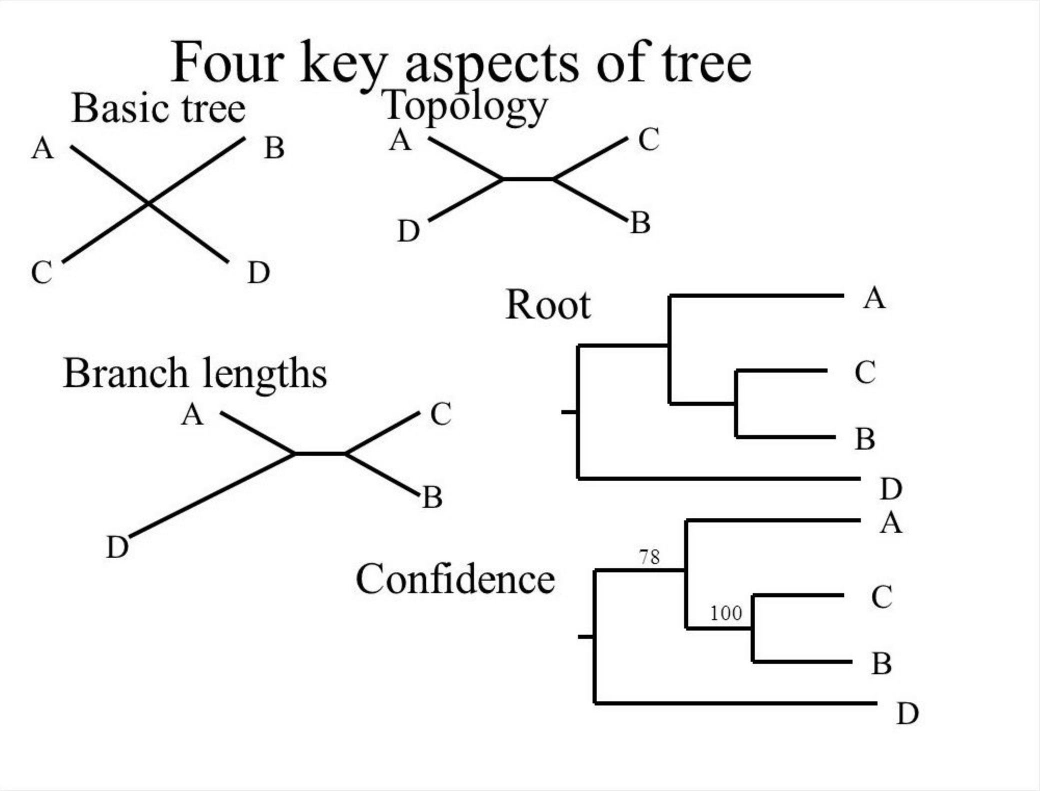


Minimum spanning tree

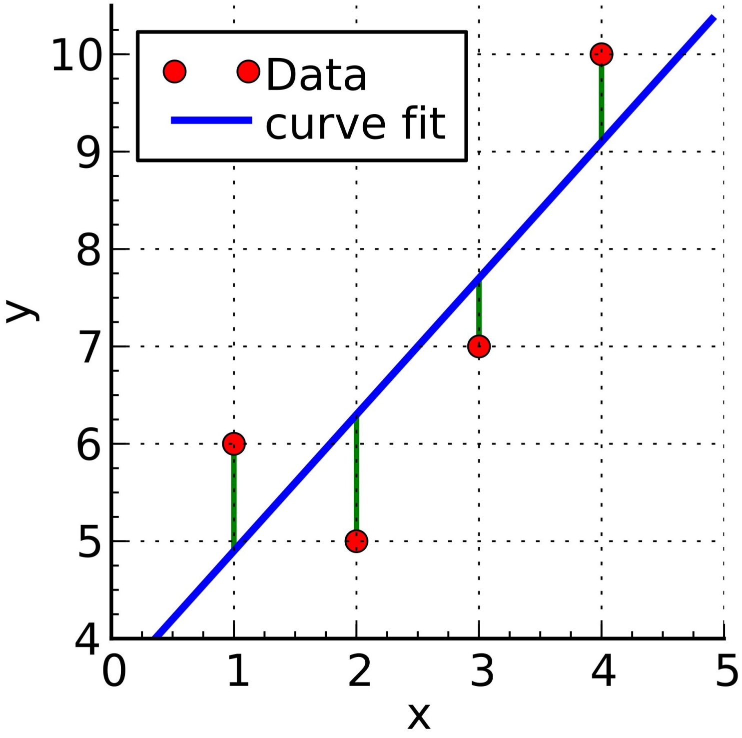
	+	-	*	/	x	1
+		3	2	1	3	4
-	3		1	2	2	3
*	2	1		1	1	2
/	1	2	1		2	3
x	3	2	1	2		1
1	4	3	2	3	1	

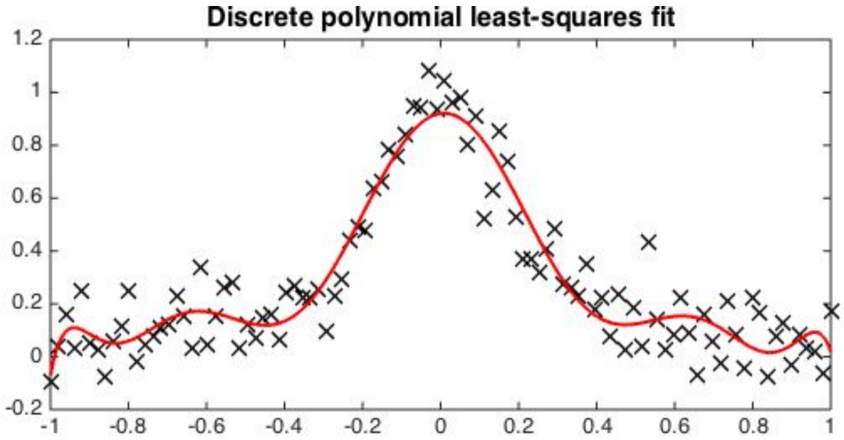
Distance matrix

Tree examples



Least Squares Fitting





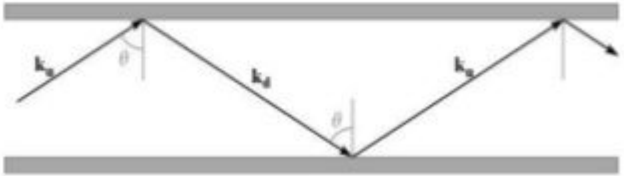
Building from available parts

Wave guides

Waveguide

- A waveguide is a structure that guides waves, such as electromagnetic waves or sound waves They enable a signal to propagate with minimal loss of energy by restricting expansion to one dimension or two
- Zigzag reflection, waveguide mode, cutoff frequency

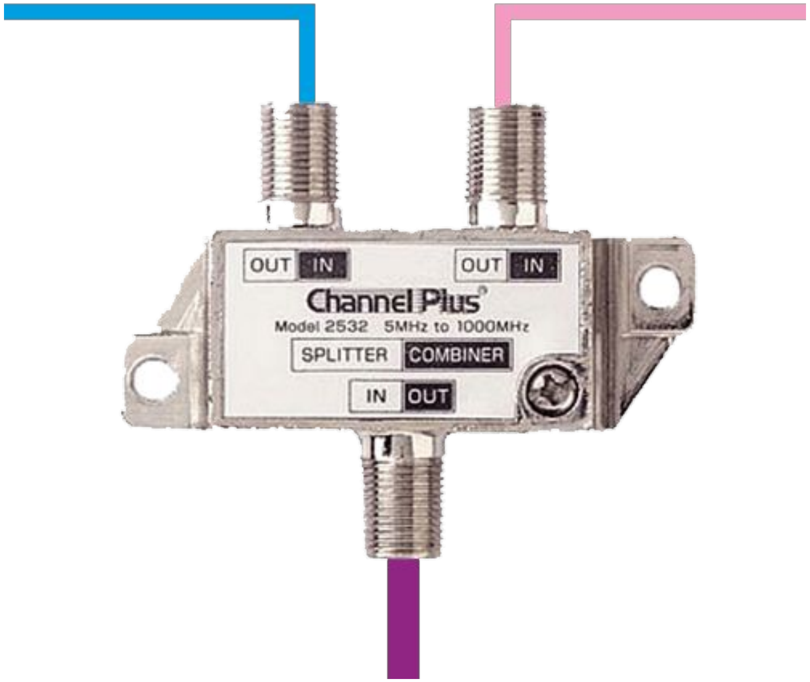
$$|\mathbf{k}_u| = |\mathbf{k}_d| = k = \omega\sqrt{\mu\varepsilon}$$



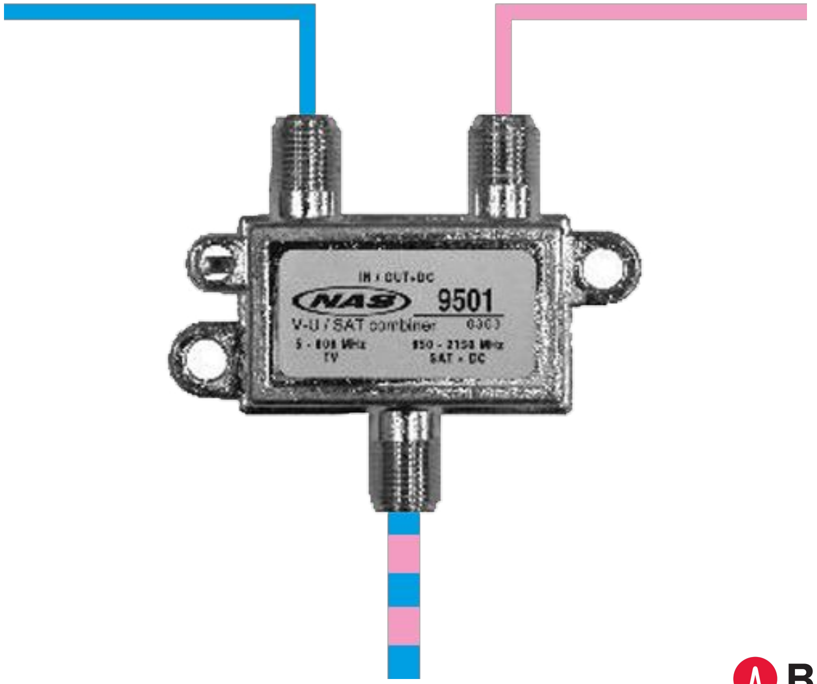
(b)

Fixed parts: e.g. Splitter/Combiner, Diplexers

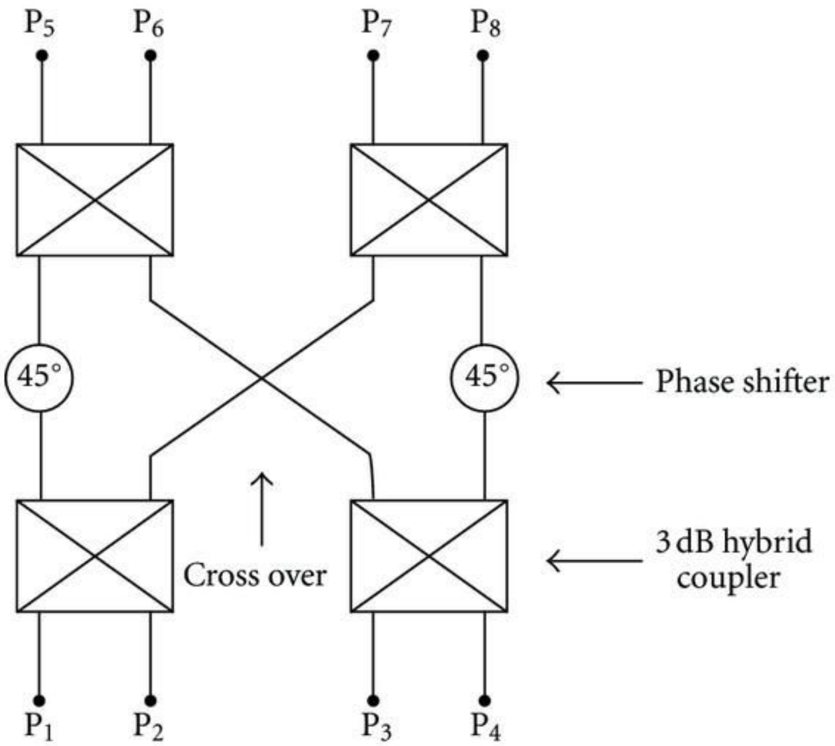
COMBINER



DIPLEXER



Butler Matrix



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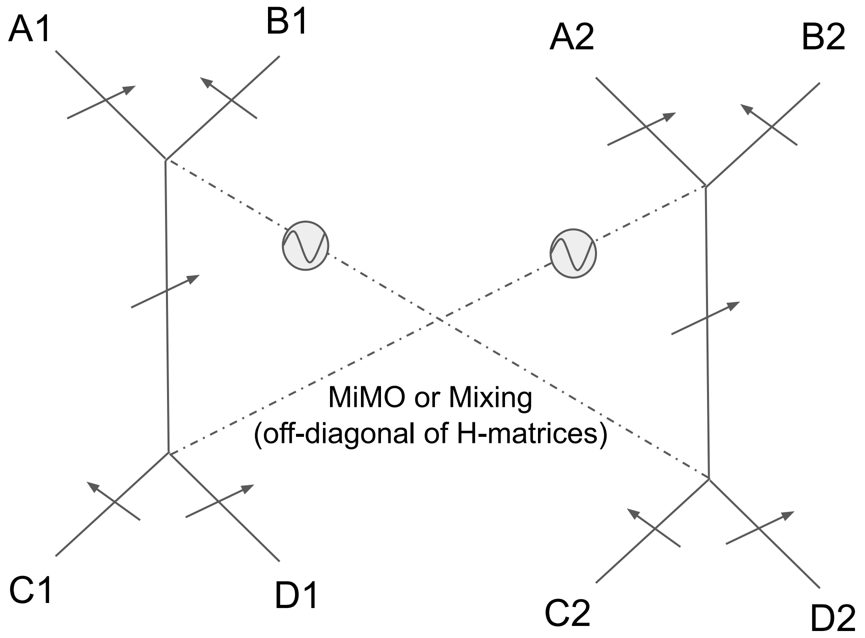
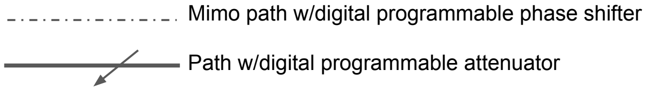
Programmable parts: attenuators and phase shifters

Generalized WiFi Graphs

Four Node, 5-Branch Tree with 2x2 MIMO



***Variable notch filter for OFDMA in discussion**



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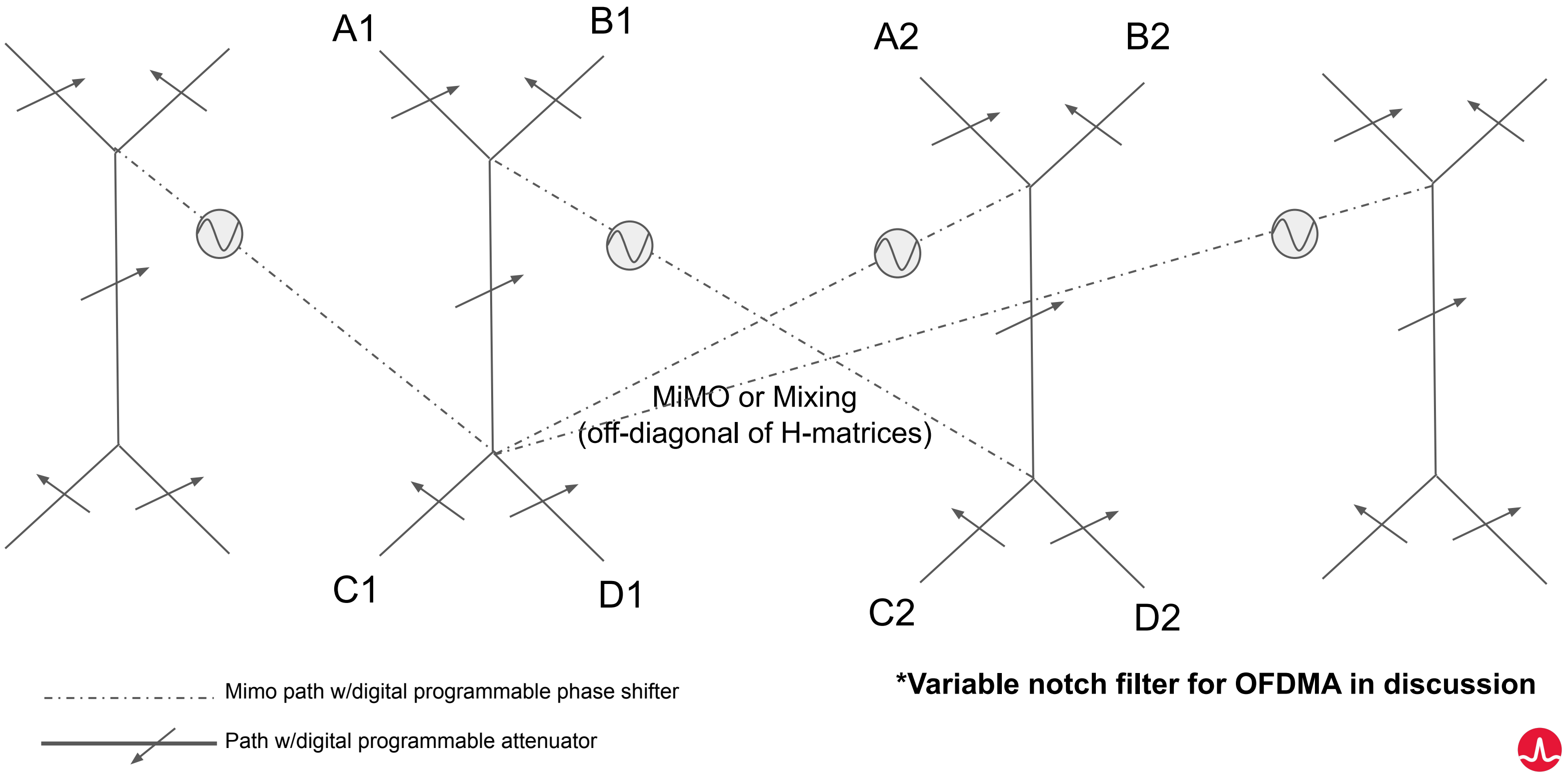
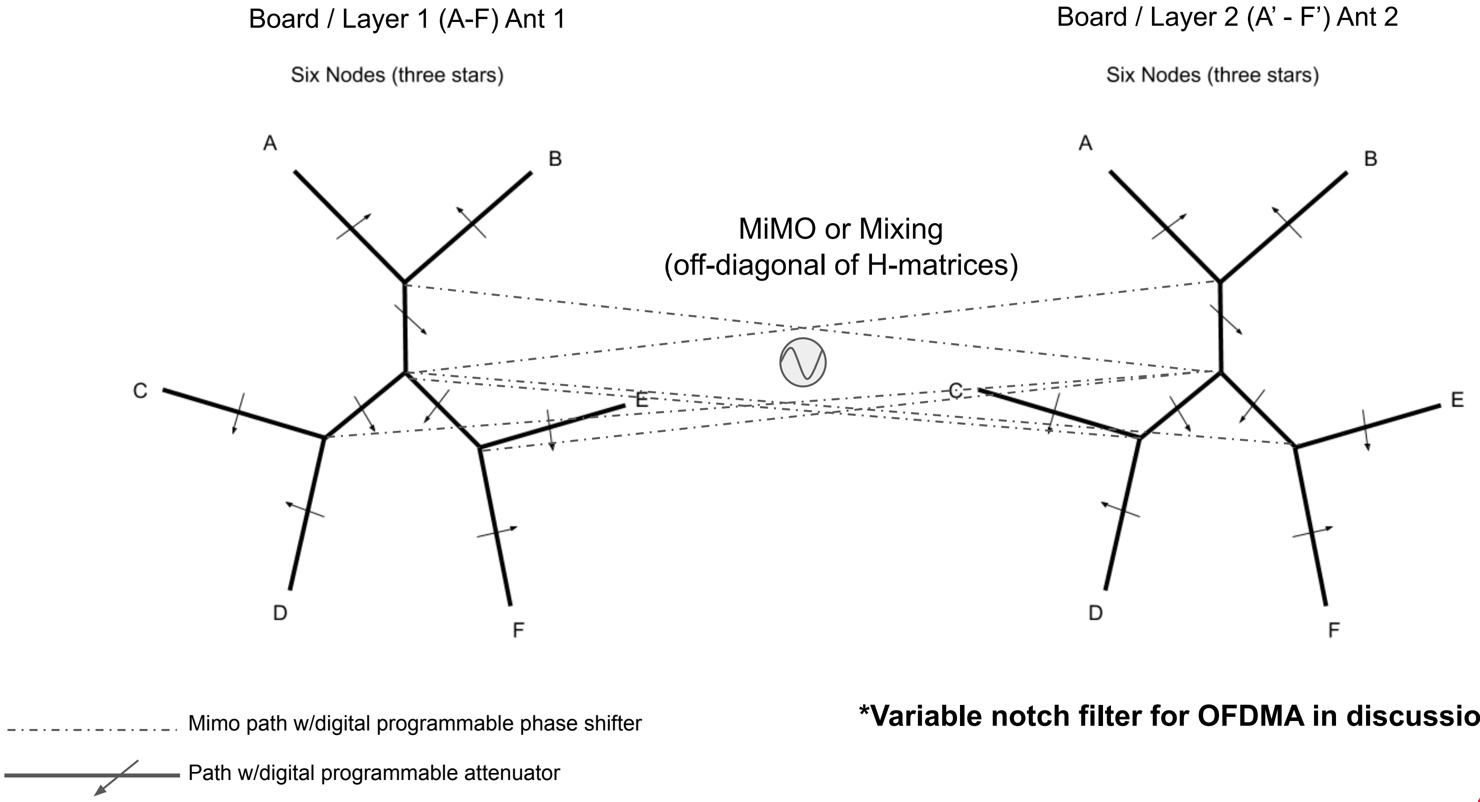
Four Node, 5-Branch Tree with 4x4 MIMO



***Variable notch filter for OFDMA in discussion**

6 Node, 3 BSS topology (3 BSS, 6 nodes, 2x2 MIMO)



***Variable notch filter for OFDMA in discussion**

Python Code

Minimizing Total Error (Partial diff eq)

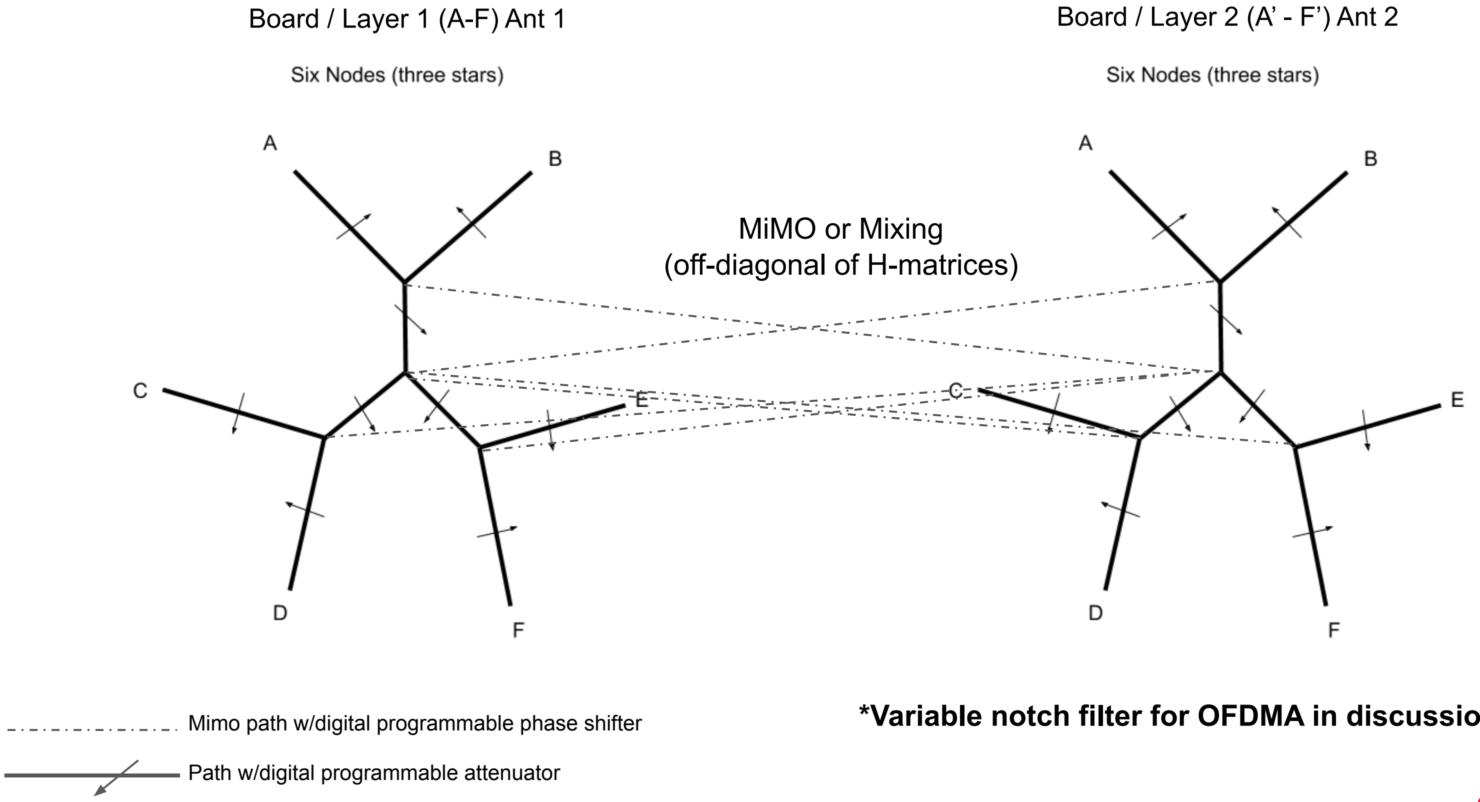
```
#
#  S1                    S3
#    \                  /
#   a \      b         /c
#      \______________/
#      /              \
#   d /                \ e
#    /                  \
#  S2                    S4
#
# D12 = a + d
# D13 = a + b + c
# D14 = a + b + e
# D23 = d + b + c
# D24 = d + b + e
# D34 = c + e
#
# Q = (D12 - a - d)**2 + (D13 - a - b - c)**2 + (D14 - a - b - e)**2 - (D23 - d - b - c)**2 + (D24 - d - b - e)**2 + (D34 - c - e)**2
#
# Substitute the desired RSSI (or distance) into D(i,j) then
# Find the minimum for Q by taking the partial derivatives respect to a,b,c,d and e
# and then solve the five simultaneous equations
```

Python Code

Q = (D12 - a - d)2 + (D13 - a - b - c)**2 + (D14 - a - b - e)**2 - (D23 - d - b - c)**2 + (D24 - d - b - e)**2 + (D34 - c - e)**2**

```
@property
def attnsettings(self):
    # Create the expression for the tree, i.e. the Summation of the squared errors
    q = ((Float(self.distances[0]) - self.a - self.d) ** 2) + ((Float(self.distances[1]) - self.a - self.b - self.c) **
2) + ((Float(self.distances[2]) - self.a - self.b - self.e) ** 2) + ((Float(self.distances[3]) - self.d - self.b - self.c) **
2) + ((Float(self.distances[4]) - self.d - self.b - self.e) ** 2) + ((Float(self.distances[5]) - self.c -  self.e ) ** 2)
    # perform the five partial differentiations and solve the five equations to minimize Q
    solution = linsolve([diff(q, self.a), diff(q,self.b), diff(q,self.c), diff(q,self.d), diff(q,self.e)],
self.a,self.b,self.c,self.d,self.e)
    (a0, b0, c0, d0, e0) = next(iter(solution))
    error = q.subs([(self.a,a0),(self.b,b0),(self.c,c0),(self.d,d0),(self.e,e0)])
    # print("{}".format(solve([diff(q, self.a), diff(q,self.b), diff(q,self.c), diff(q,self.d), diff(q,self.e)])))
    print('Error:{:.2f}'.format(float(sqrt(error))))
    return solution
```

Common/Generalized WiFi topology (3 BSS, 6 nodes, 2x2 MIMO)



***Variable notch filter for OFDMA in discussion**

6 Nodes, (11 degrees vs 22)

```
#              S3      S4
#               \     /
#              f \   / g
#                 \ /
#  S1              *
#     \           /
#    d \         / b
#       \   a   /
#        *-----*
#       /       \
#      /         \ c
#   e /           \
#    /             *
#  S2             / \
#              h /   \ i
#               /     \
#              S5     S6
#
#  0) D12 = d + e
#  1) D13 = d + a + b + f
#  2) D14 = d + a + b + g
#  3) D15 = d + a + c + h
#  4) D16 = d + a + c + i
#  5) D23 = e + a + b + f
#  6) D24 = e + a + b + g
#  7) D25 = e + a + c + h
#  8) D26 = e + a + c + i
#  9) D34 = f + g
# 10) D35 = f + b + c + h
# 11) D36 = f + b + c + i
# 12) D45 = g + b + c + h
# 13) D46 = g + b + c + i
# 14) D56 = h + i
```

Python Code

Q = (D12 - d - e)2 + (D13 - d - a - c)**2 + (D14 - a - b - e)**2 - (D23 - d - b - c)**2 + (D24 - d - b - e)**2 + (D34 - c - e)**2**

```
@property
def attnsettings(self):
    # Create the expression for the tree, i.e. the Summation of the squared errors
    q = ((Float(self.distances[0]) - self.d - self.e) ** 2) + ((Float(self.distances[1]) - self.d - self.a - self.b - self.f) ** 2) + ((Float(self.distances[2]) - self.d - self.a - self.b - self.g) ** 2) +
((Float(self.distances[3]) - self.d - self.a - self.c - self.h) ** 2) + ((Float(self.distances[4]) - self.d - self.a - self.c - self.i) ** 2) + ((Float(self.distances[5]) - self.e - self.a - self.b - self.f) ** 2) +
((Float(self.distances[6]) - self.e - self.a - self.b - self.g) ** 2) + ((Float(self.distances[7]) - self.e - self.a - self.c - self.h) ** 2) + ((Float(self.distances[8]) - self.e - self.a - self.c - self.i) ** 2) +
((Float(self.distances[9]) - self.f - self.g) ** 2) + ((Float(self.distances[10]) - self.f - self.b - self.c - self.h) ** 2) + ((Float(self.distances[11]) - self.f - self.b - self.c - self.i) ** 2) +
((Float(self.distances[12]) - self.g - self.b - self.c - self.h) ** 2) + ((Float(self.distances[13]) - self.g - self.b - self.c - self.i) ** 2) + ((Float(self.distances[14]) - self.h - self.i) ** 2)
    # perform the nine partial differentiations and solve the nine equations to minimize Q
    solution = linsolve([diff(q, self.a), diff(q,self.b), diff(q,self.c), diff(q,self.d), diff(q,self.e), diff(q,self.f), diff(q,self.g), diff(q,self.h), diff(q,self.i)], self.a, self.b, self.c, self.d, self.e, self.f, self.g,
self.h, self.i)
    (a0, b0, c0, d0, e0, f0, g0, h0, i0) = next(iter(solution))
    error = q.subs([(self.a,a0),(self.b,b0),(self.c,c0),(self.d,d0),(self.e,e0), (self.f,f0),(self.g,g0),(self.h,h0), (self.i,i0)])
    print('Error:{:0.2f}'.format(float(sqrt(error))))
    return solution
```

Take aways

- Seminal MIMO paper
- David Reed's myth of interference
- Least Squares Five Branch Tree link