

Master Thesis Presentation

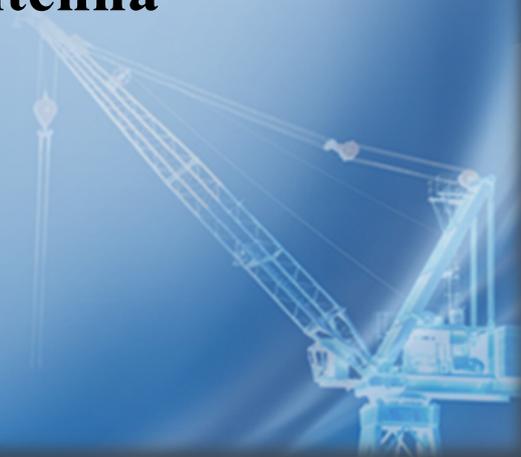
Development of a novel Switched Beam Antenna for Communications

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Outline

- ❖ **Motivation**
- ❖ **Experimental model for 1 GHz operation**
- ❖ **Remote Antenna Switch System**
- ❖ **Baluns**
- ❖ **A Full function model for short-wave operation (14 MHz)**
- ❖ **A Brief comparison between our switched beam antenna and the 3-element rotary beam antenna (3-element Yagi)**
- ❖ **Conclusion**

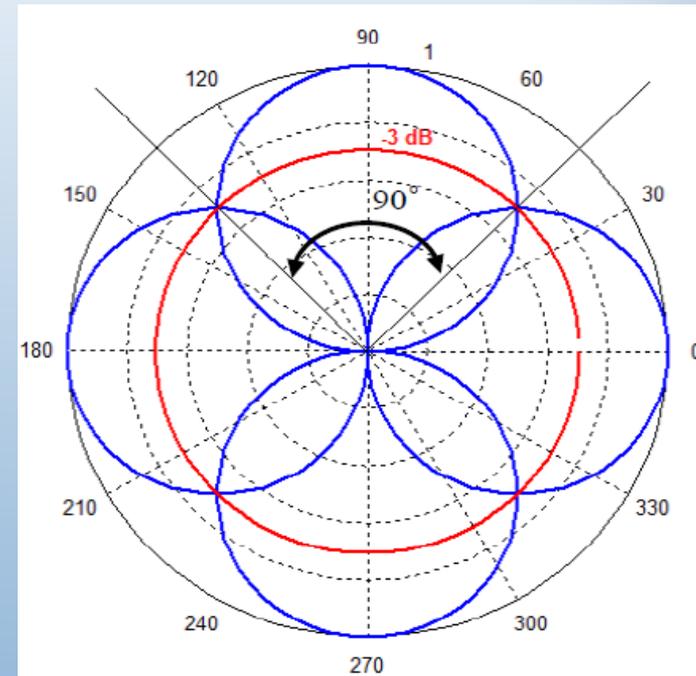
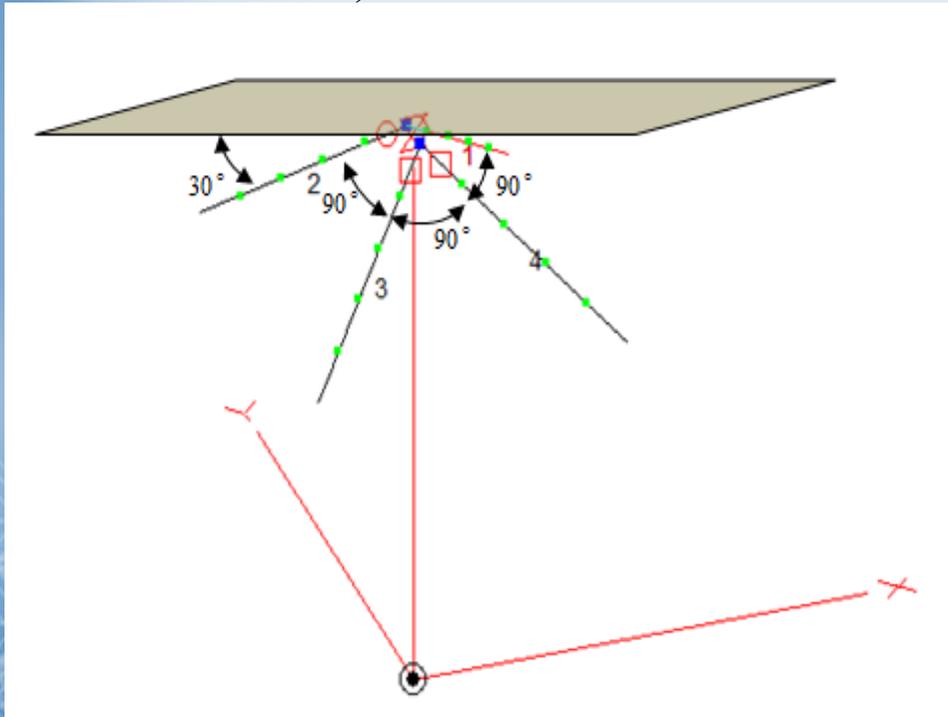


- To build an antenna model for broadcasting purposes, capable of providing omni-directional coverage and high gain at the same time.
- The azimuthal plane is subdivided into several sectors. Each sector has a pre-defined beam pattern with maximum gain placed in the center of the beam.
- Remote antenna switch system is used to choose from one of several predetermined, fixed beams, and switch from one beam to another.
- Only a single beam pattern is employed at any given time.



A model for 1 GHz using four quarter-wave conductors

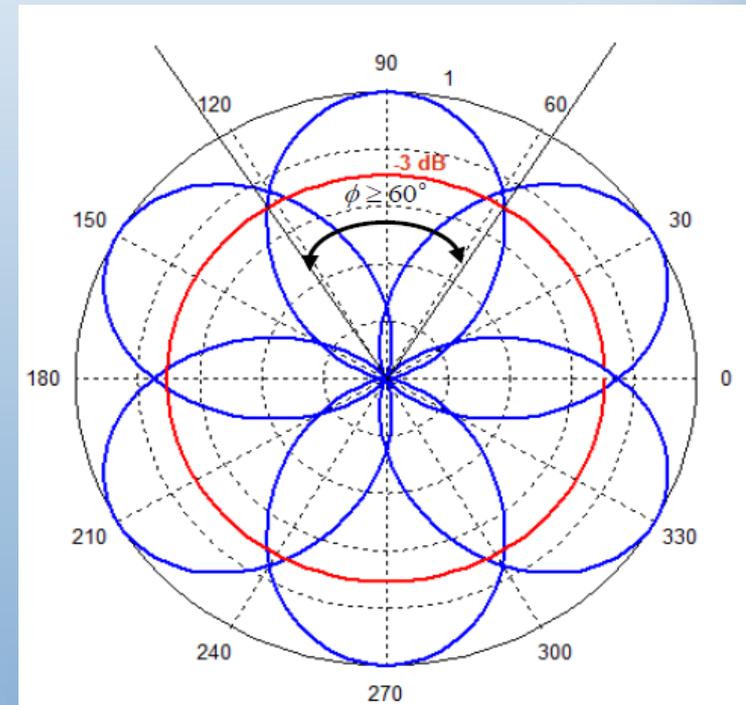
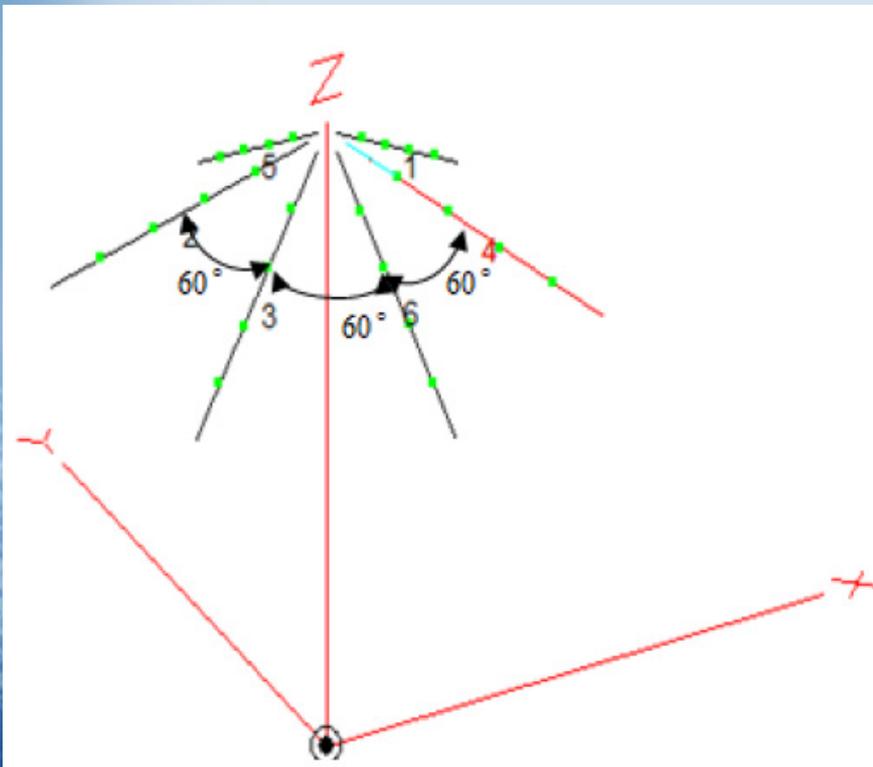
Four quarter-wave conductors arranged in a crossed configuration to create two V-shaped dipoles which act as two element array antenna (Driven element and Parasitic element).



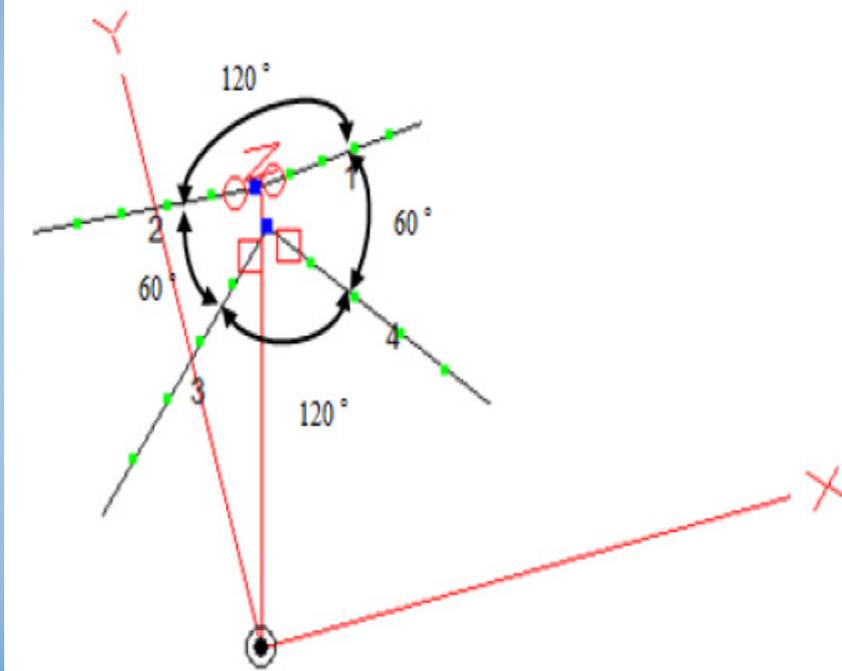
- The HPBW of 90 degree for each main beam could not be realized by arranging the conductors using such a configuration. It is actually less than 90 degree.

A model for 1 GHz using six quarter-wave conductors

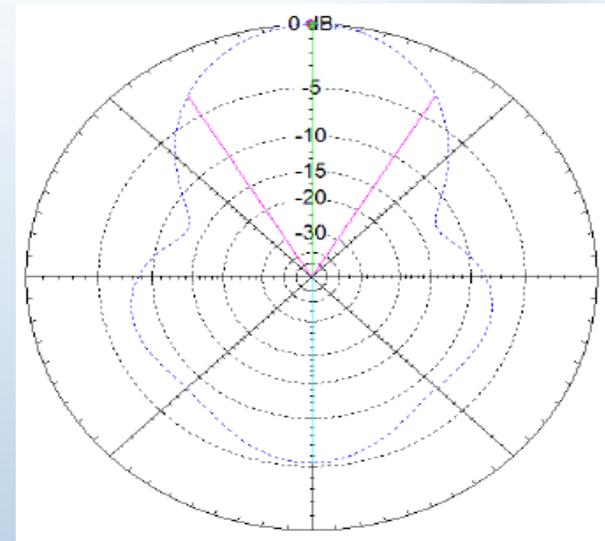
Six quarter-wave conductors with different settings of the switches, six different array antennas with six overlapping main beams covering the full 360 degree in azimuth can be realized.



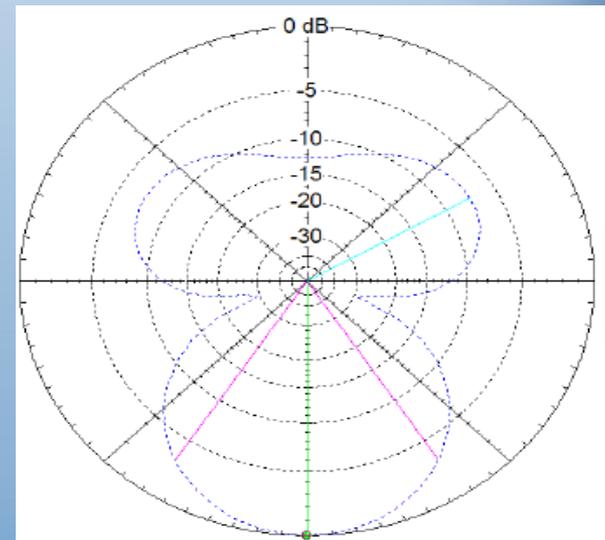
Four of six conductors will be used in each switching case



- The reactive load is used to change the electrical length of the loaded element.
- When the parasitic element is longer than its resonance length \longrightarrow acts as a reflector.
- When the parasitic element is shorter than its resonance length \longrightarrow acts as a director.
- Using the parasitic elements as a director will lead to higher F/B ratio than that could obtain when using the parasitic elements as a reflector.



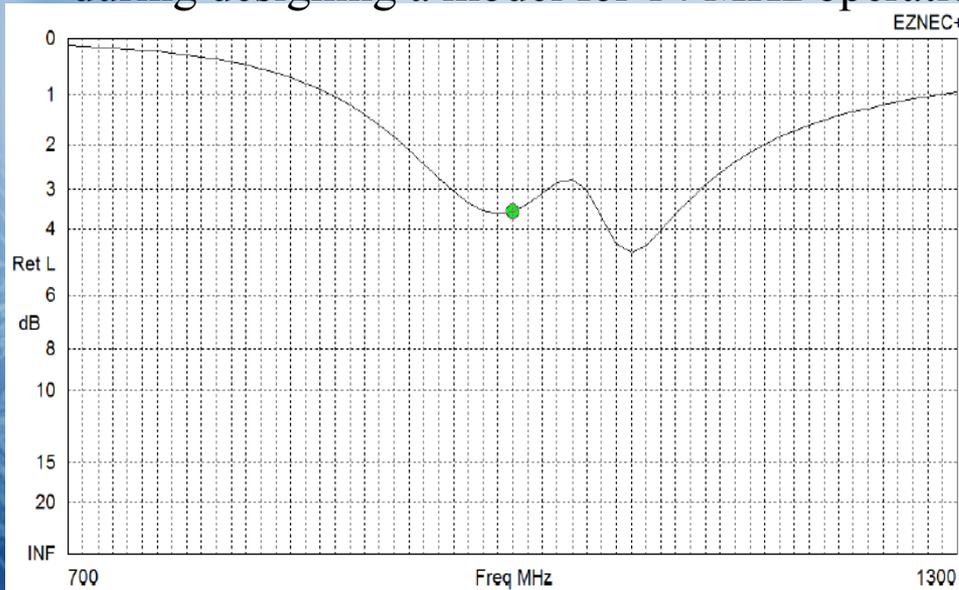
Parasitic element acts as a reflector



Parasitic element acts as a director

Which reactive load (inductive or capacitive) is better to be connected to the parasitic elements?

- Both reactive loads could achieve high gain with high F/B ratio by using the suitable conductor's length for each case.
- Nevertheless, using a capacitive load is preferred in order to obtain higher return loss value.
- A further advantage that found from using a capacitive load will be more obvious during designing a model for 14 MHz operation.



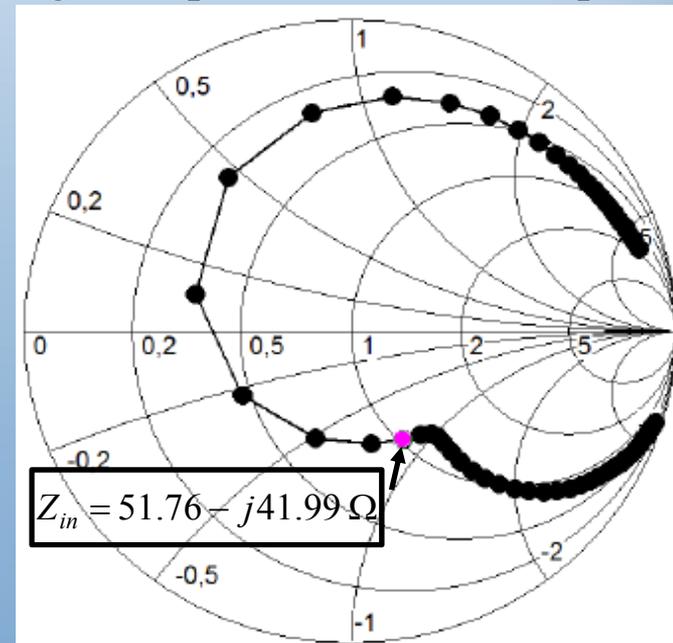
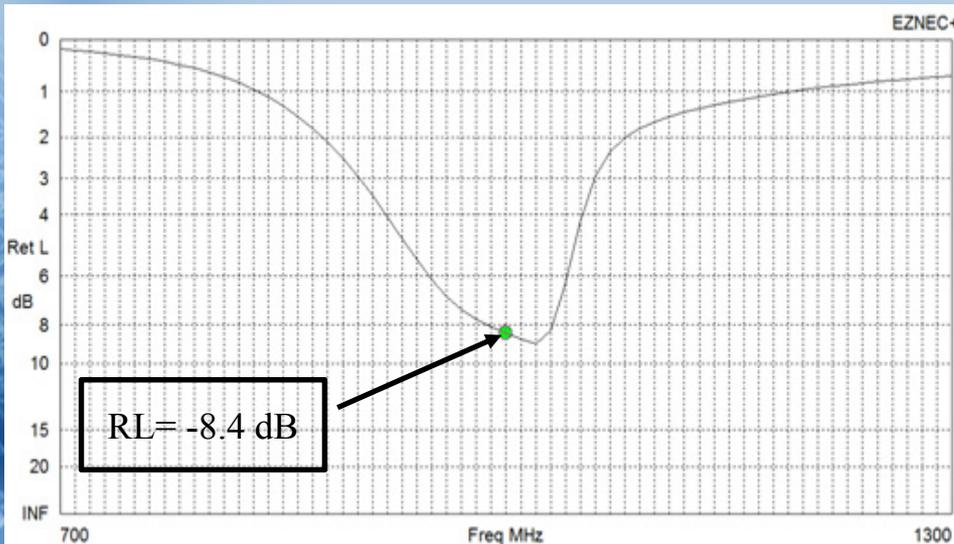
When the parasitic element is connected with inductive load.



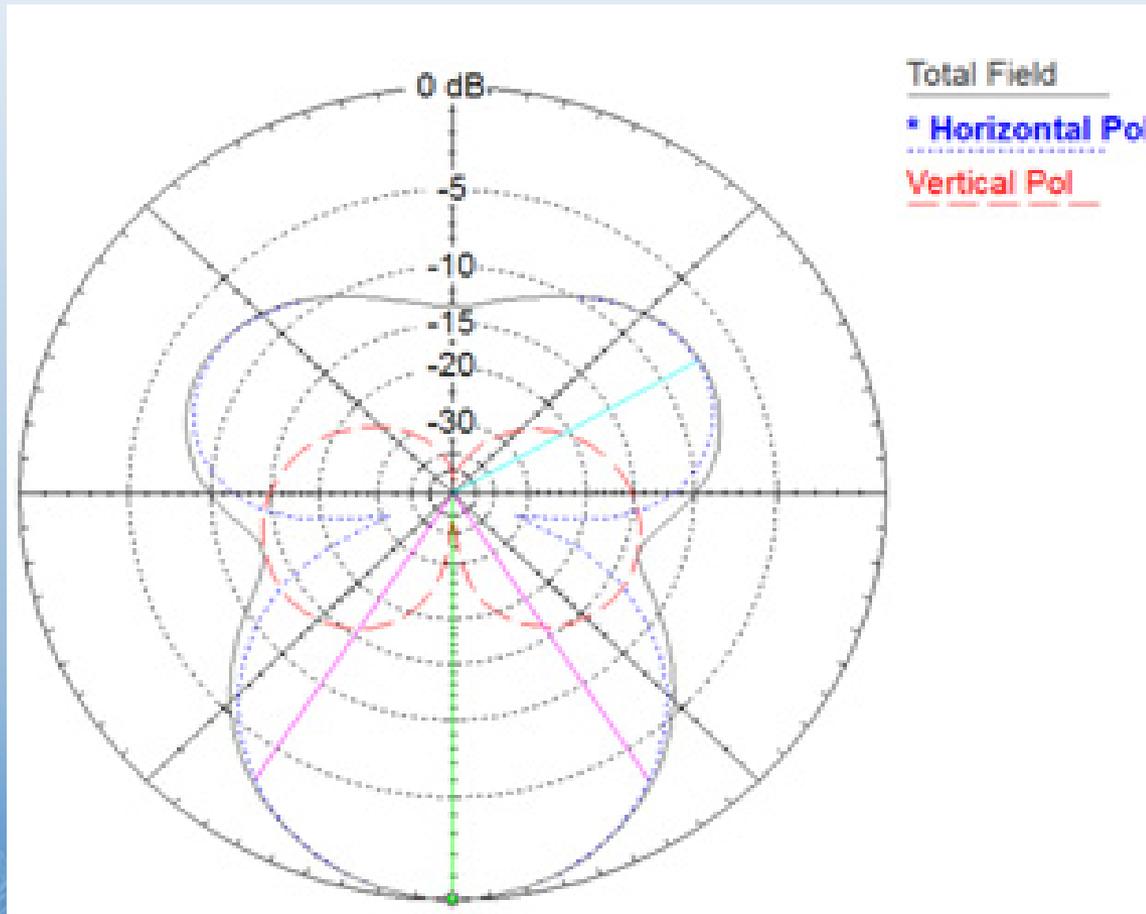
When the parasitic element is connected with capacitive load.

Parameters optimization and simulation results in free space:

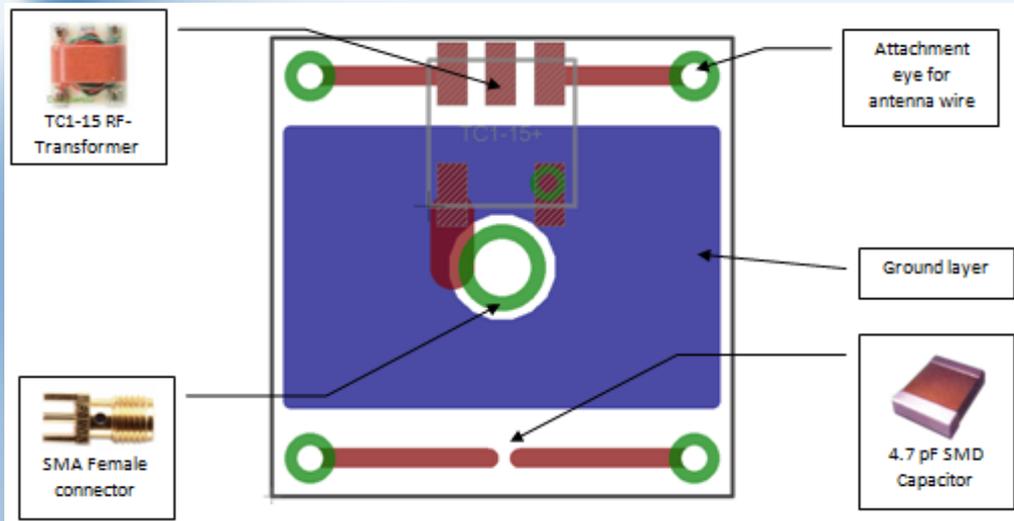
- In order to achieve the best gain and F/B ratio, conductor's length and the value of the reactive load (capacitive load) should be optimized.
- The distance between the driven element (at feed point) and the parasitic element (at reactive load) is required to be small as possible in order to increase the coupling between the antenna elements.
- Using copper conductors of 0.5mm diameter and a spacing distance of 1cm between the two array elements.
- The optimal length of conductors when inserting a capacitive load of 4.7pF at the center of parasitic element is 74mm ($L \approx \lambda/4$).



- Maximum gain (at azimuth plane) = 4.81 dB_i
- HPBW = 65.7 degree
- F/B pattern ratio = 13.28 dB
- F/S pattern ratio = 7.32 dB

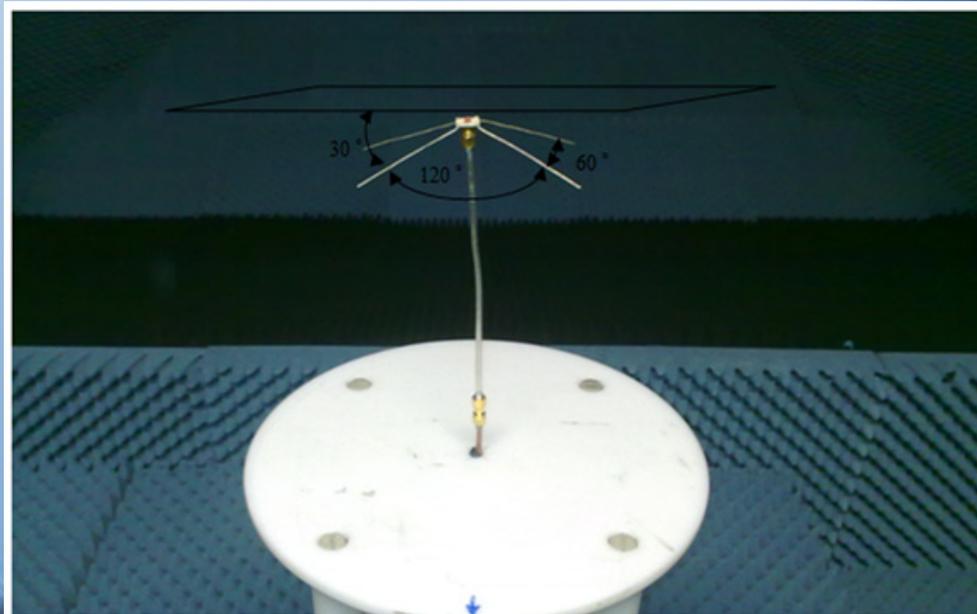


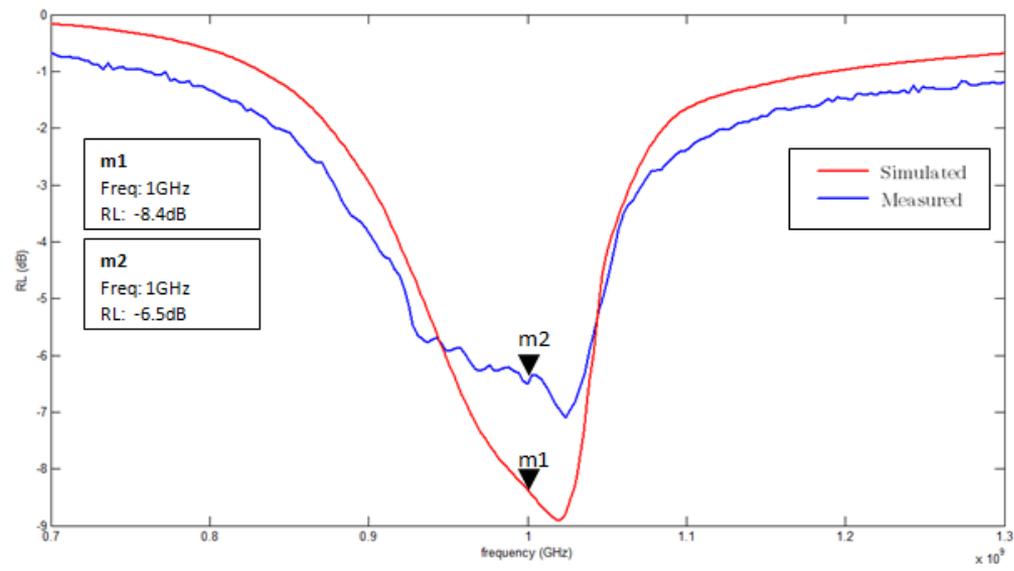
Realization of 1GHz experimental model (without switch):



1cm × 1cm PCB layout for 1GHz model

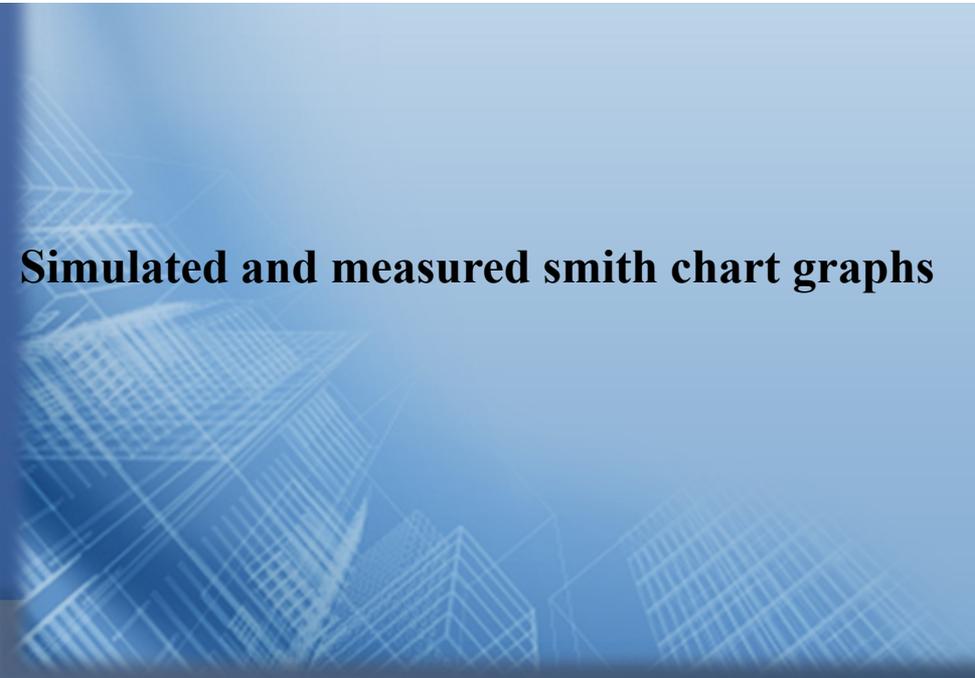
The complete structure of antenna installed on the anechoic chamber base.





Simulated and measured return loss.

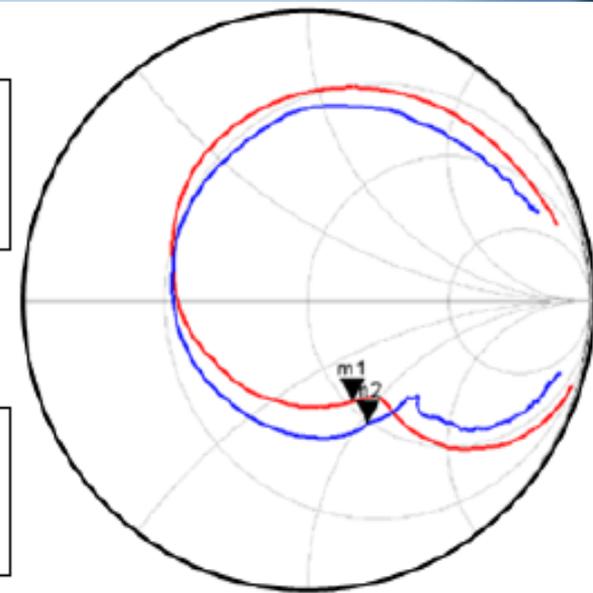
➤ The physical length of antenna wires are less than simulated one with few percents.



Simulated and measured smith chart graphs

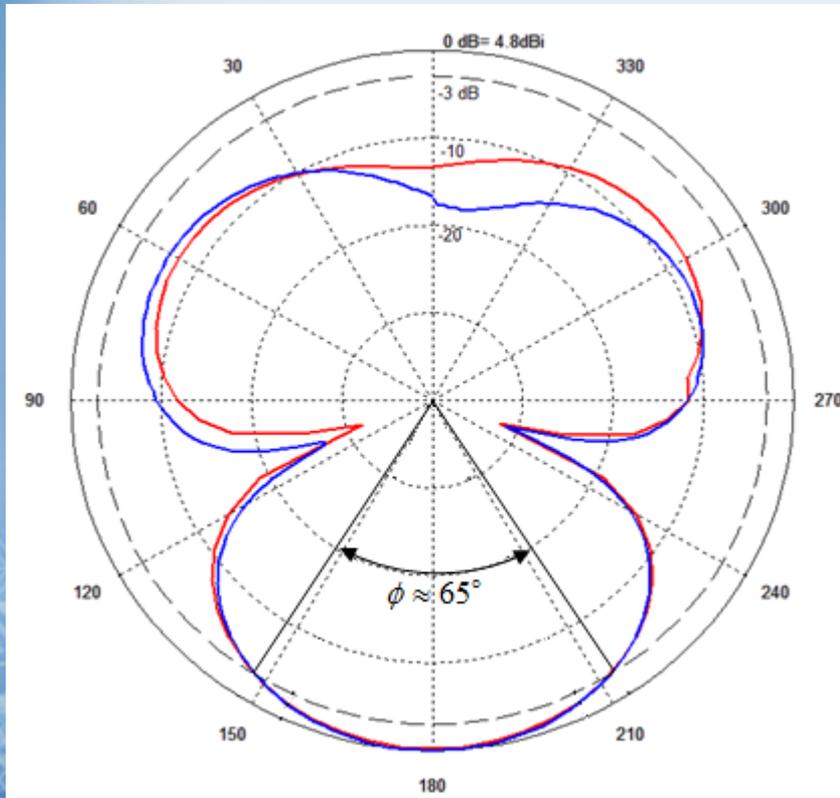
m1
Freq: 1GHz
Ref. Coeff: 0.3818@-65.18 deg
 $Z_{in} : 51.76-j41.99$

m2
Freq: 1GHz
Ref. Coeff: 0.473@-63.138 deg
 $Z_{in} : 48.746-j52.986$

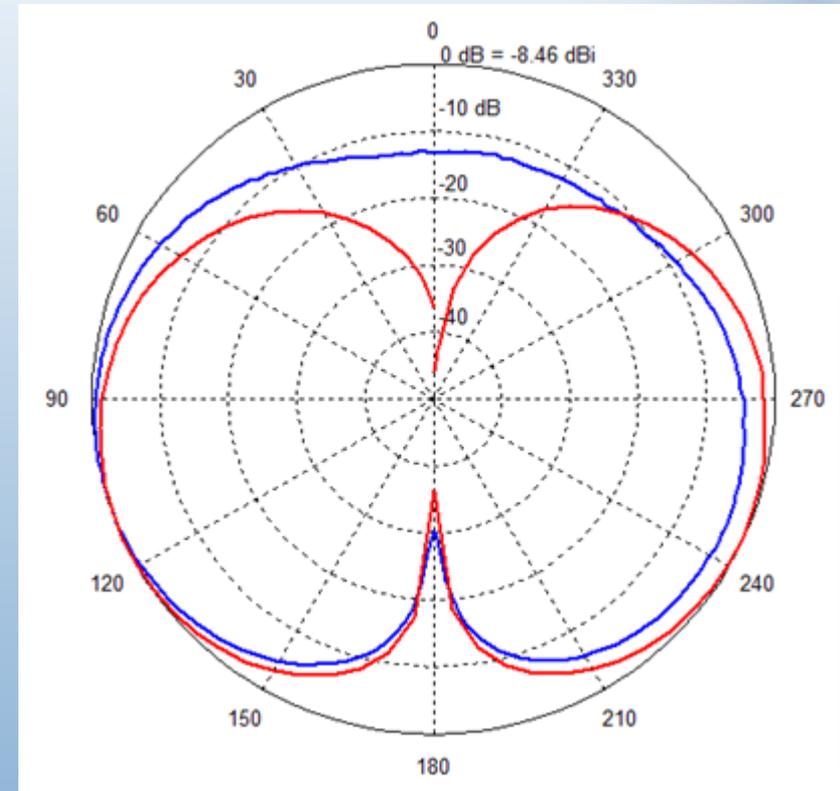


freq (700MHz to 1300 MHz)

— Simulated
— Measured

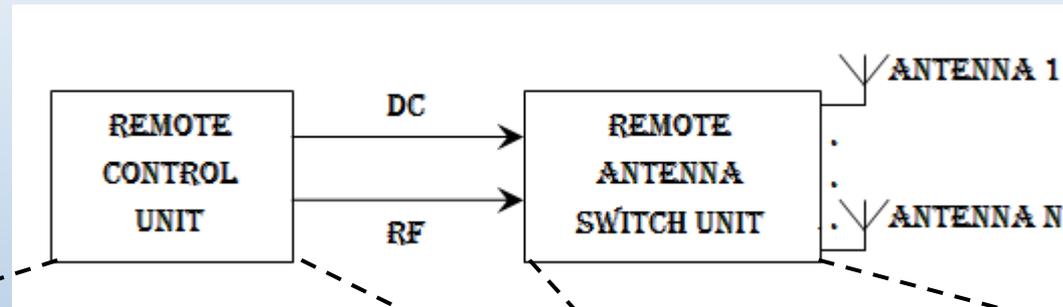


Simulated and measured horizontally polarized radiation pattern.



Simulated and measured vertically polarized radiation pattern.

- Remote switching system allows us to choose from one of several predetermined, fixed beams, and switch from one beam to another.
- It consists basically of two major units, the remote control unit and the remote antenna switch unit.



❖ RF Generator/Receiver.

❖ DC power supply.

❖ The rotary switch box

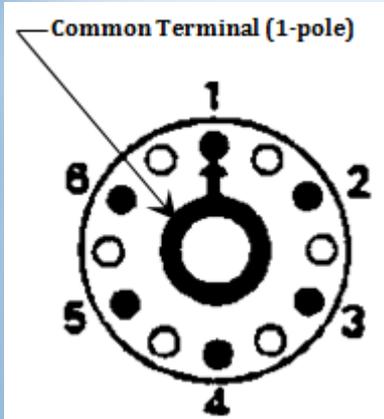
- Rotary switch
- Logic gates
- Encoder
- Transistors
- Resistors

❖ Relays

- SPDT
- DPDT

➤ The rotary switch box

❖ A rotary switch

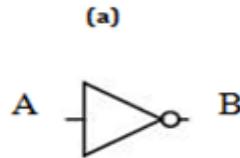


1-pole 6-position rotary switch



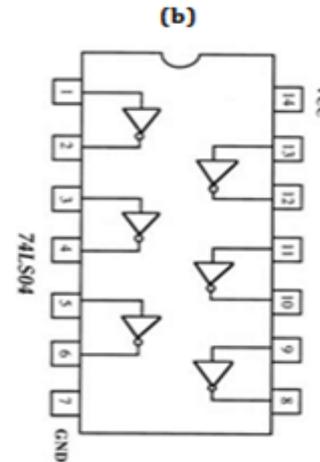
❖ Logic gates

▪ NOT gate (Inverter)



| | | |
|---|---|---|
| A | 0 | 1 |
| B | 1 | 0 |

Table 4.1 NOT gate



▪ OR gate

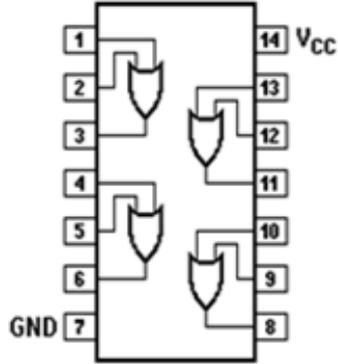
(a)



| A | B | Output |
|---|---|--------|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |

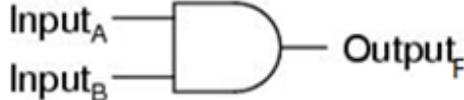
Table 4.2 2-input OR gate

(b)



▪ AND gate

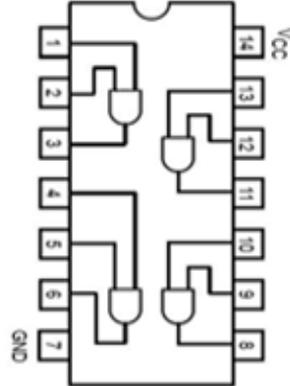
(a)



| A | B | Output |
|---|---|--------|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 0 | 0 |
| 1 | 1 | 1 |

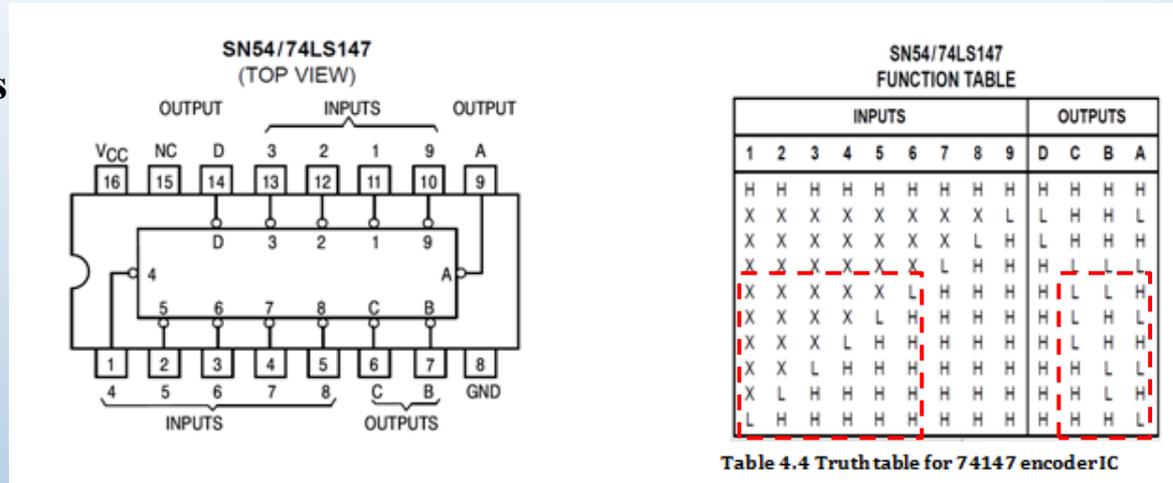
Table 4.3 2-input AND gate

(b)

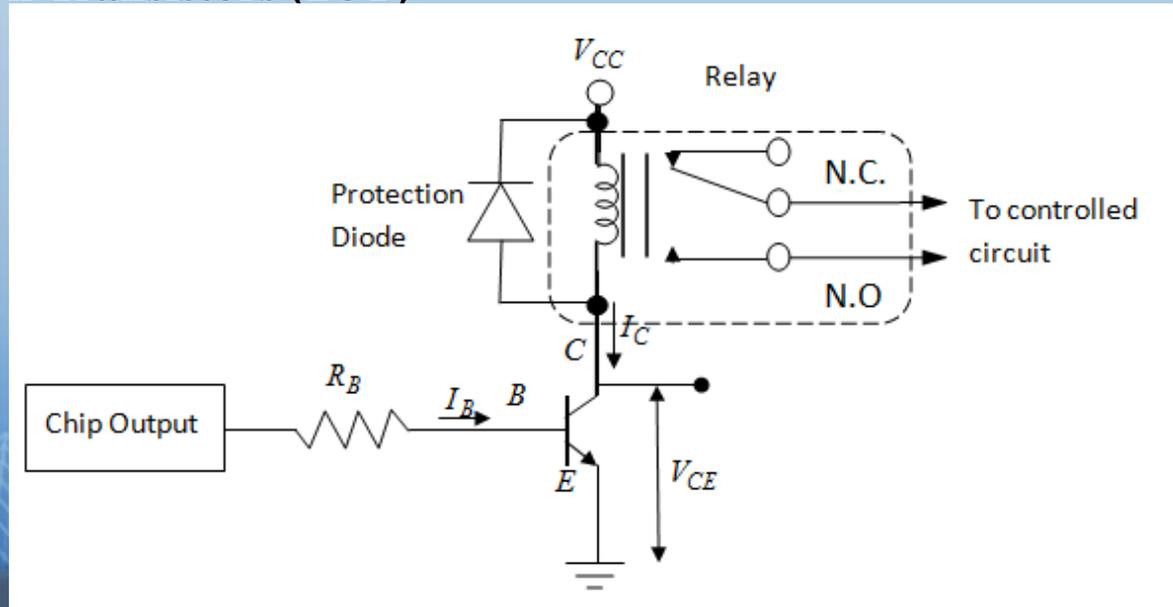


❖ **Encoder:** convert a decimal number to binary number

➤ **Active low inputs and outputs**

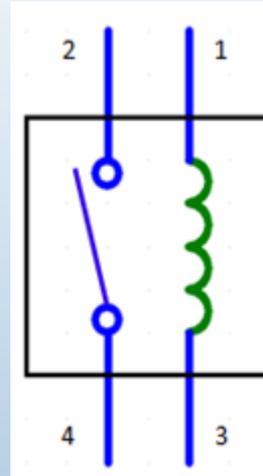


❖ **Bipolar Junction Transistors (BJT)**

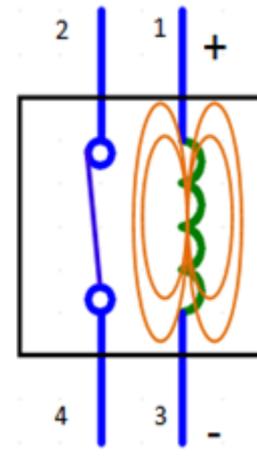


➤ **Relay:** is an electrical switch, consists basically of two circuits : a control circuit (the coil) and a load circuit (the switch).

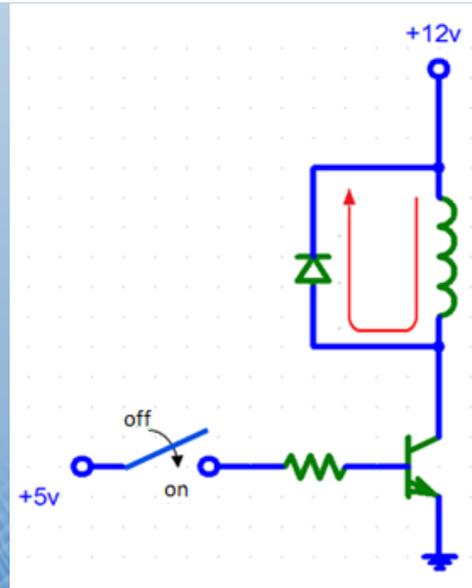
Relay De-Energized



Relay Energized

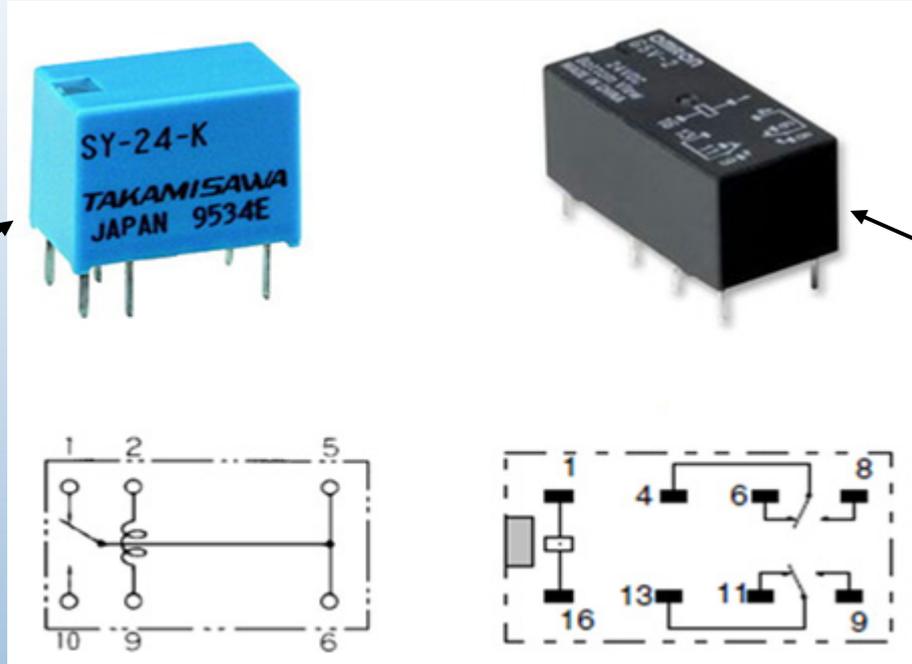


Relays with external De-spiking Diodes



❖ SPDT and DPDT relays

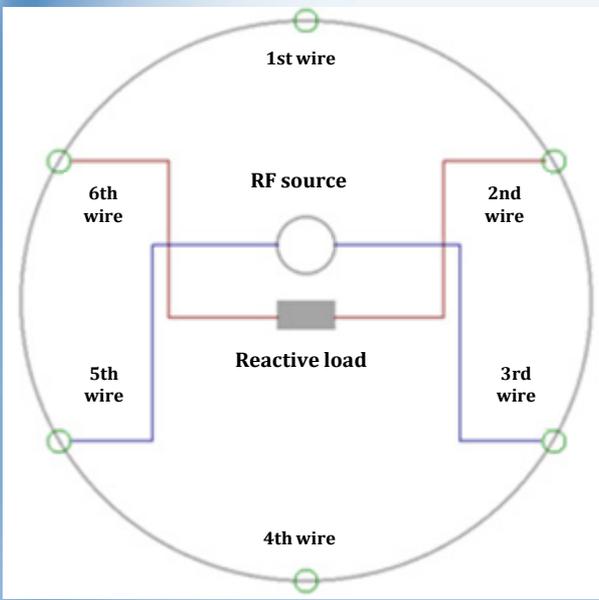
SPDT relay



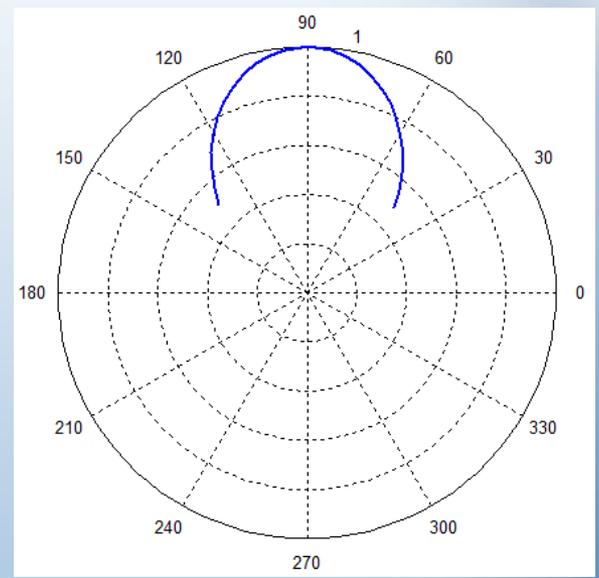
DPDT relay

The relays are characterized with low capacitance (ca. 1pf) between contacts.

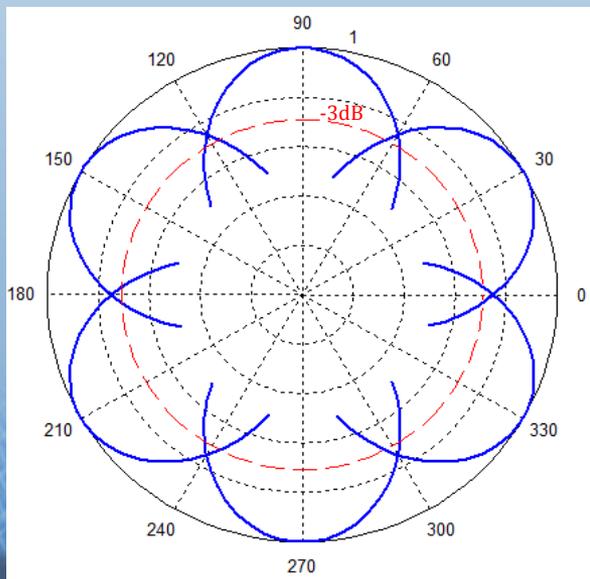
➤ The switch unit:



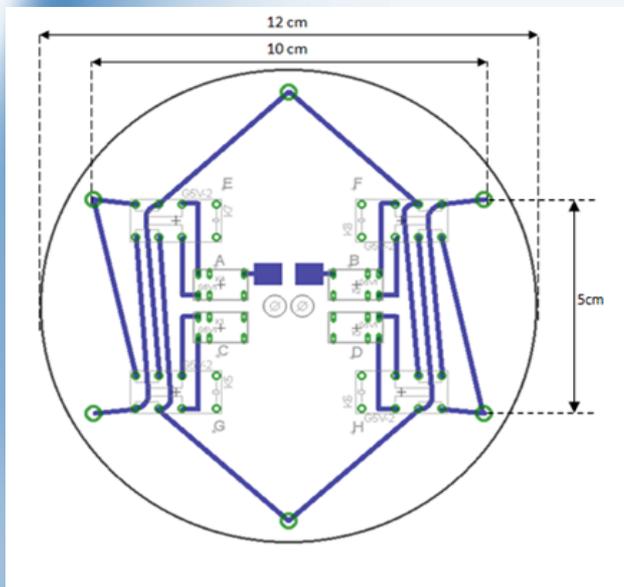
Routing configuration of the switch unit for a beam pointing to 90 azimuth



Six overlapping main beams covering the full 360 degree in azimuth

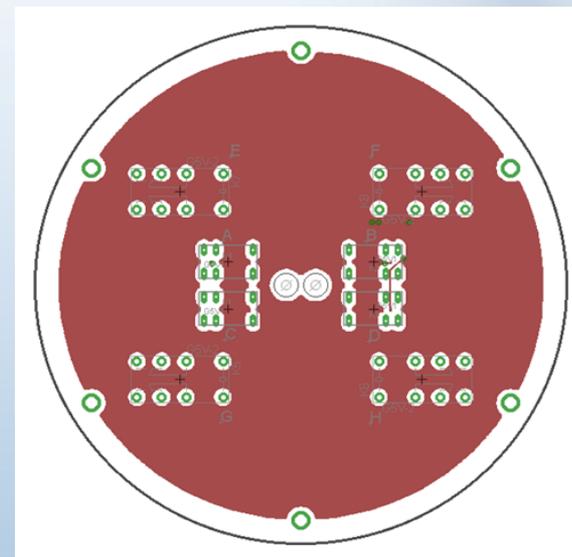


➤ Designing switch unit PCB



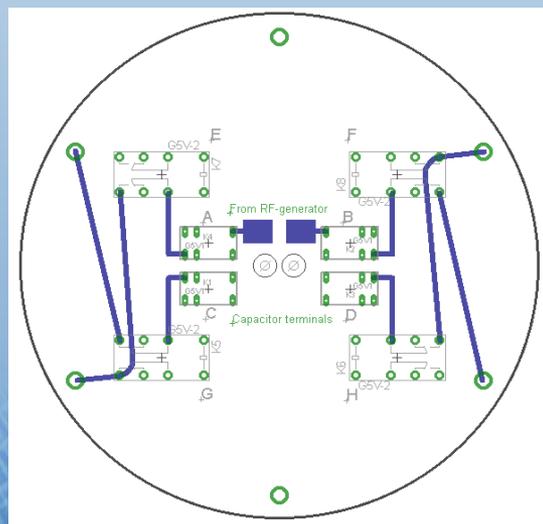
Upper layer

Relays arrangement on PCB

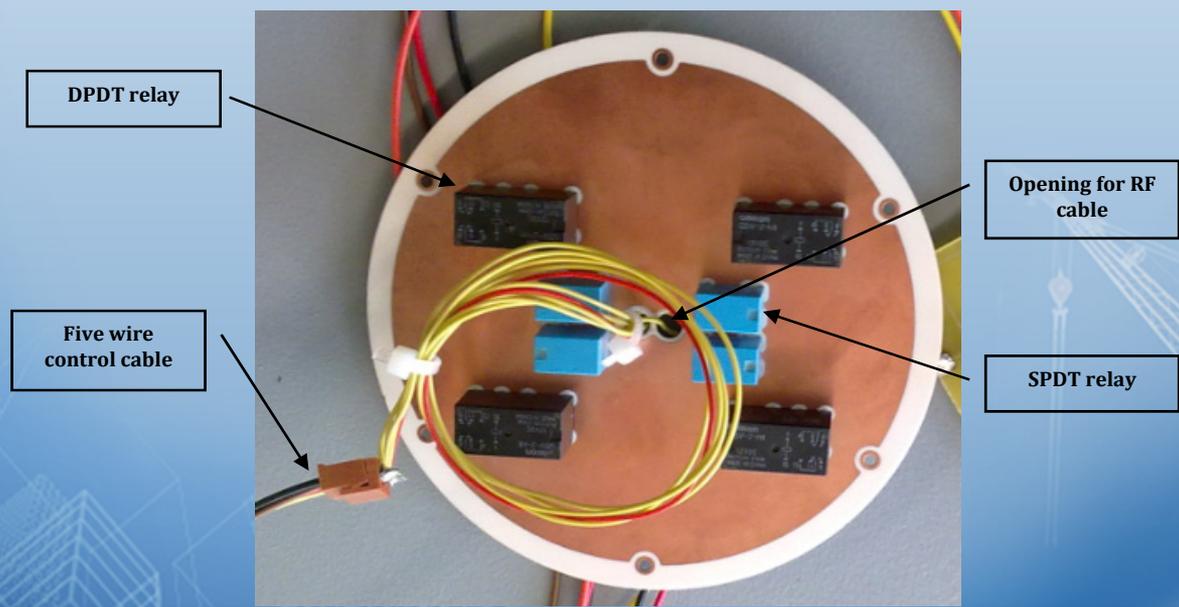
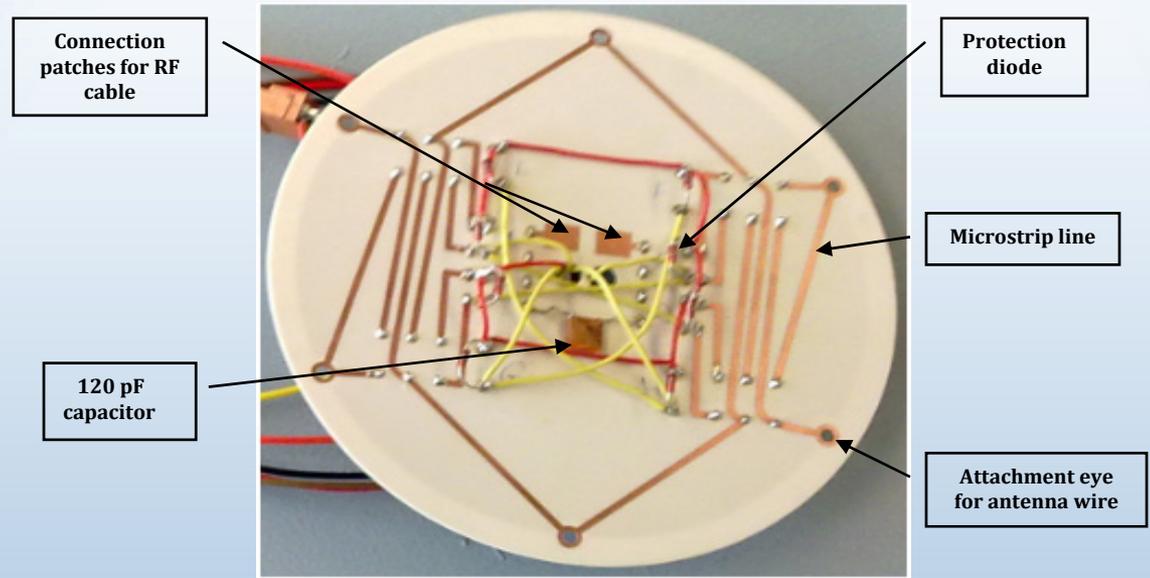


Lower layer

The active traces as shown on PCB for 1st case when relays A, E, F, D, H and G are energized



Remote Antenna Switch System



➤ How to construct the control unit

| Relays Cases | A | B | C | D | E | F | G | H |
|----------------------|-----|-----|-----|-----|-----|-----|-----|-----|
| 1 st case | Yes | No | No | Yes | Yes | Yes | Yes | Yes |
| 2 nd case | No | No | No | No | Yes | No | No | Yes |
| 3 rd case | Yes | Yes | Yes | Yes | Yes | No | No | Yes |
| 4 th case | No | Yes | Yes | No | Yes | Yes | Yes | Yes |
| 5 th case | No | No | No | No | No | Yes | Yes | No |
| 6 th case | Yes | Yes | Yes | Yes | No | Yes | Yes | No |

The state of relays at each switching case

| X_1 | X_2 | X_3 | A&D | B&C | E&H | F&G |
|-------|-------|-------|-----|-----|-----|-----|
| 0 | 0 | 1 | 1 | 0 | 1 | 1 |
| 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 | 1 | 0 |
| 1 | 0 | 0 | 0 | 1 | 1 | 1 |
| 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| 1 | 1 | 0 | 1 | 1 | 0 | 1 |

Representing the state of relays in a binary system

❖ Three-variable Karnaugh maps are extracted from previous table in order to obtain the logical expressions

| | | | |
|-------|-------|-------|---|
| | | X_1 | |
| | | 0 | 1 |
| X_2 | X_3 | | |
| | 0 | 1 | |
| 0 | 0 | X | 0 |
| 0 | 1 | 1 | 0 |
| 1 | 1 | 1 | X |
| 1 | 0 | 0 | 1 |

$$A = \bar{X}_1 \cdot X_3 + X_1 \cdot X_2 = D \quad (4.12)$$

| | | | |
|-------|-------|-------|---|
| | | X_1 | |
| | | 0 | 1 |
| X_2 | X_3 | | |
| | 0 | 1 | |
| 0 | 0 | X | 1 |
| 0 | 1 | 0 | 0 |
| 1 | 1 | 1 | X |
| 1 | 0 | 0 | 1 |

$$B = X_1 \cdot \bar{X}_3 + X_2 \cdot X_3 = C \quad (4.13)$$

| | | | |
|-------|-------|-------|---|
| | | X_1 | |
| | | 0 | 1 |
| X_2 | X_3 | | |
| | 0 | 1 | |
| 0 | 0 | X | 1 |
| 0 | 1 | 1 | 0 |
| 1 | 1 | 1 | X |
| 1 | 0 | 1 | 0 |

$$E = \bar{X}_1 + \bar{X}_2 \cdot \bar{X}_3 = H \quad (4.14)$$

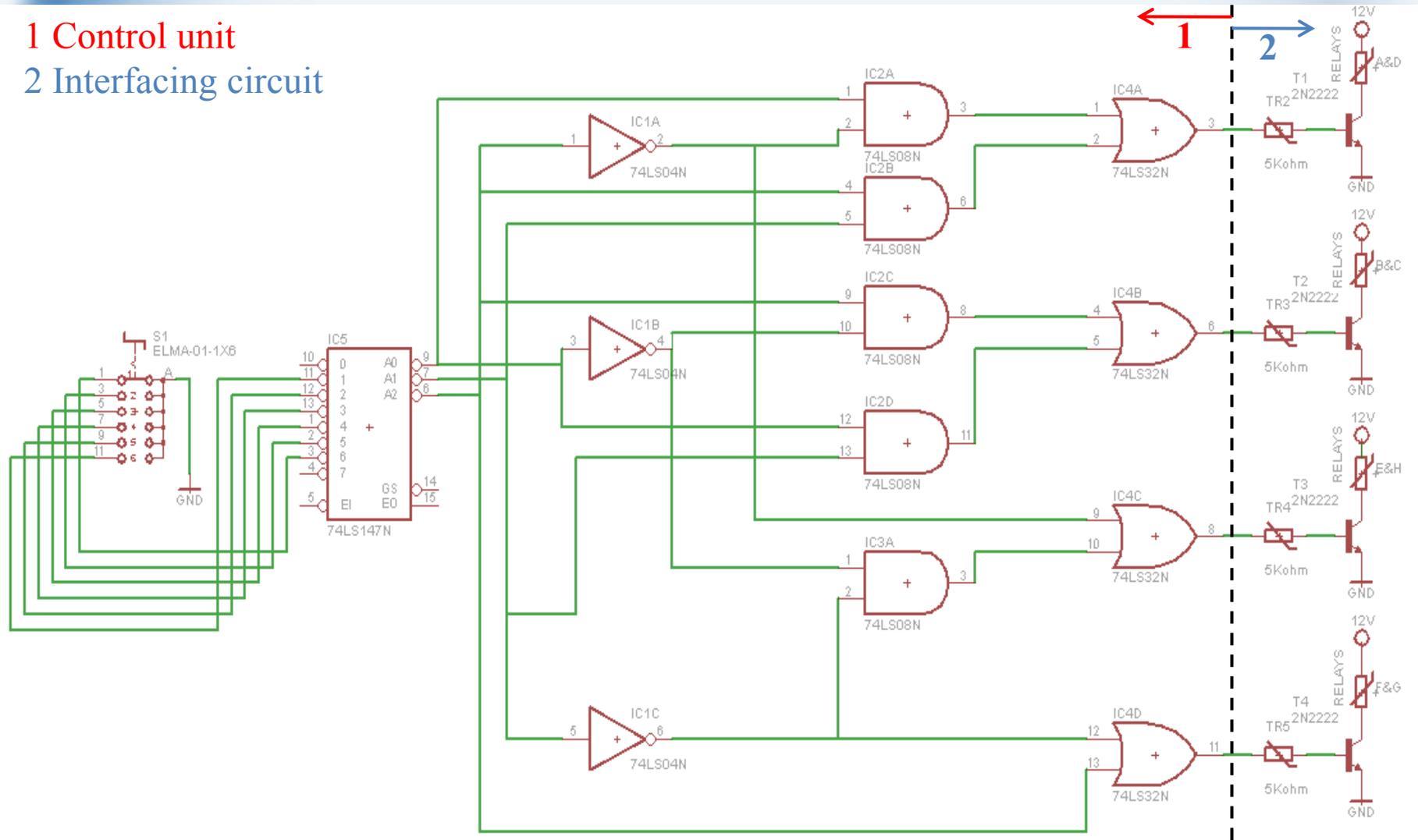
| | | | |
|-------|-------|-------|---|
| | | X_1 | |
| | | 0 | 1 |
| X_2 | X_3 | | |
| | 0 | 1 | |
| 0 | 0 | X | 1 |
| 0 | 1 | 1 | 1 |
| 1 | 1 | 0 | X |
| 1 | 0 | 0 | 1 |

$$F = X_1 + \bar{X}_2 = G \quad (4.15)$$

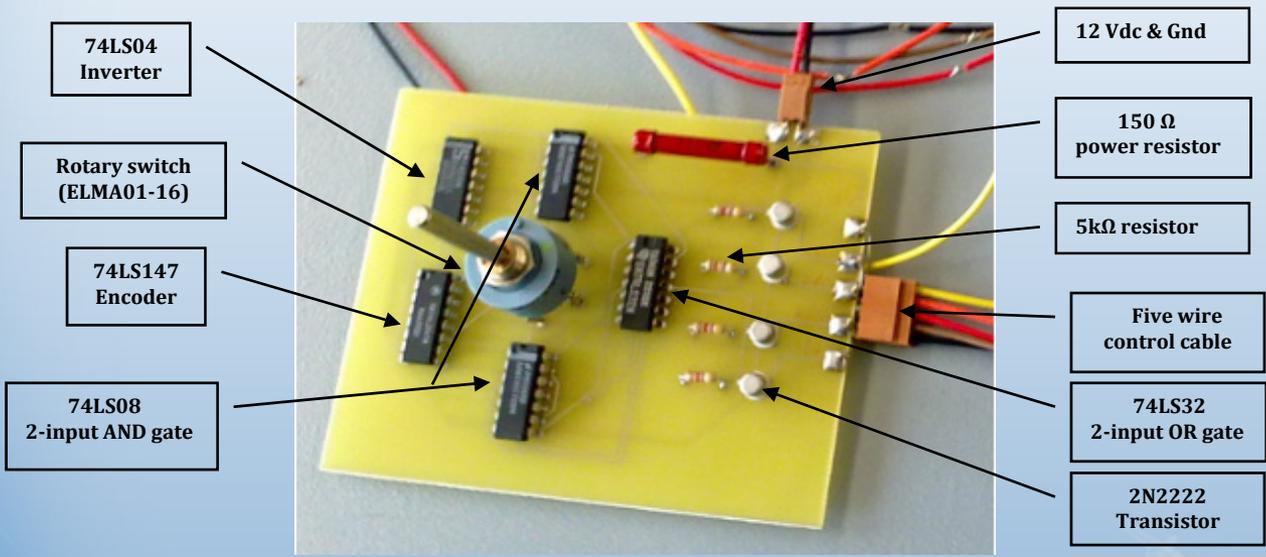
❖ Circuit diagram that combines the control circuit and the interfacing circuit

1 Control unit

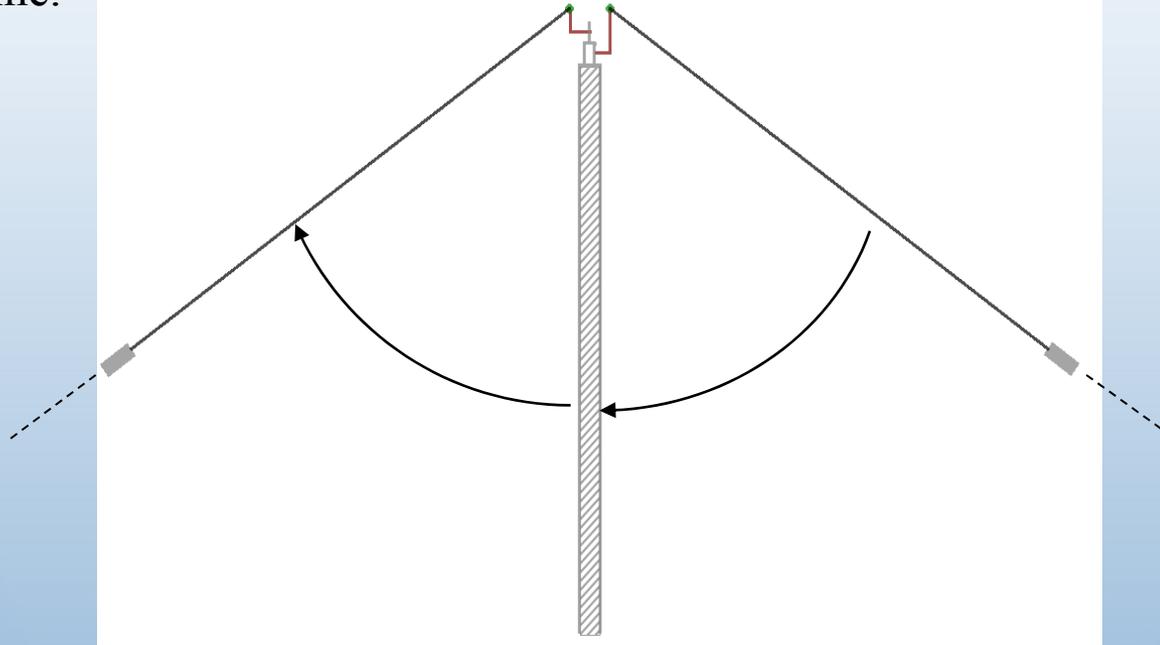
2 Interfacing circuit



❖ Remote control unit as appears in reality



- Baluns are special type of transformers. They are widely used in ham stations.
- Their primary function is to minimize the interaction of antenna with the transmission line.

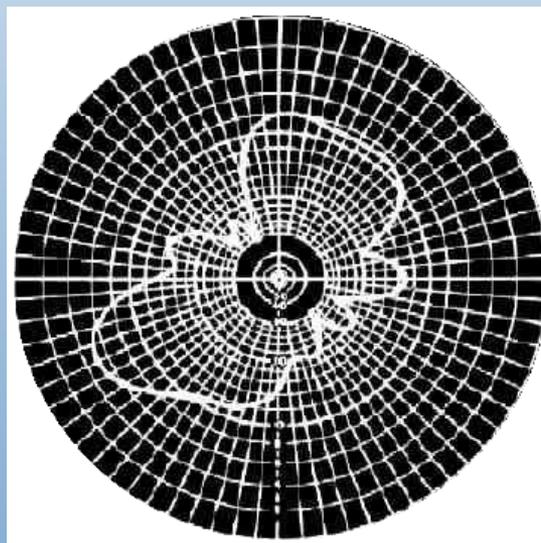
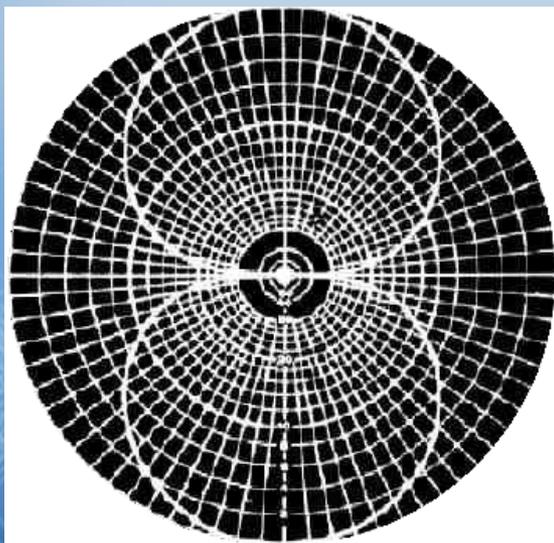
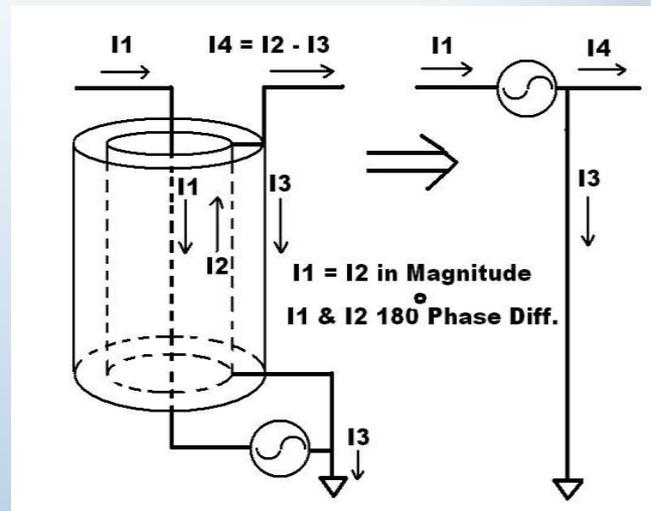


Field between antenna and coaxial cable creates an induced current on the outside of the shield.

- Choke balun is connected at feed point of antenna to decouple the feedline from the antenna by inserting high common mode impedance in series with feedline.
- High common mode impedance choke off unwanted RF-currents which try to flow on the common mode paths along a feedline.

➤ Effect of common mode current in antenna system

The common mode current formed on the outside of the shield would actually cause energy to radiate from the coax itself, making it appear to be part of the antenna.



The distorted radiation pattern due to the effect of common mode current

➤ Constructing Choke balun

- ❖ With winding number of turns of coax “RG 174” around Ferrite ring “FT240-77” we get a 50Ω , 1:1 choke balun.
- ❖ The 77 material provides excellent attenuation of RFI caused by amateur radio frequencies from 2 to 30 MHz.



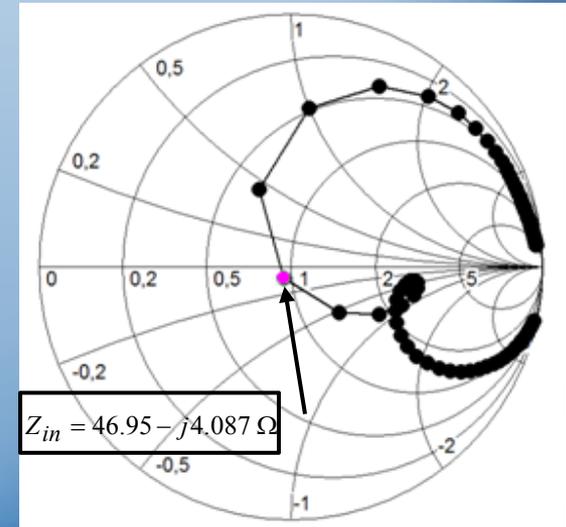
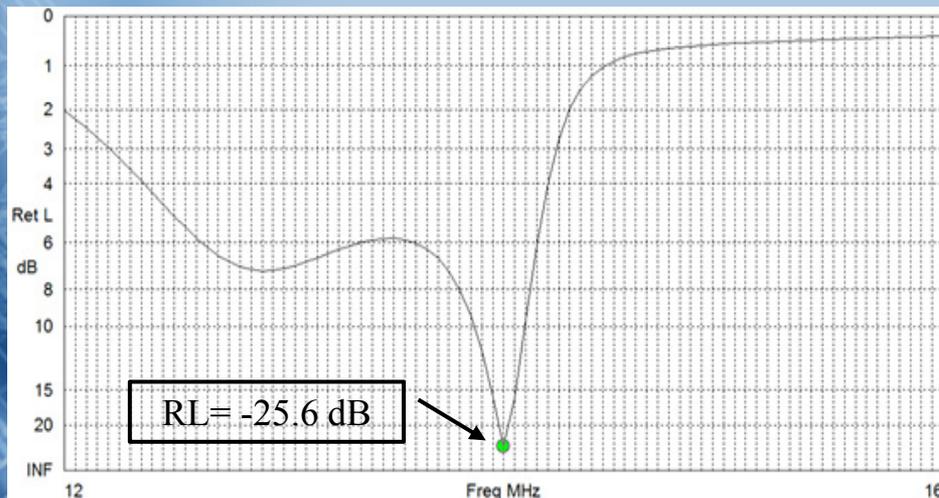
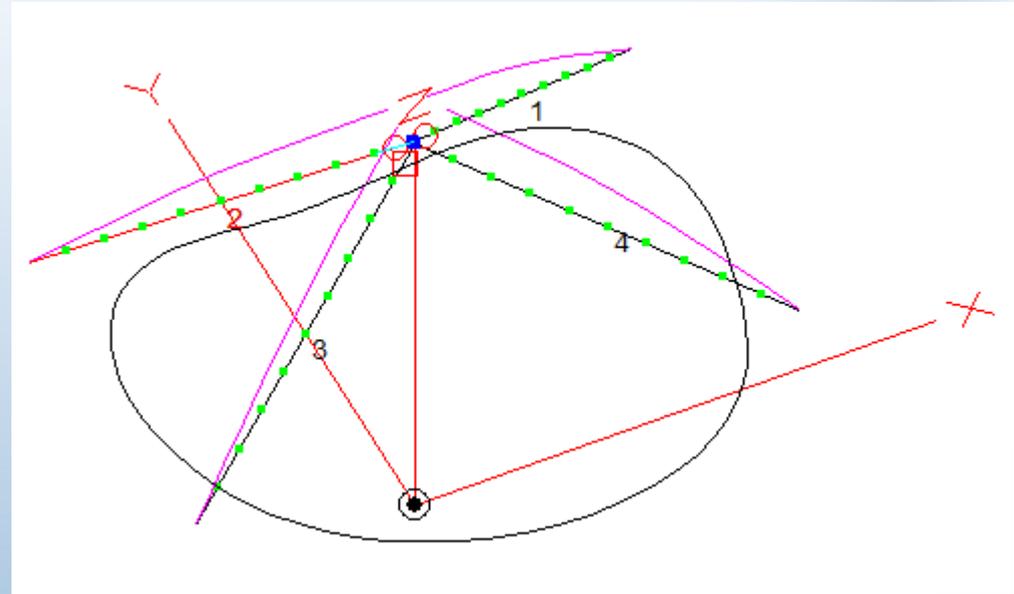
- ❖ The attenuation coefficient that achieves for common mode current is -23dB at 14MHz .
- ❖ The common mode impedance that will be inserted in series with feedline is about $900\ \text{ohm}$.

➤ A full function model for short-wave operation (14 MHz) is simulated and installed above perfect conductivity ground.

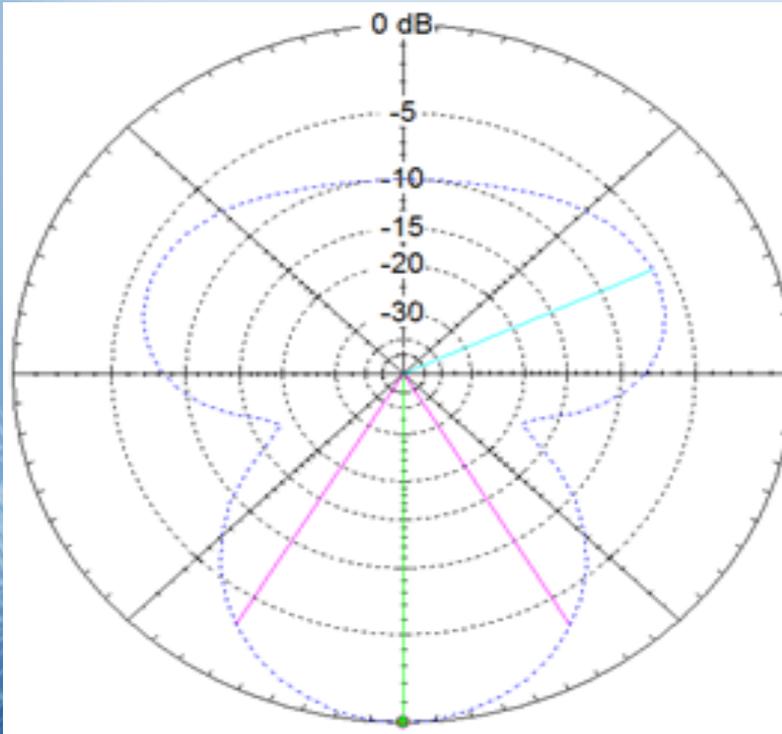
➤ Using insulated copper stranded wires with cross section of 0.14 mm^2

➤ The optimal length of conductors when inserting a capacitive load of 120 pF at the center of parasitic element is 5.6 m ($L \approx \lambda/4$).

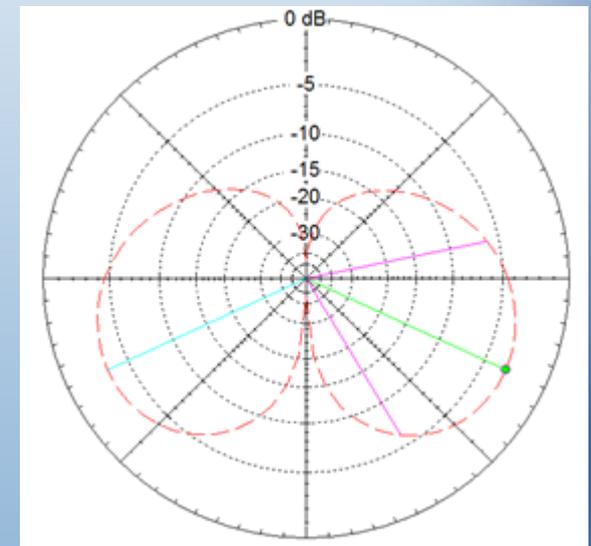
The geometry of antenna and typical azimuth pattern for 14 MHz operation.



- The maximum gain of main beam is tilted by about 45 degree above the ground plane and equal 7.44 dB_i
- HPBW = 61.5 degree
- F/B pattern ratio = 10 dB
- F/S pattern ratio = 6 dB
- Due using copper wires, our model contains losses estimated to be 1.31 dB.
- 0.8 dB losses due coaxial cable

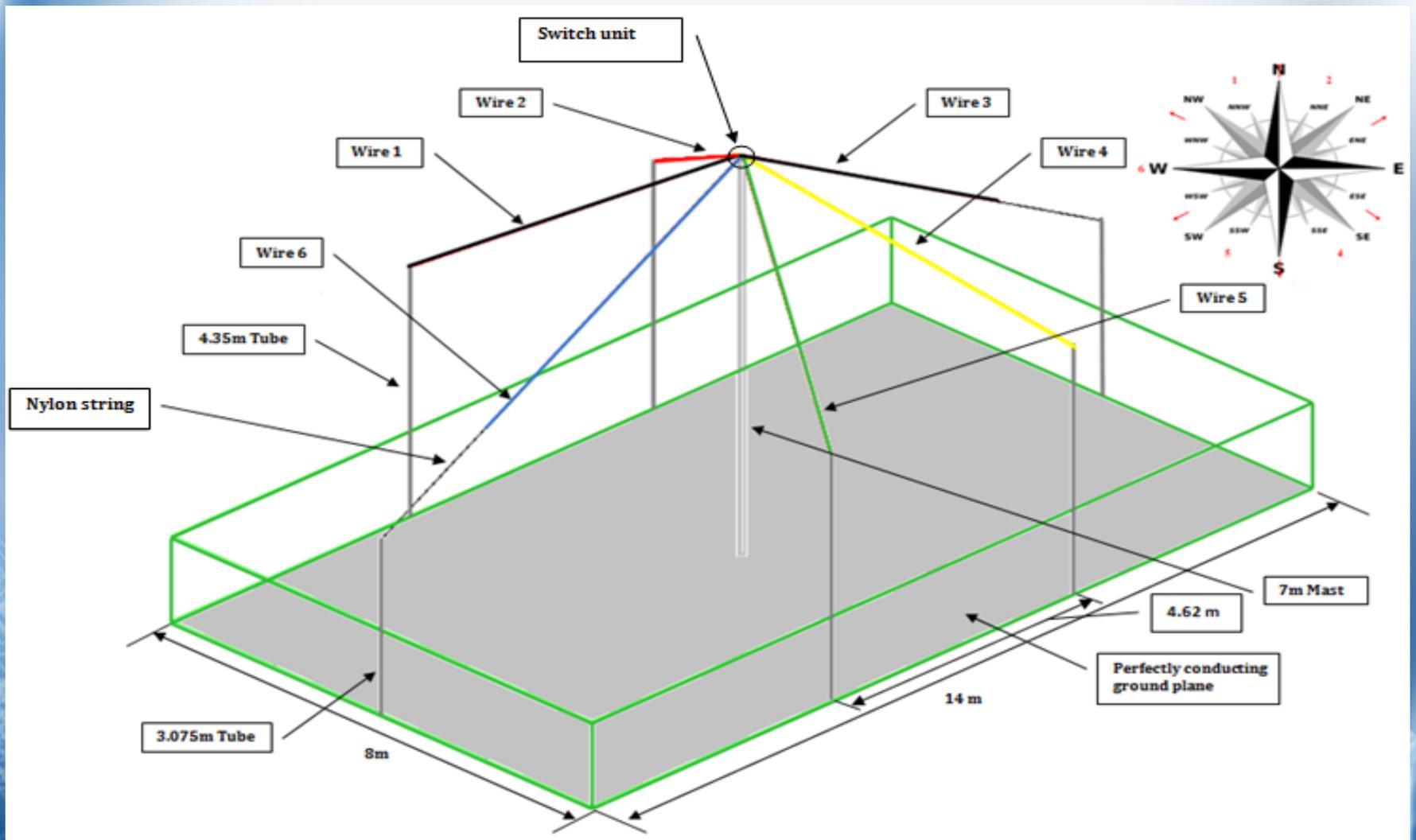


Simulated horizontally polarized radiation pattern

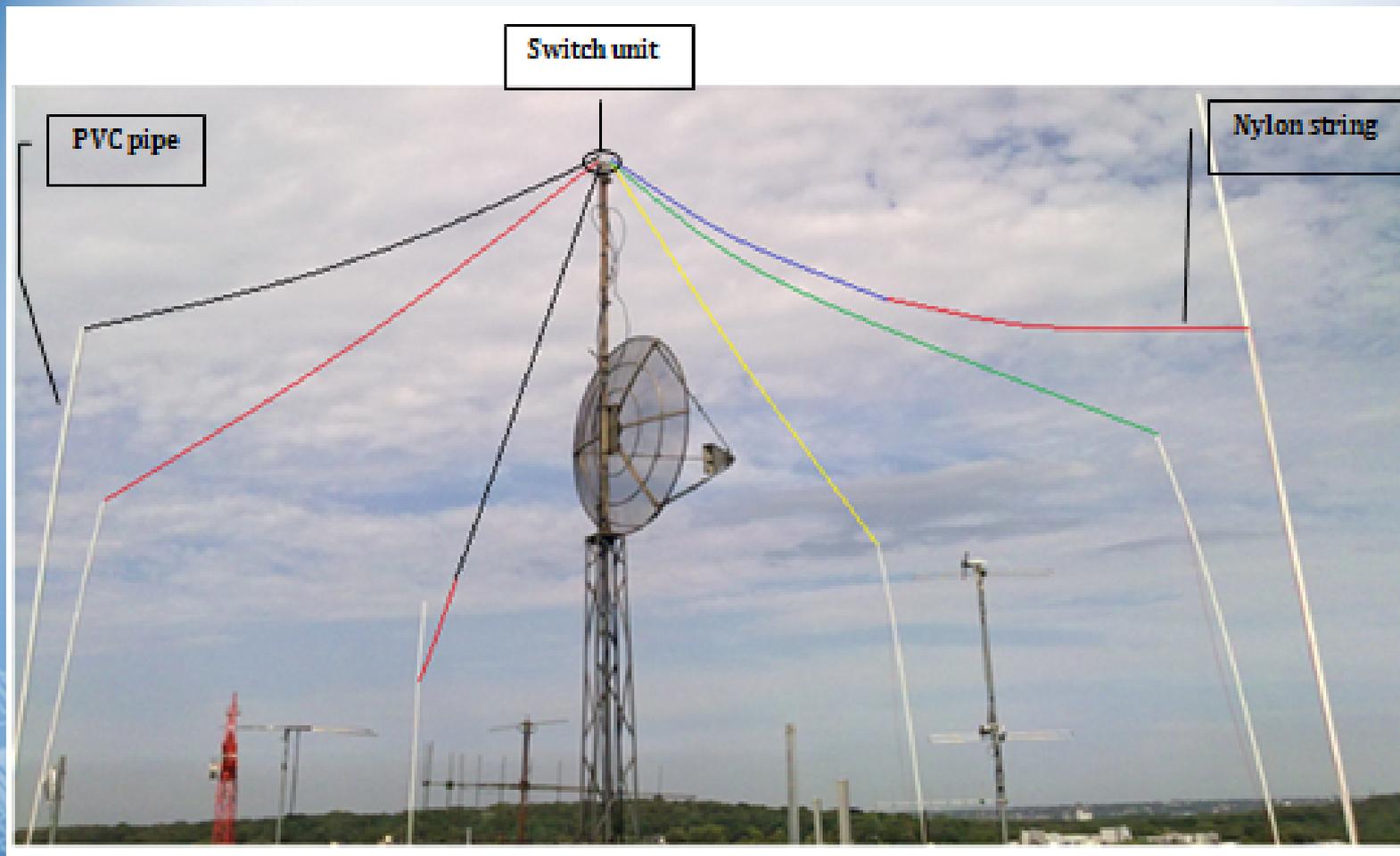


Simulated vertically polarized radiation pattern

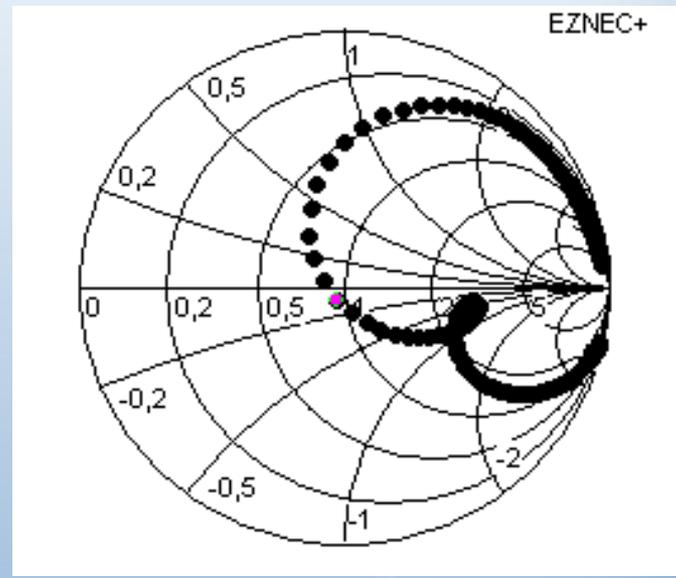
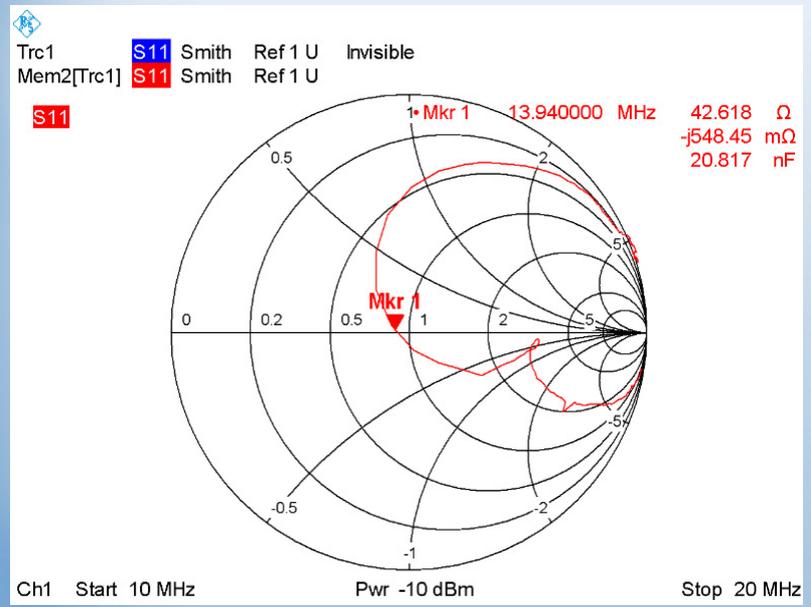
- The maximum gain of main beam is tilted by about 65 degree above the ground plane and equal 4.4 dB_i



A scale drawing of antenna model placed on the platform



Our antenna model as seen above the roof platform of BB-building from the southwest side. For better visibility, the dipole wires have been colored.



Measured and simulated smith chart graphs

- The 3-element rotary beam antenna represents a high gain antenna rotated mechanically by using a rotator system
- The antenna is set at a 3m height above the roof platform.

➤ A comparative test has been done at 14MHz between both antennas and showed that the received signal strength by both antennas are almost the same.



The 3-element rotary beam antenna

- A novel switched beam antenna with omni-directional coverage and high gain has been developed.
- A special remote antenna switch system has been constructed in order to steer the beam over a beam scan angle in azimuthal increments.
- The six-beams that are obtained from the different antenna arrays are located at where the 3 dB-beam widths are about 60 degree.
- At 1 GHz the measured radiation pattern in the azimuth plane shows a good correlation with the theoretical prediction.
- At 14 MHz the antenna array yields over its entire beam scan range a gain of 7.5 dBi, a VSWR of 1.11, beamwidth of 61.5 degree and a front to back ratio of 10 dB. The bandwidth of the array is 1.71 % for a VSWR<2.

Thank you for your attention

