2-element Single Mast Wire Beam with 4 Switchable Directions

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We need a directional antenna field day style for 20 m band. The requirements are:

- single mast wire beam
- light weight feeder
- impedance that will be in the range of the automatic tuners of the modern transceivers
- switchable directions

The single mast requirement obviously led us to elements with inverted V configuration. After trying several models in MMANA *[3]* the result was that it is possible to obtain acceptable directional properties with two opposite placed sloped inverted V but the antenna impedance was quite low due to the closely spaced elements.

Fortunately we found out that there is a solution published by DK3BA - an article in QST *[1]* where a 2-element beam switched in 6 directions was described. We implemented this design but only for 4 directions in order to simplify the switching. A model for 20 m band was tested in MMANA and NEC2 *[4]*. The antenna is shown on ***Fig.1*** and ***Fig.2***. It consists of 4 equal length sloped wires which are connected as two inverted V opposite elements. The beam consists of a driven element and a director. The inverted V that takes a role of a director is shortened with capacitor (***Fig.1)***. The wire used is bare copper (or magnet wire). Insulated wire was not used since we cannot predict the effect of the wire insulation in the model. The antenna is placed on top of a 12 m mast. The antenna behavior is sensitive to wire slope angle and should be duplicated as exact as possible according to the drawings.

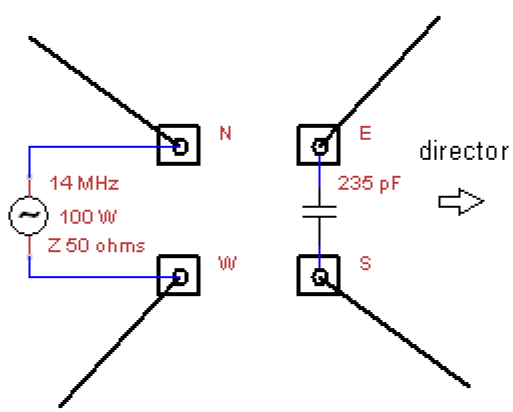

Fig.1 *Top view of the 2-element inverted V . The example geographic directions of wires are denoted with N, E, S, W. The direction of the radiation (South-East) is shown with an arrow. Changing the feed point between e.g. N and E and capacitor between W and S will change the radiation direction to S/W.*

Antenna

The length of each wire is 5.47 m with 1.2 mm bare copper (or magnet wire) ***Fig.2***. The design center frequency is 14.1 MHz. Keeping the size of the antenna footprint and the mast height will guarantee proper angles between wires. The area occupied by this antenna is shown on ***Fig.3*** where the antenna rope ends are denoted. The design goals were to use minimal area and this model is a compromise between the occupied area and the antenna impedance. We tested 45° slope but the antenna impedance becomes quite low. The proposed antenna has impedance which is close to 50 Ω and the bandwidth (SWR 2) is about 200 KHz. A 50 Ω coaxial cable can be used but it is very heavy so we decide to use 300 Ω twin cable. In order to reduce the feeder losses a 3:1 transformer was used between the antenna terminals and the feeder. It gives 9:1 impedance transformation ratio which is acceptable for 300 or 450 Ω twin feeders.

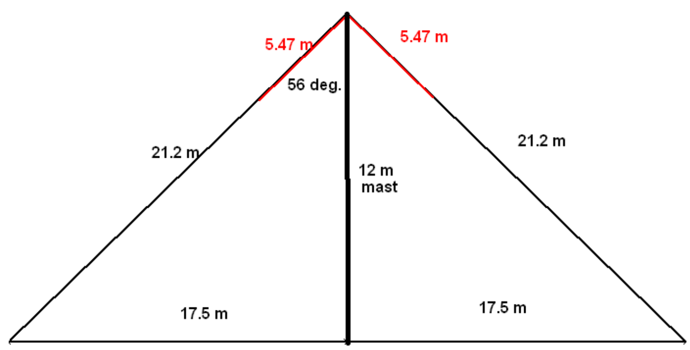

Fig. 2 *Side view in the plane of two opposite wires. The angle between mast and the wire is 56° . The total length of the wire plus the rope is 21.2 m.*

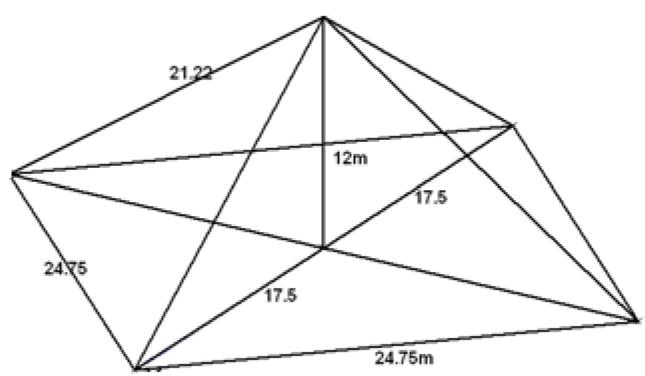

Fig. 3 *Occupied area of the antenna. A square of 24.75 x 24.75 m is needed for the antenna ropes.*

Switching

At the mast top there is a small board with 4 relays and transformer (***Fig.7*** and ***Fig. 8***). There are two connectors – for the feeder and for the control cable.

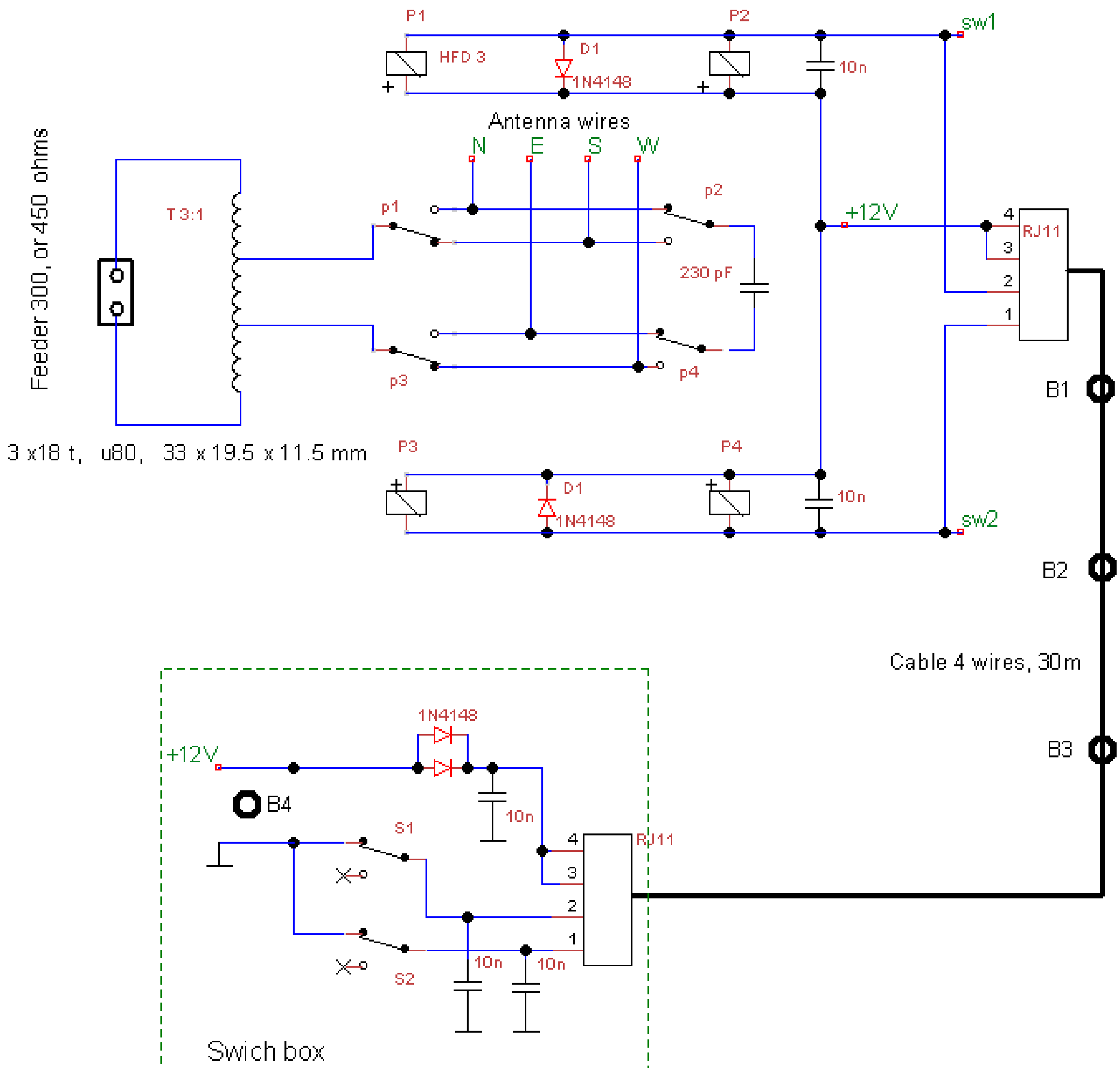

Fig. 4 *The schematic diagram. SPST switches are used for direction change but also a rotary switch can be used. The control cable is RF split by 3 small common mode baluns B1 – B3.*

	P1	P2	P3	P4	S1	S2
NE	0	0	0	0	Off	Off
SE	1	1	0	0	GND	Off
SW	1	1	1	1	GND	GND
NW	0	0	1	1	Off	GND

Fig. 5 *Relay and switch truth table. 1 means energized relay.*

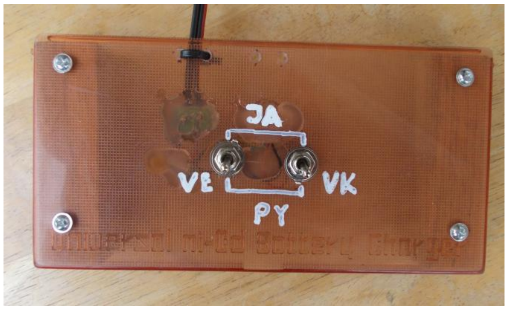

Fig.6 *Switching box*

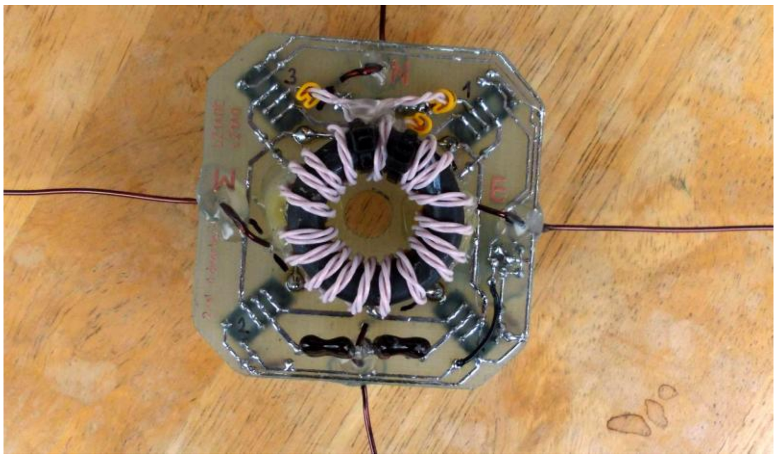

Fig**.**7 *Top view of the relay board. This board is inserted onto the top of the mast. The DPDT relay contacts are connected in parallel. The transformer is fixed with hot glue. The capacitor consists of two serially connected 470 pF silver-mica capacitors. The antenna wires (1.2 mm magnet wire) pass through additional openings to reduce the strain on the soldered joints.*

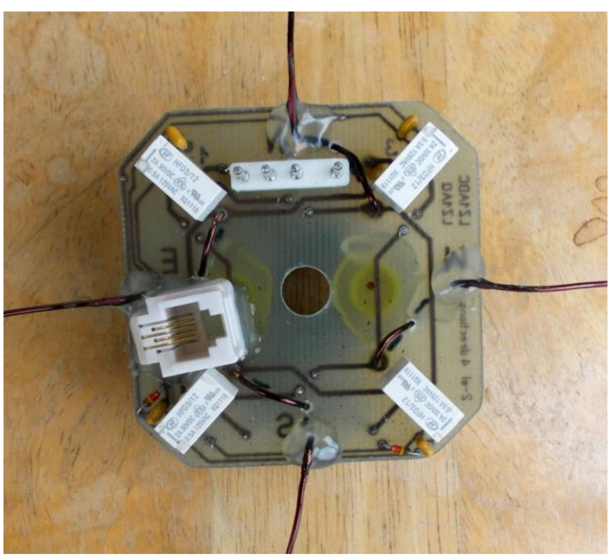

Fig. 8 *Top bottom view of the PCB which holds the relays and the transformer. The control cable is connected to RJ11 connector. A power supply type connector is used for the twin lead cable.*

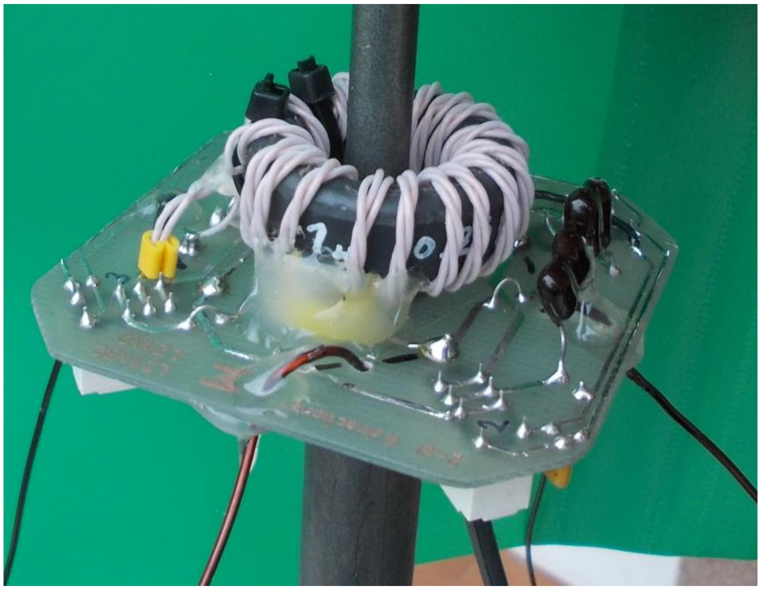

Fig.8a *The transformer. The board is inserted into the top of the mast.*

RF Transformer

In order to use 300 Ω or 450 Ω feeders a transformer is needed. The 3:1 transformer is wound on toroidal core 33 x 19.5 x 11.5 mm (***Fig.8a***) . The core is ferrite with u=80 taken from old military equipment.18 twisted trifilar turns with Teflon insulated stranded wire were wound. Since the core parameters were not known we measured the Q-factor of one of the windings at 14 MHz - it was 120. Then we measured the balun losses with signal generator and power meter - approximately 0.25 dB. At 100 W RF power the losses will be 6 W. This core is not very suitable for this purpose but that was found in the junk box. It is better to use iron powder core. We will suggest using the popular T130-2 with 18 to 20 trifilar turns. It has approximately the same size. According to some calculations the losses at 100 W will be in order of 0.5 W. Probably such a transformer can be used safely up to 500 W RF power.
A 50 Ω coaxial feeder can be connected directly to the antenna feed point but then additional 1:1 common mode balun must be used. Here the requirements for the core are different. Ferrite cores with 43 or 31 material must be used with as much windings as possible. For example 6 turns with thin Teflon coaxial cable on a ferrite core with a similar size will have impedance above 3 KΩ on 14 MHz which is a good value.

Feeder

We used symmetric 300 Ω twin lead feeder. In order to have predictable impedance at the feeder end we used lengths multiple of 8.5 m which is ½ wave length (the velocity factor is 0.85). For practical reasons our cable was 25.5 meters which is a comfortable length to reach the nearby car where the transceiver was located. This length is not critical; ±1 m will still give acceptable match impedances for the antenna tuner. Do not permit the symmetric feeder to lie on the ground - this will increase the losses.

Control Cable

4- wire standard lightweight telephone communication cable is used for antenna control. RJ11 connector is the natural choice. The control cable has 3 common mode baluns (B1,2,3 on Fig.8) in the part that is close to the antenna. They are spaced approximately at λ/4 distance. The reason is to avoid parasitic resonances of the cable that might influence the antenna radiation pattern and also to reduce the interactions with the symmetric open wire feeder. This might be not entirely necessary but in any case will do no harm.

B1, B2, B3 baluns: 3 turns on 3 cores, 16 x 9.5 x 6.3 mm, u=2000, 3F3 material. The distances from the top of the mast are B1 1m, B2 6 m, B3 11 m.

Fig.9 *Control cable with common mode balun*

Capacitor

The capacitor value must be 235 pF. We used two serially connected 470 pF silver-mica capacitors with 500 V working voltage each because we do not have suitable single capacitor in our junk box. Low loss ceramic capacitors also can be used. The voltage across the capacitor depends from the power. At 100 W RF power the peak voltage will be approximately 100 volts at 50 Ω load. At this power NEC2 gives approximately 2.0 A peak current in the director wires. At this frequency 235 pF has 49 Ω impedance, so approximately 100 V peak voltage will develop between the capacitor terminals.

Relays

We used 12 volts signal relays HFD3 (*Hongfa*, http://www.hongfa.com/pro/pdf/HFD3_en.pdf) which maximal current is 2 A per contact. The relays are DPDT so we connected in parallel the two contact systems reaching 4 A maximal current. A similar to HFD3 relay is IM6 from Axicom which can be find in all major electronic components distributors.

At 100 W RF power according to NEC2 model, the RMS current values in the wires will be between 1 A and 2 A. It is difficult to say how much RF current can flow through these relays since the catalogue data are for low frequency or DC current. The good thing is that here we do not have “hot” switching which is the main reason for contact damage. The voltage stress at the relays is small. We can expect maximal voltages between open contacts not more than 100 – 150 V at 100 W RF power. HFD3 limits are 1000V between contacts and 2000 V between contacts and coil. These types of relays probably can withstand 200 – 300 W max RF power and the limitation will be the current requirements not the voltage limitations.

Balun at the feeder output

Our tuner is unbalanced so we used 1:1 current balun (***Fig.10***) between the feeder and tuner input. The balun has 17 bifilar turns on high mu core (similar to 43 material). It is connected with short coaxial cable to the antenna tuner.

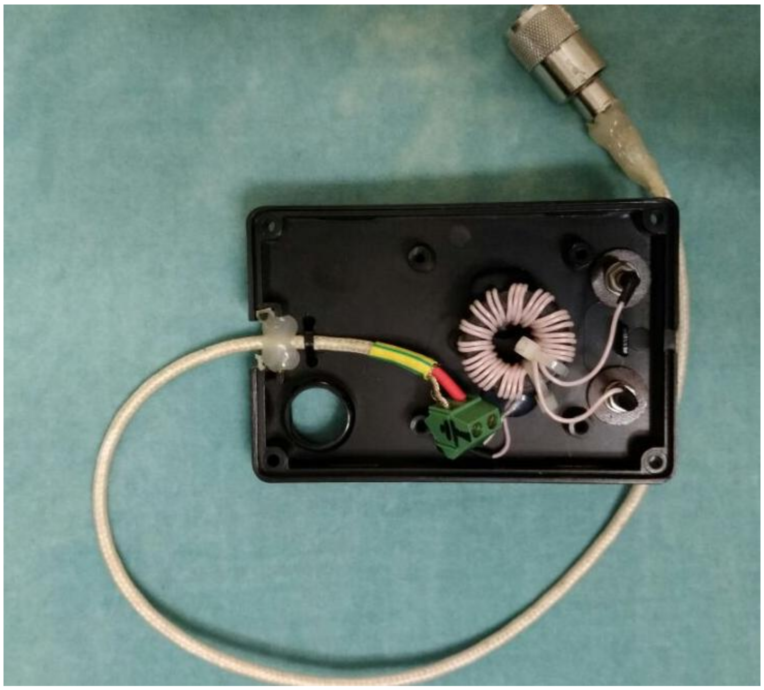

Fig.10 *Balun at the feeder output*

Losses

We estimated theoretically the losses in the system: 0.3 – 0.4 dB in 25.5 m feeder; 0.2 – 0.3 dB in the transformer; 0.2 – 0.3 dB in the antenna tuner. The total losses are in order of 0.7 - 1 dB - which is quite acceptable.

Erection of the antenna

The erection of the antenna for the first time took about an 1 hour (two people). If two or three persons are involved and the guy ropes are prepared, the erection will take probably not more than 15 minutes. At the beginning we tried to erect the mast only with the antenna ropes which are tied to the wires but the construction was unstable. So we added three guy ropes each at 120°, 4 m below the top of the mast.

Needed materials:

- Antenna system – prepared as shown on ***Fig.11***. The relay board has an 8mm hole in the middle so that it can be slid onto the top element of the mast and fixed approximately 10 cm below the top.
- Fiberglass mast - 12m length; 12segments; top segment has diameter of 8mm (Spiderbeam, *[2])*

- Plastic plate with a hole at the center and 3 holes on the sides for the guy ropes. The central hole diameter depends on the height where the guy ropes must be placed.
- 7 wooden pegs for guy ropes and antenna ropes
- 3 guy ropes for the mast
- 4 antenna ropes ; thin ropes for the 4 antenna wires
- A wooden pole; the base of the mast is tied there .

Fig. 11

Erecting algorithm which worked well for us (a single person is required):

First of all we erect the mast using only the guy ropes (without the antenna). The idea is to determine the exact length of the three guy ropes and fix the mast to the central wooden pole. This will allow us when erecting the entire antenna to extract the mast sections, directly from vertical position. We do this because the relay board makes the top of the mast heavy. If we try to raise the antenna with an already extracted mast which is lying on the ground, we might break it or at least we will need a second person.

1. Mark the end points of the guy ropes (at 120°) and insert 3 pegs there.
2. Prepare two equal guy ropes with the calculated length -the third rope must be slightly longer
3. Extract the mast to full length on the ground.
4. Slide the plastic plate with 3 guy ropes onto the mast. ***Fig.12***
5. Tie the two equal length guy ropes to the pegs. The third guy rope is left open.
6. Erect the mast and fix its base temporarily at a place where the two guy ropes tightly support the mast. Then holding tightly the third guy rope, fix it to the third peg. This is an adaptive procedure which will allow finding the proper mast center without the need to make precise measurements. Now, the mast base point is determined and we can insert there the wooden pole into the ground and fix the mast to it permanently. The mast is now in vertical position, secured by the three guy ropes.
7. Retract the mast while in vertical position without removing the guy ropes.
8. Mark the four end points where the antenna ropes will be tied (***Fig.2***, square 24.75 x 24.75 m). Use a measurement rope with 17.5 m length for this purpose. Insert into the ground four pegs. These distances are important since the antenna slope depends on them.

9. Mount the relay board to the top of the mast (***Fig.13***) - you can use rubber tape to prevent the relay board from sliding down. Don't forget to connect the control cable and the feed line.
10. Fix the feed line and the control cable with tape to the mast so that there is no tension on the connections. Tie the antenna ropes to the four wire endings. Extract the mast.
11. While extracting, tape the control cable to the mast. Once the mast is fully extracted guy ropes should keep it straight.
12. The feed line should be kept away (at least 5 – 10 cm) from the control cable to avoid interference.
13. Tie the antenna ropes to the corresponding pegs making the antenna wires tight.

Fig.12

Fig. 13

Preliminary Results

The antenna was tested in field day style on WPX SSB contest 2017 by SP/LZ1ABC from Poland (SP6). The location was in a park near the city center of Wroclaw. The antenna was assembled and disassembled both days during the contest. We used an old FC 700 manual antenna tuner which has limited possibilities to match a wide range of antenna impedances. The tuning was easy and in the mid range of the tuner capacitors which means that the impedances are "good" and confirmed our design considerations. More than 150 KHz of bandwidth was possible without a need to adjust the tuner settings. Most of the antenna tuners can easily match impedances in order of 300 ±j(0 to300) Ω with very low losses. It was not possible to measure precisely the front-to-back (F/B) and front-to-side (F/S) ratios, but the fast switching of directions is very convenient and rough estimation of F/B is very easy. For DX stations (W, JA) the F/B was in the order of 3 to 5 S units. The F/S ratio was also good. The antenna behavior was as any normal beam antenna and we worked a lot of DX stations with 80 W output power. There are videos on Youtube demonstrating the effect of antenna directions switching [*4, 5]*.

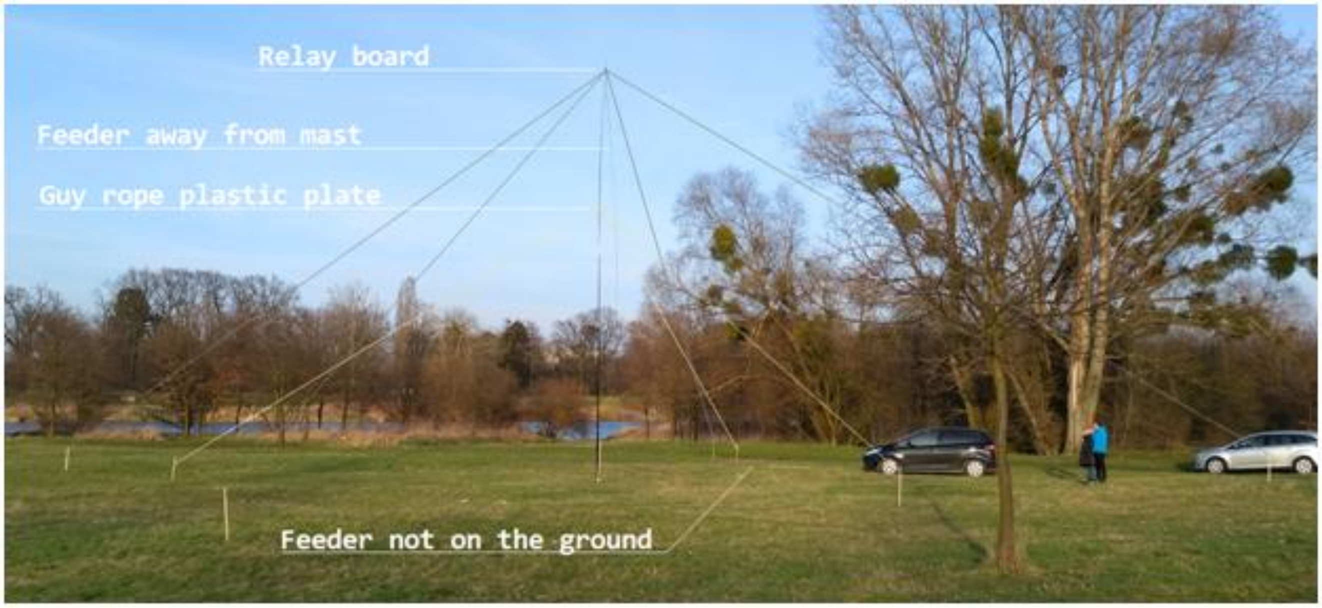

Fig.14 *The erected antenna*

Appendix Antenna Model

The MMANA model can be loaded here *2el_InvV_LZ1ABC.maa* .The radiation patterns for several frequencies are given below (***Fig. 15 to 18***) . They are from NEC2 model which gives more realistic antenna impedances. Real ground setup is average Eps=13, Sigma= 5. Height is 12 m. The average antenna gain is 9.5 dBi at 27° elevation angle and F/B ratio is between 8 to 20 dB from 14.0 to 14.3 MHz correspondingly. The gain is approximately the same as a hex beam at the same height. The next figures (***Fig.19, 20***) are Z and SWR plots from MMANA model.

We tested also a model when all wires are horizontal. With the same capacitance of 235 pF the wire length must be 5.40 m. This 2-element beam version has wider SWR= 2 bandwidth of almost 300 KHz and average gain of 10.5 dBi. It has 3 very deep nulls at 180° and +- 70° (***Fig.21***) Also the low angle radiation is much better. This is very interesting solution since we have 2-element beam without boom which might happened to have a very simple and strong mechanical construction.

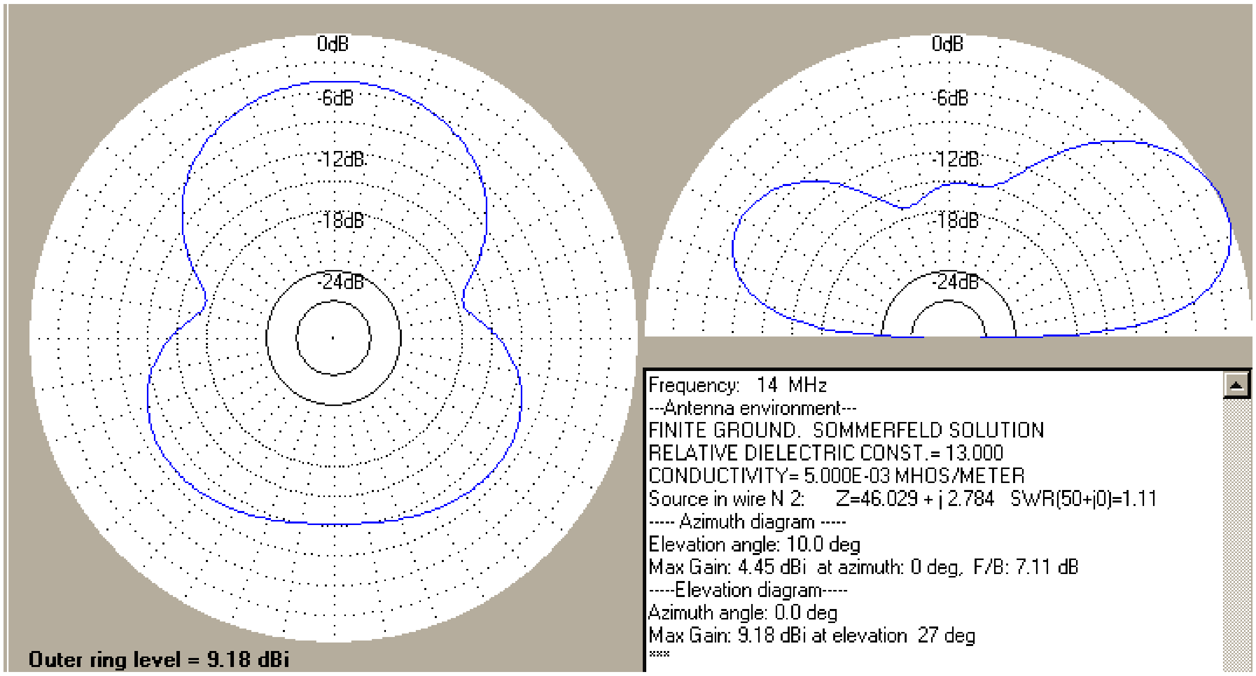

Fig.15 *Radiation pattern at 14.0 MHz at 10° elevation angle*

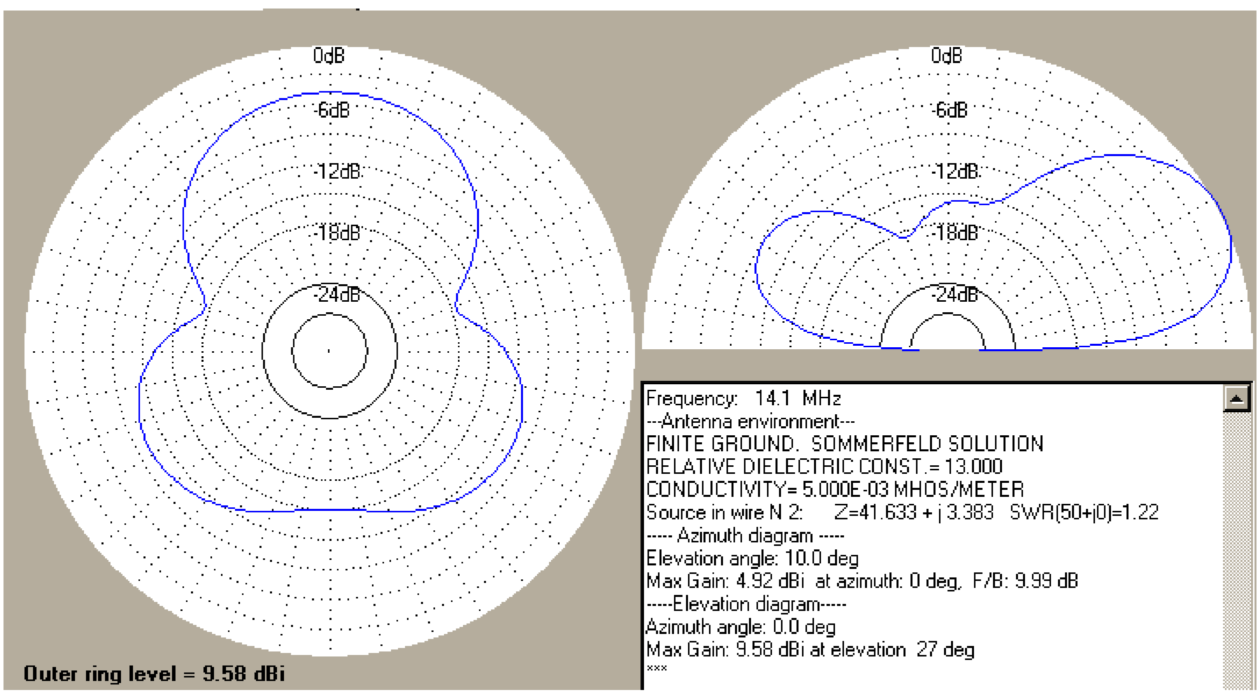

Fig.16 *Radiation pattern at 14.1MHz at 10° elevation angle*

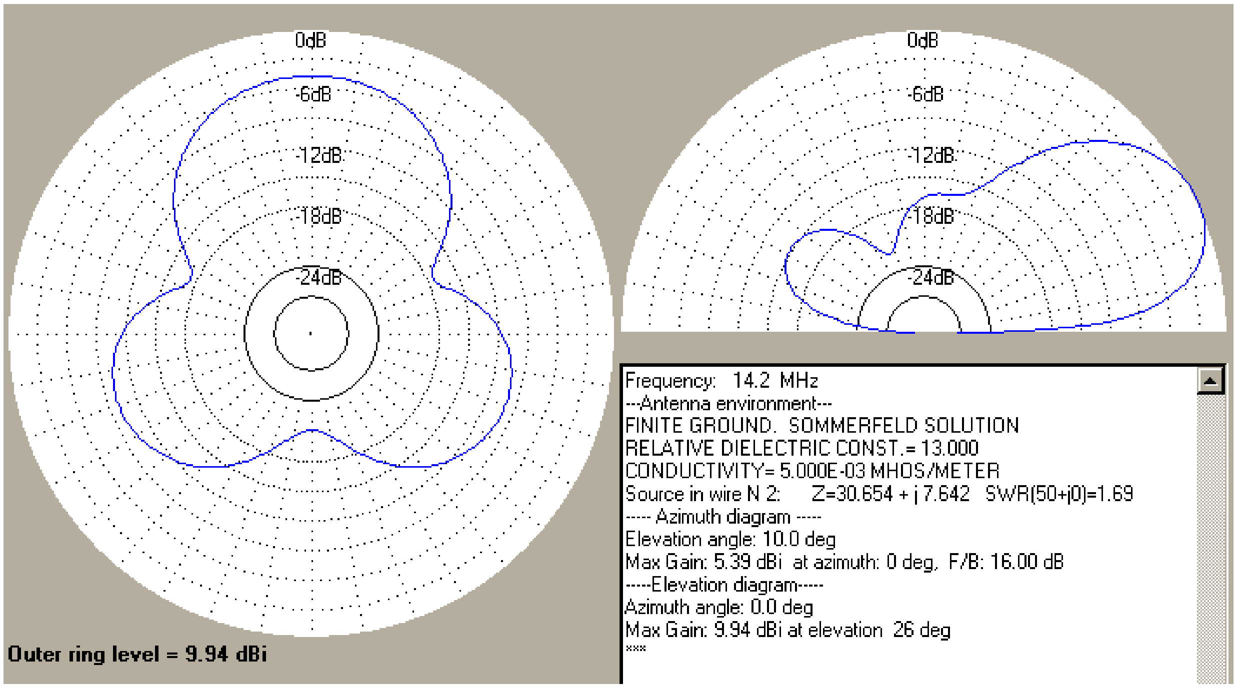

Fig.17 *Radiation pattern at 14.2 MHz at 10° elevation angle*

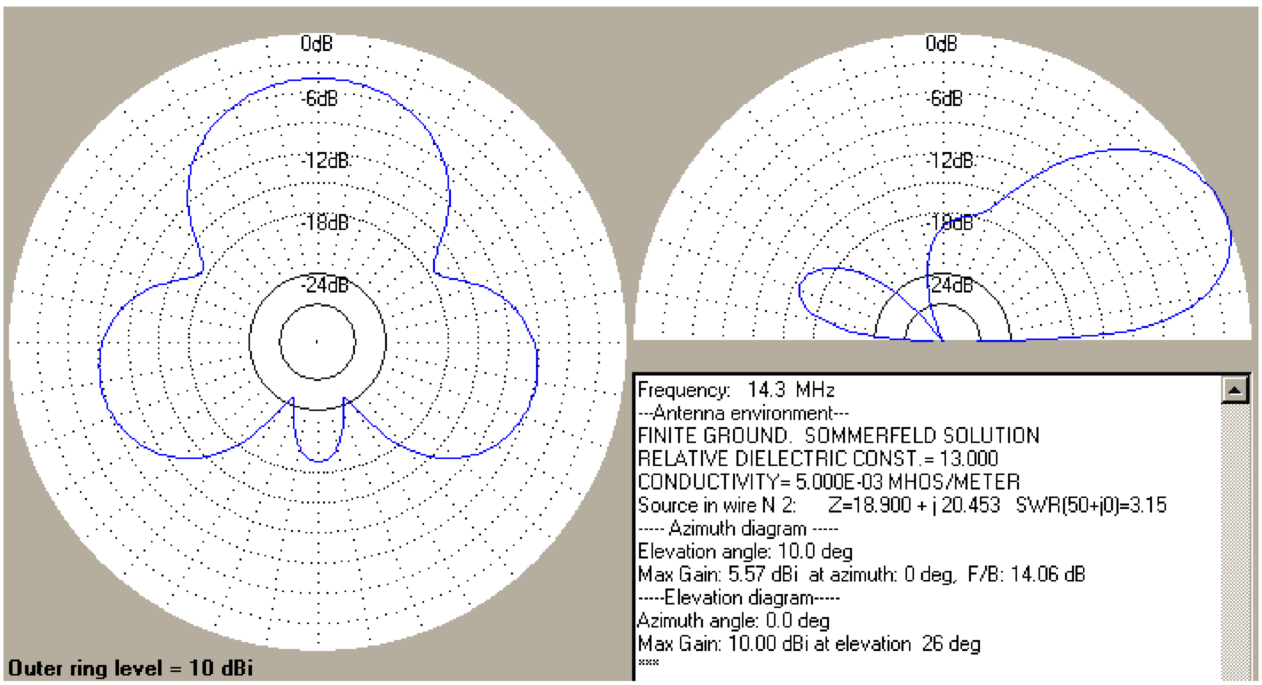

Fig.18 *Radiation pattern at 14.3 MHz at 10° elevation angle*

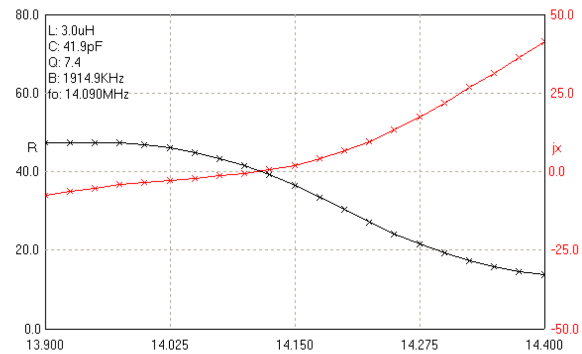

Fig.19 *Antenna impedance Z*

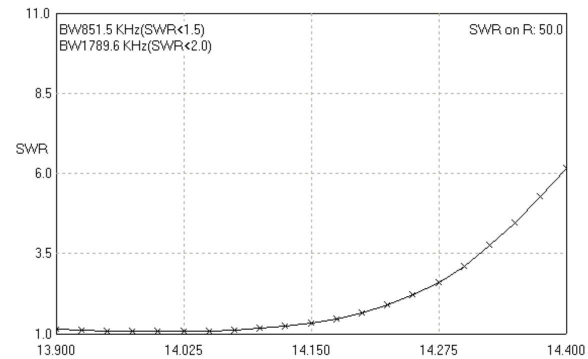

Fig.20 *SWR for 50 Ω*

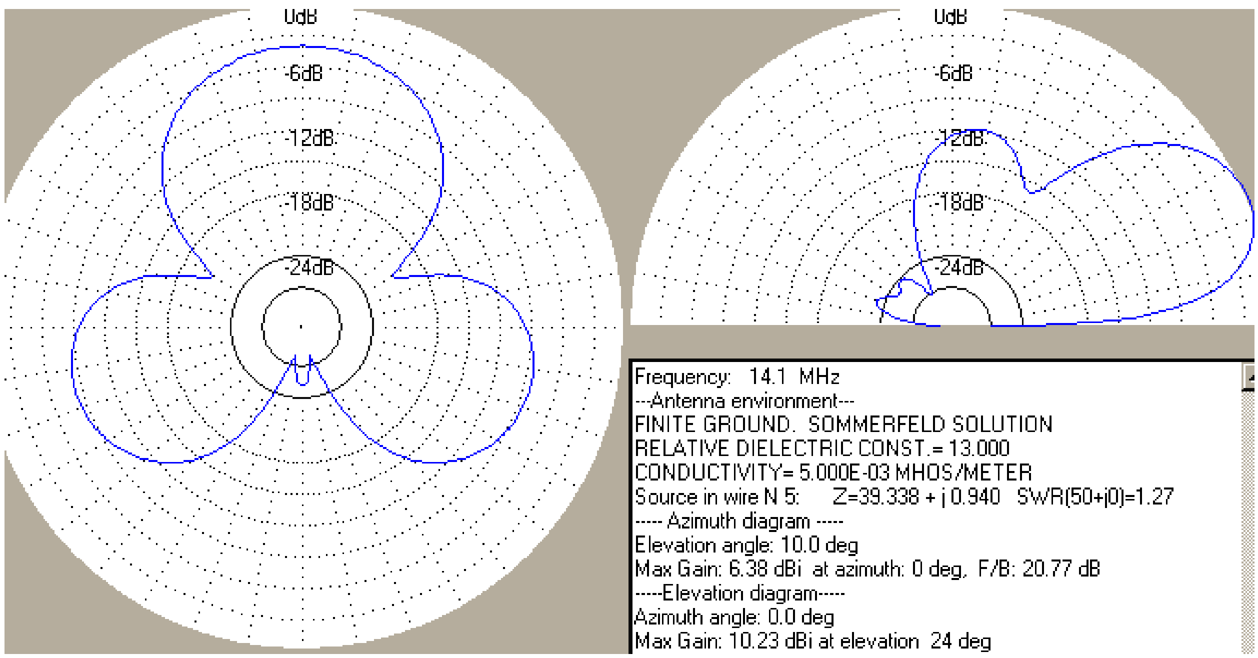

Fig.21 *Radiation pattern of the beam at 10° elevation angle with horizontal elements at 14.1 MHz, 12 m height. Compare it with Fig.16 where sloped beam pattern is shown.*

Comments

One of the problems with this antenna is that at the region of its best directional properties the impedance becomes low and more reactive. When an antenna tuner is used, this is not a problem but with 50 Ω feeder the usable bandwidth is limited to 200 KHz as noted in the original publication *[1]*. This impedance change can be swallowed easily by the most automatic antenna tuners allowing full band coverage.

In case we want to use mostly CW part of the 20 m band we can add 5 cm wire tails to all slopers keeping the same value of the capacitor.

In the original publication 6 wires were used with direction steps of 60°. We choose 4 directions since we want to keep things simple. What we lose is shown on ***Fig.22*** - there is a gap at 45° zone where the gain reduction is between 2 to 4 dB.

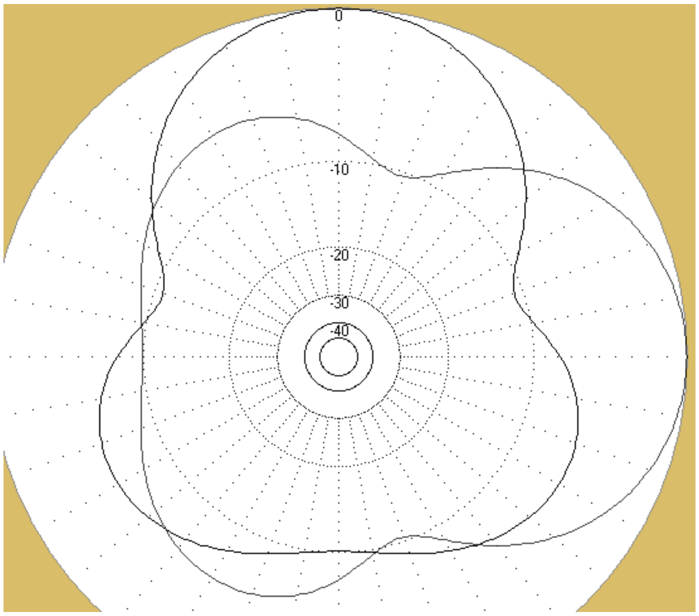

Fig. 22 *Pattern overlap between 90° rotated directions.*

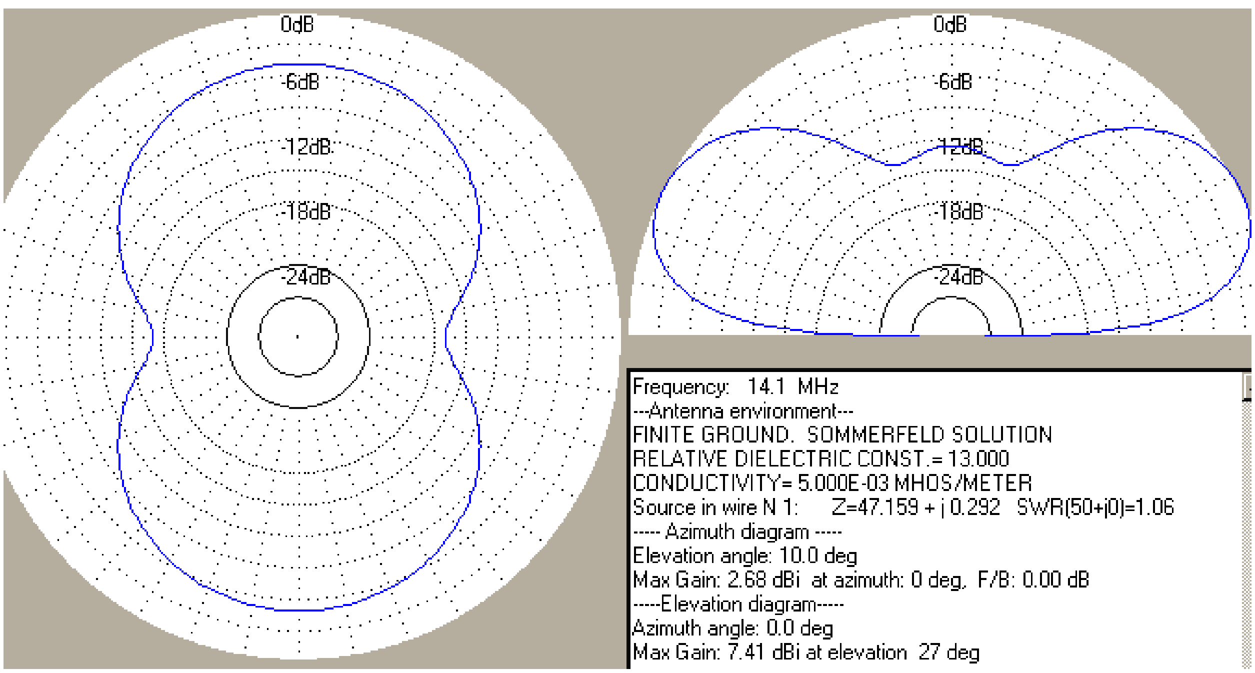

Fig.23 *Radiation pattern of a single inverted V dipole at 14.1 MHz at 10° elevation angle*

One reasonable question is what is gained with this design compared to an ordinary inverted V dipole at the same height and with the same wire angles? On ***Fig. 23*** is given its radiation pattern. To have all directions we must have two inverted V dipoles rotated at 90° to each other and to switch them with at least one DPDT relay. So the answer is: With 3 additional relays we will have almost twice TX directional power and much better RX antenna.

March 2017

Links

[1] Ashraf Abuelhaija , Klaus Solbach, DK3BA, Inverted V Wire Yagi with Switchable Pattern Rotation for 14 MHz, QST, December 2011
http://hft.uni-duisburg-essen.de/amateurfunk/Abuelhaija_Inverted_V_Wire_Yagi.pdf
[2] Fiberglass poles http://www.spiderbeam.com
[3] MMANA-GAL http://hamsoft.ca/pages/mmana-gal.php
[4] NEC for MMANA http://www.qsl.net/ua3avr/
[5]Youtube video https://youtu.be/cCRHnCGa7O4
[6] Youtube video https://youtu.be/DUrAPMrfz1Y