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Weatherproof UHF & microwave cavity antennas

Matjaz Vidmar, S53MV

Contents

For a long time now subscribers have been telling me that the quality of the artwork is poor. I have tried to improve the reproduction but the problem has been with the DTP software that I use, even the supplier could not offer any suggestions. Andrew Holme emailed me in September to say that he thought the quality was poor and I replied, as I usually do, asking if he had any suggestions to help. Usually I do not get any further emails but Andrew came up trumps and spent a lot of his time to show me how to use my DTP software to improve the quality of the artwork. Thank you to Andrew and I hope that everyone will see the improvement.

For UK constructors who have difficulty finding the tin plate boxes used in may articles, please look at page 255.

The response to my request for new articles with issue 3/2009 has been good even though I made a typing mistake in the email address. If you have an article, please email me at the address on this page. There will be some new articles from new authors in 2010, so remember to renew your subscription using the form on the flyer with this magazine or visit the web site. If you normally use one of the agents please contact them for your 2010 subscription

Merry Christmas and a happy New Year 73s - Andy

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André Jamet F9HX

DFS for Microwave Beacons

Direct Frequency Synthesiser with Auxiliary Oscillator

1.0 Introduction

Many people have made beacons for operation on our SHF bands. They are very useful to test equipment, know propagation conditions, check the azimuth of a parabolic dish, measure the directivity of an antenna and a lot of others things.

Unfortunately, very often, their frequency precision is not very good. Therefore it is quite difficult to find a beacon in the microwave bands even with a correctly calibrated receiver.

Therefore it is useful to have a device to maintain very high frequency stability for our beacons in spite of temperature variations and component ageing.

2.0 Possible solutions

Using a homemade VHF OCXO as an LO is very common. The crystal is working in an overtone mode of 3 or 5 at around 100MHz. Several difficulties with AT cut crystals are apparent. Ageing is well known but not the retrace effect. When a crystal oscillator is turned off for a time and then turned on again, the crystal requires a re-stabilisation period. Beacons are operated continuously but some breaks can occur for repair or maintenance. Moreover, to force an overtone mode needs a tuning circuit that is very influential on the frequency. In practice everybody working on the SHF bands is aware of the frequency inacuuracy of beacons.

Therefore, as in our transverters LO, we need a high quality frequency reference for the beacon LO. This is the reason that 5 or 10MHz professional OCXOs are used. These are expensive when new but can be found at a very reasonable prices second hand.

Starting from the reference frequency we have to generate the required frequency. A PLL or a DDS is able to give a solution. Personally, I do not like PLLs very much because of their tendency to be unstable and noisy. Also, for people of my age, soldering of multiple very tiny pins exceeds our ability!

3.0 Proposed solution

The F5CAU/F9HX DFS for SHF RX/TX

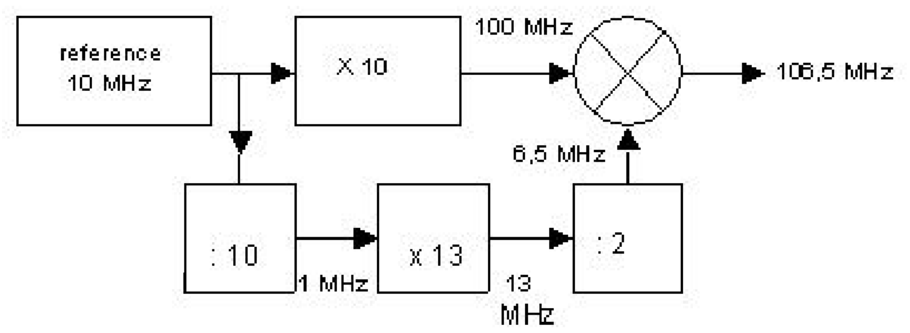

Fig 1: Block diagram of a 106.5MHz DFS.

has been described in several magazines [1,2,3] and more than one hundred have been made. Others have done a lot of work on DFS usable up to at least 47GHz [4,5,6].

Using a DFS, the desired frequency can be produced by multiplication, division and addition of a reference frequency. Fig 1 shows one typical application of a 106.5MHz reference used to generate a 10,224MHz local oscillator for a 10GHz / 144MHz transverter.

However this technique is not suited to generate any frequency with a DFS because of the elementary operations available. The idea, probably not new, is to add an auxiliary oscillator into the LO. Obviously, its frequency stability must be very good but less than the 10MHz reference. Let us take an example as in Fig 2. For a 10,368.900MHz beacon, the LO frequency must be:

10,368.900 / 96 = 108.009375MHz.

That means an auxiliary frequency of:

110 – 108.009375 = 1.990625MHz

What frequency precision and stability is required for this auxiliary oscillator? It is not locked to the 110MHz source.

For example, if it has a 10^{-7} (0.1 ppm) precision, the deviation will be:

1.990625×10^{-7} 0.2Hz

After multiplication by 96 to get to 10,368.900MHz the deviation will be:

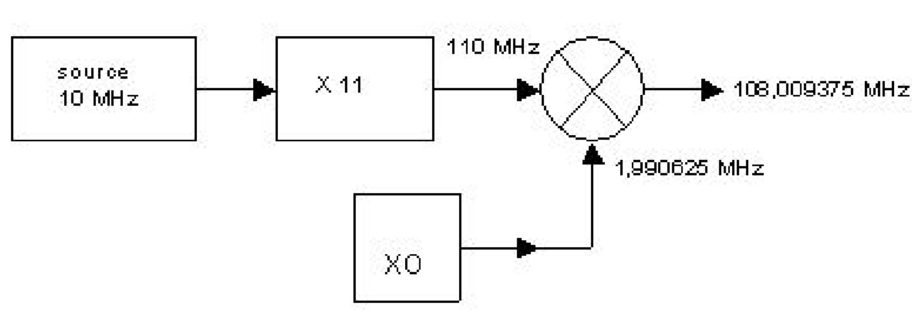

Fig 2: Bolck diagram of a DFS with auxilliary oscillator.

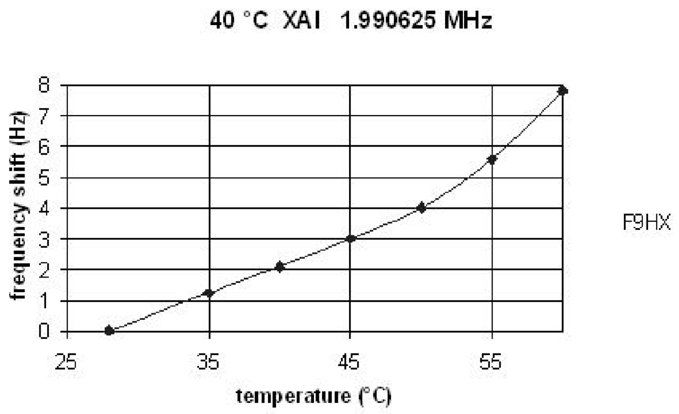

Fig 3: Crystal frequency drift versus temperature.

0.2 x 96 = 19.2Hz

Thus the reference frequency is perfectly accurate.

The auxiliary oscillator influence is about 50 times less than would be produce by a VHF OCXO.

With such beacon and a RX having a DFS LO, the total frequency discrepancy will be less than one hundred hertz. That means no problem to be certain of tuning in for CW or SSB.

4.0

A stable 1.990625MHz oscillator

We already pointed out that VHF OCXO show ageing and retrace. At 100MHz, if their stability were 10^{-7} (0.1 ppm), the possible frequency discrepancy would be:

100MHz x 10^{-7} = 10Hz and therefore:

10 x 96 = 960Hz at 10GHz

That would be acceptable.

In the field, every user knows that such devices do not complying with the above stability statement.

The auxiliary oscillator works in fundamental mode and the crystal is "more robust". Tests have shown stability that meets our requirements with affordable crystals.

Nevertheless, design and construction should be done with care. To do that it is best is to get advice from diagrams and arrangements of professional 5 or 10MHz OCXOs.

Fig 5 and 6 show the circuit diagram of the DFS source. The oscillator itself is a simple Colpitts circuit made of premium passive components.

The DC regulator output voltage is well filtered to avoid phase noise. A separate DC regulator supplies the temperature regulator.

Without copying a good OCXO, we can try to maintain the temperature of the crystal as stable as possible by simple means. A PTR (positive coefficient resistor) clipped to the crystal can be used. Better, is a temperature regulator (heater) made with SMD components on a small ceramic printed circuit (see [7] and Appendix 2). The crystal temperature is maintained at about 40°C for common ambient temperatures.

Crystal should be ordered in accordance to the following requirements:

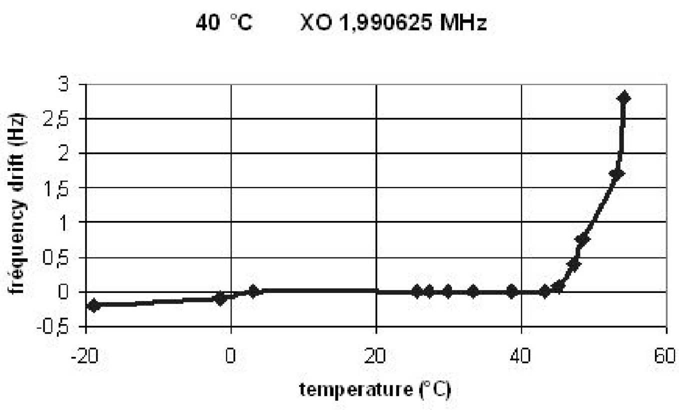

Fig 4: Frequency drift versus temperature of the crystal oscillator.

- 1.990625MHz fundamental parallel mode crystal, 30pF load, case HC49U, working temperature + 40°C, precision ± 5 ppm, AT-cut with about 0 minute angle.

The crystal is the key of our device. Fig 3 shows the frequency shift versus temperature.

4.1 Auxiliary oscillator performance

Fig 4 shows the frequency drift versus temperature of the auxiliary oscillator. The behaviour is excellent from –20°C up to 45°C. Above this the temperature regulator is ineffective and the crystal temperature follows the ambient temperature.

Frequency shift is negligible for the DC supply from 10 to 14 volts because it is close to our 1/10Hz resolution frequency meter.

After one week switched on, no drift was measurable. After one month switched off, the drift retrace is:

- after 15 minutes: 0.7Hz (i.e. 67Hz at 10GHz!)
- after 1 hour: 0.5Hz
- after 5 hours: 0.3Hz

In fact it reached the limits of our frequency meter that is not GPS locked.

4.2 Beacon modulation

A beacon should be identified by a message giving its callsign and some information. On the microwave bands F1A modulation is usually used with a 400Hz shift. To get that shift at 10GHz, we need a 400 / 96 = 4.166Hz shift for the auxiliary oscillator using a varicap diode.

As the DFS output frequency is generated by a subtraction, we have to invert the shift direction. Therefore, a 0/5 volts modulating signal must be reversed by transistor Q6 to increase the output frequency. Potentiometer P1 allows a shift from 0 up to about 800Hz.

5.0

Operation

Looking at Fig 2 then 5 and 6, we can understand the behaviour of several stages. The 10MHz input signal comes from an external reference, a professional OCXO possibly disciplined by GPS. A first chain produces the eleventh harmonic, a sine wave at 110MHz.

The auxiliary oscillator is the second chain. A mixer delivers the difference between the two chain frequencies. A

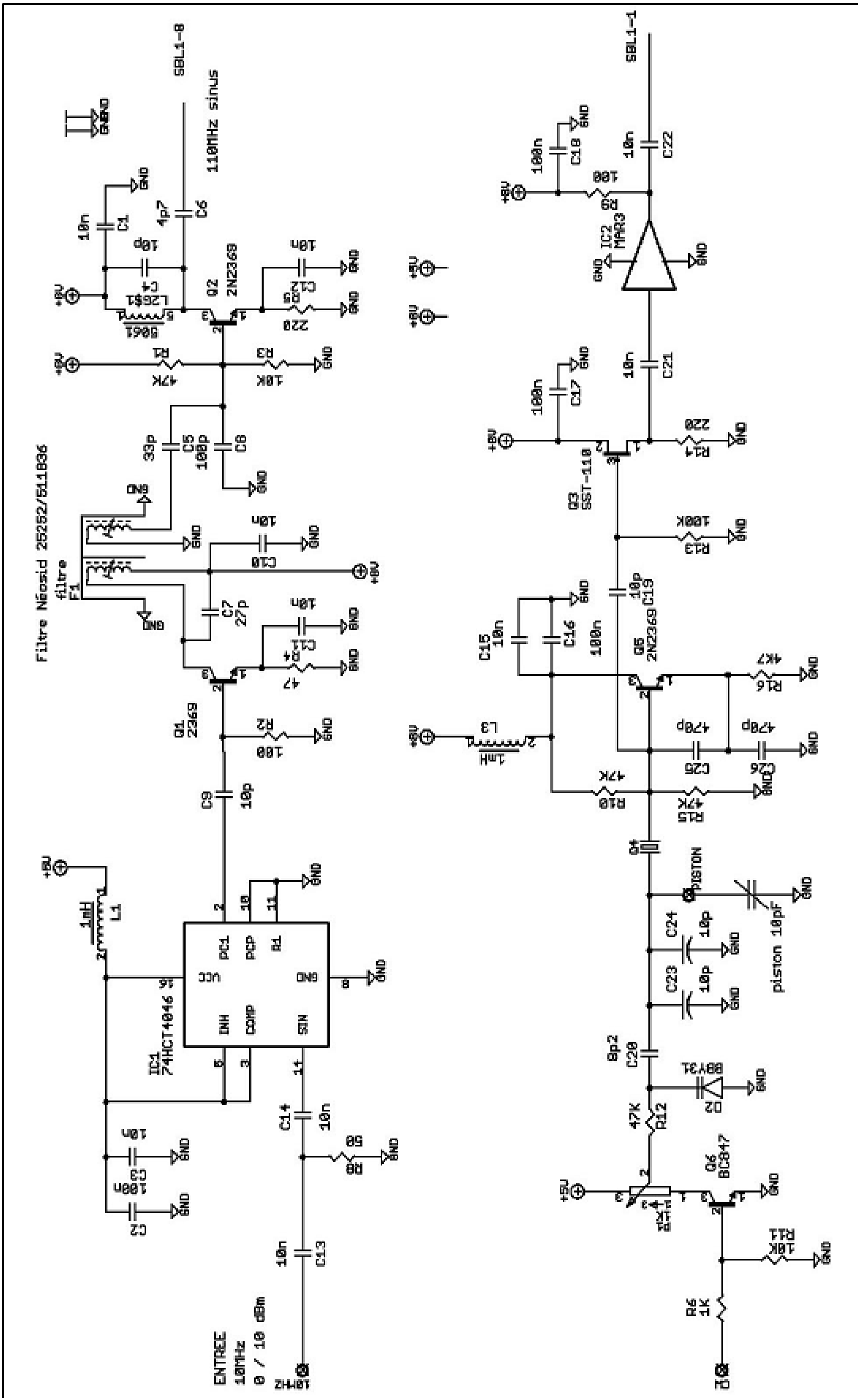

Fig 5: Circuit diagram of the oscillator chains.

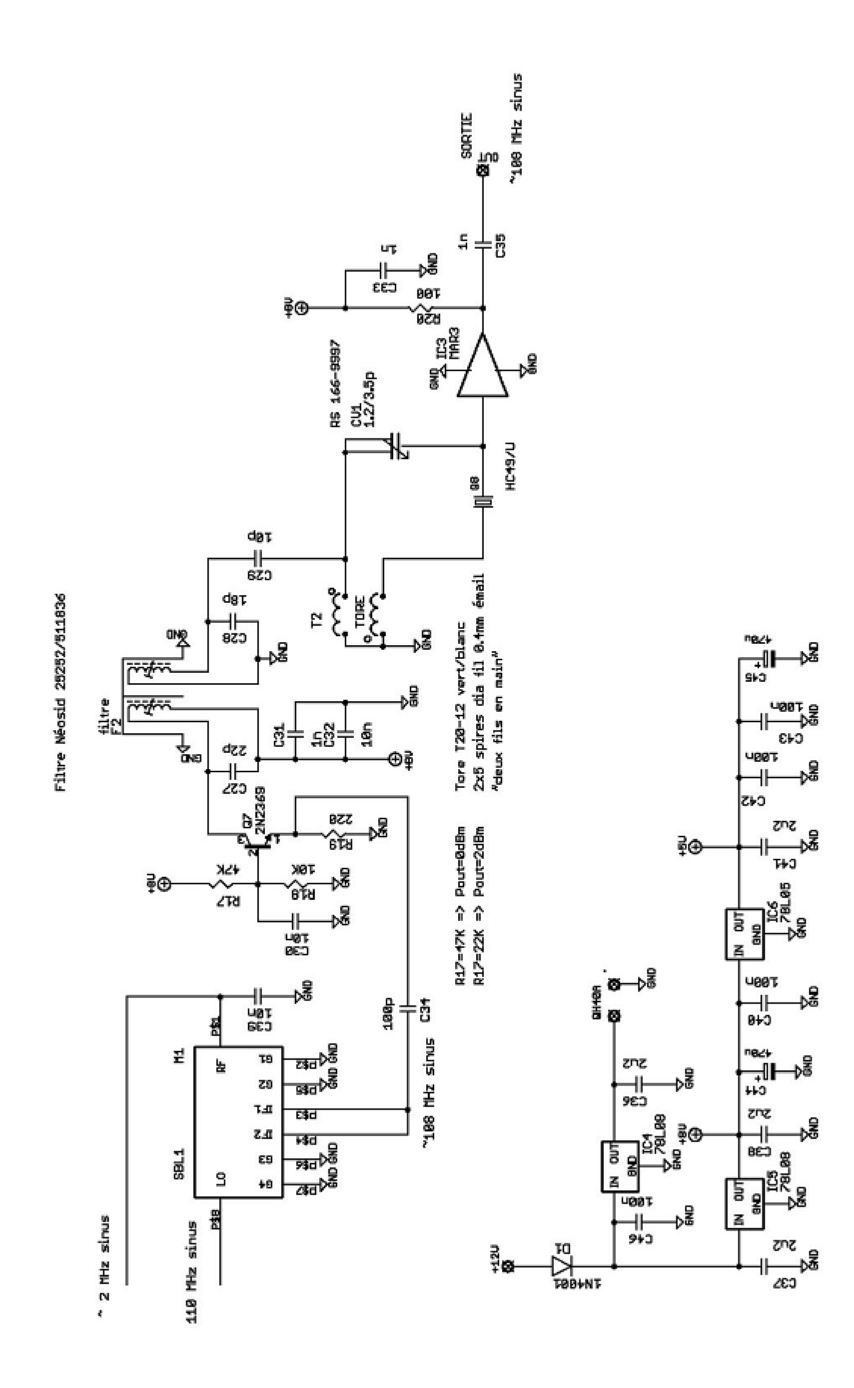

Fig 6: Circuit diagram of the power supplies and output stage.

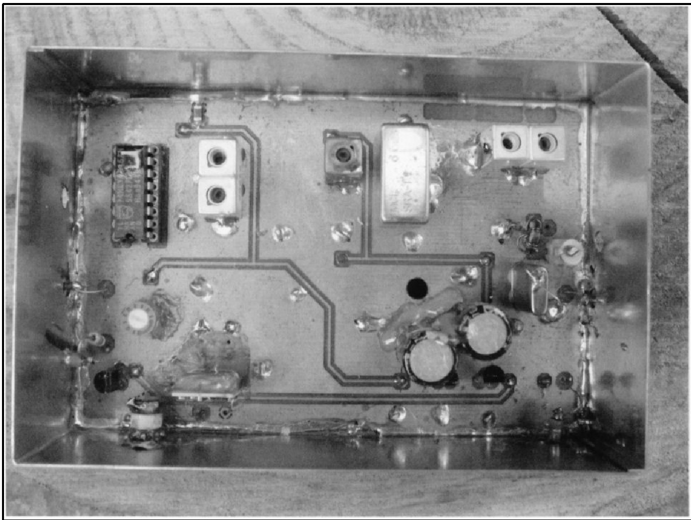

Fig 7: Picture of the top side of the completed DFS.

crystal filter cleans the output signal before the output is amplifier by an MMIC as it is done in a classical DFS [1,2,3].

5.1 Mechanical and electrical construction

The device uses SMD components, when they are available, resistor, capacitors, transistors and IC. A double-sided FR4 PCB without plated holes makes it possible for homemade construction or by affordable professional manufacture.

Several Vias made using a piece of wire soldered on both sides are used at critical places. They decrease spurious coupling between different circuits. A drop of more than 10dB can be expected using this technique [8].

A tin plate box 74 x 111mm and 50mm high avoids detuning by the covers.

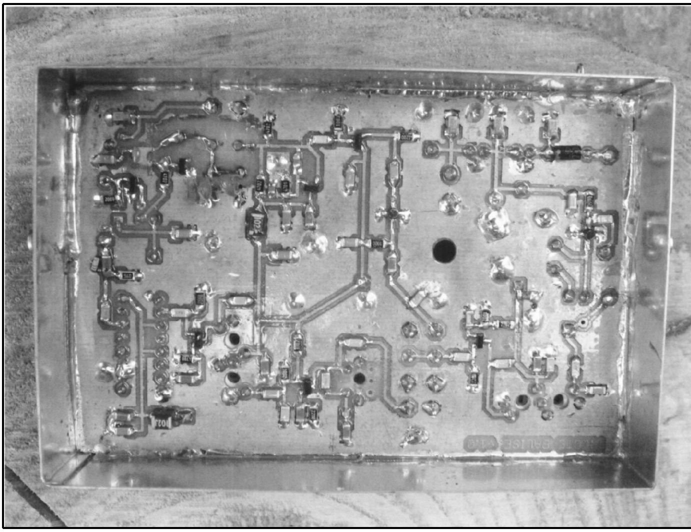

Fig 8: Picture of the bottom side of the completed DFS.

After some tests to be sure it works, wash the PCB with a special solvent to remove all soldering residue. It has to be dried in an oven to remove humidity. A silicon spray protects against corrosion. Take care to mask components such as filters and adjustable capacitors. Finally, the varnish is cured at 50°C for one hour.

5.2 Set-up

Set the 110MHz chain on the correct frequency (and not at 100 or 120MHz) using the ferrite screws of F2 and L2.

Set the 2MHz chain on the correct frequency using the air trimmer capacitor and the shift by potentiometer P1. It is advisable to keep the device switched on for one month before these settings. A frequency meter having a tenth of hertz resolution at 2MHz is required.

The F2 filter is set for maximum at the output frequency.

The setting of the adjustable capacitor in the output filter must be done with a spectrum analyser to "clean" the output signal. This setting is very tricky and needs a plastic screwdriver.

6.0 Results

Measurements at 10,368.900MHz with a GPS 10MHz, 1MHz and 100kHz reference [9]

- Output power: 0 up to +2dBm depending on the value of R17
- Spurious: -65dBc or better (except H2 and H3)
- Frequency shift is that measured at 2MHz but multiplied by 96:
  - 10 to 14 Vdc: below ability to see a drift owing to our measurement conditions
  - temperature: auxiliary oscillator measurements confirmed.

Note

It is advisable to increase the crystal working temperature up to 50 or 60°C and fitting the auxiliary oscillator in a separate case in order to make a true OCXO. The crystal specification should be modified in accordance to a different temperature.

7.0 Conclusion

It is understandable that people who have spent time (and money) to make beacons would be reluctant to modify them. However, it is advisable to take advantage of a repair or maintenance period to make the changes. For new beacons, it is advised. For any comments or inquiry: agit@wanadoo.fr

8.0 References

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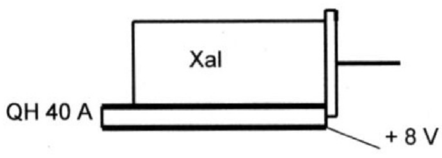

Fig 9: Crystal and temperature regulator assembly.

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Appendix 1

Microwave beacons modulation is usually done by F1A mode with a 400Hz shift. That shift is below (space) the nominal frequency (mark) to appear as A1A using an SSB receiver. With keying, the frequency goes from space to mark.

Appendix 2

To maintain the crystal at 40°C, a regulator QH40A [7] is join to its case. It is a small 10.5 x 14mm ceramic PCB with SMD components. A constant 8 volts regulator supplies the QH40A regulator.

To really maintain the crystal case at the correct temperature good contact is needed. The crystal must be prepared on the face that will be joined to the PCB. A very thin layer of thermal compound is put on the PCB before joining to the crystal case. A temporary jig holds the two parts together. Use two-part adhesive around the PCB to make a solid assembly (see Fig 9).

Fig 3 shows the advantage in exceeding 40°C as regulated temperature. I reduced one resistor in the regulator to be sure that the temperature was above 40°C.

Matjaz Vidmar, S53MV

Weatherproof UHF & microwave cavity antennas

1. Weatherproof antennas for UHF and lower microwave frequencies

1.1. Radio amateurs, weather effects and antenna design

Quite frequently, radio amateur antenna design is limited to a few popular antenna types. Directional antenna designs are usually limited to Yagi antennas for the lower frequencies and parabolic dishes for the microwave frequency bands. The operation of a Yagi antenna is based on a collimating lens made of artificial dielectric like rods, loops, disks or helices. The basic design goal of all these slow-wave structures is to achieve the maximum antenna directivity with the minimum amount of material (metal).

The situation is actually made worse with the availability of inexpensive antenna simulation tools for home computers. The latter provide designs with fantastic gain figures using little hardware. Unfortunately, these results are barely useful in practice. Besides impedance matching problems, such designs are extremely sensitive to manufacturing tolerances and environmental conditions: reflections from nearby objects and accumulation of dirt or raindrops on the antenna structure.

The operation of a 2m (144MHz) Yagi with thin rods (or loops or helix) antenna will be completely disrupted if snow or ice accumulates on the antenna structure. Raindrops accumulated on the antenna structure will completely compromise the operation of a 23cm (1.3GHz) or 13cm (2.3GHz) Yagi antenna. Manufacturing tolerances limit practical Yagi antennas to frequencies below about 5GHz.

Professional VHF Yagi antennas use very thick rods to limit the effects of snow and ice on the antenna performance. All professional Yagi antennas above 300MHz are completely enclosed inside radomes made of insulating material that is transparent to radio waves. Since any radome includes some dielectric and the latter has a considerable effect on any Yagi antenna, a Yagi antenna has to be completely redesigned for operation inside a weatherproof enclosure. If some natural dielectric (radome) is added, then some artificial dielectric (Yagi rods) has to be removed to maintain the same focal length of the dielectric collimating lens.

Simply speaking, any serious design of a weatherproof Yagi antenna for frequencies above 300MHz is out-of-reach for most amateurs. Fortunately there exist other antenna solutions for amateur radio equipment that has to operate unattended

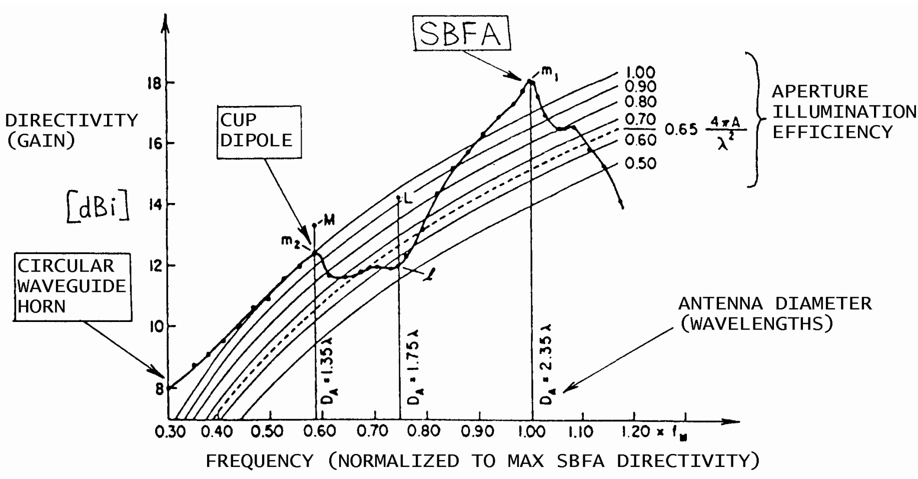


Fig 1: Ehrenspeck's directivity plot for round cavities.

on mountain tops like FM voice repeaters, ATV repeaters, packet radio nodes and microwave beacons. The most popular solutions are arrays of dipoles, quads, eights etc. The installation of the latter inside suitable weatherproofing radomes is much less critical than the weatherproofing of Yagis or helices.

1.2. Practical cavity antennas

Of course, a different antenna design approach may provide much better results, like considering the weatherproofing issue right from the beginning! Cavity antennas may initially require more metal for the same decibels of antenna gain. On the other hand, a cavity antenna is relatively easy to weatherproof: most of the radome is the metal cavity itself and just a relatively small radiating aperture has to be additionally protected with some transparent material.

Before deciding for a particular cavity antenna design, it makes sense to check well-known solutions. A comprehensive description of many different cavity antennas is given in the book [1]. A useful selection tool is Fig 1, the directivity plot as a function of cavity diameter as published by Ehrenspeck [2]:

Although Ehrenspeck's diagram is a little bit optimistic regarding the achievable antenna directivity, it shows many important features of cavity antennas. The plot has local maxima and minima, meaning that not just every cavity size works fine. There are some cavity sizes that provide particularly good antenna performance. These fortunate cavity sizes may achieve aperture efficiencies beyond 100%!

It is interesting to notice that the real directivity plot does not come to an end as suggested by Ehrenspeck many years ago. As shown at the end of this article, the real directivity plot has at least one additional maximum, corresponding to the recently developed "archery target" antenna [3]. Probably there are many more maxima at larger cavity diameters yet to be investigated.

Another important design parameter is the cavity height or (conductive) rim height surrounding the cavity. The maximum directivity is achieved at rim heights of one half wavelength or slightly

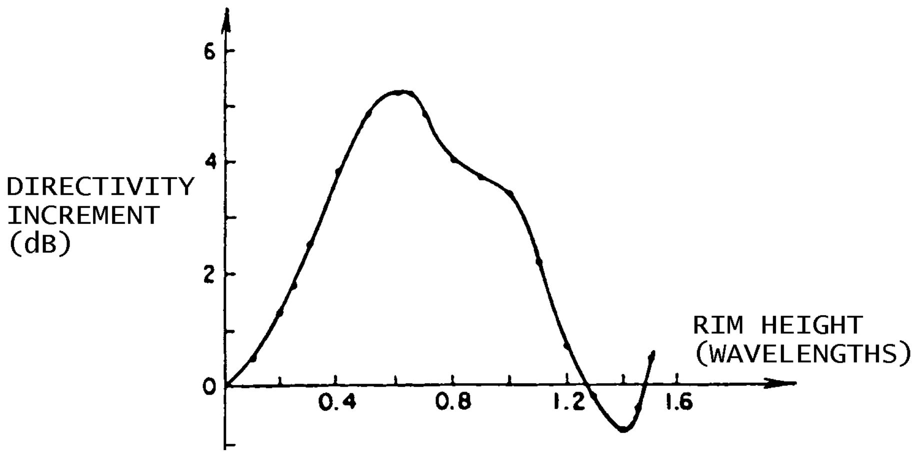


Fig 2: Directivity increment as a function of rim height.

above this value, regardless of the particular cavity diameter, as shown in Fig 2.

As shown in Fig 2, cavity antennas fill an important directivity gap between at least 7dBi and 20dBi. Since cavity antennas are simple to manufacture including weatherproofing, parabolic dishes become practical only if directivities of 22dBi or above are required.

Many practical cavity antenna designs follow directly the above mentioned directivity plots. The most important are presented in this article including practical weatherproof designs for the amateur radio frequency bands of 435MHz (70cm), 1.3GHz (23cm) and 2.3GHz (13cm). Some other important designs are omitted due to space limitations, like square cavities and cavities fed with microstrip patches.

All presented antennas were built and accurately tested many years ago at our outdoor antenna test range at the Department for Electrical Engineering of the University of Ljubljana, thanks to Mr. Stanko Gajsek. All directivity values and plots were computed from the measured E plane and H plane radiation patterns.

The measured radiation patterns shown in this article are all plotted on a 40dB logarithmic scale to have an excellent view of the sidelobes and any other side effects. Please note that it is relatively easy to hide antenna design deficiencies by using a linear scale or a 20dB logarithmic scale!

All presented antennas include a transparent radome that is already part of the antenna structure. Therefore little if any additional effort is required for complete weatherproofing of these antenna designs. For terrestrial (horizontal) radio links the radiating surface is vertical, therefore rain drops, snow and ice quickly fall away if they ever stick onto the radome. Finally, the radiating surface is an equi-phase surface, meaning that a uniform coverage with ice or other foreign material does not defocus the antenna.

The presented antennas were initially used for 38.4kbps and 1.2Mbps links in the amateur packet-radio network in

Fig 3: Cup dipoles and SBFAs of CPRST:S55YCP.

Slovenia. Some of these antennas accumulated 15 years of continuous operation in extreme climatic environments on mountaintops. During these 15 years, rain, snow and ice never caused any link dropouts.

A typical example is the packet-radio node CPRST:S55YCP installed on a mountain hut about 1840m above-sea-level and powered by solar panels. The antenna system of the latter includes a GP for 2m, two cup dipoles for 70cm, one cup dipole for 23cm, one SBFA for 23cm, one SBFA for 13cm and a webcam as shown in Fig 3.

2.

Circular waveguide horns

2.1. General circular waveguide horn design

The simplest cavity antenna is a waveguide horn. Waveguide horns are foolproof antennas: whatever horn of whatever size and shape will always provide some useful directivity. Waveguide horns are also among the best-known cavity antennas in the amateur radio community, therefore they will be just briefly mentioned in this article.

The simplest waveguide horn is just a truncated waveguide, either of rectangular or circular cross-section. Such an antenna provides a gain of about 7dBi and a main lobe width (-3dB) of around 90 degrees. These figures are useful when a broad coverage is required or to illuminate a deep (f/d=0.3-0.4) parabolic dish.

At UHF and lower microwave frequencies such an antenna usually includes a coax-to-waveguide transition. A practical solution is shown in Fig 4.

A quarter wavelength probe is used to excite the fundamental TE11 mode in a circular waveguide. One end of the waveguide is shorted while the other end acts as a radiating aperture. The distance between the probe and the short should be around one quarter wavelength, to be adjusted for best impedance matching. The distance between the probe and the aperture should be at least one half wavelength to suppress higher order modes inside the waveguide. One or more tuning screws may be added to improve impedance matching. A simple

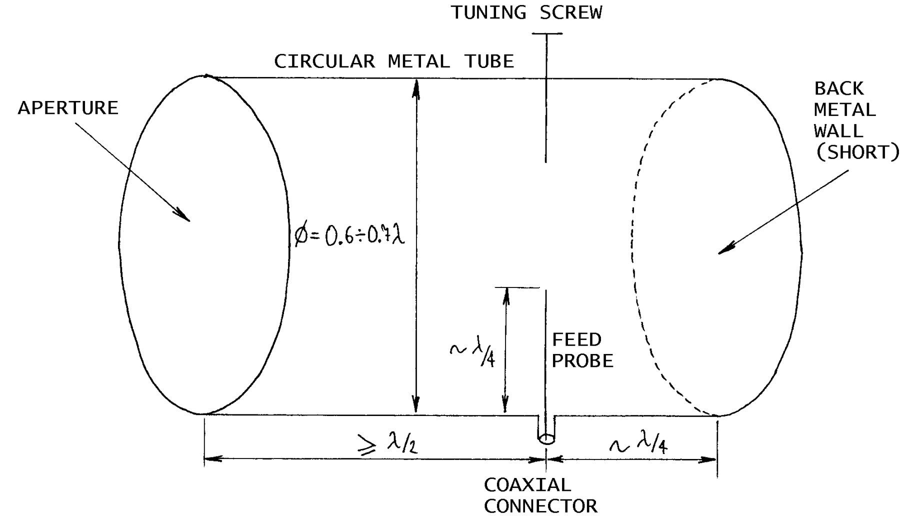


Fig 4: Circular waveguide horn design.

feed probe generates a linearly polarised TE11 mode. Two feed probes fed in quadrature or a single feed probe and many more tuning screws inserted in a longer circular waveguide are required to obtain circular polarisation.

2.2. Practical circular waveguide horn for 23cm

Various size coffee cans usually make useful linearly polarised horns for 1.7GHz and 2.4GHz. A weatherproof waveguide horn for 1.3GHz (23cm) is a

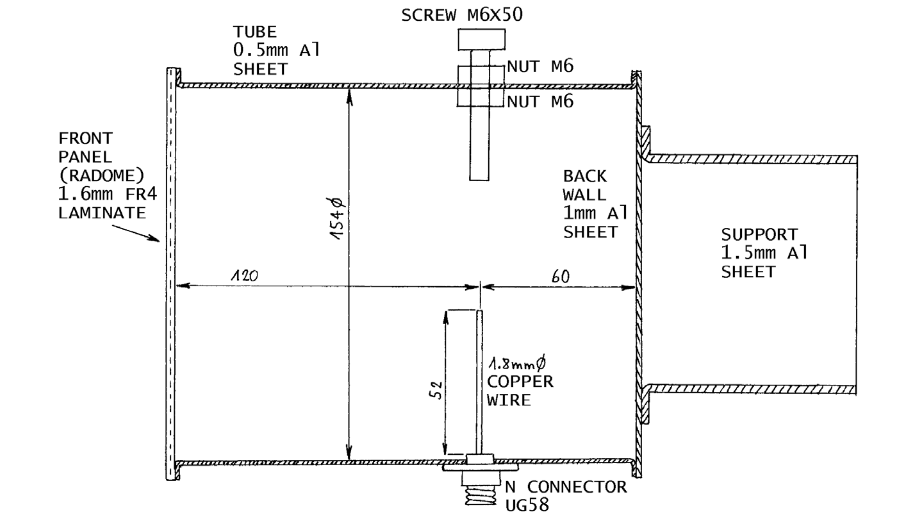


Fig 5: Practical horn for 23cm.

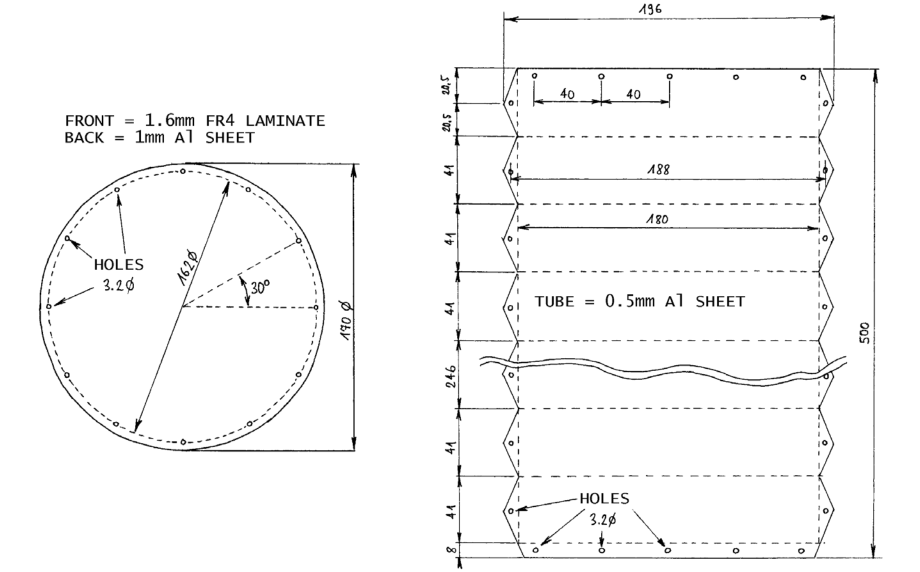


Fig 6: Mechanical components of the horn for 23cm.

little bit too large for practical cans and will probably have to be purpose built from aluminium sheet. The required dimensions for operation around 1280MHz are shown in Fig 5.

The radiating aperture is covered by a disc of FR4 laminate (with any copper plating removed!) or thin plexi-glass that acts as a radome. The position of the tuning screw and the length of the feed probe correspond to the given design including all dimensions and the effect of the radome. If the waveguide section is made longer, the position of the tuning screw and the length of the probe will necessarily change!

If only simple tools are available, then it makes sense to build the individual components of the horn from aluminium sheet and bolt them together with small M3 x 4 or M3 x 5 screws. Aluminium is a good electrical conductor providing low losses in the antenna structure and does not require any special environmental protection. The required mechanical components for the horn for 23cm are shown in Fig 6.

The antenna is first assembled together using just bolts, making all necessary adjustments like feed probe length and tuning screw position. Afterwards the antenna is disassembled so that all seams can be sealed with small amounts of silicone sealant. Finally, do not forget a venting hole or unsealed seam in the bottom part of the antenna, where any (condensation) moisture can find its way out of the antenna!

The measured E plane and H plane radiation patterns of the prototype antenna are shown in Fig 7.

The measured patterns in both planes at a number of different frequencies were used to compute the directivity as shown in Fig 8.

The operation of a simple waveguide horn is disrupted when higher order modes are excited. In the case of a simple feed probe in a circular waveguide, the first disturbing mode is the TM01 mode. The latter causes an unsymmetrical illu-

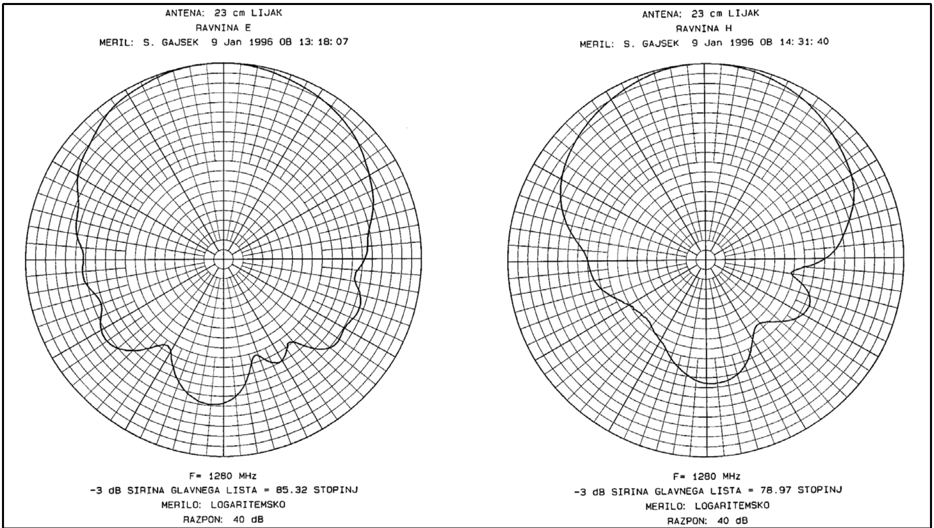


Fig 7: E plane and H plane radiation patterns of the horn for 23cm.

mination of the aperture resulting in a squint of the direction of radiation.

The appearance of higher order waveguide modes means that not every coffee can makes a useful antenna for the desired frequency range! The prototype horn for 23cm displays a large squint of the main lobe due to higher order modes at 1450MHz as shown in Fig 9.

3. Cup dipole

3.1. Basic design of a cup dipole

In order to increase the gain of a waveguide horn, the size of the aperture has to be increased without exciting too many higher order waveguide modes. A

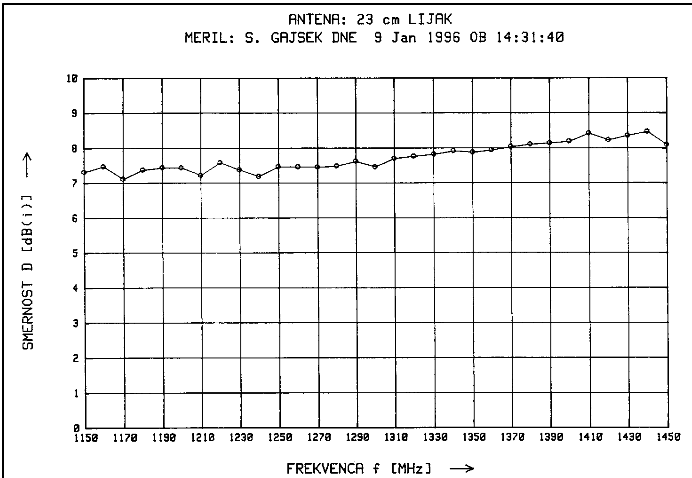


Fig 8: Directivity of the horn for 23cm.

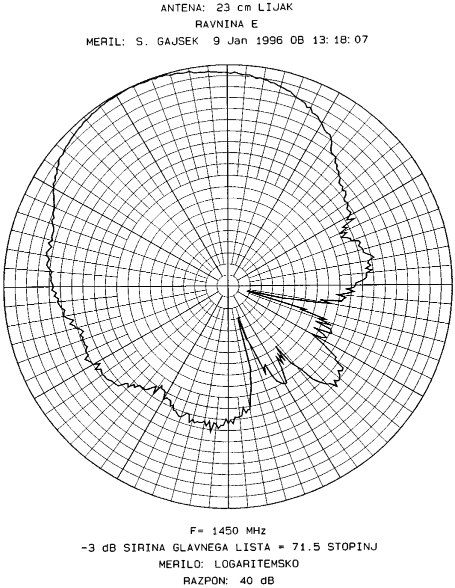


Fig 9: Main lobe squint due to higher order modes.

rather simple solution is to make a smooth transition from the waveguide to the larger aperture in the form of a pyramidal or conical horn. Such a solution becomes unpractical at lower microwave frequencies and UHF, where the

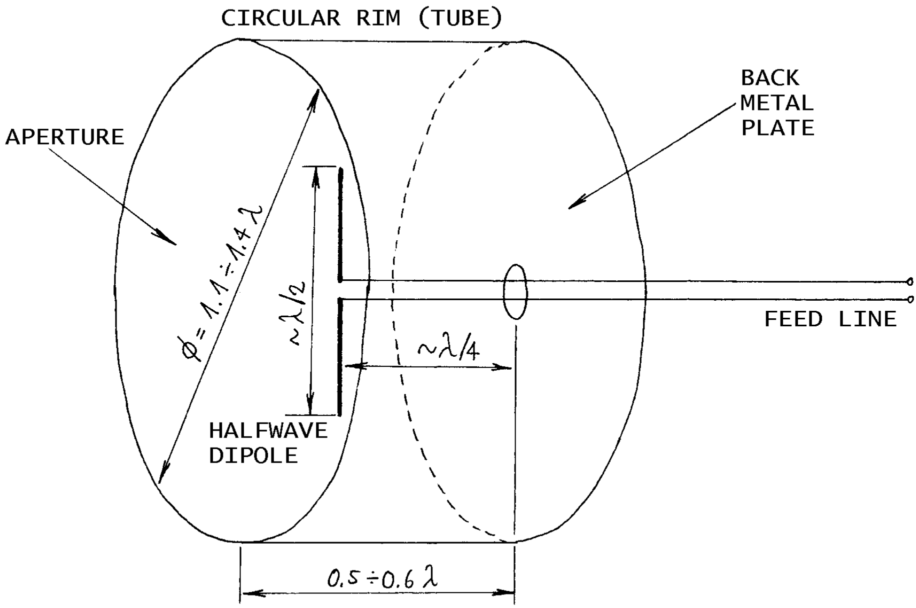


Fig 10: Basic design of a cup dipole.

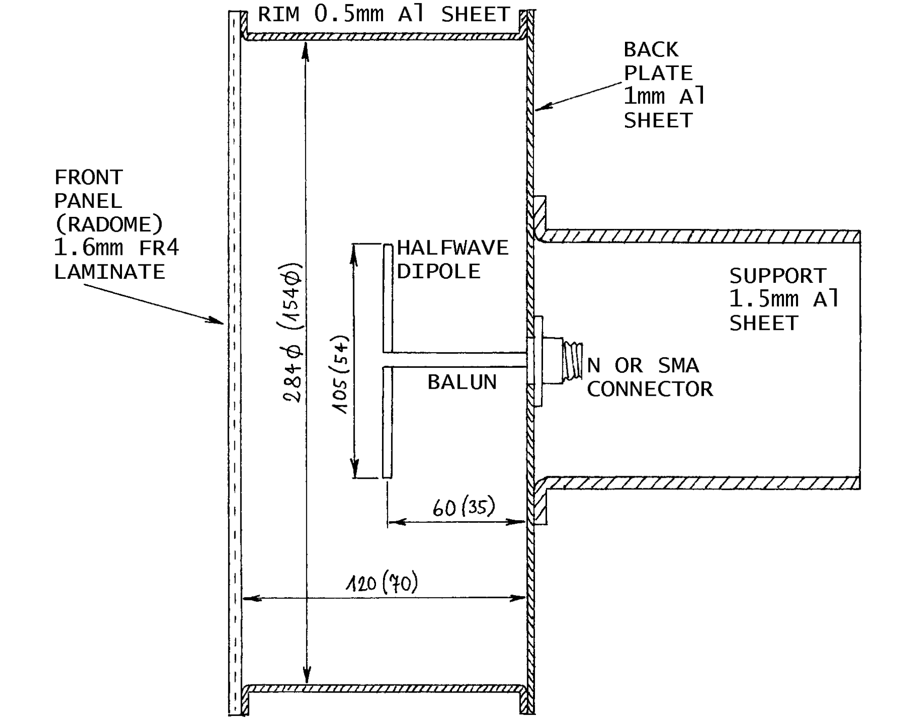


Fig 11: Practical cup dipole for 23cm (13cm).

size of the horn is too large.

An alternative solution is to avoid exciting unwanted modes already at the transition from an arbitrary TEM feed line to the waveguide. Replacing a simple feed probe with a symmetrical half wave dipole avoids exciting the unwanted TM01 mode while exciting the desired TE11 mode. Such a solution is called a cup dipole and is represented in Fig 10.

A cup dipole is a really compact antenna with a directivity of up to 12dBi and a very clean radiation pattern with very weak side lobes. The directivity achieves its maximum at the second peak on the Ehrenspeck 's diagram [2]. Again, most of the metallic antenna structure can be used as a radome at the same time and just the radiating aperture needs to be covered with a transparent cover.

A cup dipole provides a -3dB beam width of about 50 degrees. Besides operating as a stand-alone antenna, a cup dipole also makes an excellent feed for a shallow (f/d=0.6-0.7) parabolic dish.

3.2. Cup dipole for 23cm

The construction of a practical cup dipole for 23cm (13cm) is shown in Fig 11.

If only simple tools are available, then it makes sense to build the individual components of the cup dipole from aluminium sheet and bolt them together with small M3 x 4 or M3 x 5 screws. Aluminium is a good electrical conductor providing low losses in the antenna structure and does not require any special environmental protection. The required mechanical components for the cup dipole for 23cm are shown in Fig 12.

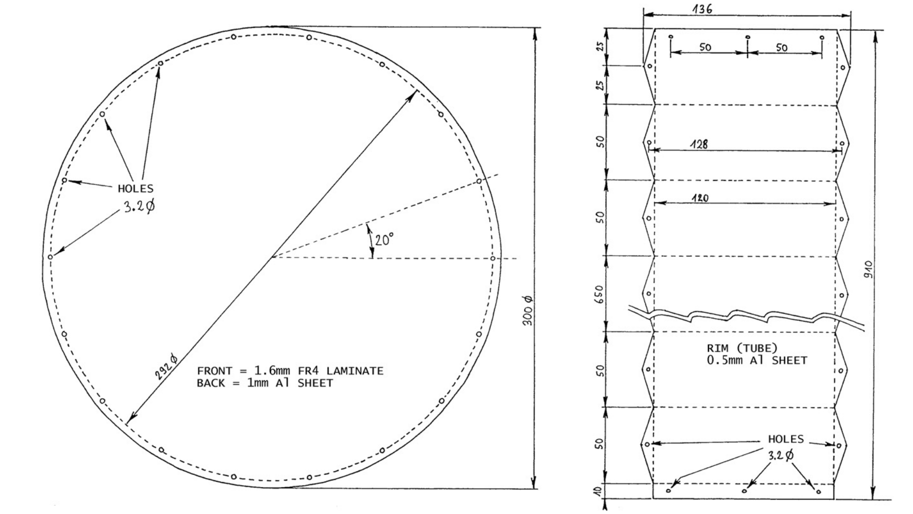


Fig 12: Mechanical components of the cup dipole for 23cm.

The front cover may be quite thick FR4 laminate or plexi-glass, since a dielectric plate in this position actually improves the performance of a cup dipole.

The measured E plane and H plane radiation patterns of the prototype cup dipole are shown in Fig 13.

The measured patterns in both planes at a number of different frequencies were used to compute the directivity as shown in Fig 14.

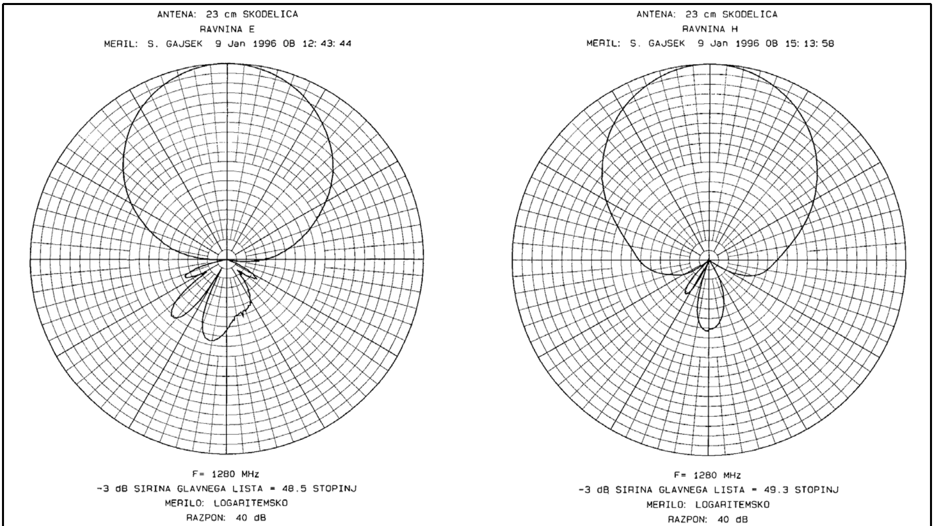


Fig 13: E plane and H plane radiation patterns of the cup dipole for 23cm.

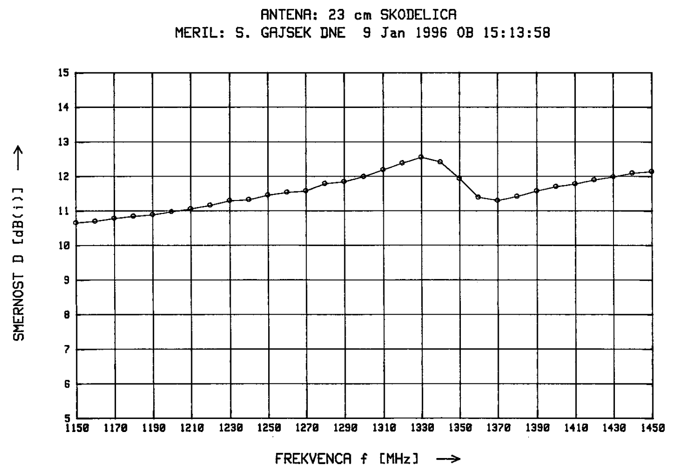


Fig 14: Directivity of the cup dipole for 23cm.

The kink in the directivity curve will be explained later together with the same effect observed with the prototype for 13cm.

3.3. Cup dipole for 13cm

The design of the cup dipole can be easily scaled to the 13cm band. The required mechanical components for the

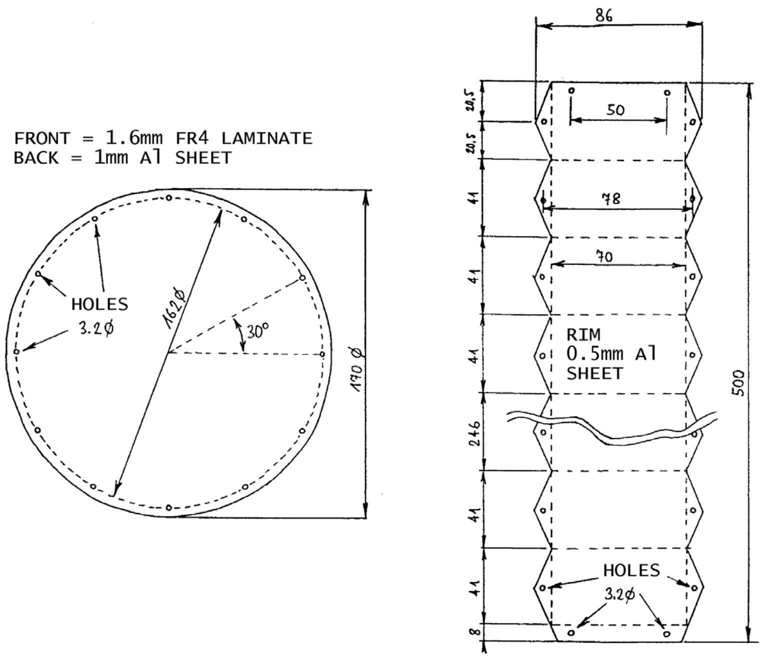


Fig 15: Mechanical components of the cup dipole for 13cm.

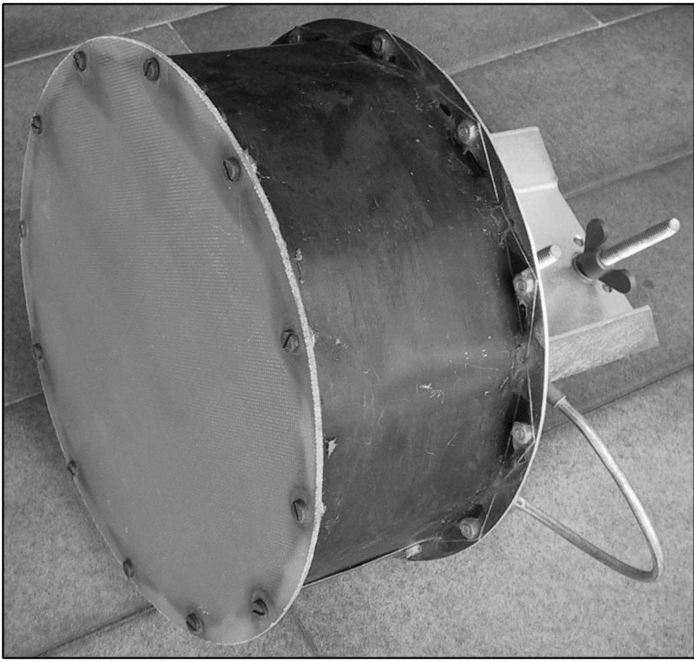


Fig 16: Cup dipole for 13cm.

cup dipole for 13cm are shown in Fig 15.

The antenna is first assembled together using just bolts, making all necessary adjustments and checkouts. Afterwards the antenna is disassembled so that all seams can be sealed with small amounts of silicone sealant. Finally, do not forget a venting hole or unsealed seam in the

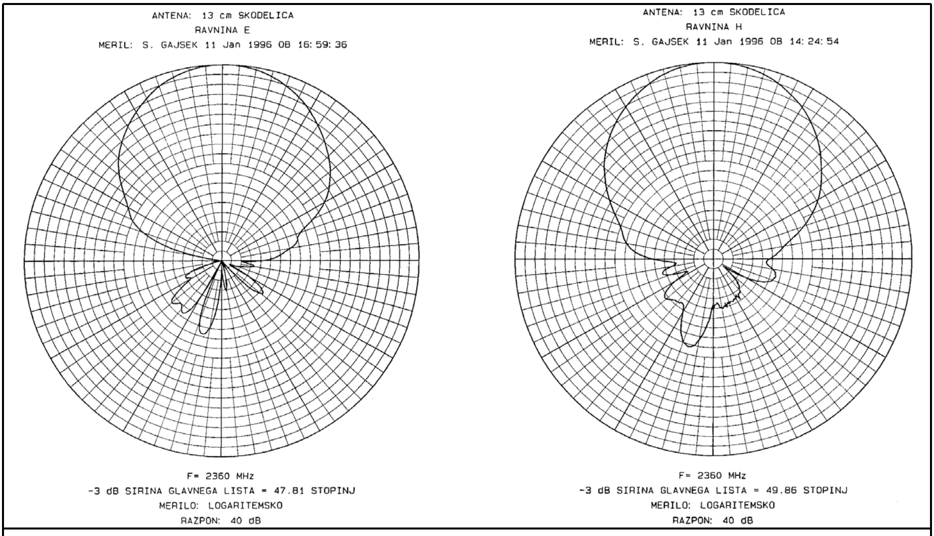


Fig 17: E plane and H plane radiation patterns of the cup dipole for 13cm.

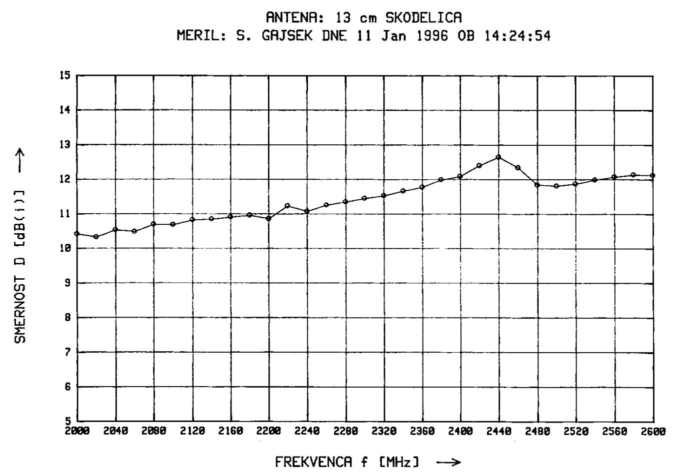


Fig 18: Directivity of the cup dipole for 13cm.

bottom part of the antenna, where any (condensation) moisture can find its way out of the antenna!

A homemade cup dipole for 13cm that already provided several years of outdoor service is shown in Fig 16.

The measured E plane and H plane radiation patterns of the prototype cup dipole for 13cm are shown in Fig 17.

The measured patterns in both planes at a number of different frequencies were used to compute the directivity as shown in Fig 18.

As the frequency increases, the directivity plots of both cup dipoles for 23cm and 13cm include a kink. A further explanation of what is happening is given by the two E plane radiation patterns for both investigated antennas: the 23cm cup

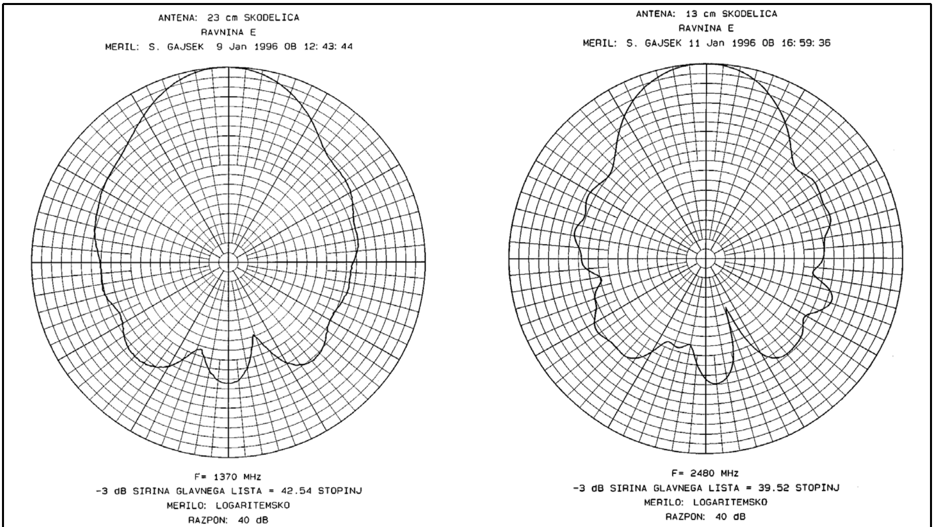


Fig 19: Corruption of the radiation patterns of cup dipoles at high frequencies.

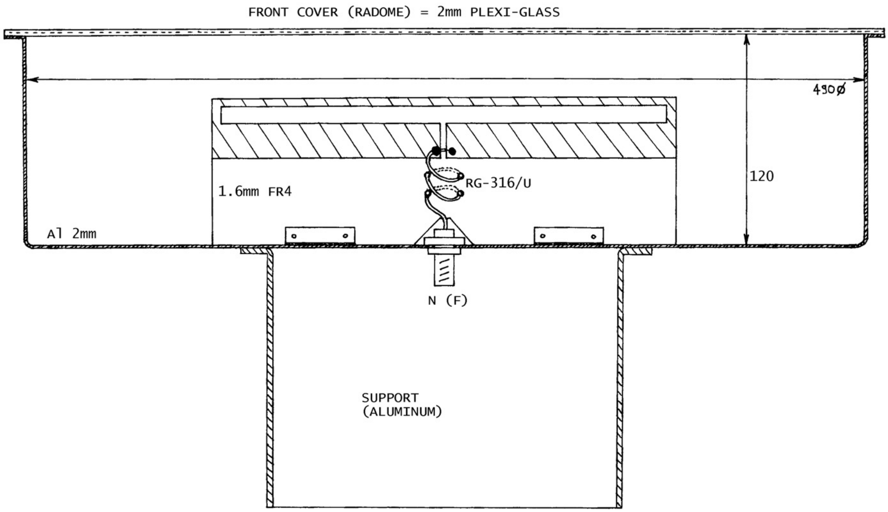


Fig 20: Practical (downscaled) cup dipole for 70cm.

dipole at 1370MHz and the 13cm cup dipole at 2480MHz: shown in Fig 19.

Both radiation patterns are badly corrupted due to the appearance of higher order symmetrical waveguide modes. These are excited by a perfectly symmetrical half wave dipole and are no longer suppressed by the waveguide. The size and directivity of a cup dipole therefore has a practical upper limit.

Beyond this limit different solutions are required to control the illumination of the aperture to obtain even narrower radiation beams and higher values of directivity.

3.4. Cup dipole for 70cm

The opposite happens at UHF and lower frequencies: all presented cavity antennas are physically too large to be practical. At low frequencies, a good hint is to look at the design of very compact coaxial-to-waveguide transitions. A practical solution in the 70cm band is a downscaled cup dipole as shown in Fig 20.

The aperture of this downscaled cup dipole corresponds to a simple waveguide horn. The expected radiation pattern is therefore similar to the much longer waveguide horn and the expected directivity is 8dBi or less. 8dBi may not seem much, but remember that this figure is achieved with a compact and weatherproof antenna at a relatively low frequency!

Since the half wave dipole is installed rather close to the cavity wall, its expected radiating impedance will be very low. A folded dipole is therefore used for impedance transformation. The folded dipole is built on a printed-circuit board and requires a balanced 50Ω feed.

The balun is simply a quarter wavelength piece of RG-316/U thin Teflon dielectric coaxial cable forming a two-turn coil. The dipole is built on a piece of 1.6mm thick FR4 laminate with 35um or thicker copper cladding. No etching is usually required. The copper cladding is marked with a sharp tip and the unnecessary copper foil is simply peeled off.

All of the folded dipole components are shown in Fig 21, including two aluminium brackets used to bolt the dipole

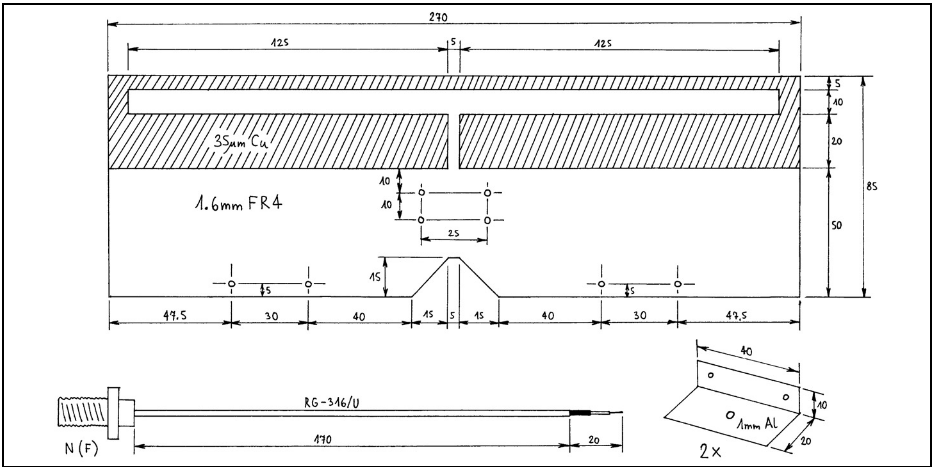


Fig 21: Folded dipole components for 70cm.

to the cavity wall.

The measured E plane and H plane radiation patterns of the prototype cup dipole for 70cm are shown in Fig 22.

The measured patterns in both planes at a number of different frequencies were used to compute the directivity as shown in Fig 23.

4. Short backfire antenna (SBFA)

4.1. Design of a short backfire antenna (SBFA)

As the diameter of the cup dipole cavity increases beyond 1.4 wavelengths, addi-

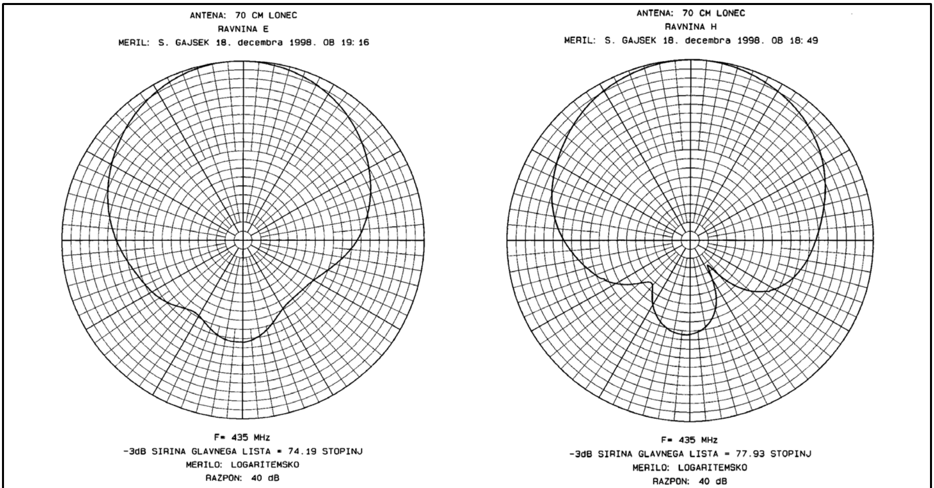


Fig 22: E plane and H plane radiation patterns.

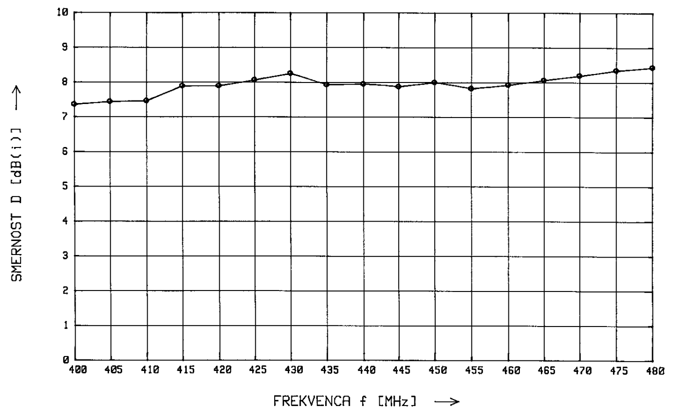


Fig 23: Directivity of the cup dipole for 70cm.

tional symmetrical circular waveguide modes are excited by the dipole feed and propagated in the waveguide. These modes spoil the aperture illumination, increase the side lobe levels and decrease the antenna directivity. In order to build even larger cavity antennas, some means of controlling the amplitude and phase of all contributing modes has to be introduced.

The most popular solution to control the amplitude and phase of symmetrical modes inside a circular waveguide is to introduce an additional circular plate in the aperture plane. This plate is called the small reflector while the cavity is called the large reflector. Together with one or more feed dipoles, these two reflectors form a very efficient cavity antenna called the short backfire antenna or SBFA as shown in Fig 24.

The large reflector of a SBFA has a diameter D of up to 2.5 wavelengths while the small reflector has a diameter

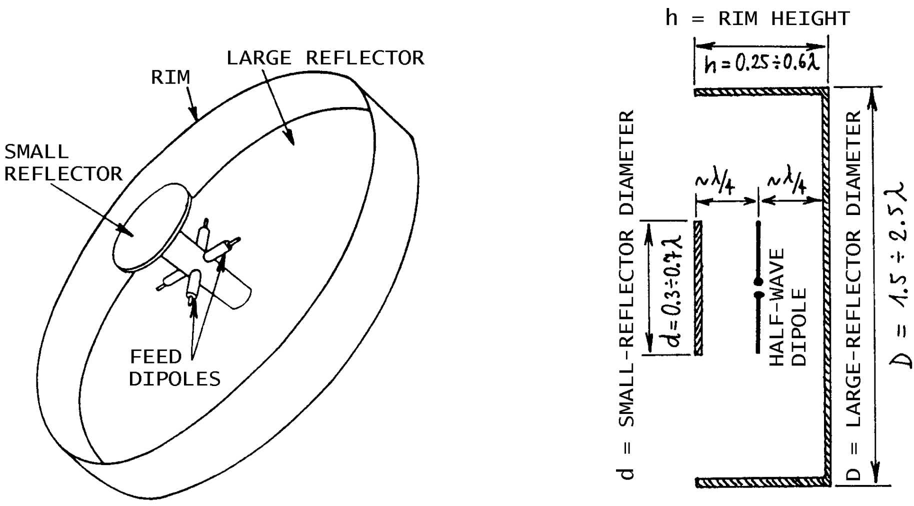


Fig 24: Design of a Short BackFire Antenna (SBFA).

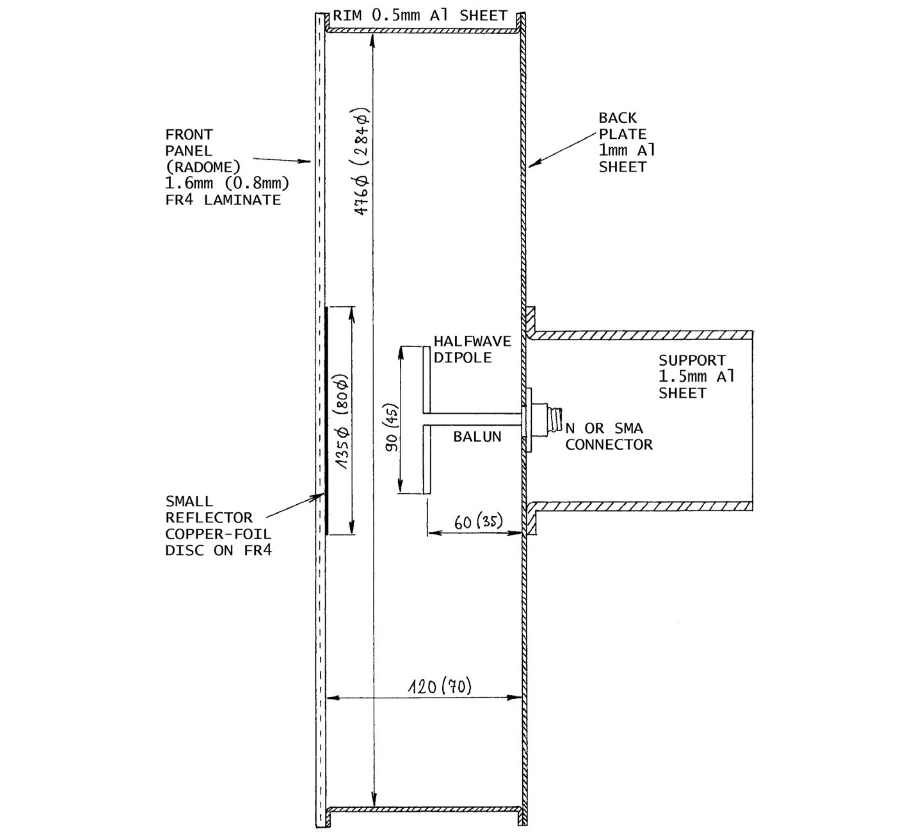


Fig 25: Practical SBFA for 23cm (13cm).

of about one half wavelength or slightly more. The rim height h is usually around one half wavelength. The directivity of such a simple antenna exceeds 16dBi with an aperture efficiency close to 100% corresponding to the third peak on the Ehrenspeck's diagram [2]. Again, most of the metal structure can be used as a radome and just the radiating aperture needs to be covered with a transparent cover.

A SBFA provides a -3dB beam width of about 30 degrees. The whole antenna structure is not critical and is able to operate over bandwidths of more than 10% of the central frequency. Since the SBFA reflector structure is rotationally symmetrical, the polarisation only depends on the feed. Two feed dipoles may be used for dual polarisation or circular polarisation.

4.2. SBFA for 23cm

The construction of a practical SBFA for 23cm (13cm) is shown in Fig 25

The front panel (radome) may act as a support for the small reflector, thus considerably simplifying the mechanical design of the antenna. The radome has some measurable effect on the SBFA and any dielectric should not be too thick. If only simple tools are available, then it

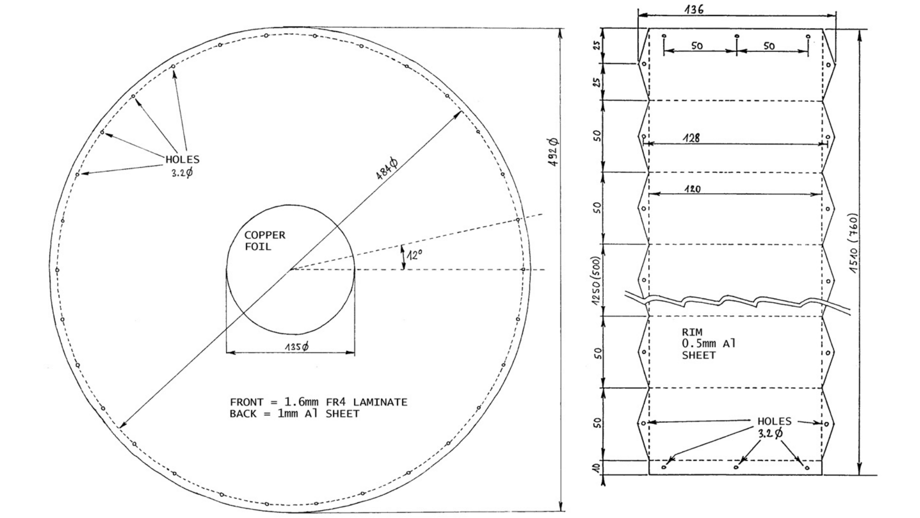


Fig 26: Mechanical components of the SBFA for 23cm.

makes sense to build the metal components of the SBFA from aluminium sheet and bolt them together with small M3 x 4 or M3 x 5 screws.

The front panel (radome) is a disc of 1.6mm (0.8mm for 13cm) FR4 laminate. The small reflector is a disc of copper foil (35um or thicker cladding). No etching is usually required. The copper cladding is marked with a sharp tip and the unnecessary copper foil is simply peeled off. The required mechanical components

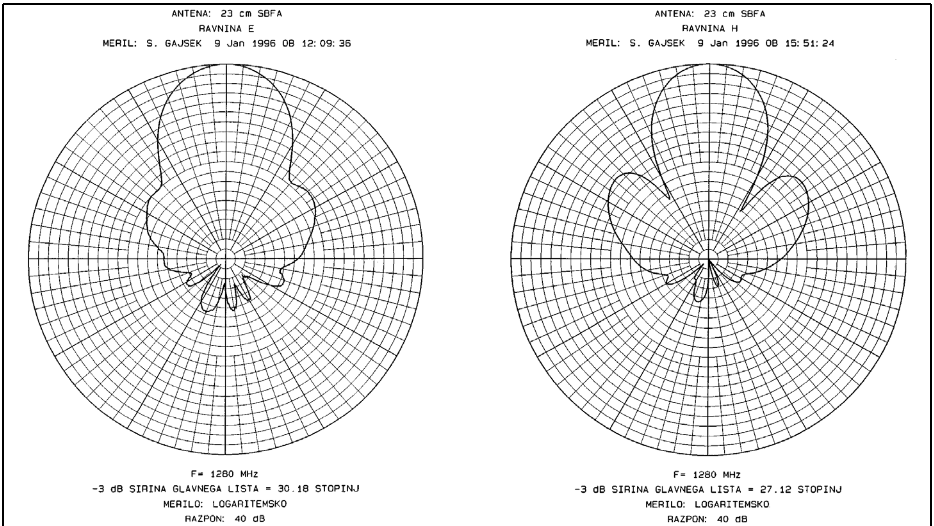


Fig 27: E plane and H plane radiation patterns of the SBFA for 23cm.

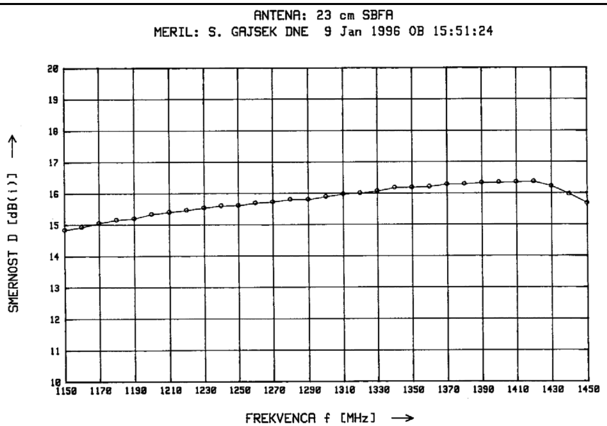


Fig 28: Directivity of the SBFA for 23cm.

for the SBFA for 23cm are shown in Fig 26.

The measured E plane and H plane radiation patterns of the prototype cup dipole are shown in Fig 27.

The measured patterns in both planes at a number of different frequencies were used to compute the directivity as shown in Fig 28.

4.3. SBFA for 13cm

The design of the SBFA can be easily scaled to the 13cm band. Since the SBFA is sensitive to the radome thickness, the latter has to be scaled to the higher frequency as well! The required mechanical components for the SBFA for 13cm including the radome from 0.8mm thick FR4 laminate are shown in Fig 29.

The antenna is first assembled together using just bolts, making all necessary

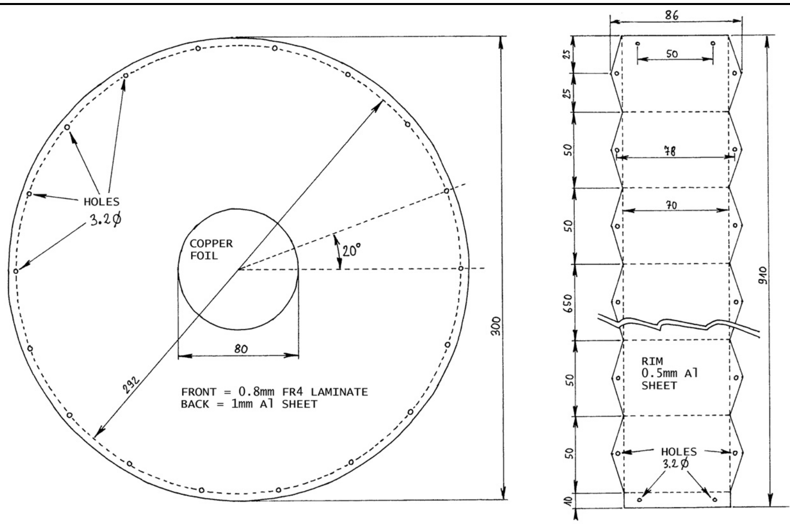


Fig 29: Mechanical components of the SBFA for 13cm.

Fig 30: Homemade SBFA for 13cm.

adjustments and checkouts. Afterwards the antenna is disassembled so that all seams can be sealed with small amounts of silicone sealant. Finally, do not forget a venting hole or unsealed seam in the bottom part of the antenna, where any (condensation) moisture can find its way out of the antenna! A homemade SBFA for 13cm is shown in Fig 30.

The measured E plane and H plane radiation patterns of the prototype SBFA for 13cm are shown in Fig 31.

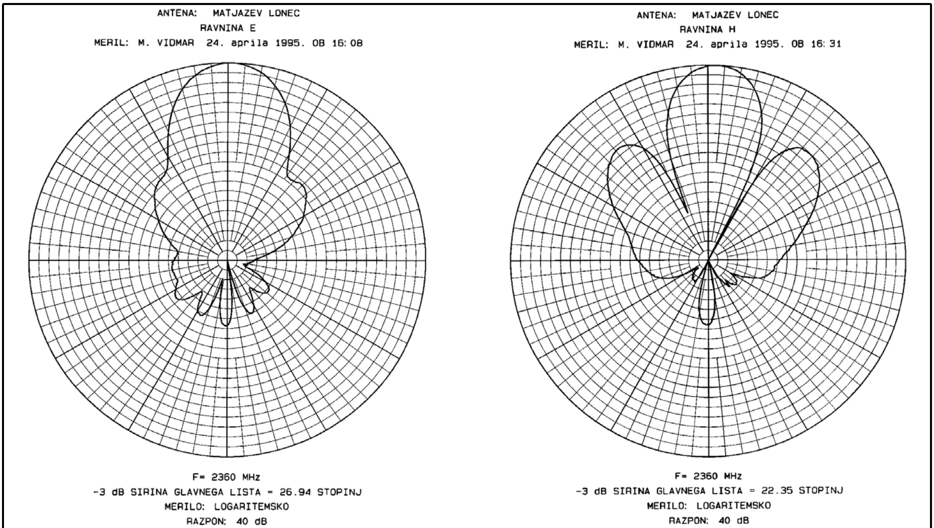


Fig 31: E palne and H plane radiation patterns of the SBFA for 13cm.

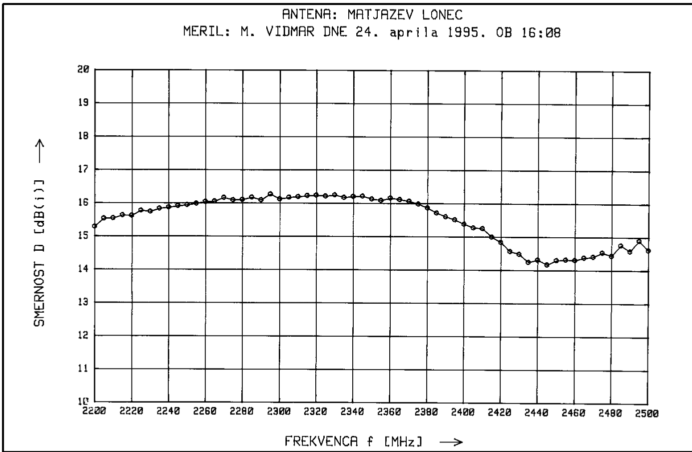


Fig 32: Directivity of the SBFA for 13cm.

The measured patterns in both planes at a number of different frequencies were used to compute the directivity as shown in Fig 32.

As the frequency increases, the H plane side lobes of both SBFAs for 23cm and 13cm increase. As the diameter of the antenna D exceeds 2.5 wavelengths, the side lobes become so large that the directivity of the antenna starts decreasing.

4.4. Feeds for SBFAs and cup dipoles

A half wave dipole is the simplest way to feed cup dipole or SBFA cavities. Microstrip patch antennas or rectangular or circular metal waveguides can also be used. A half wave dipole requires a balun to be fed with standard 50Ω coaxial cable.

Besides the directivity bandwidth of a cup dipole or SBFA, the gain bandwidth of these antennas is also limited by the impedance matching of the feed. In the case of a SBFA, the feed is enclosed between the large and small reflectors, resulting in a low radiation impedance and corresponding sharp resonance. The impedance matching bandwidth is likely much narrower than the bandwidth of operation of the SBFA cavity.

An impedance mismatch results in a loss of antenna gain. In the case of microwave cavity antennas, this is the only significant loss mechanism, since the electrical

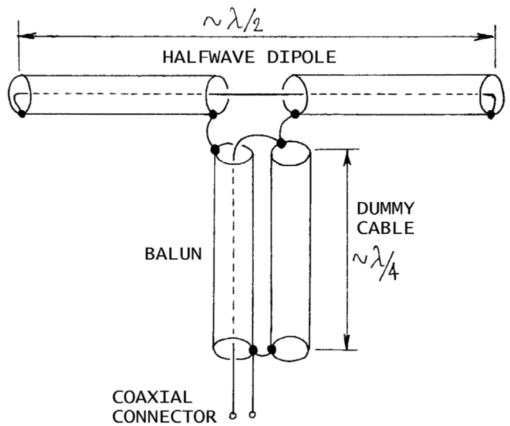
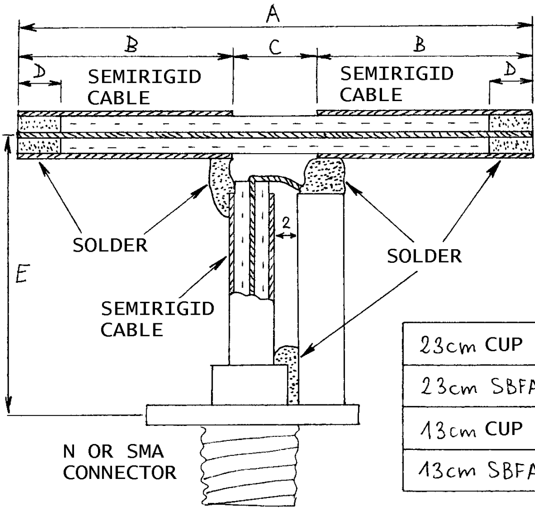


Fig 33: Dipole and balun wiring diagram.



	A	B	C	D	E	COAX
23cm CUP D.	105	48.5	8	4	60	UT-141
23cm SBFA	90	41	8	4	60	UT-141
13cm CUP D.	54	24	6	3	35	UT-085
13cm SBFA	45	19.5	6	3	35	UT-085

Fig 34: Feeds for 23cm and 13cm cup dipoles and SBFAs.

efficiency of the cavities themselves is close to unity. A good estimate for the antenna gain is therefore just subtracting the impedance mismatch loss from the directivity.

The antenna bandwidth can be improved by a broadband feed dipole. One possible solution is to build the feed dipole from semi-rigid coaxial cable and use its internal conductor as a reactive load to broaden the impedance matching bandwidth. The same type of semi-rigid cable can also be used for the balun including a dummy arm. The wiring of such a dipole and corresponding balun is shown in Fig 33.

A practical solution is to build the feed dipoles and corresponding baluns from UT-141 semi-rigid cable (outer diameter about 3.6mm) in the 23cm frequency band and from UT-085 semi-rigid cable (outer diameter about 2.2mm) in the 13cm band as shown in Fig 34.

A suitable coaxial connector for semi-rigid cable should be selected first. N connectors may be useful in the 23cm band. Smaller SMA or TNC connectors may be used in the 13cm band. While soldering semi-rigid coaxial cables one needs to take into account the thermal expansion of their Teflon dielectric!

The dipole is made by cutting the specified length "A" of semi-rigid cable. Then "D" millimetres of outer conductor and Teflon dielectric are removed at both ends. After this operation the outer conductor copper tube is carefully cut in the centre and both parts are pulled away to form the gap "C". Finally both dipole ends are filled with solder to connect the centre and outer conductors.

The published 23cm SBFA with the described feed achieves a return loss better than -10dB over the whole 1240-1300MHz frequency band. The 13cm SBFA design has a slightly higher directivity resulting in a narrower bandwidth. The 13cm SBFA with the described feed achieves a return loss of -10dB over the frequency band 2300-2360MHz.

The cavities of cup dipoles represent a different load for the feed dipoles; therefore the dimensions of the feed dipoles are necessarily different from those used

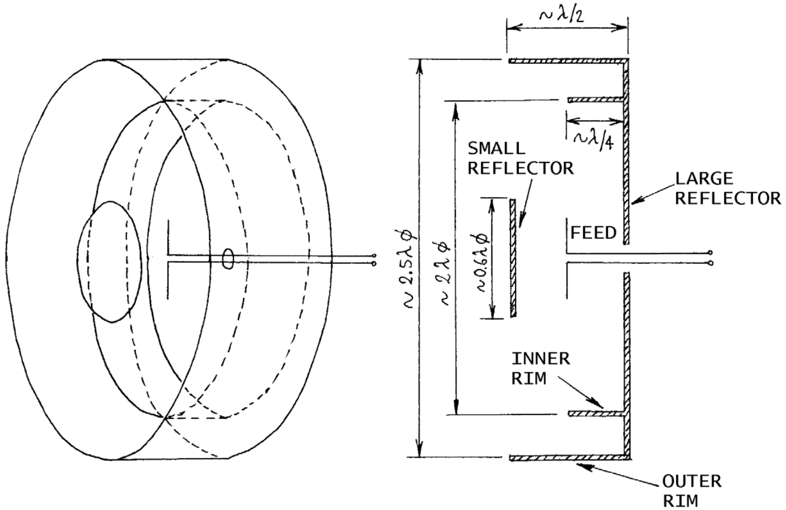


Fig 35: Double rim SBFA.

for the SBFAs. The impedance matching bandwidth of cup dipoles is much broader than SBFAs and a return loss of -15dB can usually be achieved.

5. Beyond the SBFA directivity

5.1. Double rim SBFA

The simplicity, efficiency and performance of the short backfire antenna suggests looking for similar antenna solutions also for a cavity diameter larger than 2.5 wavelengths and directivity larger than 17dBi. Since a SBFA roughly looks similar to a parabolic dish, a possible extension is to modify the large reflector of a SBFA towards a parabolic shape. Several different solutions have been described in the literature [1].

The simplest but not very efficient extension is the double rim SBFA. The latter includes a large reflector with two concentric rims. The inner rim is just a quarter wavelength high while the outer rim is one half wavelength high as shown in Fig 35.

The effect of two rims is barely appreciable. A maximum directivity increase of about 1dB can be expected when compared to a conventional single rim SBFA. As the directivity increases, the antenna becomes more sensitive to environmental conditions including the built in radome. The plots in Fig 36 show the difference between two double rim SBFAs for 13cm: one antenna without radome and the other with the aperture covered by a 1.6mm thick FR4 laminate:

As a conclusion, a double rim SBFA without radome provides about 0.5dB more directivity than a conventional SBFA at 2360MHz. Installing a 1.6mm thick radome from FR4 laminate, the directivity drops by about 1dB and the final result is 0.5dB less directivity than a conventional SBFA. The double rim SBFA is therefore an academic curiosity with little practical value.

A side result of all measurements is that a radome made from FR4 laminate has a

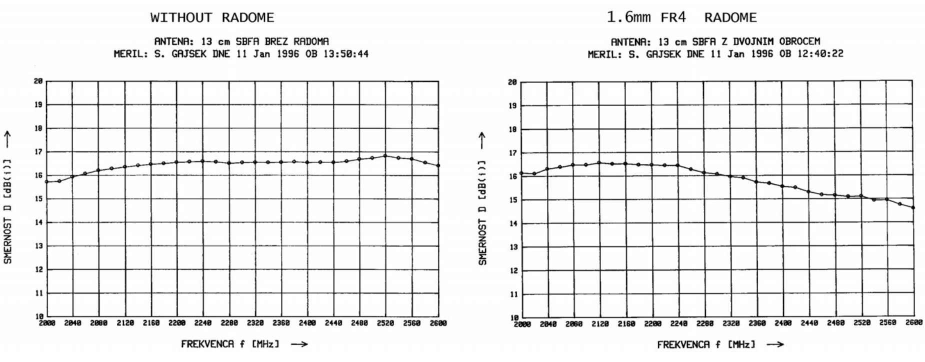


Fig 36: Radome effect on double rim SBFA directivity.

considerable effect on the SBFA performance already in the 13cm band. Therefore it is recommended to reproduce the described conventional SBFA with exactly the same materials, using 0.8mm thick FR4 or slightly thicker plexi-glass for the radome.

5.2. Archery target antenna

As the SFBA cavity becomes larger, additional circular waveguide modes are excited. Rather than changing the shape of the large reflector, additional structures can be placed to control the amplitudes and phases of different modes. Thinking in terms of wave physics, a collimating structure in the form of Fresnel rings is required. The SBFA is already the first representative of such antennas, placing a small reflector in front of the feed dipole to control the lowest order Fresnel zone.

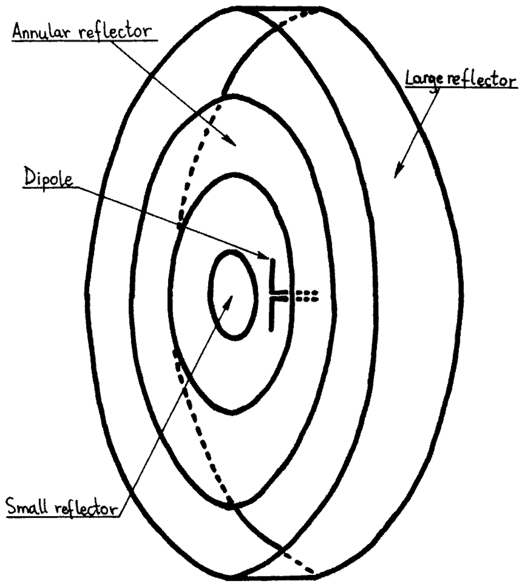


Fig 37: Archery target antenna structure.

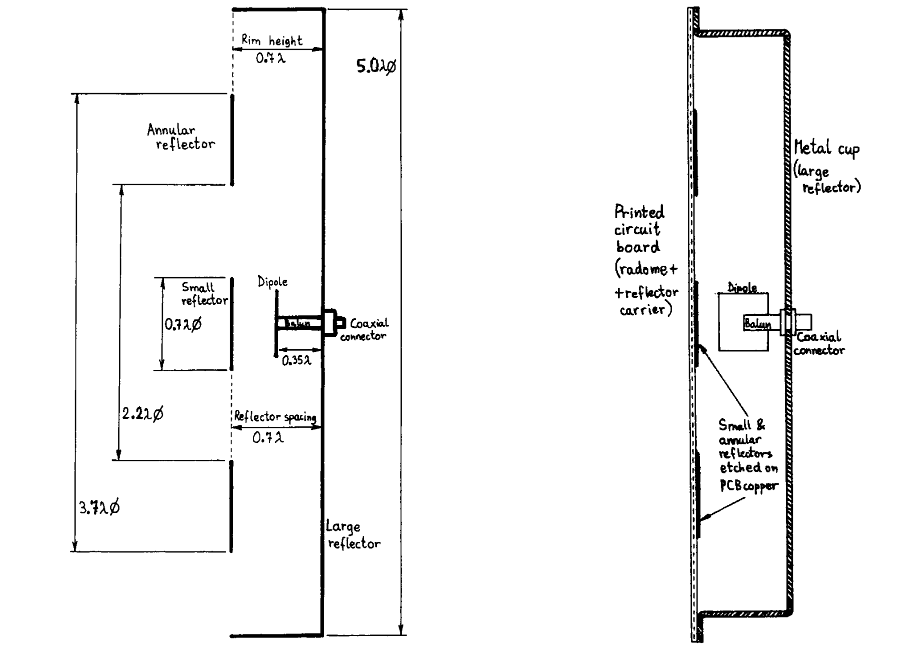


Fig 38: Archery target antenna design.

A further evolution of the above theory is a collimating structure including one small reflector disc and one annular reflector ring. Such a structure results in a rather efficient "archery target" antenna [3] as represented in Fig 37.

The "archery target" antenna described in this article achieves a directivity of 20.6dBi at an aperture efficiency of about 46%. The -3dB main lobe beamwidths are about 13.8 degrees in the E plane and 10.2 degrees in the H plane. This new antenna is simple to manufacture, since the supporting structure for the small and annular reflectors can perform as a radome at the same time.

Probably the "archery target" antenna could be further optimised. Some computer simulations suggest that both a directivity of 22dBi and better aperture efficiency could be achieved although at a reduced bandwidth. Last but not least, the structure could be extended further to include several concentric annular reflectors.

The successful "archery target" antenna design presented in this article includes a large reflector with a diameter of about 5 wavelengths, much larger than in a typical SBFA. On the other hand, the small reflector has a diameter of 0.7 wavelengths and is comparable to the SBFA. The annular reflector extends from an inner diameter of 2.2 wavelengths to an outer diameter of 3.7 wavelengths. The reflector spacing and rim height are identical and equal to 0.7 wavelengths and Fig 38 is also somewhat larger than in a typical SBFA.

The prototype antenna has a large reflector diameter of 570mm, an annular reflector with an inner diameter of 252mm and an outer diameter of 420mm and a small reflector with a diameter of 80mm. The reflector spacing and rim height are set to 80mm. The small and annular

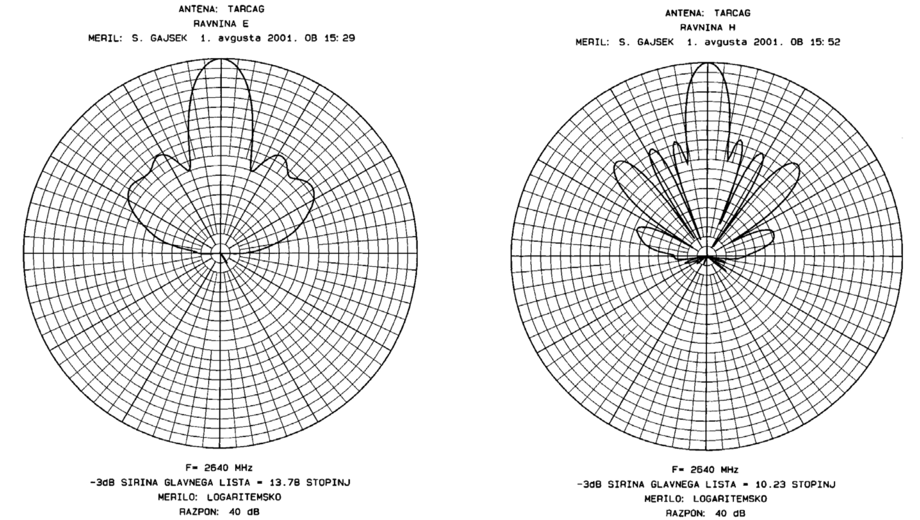


Fig 39: E plane and H plane radiation patterns of the archery target antenna.

reflectors are carried on a large dielectric plate: 0.8mm thick FR4 laminate with a dielectric constant of about 4.5. Although thin, this carrier plate has the effect of decreasing the optimum frequency by as much as 100MHz in the S-band frequency range.

This prototype antenna achieved the best directivity of 20.6dBi at an operating frequency of 2640MHz. The measured E plane and H plane radiation patterns shown in Fig 39.

The measured patterns in both planes at a number of different frequencies were used to compute the directivity as shown in Fig 40.

The first experiments with the "archery target" antenna were made with a simple thin wire half wave dipole feed. The dipole was positioned on the antenna axis of symmetry exactly halfway between

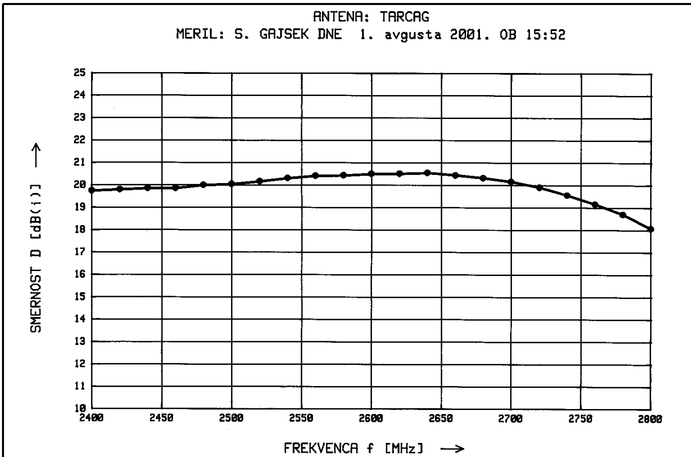


Fig 40: Directivity of the archery target antenna.

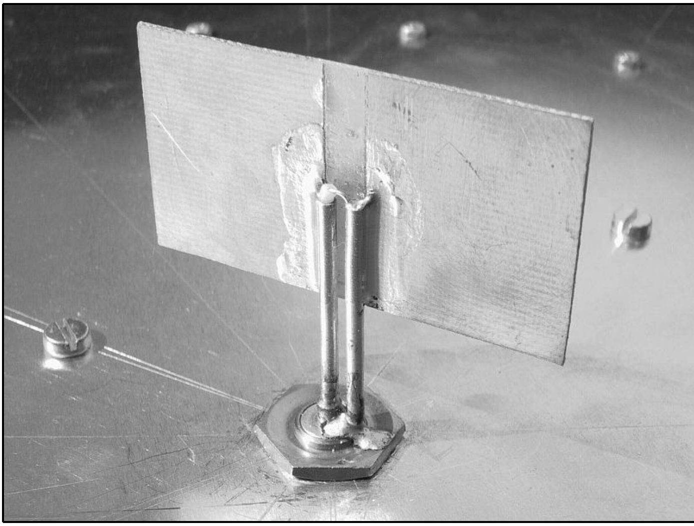


Fig 41: Dipole feed of the archery target antenna.

the small and large reflectors just like in a SBFA. Since the thin-wire dipole had a poor impedance match to a 50Ω source even over a narrow frequency band due to the antenna cavity loading, several other feeds were experimented.

Reasonable impedance matching (-15dB return loss over a 10% bandwidth) was obtained with a single wide dipole feed built on a printed circuit board as shown in Fig 41.

While experimenting with different feeds, small (up to +/-0.2dBi) but repeatable variations of the antenna directivity were observed as well. In particular, the directivity decreased when the wide dipole printed circuit board was installed parallel to the reflector plates. On the other hand, the directivity improved when the wide dipole printed circuit board was installed perpendicular to the reflector plates.

The feed radiation pattern can therefore contribute to a more uniform illumination of both annular apertures of the "archery target" antenna. Effects of different feeds on other cavity antennas (cup dipoles and SBFAs) were not experimented yet. The complete archery target antenna prototype is shown in Fig 42.

6.

Selection of the most suitable antenna

Although the whole family of microwave cavity antennas is very large, many of these antennas are not known to the wider public. Little if any serious articles have been published in the amateur radio literature. Therefore it was decided to write this article including the description of the most interesting microwave cavity antennas, their past experience, present performance and expected future developments. Fig 43 shows the 23cm & 13cm SBFAs used for 1.2Mbps packet-radio access.

Unfortunately, most people select an antenna only according to its directivity or gain. WRONG! There are many more selection parameters and all of them need to be considered: width and shape of the main beam, side lobe levels and directions, frequency bandwidth, sensitivity to environmental conditions and weather effects, ease of manufacturing etc.

Microwave cavity antennas may not provide the maximum number of decibels

Fig 42: Archery target antenna prototype.

for a given quantity of aluminium. This may explain why they are not so popular. On the other hand, microwave cavity antennas may be simple to manufacture, insensitive to manufacturing tolerances, have low side lobe levels, be reasonably broadband, easy to make weatherproof and insensitive to environmental conditions, quickly rejecting rain drops, snow and ice from accumulating on their radiating apertures.

While designing a radio link, the first consideration should be the antenna beamwidth according to the desired coverage. Antenna arrays should only be considered in a second place, when a single antenna is unable to provide the desired coverage. The most common mistake is to select the antenna with the largest number of decibels. Its beam may be too narrow, its large side lobes may pick interference and multipath and its deep nulls in the radiation pattern cause dropouts and pointing problems.

This article includes detailed descriptions of different cavity antennas: simple horn (7dBi & 90 degrees), cup dipole (12dBi & 50 degrees) and SBFA (16dBi & 30 degrees). All these designs are well tested and foolproof: it is just a matter of selecting the right design for a particular application. A SBFA is an excellent replacement and performs better than small (less than 1m diameter) parabolic dishes with poorly designed feeds at relatively low frequencies (below 2GHz).

On the other hand, a successful duplication of the "archery target" antenna (20.5dBi & 12 degrees) and its likely future developments requires some skill and appropriate test equipment. The intention of this article was to show that

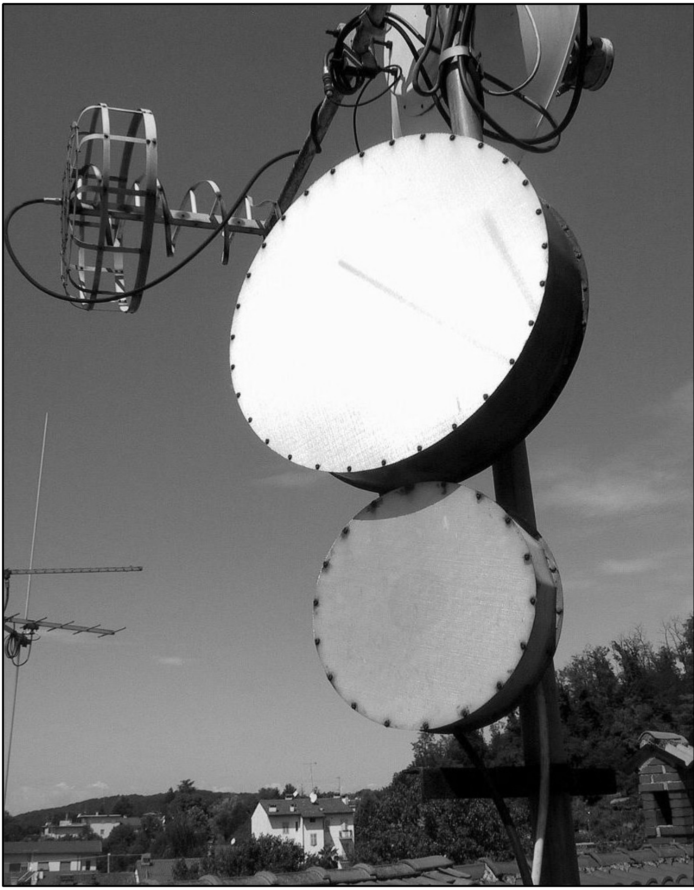


Fig 43: 23cm and 13cm SBFAs used for 1.2Mbps packet radio access.

there is still development going on in the antenna field, providing some hints to serious antenna experimenters.

7.

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[3] Matjaz Vidmar: "An Archery-target Antenna", Microwave Journal, May 2005, pp. 222-230.

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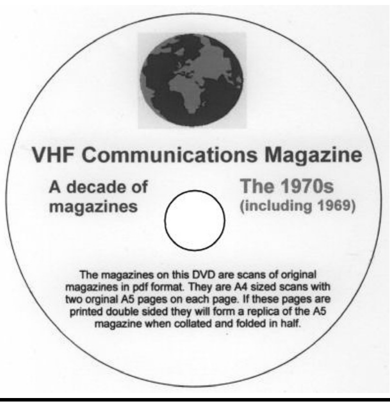

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Roy Stevenson

A Stroll Through Military Communications History

1. England's Royal Signals Museum Highlights Developments In Communications Warfare

A Saracen Armoured Command vehicle and an AFV439 Armoured Communications Vehicle guard the parking lot outside the Royal Signals Museum, located at Blandford Camp in Dorset, England. The large, gray, metal-walled repository of history opened in 1997 to showcase the history of the Royal Corps of Signals. It's also a crash course on the science and technology of military communications from the Crimean War to the Gulf War.

Providing marvellous insight into a relatively little known area of military operations, the museum tells about the men and women who operated signalling equipment and their contribution to England's history in the past 150 years. There's also a great selection of books, souvenirs, and gifts about military signals and radios found in the bookstore by the front entrance. You'll need two to three hours to view this museum.

Fig 1: The Royal Signals Museum at Blandford Camp in Dorset.

Fig 2: The sign that says what the museum is about.

There are enough radios and communications equipment displayed here to qualify it as nirvana for radio and signals enthusiasts. In addition, some unsung but fascinating aspects of military communications are represented in its exhibits, such as women at war, behind enemy lines, D-Day, special forces, animals at war, dispatch riders, military signalling vehicles, and antique signalling equipment.

2.

The Evolution Of Communications

The first exhibits, a combination of reader boards and display cases, tell the general history of military communications. Runners provided the first form of long-distance signalling, followed by men on horseback. Another primitive but effective method of signalling used chains of soldiers on hilltops shouting messages to each other, a method the Persian King Darius used in the 5th century B.C. Drums and trumpets were also used. The Greeks had a torch telegraph system and the Romans used coloured smoke as a means of communications.

Fire signals, lights in signal towers, and beacons were all early warning methods of impending invasion, and were put to use during Napoleon's threatened naval invasion of England in 1795. The Duke of Wellington organized regular mounted messengers, an approach that evolved into the motorbike dispatch riders in the 20th century. You'll see a beautifully restored Triumph motorcycle and several other motorbikes with models of signals riders in uniform.

The History of the Heliograph exhibit tells how reflected sunlight was used to flash messages as long ago as the Greek and Persian Wars, when the combatants used polished shields as mirrors. Depending on the size of the mirror used, messages could be sent over distances over as great as 80-plus miles. Flags or banners were also used later. Heliographs communicated messages during WWII as late as 1941.

3.

Technology Enters The Picture

The History of the Royal Corps of Signals theme rooms trace the Corp's evolution from men shouting to each other to modern radio transmissions. In 1870 the War office formed a Telegraph Battalion from the Royal Engineers, which served from 1884 into the late 19th century, and brightly polished vintage brass and wood telegraphs are displayed.

You'll see many other antique pieces of communications equipment here. Two

Fig 3: A display of a communications truck.

years after Alexander Graham Bell invented the telephone, in 1876, the U.S. Army began using telephones, several early examples of which are exhibited, including the C Mark 1 Ericsson portable military telephone (which weighs 18 pounds), the C Mark 2, D Mark 1, and D Mark 3 models.

The Admiralty Shutter Telegraph System on display proved that even simple systems could be highly effective. Its three chains of huts with signalling frames and shutters were set up five to 10 miles apart, running from London to Deal, Sheerness, and Portsmouth in the south in 1795. Its purpose was to alert the Admiralty in London in the event of an invasion by Napoleon's Navy. This communications system was so fast that messages took only 15 minutes to pass the 238-mile chain from Plymouth to London. If the message was prearranged, it took only three minutes.

A large number of World War I and II displays show how the Royal Signals Corps expanded, developed, and used improved communications equipment as the wars progressed. As the telephone became the prime means of communications in World War I, the Royal Engineer Signal Service burgeoned from 6,000 to 70,000 by 1917. During World War II it mushroomed to 8,518 officers and 142,472 soldiers, with 4,362 killed in action.

4. Wireless Emerges

The museum also illustrates how military inventions enter civilian life after a war

Fig 4: Some of the communications vehicles used by RSM.

ends. For instance, because telephone wires were constantly cut by artillery fire, military communications took a great revolutionary step forward in World War II with the transition to wireless radio. Wireless radio became common in civilian communications after the war, thus shaping today's communications.

As the Royal Signals reorganized and retrained in World War II, their equipment became more compact, lightweight, and easier to operate as they geared up for a more mobile type of warfare. By now indispensable to all of the allied services, they worked with the Royal Navy as Beach Signals Units or trained as parachutists to provide communications for commandos or Special Operations Executive (SOE) agents (see "A Spotlight On The SOE").

The World War II Wireless Sets display shows how military wireless rigs had to operate a number of interference-free channels, offer good range, be robust yet portable, as well as easy to operate and simple to maintain. The 1943 Wireless Station No. 10 is one example of such then-state-of-the-art equipment. It used radar techniques to beam eight telephone channels over a duplex radio path between land links and was used after the D-Day landings. Housed in a four-wheel two-ton trailer, an example of which is on exhibit, its innovative techniques made it the technological wonder of its time, a forerunner of modern day radio relay equipment and the radiotelephone.

Fig 5: D-Day radio and folding bicycle.

5.

Clandestine Radio

The "Deception" exhibit shows how special signals units simulated radio traffic of whole army groups to deceive the Germans. Vans travelling around south-eastern England emitted vast volumes of fake wireless traffic simulating troop movements. The illusion convinced the Germans that the U.S. 3rd Army was in this area, waiting to embark for the Pas de Calais area, when it was actually 150 miles away in Cheshire.

Code-named Operation Fortitude, this operation was so effective that the Germans held several of their divisions back around Pas de Calais for several weeks after D-Day. They believed another army would be landing at Calais because of the heavy signals traffic they were intercepting from these deception units.

The Royal Signals was also involved in every phase of Operation Overlord - the Battle of Normandy - and every aspect of the D-Day landings. Among their tasks were creating signals communications for the combined headquarters and for the assembly of troops for embarkation, creating fake radio traffic to deceive the

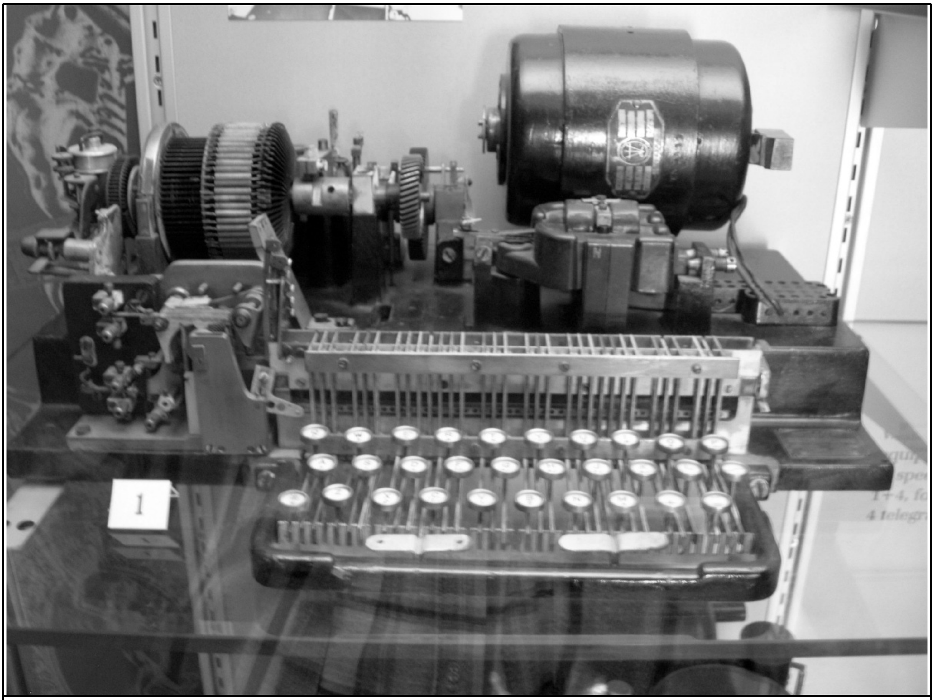

Fig 6: Encryption machine.

enemy as to landing sites, preparing cross-channel communications links, and providing beach signals for the landings. They also allocated radio frequencies to ensure there was no unintentional jamming and re-established telephone and telegraph lines once they had been captured and repaired.

As the Allies moved through Northwest Europe, Royal Signals laid hundreds of miles of telephone and telegraph cables. Communications to the United Kingdom were made via a cable laid under the Channel connected to signal stations at Bayeux and Cherbourg in France.

The Y Service Units comprised another clandestine intercept group, serving in England, which was staffed by Royal Signals men and women. They listened to enemy radio messages, copied them down, and sent them to the huge Bletchley Park decoding centre, which they knew only as “the big place.”

The Enigma Codes and Code Breaking gallery relates the history of wartime codes and code breaking centred at Bletchley, highlighting the German code encryption machine, The Enigma. There’s an authentic enigma machine on display.

An exhibit about the General HQ “Phantom” Liaison unit tells how its purpose was to keep allied air forces and artillery aware of where the front lines of Belgian and British troops were on the ground. Using armoured cars, motorcycles, and radio sets, this group performed ground reconnaissance to locate the enemy forces. After the evacuation of allied forces from Europe, the Phantom unit of 48 officers and 479 soldiers was tasked with observing possible seaborne landing areas in Southern England. They were to give an early warning of the anticipated

Fig 7: An Enigma machine.

German invasion in late summer 1940. Some No. 11 wireless sets they used are on display.

6.

Other Points Of Interest

A Pigeons at War display pays homage to the plucky little bird used in military communications. They carried military messages as early as 1815 for Wellington at the Battle of Waterloo. In World War I, 22,000 pigeons flew in service, from 150 mobile lofts, with 400 loftsmen to tend them.

A Far East Prisoners of War display tells of the more than 100,000 Allied Prisoners of War who were held by the Japanese and forced to work in extremely harsh conditions. A homemade receiver set used by the POWs to listen to allied radio news sits in a glass case.

There are also displays on conflicts and wars since World War II, including Malaya, Korea, Northern Ireland, the Falklands War, The Gulf War, and Kosovo, Macedonia, and Bosnia. Several modern signals vehicles stand on display to illustrate the evolution and increasing sophistication of these mobile headquarters.

7.

If You Visit…

Royal Signals Museum, Blandford Camp, Dorset, DT11 8RH, England

Fig 8: Radio used by SOE.

Website: http://www2.armynet.mod.uk/museums/royalsignals/

The easiest way to get to the museum is by car, although it can be reached by bus from Salisbury or Weymouth. The 30-minute bus ride through the English countryside is most enjoyable, giving you a chance to see the small towns, green fields, hedges, and narrow country roads typical of rural England.

You'll need your passport to enter The Royal Signals Museum because it's located on the Blandford Camp Army Base. A soldier will get on the bus at the entrance to the camp, check your passport, and then get off as the bus exits the other end of the camp.

- Opening Hours: Monday to Friday (all year) 10a.m. to 5p.m.
- Saturday and Sunday & Bank Holidays 10a.m. to 4p.m. (Last entry 3p.m.)
- Admission Charge:
- Adults: £7.00
- Senior Citizens and concessions: £6.00
- Children (5 – 16): £5.00
- Family Ticket (2 + 2): £20.00

Roy Stevenson is a freelance writer based in Seattle, Washington. He writes on Military History, Travel and Culture, Sports, Fitness, and Film Festival Reviews.

8. A Spotlight On The SOE

The SOE gallery is especially interesting and explains the history and adventures of this brave group of spies, many of who were caught and executed by the Germans. One of Churchill's brainchildren, he told its director to "set Europe ablaze." Their mission: "to co-ordinate all action by way of subversion and sabotage against the enemy overseas." By summer 1944 the SOE had grown to 10,000 men and 3,200 women, of whom about 5,000 were field agents overseas in France, Germany, and Holland.

SOE agents worked closely with the resistance forces and used all manner of advanced secret equipment, including plastic explosives, limpet mines (for attaching to armoured vehicles and ships), and the Mark III suitcase radio set.

Military radios of the time were too large and heavy for clandestine operations, so a range of radios was designed to fit into suitcases. Despite the size and weight reductions (the early A Mark II radio was housed in three metal boxes that fitted neatly into a suitcase), it still weighed 22 pounds and proved difficult for female agents to carry at speed over long distances. This model gave an output of 5 watts over 3 - 9MHz. The next model, the A Mark III, weighed only 8.8 pounds with 5 watts output and 3.5 - 16MHz frequency range, and provided a 500-mile range. Needless to say, all SOE operatives had extensive training in communications devices.

It was vital that the secret agents kept in touch with SOE HQ for supplies to be sent. Members of the Royal Signals and Women's Transport Service, known as FANYs (First Aid Nursing Yeomanry) provided the staff for wireless operators and coders, playing a major part in their successful operations. The FANYs were women trained as first aid specialist plus other important duties such as signalling. You'll see some suitcase wireless radios on display in this section.

9.

History of the royal signals corps

The precursor to the Royal Signals Corps was formed in 1869 as the Signal Wing of the Royal Engineers, followed a year later by C Telegraph Troop, to provide telegraph communications for the British field army. Captain Montague Lambert was the first Commander of the Telegraph Troop. In 1908 the Royal Engineer Signal Service was formed. The modern Royal Signals was born on June 28, 1920, when Winston Churchill signed a royal warrant decreeing the formation of a 'Corps of Signals'. Six weeks later the King conferred the title 'Royal Corps of Signals'.

The function of Royal Signals has always been to provide communications for the army, and its methods have changed and evolved with each new development of modern communications. Today's Royal Signals Soldiers have been deployed to every theatre where British Military forces have been seen action. These include Bosnia, Croatia, Yugoslavia, Cambodia, Rwanda, Angola, and the Persian Gulf. There are three signals brigades in the regular British Army, comprising over one dozen Royal Signals regiments attached to the regular army and over one dozen regiments attached to the Territorial (reserve) Army.

The Royal Signals Gallantry Awards Honours Board in the museum lists all Royal Signals soldiers who received medals for their bravery.

Henning C. Weddig, DC5LV

The AGC module

Part 2: Continuation from VHF Communications Magazine 1/2008

7. Authors's note

Although only DC voltages are processes in the AGC section up to the two amplifier stages before rectification of the high frequency output voltage of the IF amplifier, no technical RF problems should have been expected. Nevertheless the author experienced many bad surprises that delayed part 2 of this description considerably.

The basics of control engineering had to be endured again to find the solution of these problems.

There is extensive literature on the topic of control engineering. However the ones that cover the technical aspects of controlling the non-linear behaviour of an automatic gain control are rare.

During a lecture by Thomas Valten [18] it became clear how far the gain must be driven in order to realise automatic gain control of a radio with digital signal processing.

The computation of an automatic gain control has not been covered in amateur radio literature to date this article will correct that.

7.1. First measurements with the AGC module

After the circuit [1] was finished, constructed and completed the manuscript was produced and submitted for publication. Subsequently, further measurements of the prototype were made. These showed that the rise time of the AGC Short control voltage was around 5 times greater than calculated for RF level changes. It was assumed that the internal resistance of the last stage of the AGC amplifier was too high. This assumption was therefore inserted as a comment to the results of measurement. The circuit could be published if there was a simple solution.

This solution was to make diode D4 charge only one small value capacitor. An operation amplifier then buffers the parallel voltage. The low impedance output drives the actual time determining RC components. A new circuit diagram was produced and it was that diagram that was published. Due to lack of time because of an official travel arrangement the circuit was not tested.

Unfortunately with the circuit shown in Fig 2 C17 prevents the AGC Short from discharging quickly. Thus the decay time constants for AGC short and AGC long are the same. This problem was only discovered when the new printed circuit board was tested.

This problem could be solved with a further buffer amplifier connected between IC3a and IC4. The output of the buffer amplifier IC3a is the AGC Short output. IC3a drives IC4a that charges the

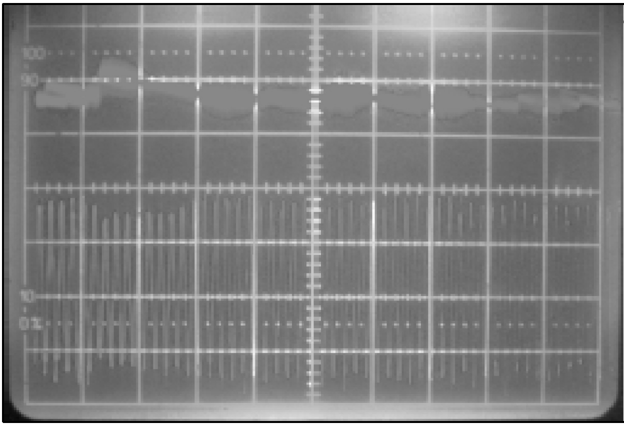

Fig 8: Unstable AGC. Upper curve: Control voltage (20mV/div). Lower curve: demodulated signal (200mV/div.). Sweep: 10ms/div. Clear breaks of the modulated signal during level changes. AGC voltage is overlaid with RF disturbances.

long AGC capacitor C17 via D19 and R30 C17.

IC4 is now a CA3240 dual amplifier like IC3. With these changes a further printed circuit board was necessary.

Also the operating points of T1 and T2 were examined and found to need improvement. Therefore both resistors R2 and R12 were increased to 2.7kΩ. The quiescent voltage at the collector of T1 is now approximately 6V. The collector current of T1 was increased to approximately 5mA with a smaller emitter resistor and 10mA for T2. With these changes the gain of the two stages increases. The over regulation with level changes is however improved.

Because of the higher gain of T1 and T2 the information signal at the output of the IF amplifier in the regulated state is approximately 10dB low when the AGC module is connected to the IF amplifier. It is only -40dBm instead of -30dBm as shown in the requirement specifications (see [2 - 5]).

The lower output level makes the signal signal-to-noise ratio worse by approximately 10dB because the broadband noise from the IF amplifier remains the same. Changing R9 to 47Ω and R18 to 33Ω can correct the gain.

The lower gain of the stages around T1 and T2 restores the regulated level of the IF amplifier to the desired value of –30dBm. The SINAD at nominal sensitivity (point of regulation) can now be achieved.

7.2. Measurements of the rise time with level changes

A control voltage rise time of 1ms on St5 (VAGC/MGC out) was expected with the RC combination R23 = 1kΩ, C17 = 1µF with a signal level change of >-30dBm from a signal generator at the RF input of the AGC module.

For this test the AGC module was connected to the IF amplifier (VHF Communications Magazine 3/2007) and the demodulator output used for measurements. A second signal generator was used as a BFO for the product detector.

7.3. Stability of the IF amplifier and AGC module control loop

Why were there strange breaks in the AF signal envelope despite a sufficiently high and constant input level (-80dBm) and why at the same time were there breaks in the control voltage?

The breaks in the audio signal were obviously a consequence of the peaks in the control voltage. But why were there these control voltage peaks? Is the regulation unstable?

A screen photograph of this condition is show in Fig 8. The breaks in the demodulated signal are clearly during the positive level increases of the AGC despite a constant RF input signal. The AGC voltage is superimposed by high frequency disturbances at a frequency that cannot be seen in Fig 1. Actually the control voltage was sinusoidal with varying regulation because the rise and fall decay time constants are different. The assumption was that the regulation was unstable.

As a test C17 was increased to 100µF, this brought peace to the previously erratic control voltage. The assumption of unstable regulation was thus proven.

The test with the large capacitor value should show if the instability is in the complete control system due to incorrect design of the time determining RC components, or other causes e.g. feedback through the supply voltages to the individual modules.

8.

Optimisation of individual circuits

Following this disastrous discovery an investigation and optimisation of the individual circuits is required to correct the control characteristics of the overall system – IF amplifier and AGC module. However optimisation without precise knowledge of the theory is not advisable. It is necessary to do battle with control engineering. Key words belong to this theory such as transfer function, Laplace transform, pole zero diagrams, Nyquist theory, Bode diagram, PT1 and PT2 and PI or PID automatic controllers.

8.1. Literature search

Using the Internet the author found the literature [2]. This deals with the basics of automatic control loops and non-linear automatic control loops. However formulae and data for the rise time and step response in closed automatic control loops are missing.

The remarks of the authors in [3] and [4] are not simple to reconstruct, the units dB, dBm and dBV are mixed. Also the formulae are full of uncommon symbols making heavy reading. The reason is that in the automatic control loop both there are two types of gain, one in the high frequency range and another voltages in the video range i.e. voltages at the output of a rectifier. Therefore the designation dBm is used for high frequency and dBV for the stress ratios in the video range. The problem of the different units could be overcome with a skilful standardisation.

In [5] the influence of a crystal filter on the stability an automatic control loop is discussed (chapter 5.6.4). Comparing the mathematical treatment of the automatic control loop certain similarities were discovered to the literature in [7].

The literature [2], [3], [4] and [5] refer to further literature [7 to 14] that are concerned with the calculation of automatic gain regulation. The oldest literature originates from 1948.

The author was amazed to read in [6] from 1966 that the problem of instability of AGC in a receiver is treated in great detail. Unwanted phase shifts as function of the magnitude of the IF amplifier control voltage and the phase response of the IF crystal filter are described but no formulae are included in the newest version.

The literature [20] gives a good overview of coupled amplifier stages, [21] an understandable introduction to control engineering, [22] is clearly written and supported with many good examples. In [23] the terms of control engineering are clearly described.

In order to understand the differences between nonlinear and linear automatic control loops in the following, first the linear automatic control loop is to be described.

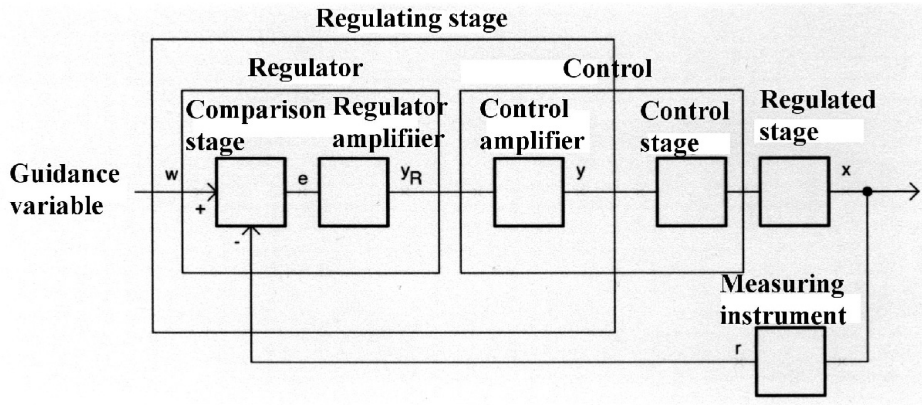

Fig 9: Block diagram of a control system according to DIN 18226, part 4.

8.2. The linear automatic control loop

8.2.1. Definition of Control and Regulation

Control

From [23] control is a procedure where one or more inputs of a system affect a process variable. The value of the process variable is not examined so that a possible deviation can affect the control process e.g. caused by outside disturbances.

The characteristic of control is an open loop system.

Regulation

For regulation the size of the thing being regulated (controlled variable x) is measured and compared with a given value (reference w).

If a difference (control difference e or offset xw) exists between these two an adjustment process is introduced dependent on the measured difference to harmonise the controlled variable with the reference.

The characteristic of regulation is a closed loop system.

8.2.2. The standard automatic control loop

In many textbooks examples of automatic control loops are given however the definition of the signals within the block diagrams are frequently missing.

An exception is [17] where on the pages 26 and page 27 there is a block diagram showing regulation of a simple linear standard automatic control loop according to DIN 19226 part 4. To assist understanding both are shown here.

The block diagram in Fig 9 shows a regulated system. The control mechanism consists of a comparison stage and a control stage that together form a servo unit. The output signal is taken from the output of the controlled system and fed to the comparison stage as signal r. All components are used to develop the so-called standard control system shown in Fig 10

The reference w is fed to the control stage. The output signal y of the control stage feeds the controlled system whose output, x, is fed either directly or via a measuring instrument to the comparison stage and subtracted from the reference. In the controlled system the variable

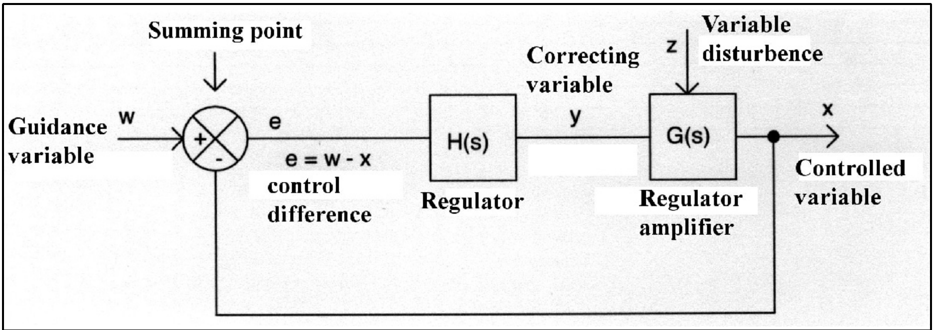

Fig 10: Block diagram of a standard linear control loop.

disturbance z can also change the output signal. The measuring instrument should not falsify the result of measurement, r = x and in Fig 3 it is omitted.

The input signal of the control stage, e, is the difference of the reference w and the output signal x,

$$e = w - x$$

Using a comparison stage has a crucial consequence: the error e is zero if x and w are the same. In this case the signal for the control stage is zero so it has no input signal. From this fact we can conclude that a small error signal, e, must be present.

8.2.3. Definition of the signals

The definition of the symbols and the abbreviations used for an automatic control loop are described in [23]. In the German version of DIN 19,221 the German symbols are used, these correspond to the international symbols in the International Electronic Commission 27-2A publication:

x (International Electronic Commission main symbol: y)

In an automatic control loop this is the process variable x that is to be regulated.

w (International Electronic Commission main symbol: w)

This is also called the reference and gives the value that the process variable is to assume (desired value). Their physical value may take the form of a mechanical or electrical value (strength, pressure, current, voltage etc.). It is compared in the closed loop system with the process variable x.

r (International Electronic Commission main symbol: f)

The value from measurement of the process variable that is fed to the comparison stage.

e = w - x (International Electronic Commission main symbol: e)

The input of the control stage is the difference of the reference and process variable calculated by the comparison stage. If the effect of the measuring instrument is considered then: e = w - r.

$$xw = x - w$$

The definition equation shows that the offset has the same value as the control difference e, but the reverse sign. If the measuring instrument is included then:

$$xw = r - w.$$

y (International Electronic Commission main symbol: m)

The correcting variable is the initial value of the controlled system. It depends on the attitude of the control parameters as well as on the value of the offset.

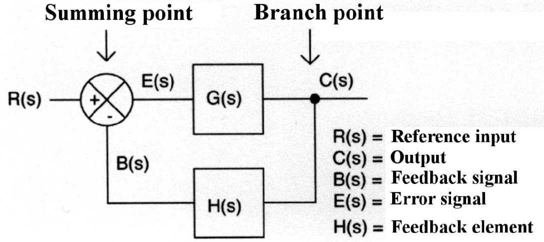

Fig 11: Block diagram of a coupled system.

yr

If the controlling system is divided then yr is the factored initial value of the controlled system.

z (International Electronic Commission main symbol: v)

Variable disturbances affecting the control loop that effects the controlled variable in unwanted way. It is a task of the regulation system to compensate for this influence.

yh

Within the setting range yh is the correcting variable y that can be given by the controller.

8.2.4. Ambiguity

Often it is not clear where the output signal of the control loop lies. It could be the output signal that is fed back to the comparator to be subtracted from the guidance signal w.

The output signal can also be from an arrow directed outward that does not go to anywhere else in the block diagram. According to Fig 10 the output signal is the signal x.

In reference [17] Fig 1.13 and Fig 1.14 the output signal, x, is the engine speed. A tacho-generator is used to transform this before it is fed to the comparator stage. Similar deviations are represented in the Fig. 1.15 and 1.16. The tacho-generator is a measuring instrument as shown in Fig 2, this converts the output signal into another dimension (number of revolutions per minute into voltage) so that two physically identical values can be processed by the comparator stage.

A further example of an automatic control loop shown in Fig 11, it is taken from reference [15] illustration 3-5 (closed loop system). The output of the automatic control loop is the output of stage G(s). R(s) is the input signal (reference), H(s) the automatic controller stage. The derivation of the formulae on page 61 of this reference are not easy to understand, unfortunately numerical examples are used. If numbers are used, at first sight illogical results are produced that are confusing to interpret.

8.2.5. Calculation of the open control loop

A transfer function (open loop transfer function) of a stage is the relationship of the output signal to the input signal. From Fig 11 the transfer function of stage G(s):

$$G(s) = \frac{C(s)}{E(s)} \qquad (1)$$

The transfer function of stage H(s) is:

$$H(s) = \frac{C(s)}{B(s)} \qquad (2)$$

If the connection at the output of stage H(s) is opened, the total transfer function of both stages is the product of the transfer functions of G(s) and H(s), B(s) is the output, E(s) the input:

$$\frac{B(s)}{E(s)} = G(s) \cdot H(s) \qquad (3)$$

The relationship of the output signal C(s) to the error signal E(s) is called forward transfer function G(s):

$$G(s)=\frac{C(s)}{E(s)} \qquad (4)$$

8.2.6. Calculation of the closed control loop

The transfer function if the connection is closed (closed loop transfer function) with C(s) as the output signal and R(s) as input signal is deduced as follows:

In the open case C(s) was the output signal and R(s) was the input signal was, now the signal directions are turned around, see also [24]:

$$C(s) = G(s) \cdot E(s) \qquad (5)$$

The error signal E(s) is the difference between the reference signal R(s) and output signal of the stage H(s):

$$E(s) = R(s) - H(s) \qquad (6)$$

The output signal B(s) is the forward transfer function described above and therefore the product of C(s) and H(s):

$$B(s) = C(s) \cdot H(s) \qquad (7)$$

With (7) transposed into (6) results in:

$$E(s) = R(s) - H(s) \cdot C(s) \qquad (8)$$

and (8) in (5) gives:

$$C(s) = G(s) \cdot [R(s) - H(s) \cdot C(s)] \qquad (9)$$

Since the transfer function of the closed control loop is the quotient of the output signal C(s) to the input signal R(s). Transforms (9) by multiplying out the right bracket:

$$C(s) = G(s) \cdot R(s) - H(s) \cdot C(s) \cdot G(s) \qquad (10)$$

Bring the second term to the right side of the equation:

$$C(s) + H(s) \cdot C(s) \cdot G(s) = G(s) \cdot R(s) \qquad (11)$$

Exclude C(s) from the left side of the equation:

$$C(s)\,(1+H(s) \cdot G(s)) = G(s) \cdot R(s) \qquad (12)$$

Divide both sides of the equation by R(s) and transpose the bracketed term:

$$\frac{C(s)}{R(s)}=\frac{G(s)}{1+G(s)\cdot H(s)} \qquad (13)$$

Multiplying equation (13) by R(s) gives the output signal C(s):

$$C(s)=\frac{G(s)}{1+G(s)\cdot H(s)}\cdot R(s) \qquad (14)$$

Example:

G(s) = 100
H(s) = 10

Both values should be real.

G(s) is called the control block in most literature and H(s) is the regulator.

Then:

$$C(s)=\frac{G(s)}{1+G(s)\cdot H(s)}\cdot R(s)=\frac{100}{1+100\cdot 10}\cdot R(s)=\frac{100}{1001}\cdot R(s)=0.0999\cdot R(s) \qquad (15)$$

From this example it is amazing that despite the high forward gain of G(s) and the lower gain of the regulator H(s), the overall gain of the closed control loop falls i.e. C(s) / R(s) is 0.099. This relationship does not change if other values are used for G(s). The reason lies in the fact that G(s) occurs both in the numerator and denominator of the equation.

The interpretation of this result is contradictory. The overall gain becomes smaller if higher values are used for H(s). This means that automatic controllers (and controlled system) should have as high a gain as possible in order to keep the control error small.

How is the output signal C(s) to be understood? It is only the output signal of the G(s) stage; it does not have to be that of the control loop.

If one proceeds with above considerations from the model of the approximately coupled

Using this information for an operation amplifier circuit then G(s) is the operational amplifier and H(s) the negative feedback (a voltage divider). In this case the transfer function of the controller H(s) is always 1 so that for this case the overall gain is 1. Active negative feedback with another amplifier is not usual in operational amplifier circuits.

8.2.7. The control error

The difference between desired value w(s) and x(s) is produced at the output of the comparison stage. In reference [18] page 65 and 66 shows:

$$e(s) = \frac{G(s)}{1 + G(s) \cdot H(s)} \qquad (16)$$

This control error becomes smaller as the product of G(s) and H(s) becomes greater. Thus both factors G(s) and H(s) must be as large as possible.

This realisation changed the view of the author concerning control engineering.

The finite control error with a finite open loop gain product of G(s) and H(s) means that an error is always present.

If the product is too high it will cause an unstable control loop [18, page 10]. During optimisation of the control loop the two parameters of minimum control errors and maximum possible gain must be weighed against each other.

Sometimes the controller has another input to determine the starting point from the reference w where the controller starts to action.

8.2.8. Negative feedback, positive feedback

What happens if the minus sign in the comparator stage is replaced by a plus sign? In [18] two modes of operation defined as counter or positive feedback.

For negative feedback the signal x(s) is subtracted from the signal w(s) and added for positive feedback.

The formula of the gain of the closed control loop for positive feedback is therefore:

$$\frac{x}{w} = \frac{G(s)}{1 - H(s) \cdot G(s)} \qquad (17)$$

Setting the values [G(s) = 100; H(s) = 10] from above example gives:

$$\frac{x}{w} = \frac{100}{1 - 100 \cdot 10} = \frac{100}{-999} = -0.1001001001 \qquad (18)$$

In the negative feedback case the quotient 100/1001 = 0.0999001.

In the positive feedback it hardly differs from the negative feedback case. In the case of positive feedback the output signal has a minus sign. Therefore a small signal is added to the reference signal (by the double negative).

Thus x(s) increases leading to a further increase of x(s) this is an escalation of the output signal.

The double negative is not caused by a change in comparator stage but is due to the changed sign of the output signal (the other half wave).

The reader may ask why in the reverse case does the output signal not become ever smaller until it disappears completely? By subtraction x(s) - w(s), e(s) becomes smaller so that the difference reduces. The smaller difference outweighs w(s) so a stable condition is reached.

To be continued

X. Literature

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John Fielding, ZS5JF

John's Mechanical Gem

Number 8, Know your metric nuts and bolts

Nuts and bolts for attaching various items together are common items used by amateurs. Most amateurs have little knowledge of the correct types to use for some applications. There is a standard marking method that identifies the tensile strength of bolts and nuts. For non-critical application a common bolt and nut purchased at the local hardware store will normally suffice. But what about critical applications?

A typical critical application is antenna towers; antenna mounting and holding down bolts set in the concrete base. If the wrong type is used there is a potential disaster waiting to happen!

Note *that a bolt and a screw are different. A bolt has a plain unthreaded portion between the head and the threaded portion. A screw is threaded all the way up to the head.*

The material it is made from determines the ultimate tensile strength of a bolt. For a bolt and nut to hold two items firmly together the bolt needs to be stressed so that it elongates slightly, like a spring. Modern automobile design uses special "stretch-bolts" to attain the necessary clamping pressure for the cylinder head to block interface.

Common or garden bolts bought from the local hardware store usually have no marking on them but most professional isometric bolt manufacturer's use a numbering system to identify the bolt material. The lowest grade bolt will have a code stamped on the head such as 4.6 or 4.8. The first digit gives the tensile strength of the material in hundreds of Mega-Pascals (MPa). The second digit after the decimal point gives the maximum safe elongation relative to the tensile strength. Hence, a bolt stamped 4.8 means 400 MPa and a safe tensile load of 80% or 320 MPa. These are the lowest grade bolts marked. The manufacturer's name or logo and the grade are shown in the Fig 1. These are normally raised lettering and not recessed.

Fig 1: Name and grade on a bolt head.

Some unscrupulous sellers of bolts stamp the blank bolt head with punches, which produces an indented type. These bolts are hence suspect as they may be lower tensile strength passed off as higher-grade types, so beware when you purchase this type.

Note *that American bolts use a different marking system than isometric bolts, which will not be considered here.*

For critical application a higher tensile strength bolt is required. For example, seat belt attachment bolts are required to be a minimum of 8.8 grade. This is a maximum tensile strength of 800 MPa and safe up to 640 MPa when torqued up. Critical items, such as suspension and brake calliper attachments, require much higher tensile strength bolts. For example, connecting rod cap bolts are often 12.9 grade. Aircraft grade bolts start at 10.9 and go up to 12.9. Tower holding down bolts should be a minimum of 10.9 grade and adequately sized for the intended stress under tension.

As well as the tensile strength the shear strength rating need to be carefully considered. Shear is what happens when you use a pair of scissors to cut paper, the blades cut into the paper and generate a weakened area. In some applications shear strength is more important than tensile strength. A pair of pipes connected with a bolt passing through both pipes in an antenna rotator system places the bolt in shear.

A common mistake is to utilise stainless steel bolts because they are resistant to corrosion. This can be a dangerous assumption as there are several different stainless steel grades used for bolts and nuts. EN302 is a corrosion resistant material and EN316 is a material resistant to acids and alkali. EN316 was developed for things like attaching lugs to battery terminals that require little tensile strength. A bolt made from EN302 is marked A2 and one made from EN316 is marked A6. The problem with stainless steel is that the tensile strength is lower than normal steel bolts. A2 bolts are about 60% of the tensile strength of 4.8 grade and A6 bolts are only about 40% of a 4.8 grade bolt.

If you must use stainless steel in critical applications it is essential to increase the bolt diameter by at least 25%.

Hence, if the normal bolt is 8mm then an A2 bolt will need to be 10mm or larger to be comparable.

Another problem with stainless steel fasteners is that the material does not slide easily on another piece of stainless steel and often the threads “pick-up” or seize. This is known as “galling” and is a serious problem as once the bolt and nut have seized they are impossible to undo without snapping the bolt. When trying a nut on a stainless steel bolt by hand it often feels as if there is a gritty substance between them and they are stiff to turn. In such a case it is advisable to run a tap through the nut and a die along the bolt to clean up any whiskers formed when the parts were made. Many modern bolts are not cut with a threading die as in the older days and the thread is formed under immense pressure by a thread rolling process. Although rolled threads have superior tensile strength to die cut threads this leaves the bolt thread slightly trilobular and hence not perfectly round which aggravates the galling problem.

Another problem with stainless steel fasteners is that to obtain the same tensile load when tightening the bolt or nut requires about twice the torque as a conventional high tensile bolt. Stainless steel bolts and nuts must be used with an anti-seize compound (Copper-Slip compound) or grease to reduce the torque required to attain the same tension. Common black high tensile bolts and nuts are heat treated and then quenched in oil, this produces the black surface finish and the bolt and nut is naturally oily and requires less torque to obtain the required tension. No matter what grade of bolt is used it should never be torqued up dry, always use oil or anti-seize compound. Another important consideration is the use of flat washers under the bolt head and the nut to allow lower friction when torquing up the joint.

Cap screws (known as Allen screws) are normally grade 12.9 and are normally black. Other type made in stainless steel are shiny and have the marking A2 or A6 depending on the material used.

Common surface treatment of lower grade bolts is zinc plating, often done by electroplating or cadmium plating which has a golden colour. These reduce the safe tensile load rating by about 2 to 5 %.

High tensile steel bolts and screws contain a fair amount of carbon which gives the material extra strength under tension, that is the bolt is more difficult to stretch. Stainless steel bolts contain very little carbon but are an alloy of iron and chromium, typically 10 to 15%, which gives the corrosion resistant properties. Alloyed stainless steel bolts because they contain little carbon therefore stretch more for the same tension and are unpredictable unless the torque setting is below the elastic limit.

For further reading:

http://reviews.ebay.com/Stainless-Bolts-Usually-very-weak_W0QQugidZ10000000001623345

Gunthard Kraus, DG8GB

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SAC - EDUCULT: Education, hobby and culture related programs and texts

This site has an amazing list of software, it is displayed a page at a time but unfortunately there is no index. If you are patient you will find such things as the CAD program pcaad.zip to design antennas like log-periodic, patch antennas and the horn radiators.

Address:
http://www.sac.sk/files.php?d=4&1=P

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This site is dedicated to design and analysis of micro and millimetre wave filters from 0.5GHz to above 100GHz

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Address: http://www.sigfox-system.com/pages/synfox_epag.html

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Many of the projects published ion this magazine are designed to fit into tin plate boxes. These are nor easy to find in the UK but Alan Melia stock quite a range of these boxes.

Address:
http://www.alan.melia.btinternet.co.uk/componen.htm

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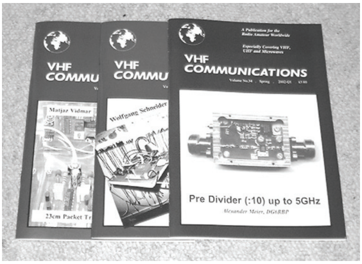

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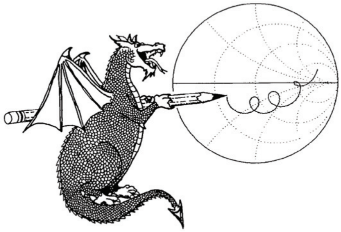

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