Dreams and Reality

Demystifying the PA0FBK antenna

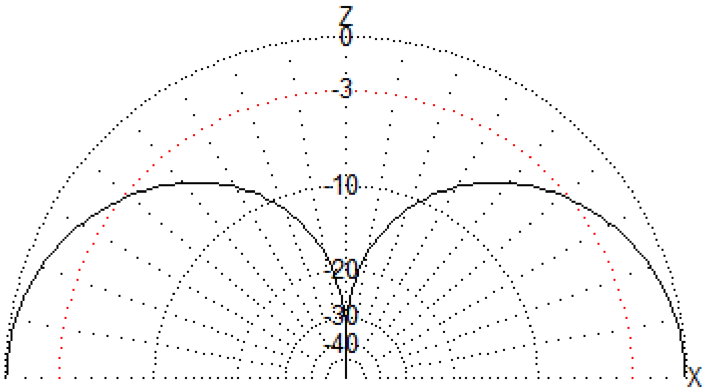
In my original version of the article about the PA0FBK dual-band antenna I have provided information on directivity and gain. Several radio amateurs from different countries of the world have expressed doubts about these figures. Their experience was, that in fact there will not be any difficulty in building and matching the antenna structure itself. Also their practical experience showed that my predictions on the 2m band were in line with their measurements. However, when the antenna was mounted relatively high and clear of obstacles, the field strengths observed on 70cm did not agree with my prediction of a gain of about 5 dBi. Normally the signals were all significantly weaker. So, have all these people done something wrong or is it more plausible that I was wrong in my simulations and the conclusins I drew?

Let me begin with the following **note**: The antenna presented by PA0FBK is made of RG-58 coaxial cable. Both the inner conductor and the shield are used as antenna elements. Datasheets of RG-58 normally specify a diameter between 0.9 to 1.0 mm (usually 0.95 mm). The antenna models provided in this article, which have all been used for simulation with MMANA-GAL, will be using an element *radius* of 0.5 mm for every individual element. All simulations were performed in free space and without consideration of any losses.

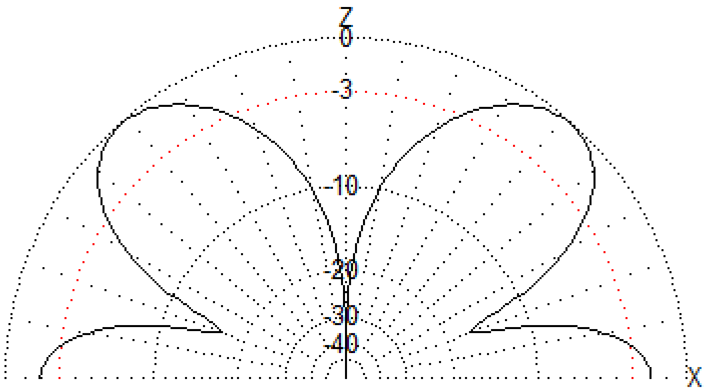
Preliminary considerations

The PA0FBK antenna is in principle a half-wave radiator on the 2m band and a 3λ/2-radiator on the 70cm band. The vertical radiation patterns of these basic shapes of antenna (regardless of the location of the feeding point) look like this:

- Model 1: Basic form of the PA0FBK antenna



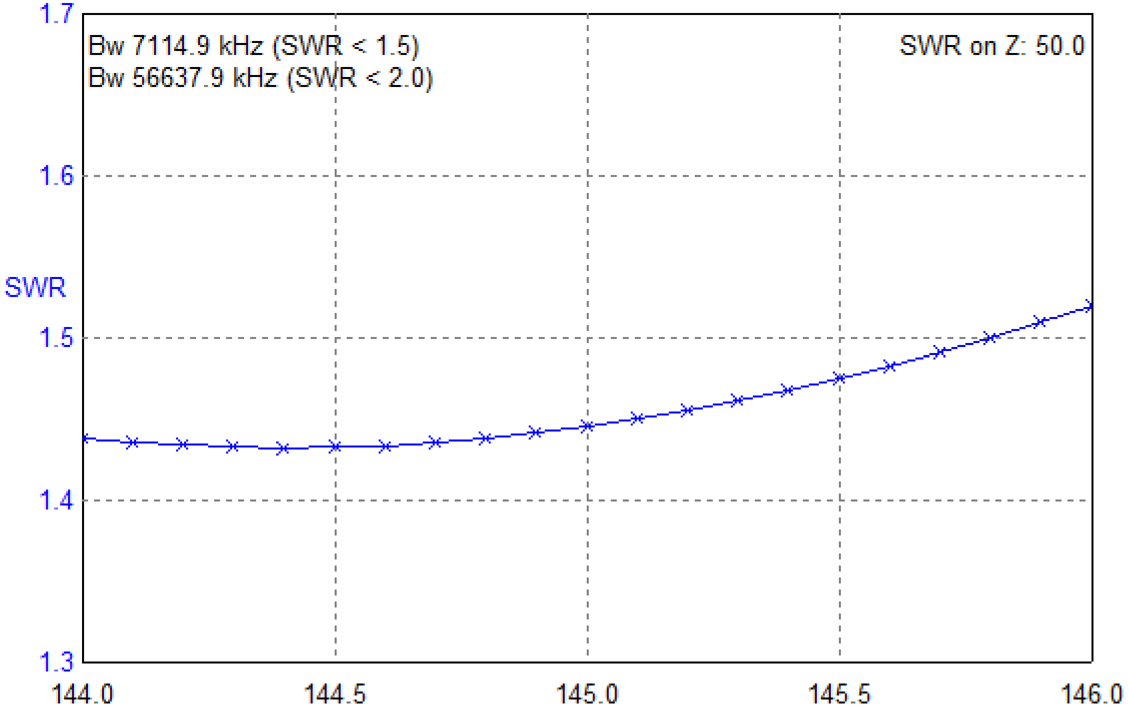
Vertical pattern 145 MHz
Impedance: 72.26 + j1.22 Ω
Gain: 2.13 dBi
Elevation: 0.0°



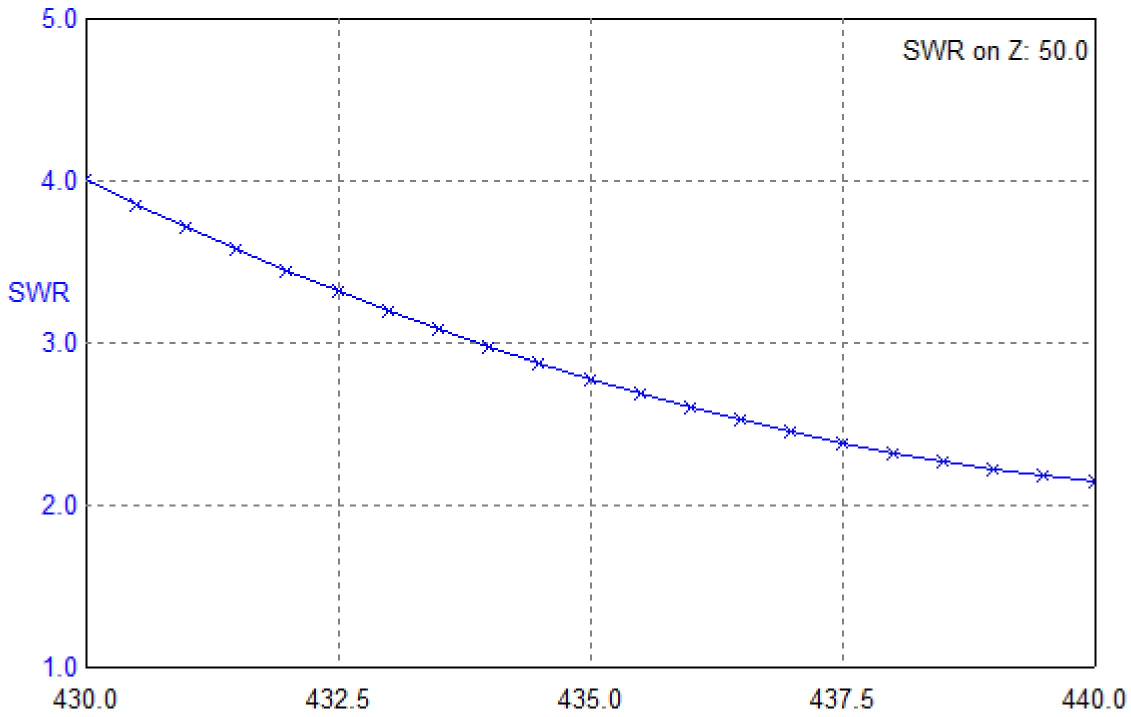
Vertical pattern 435 MHz
Impedance: 93.62 – j58.71 Ω

Gain: 3.17 dBi
Elevation: 48.4°

The SWR curves of this model show that this basic antenna (simulated as a dipole) is practically only useable on the 2m band. It is far away of what we call a dual-band antenna.

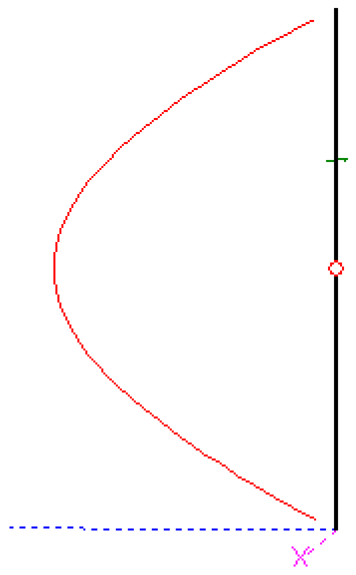


SWR plot 2m band

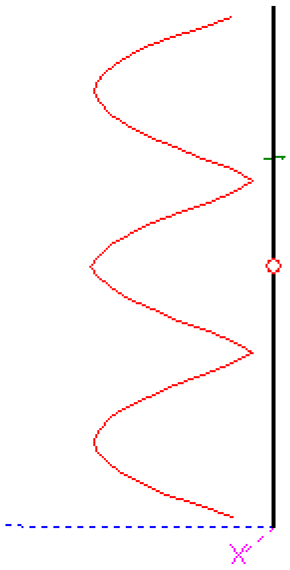


SWR plot 70cm band

It is, however, important to observe the current distribution of this elementary shape of antenna.



Current distribution 145 MHz

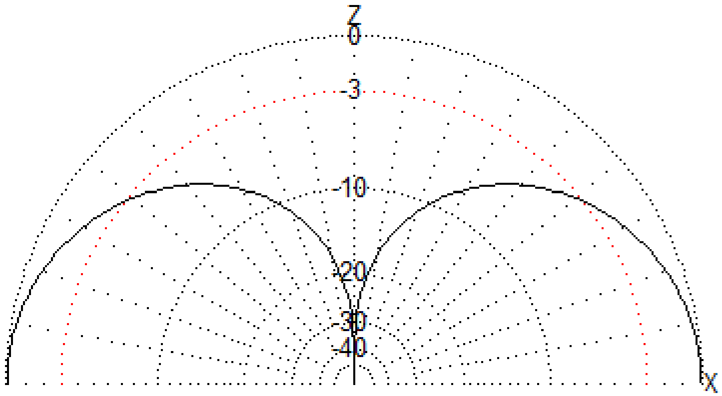


Current distribution 435 MHz

In contrast to this basic shape, the antenna according to PA0FBK contains an open section of coaxial cable (i.e. the shield is unconnected) in the center of the radiator. This open shield measures roghly half a wavelength in the 70cm band. This arrangement is in principle an **open-sleeve antenna** (see [LiGan]). The open coaxial section is meant to resonate on 70cm. Because of the close coupling to the radiator, high currents will occur. Because of this parasitic element, the directional pattern would firstly flatten significantly compared to that of a 3λ/2-radiator and secondly a very good match to 50Ω would be achieved on the 70cm band.

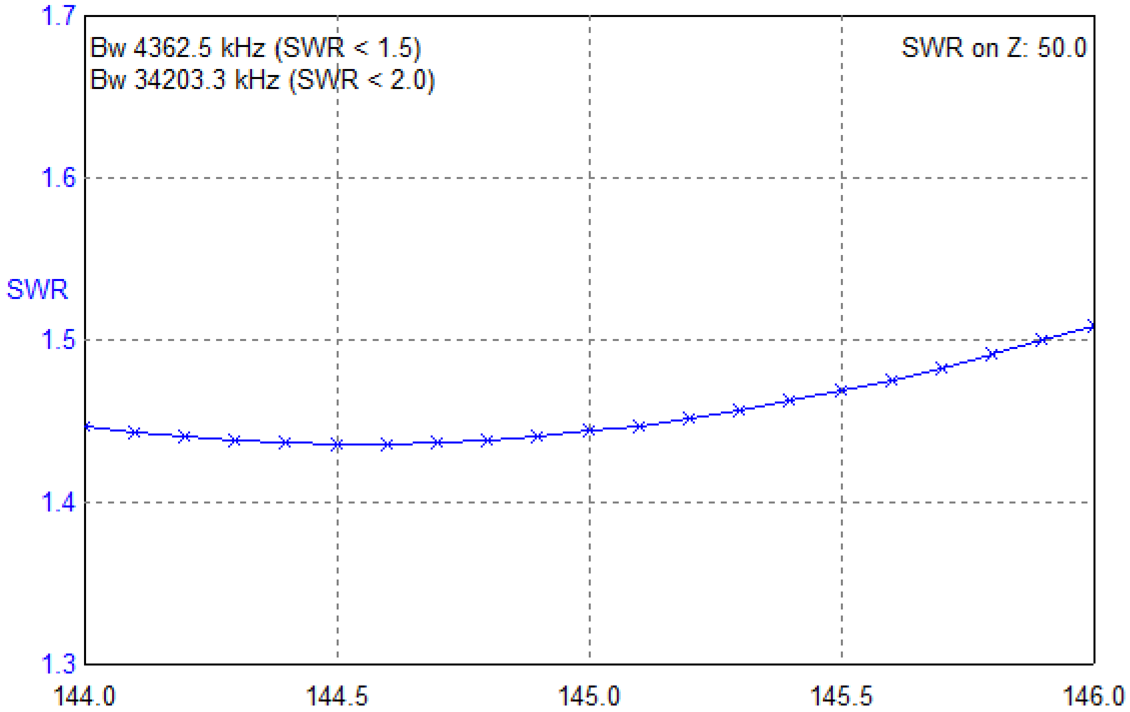
- Model 2: Basic form of the Open-Sleeve-Dipole

On **2m** the antenna will still behave like a regular half-wave radiator.



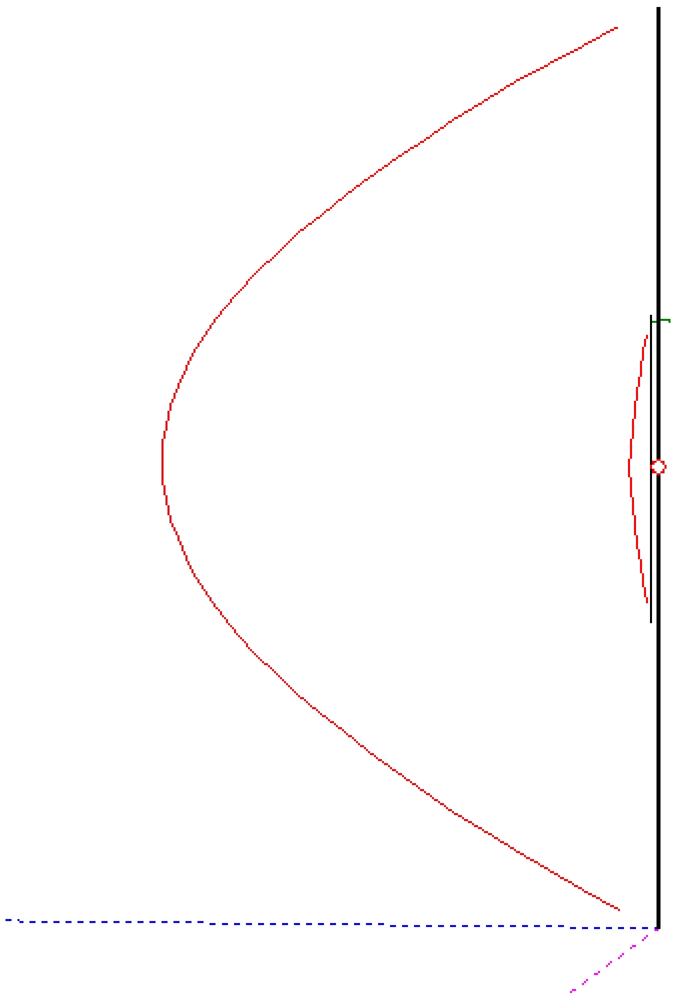
Vertical pattern 145 MHz
Impedance: 72.26 - j0.65 Ω
Gain: 2.14 dBi
Elevation: 0.0°

The SWR curve still shows a good match all over the 2m band.



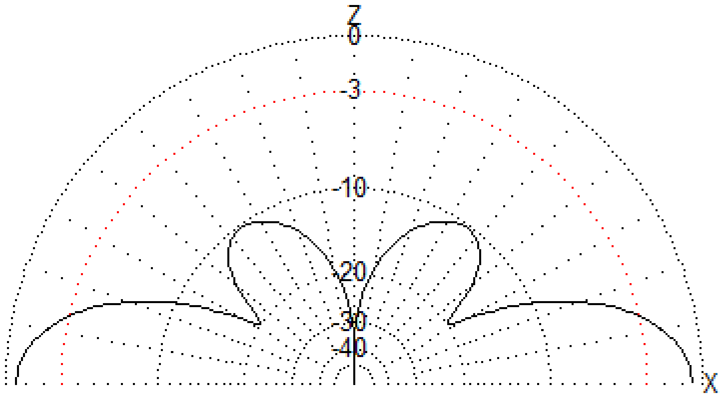
SWR plot 2m band

The open-sleeve section only carries little current and does not significantly effect radiation.



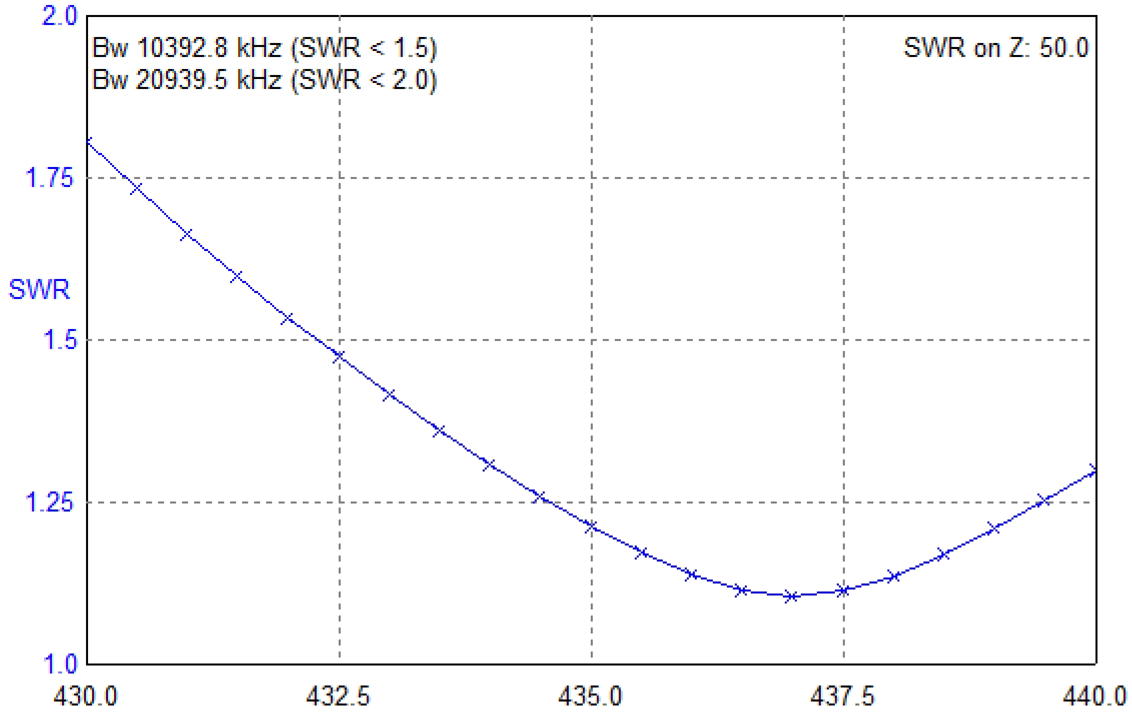
Current distribution 145 MHz

Things become totally different on **70cm**. In contrast to the 3λ/2-radiator shown above, the open-sleeve antenna has a much higher gain and obviously a very flat radiation pattern.



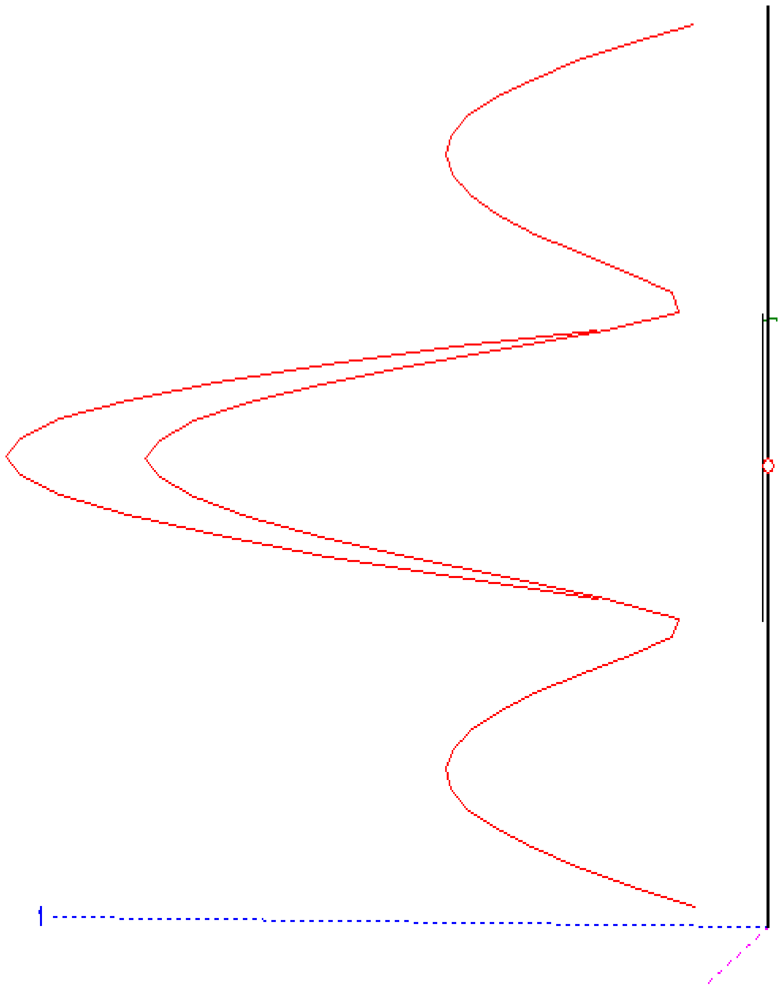
Vertical pattern 145 MHz
Impedance: 44.95 - j7.80 Ω
Gain: 5.80 dBi
Elevation: 0.0° (!)

Also, the impedance is much better. The SWR curve now shows a very good match throughout the 70cm band. The open-sleeve antenna is therefore suitable as a dual-band antenna.



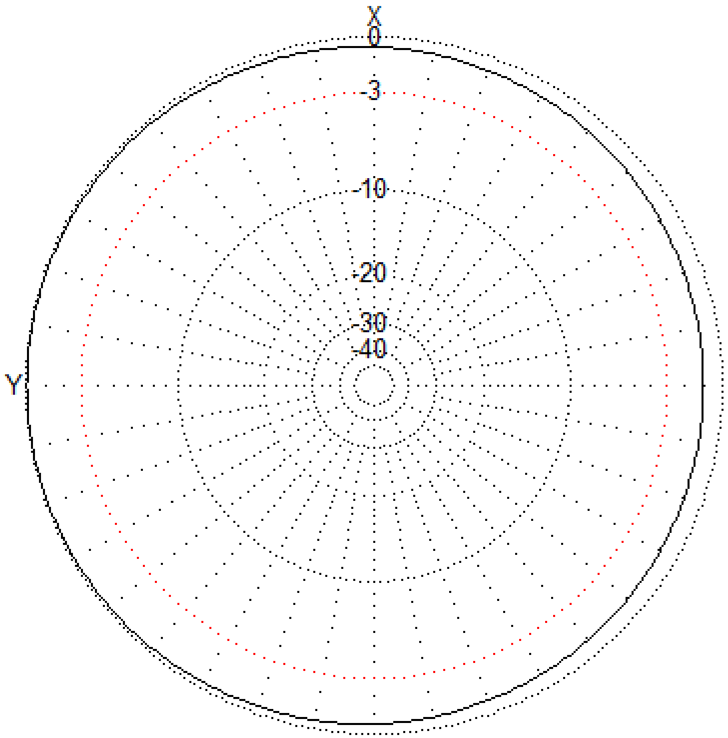
SWR plot 70cm band

The impact of the open-sleeve piece can be clearly seen when observing the current distribution. Because of the close coupling with the radiator, it resonates and carries an extremely high current. In effect a flat radiation pattern together with relatively high gain occur.



Current distribution 435 MHz

However, only one open-sleeve element leads to a slight "imbalance" in the horizontal pattern:



Horizontal pattern 435 MHz

This effect can be compensated easily by inserting another parasitic element on the other side of the dipole.

- Model 3: Open-Sleeve-Dipole with two parasitic elements

This will have little effect on the 2m band, but the horizontal pattern on 70cm is now perfectly round again. I will omit the plots resulting from model No. 3 here for the sake of clarity. It has to me mentioned, however, that because of coupling into two parasitic elements, model No. 3 will show a somewhat decreased gain of about 5.2 dBi. Impedance match as well as gain are a function of the distance between radiator and parasitic elements as well as the length of the parasitic elements themselves. The distance is the most critical variable here. In order to understand this, just take one of the above models and modify the antenna structure (especially distance and length of the open-sleeve sections) yourself.

Differences between Open-Sleeve-Dipoles and the PA0FBK antenna

The preliminary considerations focussed mainly on a dipole, i.e. considered a center fed antenna. We saw that by adding one or more parasitic elements at a suitable position close to the radiator, a monoband antenna could be turned into a dual-band antenna with very little effort. Of course this is not exactly how the PA0FBK antenna works. Therefore we have to consider the differences between PA0FBK's model and our previous simulations in order to find out whether and how these results can be validly transferred to our antenna of interest.

1. The models provided above consist of single wires. PA0FBK's antenna completely consists of coaxial cable.
2. It is to check whether the open piece of coaxial cable can be seen as an "open-sleeve element".
3. The (electrical) distance between open-sleeve element and radiator is invariant in PA0FBK's setup because of the fixed dimensions of the coaxial cable as well as the properties of its dielectric material.
4. Open-sleeve antennas are (center-fed) dipoles, the antenna according to PA0FBK is end-fed instead.

The first two points can be quickly clarified: Consider the following antenna model, in which four parasitic elements are now arranged concentrically around the radiator:

- Model 4: Open-Sleeve-Dipole with four parasitic Elements

Although some minor changes in length are necessary, the directional patterns both on 2m than 70cm will not change significantly. Extending the model to 8, 16 or 32 further parasitic elements around the radiator (I do not provide these models here) confirms: It doesn't matter at all whether the shield of a coaxial cable or a single wire is used as an open-sleeve element. Therefore I can conclude:

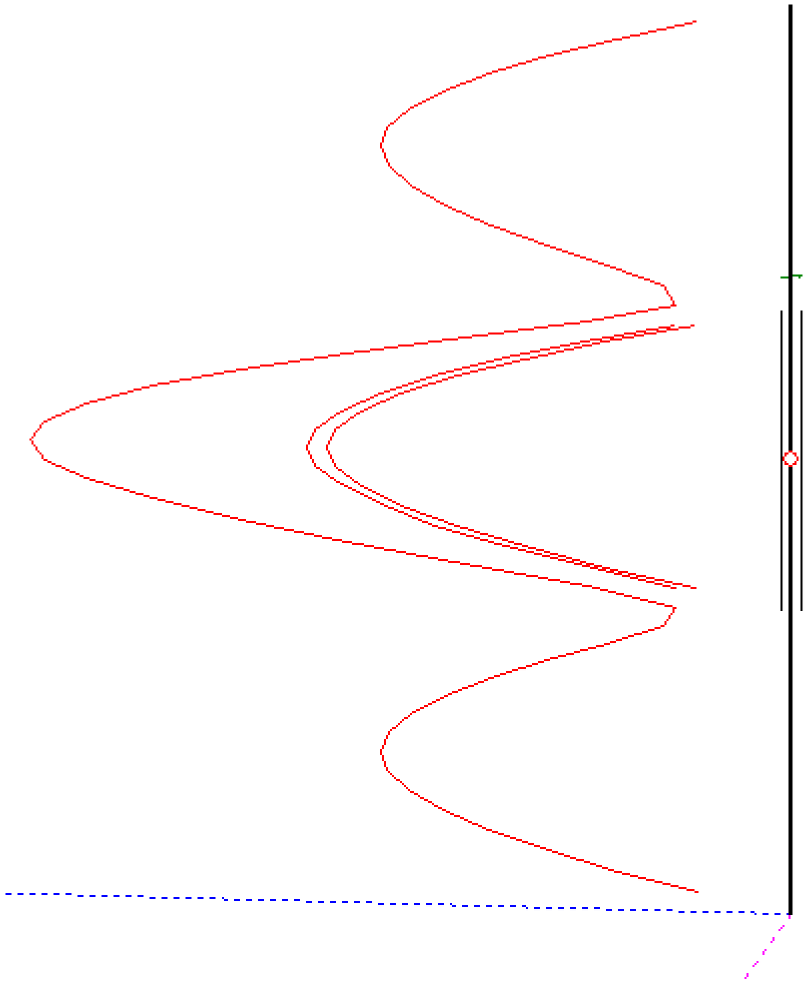
The open-sleeve model with two parasitic elements (model No. 3) is a simplified but valid model for the radiator of the coaxial antenna according to PA0FBK.

The third point, namely the impact of the fixed dimensions of the coax cable and its dielectric, still remais open. However, this doesn't have to be discussed here, since considering the last point (center-fed vs. end-fed) reveals another serious weakness of the PA0FBK coaxial antenna:

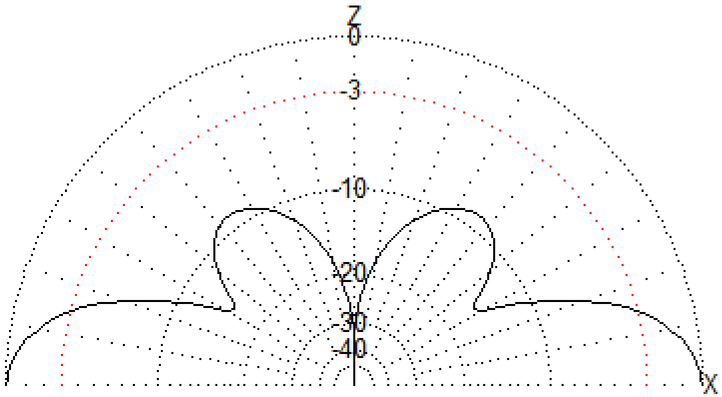
While open-sleeve antennas are always designed as a half-wave dipole, the PA0FBK antenna is an end-fed one. In order to achieve a good match to 50Ω systems commonly used today, a short-circuited quarter-wave stub is used. The principle is thus the same as for J-pole antennas. While in a "real" open-sleeve antenna feed point and parasitic element are located close to each other, they are very far away from each other in the end-fed variant of PA0FBK. In end-feeding an antenna, the current distribution does not change as long as the dimensions of the antenna remain untouched. But, by moving the feedpoint out of the open-sleeve element towards the bottom of the radiator, the coupling between feedpoint and parasitic element is reduced. This raises the question whether or how this will effect gain and directivity.

Let us take model No. 3 (two parasitic elements) and slowly move the feed point towards the lower end of the antenna. The farther the feeedpoint moves away from the parasitic elements, the steeper the antenna will radiate. At the same time the gain of the antenna is more and more reduced.

Case 1: Center-fed Open-Sleeve-Antennas

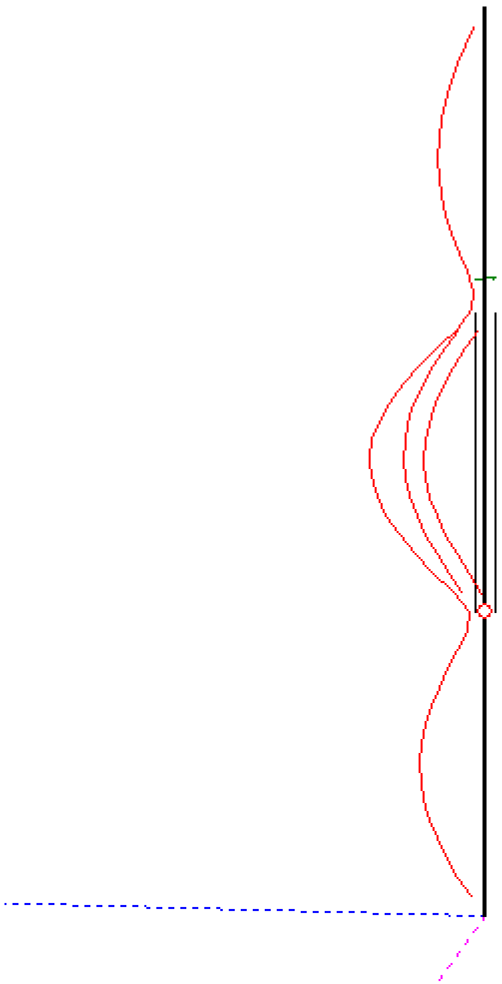


Center-fed antenna

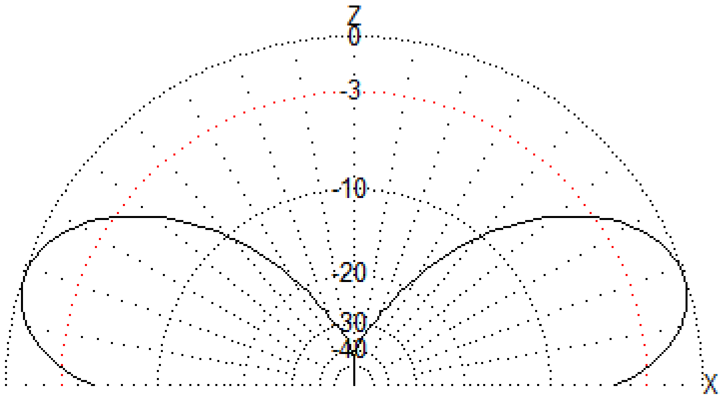


Vertical pattern 435 MHz
Impedance: 47.13 - j2.88 Ω
Gain: 5.23 dBi
Elevation: 0.0°

Case 2: Feedpoint at the end of the Open-Sleeve-Section

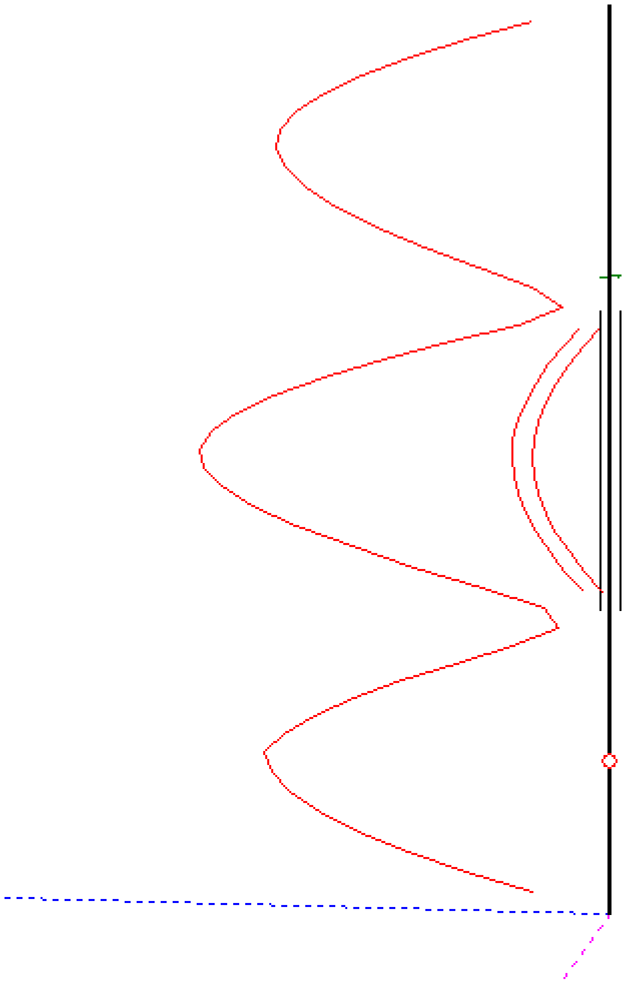


Feedpoint at the end of Open-Sleeve

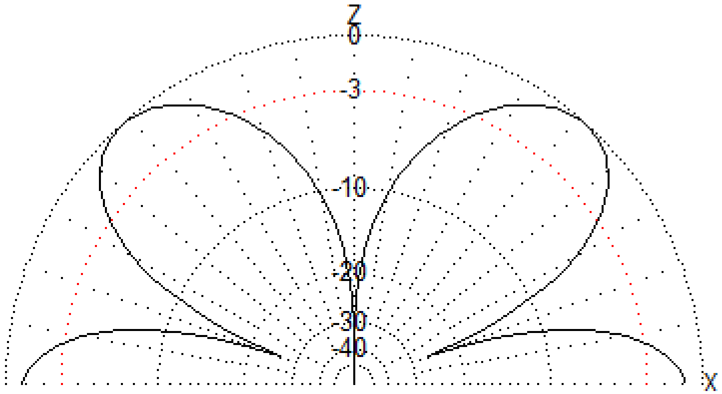


Vertical pattern 435 MHz
Impedance: 2129 + j92.4 Ω
Gain: 4.91 dBi
Elevation: 18.2°

Case 3: Feedpoint moved further towards bottom

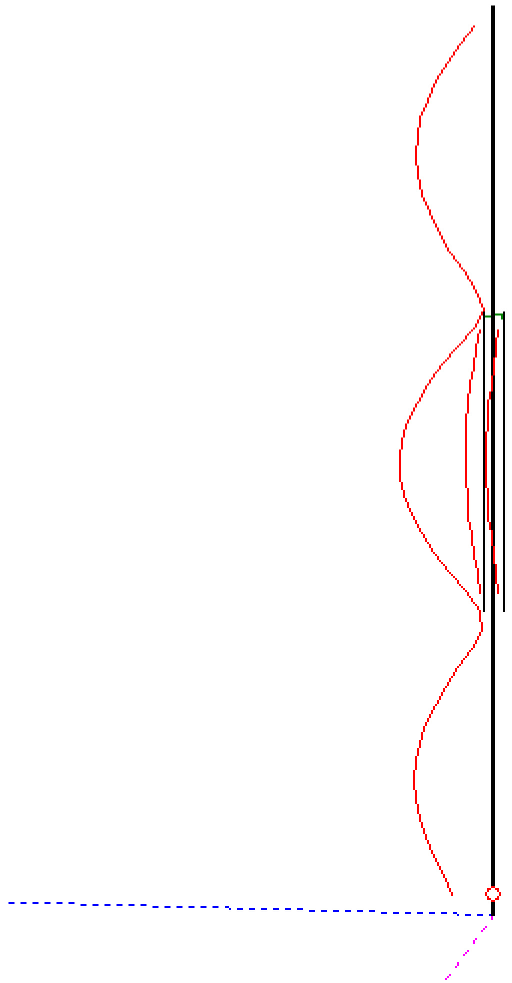


Feedpoint towards bottom

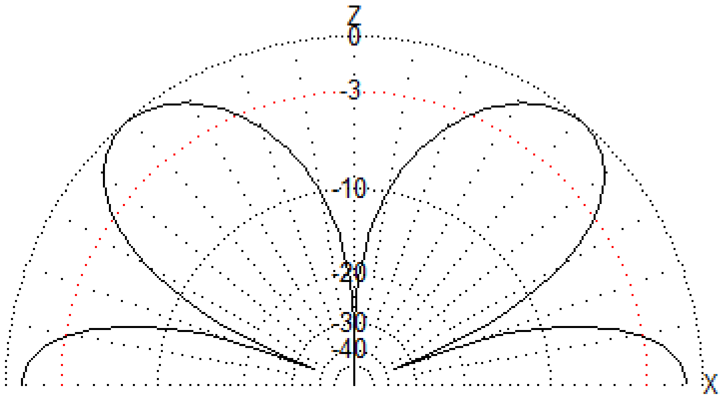


Vertical pattern 435 MHz
Impedance: 58.11 - j58.63 Ω
Gain: 3.61 dBi
Elevation: 48.2°

Case 4: End-fed Open-Sleeve-Antenna



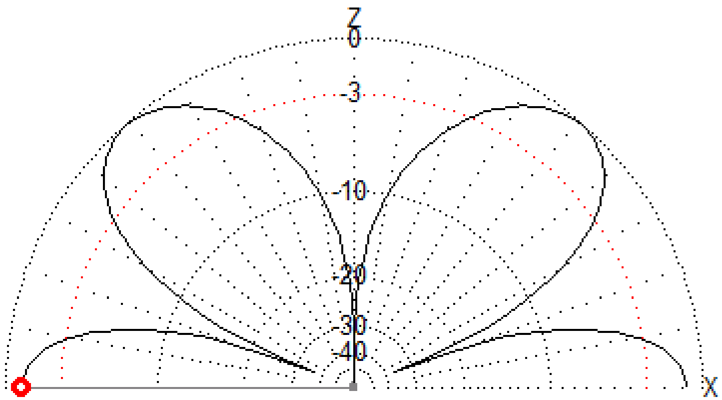
End-fed antenna



Vertical pattern 435 MHz
Impedance: 344.3 - j799.9 Ω
Gain: 3.55 dBi
Elevation: 49.1°

There is still a strong sidelobe into the desired direction (elevation angle of 0°). Into this direction the antenna nevertheless still provides a gain of 2.8 dBi. But all in all the following (sad) conclusion has to be drawn:

The end-fed open-sleeve antenna (and thus also the antenna by PA0FBK) behaves like an ordinary 3λ/2-radiator. The positive effects of the parasitic element are more or less completely lost.



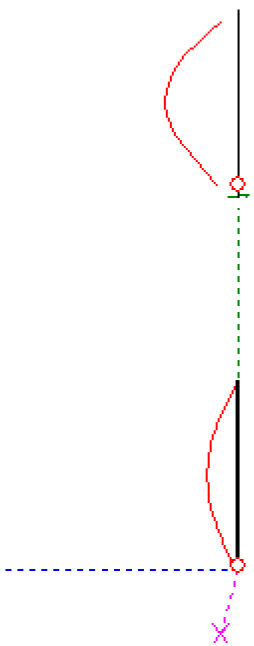
Vertical pattern 435 MHz
Impedance: 344.3 - j799.9 Ω
Gain: 2.80 dBi at an elevation of 0.0°

At an elevation of 0° the PA0FBK antenna therefore only provides a gain of approx. 2.1 dBi on 2m and 2.8 dBi on 70cm. At 70cm a significant portion of the power fed into the antenna will be radiated steeply into a rather unwanted direction.

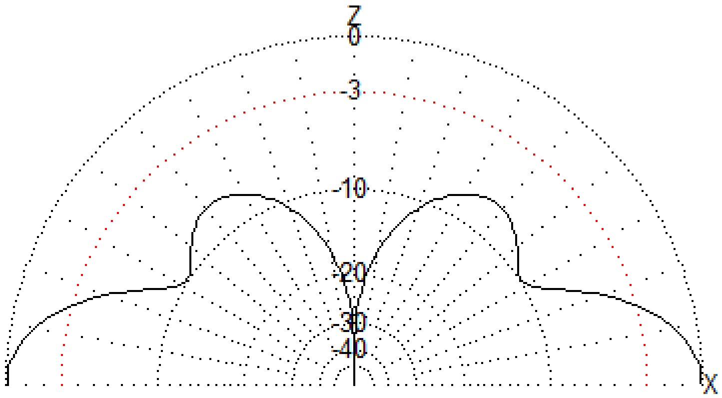
Open-Sleeve or stacked dipoles?

Besides the PA0FBK coaxial version, several similar variants of this antenna, using twin-lead or ribbon cable, can be found when searching the internet or publications of HAM radio magazines. Often in these instructions an alternative explanation is given when discussion the behaviour of this antenna on 70cm: It is claimed that the middle section (called the "open-sleeve section" in this article) was 1/2λ-transformer, the antenna therefore behaving like a system of two collinear half-wave radiators. It is argued that the end-fed half-wave radiators had an extremely high impedance, so that it wouldn't matter if the shield of the coaxial cable was to remain unconnected. In fact such an antenna system would provide a gain of about 4.7 dBi and would also show a wonderful flat radiation pattern. Gain and directivity at 70cm would very much resemble the values calculated from the open-sleeve antenna shown in model No. 3.

- Modell 5: Stacked system on 70cm



stacked half-wave antennas



Vertical pattern 435 MHz
Gain: 4.7 dBi

However, the interpretation as a stacked halv-wave system is a **deceptive mistake** – which I originally naively also believed: If the open-sleeve section would really behave like a "transmission line" (in the 70cm band), no current would flow on the outside of the braid of the coaxial cable, because in a coaxial cable the electromagnetic wave is only propagated between the inner conductor and the inside of the braid. Thus, a current flow could only be caused inside the coaxial cable. Furthermore, the impedance of an end-fed halv-wave radiator is indeed quite high, yet it isn't infinitely high but still on the lower four-digit range (both the active and the reactive component). Consequently, the current flowing on the inner conductor does not get infinitesimally close to zero, but also takes a small value, significantly different from zero. This current would as well, of course, upon considering the coax section as a transmission line, flow on the inside of the braid, yet into the opposite direction. The braid however remains unconnected, i.e. is terminated with a resistance close to infinity. However, there is still the low-impedance path via the outside of the braid – and the current will definitely choose this path. The current flowing on the inside of the unconnected braid of the "transmission line" will therefore also flow on its outside – into the the same direction as on the inner conductor. As there will always be a more or less significant current flow on the outside of the coaxial section (both on 2m and 70cm), the coax section therefore always contributes to the radiation of the antenna and does not just behave like a simple "half-wave transmission line".

The current flow on the outside of the coaxial section also becomes obvious when closely observing the simulation results: The open-sleeve section always carries different currents on both conductors. Therefore it is impossible that both currents could completely cancel each other out. So this section must always contribute to the radiation of the antenna.

Finally, I would like to express a **speculation**: The additional losses introduced by this (probably superfluous) open coaxial section might contribute to the fact that the antenna can be matched equally well on 2m and 70cm. In "conventional" J-pole antennas without any open-sleeve element this is usually not the case. According to experience, either both bands – measured directly at the feed point of the antenna and not after several meters of coaxial cable inside the station – are rather poorly matched, or one provides a very good match, while the other one doesn't. The precise impact of the open-sleeve element, however, has not been investigated any further. If this speculation was correct, the gain figures given above would definitely have to be reduced by several tenths of a decibel. In addition, of course, the losses of the quarter-wave matching stub have not been considered at all in this article. Losses of the stub must however also contribute significantly to the good SWR values and to the relatively flat SWR curves measured in practice.

Conclusion

First of all I would like to point out that PA0FBK himself has **never** published any details about gain or directional patterns and therefore also never made any untenable claims about this antenna. Frank Bremer merely provides detailed instructions on how to build this antenna. He points out that a good match can be achieved on both bands. Numerous emails from around the world as well as my own experience with this antenna confirm this. When using this antenna for portable use together with hand-held radios, higher signal strengths will definitely be observed – compared to the short helical whip antennas normally used with these radios. However, on 70cm the PA0FBK antenna is neither a stacked or collinear system, as one might first assume, nor is it a "real" open-sleeve antenna. The braid of the coaxial section contributes significantly to the radiation of the antenna an (probably) also adds some minor losses. By end-feeding the radiator all the positive effects of this (pseudo-) open-sleeve antenna will be lost. What remains is a simple 3λ/2-antenna on the 70cm band.

This also explains the rather bad reports from fellow HAMs, who were able to install this antenna on their roof or mast in relatively high altitude and clear of obstacles, who could not confirm my original statement predicting a gain of about 5 dBi on 70cm with a completely flat radiation pattern. Despite the fact that I first misunderstood the principle of operation of the antenna and as a result of that provided a false explanation, the PA0FBK antenna will continue to be an integral part of my station, because for portable use, local rounds or relay operation, it is not only a simple and easy to build antenna, but it can also be build at a fraction of the price of comparable commercial antennas.

I still recommend this antenna to everybody.

DL8KDL
June 15, 2013

Literature

- Frank Bremer, PA0FBK:
  FBK 2/70 portable coax antenna
  last visited in February 2013
- J.-Y. Li und Y.-B. Gan:
  Multi-Band Characteristic of Open Sleeve Antenna
  Progress In Electromagnetics Research, PIER 58, 135–148, 2006