The pa0rdt-Mini-Whip ©, an active receiving antenna for 10 kHz to 20 MHz

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This article is about the development of a receiving antenna for longwave. The result is an excellent antenna for receiving signals between 10 kHz and 20 MHz. This antenna has very small dimensions: the smaller version fits in half a film canister.
Reception at the longwave has its own dynamics. The possibilities and problems are quite different with respect to reception on shortwave.

Local noise

Before the antenna is dealt with, I want to focus on a key problem: local noise. When listening to weak signals in the longwave you always have to deal with noise.
This noise can come from electrical equipment in the immediate vicinity. But it may also be caused by a thunderstorm complex over the Mediterranean Sea. Against the thunderstorm noise there is usually not so much to do. Luckily, this is not the case for the so-called local noise.
When consulting the literature and sources on the Internet, it becomes clear that antennas for longwave can be roughly classified into two types: antennas that are sensitive to the magnetic field and antennas that receive the electric field. Loop antennas are among the first group. The second group consists of (active) whip antennas. Furthermore, it appears that local noise is mainly present in the electric field. So it appears obvious (in presence of local noise) to use an antenna which is only sensitive to the magnetic field, e.g. a loop antenna. Some are equipped with an additional shielding for the electric field.

Experiments with loop antennas

Armed with this knowledge, I started with loop antennas. It was a very long winter, so I enjoyed it well. Many models were built with many windings, active and passive, whether or not electrically shielded and so on. Unfortunately, these antennas had one thing in common: local noise was extremely well received. Figure 1 is the diagram of an active loop antenna. This has the advantage that it is broadband and does not need to be tuned. The amplifier is balanced. To keep good balance, the loop can be connected via an high-frequency isolation transformer and the center of the loop windings can be connected to ground. This does not make much difference though.
The loop can consist of a length of plastic pipe of four meters with one or two turns of copper wire placed inside. The outer jacket of a piece of coaxial cable works well. This is a good antenna, until a local noise is present. The delivered signal is proportional to the square of the number of turns. Too many turns give too signal, so the amplifier is overloaded. Furthermore, the highest receive frequency is much lower. This antenna works approximately 100 kHz to 10 MHz.
Because the problem with the local noise could not be resolved, I decided to give up the whole idea of longwave reception. Apparently in an urban environment it was not possible to listen to weak signals.

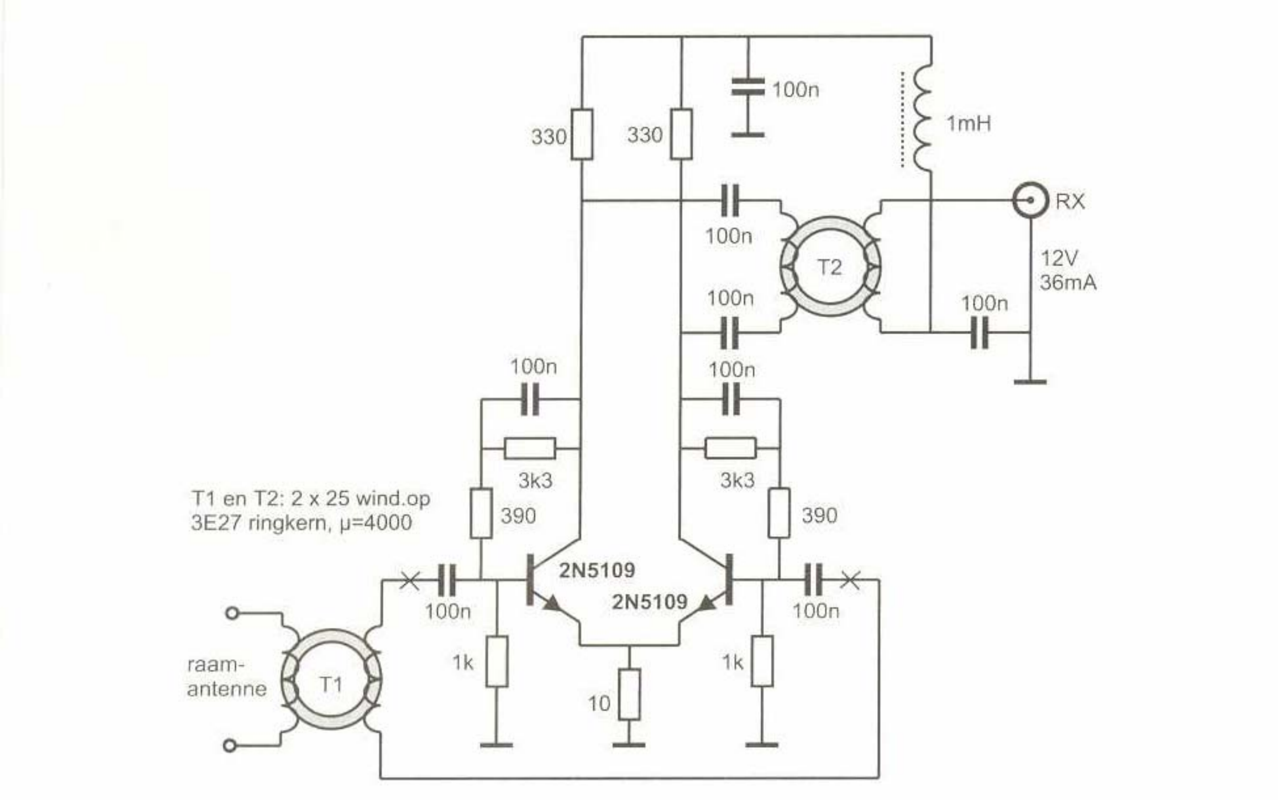

Figure 1 - Balanced active loop antenna.

HF dipole used as a 'T' antenna

After a while I could not resist to try again. For shortwave I use a dipole of 2x20 meters. This is fed by a balanced line of 12 meters long. If the two wires are connected at the begin of the fed line, the result is a vertically polarized antenna. The two halves of the dipole form a top (hat) capacity. This was already a lot better than the loop antennas. There was still noise, but much less. Please note that the fed line runs over a length of six meters along the outside wall of the house. Subsequently, I installed a high-frequency isolation transformer. See Figure 2. The primary winding was connected to the antenna and to a separate earth. The secondary winding was connected to a coaxial cable bringing the signal to the receiver. This was much better and it seemed that the problem with the local noise was solved.

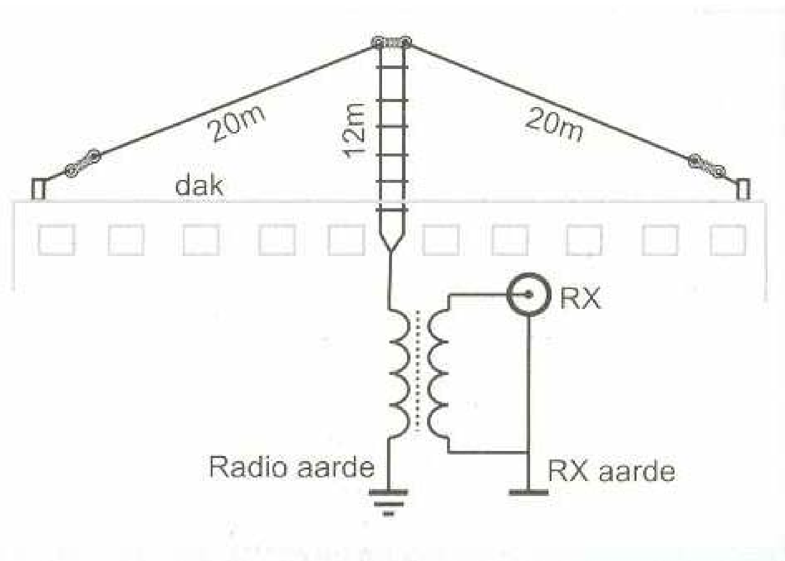

Figure 2 - HF dipole used as a 'T' antenna for LF/MF.

However, it was not completely noise-free yet, especially in the evening. Given the good results with the vertical antenna I decided to try with an active whip antenna. This went much better. At a distance of five meters from the house the noise was virtually gone and weak stations could be received well.

Measurement on active antennas.

Once I was on the radio flea market in Rosmalen and I bought a selective voltmeter for a reasonable price. With it some parameters could be seriously measured. It is an older analog device from Wandel & Goltermann (photo 1). The model number is SPM-3 and it covers the range of 2 to 612 kHz. It can measure from +20 dBm to -100 dBm, even to -135dBm with an external tunable preamplifier. This type is also designed for portable use and is using internal batteries independent of the mains. On a cold winter day the equipment was setup in the garden. First, the active loop antenna was connected to the selective voltmeter. The loop antenna and the selective voltmeter were independent of the mains input. The loop antenna was at a distance of one meter from the wall and then it was placed (in increments of one meter) up to six meters further away.
The same procedure was also followed for the active whip antenna. The sensitivity of each antenna was adjusted at the same level. When the loop was used, the distance from the wall made almost no difference in the level of noise. With the active whip antenna the difference was evident. It was literally to be kept against the wall to receive as much noise as with the loop antenna. The measurements took place at frequencies between 150 and 500 kHz. The frequency did not appear to affect the overall picture.
As an active whip antenna only receives the electric field, there was only one possible conclusion: the electric field of a local noise source remains within the house and do not go outside. A loop antenna receives only the magnetic field: the magnetic field of a local noise source remains obviously within the house but also it goes outside. No wonder the loop antennas received so much noise. Later I found a reference in the literature to this effect. It was now clear what the antenna had to be: an active whip antenna.

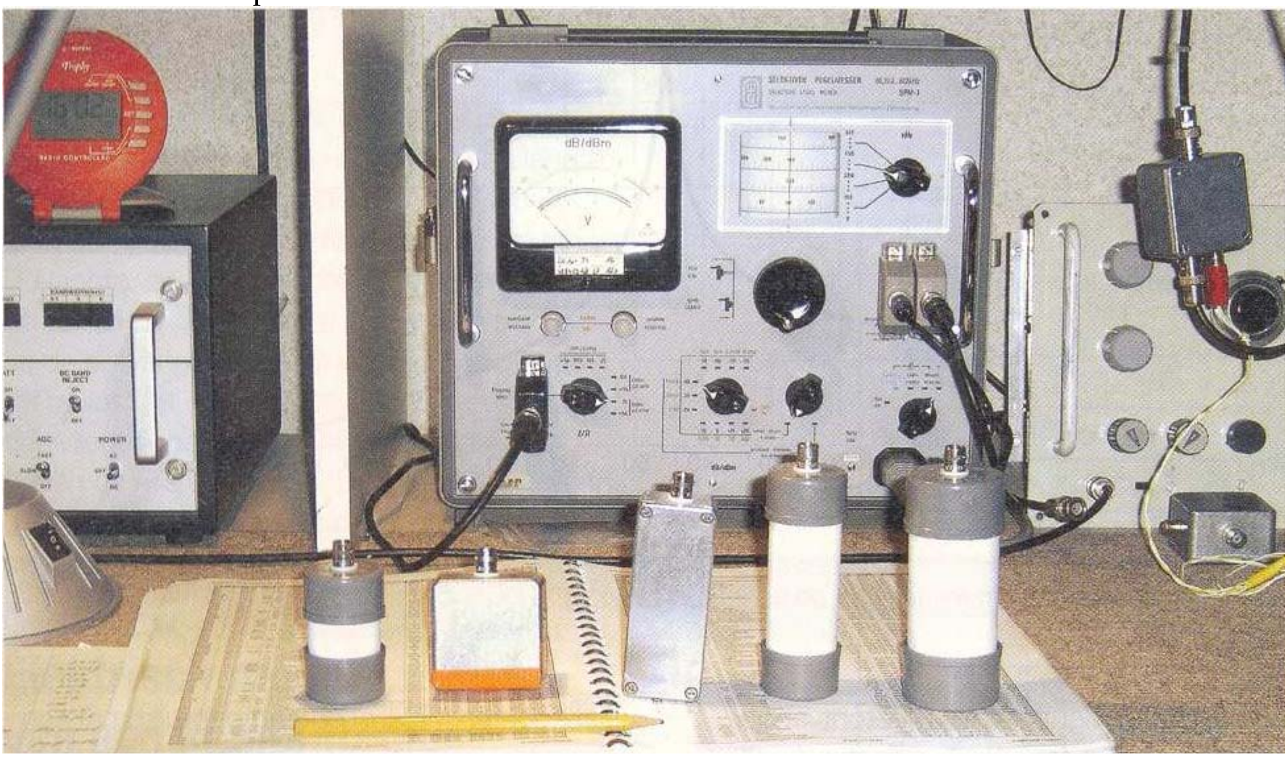

Photo 1 - Selective voltmeter SPM-3 with some samples of the pa0rdt-Mini-Whip ©.

Shielding by a building

An interesting question is how much the electric field is weakened when shielded by a building. During a lecture for the department of Walcheren of VERON, the pa0rdt-Mini-Whip © was demonstrated. The lecture took place on the first floor of a community center. The walls were made of concrete. The antenna was installed on a long pole with four meters of plastic pipe. The mast was put out through the window. The receiver was tuned to ONO, an aircraft beacon (NDB) in Oostende (399,5 kHz).
Inside the building there was virtually no signal. With the antenna at one meter away from the wall, the signal was at full strength. There was a measured attenuation of 40 dB. That corresponds to almost seven S-points. These measurements were repeated again at home. My house is traditionally built entirely in bricks. Here the attenuation was 31.5 dB (over 5 S-points). The attenuation depends on the frequency. The higher the frequency, the lower the attenuation.

More noise

During the experiments in the garden I noticed that the active whip antenna was picking up some noise. It seemed that it was less than within the house. This was indeed the case. When the receiver was mounted inside, the noise was about 8 dB higher than outside. When receiving weak stations 8 dB can make a big difference. At first I thought that the noise came from the mains. Supply from a battery proved to be no difference. Then I moved the SPM-3 back to the garden. The level of interference was now 8 dB lower. Then I connected the selective voltmeter to the coaxial cable that ran inside the house. The noise was now 8 dB stronger. This disappeared when the braid of the coaxial cable was connected to a separate ground at the place where the cable enters the house. Applying an RF choke on the braid of the coax cable close to the receiver had almost the same effect. This choke consisted of 30 turns RG174 coaxial cable wound on a 35-mm 3E25 core.
The noise was apparently received on the coaxial cable which was inside the house. The house where I live is about fifty years old. Earth connection is not present everywhere. My receiver is not connected to the earth from the mains. If I do it, the noise level increases by 7 dB. On the earth from the mains there is apparently a noise voltage. If the ground of the receiver is connected with this, the noise voltage appears in series with the antenna signal.

Experiments with active whip antennas

Figure 3 is the schematic drawing of an active whip antenna. The whip antenna is connected to the gate of a JFET source follower. The source of the J310 is directly connected to a switching transistor in an emitter follower configuration. Through the 10K adjustment potentiometer, the current can be set by the J310. Steve Ratzlaff, AA7U, kindly performed intermodulation measurements for this circuit.

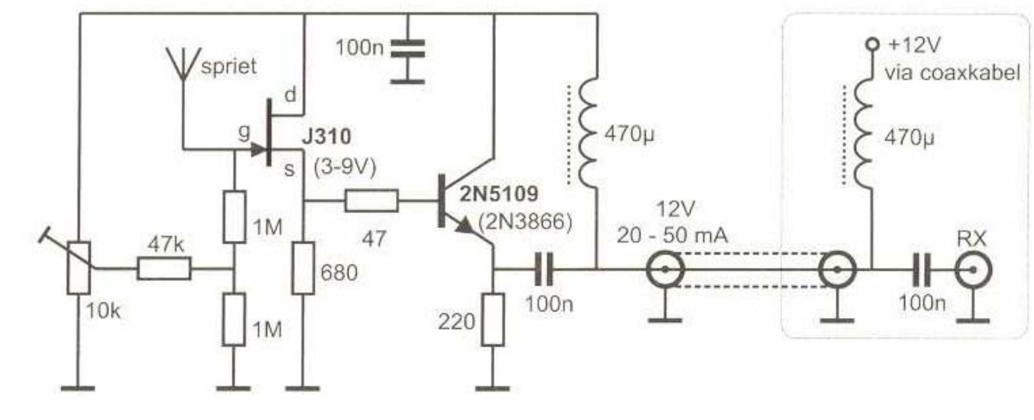

Figure 3 - Experimental version of the Mini-Whip.

This was at a minimum supply voltage of 12 volts and a drain current of 10 mA. The circuit attenuated 4 dB. The third-order intercept point at output was +31 dBm. The second-order intercept point was +67 dBm. Not bad for this simple circuit and better than the second and third-order input intercept point of most receivers. These figures were later confirmed by own measurements. The power consumption of this circuit is 40 mA. The active whip antenna is fed with power-supply voltage via the coaxial cable. The diagram shows how the RF signal and the power-supply voltage are separated.
With this antenna quite a few tests were done: in the garden, but also at two locations in the vast landscape of Zeeland. These locations, in the vicinity of Lake Veere, are free from noise. Within a radius of 600 or 1000 meters, no buildings are present. It is a rural area. Powerlines are therefore not to be found.

The measurement method

For the signal source I used the carrier of three stations on the longwave: DCF39 on 138,83 kHz, WW on 309 kHz and ONO on 399,5 kHz. DCF39 is near Magdeburg, Germany. The distance is about 575 km. This station has a radiated power of 40 kilowatts. WW and ONO are Non Directional Beacons (NDB's), navigation beacons for aviation with a radiated power less than a few hundred milliwatts. WW is at Deurne near Antwerp at a distance of 71 km. ONO is near Ostend and is 59 km away from my home. Of these stations, the ground wave is received. This has a constant strength during the day. Figure 4 shows the measurement setup.

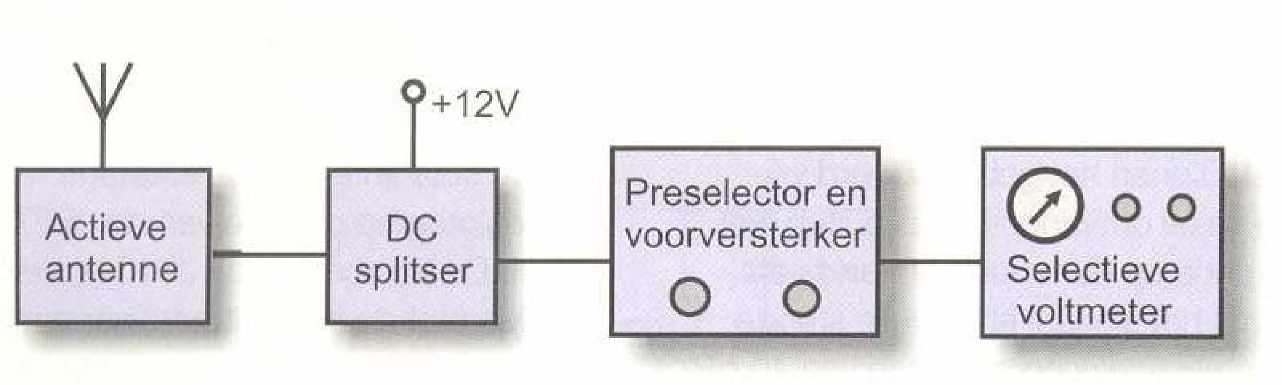

Figure 4 - The measurement setup.

The measuring antenna is installed on a non-conductive mast. This is a surplus military mast. The mast sections are four feet tall, about 120 cm. They are made of fiberglass and the ends fit together. In steps of 120 cm, a mast height of six meters or more is quickly achieved. The antenna is connected using a coaxial cable, type RG58, approximately 20 meters long. The signal first goes to a tunable amplifier. This has a gain of 35 dB. The circuit diagram is shown in Figure 5.

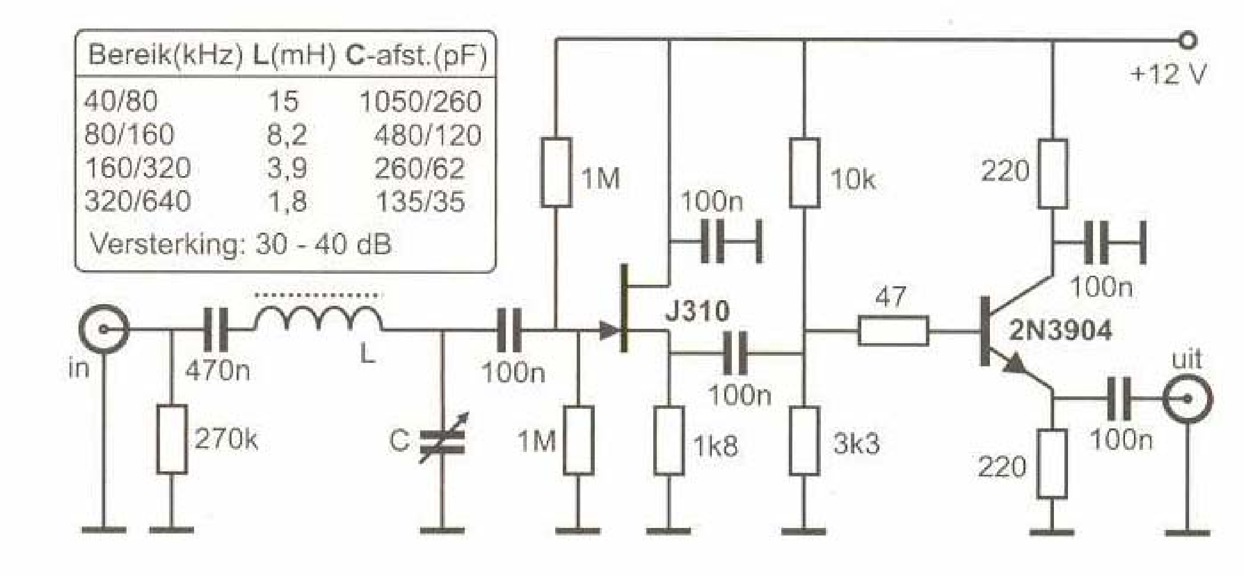

Figure 5 - Tunable preamplifier.

The frequency response is given in Figure 6. As previously mentioned, the measurement receiver was a selective voltmeter SPM-3 by Wandel & Goltermann. The amplitude of the signal can be read with a resolution of 0,5 dB. It can be measured from +20 dBm to -100 dBm. The signal can be attenuated in steps of 10 dB.

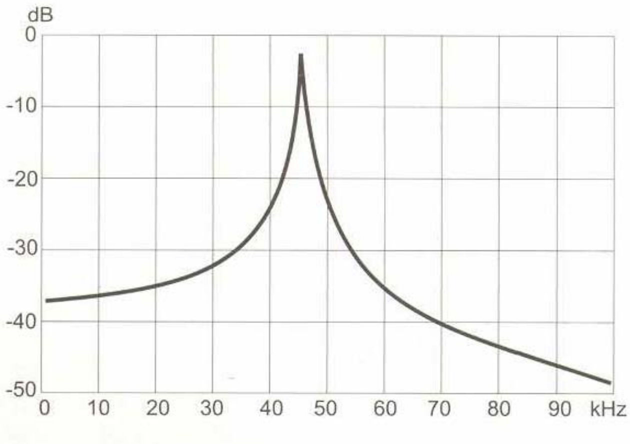

Figure 6 - Frequency response for the circuit in Figure 5.

With the preamplifier, the lower limit is -135 dBm. The measurements are not about the absolute signal strength. Only the relative differences can be measured reliably. The 3 dB bandwidth of the SPM-3 amounts to 150 Hz.

Measurements

The first series of measurements was about the relationship between the length of the whip antenna and the strength of the received signal.
They took into account the difference between signal and noise. The whip was a solid copper wire with a diameter of 1,25 mm. The starting point was a wire with a length of 100 cm. This was then every time shortened by 10 cm. The signal strength is displayed in dB relative to the signal received by a whip of 100 cm. This measurement was carried out in the open field. The antenna was mounted at an height of 360 cm.
The reception quality is determined solely by the ratio of the received signal over the received noise. The strength of the received signal is of less importance as long as the noise from the antenna is larger than the noise of the receiver.

A method was developed to compare the signal to noise ratio of active whip antennas. The carrier of ONO, Ostend, Belgium, is transmitted on 399,5 kHz. With the 100 cm active whip antenna, the relative signal strength was -19 dBm. This was the signal read at the SPM-3 with preamplifier. The antenna noise was measured at 399,15 kHz. The measurement was carried out during daytime to avoid interferences by remote stations through the sky wave. The antenna noise was about -90 dBm. The measurement was as follows. The receiver was tuned to 399,5 kHz. The signal from the test antenna was adjusted for -40 dBm using the RF attenuator. Then at 399,15 kHz the antenna noise level was determined. Table 1 shows the results of the measurements.

Lengte cm	DCF39 dB	WW-309 dB	ONO-399,5 dB	399,5/399,15 dB
100	0	0	0	–40 / –88
90	–0,5	–1,0	–1,0	–40 / –88
80	–1,5	–2,0	–1,5	–40 / –88
70	–2,5	–3,5	–2,5	–40 / –88
60	–3,5	–4,5	–3,0	–40 / –88
50	–4,5	–5,5	–4,5	–40 / –88
40	–6,0	–6,5	–5,5	–40 / –88
30	–8,0	–8,5	–7,5	–40 / –88

Table 1 - Antenna length, signal strength and signal to noise ratio.

If the whip is shortened, the signal strength decreases gradually. A whip with a length of 30 cm gives a signal that is 7 to 8 dB lower than with an antenna of 100 cm. The length of the whip does not affect the ratio between the received signal and the received noise. This is confirmed by the practice. In the Faroe Islands there are three aircraft beacons coming out in daytime just above the noise level. They were received on a 30 cm long whip as well as with the 100 cm one.

Electrical model of a whip antenna

A whip antenna receives signals from the electrical portion of the electromagnetic field. Figure 7 is the model of a whip antenna. This helps us to understand it.

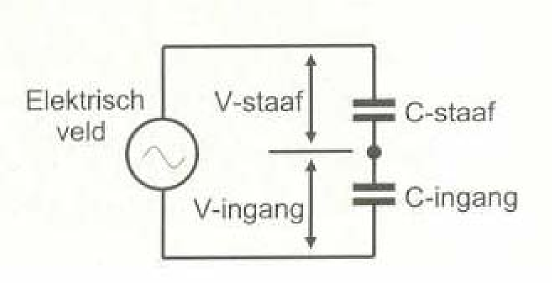

Figure 7 - Model of an active whip antenna.

The whip antenna is connected to the electric field through a capacitor C-staaf. This usually has a value of 10 pF or less. The antenna is connected to the input of the buffer amplifier. The buffer amplifier has an input capacitance C-ingang which depends on the used FET or transistor circuit. C-staaf and C-ingang form a voltage divider. A higher value of C-staaf gives more signal. The reverse is true for C-ingang. A longer whip has a greater capacity and deliver more signal. If the input capacitance of the buffer amplifier is reduced, the signal strength is increased and the whip antenna can be made shorter.
The behavior of whip antennas is well known. The U.S. standardization office has issued a publication about it. This specifies how the capacity of a whip antenna can be calculated. If the signal strength is proportional to the capacity of the whip, the relative signal strength of a whip of

any length can be calculated as well. See Table 2. We take a whip with a length of 100 cm and a diameter of 1,25mm as the 0 dB reference. The calculated signal strength matches the measured signal strength (Table 2) consistently.

Lengte cm	Capaciteit	Berekende signaalsterkte	Gemeten signaalsterkte DCF39
100	8,718 pF	0 dB	0 dB
90	7,978 pF	– 0,8 dB	–0,5 dB
80	7,227 pF	– 1,6 dB	–1,5 dB
70	6,646 pF	– 2,3 dB	–2,5 dB
60	5,686 pF	– 3,7 dB	–3,5 dB
50	4,890 pF	– 5,0 dB	–4,5 dB
40	4,072 pF	– 6,6 dB	–6,0 dB
30	3,224 pF	– 8,6 dB	–8,0 dB
20	2,332 pF	–11,5 dB	
10	1,364 pF	–16,1 dB	

Table 2 - Antenna capacity and signal strength.

Different perspectives

Looking at a whip antenna, we see something familiar. You see them everywhere, as a receiving antenna on a car, or as a vertically polarized antenna for 2 m/70 cm. Electrically, there are big differences. A whip antenna of 100 cm is an half-wave antenna on 2m, where voltage and current assume different values along the length of the whip. At a wavelength of 2200 meters, the 137 kHz amateur band, this antenna behaves completely different. At 137 kHz the whip is a capacity that receives signals from coupling to the electric field.

The pa0rdt-Mini-Whip ©

If we accept that a whip antenna is a capacity coupled to the electric field, the form is no longer important. The antenna works as long as it has enough capacity. This may be a copper surface on a circuit board. To see if this is true, I built the buffer amplifier of Figure 3 on a single sided PCB strip. The "whip" consisted of a copper area of 35 mm x 140 mm. This was isolated from the rest of the circuit by a 10 mm wide copper-free area, see Photo 2. Then the signals of DCF39, WW-309 and ONO-399,5 were measured again.

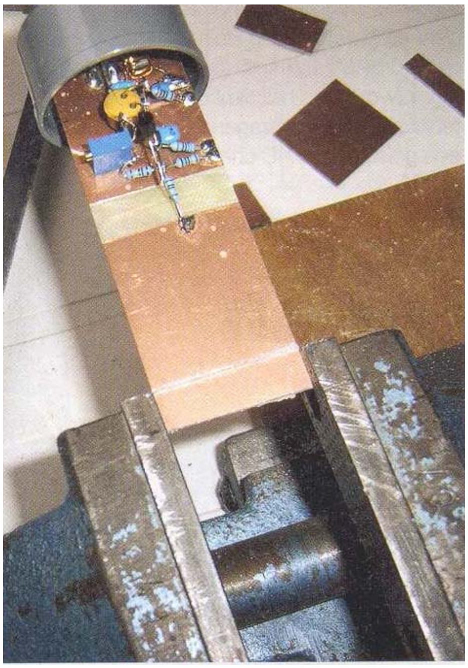
Photo 2 - Prototype of the pa0rdt-Mini-Whip ©.

These measurements were done at home with the antenna up in the garden. The results of the measurements are in Table 3.

Oppervlakte mm²	DCF39 dB	WW-309 dB	ONO-399,5 dB
35×140	0	0	0
35×100	–1,0	–1	–1,0
35× 80	–2,0	–2,2	–2,0
35× 60	–3,5	–3,3	–3,0
35× 50	–4,0	–4,0	–4,0
35× 40	–5	–4,5	–4,7

Table 3 - Signal strength vs. surface.

We can see that the antenna behaves as a capacity. In half of the surface, the capacitance value is also half. The strength of the received signal is half of the original signal. This corresponds to a reduction of 3 dB. Just look at the data for an area of 35 mm x 100 mm and 35 mm x 50 mm.
The signal level received by an antenna is interesting. This value depends on the time of day. It is the highest at the start of the evening. With my 2x20 meter dipole with open feed line, this value was -15 dBm.
The dipole had a 4:1 balun and 15 meters coaxial cable connected to an RF power meter. In a pa0rdt-Mini-Whip © with 35 mm x 140 mm copper surface the level of the received signal was -11 dBm. At 35 mm x 40 mm this was still -17 dBm. So we do not need to worry about the lack of signal intensity. In photo 3 there is a pa0rdt-Mini-Whip ©. This active antenna is only 10 cm long. Installed at an height of 4 meters it provides the same signal level as the dipole antenna on 3.5 MHz.

Photo 3 - Standard form of pa0rdt-Mini-Whip ©.

Variations on the theme

An active whip antenna does not need necessarily to be a rod. Other shapes are possible as long as the capacity is large enough (Photo 4).

Photo 4 - PA0RDT Micro-Whip, fourth from left, sized half a film canister.

The smallest version of the pa0rdt-Mini-Whip © (the "micro-Whip") was built in half a film canister. The buffer amplifier was supported by the insulated BNC connector.
Another version is the "diecast-box Mini-Whip" (Photo 5). This is a box of aluminum of 5 cm x 5 cm x 3 cm (Hammond 1590LB). The box itself is the actual antenna. The electronics is in the box, supported by the insulated BNC connector.

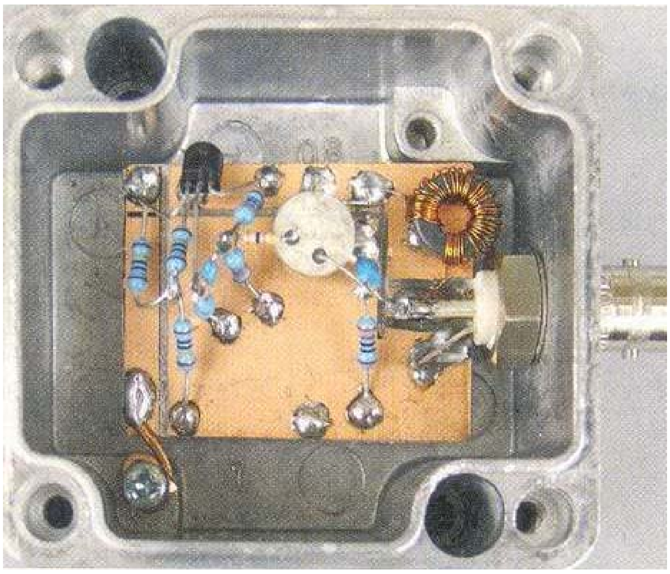

Photo 5 - Diecast-box Mini-Whip.

There were also experiments with a passive antenna for the electric field, in this case an empty 5 Kg coffee can was used (Photo 6).

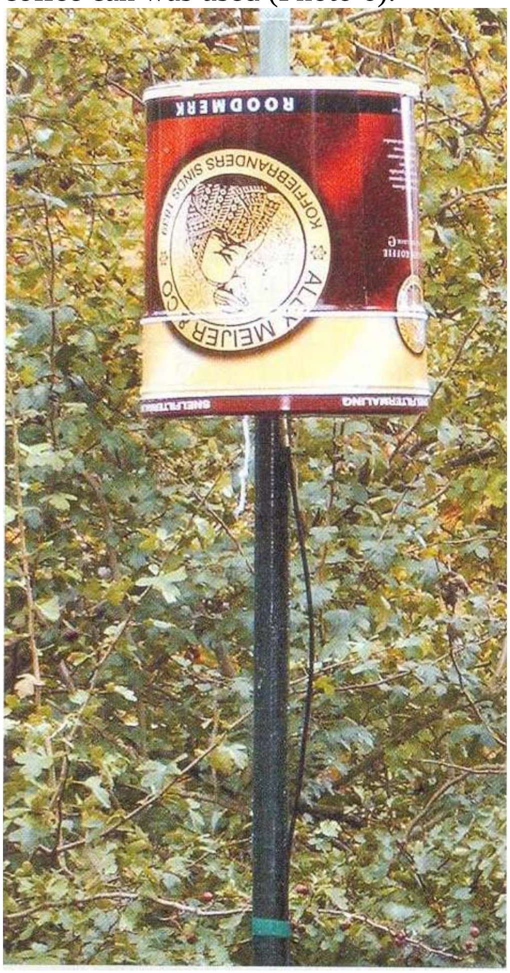

Photo 6 - Passive E-field antenna.

The signal was coupled using a 150:1 RF ferrite core transformer (Photo 7). The bandwidth was limited by the transformer to the long and medium wave. This worked perfectly.

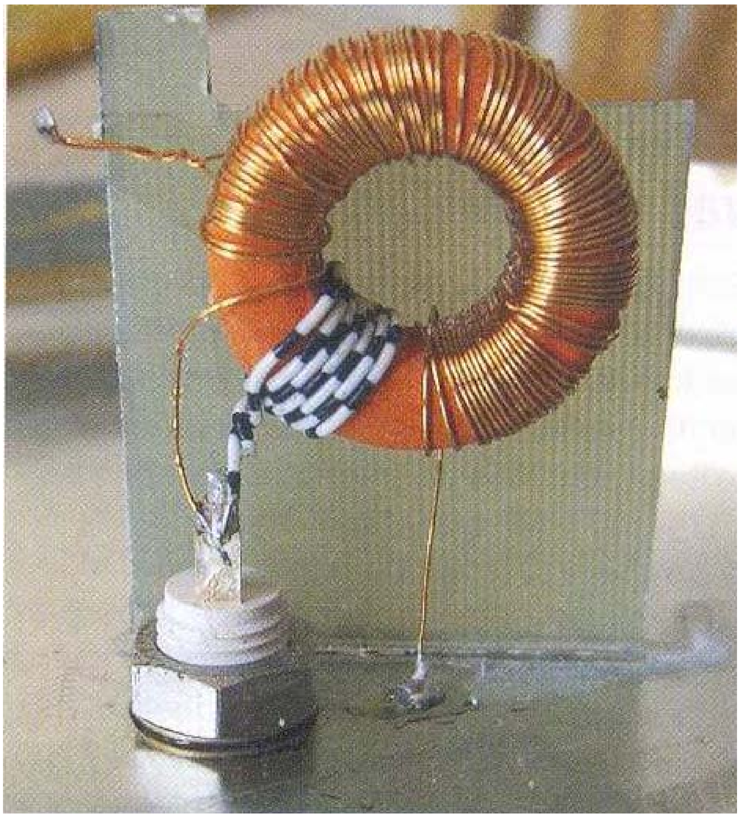

Photo 7 - 150:1 RF transformer for the passive antenna.

I also tried to use the body of my car as a passive electric field antenna. The receiver was placed inside the car. The signal was coupled using a 100:1 transformer. It worked, but the signals were 12 dB lower than with the coffee can. When I was distant I watched at the car and saw where the problem was. The bottom surface is a big capacitor shorting the signal to ground.

Dimensioning

The strength of the received signals is determined by the size of capacity, so the size of the copper surface. If this capacity is too large, then the buffer amplifier is overdriven. If the capacity is too small, then there is not enough signal into the receiver. Overload creates intermodulation products. The buffer amplifier output third-order intercept point is +31 dBm. The second-order intercept point is +67 dBm. The third-order intermodulation products in practice have little effect. Second-order intermodulation products are a problem. There we find the sum or difference between the frequencies of strong broadcast stations, such as broadcast stations around 9 and 12 MHz. Excess signal to the input of the buffer produces intermodulation products as a continuous noise of S5 in the 21 MHz amateur band. The inter-modulation occurs in the amplifier. On a receiver with a narrow input filter the intermodulation noise is as strong as on a receiver with a wide input filter. There is a reason to pay attention to the signal level. If we increase the input signal, more signal is also available at the amplifier output. This may give rise to intermodulation in the receiver. I always use the following rule of thumb: the third order input intercept point of a receiver must be 30 dB higher than the maximum input signal.
A reasonable receiver has s third-order input intercept point of +10 dBm. The maximum output of an active antenna is thus at -20 dBm. With a copper surface of 30 mm x 140 mm, the output signal in the evening has a maximum of -11 dBm. As at 7150 kHz and 7250 kHz strong broadcasting stations are present, third-order intermodulation products could be found at 7050 kHz and 7350 kHz. When listening to 7 MHz, however, I can not perceive them.
Interference caused by third-order intermodulation is apparently no problem. Interference caused by second-order intermodulation is much more worrying. With a maximum signal level of -11 dBm, a

wide spectrum noise is present at 21 MHz. This allows reception of all signals almost impossible. If we make the copper surface 30 mm x 40 mm, then the maximum is -17 dBm. The interference on 21 MHz is now completely absent. It is therefore important that the input signal is as small as possible.
The resistors on the input of the buffer amplifier form a voltage divider. The values can be adjusted to weaken the input signal. The size of the input signal is also dependent on the height at which the Mini-Whip is installed. See Table 4. It shows the relative signal strength up to a height of 4.8 meters included. This measurement was carried out in the open field. The height does not affect the signal to noise ratio.

Hoogte cm	Relatieve signaalsterke
120	–8
240	–4
360	–2
480	0

Table 4 - Signal strength and height of installation.

Figure 8 is the schematic drawing of the final version of the pa0rdt-Mini-Whip ©. The circuit is built with standard components and is an improvement in the circuit of figure 3. The second-order intercept point is greater than +70 dBm. The third-order intercept point is better than +30 dBm. There are measured values of 78 dBm and 33,5 dBm. The emitter of the 2N5109 now has its own current setting using the 10K and 2K2 resistors. The intermodulation is less, while the power dissipated in the transistor is also less. The 2N5109 does not need to be further cooled. If the J310 even breaks down, the 2N5109 will remain intact.

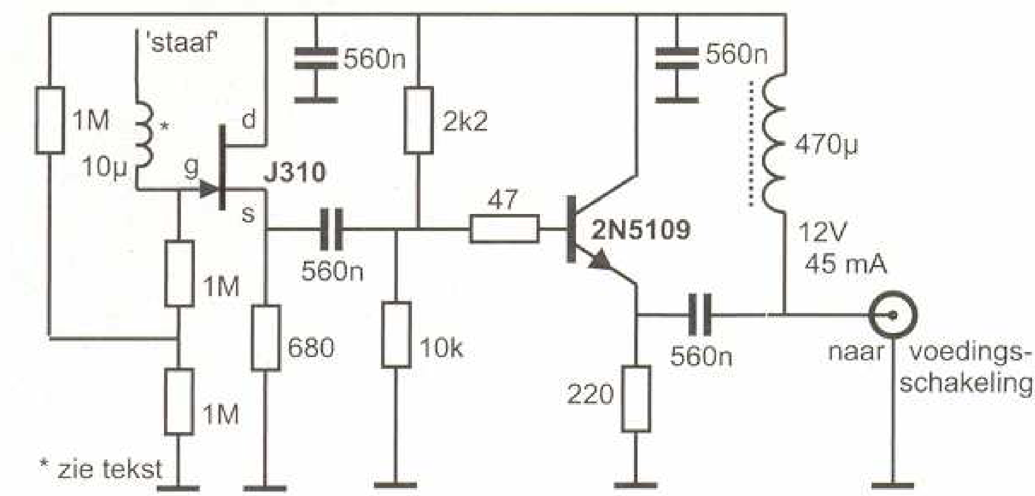

Figure 8 - pa0rdt-Mini-Whip ©

Above 15 MHz, the input capacity of the J310 plays a role. In a normal active whip antenna you will notice not so much. The whip at higher frequencies works more and more like a regular antenna and this compensates the losses. On the pa0rdt-Mini-Whip © this effect can be reduced by inserting an inductor coil between the "antenna" and the gate of the J310, in series with the input capacity of the circuit. The best resonance frequency is around 25 MHz. For the inductor, a value of

5 to 10 uH can be used. Figure 9 Shows how the pa0rdt-Mini-Whip © is power-supplied.

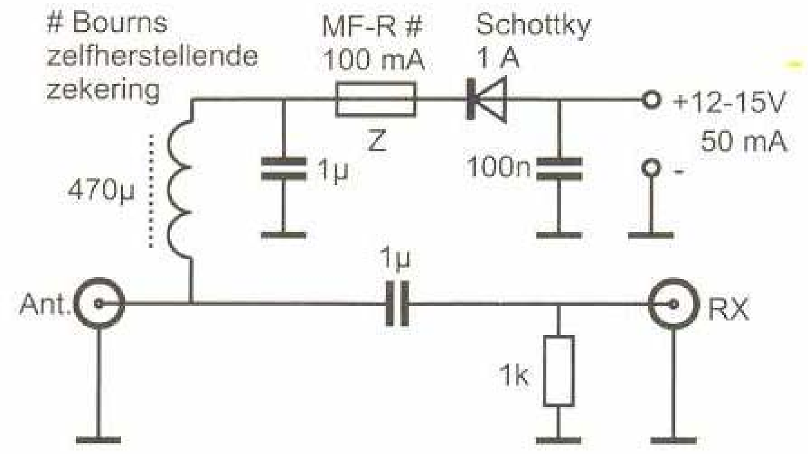

Figure 9 - Power-supply via the coaxial cable for the pa0rdt-Mini-Whip ©.

The 1K resistor ensures that when connecting the receiver no power (current peak of the 1 uF coupling cpacitor) is sent to the receiver input. The Z component is called a "Bourns multifuse". This is a self-healing fuse. In case of short-circuit the power is interrupted. If the power is then switched off and on, the fuse is restored. Very handy when experimenting.

The pa0rdt-Mini-Whip © in practice

There's a lot to tell, but I will be brief. This antenna does what you expect: it does receive well. From 10 kHz it works perfectly. The historical Alexanderson's Alternator in Grimeton, Sweden, at 17.2 kHz was received with a signal level of 15 dB above the band noise. Aviation beacons in the range of 200-600 kHz can be well received with this antenna. I've been hearing more than 1250 different NDB's: from Alert in northern Canada to the Cape Verde Islands in the south, from Kazakhstan in the east to Puerto Rico in the west.

Figure 10 is an ARGO screenshot showing the signal of NDB PVQ on 376 kHz. Normally, the frequency of ARGO scale is set to the audio band, but I had just given an offset to my receiver for tuning to listen on 137 kHz. The signal of PVQ is at 376 kHz. The location is Put River Deadhorse, Alaska, at a distance of 6288 km. This was the first time this station was received in Europe. The signal is received via a path that runs over the North Pole. The a0rdt-Mini-Whip © also works well on 137 kHz. Figure 11 is a screenshot on which five different trans-atlantic stations are shown.

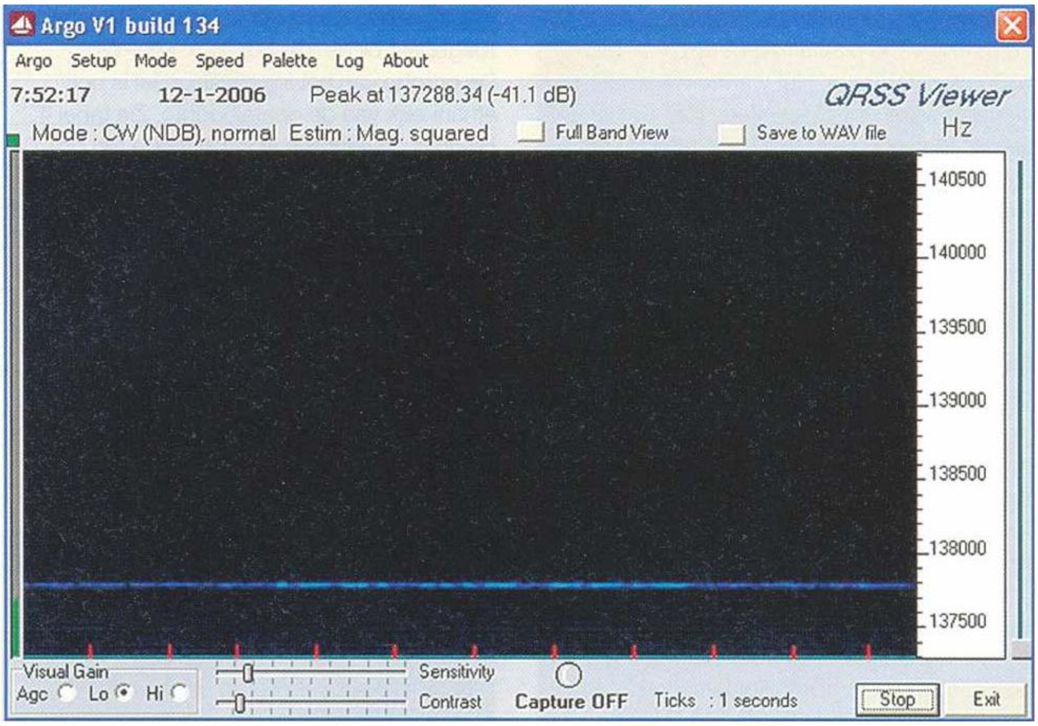

Figure 10 - Reception of NDB PVQ (Alaska).

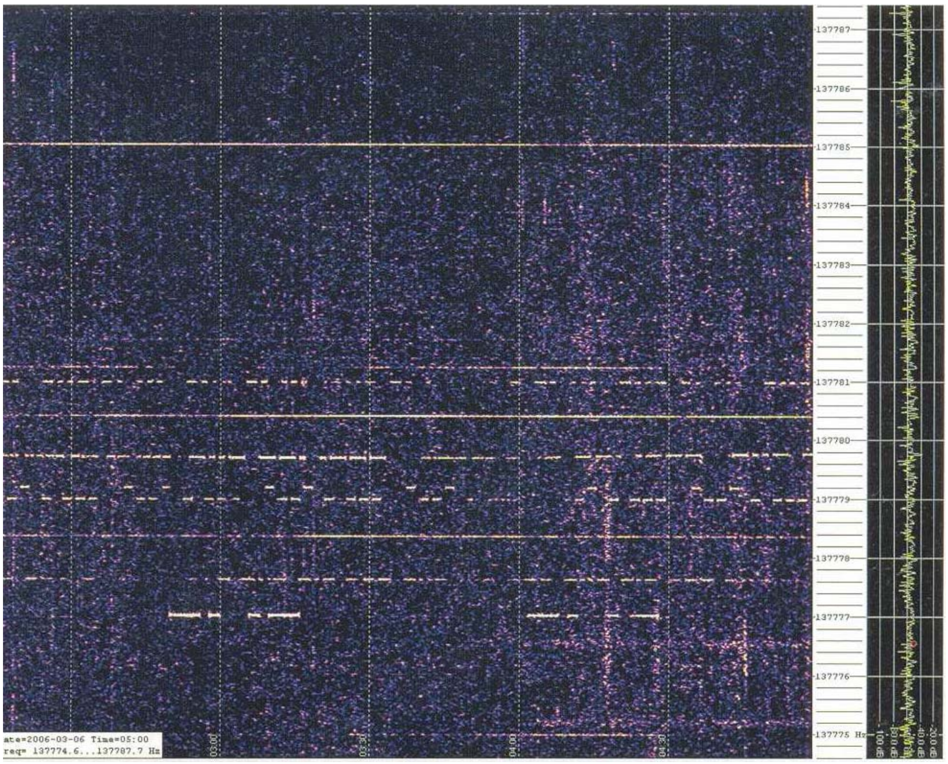
Figure 11 - Signals on 137 kHz.

It works also on HF very well, particularly on the 160, 80 and 40 meters band. So I spent the CQ WW Contest in Autumn 2004 from 12.30 until 14.30 local time listening to JA3AEP. Nothing special, you might think, but this was at 7 Mhz.

This antenna must be installed as much as possible free of obstacles. Any shielding of the electric field reduces the reception. In house, it performs very bad.
It often sits on a magnolia tree at a height of five meters. For /P activity remember to take a short mast, preferably plastic (photo 8).

Photo 8 - Westkapelle, the Mini-Whip on a plastic mast section.

Please send me a picture of the radiation pattern to show. I have approached a number of experts in the field of antenna simulations at home and abroad. It resulted that with current programs it is not possible to simulate the pa0rdt-Mini-Whip ©. These programs decompose an antenna in smaller segments. The segments carry each a different current/voltage. This is calculated to determine the radiation pattern. In an antenna for the electric field this does not work, because only power is available. However, the signal of a 7 MHz local station was as strong on the Mini-Whip as on my 80m dipole used as a T antenna. Vertically polarized signals are obviously received in an excellent way by the Mini-Whip.

Conclusion

This article has demonstrated that local noise, present in the electric field at low frequencies, do not propagate outside the house. Noise present in the magnetic field, propagates outside. A whip antenna behaves at longwave like a capacity coupled to the electric field. If we accept this fact, the form is not of great importance.

The whip can be replaced by e.g. a copper surface. Based on this information an active antenna was developed, where the antenna is integrated into the board: the pa0rdt-Mini-Whip ©. Much attention was paid to the sizing. The pa0rdt-Mini-Whip © in current implementation is only 8 inches long and can receive full 10 kHz to 20 MHz (30 MHz). To anyone who needs a small receiving antenna, I recommend to build for yourself one pa0rdt-Mini-Whip ©. There are over 70 built. If this is an insurmountable problem, you can always contact me via this e-mail address: pa0rdt@amsat.org.