- Short Monopole Antenna Basics
- Role of ground, mast and height – effective height
- Install and operate a mini-whip
- Examples of practical circuits
- References and further reading

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Some History of the „Mini-Whip“

The idea of combining antennas with active components became a technical reality when field-effect transistors got widely available in the 1970s. Since then, reception of very long waves up to short wave has become easily possible with small capacitive broadband antennas instead of long and expensive passive wire antennas.

Much research has since been published by Lindenmeier [9,10], Landstorfer and others. Active whip antennas from manufacturers such as R & S, RFT, Schwarzbeck, RF-Systems, Dressler etc. were widely used for radio-monitoring, military, maritime and EMC laboratory applications. Radio amateurs and shortwave listeners soon discovered the advantages of these simple active antenna concepts. Circuits and building instructions for active rod antennas have since been published in various magazines.

Some years ago Roeloff Bakker, PA0RDT, had the clever idea to use a piece of copper plated printed circuit board as an antenna element instead of a rod/whip and to place a simple amplifier on the same piece of the pcb. He published this active antenna in an article [3] and called his design "Mini-Whip". Since then the Mini-Whip has been copied and built by the thousands. The name "Mini-Whip" is now a common synonym for active whip antennas.

Although the principle of operation is well understood in scientific and professional circles, there have been many misunderstandings in the amateur community about how this antenna works. Thanks to the work done by Pieter-Tjerk de Boer, PA3FWM, and his publications [5] [6] [7], as well as blogs by Owen Duffy and others, some light has been shed on the basic theory of the mini-whip.

This set of slides is intended to provide some basic knowledge of the function, to show examples of practical circuits and to give some practical advice on how to get the most out of active whip antennas.

Mini-Whip - Smart Implementation of a Known Principle

Aktive Rod Antenna
HE011, Rohde & Schwarz
ca. 1975

Genuine mini-whip
Roeloff Bakker
PA0RDT

mini-whip
China ebay

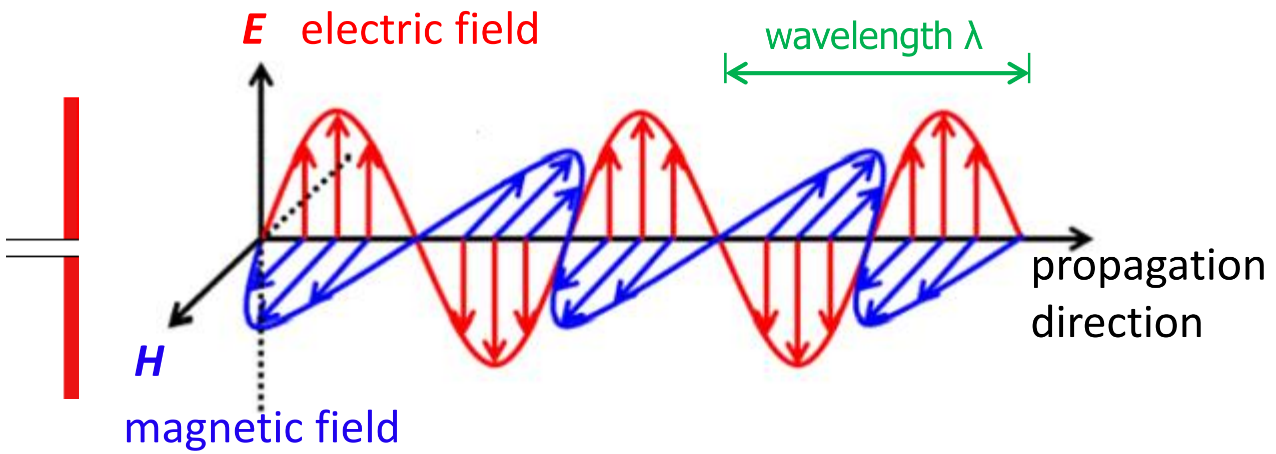
mini-whip Pro
dl4zao

Blue-Whip
dl4zao

Boni-Whip
Bonito / NTI

„Mini-Whip“ is now a common synonym for short monopole E-field active antennas
A Mini-Whip is a monopole with a very short antenna-element

Electromagnetic Wave (Radiowaves)

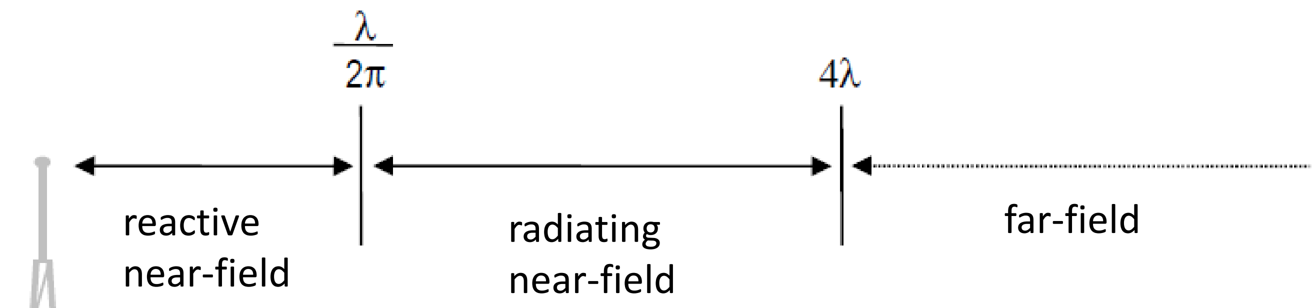


- ***E*-field** (electric field), fieldstrength in V/m
- ***H*-field** (magnetic field), fieldstrength in A/m

wave-impedance $Z_0 = \frac{E}{\mathrm{H}}$ *Dimension: (V/m) ⁄ (A/m) = Ω*

The electric and magnetic field strengths of electromagnetic waves travelling in free space are related by a proportionality factor, the "Wave Impedance" $Z_0 \approx 377\ \Omega$. The characteristic impedance of vacuum Z_0 of 376.730 Ω is a physical constant.

Field-Zones Around an Antenna



- **near-field** – distance up to 0,16 λ from the antenna
- **far-field**– distance beyond 4 λ from the antenna

In the near-field region the electric and magnetic fields are unpredictable and displaced by 90 degrees from each other, turning the field reactive. The fields remain electrically attached to the antenna, no power is being radiated.

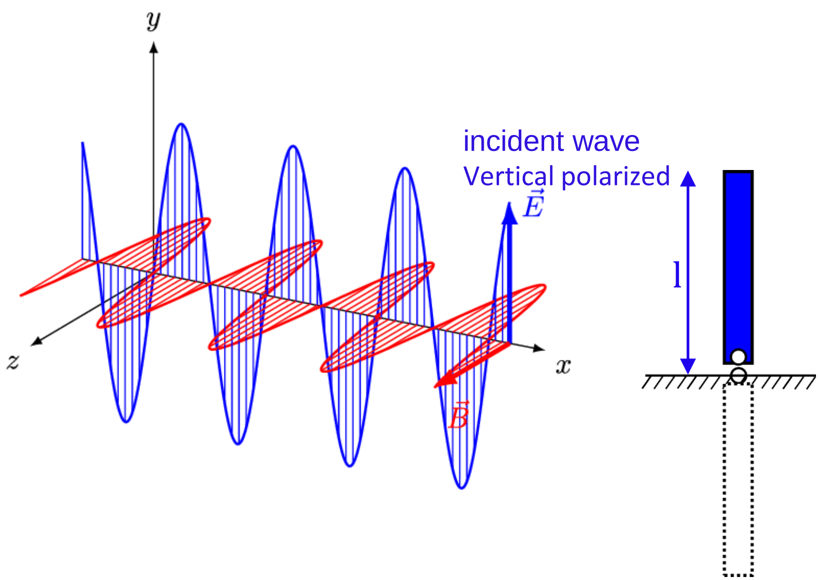
The region where the transition of the electromagnetic field from reactive to radiative begins is called the radiating near-field region. Its boundaries are vaguely defined.

In the far field the electromagnetic wave has left the antenna. Electric and magnetic field are in phase. Energy is being radiated and propagating.

Short Monopole and Dipole as E-field Probe

Electromagnetic waves are always composed of both field components, the electric field and the magnetic field. They are perpendicular to each other and perpendicular to the direction of propagation. In the far field of an antenna, the electric and magnetic field components are in phase.

The polarization of an electromagnetic-wave is defined as the orientation of the plane of the electric field component.



Short monopoles (length l is less than 0.15 λ) are predominantly sensitive to the vertically polarized electric field of a radio wave. A very short monopole can therefore be considered as an E-field probe.

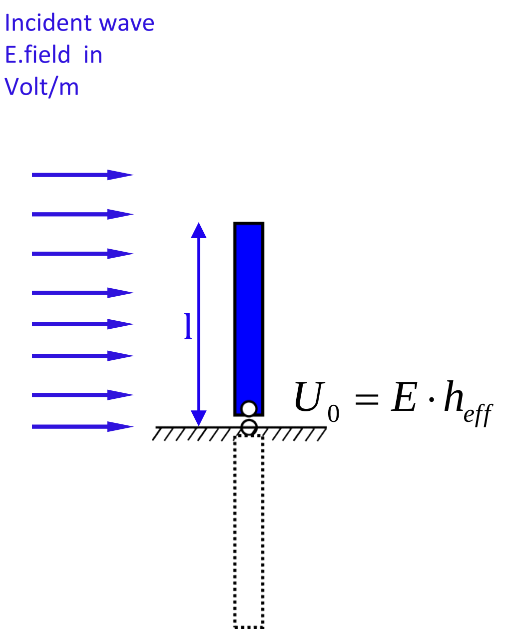
The near-field wave impedance of a short monopole is high.

Monopole (Whip) on Ground - Effective Height h_{eff}

The effective height h_{eff} is a conversion factor that is used to determine the voltage induced on the open-circuit terminals of the antenna when a wave impinges upon it. The effective height is not identical to the physical height l.

Multiplying the effective height by the incident field E (volts per meter) of a wave of the same polarization gives the induced open circuit voltage U_0.

$$U_0 = E \cdot h_{eff}$$



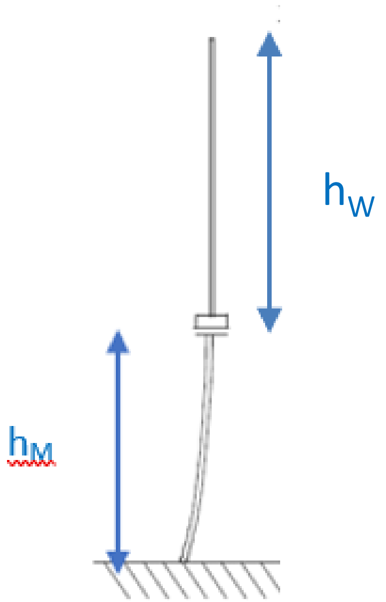
h_{eff} of a short monopole, l< 0.15 λ on a conductive surface (see attachments) ís:

$$h_{eff} = ½ \cdot l$$

- Example: a wave with a fieldstrength E of 1µV/m induces in a rod or whip of 1m physical height an open circuit voltage:

$$U_0 = E \cdot ½\, l = 0.5\ \mu V$$

h_{eff} of a Monopole on a Mast



When the whip is mounted on top of a grounded conductive mast the effective height h_{eff} is:

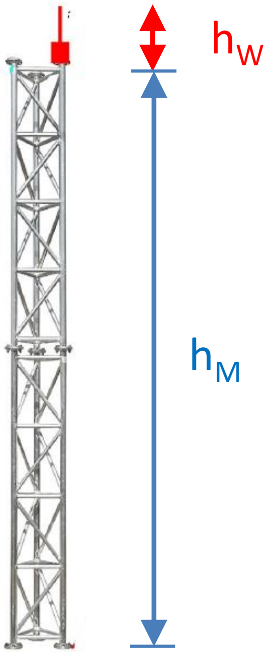
$$h_{eff} = 1/2\ h_W + h_M$$

thus the induced open circuit voltage U_0 is:

$$U_0 = E \times h_{eff}$$

$$U_0 = E \times\ 1/2\ h_W + h_M$$

h_W = physical height of the whip
h_M = physical height of the mast



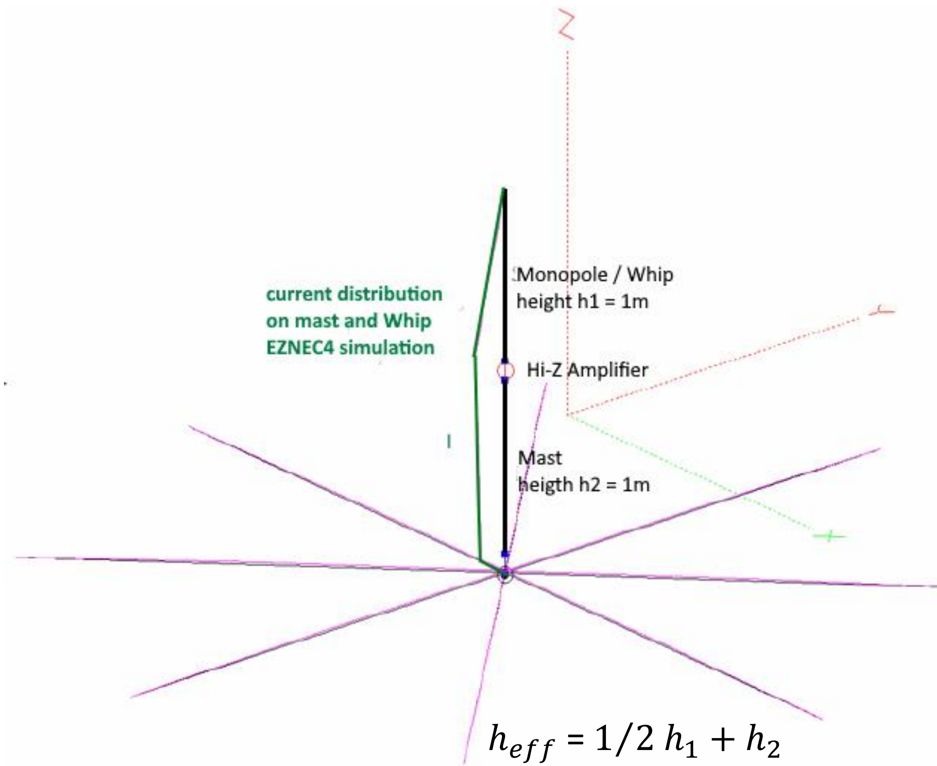
mini-whip on a mast

- When an antenna is mounted on a mast, the mast is integrated into the antenna structure and must be considered as part of the antenna. The voltage U_0 increases proportionally with height. The mast height h_M dominates the effective height h_{eff} and thus the signal voltage. The height of the mast has twice the effect on h_{eff} as the length of the whip.

- With an insulated mast, the shield of the coaxial-cable takes on the role of the mast.

Prerequisite: overall height of mast and whip is small compared to the wavelength, $l < 0.15\,\lambda$

1m Whip/Rod on Top of an 1m Mast - EZNEC Simulation



$$h_{eff} = 1/2\ h_1 + h_2$$

Another way to view the effective height is by considering the average of the normalized current distribution over the length of the antenna and multiplying that value by the physical length of the antenna.

The current distribution of a mini-whip (short monopole with $l < 0.15\ \lambda$) is approximated by a right-angled triangle with maximum current at the bottom and zero current at the top. The triangle has half the average current area of the rectangle, so heff = ½.

The average current distribution on the mast is approximated rectangular. Thus $h_{eff} \approx 1$

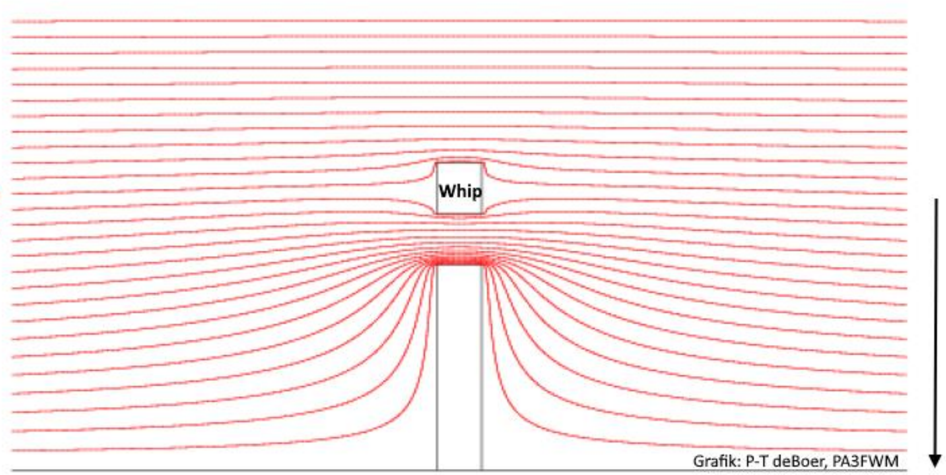
example:
whip height 1m
mast height 1m
E of incident wave is 1µV/m

$h_{eff\ (mast\ +\ whip)}$ = (1m x 0.5) + (1 m x 1) = **1.5 m**;

U_0 = E x h_{eff} = 1µV/m x 1.5 = **1.5 µV**

Prerequisite: overall height of the set-up is small compared to the wavelength, $l < 0.15\ \lambda$

Whip on a Mast – Field-Simulation (PA3FWM)



A short earthed conductive mast distorts the electric field, the potential at the top of the mast can be assumed to be earth potential* and used as the reference potential. With a non-conductive mast, the ground reference is instead provided by the shield of the coaxial cable or by a separate ground wire.

The whip element carries the average potential induced by it’s surrounding field lines.

* Prerequisite: overall heigh tof mast and whip is small compared to the wavelength, l $< 0.15\,\lambda$

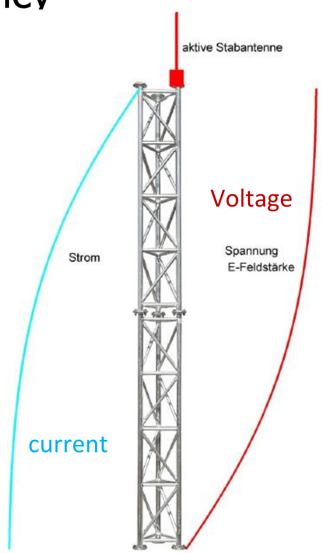
Behaviour when Mast and Whip are higher than 0.15 λ

The current distribution over a quarter-wave or a half-wave monopole is becoming nearly sinusoidal.

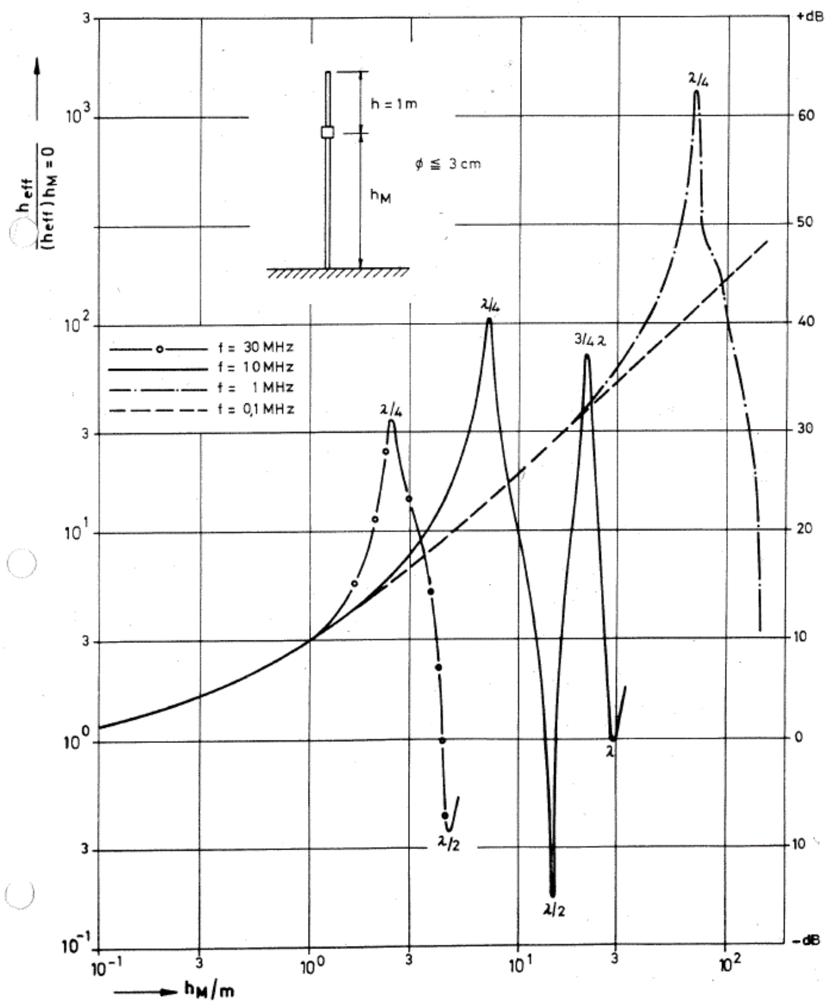
At multiples of λ/4 height, peaks and dips of h_{eff} and the signal voltage occur due to resonances.

The antenna will no longer be broadband and loses its flat frequency response.

A 10m mast for example has its first resonance peak at 7 MHz

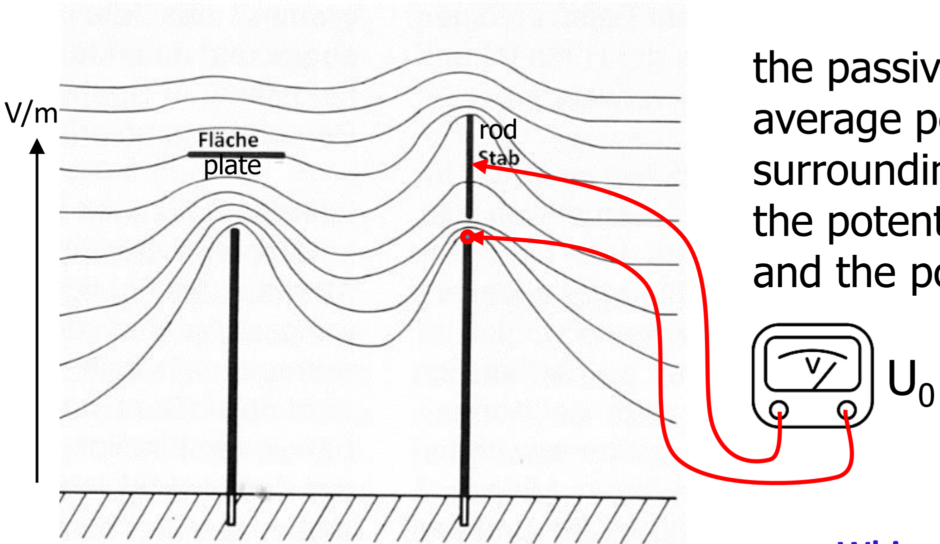


Grafik DL2NI [3]



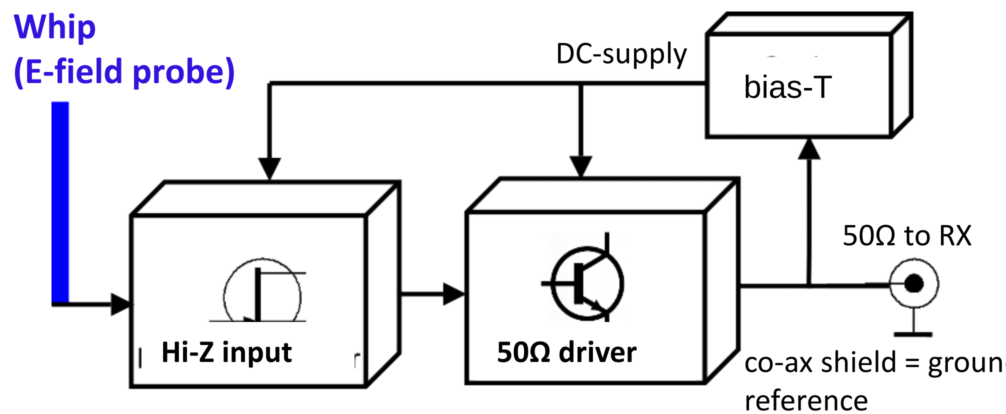
Source: Lindenmeier [10]

Mini-Whip Active-Antenna – How it Works



the passive rod or a conductive plate receives the average potential from the corresponding potential lines surrounding it (E-field probe). The Voltage U_0 represents the potential difference between the antenna element and the potential at the top of the conductive mast.

A high-Z-input amplifier picks up the open circuit voltage of the antenna element and "measures" the potential difference between the "probe" and the "ground" connection o the amplifier circuit U_0.



The amplifier is a FET voltage follower with a very high input impedance and a low input capacitance in order not to load the open circuit voltage, followed by an output driver to deliver sufficient power to drive a 50 ohm coaxial cable.

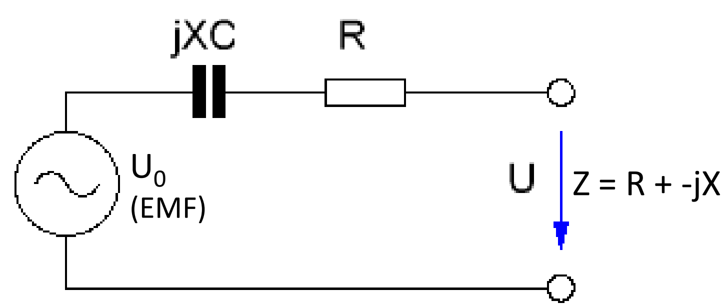
earth/rf-ground reference potential at the amplifier is essential for proper operation as an antenna.

Input Impedance of a Short Monopole (l<<λ)

The input impedance of an antenna is dependent on the size and the length of the whip element, compared to the received wavelength. An antenna is said to be 'short' if its geometric length is less than 0.15 of the operating wavelength ($l < \lambda/2\pi$). A short dipole or monopole then preferentially responds to the electric field component of a radio wave, hence the name: electric antenna or E-field antenna.

During reception, a short monopole behaves like a voltage source with a capacitor and a small resistor R in series. The voltage U_0 is proportional to the received field-strength

Receive short whip antenna equivalent circuit



Z_{Ant} = R + jXc (antenna impedance)

R = negligibly small

$jX_C = 1 / (2 \cdot \pi \cdot f \cdot C)$

(a high jX_C means a small capacitor)

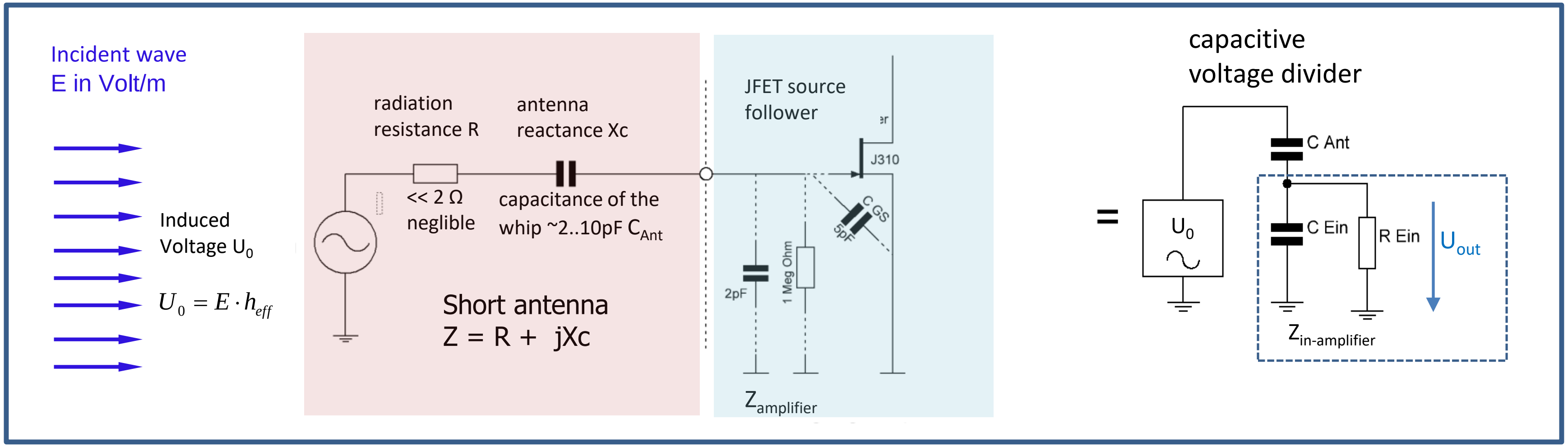
The real part R of the impedance Z of a short whip is made up of its ohmic resistance and its radiation resistance, both of which are quite small and will be neglected for now.

The frequency dependent reactance jXc becomes very large towards low frequencies.

⇨ The input impedance Z_{Ant} of a short whip is dominated by the high series reactance X_C of the anntenna capacity, assumed as 2 to 10 pF, depending on the size/thickness of the whip.

Short Monopole + Hi-Z Input Amplifier = Mini-Whip

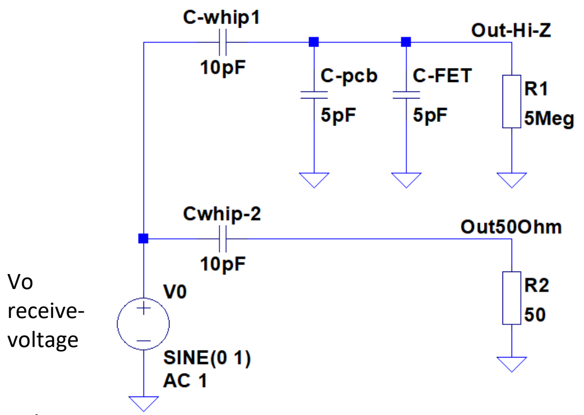
- The whip itself essentially behaves as a voltage source in series with a (negligibly small) resistor and a small capacitor C_{Ant} (i.e. the reactance Xc is high).
- The input impedance Z of the FET amplifier is largely determined by the parasitic capacitances of the JFET and the PCB to ground.
- This leads to an equivalent circuit which can be recognised as a capacitive voltage divider.

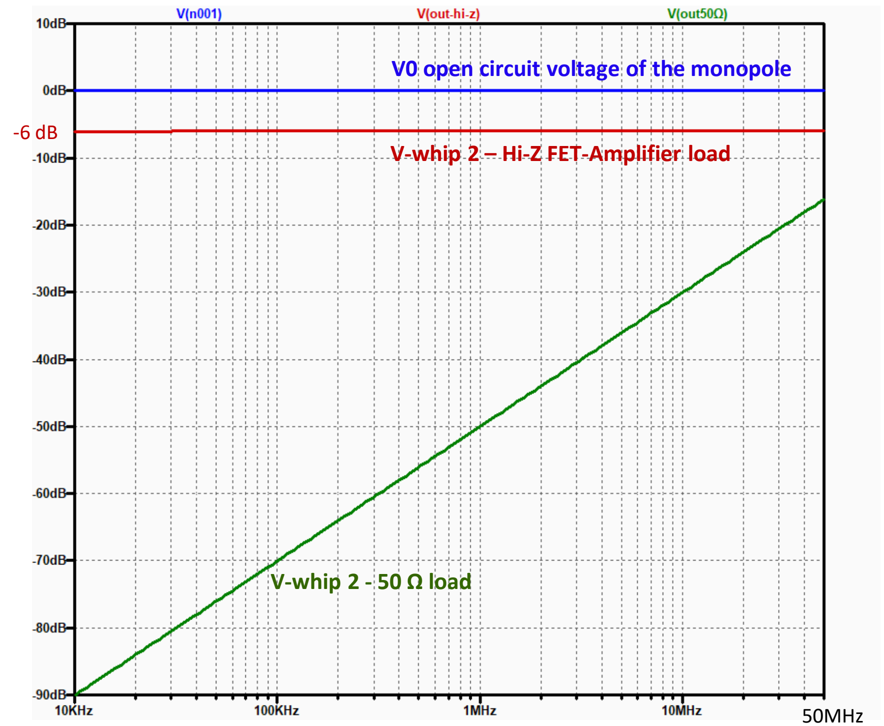


To pick the maximum voltage from the antenna element, the input impedance of the amplifier must be high with low capacitance, in order not to load the open circuit voltage of the whip. A Hi-Z input is particularly important at low frequencies, where the frequency-dependent reactance Xc is high. A JFET source follower normally meets this requirement.

Higher antenna element capacitance results in higher JFET source follower output voltage because the loss due to capacitive voltage splitting is lower. However U_{out} never exceeds U_0

Short Monopole – 50 Ω Load vs. FET Hi-Z Load





Simulation:
two short monopole whip antennas, each assumed with 10 pF capacity of their antenna element .
V_0 is the induced open circuit voltage of the whip.

whip 1 connected to a FET Amplifier with high Zin = (5pF Cgs + 5 pF pcb parasitic cap.) || 5 MΩ R_{in}

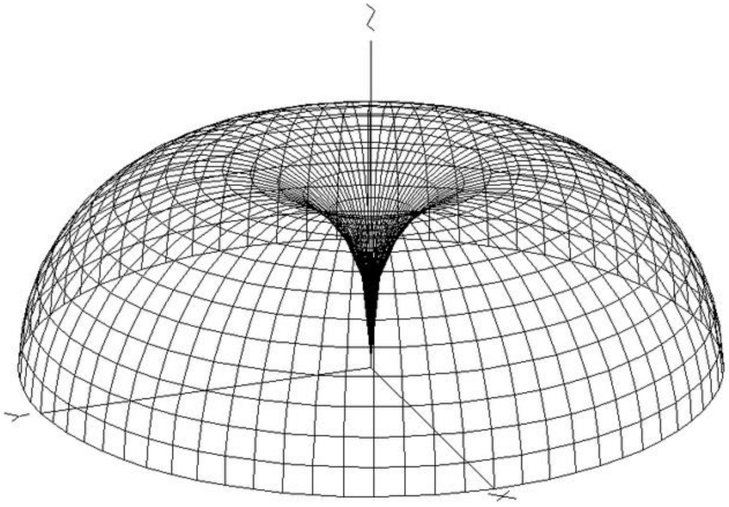
Whip 2 directly connected to a 50 Ω load, e.g an RX

The output voltage of whip-1 (Hi-Z load) has an almost flat frequency response. It works as a broadband antenna. Around 6 dB loss due to the capacitive voltage division of X_C (10 pF) of the antenna capacitor and the FET-amplifier Zin (capacitors of 10 pF || 5 MΩ)

The output voltage of the whip-2 (50 Ω load) is highly frequency dependent. High loss at low frequencies due to the voltage division of X_C of the antenna capacitance with 50 Ω load.

Mini-Whip Radiation Pattern and Polarization

EZNEC Simulation with a perfect ground. The 3D radiation pattern looks like this:



The radiation pattern is very similar to the upper half of an ideal vertical dipole. Mini-Whip active antennas are perfect omnidirectional antennas with it’s maximum sensitivity to signals at low elevation angles.

There is a deep, sharp null for near-vertical sky waves, which means a mini-whip is less sensitive to NVIS signals.

Active-whip antennas respond primarily to vertically polarized waves [5]. They are most effective at frequencies below 10 MHz, but can be widely used up to VHF frequencies.

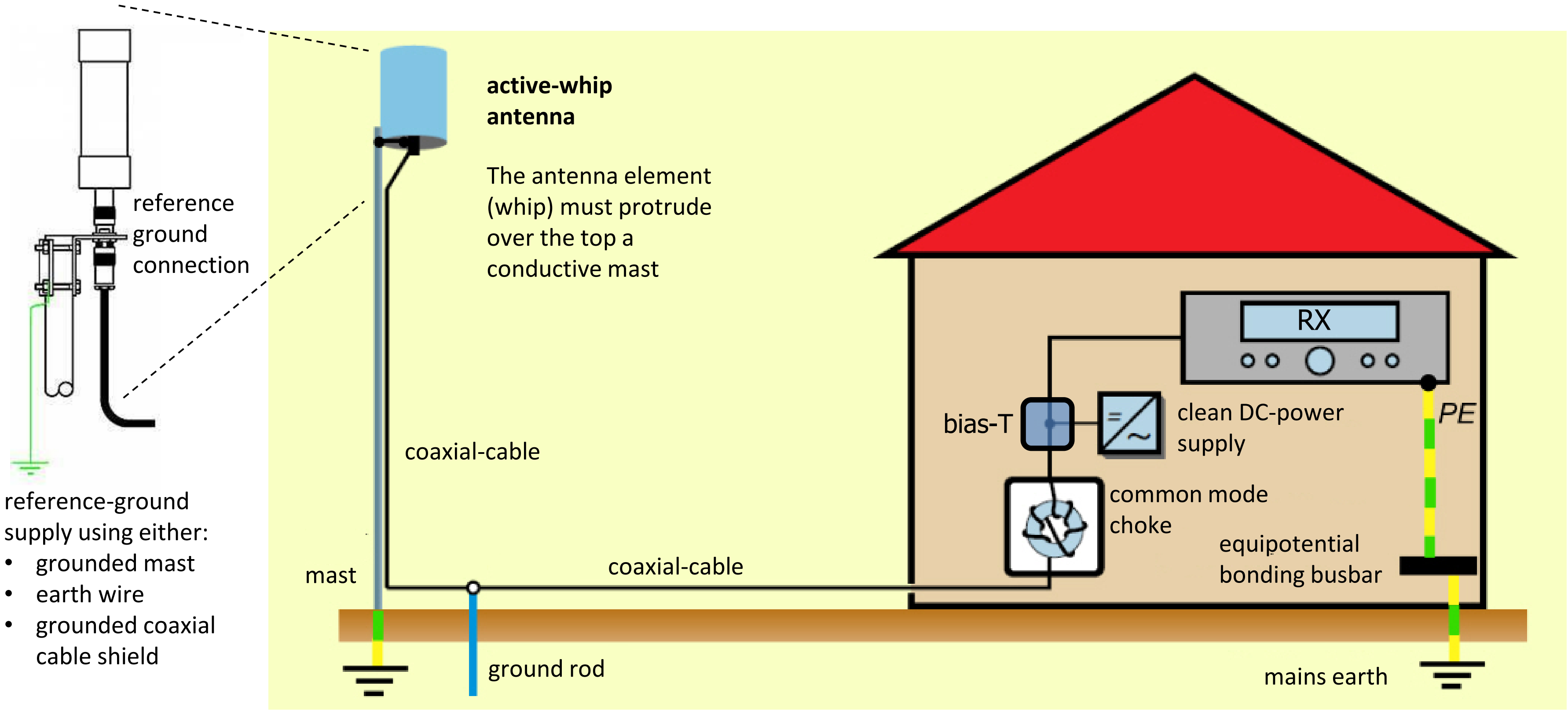
Mini-Whip – Practical Aspects

Many SWLs dismiss the Mini-Whip as "noisy"– however with proper installation and grounding, it performs very well.

The Mini-Whip is not a miracle antenna, but an active broadband antenna with impressive capabilities.

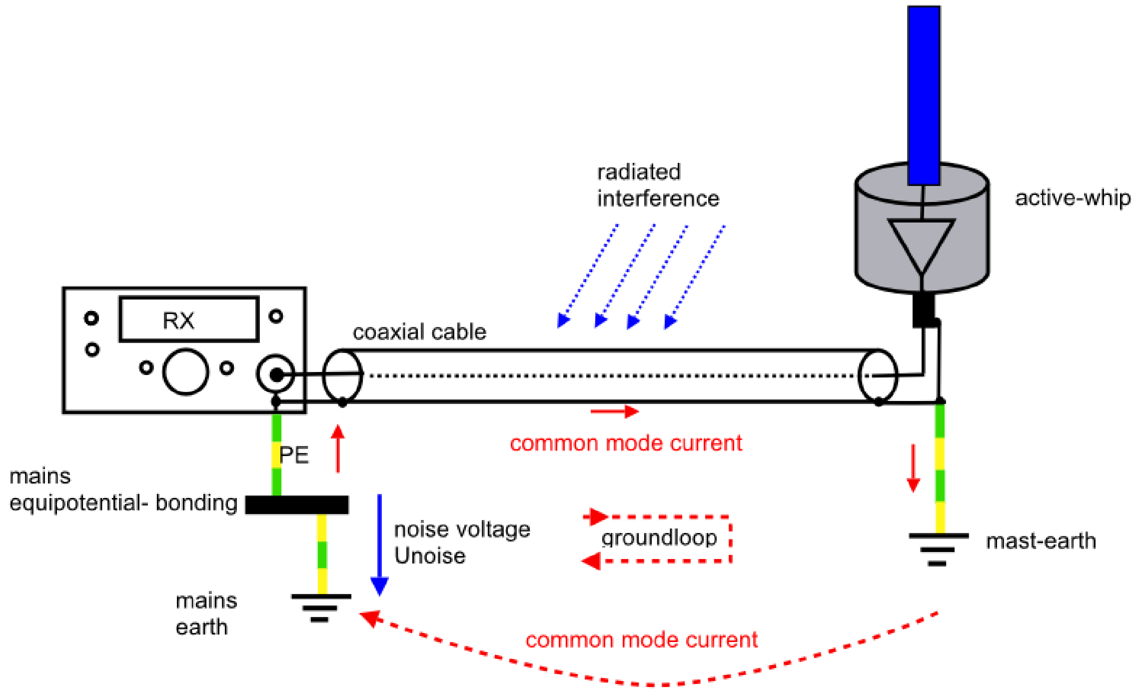
A benchmark example of a Mini Whip's performance is the Twente Wide Band Web SDR.

Proposed Installation of an Active-Whip



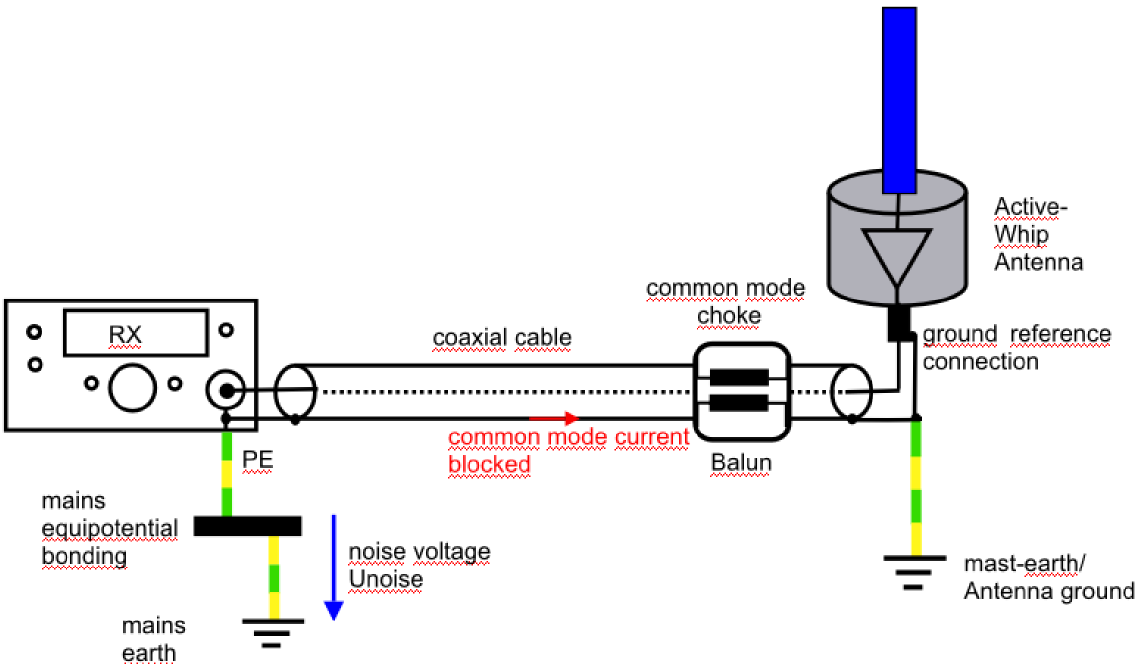
Place the active-whip away from domestic noise sources. A mast-height of 2 - 5 m (6-18 ft) is sufficient for most purposes. If the mast is non-conductive, an earth wire between the active whip and an earth rod at the base of the mast is recommended. Otherwise, the shield of the coaxial cable must be connected to an ground rod at the mast base. If the earth potential at the Mini-Whip is supplied only via the shield of the coaxial cable from a distant, noisy earth connection of the mains in the shack, there is a high risk of interference being coupled in.

Radiated and Conducted Common Mode Noise Ingress



A voltage difference between antenna earth and a noise contaminated mains earth of a building can cause common mode noise current flow over the coaxial cable shield, adding and injecting noise into the receive signal. Radiated interference can also induce common mode currents. The noise contribution can vary with the antenna's ground connection resistance and the soil moisture.

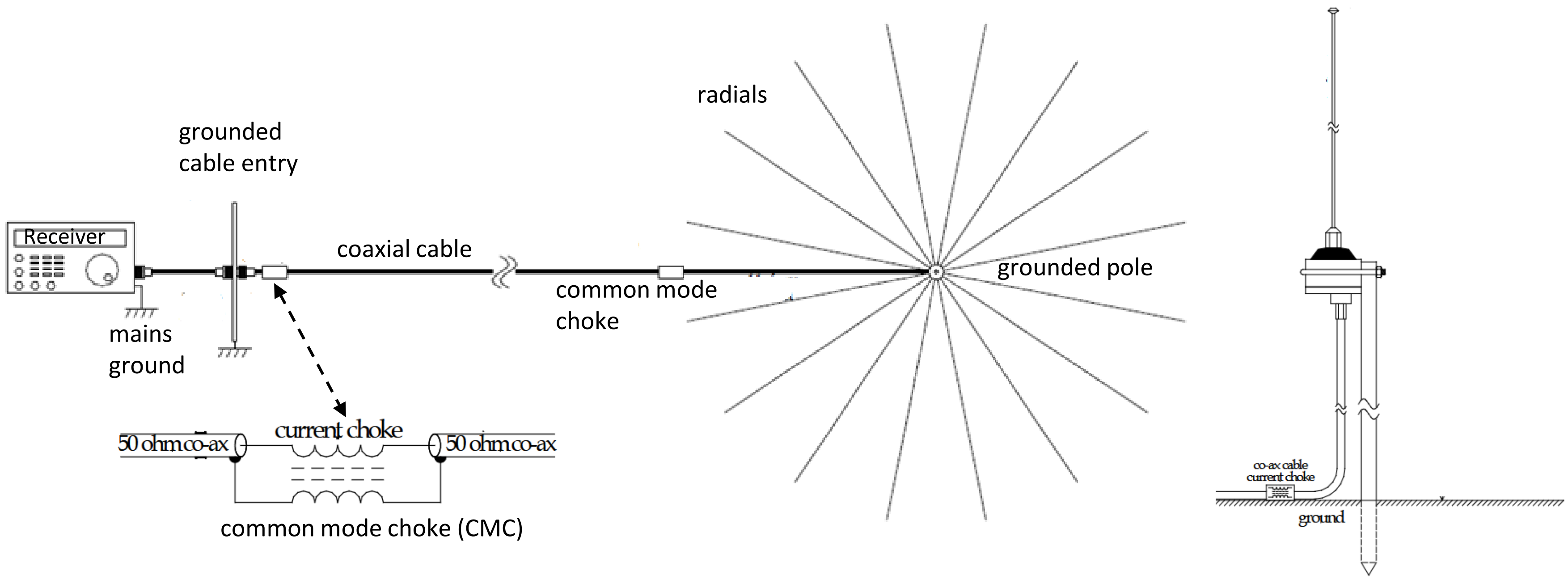
Solution: Common-Mode-Choke(s)



One or more common mode chokes (CMC) inserted into the coaxial cable may solve the problem. The inductive reactance X_L of a CMC prevents common mode currents on the cable shield. The signal current inside of the coaxial-cable is not affected. The CMC works best, when its inductive reactance X_L is high in comparison to the ground resistance.

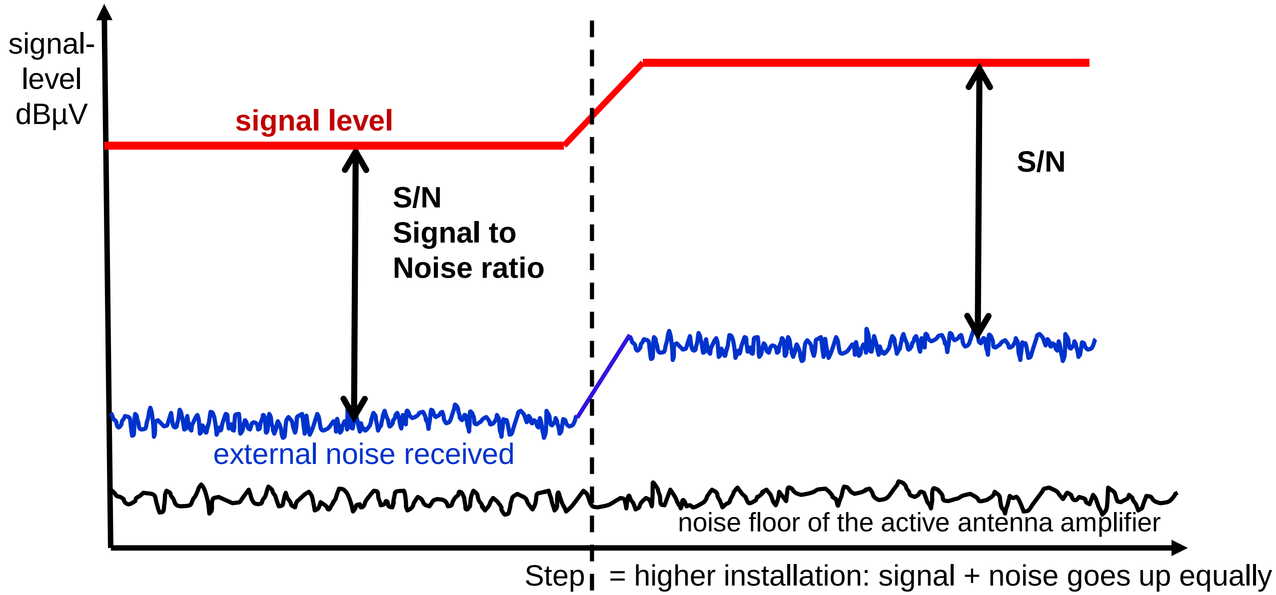
It should be noted that a CMC also prevents the supply of ground potential via the cable shield if it is inserted between ground and the active whip. In this case, the ground reference must be provided otherwise, e.g. via a conductive mast or a ground wire.

Professional Grade Set-Up



Efective grounding with radials and the use of common mode chokes (current Balun, CMC) inserted in the coaxial cable help to prevent the ingress of radiated and conducted noise. The inductive reactance X_L of a CMC prevents unwanted RF-current flow on the coaxial cable shield [21].

Signal to Noise Ratio SNR

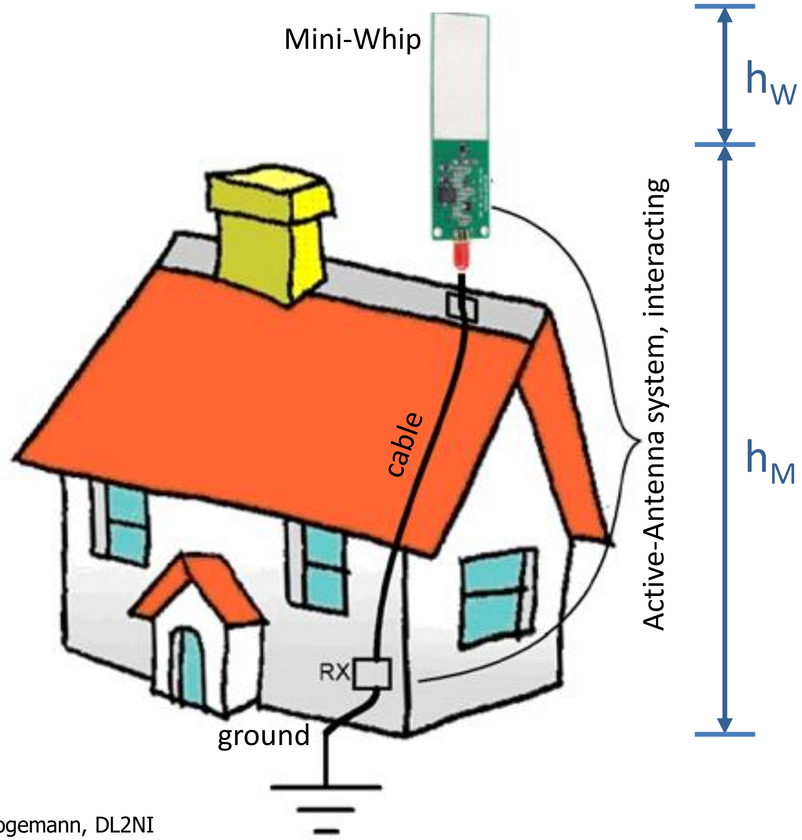


In reception, it is the signal-to-noise ratio (S/N or SNR) that one should be aiming for, not the highest possible S-meter deviation. Increasing the installation height will increase the level of the received signals proportionally, but this will not necessarily improve the SNR as the external noise received will also increase by the same factor.

high absolute signal levels come with the risk of amplifier overload and intermodulation-distortion. IMD is rogue or ghost signals that are created, they also may appear as hiss.

Select the height of the active antenna to be just high enough so that the external received noise is higher than the internal noise floor of the active antenna amplifier.

Mini-Whip on the Roof – Top or Flop?



J. Logemann, DL2NI

The house acts as a mast. The height between the roof antenna and ground determines the effective height h_{eff}.

antenna and cable are located within the near-field of typical domestic noise sources: switched power supplies, LED lighting, computers, etc.

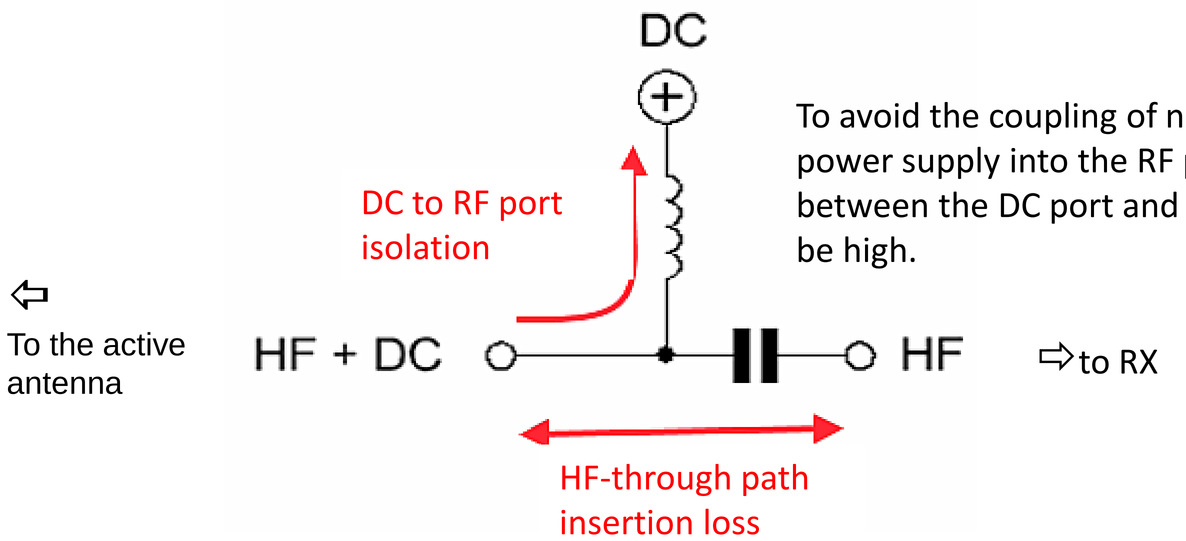
high height = high signal levels, which means risk of overload and intermodulation distortion

If the height above ground is greater than 0.15 λ, there will be resonance peaks and dips at the respective resonance frequencies.

However: a large conductive surface, such as a flat welded roof can act as a ground counterpoise that substitutes earth.

The Often Underestimated Role of Bias-T and a clean, noise free Power Supply

The Bias-T is a T-shaped three-port diplexer that is used to insert DC power into an HF-path to remotely bias HF circuits. The through-path passes the RF, a capacitor blocks the DC-voltage from the RX port.



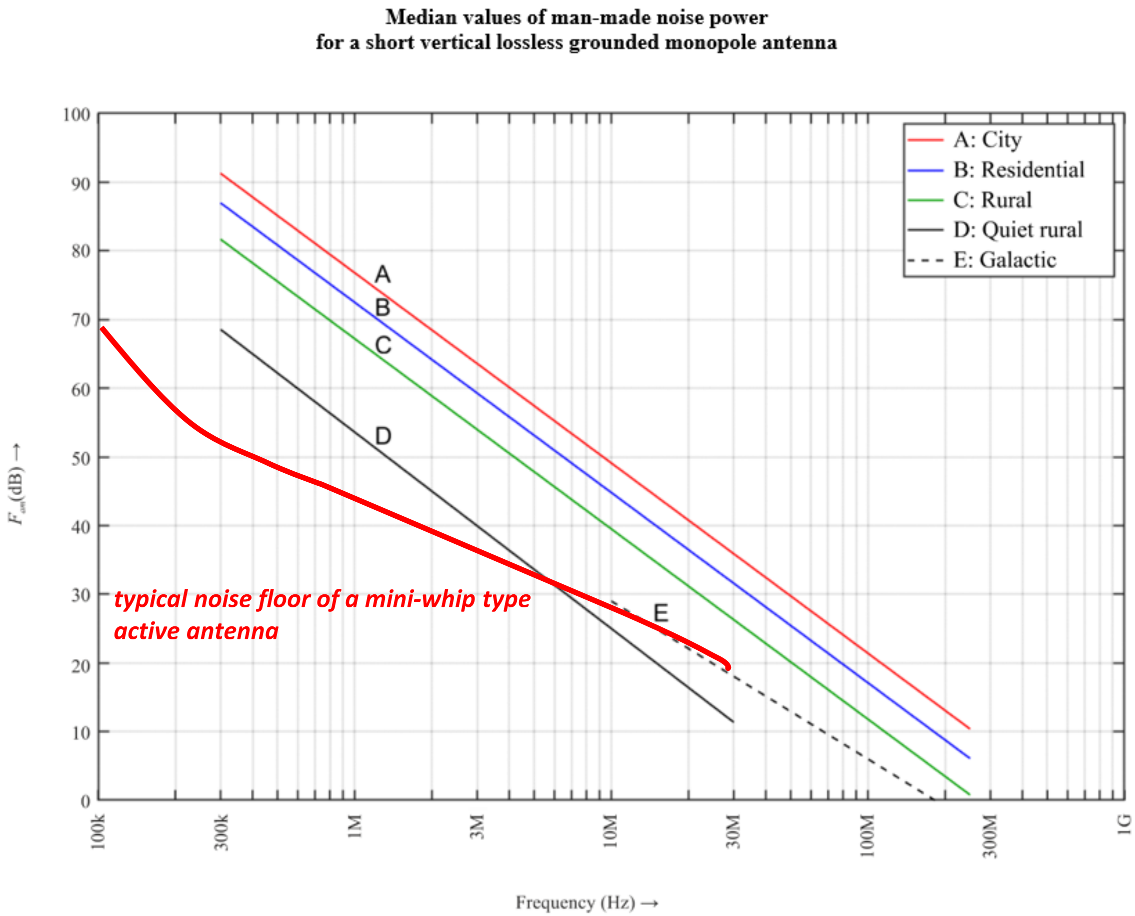
To avoid the coupling of noise from the power supply into the RF path, the isolation between the DC port and the RF path must be high.

Key requirements to meet over the full specified frequency range :

- sufficient isolation between DC-Port and HF-Ports, > 50 dB
- low insertion loss, wide band with flat frequency response
- good match to the coaxial-cable - low VSWR

The DC-power supply should be as clean as possible and free of noise and ripple. Preferably from a linear regulated power supply. Cheap and poorly filtered switched supplies are often not clean enough and have residual switching-frequency pulses that couple into the RF-path

External Noise – ITU-R P.372-17



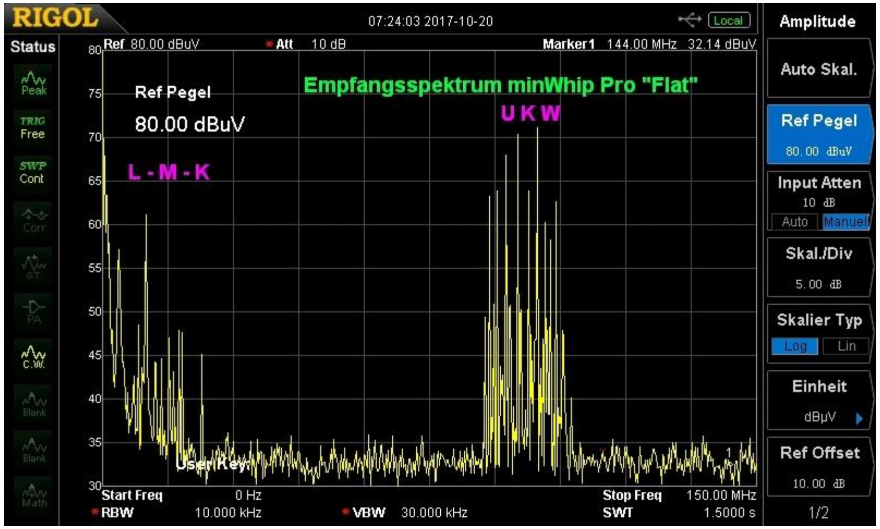
FET Hi-Z amplifiers have an inherently poor noise figure. Especially at low frequencies, the thermal noise of the gate resistors combined with the input capacitance of the FET determine their noise floor.

However up to frequencies of around 20 MHz, the median external noise (diagram) will most of the time exceed the internal noise floor of a JFET active-whip antenna.

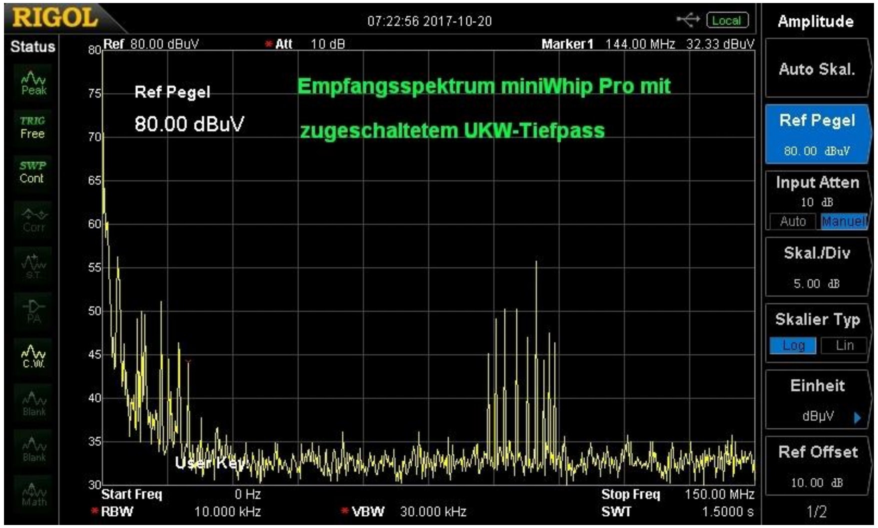
With the omnidirectional receive pattern of a Mini-Whip, the SNR is mostly dominated by external noise sources.

Recommended: Attenuation of FM-Radio Signals

In locations with nearby strong FM stations, the amplifier input should be fitted with a low-pass filter to prevent overloading and intermodulation.



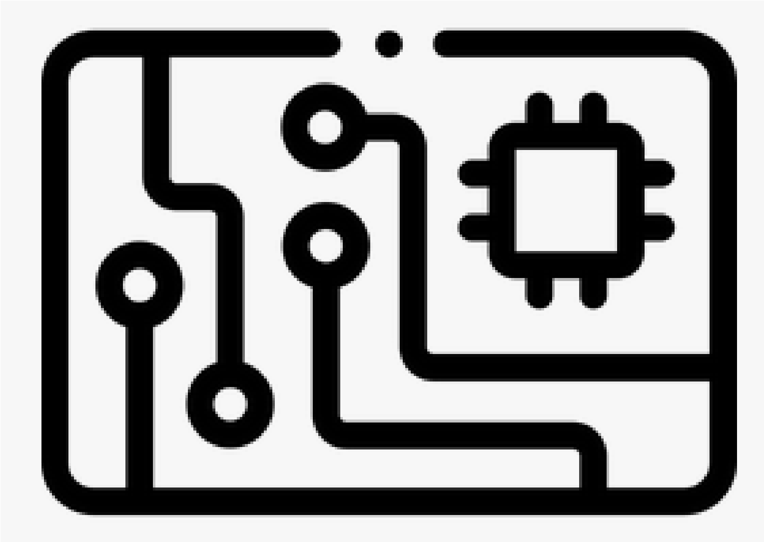
receive spectrum with flat frequency response



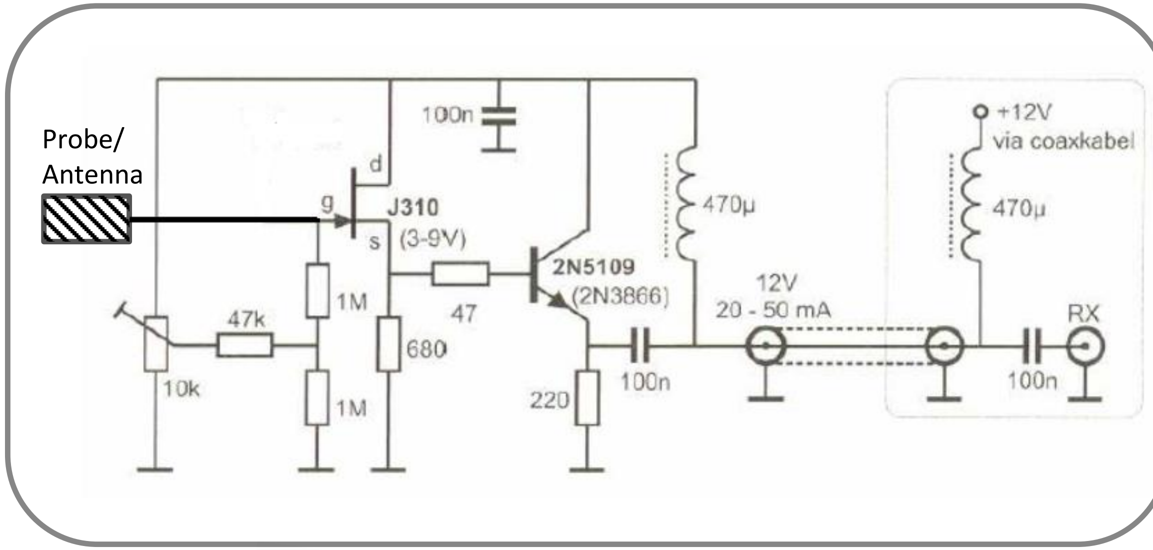
receive spectrum with FM lowpass activated

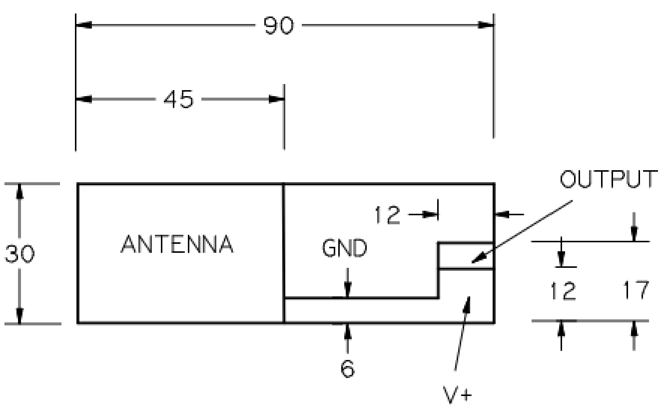
Mini-whip amplifiers often have a fairly high gain bandwidth. The wider the bandwidth, the more strong signals the amplifier has to process simultaneously. Even small non-linearities in the amplifier can cause unwanted intermodulation products. Intermodulation products of multiple signals occur in the form of noise and ghost signals (artefact signals at frequencies where they should not be). An linear amplifier with high IP2 and IP3 is therefore desirable.

proven practical circuits



The genuine mini-whip from Roeloff Bakker, PA0RDT

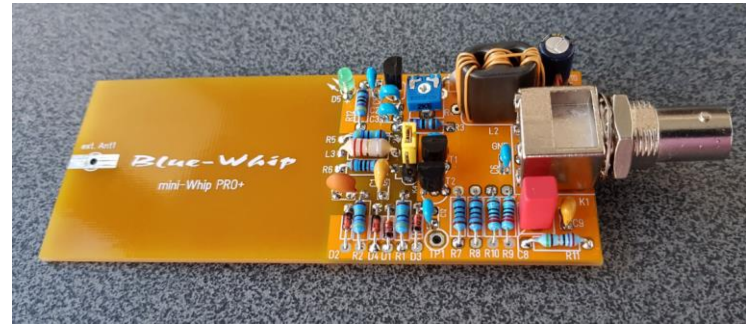


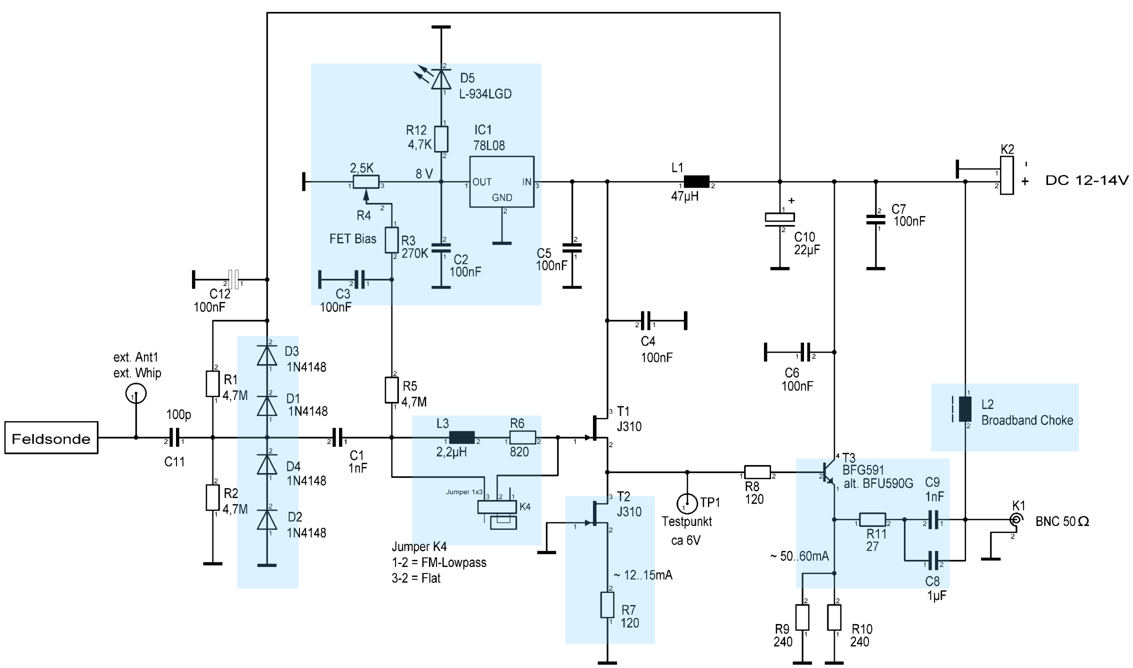


Amplifier specs measured by AA7U.
Frequency range: 10 kHz – 20 MHz
Power: 12 – 15 volts at 50 mA.
Second order output intercept point: > + 50 dBm.
Third order output intercept point: > + 30 dBm.
Maximum output power: in excess of – 15 dBm
PCB Dimensions:
Length: 80 mm, diameter: 32 mm

DL4ZAO Mini-Whip Pro+

Design aim: To eliminate some of the minor shortcomings of the original mini-whip circuit and improve its performance. Mostly use of through-hole components to make it easier for inexperienced experimenters.





List of improvements (shadowed areas):

- ESD protection with biased diodes
- FM lowpass, can be bypassed
- Stabilized adjustable FET bias
- FET Source follower works on a FET constant current sink T_2. That eliminates the voltage offset between Vgs and the source-voltage. Gain of the source-follower is now closer to 1. That improves noise figure and linearity
- Output resistor to improve S22, prevents parasitic oscillation in case of a capacitive load (open coax) of the emitter-follower
- Lossy 1 mH bias-t choke with supressed self resonance.
- Modern actively produced SMD-transistors: MMBFJ310, BFU590G

Improved Mini-Whip – in use at the Web-SDR Twente

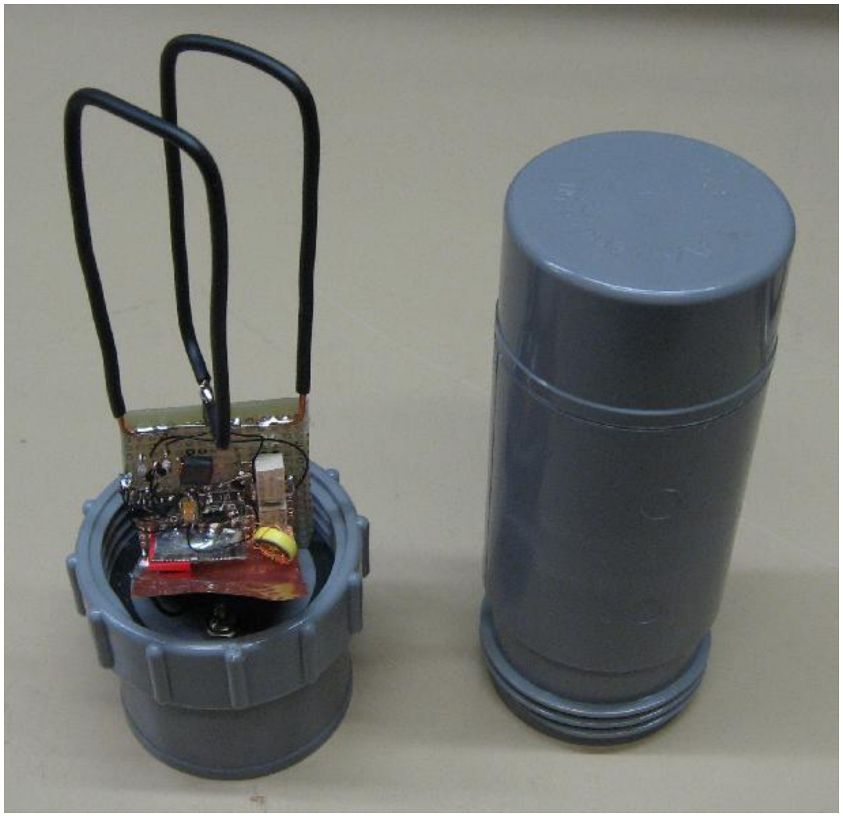
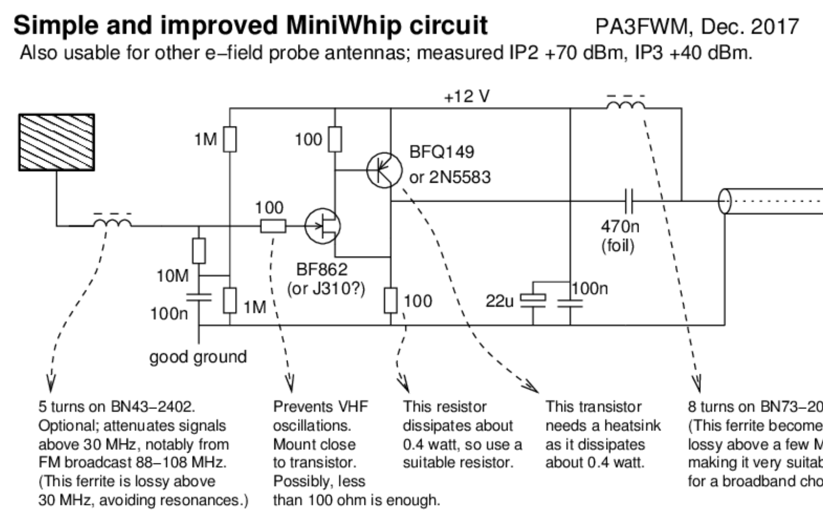


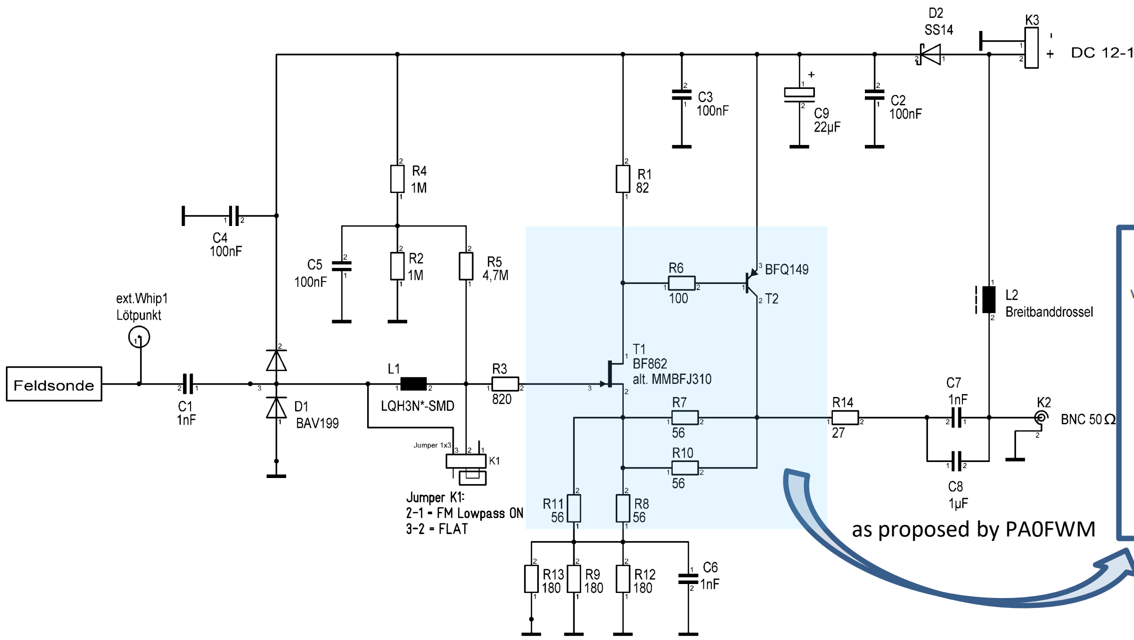
photo: © P-T. de Boer PA3FWM

JFET/PNP compound, published in a National Semiconductor Application Note from 1970 (TI AN-32). Improved by Pieter-Tjerk de Boer, PA3FWM.

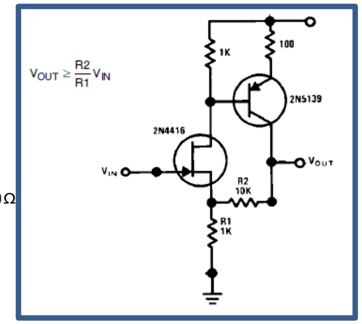


Instead of a pcb’s copper plate, PA3FWM in Twente uses thick wires bent around a hypothetical antenna surface. This creates the same antenna effect as a filled surface [7]

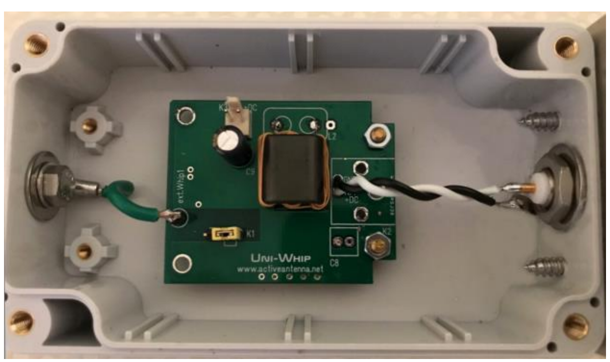
DL4ZAO *UniWhip – FET-PNP compound*



as proposed by PA0FWM



TI/National Semiconductor Application Note AN-32 from 1970

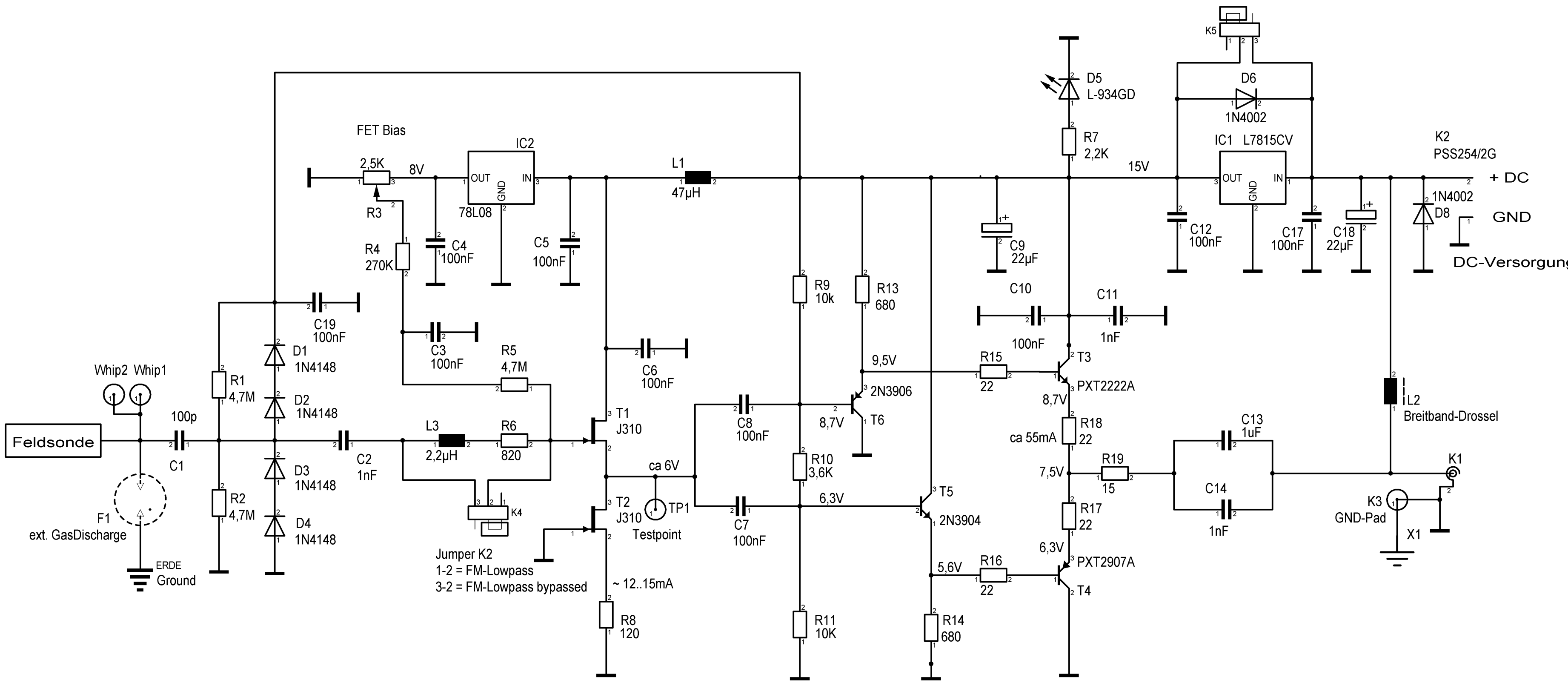


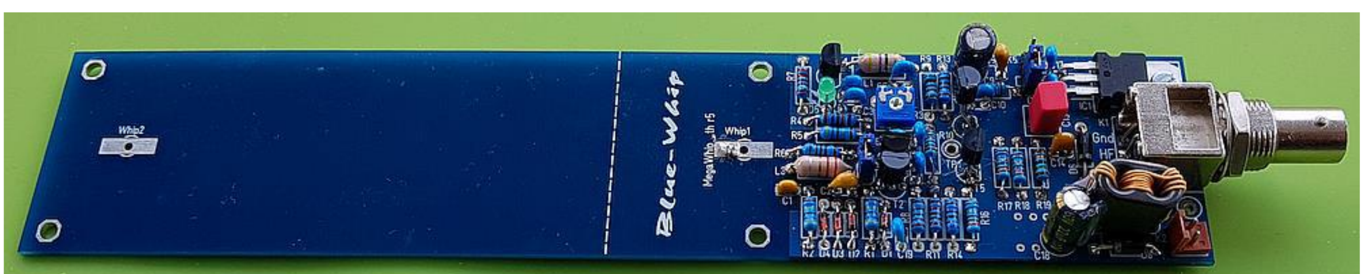
detailled assessment with various antenna element forms and sizes

https://www.fenu-radio.ch/UniWhip_by_DL4ZAO.htm

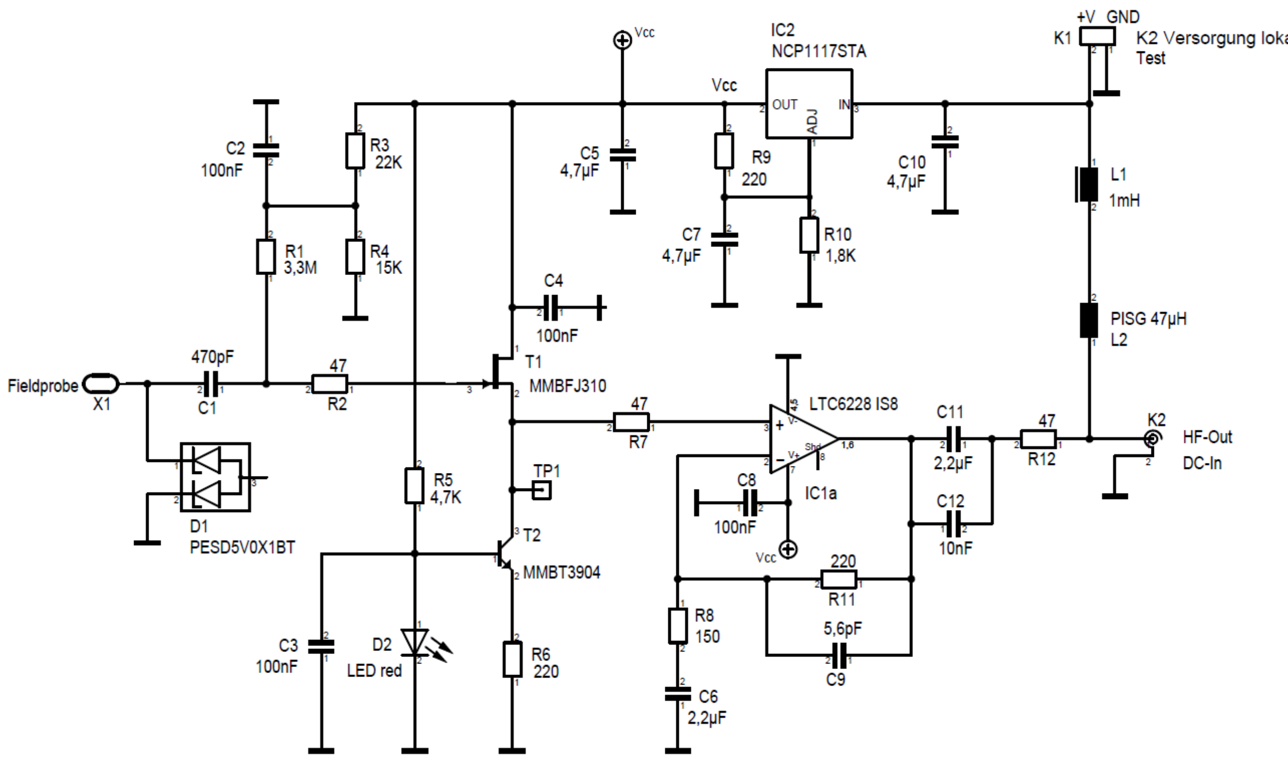
DL4ZAO „Blue-Whip“

improved IP2 and IP3 due to a buffered push-pull driver stage

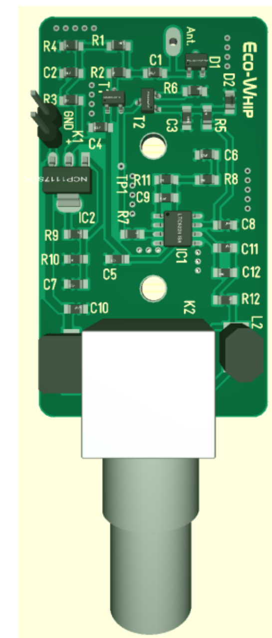




DL4ZAO Whip-4U

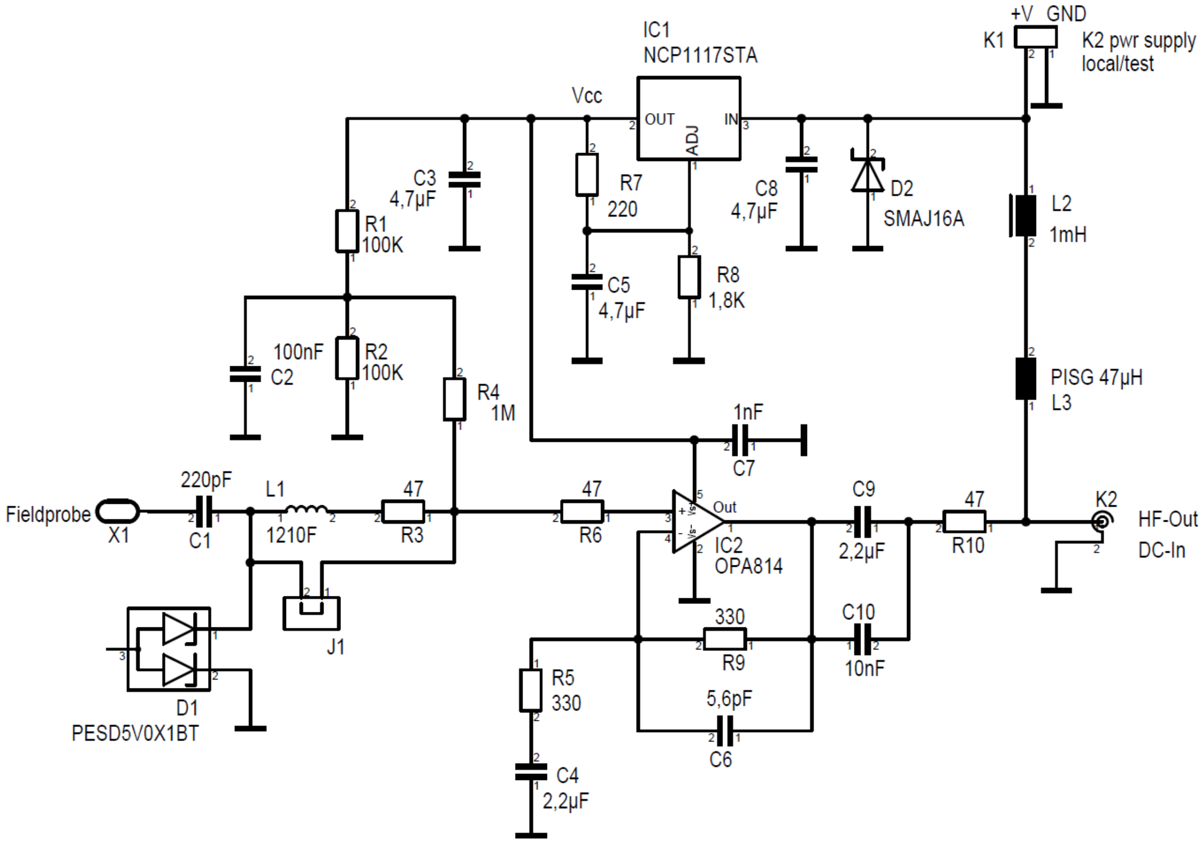


56 x 32 mm

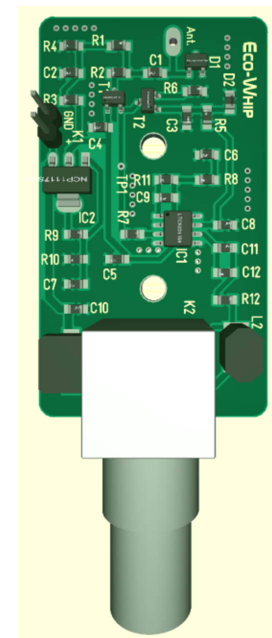


The FET source follower operates on a temperature-compensated constant current sink to eliminate the FET voltage offset. The gain of the operational amplifier can be adjusted to compensate for the losses and achieve unity gain. The Whip-4U has excellent linearity and qualifies for calibrated field-strength measurements. Uses an external whip. Supply current is ≈40 mA only.

DL4ZAO Eco-Whip, 18 mA supply current

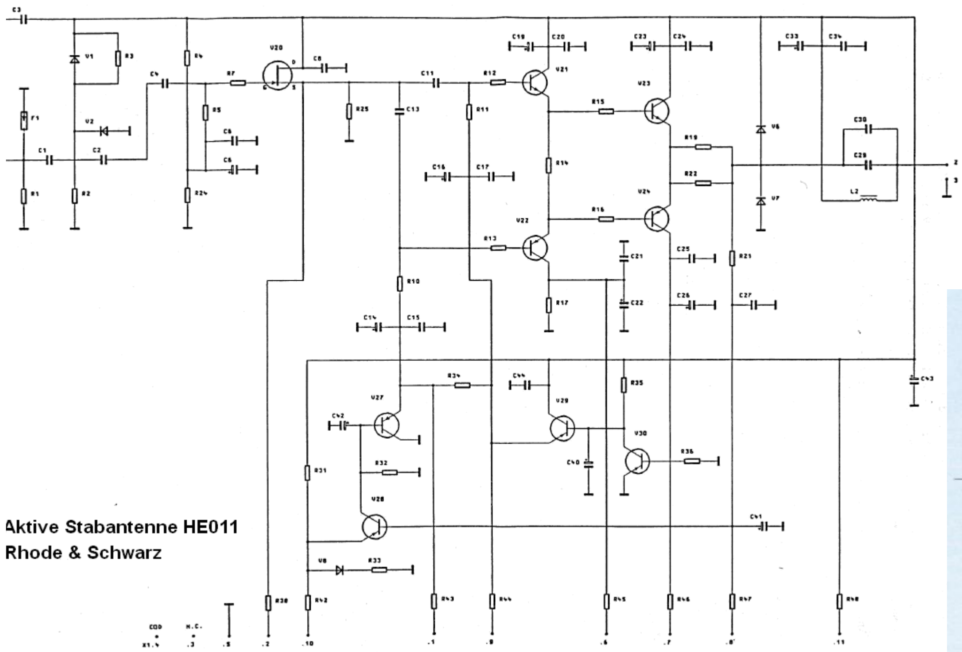


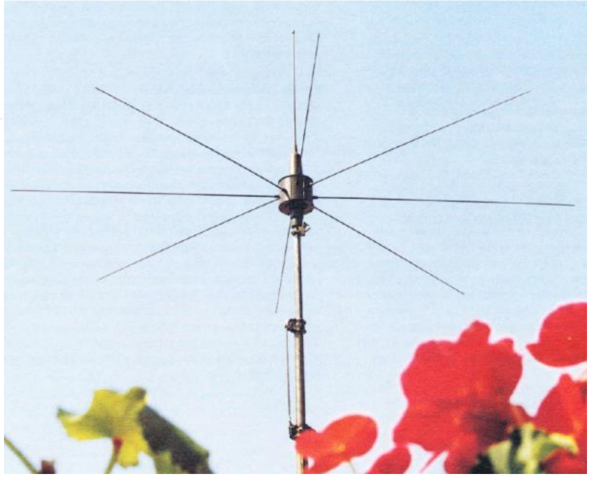
56 x 32 mm



Unity gain with FM-trap (can be bypassed). The low power JFET op amp can be powered from a 9V battery block, eliminating the need for the voltage regulator. Uses an external whip, good for portable use.

Rohde & Schwarz HE011





The Rohde & Schwarz HE011 it a professional grade active-rod antenna and was first introduced in 1975. Combined with HE003 active turnstile dipoles, it provided a remotely switchable horizontal and vertical polarized omnidirectional antenna system for radio-monitoring purpose.

The Mini-Whip at a Glance

- An Mini-Whip type active antenna is mainly sensitive to the electric field of a radio wave. It receives vertically polarised waves. The frequency response is almost flat when $l < 0.15\ \lambda$
- Mini-whip, mast, height, cable and earth/ground connection all interact and must be considered as a system.
- The received signal strength increases proportionally to the height above ground or the effective height of the antenna system.
- Mast heights above $\approx 0.15\ \lambda$ result in resonance peaks and dips in the receive voltage at the corresponding frequencies. No more flat frequency response. Risk of amplifier overload and intermodulation distortion.
- The SNR is the figure of merit, not a maximum S-Meter level. An installation height between 1 m and 5 m (4 to 18 ft) seems to be a good compromise to achieve a sufficient signal-to-noise ratio (SNR) over a wide frequency range.
- A functional earth connection to the Mini-Whip amplifier - either via a grounded conductive mast, via an earth wire or via the braid of the coaxial cable - is essential for proper operation. The earthing connection is best made near the base of the mast.
- Place the Mini-Whip away from sources of interference. Common mode chokes help to interrupt common mode noise currents on the coaxial cable shield.

References and Further Reading

[1] Guenter Fred Mandel, DL4ZAO, https://www.dl4zao.de practical circuits of active whips, loops, dipoles

[2] Roelof Bakker, PA0RDT – „Mini-Whip"

[3] J. D. Kraus, R. Marhefka – „Antennas and Wave Popagation" 4th. ed.

[4] Jan M Simons, PA0SIM „The (mini) whip in EZNEC Pro2+"

[5] **Pieter-Tjerk de Boer, PA3FWM, "Fundamentals of the Mini-Whip Antenna"**

[6] Pieter-Tjerk de Boer, PA3FWM, "Grounding of mini-whip and other active whip antennas"

[7] Pieter-Tjerk de Boer, PA3FWM, "Capacitance of Antenna Elements"

[8] Detlef Burchard „Active Reception Antennas", VHF-Communications 2/1996

[9] H. Lindenmeier, Relation between minimum antenna height and bandwidth of the signal-to-noise ratio in a receiving system". Antenna and Propagation Symposium at Amherst

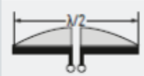
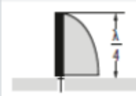
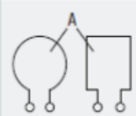
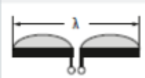
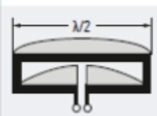
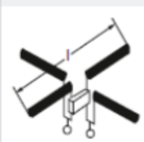
[10] H. Lindenmeier, "The transistorized receiving antenna with a capacitive high impedance amplifier an optimum solution for receiving at low frequencies, Nachrichtentechn. Z. 27 (1974)

[11] Dr. F. Landstorfer, „Ein neues Ersatzschaltbild für die Impedanz kurzer Strahler", NTZ 1973, S490ff

[12] Wayne Martinsen „A High Performance Active Antenna for the High Frequency Band" DST-Group

[13] ITU Recommendation ITU-R P.372-17 „Radio Noise"

Attachments

Parameters of selected antenna types			h_{eff}	
Type of antenna	**Current distribution**	**Directivity factor D**[5]	**Effective antenna length**	**Radiation resistance R in Ω**
Isotropic radiator		1 ≙ 0 dB		
Short dipole without end capacitance[7]		1.5 ≙ 1.8 dB	$\frac{l}{2}$	$20\,\pi^2\left(\frac{l}{\lambda}\right)^2$
Short antenna on infinitely conducting ground without top capacitance[8]		3 ≙ 4.8 dB	$\frac{h}{2}$	$40\,\pi^2\left(\frac{h}{\lambda}\right)^2$
Half-wave dipole		1.64 ≙ 2.15 dB	$\frac{\lambda}{\pi}$	73.2
Quarter-wave antenna on infinitely conducting ground		3.28 ≙ 5.2 dB	$\frac{\lambda}{2\pi}$	36.6
Small single-turn loop in free space		1.5 ≙ 1.8 dB	$\frac{2\pi A}{\lambda}$	$80\,\pi^2\,\frac{4\pi^2 A^2}{\lambda^4}$
Full-wave dipole		2.4 ≙ 3.8 dB		
Folded half-wave dipole		1.64 ≙ 2.15 dB	$\frac{2\lambda}{\pi}$	$4 \cdot 73.2 \cong 280$
Turnstile antenna (Hertz dipole) radiating in horizontal plane		0.75 ≙ 1.2 dB	l	$40\,\pi^2\left(\frac{l}{\lambda}\right)^2$

have fun with active-Whips