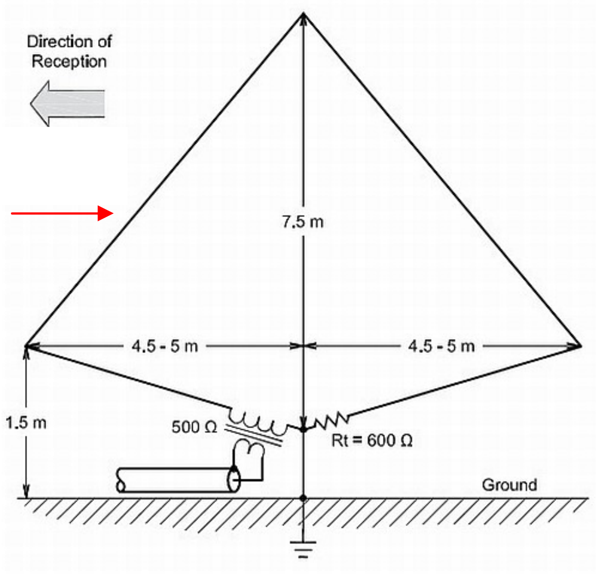
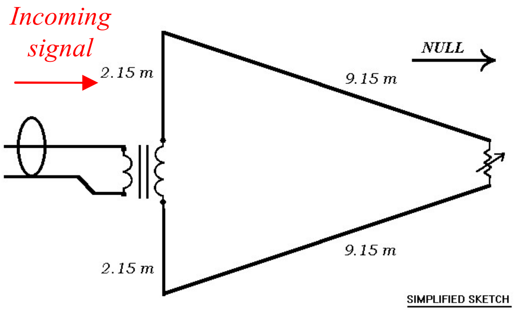
This is how the K9AY receiving antenna works

The K9AY loop antenna is a loop antenna with front-back ratio of around 25 dB. Here (right-hand) is an example of the structure.



The operation principle is almost identical to the Pennant antenna (figure below). This will be clear after reading this document. Also EWE and flag antennas are according the same principle. *Shared Apex is based on a different principle.*



The operation is based on a well-known directivity effect, already used in airplane direction finding systems since the Second World War. The combination of a loop antenna and an E-field antenna make a cardioid directivity diagram with a sharp rear-side null. Just adding the signals of the two antennas is not enough. The requirements for a deep null are:

1. Equal amplitude of the two signals from E and H antenna
2. Identical phase (or 180 degrees phase difference) from the two antennas.

The antennas need to have an identical frequency dependency, i.e. the field-to-voltage conversion must have identical frequency response.

In short: a loop antenna, with flat frequency response, combined with the more or less standard wide-bandwidth E-field antenna fulfills the phase requirement. The amplitude ratio must be aligned.

This E-H signal combination is the base for the Pennant and K9AY antenna operation.

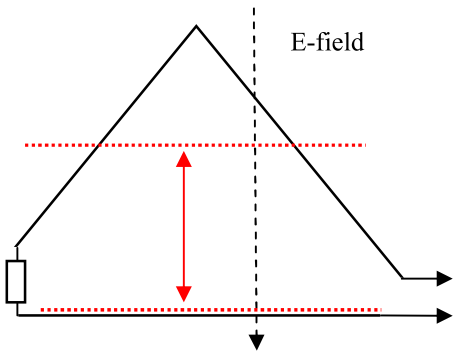
The basic transfer from H-field to induced voltage of a small (related to the wavelength) loop antenna is proportional with frequency. The short-circuit current from a loop antenna is a frequency-independent measure for the magnetic field strength.
The basic transfer from E-field to unloaded output voltage of a conducting structure (small related to the wavelength) is frequency independent, with a conversion factor smaller than one times the size of the structure. The E-field conversion is a sense antenna. For a telescopic antenna with ground as counterpoise the conversion (H_eff = E_unloaded / Field strength) is 0.5 times the total length of the structure.

Pennant as well as K9AY antennas do not have flat frequency response, but ***identical transfer for E and H field***. Both antennas (Pennant and K9AY) are loop antennas, combined with resistor-adjustable E-field contribution to the output signal. The resistor needs to be aligned for best front-back ratio.

In simple words:

1. Induced voltage by the magnetic field component is independent from the resistance in the loop
2. Induced voltage in the loop is proportional with frequency for a given field strength
3. Only the E-field antenna is loaded with the adjustable resistance. This leads to first-order high-pass filter that fits to the frequency-dependent transfer of the loop antenna.

The frequency transfer of the antenna depends further highly on the output load impedance.



For the E-field conversion (in red) the conversion is equal to half the height of the structure, multiplied with the E field strength. This source has impedance C_source and is loaded with the resistor that connects the upper and lower part of the antenna.
C_source can be estimated with the rule-of-thumb for capacitance of wires: 10 pF per meter.

The unloaded output voltages of H and E field can be balanced by variation of the resistor value: the H-field output is not influenced, but the E-field output is.

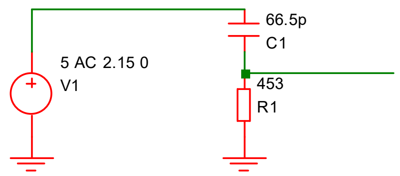
The addition of an earth connection affects only the E-field sensitivity, so R depends on that ground connection.

Loading the output
The source impedance of the antenna is R + j * ω * L. ***When the output is loaded then the ratio between E en H signals is not affected and the front-back ratio will not change!***

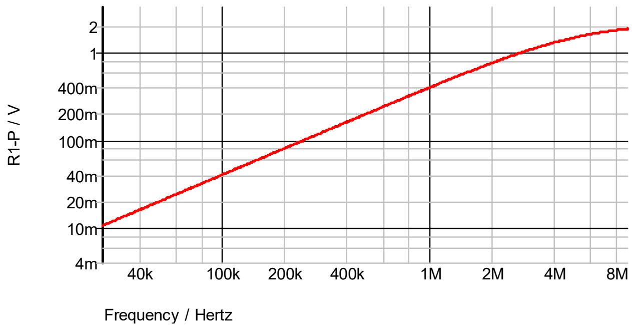
Calculations
Pennant antenna: the H-field conversion can be expressed as Heff or the conversion from field strength to unloaded output voltage. Heff = 2 * PI * A / wavelength (meters). The conversion is thus proportional with frequency.
Example for loop conversion: A = 19.12 square meter. Heff = 0.4 meter per MHz.

The E-field conversion of a straight vertical wire equals 0.5 * length when the ground is the counterpoise. For the Pennant antenna from the given figure (above) the H_eff is for the upper half with counterpoise the lower half, thanks to the symmetry, equal to 2.15 meter. The capacitance of the source, in the order of 10 pF per meter, is for 11.3 meter for each half of the structure equal to 113 pF in series with 113 pF, or 66.5 pF.

To make the contributions of E and H in balance, the resistor value needs to be 453 Ohm. Then the contribution from the E-field corresponds to the contribution of the H-field (free environment; no objects present). The 2.15 volt source is attenuated to 0.4 volt at frequency 1 MHz.



In practice the resistor value needs adjustment for local variation of the ratio between E and H field.
E-field depends on trees etc. H-field does almost not.



Clear from this graph is also that the balance between E and H is only stable up to a few MHz (At 3 MHz the slope deviates from a first-order slope). For higher frequencies the resistor value needs adaptation. In fact: the front-back ratio is only stable for low-frequency ground wave signals.

The E-field antenna has lower sensitivity for NVIS-signals. The loop antenna directional diagram has, in contrast to the E-field directivity, no null straight-upwards. Again: expect only good F/B ratio for ground waves.
Do not expect the properties of a beam antenna when listening to short wave frequencies.

The source impedance of the Pennant example antenna is R + j * ω * L or about 453 Ohm plus 22 µH.

K9AY calculation
For the K9AY antenna the E-field conversion depends on an additional earth connection. The H-field conversion is just the area of the loop, with the formula 2 * PI * A / lambda; *the E-field conversion is now related to that ground and Heff is 0.5 times the height of the antenna*. It will be slightly lower since the structure is not symmetrically. Inductance (dimensions of structure in given figure) is about 20 µH and Heff for E-field will be around 4 meters. The source capacitance is about 200 pF. The requirement for the ground resistance is very low:

the ground is only a counterpoise for the high-impedance E-field antenna capacitance. It will be clear that the K9AY resistance value is lower than in the Pennant application, thanks to the higher E-field sensitivity. Consequently the thermal noise contribution in series with the induced voltages is lower for the K9AY antenna.

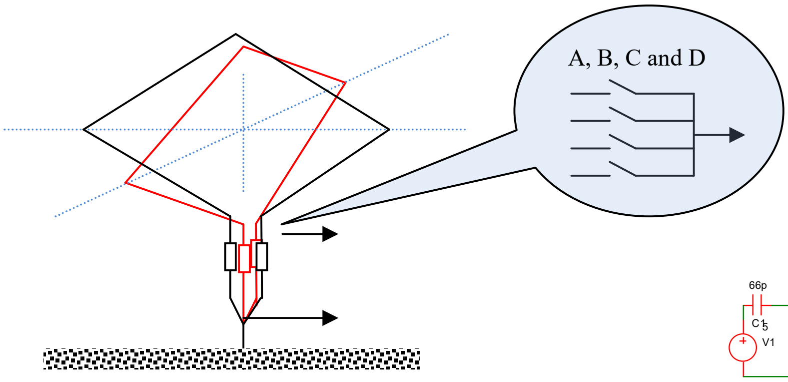
Noise properties
The noise of the resistor in the loop sets a basic noise floor for the antenna. In a well-designed antenna, the contribution of the E and H fields are equal. So the total H_effective of the antenna in the forward direction is twice the H_effective of the loop solely. The noise of the resistor is just in series with this output voltage. Noise matching is not a problem; even without amplifier the result can be good.

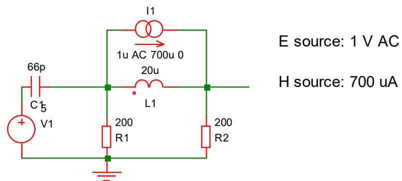
In short: the conversion of a loop antenna is 2 * PI * A / lambda. For the aligned antennas it will be 4 * PI * A / lambda in the front direction. For the Pennant loop this comes to twice the mentioned 0.4 meter/MHz or H-effective of 0.8 meter per MHz. The noise of a resistor of 400 Ohm **in 3 kHz bandwidth** is SQRT (4*K*T*R*B) = 138 nanovolt rms. So the noise equivalent field strength (N.E.F.S. in RBW of 3 kHz) of this antenna is noise divided by H_eff = 172 nV/m at 1 MHz and proportionally lower with increasing frequency. This noise limited sensitivity is far below the external noise floor!

Shared Apex: no single-point
The Shared Apex is not using the E-field as sense antenna. The Shared Apex is a small array of, in its basic form, two loop antennas that make a front-back ratio by cancellation of the rear-signal. Two antennas in a row have identical signal with position-dependent delay. For the rear direction the signal from the first antenna (for that signal direction) is delayed (extra coax cable) and subtracted from the signal of the second antenna.

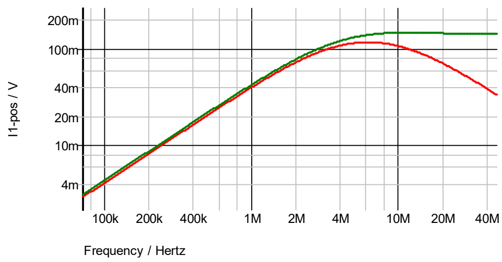
Creating a null with antenna distance of 10 meter requires a delay-difference of 33.3 nanoseconds. The null in the rear direction is ***at the cost of signal subtraction for the forward direction*** with delay difference 66.6 ns. At frequency 1 MHz this corresponds to 24 degrees phase difference. The destructive addition gives, again for 1 MHz, an attenuation of -7.6 dB (compared to the output of one of the loops). For higher frequencies this destructive addition is proportionally lower. The N.E.F.S of Shared Apex for lower frequencies is poor.

Controlled directivity PA0FSB
Since the load impedance does not affect the front-back ratio there is, for the K9AY antenna, the option to replace the load impedance by an identical resistor; the alignment for the opposite direction. Just a selector switch is sufficient to exchange the front and back directions. ***At the acceptable cost of 6 dB sensitivity loss!*** The combination of two loops, orthogonal, and the use of 4 resistors and 4 selector switches makes a four-direction antenna. When two signals (parallel) are selected, the antenna can be used for 8 favorite directions.





My antenna is realized in this way in an apple tree.
According simulations the F/B-ratio is stable up to 4 MHz.
That is corresponding with my observations.



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Brightnoise