THE ACTIVE RECEIVING ANTENNA AN APPROPRIATE ELEMENT FOR HF-RADIO RECEPTION

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INTRODUCTION

New techniques of highly linear and low noise amplifier circuits provide extremely broadband active antennas and antenna couplers for application in HF-VHF receiving systems. The undesired frequency dependence of the performance of antennas mounted on masts can be effectively suppressed by the use of small active loop antennas. By multiple use of the diversity antennas in combination with appropriate circuit devices the decoupling from the mast can also be obtained with active electric dipoles. Therefore antennas of this kind being mounted upon masts of appropriate heights are highly qualified elements for application in antenna arrays.

ACTIVE ELECTRIC DIPOLES

Broadband antennas \(1,2\)/

In the case of a capacitive active monopole or dipole the optimum signal-to-noise ratio (snr) is obtained by choice of an appropriate active element and its bias in such a way that the noise characteristics satisfy the impedance condition with a radiator of minimum size. In many cases a short rod with capacitance \(C_a\) is directly connected to a FET-amplifier. \(C_a\) represents the inevitable input capacitance of the amplifier which should be as small as possible, since the required length of the rod is proportional to the factor \(1 + \frac{C_a}{C_f}\). With this principle broadband antennas have been designed covering the frequency range from 10 kHz to 200 MHz. It is well known that with a rod monopole of given total height \(h_t\) maximum emf is not found if the feeding gap is located at the base of the rod. Considering the emf in combination with the voltage divider ratio between the passive antenna part and the amplifier it is obvious that there is a location at height \(h_{opt}\) for optimum snr at the active antenna's output. \(h_{opt}\) reads roughly:

\[
\frac{h_{opt}}{h_t} \approx \left(1 + \frac{C_a}{C_f h_t}\right) - \sqrt{\left(1 + \frac{C_a}{C_f h_t}\right)^2 - 1}
\]

with \(h_t\) representing the total height, and \(C_f = 10\) pF/m.

In many cases however the frequency dependent effect of the mast on the monopole thereon must be avoided. This can be achieved by means of a nonconductive mast in combination with means to suppress surface waves on the outer conductor of the antenna cable. With short-wave polarization-diversity antennas the crossed horizontal polarization diptoles can be advantageously used as a ground-plane for the rf-insulated vertical antenna. Nonlinear effects can be avoided either by selective means or by means of a high reverse feedback, which has to be designed in a way that the sensitivity of the active antenna is not diminished. In case of the broadband antenna a high reverse feedbacked antenna amplifier is necessary.

Fast Tunable active receiving antennas

In the very vicinity of a transmitting station an undesired field strength of up to 100 V/m may occur. In these cases for an undisturbed operation the active antenna must be tuned. In \(3/4\) design considerations of a highly selective active antenna are presented and it is shown that nonlinear effects in the ferrite tuning elements become a severe problem. Fig.1 shows the general principle and the equivalent circuit of an antenna of this kind which must be tunable over a frequency range from 1 to 30 MHz. With \(V_{na}\) representing the noise source of the amplifier and \(V_{fa}\) representing that of the losses of the Inductor \(L\) it is obvious that the inevitable parallel capacitance \(C_p\) and the transformed capacitance \(C_{fa}/L\) must be as small as possible. This sensitivity problem can only be solved by the principle of the active antenna providing minimum effective capacitive load in combination with inductive tuning which advantageously can be achieved by premagnetizing ferrite.

ACTIVE MAGNETIC DIPOLES

In contrary to rod antennas loop antennas can be advantageously decoupled from the mast by symmetrical mounting on top of a rotationally symmetrical mast. With passive loop antennas the required diameter is unsuitable large for application in a mobile receiving system. For this reason an active loop antenna of only 0.8 m in diameter has been developed which covers the frequency band from 1 MHz to 30 MHz. A special coupling between the loop and the amplifier provides maximum signal-to-noise ratio. By means of a highly selective antenna amplifier the connection of a circuit with low input impedance. Its noise contribution can be described by an equivalent noise voltage source in series. At the output of this amplifier stage a highly linear low noise-field transistor amplifier is cascaded. An appropriate transformer coupling between the amplifier and the loop in combination with a smallest possible load capacitance \(C\) are the determining factors for broadband sensitivity optimization. The analysis of the noise concentrates on the noise contribution of the conductance \(G\). The shot noise of the FET, described by an equivalent noise source in series with \(R_e\) representing the equivalent noise resistance in this circuit. The equivalent noise-fieldstrength \(E_q\) of the active loop antenna reads as displayed in Fig.2 with \(h_{opt} = 2 \alpha A\) representing the effective height of the passive loop with area \(A\). As a result of the inevitable capacitor \(C\) and the transformed loop inductance an undesired
Fig. 1 Basic schematic and equivalent circuit containing noise sources of tunable active rod antenna.

Fig. 2 Equivalent circuit of active broadband loop antenna, and equ. for the fieldstrength-sensitivity $E_a$ and the drain-current $I$.

Fig. 3 Fieldstrength-sensitivity of active loop antenna for various values of $t, C$ and $Q$ with $t=2$ and $C=2\mu F$ providing optimum design.

Fig. 4 Comparison between the excitation of a loop and a rod receiving antenna in the vicinity of a transmitting mast antenna.
resonance is formed at frequency $f_0$ with a
quality factor $Q = \omega C / G$. Curves of the
equivalent noise field strength of the active
loop antenna for a channel bandwidth of $B = 1 \text{ Hz}$ are plotted versus frequency in Fig.3.
The external noise field strength is
represented by the dash-dotted line in Fig.3.
With a broadband active loop antenna with
inductance $L$, the ratio of the output current
$1$ of the first transistor stage and the
electric field $E$ should be frequency
independent. Under the assumption of a
$G = q_m$, which in practice is always true, this
charge $q$ is described by Fig.4 where $q_0$
represents the light velocity. In Fig.4 the
application of an electric monopole and a
magnetic monopole in the vicinity of a
vertical mast transmitting antenna is
compared. The field strength of a vertically polarized
transmitting antenna, and the equivalent noise
field strength of the receiving system can be
regarded as a related distortion level. With this
definition the obtainable gain in the dynamic
range, which is available if a receiving loop
antenna is applied instead of a receiving rod
antenna, can be found by the negative
difference of these related distortion levels.
This difference is plotted in Fig.4 versus the
distance from a 7 m high transmitting rod
antenna.

ACTIVE RECEIVING CIRCULAR ANTENNA ARRAY FOR A
MULTITUDE OF SIMULTANEOUSLY AVAILABLE
HORIZONTAL ANTENNA PATTERN

Due to its small physical size and the low
coupling between adjacent antennas the active
antenna is a highly qualified element for
application in antenna arrays /5,6,7/. In
order to cover both polarization planes a
combined antenna system consisting of a
vertical element and a crossed horizontal
dipole system for omnidirectional reception in
the horizontal plane is proposed as array
element. The omnidirectional diagram of the
horizontal dipole system can be obtained by
combining the output signals of each
horizontal dipole by means of a 90 degree
phase shifter. In addition these dipoles form
the counterpoise for the vertical antenna
element.

Antenna arrangement and antenna pattern /8/

Over long distances usually vertical
polarization with low elevation angle of the
incident wave is used. For low distances in
many cases a steep angle of radiation is
required which is achieved by means of the
horizontally polarized antennas the signals of
which are combined in a way that the main lobe
of the resulting diagram is found at an
elevation $\psi_m$, which at the operational
frequency provides optimum reception as
displayed in Fig.6. With the proposed antenna
array and the directrix which results in a certain half-power beamwidth, a
number of 10 different main directions $\psi_m$ in
the horizontal plane are suggested. The basic
pattern is shown in Fig.5 with the main lobe
directions $\psi_m = 90^\circ$ and the $\psi_m = 45^\circ$
on each circle. The signals of the antenna
elements are combined in a way that they form
vertical pattern with a main lobe at a desired
elevation angle $\psi_m$ as to be seen in Fig.6.
Antennas with vertical polarization form a
pattern with $\psi_m = 0^\circ$ within the total frequency
range. In contrast to this the elevation angle
of the main lobe formed by the horizontally
polarized antennas varies between 75 and 25
degrees.

In order to cover the HF-frequency range five
circular arrays are proposed, the diameters of
which are chosen in 2:1 steps. The signals of
the different antenna circles are combined by
means of pass-band filters in such a way that
each circle is only operative in a frequency
band of $3:1$ with a related diameter $D_k / \lambda$
ranging from .5 to 1.5.

Central unit

Each antenna is connected to a central unit,
which may be located at the geometrical
centre of the antenna array as displayed in Fig.7
and Fig.8, where the signals of all antennas are
combined in an appropriate way by means of
phase-shifters. The electric length of the
phase-shifters for the n-th antenna on the
k-th circle is chosen according to:

$$ l_{k,n} = l_a(k,n) + l_b(k) $$

with

$$ l_a(k,n) = \frac{D_k}{2} \cdot \cos((n-1) \cdot \phi_0 - \phi_m) $$

$$ + \frac{D_k}{2} \cdot \cos((N-1) \cdot \phi_0 / 2) \cdot \sin \psi_m $$

and

$$ l_b(k) = \frac{D_1 - D_k}{2} \cdot \cos((N-1) \cdot \phi_0 / 2) \cdot \sin \psi_m $$

where $N$ = number of antennas per circle and
$D_k = $ diameter of the k-th circle. $\phi_0 = 2 \pi / N$.

According to Fig.7 and Fig.8 ten output
signals are formed at the central unit each
providing a diagram with different main
directions in the azimuth for both the
vertical monopoles and the horizontal dipole
systems respectively. In addition, in order to
provide omnidirectional reception with the
vertical and the horizontal antenna elements as
well, two additional signal outlets (RO) are
installed at the central unit. The phase-
shifters for each antenna are realized by a
filter cascade FK5...FK2 and an additional
phaseshifting filter FK1 with passband
characteristic. Equal filters FK5...FK2 are
applied for all antennas belonging to the same
circle. Each cascade provides 5 output signals
of appropriate phases which can be combined
with the appertaining signals of the
corresponding antenna on the same circle. In
Fig.8 the signal path between the active
antenna and its appertaining filter cascade
FK5...FK2 and the summation units of signals
forming the directions RO...RO10 are displayed.
This is also shown in Fig.9, where the signals of
different phases are available at the
outputs of high input impedance amplifiers,
which are highly linear and have low noise.
The sum of the 10 signals forming the signal of
a diagram with a certain main direction is
built by superposition within the transformer
output. The output of this transformer
concentrators is loaded by the passband filter
FK1. The combination of the signals for a
certain main direction being provided by the
antennas of one circle is built by means of
amplifiers the output signals of which are
impressed in parallel to a cable which
operates as a compensation for the different
propagation paths of the signals of the
different circles.
Fig. 5 Multiple horizontal pattern of circular array with vertically and horizontally polarized active antennas.

Fig. 6 Horizontal and vertical pattern with required elevation angle at the frequency of operation for horizontally polarized waves.

Fig. 7 Achievement of appropriate lengths of propagation paths for beam forming by means of different filter cascades for circles 1..5.

Fig. 8 Principle of the antenna signal paths and summation of signals for forming pattern with different main directions R1..R10.
Directivity and improvement of linearity

The directivity of the vertical monopoles is displayed in Fig.10 versus the frequency. At the low frequency end the directivity is found to be 7.5 dB only. This is a result of the limited diameter $D_t$ of the largest circle limiting the gain to this low value. With increasing frequency this gain increases up to 10.5 dB and with the horizontally polarized antennas up to 7 dB.

For some purposes often an omnidirectional diagram with increased sensitivity of the receiving system is required. Making use of the multitude of antenna signals being available in the array the effective noise figure of the receiving system is reduced. By phased superposition of the signals of all antennas being only a small fraction of the wavelength apart from each other the correlated signal adds up to a resulting signal, which by this effect is considerably more increased than the noise in this signal resulting from the noise sources in the active antennas. The cut-off frequency of the low-pass filter Fk1 in Fig.9 for this application is appropriately designed. At low frequencies the average improvement is 10 dB.

As a result of the improved sensitivity of an array with a multitude of active antennas the dynamic range of the array is increased. The improvement of the dynamic range of 2nd and 3rd order of the array over the single antenna element is found to be approximately 6 dB for second order and 8 dB for third order effects. Due to this increased range the total array is less endangered to suffer from intermodulation distortions.

REFERENCES


8/ H. Lindenmeier, G. Flachenecker, Circular array with active antennas. Patent application Nr.: P 34 37 727.1; GFR. 1984
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