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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 $(1 + C_a/C_A)$. 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 dividing effect between the passive antenna part and the amplifier it is obvious that there is a location at height h_{Mopt} for optimum snr at the active antenna output. h_{Mopt} reads roughly:

$$\frac{h_{Mopt}}{h_t} \approx \left(1 + \frac{C_a}{c \cdot h_t}\right) - \sqrt{\left(1 + \frac{C_a}{c \cdot h_t}\right)^2 - 1}$$

with h_t representing the total height, and $c = 10\,pF/m$.

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 dipoles 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 fieldstrength of up to 100 V/m may occur. In these cases for an undisturbed operation the active antenna must be tuned. In /3/ 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_{ne} representing that of the losses of the inductor L it is obvious that the inevitable parallel capacitanc C_p and the transformed capacitance C_a/t^2 must be as small as possible. This sensitivity problem can only be solved by the principle of the active antenna providing minimum effective capacitve 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 0.8m in diameter has been developed which covers the frequency band from 1 MHz to 30 MHz broadband /4/. A special coupling between the loop and the amplifier provides maximum signal-to-noise ratio. By means of a highly linear antenna amplifier a wide dynamic range can be realized which is not reduced if the antenna is mounted on a mast. Fig.2 shows the basic circuit diagram of a broadband active loop antenna. The FET in grounded-gate circuitry symbolizes an electronic 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 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 inseries with R_e representing the equivalent noise resistance in this circuit. The equivalent noise-fieldstrength E_a of the active loop antenna reads as displayed in Fig.2 with $h_{effl} = 2\pi A/\lambda$ 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

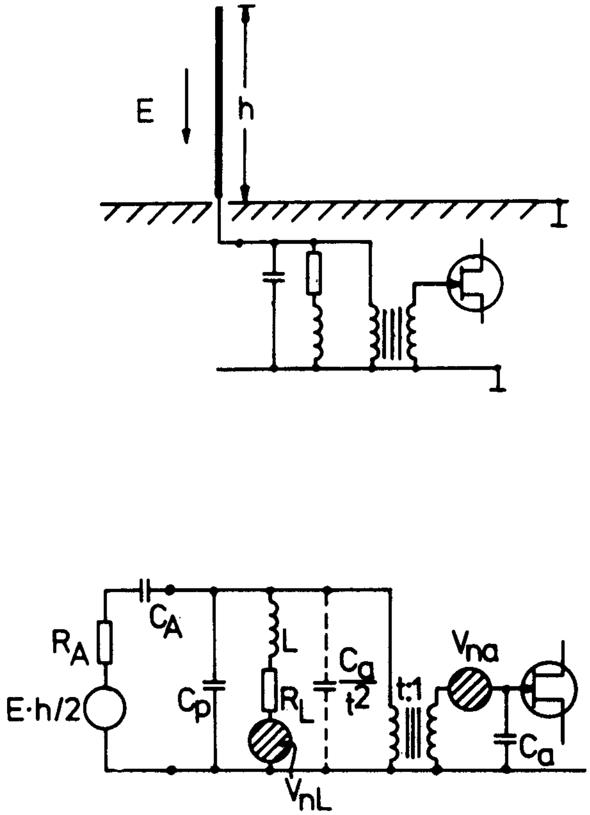


Fig.1 Basic schematic and equivalent circuit containing noise sources of tunable active rod antenna.

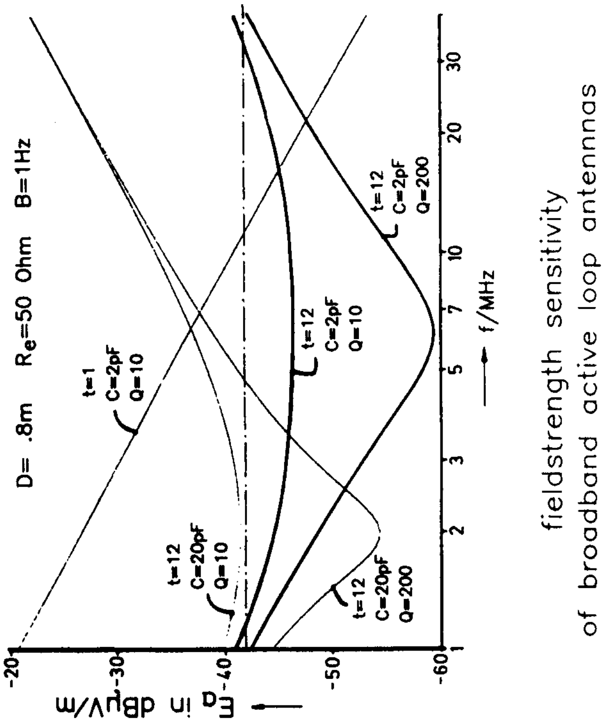
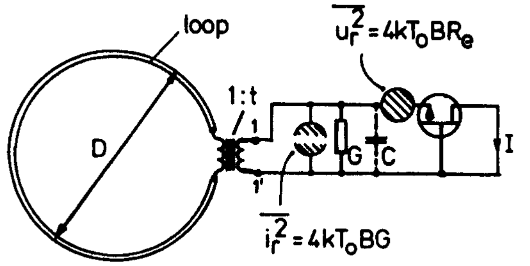


Fig.3 Fieldstrength-sensitivity of active loop antenna for various values ot t,C and Q with t=2 and C=2pF providing optimum design.



$$\frac{E_a}{\sqrt{B}} \approx \frac{1}{h_{effl}} \cdot \sqrt{4kT_0} \cdot \sqrt{R_e \cdot \frac{[1-(\frac{f}{f_0})^2]^2}{t^2} + \frac{1}{t^2Q^2G}(\frac{f}{f_0})^2}$$

$$I \approx E\frac{D^2\pi}{4\cdot L_i\cdot t\cdot c_0}\cdot\frac{1}{\sqrt{1+[\underbrace{Q\frac{G}{g_m}}_{Q'\ll Q}(\frac{f}{f_0}-\frac{f_0}{f})]^2}}$$

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

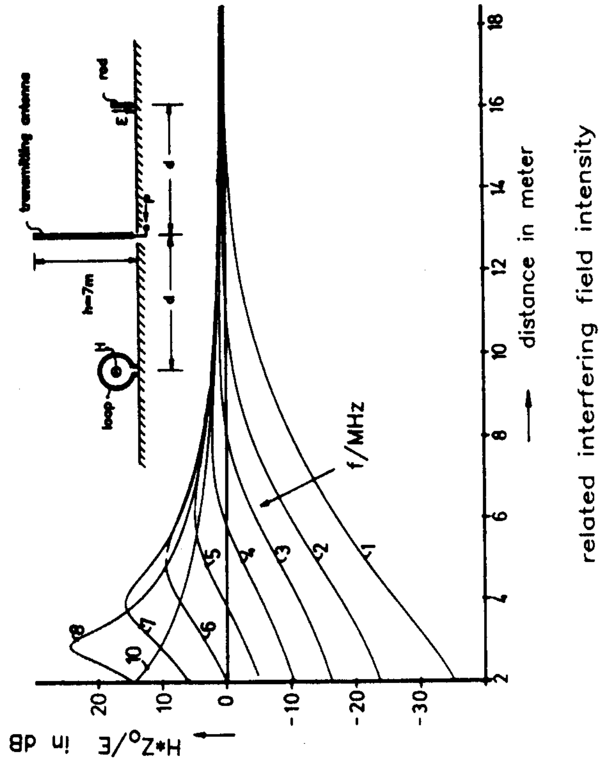


Fig.4 Comparison between the excitation of a loop and a rod receiving antenna in the vicinity of a transmitting mast antenna.

resonance is formed at frequency f_0 with a quality factor $Q = \omega_0 C/G$. Curves of the equivalent noise fieldstrength of the active loop antenna for a channel bandwith of $B = 1$ Hz are plotted versus frequency in Fig.3. The external noise fieldstrength 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 I of the first transistor stage and the electric field E should be frequency independent. Under the assumption of a $G \ll g_m$, which in practice is always true, this current can be described as in Fig.2 wherein c_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 ratio of the electric fieldstrength of a vertically polarized transmitting antenna, and the equivalent noise fieldstrength of the receiving system can be regarded as a related distortion level. With this definition the obtainable gain in 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 ϑ_m ,which at the operational frequency provides optimum reception as displayed in Fig.6. With the proposed antenna array and the directivity required, which results in a certain half-power beamwidth, a number of 10 different main directions φ_m in the horizontal plane are suggested. The basic pattern is shown in Fig.5 with the main lobe directions R1...R10 and the antennas A1...A10 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 ϑ_m as to be seen in Fig.6. Antennas with vertical polarization form a pattern with $\vartheta_m = 0$ 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 a way that each circle is only operative in a frequency band of 3:1 with a related diameter D_k/λ 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

$$l_a(k,n) = \left[\frac{D_k}{2}\cdot\cos((n-1)\cdot\varphi_o - \varphi_m) + \frac{D_k}{2}\left|\cos((N-1)\cdot\varphi_o/2)\right|\right]\cdot\sin\vartheta_m$$

and

$$l_b(k) = \left[\frac{D_1 - D_k}{2}\cdot\left|\cos((N-1)\cdot\varphi_o/2)\right|\right]\cdot\sin\vartheta_m$$

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

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 (R0) 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...Fk1 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 antennas 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 R0...R10 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 circuit and is available at the transformer output. The output of this transformer combination 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.

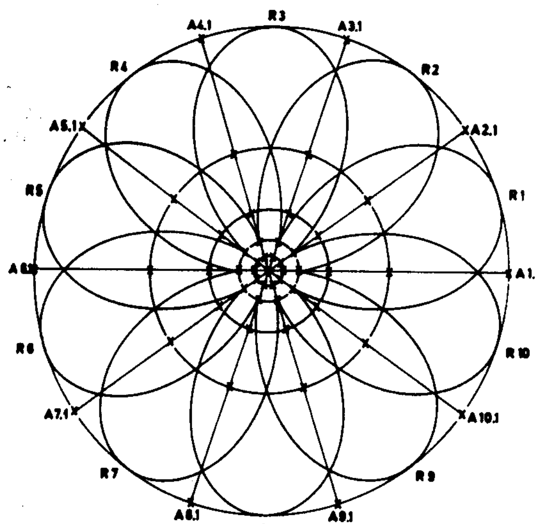


Fig.5 Multiple horizontal pattern of circular array with vertically and horizontally polarized active antennas.

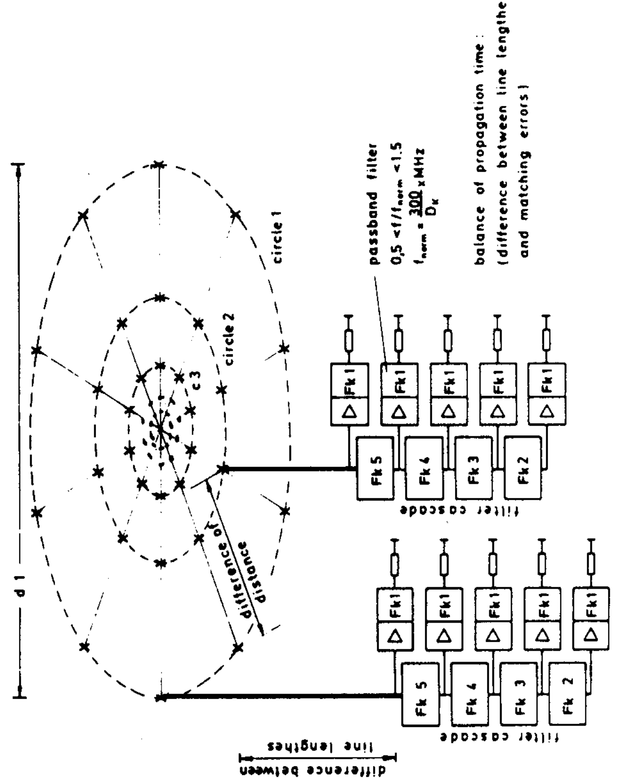


Fig.7 Achievement of appropriate lengths of propagation paths for beam forming by means of different filter cascades for circles 1..5.

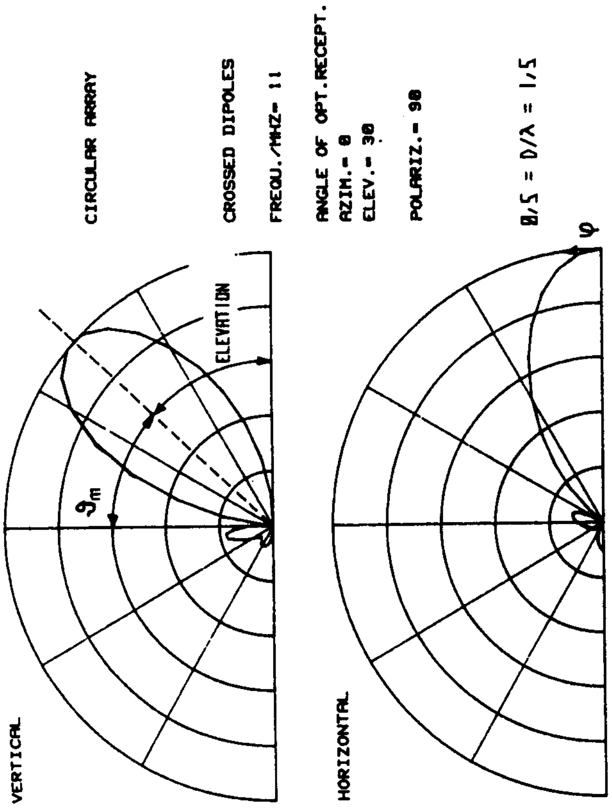


Fig.6 Horizontal and vertical pattern with required elevation angle at the frequency of operation for horizontally polarized waves.

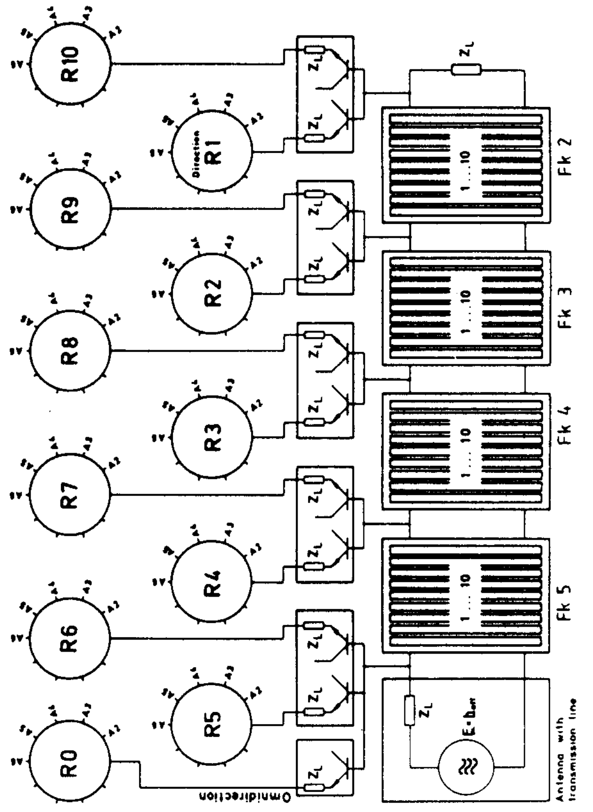


Fig.8 Principle of the antenna signal paths and summation of signals for forming pattern with different main directions R1..R10.

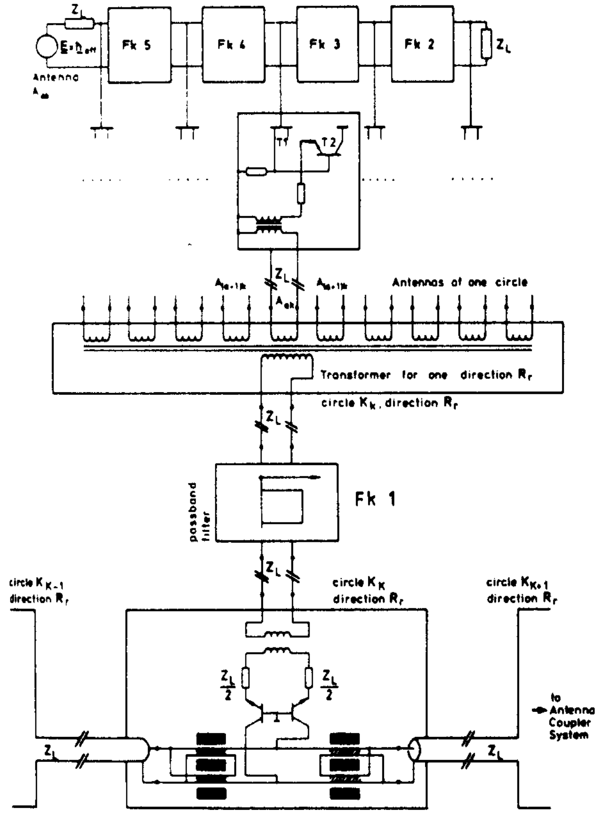


Fig.9 Diagram for filter cascade, active coupler, signal summation, bandlimitation and superpostion of signals of different circles.

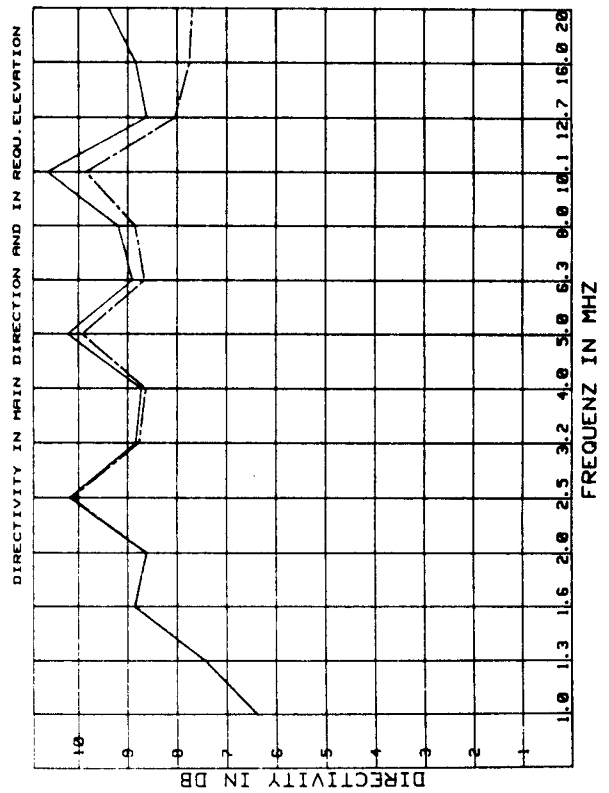


Fig.10 Directivity of vertically polarized antenna array versus frequency.

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_1 of the largest circle limitting 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 cophased superposition of the signals of all antennas being only a small fraction of the wave length 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 3d 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 dynamic range the total array is less endangered to suffer from intermodulation distortions.

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