DESIGN OF ELECTRICALLY SMALL BROADBAND RECEIVING ANTENNAS UNDER CONSIDERATION OF NONLINEAR DISTORTIONS IN AMPLIFIER ELEMENTS.

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Abstract: The design of electrically small receiving antennas is not a question of the received signal power, impedance bandwidth or antenna losses but only of the signal-to-noise ratio (snr) at the receiver output. Snr is limited by the field-to-noise ratio at the location of the antenna. It is shown that with a given antenna height optimum snr is only obtained if the first amplifier stage is directly connected to the antenna element. With vertical rod monopoles the optimum location for the amplifier in the antenna with respect to snr is found at a certain height above the ground. An antenna of this kind is an ideal element for a direction-finder system. The broadband pick up of undesired signals requires high linear and low noise amplifiers with a wide linearity range in order to suppress nonlinear distortions, which could deterioriate the snr. It is found, that an optimum antenna height may be determined, which in the frequency range from 10 kHz to 30 MHz is not greater than 1 m. At the present time antennas of this height and operational frequency range, which stand an undesired field intensity of 40V/m for 20dB suppression of cross modulation are produced in large quantities and are in practical application especially in mobile communication systems.

1. The disturbed receiving system: Fig.1 presents an active broadband receiving antenna with base amplifier, excited by the signal fieldstrength E_d and the undesired noise field intensity e_{uA}. P_d and P_{uA} represent the appertaining power components at the receiver output. Due to the electronic noise of the active antenna part the noise power P_{ua} is produced at the receiver output and the receiver itself adds its noise power P_{ur}. As a result of the broadband pick up of large undesired signals nonlinear distortions may occur in the active antenna and intermodulation products may appear within the r-f channel B_c and produce the power P_{ui}. The determining quantity for the efficiency of a communication channel is the channel capacity C_c, which is a mere function of P_d/P_u, where $P_u = P_{uA} + P_{ua} + P_{ui} + P_{ur}$ is the total undesired power:

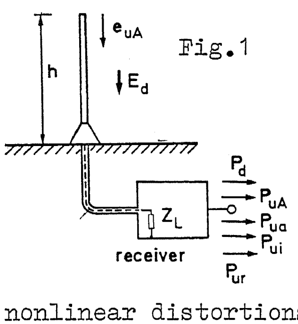

Fig.1

$$C_c/\frac{bit}{s} = B_c\cdot 3.3\cdot \log \frac{P_d/P_{uA}}{1+\frac{P_{ua}}{P_{uA}}\left(1+\frac{P_{ui}}{P_{ua}}+\frac{P_{ur}}{P_{ua}}\right)} \qquad (1)$$

Obviously even with an ideal receiving system with $P_{ua}=P_{ui}=P_{ur}=0$ the maximum obtainable snr cannot be greater than the field-to-noise ratio $P_d/P_{uA}=E_d^2/\overline{e_{uA}^2}$. With the antennas to be investigated here P_d and P_{uA} will increase simultaneously with increasing antenna height h, however P_{ua}/P_{uA} will decrease. Under the assumption of P_{ur}/P_{ua} and P_{ui}/P_{ua} being negligible small, the optimum antenna height h_{opt} for a tolerable 3dB loss of snr in comparison with P_d/P_{ua} is that height for which $P_{ua}=P_{uA}$. For h greater than h_{opt} the broad-band pick up of signals causing nonlinear distortions is greater and with this P_{ui}/P_{ua} in equ. (1) may deteriorate the snr$=P_d/P_u$ and C_c.

2. Optimum antenna height: Fig.2 presents the equivalent circuit of a short active rod antenna with a high input impedance amplifier. The passive antenna part is characterized by the signal source $E_d\cdot h_{eff}$, R_A, C_A and is loaded by C_a of an amplifier with FET T. At the output the antenna may be described by the source $E_d\cdot h_{effa}$ and Z_a. The noise source v_{ua} represents the amplifier noise which is a constant for f= 100kHz. The effect of v_{ua} is regarded to be caused by a fictitious equivalent noise fieldstrength e_{ua}, which for a FET roughly reads as:

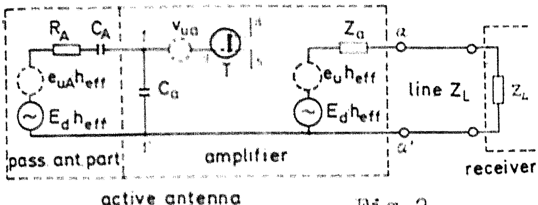

Fig.2

$$\sqrt{\frac{\overline{e_{ua}^2}}{B_c}} \approx \frac{\sqrt{\overline{v_{ua}^2}}}{h_{eff}}\cdot(1+C_a/C_A)\frac{1}{\sqrt{B_c}} \qquad (2)$$

with $\overline{v_{ua}^2} = 4kT_oB_c/g_m$

g_m:mut.cond.FET; k:Boltz.c.

If the amplifier in Fig. 2 would be removed and the line directly connected to the rod a much larger equivalent noise fieldstrength due to receiver noise is obtained than with the active

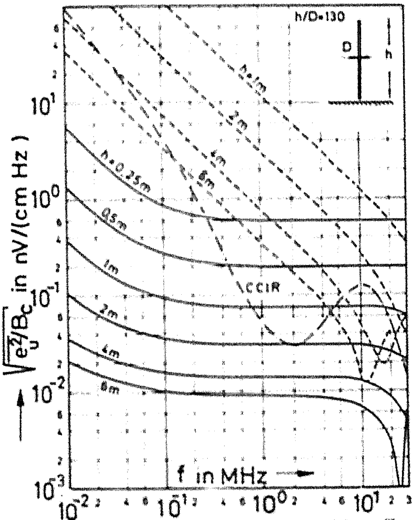

Fig.3

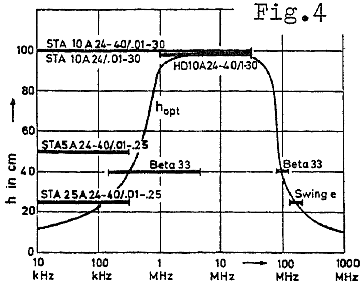

Fig.4

antenna. In Fig.3 values of equivalent noise fieldstrength are plotted versus frequency for different h of active (uninterrupted) and passive (dashed) antennas. The dash-dotted curve draws the median value of the external noise as given by CCIR. The points of intersection between the uninterrupted curves and the CCIR-curve deliver the curve of h_{opt} versus frequency for the active antenna.

h_{opt} may also be obtained from equ. (2), which with a simple rod of height $h=2h_{eff}$ reads as:

$$h_{opt} \approx 2\cdot\sqrt{(4kT_o/g_m)/(\overline{e_{uA}^2}/B_c)}\cdot(1 + C_a/C_A) \qquad (3)$$

The curve of h_{opt} in Fig.4 shows the optimum antenna height with man-made noise having been taken into account. The thick horizontal lines indicate the height and the frequency range of operation of several models of active antennas which are produced in quantity in Germany and have been developed in cooperation with industry.

<u>3. Optimum height of feeding gap</u>: For a given total height h_t of the antenna in Fig. 5a and a given input capacitance C_a of the amplifier the ratio $E_d/\sqrt{\overline{e_{ua}^2}}$ which is proportional to $(V_d/E_d)/\sqrt{\overline{v_{ua}^2}}$ is maximum if the amplifier is built into the antenna at a certain height h_M above the ground. Fig.5b presents V_d/E_d of the antenna in Fig.5a for different values of C_a and $h_t=3$m. With

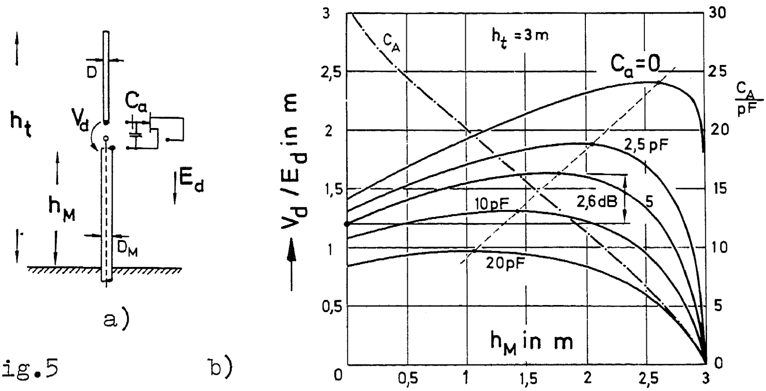

Fig.5

C_a=5pF optimum height h_M is 1,8m and the gain of sensitivity compared to h_M=0 is 2,6 dB. Use has been made of this effect with an active antenna (h_t=2m, h_M=1m) for the direction-finder system (Telefunken) shown in Fig.6. Due to the high impedance capacitive load C_a the currents on the antenna parts are very small and prevent the antennas from interaction due to radiation coupling. Besides the mast h_M forms a counterpoise to the whip h. Therefore with a very simple ground network extreme small direction finding errors are obtained even with sky wave bearings. This antenna replaces the formerly used 6m and 10m high passive rod antennas.

Fig.6

4. Intermodulation and cross modulation: As to be seen from equ. (1) intermodulation products P_{ui} are to be valuated in comparison with the inherent noise P_{ua} of the active antenna and not, as it is often done, in comparison with the undesired signal (intermodulation suppression). The immunity from disturbance can be told from limiting values of interfering carrier fieldstrengths E_{uf1} and E_{uf2} the intermodulation product of which causes $P_{ui}/P_{ua}=1$ in equ.(1) with the second and third order products respectively. With a 1m active broadband rod antenna (10kHz $\leq f \leq$ 30MHz) limiting values of $\sqrt{E_{uf1} \cdot E_{uf2}} \approx$ 45mV/m for second order and $\sqrt[3]{E_{uf1} \cdot E_{uf2}^2} \approx$ 250 mV/m for third order distortion ($B_c = 5kHz$) have been obtained. Intermodulation products caused by interfering field intensities below these values are not detectable from the inherent antenna noise. Expressed with standard data the suppression of second order and third order products respectively is better than 80dB and 120dB with $E_{uf1} = E_{uf2}$ = 100mV/m. Investigations in practice have shown, that these tolerable field intensities are so large that the antenna is not endangered by distortions due to broadband mixing. With most cases in practice the receiving system is more endangered by cross modulation from a nearby located transmitting antenna, since the remodulation of the desired signal (f_d) by the undesired (f_u) occurs broadband. In this case the tolerable rms-value E_{uc} of an unwanted amplitude modulated (30%) signal at f_u causing a certain modulation factor (3%) is important. By means of a low noise and high linear negative feedback amplifier the uninterrupted curves for E_{uc} in Fig.7 are obtained with h = 1m.

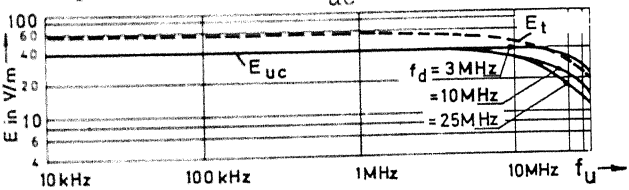

Fig.7