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NEW METHODS TO SOLVE THE NONLINEARITY PROBLEM IN ACTIVE RECEIVING ANTENNAS

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1. Optimum antenna height.

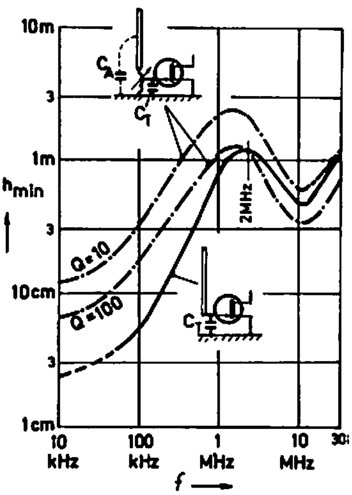


Fig.1 ↑

Though the bandwidth limitation (Chu /1/) of an electrically small antenna is valid for transmitting antennas and power considerations it has been shown in /2/ and /3/ that the bandwidth of the signal-to-noise ratio (snr-bandwidth) of an optimized active receiving antenna is much greater. The design principle to tolerate a reduction of snr of 3 dB from the theoretical value, represented by the field-to-noise ratio at the location of reception, and obtained with a noiseless receiving system, leads to a minimum required antenna height h_{min}. For the example of a rod radiator h_{min} is plotted versus frequency in Fig.1 for an active broadband antenna (uninterrupted curve) and an active antenna with tuned input and different Q-factor of the tuning variometer (dash-dotted curve). Though the antenna is tuned in an optimum way by means of a variometer, and not by a variable capacitance, to the operational frequency and no further load capacitance exists except for the inevitable input capacitance C_T of the FET the broadband version is more sensitive at operational frequencies below 2 MHz. Due to the limited linearity properties of every amplifier and receiver circuit the level of input signals should be as low as possible. This is achieved with low antenna height h. For sensitivity reasons however h should be not smaller than h_{min}. Therefore h_{min} is the optimum height h_{opt} of the system and h should not be greater. Nonlinear distortions in amplifier circuits may be suppressed either by means of selectivity, linear transistor circuits, or a combination of both. Since the variometer tuned active antenna is often impracticable, and in many cases a broadband antenna, feeding a variety of receivers, is required, the linearisation of the active antenna part is the main task in active antenna techniques. The operation of the antenna may be disturbed if an intermodulation product of two or more undesired signals is detectable from the antenna noise /5/. The sensitivity problem can be solved by means of a single antenna transistor /4/. The nonlinearity problem however requires the following considerable technical effort in order to obtain antennas for professional and consumer application.

2. Low noise linear broadband antennas.

Fig.2a presents the circuit diagram of a broadband antenna amplifier for preferential use in 1m long active rod antennas as displayed

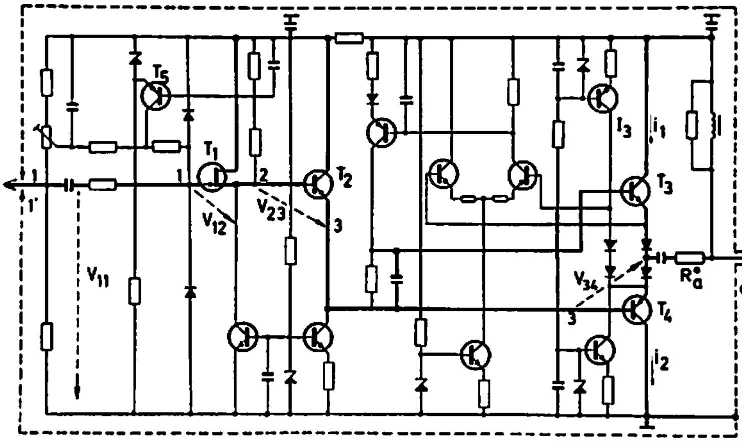


Fig. 2a

in Fig.6. The required linearity is obtained by means of the outlined circuit in Fig.2a, with a reverse feedback resistor R_a^* plus the load impedance Z_L with which the antenna is to be terminated. With $G_r = V_{11}/V_{12}$ (s.Fig. 2a), being the reverse feedback factor the fieldstrength sensitivity E_S (snr=1) reads as

$$E_S \approx (1+C_T/C_A)\sqrt{\Delta f 4kT_o/g_m}\cdot\sqrt{1+G_r/(\beta_2\cdot\beta_{34})}\;/h_{eff}$$

$\beta_2\cdot\beta_{34}$: current amplification of T_2, T_3, T_4. h_{eff} : effective height of antenna part; g_m: mutual conductance of T_1; k:Boltzmann const. By means of an appropriate value for $\beta_2\cdot\beta_{34}$ considerable high values of G_r may be realized without deterioration of the snr in comparison with an antenna with only one transistor T_1. The signal voltage V_{12} between the gate and the source of the FET at low frequencies is only 1/1000 of the total input voltage V_{11}. The small signal nonlinearity characteristics of the active antenna are estimated by the suppression of intermodulation products $a_{2,3}$ in dB with respect to 2nd order and 3rd order effects, caused by two undesired signals of 100mV/m each. There is no theoretical limitation of the obtainable G_r and the achievable $a_{2,3}$, which depend completely on circuit design and the semiconductors available. Satisfactory values of $a_{2,3}$ are obtained by means of high power transistors and transistors with low input capacitance since the nonlinear effect of the transistor capacitance, especially that of T_1, is very disturbing. The latest state of the art is a_2=105dB with a special FET and UHF-power transistors for T_3 and T_4.

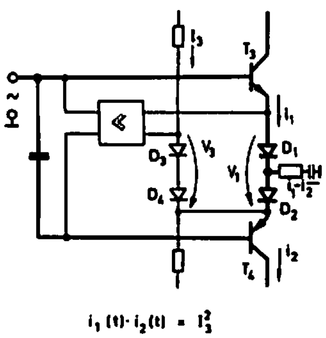


Fig.2b

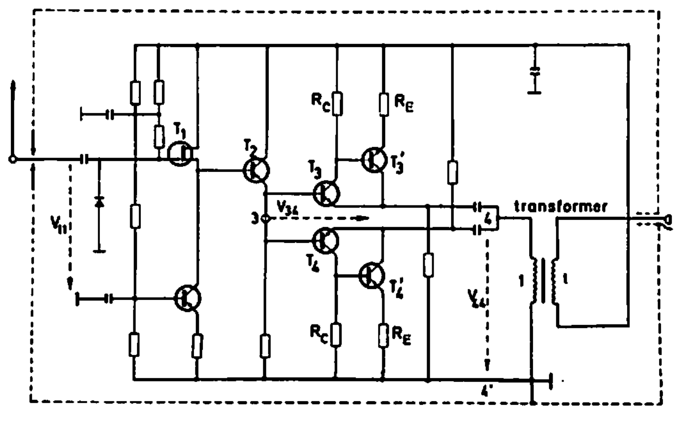
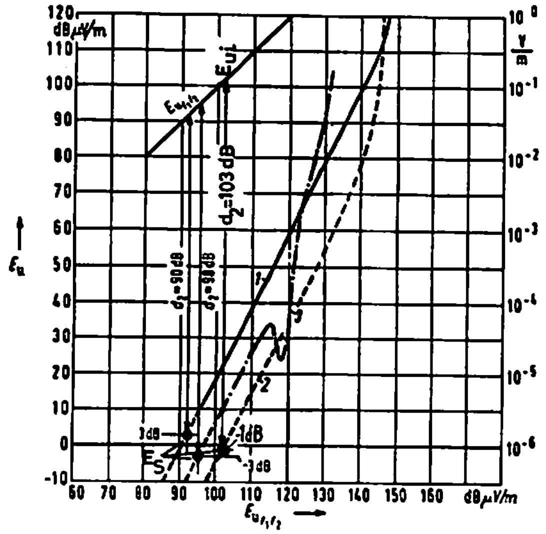


Fig.2c



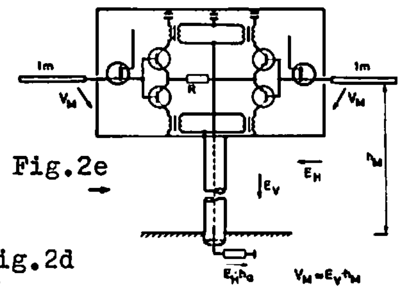


Fig.2e

Fig.2d

With this the tolerable values of two undesired signals $E_{ui} = E_{uf_1,f_2}$ causing a 2nd order product at $f_1 \pm f_2$ of same power as the antenna noise within a bandwidth of 5kHz has been improved to $\sqrt{E_{uf_1} \cdot E_{uf_2}} \approx 140$mV/m, making the antenna now applicable for all normal receiving conditions. Uptil now the 2nd order nonlinearity has been the only impediment for the general application of the active antenna. "Large signal nonlinear effects" are estimated by the tolerable rms-value E_{uc} of an undesired amplitude modulated signal, causing a 20dB suppressed undesired modulation factor on the desired signal carrier. To obtain satisfactory values of E_{uc} the development of the controlled output stage with two complementary transistors T_3 and T_4 in Fig.2a was necessary. Without the control circuit in Fig.2b the increasing transistor temperature due to large signals results in a thermal instability. This is avoided by means of the circuit in Fig.2b, where the instantaneous product $i_1(t) \cdot i_2(t)$ of the transistor currents $i_1(t)$ and $i_2(t)$ is controlled constant during the operation. A further very important component for the linearity of the circuit in Fig. 2a is transistor T_5, which supplies the FET with the appropriate gate current without regard of the ambient temperature and the dc-current components due to nonlinear effects during operation. If lower values of E_{uc} may be tolerated the reverse feedback factor of the output stage may be increased by the factor $(1+R_C/R_E)$ with a circuit as in Fig.2c, which is very advantageous for application in co-phased arrays. In Fig.2d the 2nd order modulation product E_u is plotted versus the level $E_{uf_1} = E_{uf_2} = E_{uf_1f_2}$ of two undesired signals. Curve 1 has been valid for a circuit like in Fig. 2a in 1977, while in 1978 curve 2 has been realized. Curve 3 is true with a circuit like in Fig.2c. The new design of an active horizontal dipole as part of the diversity antenna in Fig.7 consists of two amplifiers as in Fig.2a, connected at the output as displayed in Fig.2e. With this circuit optimum a_2 is obtained. Care has to be taken of nonlinear distortions as a result of the height effect and the undesired vertical field component E_V, which is suppressed at the antenna output but inspite of that could overload the amplifier.

3. Selective negative feedback.

A very adventageous solution to provide a high reverse feedback

Fig.3 ←

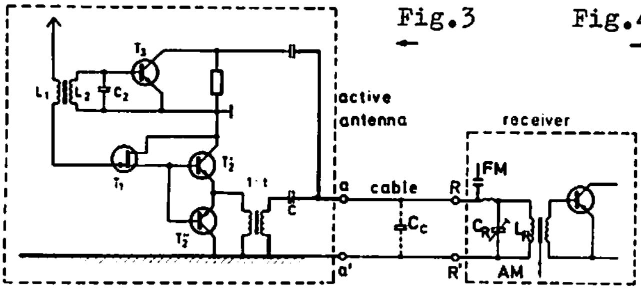
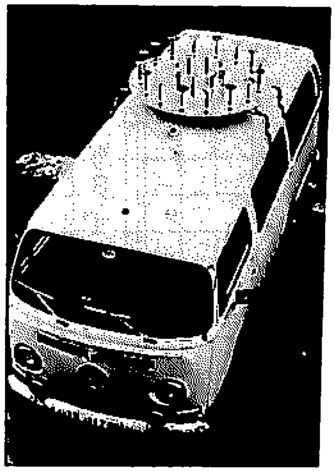


Fig.4 →



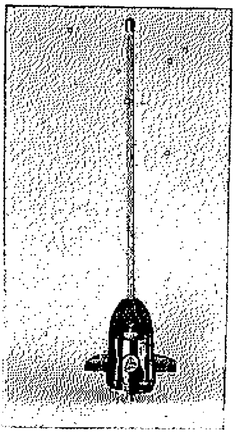
factor at undesired frequencies is to make use of the tunable resonant input circuit of a receiver. The principle of this circuit may be seen from the example of the AM-part of an active car antenna with standard receiver in Fig.3. Due to the sharp resonance at the operational frequency,to which the receiver is tuned,all undesired signals are suppressed by a very high value of G_r. In this way the sensitivity problem is solved broadband,which, according to Fig.1, is superior even to the optimum way of tuning. The required linearity is obtained by means of a selective reverse feedback, where the tuning circuit is conveniently located in the receiver and provides the active antenna with the linearity properties of a tuned antenna. Active antennas being on the market now have $E_{uc}\approx 3V/m$, while with this new type of amplifier, built into antennas shown in Fig.11 and 12, $E_{uc}\approx 30V/m$ is obtained,and no distortion occurs even in the very vicinity of an AM-radio station.

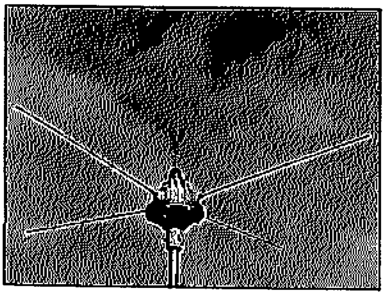
4. Linearity of active antenna arrays

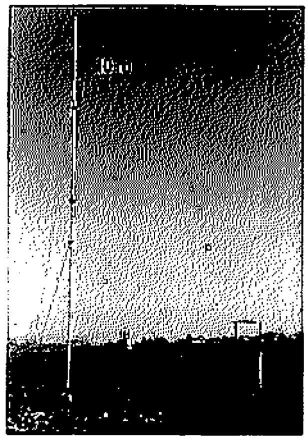
The antennas in Fig.8b (250kHz-30MHz) and Fig.9 (20MHz-300MHz) are ideal elements for application in direction finder systems (s.Fig. 4 and 8a) and in directional antenna arrays as for example Yagi structures. With S_o/N_o being the snr in every active element, the S/N of an n-element directional antenna array is $n\cdot S_o/N_o \approx D\cdot S_o/N_o$, where D is the directivity. An important nonlinearity characteristic is the dynamic range d of the active antenna, representing the difference of levels between E_{ui} and E_s as indicated by d_2 in Fig.2d for a 2nd order effect. It can be shown that the dynamic range of an active array is greater than that of a passive directional antenna with one amplifier of the same dynamic as each of the active antenna elements.

5.Examples of realized active receiving antennas:

Fig. 6:Highly linear,broadband active rod monopole (10kHz-80MHz)
Fig. 7: Broadband diversity antenna with a vertical active monopole (10kHz-30MHz) and two crossed active dipoles (1MHz to 30MHz)
Fig. 8a:Direction finder antenna system (250kHz-30MHz) with 2m high active broadband antennas(replacement for pass.ant.in Fig.8b)
Fig. 9: Top loaded, highly sensitive, 20cm high active broadband antenna (20MHz-300MHz) for application in arrays (1978)
Fig. 10: 25cm long active narrow band antenna for space rockets
Fig. 11: Several types of active AM-FM car radio antennas
Fig. 12: Active windshield antenna for AM-FM car radio
Fig. 13: TV-antenna consisting of two separate active dipoles





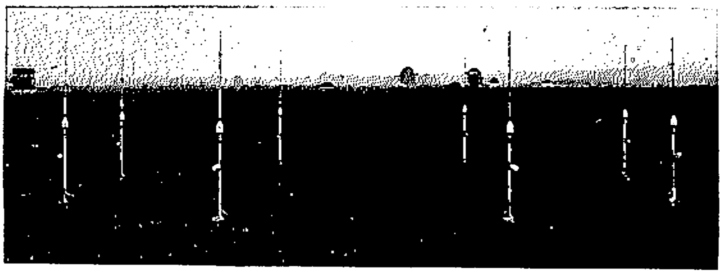


↑Fig.7

Fig.6 ←

Fig.8b →

↓Fig.8a



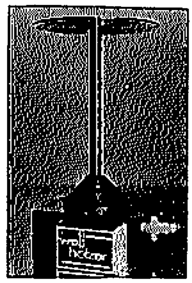


Fig.9

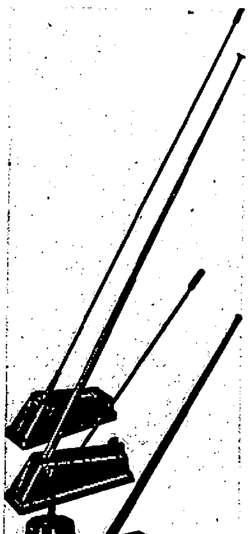
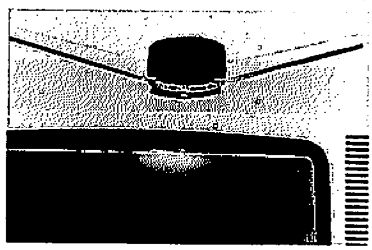


Fig.10



↑Fig.12

Fig.11 ←

Fig.13 →

↓Ref.

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