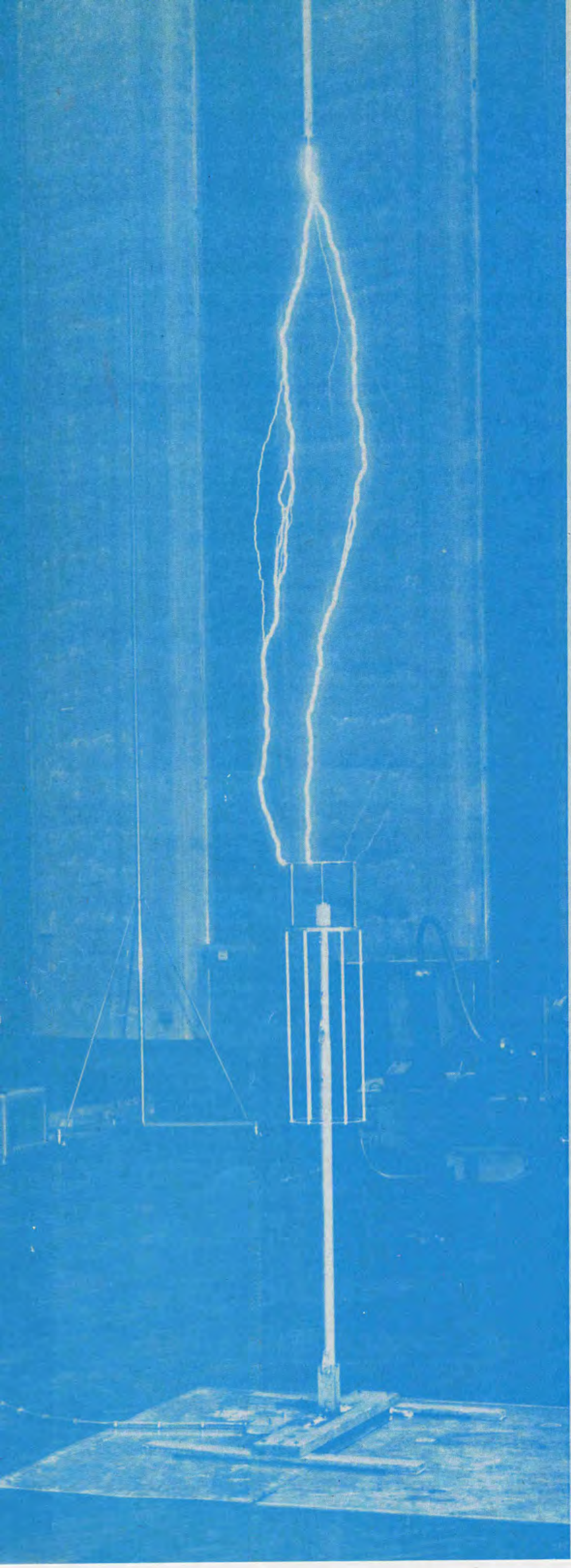

Active

A description and system analysis of an antenna that is an integrated combination of a short passive element and gain amplifier.

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The active antenna in its minimum configuration consists of a passive antenna, typically, a rod or a dipole and an integrated amplifying device.

Let us look at the simple case in which a rod antenna is directly connected to the input of a field effect transistor. As shown in Figure 1, the antenna acts as a source that feeds the transistor. The electric field strength E generates a voltage (EMF) that can be determined from $V_a = E \cdot h_e$. The antenna has a capacitance C_A and for small electrical lengths, this is 25 pFd/meter, while the transistor has an input capacitance C_T. These two capacitances form a capacitive voltage divider. The signal voltage that drives the transistor is then

$$V_T = \frac{E \cdot h_e}{1 + C_T/C_A}$$

For electrically short antennas the voltage V_T is nearly independent of frequency. Therefore, the active antenna has an extremely wide bandwidth.

The gain-bandwidth product of such a device can be computed from the performance of the field effect transistor in Figure 1. It will reproduce at the output the input voltage as long as its cut-off frequency is high enough. Additional reactances (for frequency selectivity) may be added to intentionally limit the bandwidth of the active antenna.

Antennas

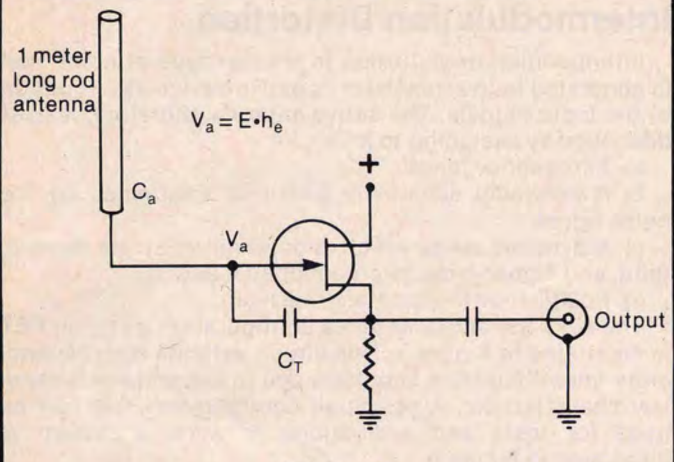

Figure 1.

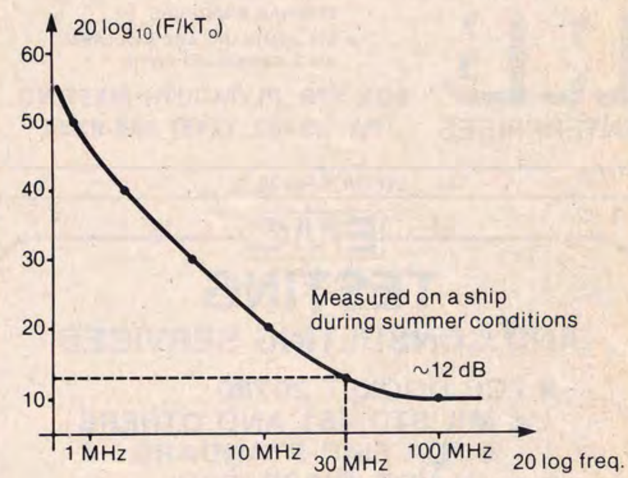

Figure 2. Atmospheric noise as a function of frequency.

Output power is not considered of primary importance since post amplifiers can always be added. Therefore, only the signal-to-noise ratio is worth considering.

Assume that the active antenna has sufficient gain. Then the signal-to-noise ratio is determined by the active antenna and not by the receiver. The only internally-generated noise is from the transistor since the passive antenna must be considered noise free.

In analyzing the output of the active antenna, there are three components to consider:

a) The signal voltage at the operating frequency,

b) The amplified noise generated by external sources (man-made or galactic), and

c) The transistor noise contribution.

As long as the noise voltage generated by the transistor at the amplifier output is less than the wideband noise picked up by the antenna, the system is capable of supplying the same signal-to-noise ratio as an optimized passive antenna for the same specific frequency.

Let us assume for a moment that we have an active antenna with a 1 meter long rod element. Its capacitance is 25 pFd. A typical value for the FET is 5 pFd or one fifth. Consequently 80 percent of the antenna output is applied to the FET input.

If a passive full wavelength long dipole were used instead at, say, 10 MHz (30 meters long), the open-circuit voltage (EMF) would be 30 times higher than that generated by the 1 meter long rod. In addition, the atmospheric noise term would be greater. However, the 1 meter rod, for all practical purposes, generates the same, or practically the same, signal-to-noise ratio as a dipole with the difference that individual (signal and noise) levels are smaller. The difference in amplitude can be compensated for by an amplifier under the restriction that atmospheric noise divided by the ratio of (full size antenna/1 meter) is equal to or better than the noise figure of the transistor amplifier.

The average noise power of the ionosphere at these low frequencies is seen in Figure 2. These are the figures measured in typical rural areas. It becomes apparent that if these voltages are divided by 50, the noise floor approaches the noise floor of the best FETS, i.e. approximately 1 to 2 dB.

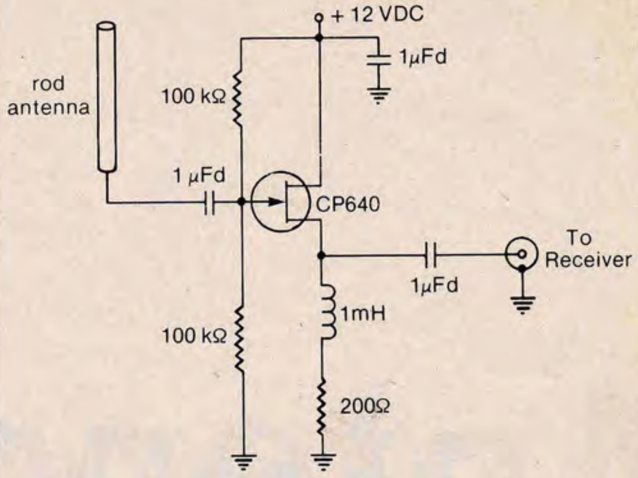

Figure 3.

Intermodulation Distortion

Intermodulation distortion is another type of noise that is generated in the transistor or active device as a function of the input signals. The active antenna, therefore, is best described by assigning to it:

a) A frequency range

b) A minimum sensitivity which is determined by the noise figure

c) A dynamic range which is determined by the second, third, and higher-order intercept points, and

d) Polarization (horizontal or vertical).

The simplest active antenna configuration using an FET is illustrated in Figure 3. This circuit exhibits high second-order intermodulation distortion due to the antenna square-law characteristic. A push-pull configuration that can be used for tests and evaluations of such a system is illustrated in Figure 4.

Table 1. Active Antenna Dynamic Analysis Terminology.

a	Cable losses
B	Receiver bandwidth
C	Noise correlation factor
F_A	Antenna noise figure
F_{min}	Amplifier noise figure (for best noise match)
F_R	Receiver noise figure
F_S	System noise figure (antenna, cable, and receiver)
G_v	Antenna gain = antenna output power
IP_2	Second-order intercept point
IP_3	Third-order intercept point
P_a	Output power into 50 ohms
$P_{am_{2,3}}$	Second or third order intermodulation products output power
P_{an}	Noise output power
V_a	Output voltage (terminated in 50 Ω)
V_o	Antenna output EMF
Z_A	Antenna rod impedance
Z_{opt}	Antenna rod impedance (for best noise matching)

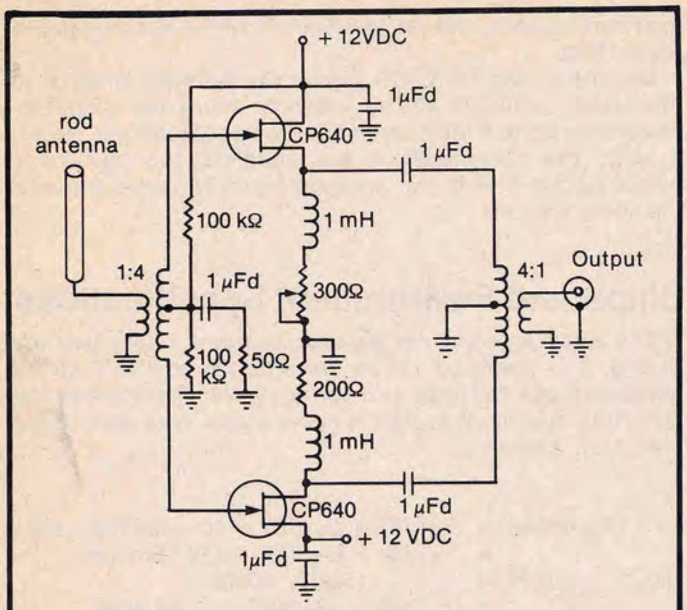

Figure 4.

Active Antenna Dynamic Analysis (See Table 1 for terminology.)

System noise figure is defined by

$$F_S = F_A + \frac{(F_R - 1) \cdot a}{G_v}$$

The electrical gain of the antenna is defined by

$$G_v = 4\left(\frac{V_a}{V_o}\right)^2 \cdot \frac{R_A}{Z_L}$$

For reasons of best dynamics, assume $V_a/V_o = 0.5$.

With these assumptions in mind, the noise figure of the antenna now becomes

$$F_A = F_{min}\left(1 + C\,\frac{(Z_A - Z_{opt})^2}{R_A \cdot R_{opt}}\right) = F_{min}(1 + A)$$

The impedance Z_A and Z_{opt} are

$$Z_A = R_A + jX_A \qquad 0.25 < C < 0.5$$

$$Z_{opt} = R_{opt} + jX_{opt}$$

If the antenna is set for the greatest possible bandwidth, X_{opt} becomes 0. The antenna noise figure then is

$$F_A = C\left(\frac{R_A}{R_{opt}} + \frac{R_{opt}}{R_A} + \frac{X_A^2}{R_A \cdot R_{opt}} - 2\right)$$

This particular type of matching requires a high input impedance. Therefore:

$$\frac{R_A}{R_{opt}} << \frac{R_{opt}}{R_A}, \quad \frac{R_A}{R_{opt}} + \frac{R_{opt}}{R_A} + \frac{X_A^2}{R_A \cdot R_{opt}} >> 2$$

f (MHz)	G_V (dB)	$F_A\left(\frac{dB}{kT_o}\right) \approx F_S\left(\frac{dB}{kT_o}\right)$
2	−31	47.4
5	−21.7	35.2
10	−15.5	28.6
15	−12	24.9
20	−10.2	23.1
25	− 7.3	20.2
30	− 5.5	18.4

Table 2.

Finally, the antenna noise figure is

$$F_A = F_{min}\left\{1 + \frac{C}{R_A}\left(R_{opt} + \frac{X_A^2}{R_{opt}}\right)\right\}$$

Using a rod antenna, its impedance is

$$Z_A \approx K_{R_1}\omega^2 + j\,\frac{k_{X_1}}{\omega}$$

The impedance diminishes much faster than the noise figure does (as a function of frequency). Consequently, optimum matching resistance should be specified at the lowest operating frequency. Consider a 2-30 MHz active antenna. Its match resistance is 2466Ω (at 2 MHz). The antenna performance can now be determined if Z_A is known.

Loss and Noise Figure Versus Frequency

Table 2 lists electronic losses and noise figure as a function of frequency. (This assumes that the noise figure of the active device is 2 dB). This data is also plotted in Figure 5. In this graph, the system's noise figure, the man-made noise, and some arbitrary noise specifications are plotted.

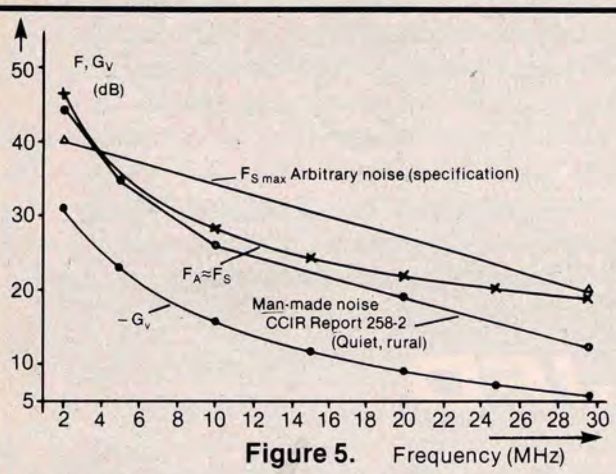

Figure 5.

Despite a loss of 30 dB (the active antenna relative to the power available at the antenna input) the signal-to-noise ratio up to 4 MHz can meet the specifications. Below 4 MHz, the specifications are equal to the man-made noise. Above 4 MHz the antenna's performance exceeds the specifications.

Shipboard Environment Specifications

The active antenna, per the specifications,* sees two 10V EMF's. The intermodulation distortion products that are generated due to these two voltages are 40 dB above the specified maximum system's noise figure, as a worst case condition. Therefore:

$$\begin{aligned}
P_{an}(dBm) &= F_S(dB) + G_v(dB) = 10 \cdot \log kToB \cdot 10^3 \\
&= F_S(dB) = G_v(dB) - 139\,dBm \text{ and} \\
P_{am_{2,3\,max}}(dB) &= P_{an\,min}(dBm) + 40\,dB \\
&= [F_S(dB) + G_v(dB)]_{min} - 99\,dBm
\end{aligned}$$

At 2 MHz, F_S equals 40 dB and G_v equals −31 dB. Therefore, $P_{am_{2,3}} = -90$ dBm.

Intercept Point Calculations

$$IP_2(dBm) = 2\,P_a(dBm) - P_{am\,2}(dBm)$$

$$P_a = \frac{V_a^2}{50\Omega}$$

With $V_a/V_o = 0.5$ and $V_o = 10V$, P_a is +27 dBm, and, therefore, $IP_2 = 144$ dBm and $IP_3 = 85$ dBm. These are the two values that are required to generate an intermodulation distortion noise floor at the rated level. For practical considerations the 1 dB compression point should be 10 dB above the operating output level. Therefore, in this case, it should be +37 dBm. This results in a voltage level of 44.3V at 0.9A in a 50 ohm system. The operating voltage of this amplifier should be set at 50V. If the input voltage ratio is changed and a higher than 0.5 voltage division ratio is utilized, then the second and third order intercept points can be reduced. Let us assume that an intercept point of $IP_2 = 100$ dBm and IP_3 of 65 dBm can be reached in a practical amplifier. The following results will then be obtained:

1. Second order intermodulation distortion products are going to be −46 dBm and the useful dynamic range will be *84 dB*.
2. Third order intermodulation products will be −49 dBm and the useful dynamic range will be *81 dB*.

These calculations assume a noise figure of 40 dB at 2 MHz and two 10V random carriers generating the intermodulation distortion products as specified.

A number of tests in extremely hostile environments have already been performed with this active antenna. However, it is not yet in mass production and, therefore, not enough information about reproducibility is available. This will be the next step for evaluation.

*Antenna system developed for use on shipboard by Communications Consulting Corp., Upper Saddle River, NJ, based on some discussions with the Naval Research Laboratory in Washington, D.C.