

NOISE AND INTERMODULATION IN A PRACTICAL ACTIVE ANTENNA SYSTEM

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INTRODUCTION

When designing an active antenna system it is necessary to satisfy a number of often conflicting criteria. In the type of antenna to be considered (a small passive element coupled directly to an amplifier) these requirements may be summarised as follows:

1. The passive element must deliver enough power to the amplifier to overcome thermal and amplifier noise.
2. The amplifier must deliver enough power to the receiver to overcome the receiver's internal noise.
3. The intermodulation performance of the antenna amplifier must be good enough to avoid degrading the performance of the receiver.

In order to establish an adequate specification for the active antenna we must first define the input and output characteristics of the system in which it is to be used:

1. The highest operating incident field strength.
2. The lowest field strength which it is required to receive.
3. The ambient noise environment of the antenna.
4. The intermodulation performance and noise figure of the receiver to which the antenna is connected.

In the discussion which follows, a typical standard of receiver performance has been assumed: 3rd-order intermodulation products (IPs) of 0 dB μ V for two input signals at a level of +90 dB μ V, together with a noise figure of 10 dB. In noise calculations a bandwidth of 3 kHz has been assumed.

We will compare a single active loop antenna with a standard quarter-wave monopole, and a linear array of 8 loops with a log-periodic antenna having similar directivity.

THE ACTIVE ANTENNA

The antenna which is considered below comprises a small unbalanced loop containing a terminating impedance (Ref. 1). We will define the effective height of the loop-amplifier combination as the ratio of the voltage delivered by the amplifier across a 50-ohm load (μ V) to the incident field strength (μ V/m).

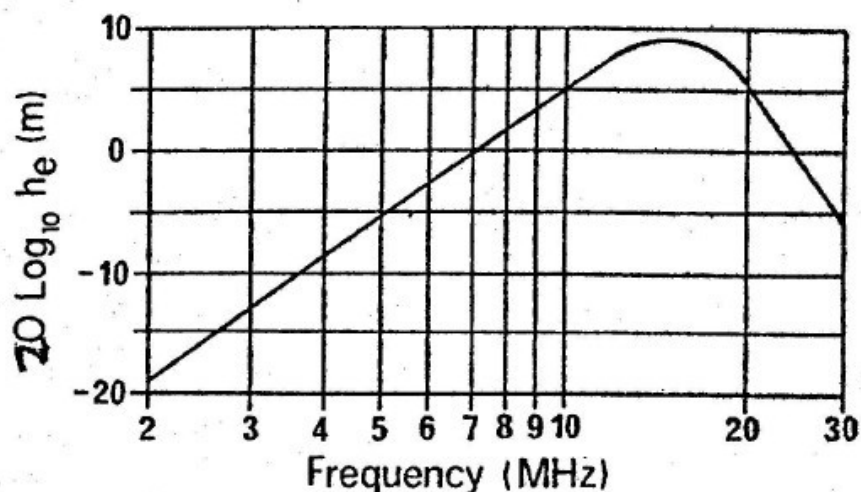


Figure 1: Effective height of loop/amplifier combination

Figure 1 shows a measured effective height/frequency curve for an active loop unit. Other characteristics of its performance are:

Frequency range	2–30 MHz
Amplifier insertion gain	16 dB
Amplifier noise figure	5 dB maximum
Intercept points referred to output:	
3rd order	+20 dBm
2nd order	+29 dBm

These IP figures are quite modest and certainly do not represent the limit of currently available circuits or devices.

INTERMODULATION PERFORMANCE

It is difficult to assess the IP performance of a conventional passive antenna, especially to allow for the degradation which may occur over a period of years as exposed joints become corroded. Certainly the performance is not infinitely good, but in the absence of information we will ignore them.

We require to compute the level of third-order intermodulation products for various input levels for both the receiver and the active antenna. For this purpose we construct a graph (Fig. 2), having input power level plotted on the x-axis and, for the active antenna only, output power on the y-axis. For the receiver the y-axis is only used to show relative and not absolute levels, so the figures used are not important.

For the receiver we plot the known data: when the input is +95 dB μ V, i.e. –17 dBm, the 3rd-order products are 90 dB down. We may draw a line of unity gradient through the upper point as (at least as far as the saturation limit) input and output are proportional. The 3rd-order IP varies as the cube of the input, so we may draw a line of gradient 3 through the lower point. These two lines intersect. The IPs of amplifiers are commonly defined by reference to this intersection, generally known as the 3rd-order intercept point (IPOP3).

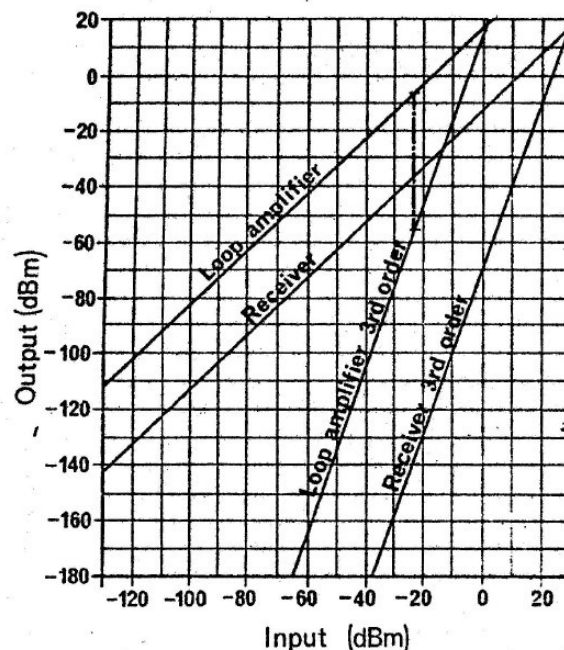


Figure 2: Input/output relationships for signals and 3rd-order IPs

Sample calculation

Let us assume an incident field strength of 0.1 V/m using antennas of 10 dB directivity (8-element loop and log-periodic antenna).

Effective area of an isotropic antenna	$= 0.079\lambda^2$
Effective area of log periodic	$= 10 \times 0.079 \times (42.9)^2$
	$= 1454 \text{ m}^2$
Power flux = V^2/Z_0	$= 0.01/120\pi = 2.65 \times 10^{-5} \text{ W/m}^2$
Power intercepted = power flux $\times$ effective area	$= 0.039 \text{ W} = +15.8 \text{ dBm}$

If fed unattenuated to the receiver this would result in 3rd-order IPs 26 dB below the incoming high-level signal (see Fig. 2).

Referring to Fig. 1, the effective height of the active antenna at 7 MHz is 1.0 m, so in a field of 0.1 V/m the output will be 0.1 V in 50 ohms (-7 dBm).

From Fig. 2 the 3rd-order IPs are 50 dB down. To obtain the receiver IPs we must first add the outputs of the 8 loops. Combined output = $-7 + 9 = +2 \text{ dBm}$. At this input level the receiver IPs are 52 dB down.

Because the effective heights of the antennas change with frequency these calculations must be repeated at different frequencies. It is interesting to note that although the excessive signal yielded by the log periodic may profitably be reduced by an attenuator, the intermodulation products generated by the receiver used with the active array cannot be further reduced because there is only a small sensitivity margin in the system. The fundamental situation has in fact improved because the lower noise figure of the antenna amplifier is being exploited by operating with lower input levels.

In a multi-element loop array the contribution to IPs from the receiver increases. To obtain equal IP contributions from the antenna and the receiver the intercept point of the amplifiers may be N dB lower (worse) than that of the receiver, where N is the net increase in signal obtained by summing the outputs of the individual loops. Thus for an 8-element array using the receiver considered there is no advantage in raising the intercept point of the amplifier above, say, $+25 \text{ dBm}$. An amplifier with a 3rd-order intercept of $+48 \text{ dBm}$ has been developed, but its use may be unjustifiable except for situations where transmitting antennas are used on the same site.

NOISE

Active HF antennas exploit the fact that at HF reception takes place in a noisy environment. The received signal/noise ratio can be enhanced by obtaining greater antenna directivity, even if the amount of signal is reduced. There is obviously a limit to how far the reduction of signal levels can be carried, and we will now investigate this aspect of the problem.

Sample calculation

Consider the situation at 7 MHz in a typical mid-latitude location where the external noise is equivalent to a noise field strength of $-8 \text{ dB}(\mu\text{V/m})$ in a 3 kHz bandwidth. (Predictions for any location or frequency may be found in Reference 2.)

1	Thermal noise at receiver input (kTB) = -139 dBm		
2	Equivalent thermal noise (NF = 10 dB) = -129 dBm		
3	Thermal noise at loop amplifier output (gain = 16 dB, NF = 5 dB) = $-139 + 5 + 16 \text{ dB} = -118 \text{ dBm}$		
	8-loop array	10 dBi passive array	
4	Let incoming wanted signal be	$1 \mu\text{V/m}$	$1 \mu\text{V/m}$
5	Signal from 1 loop	-107 dBm	
6	Signal from whole antenna	-98 dBm	-84.2 dBm
7	External noise at antenna output	-116 dBm	-102.2 dBm
8	Thermal noise at antenna output	-118 dBm	-139 dBm
9	Receiver noise	-130 dBm	-130 dBm
10	Total noise (= 7 + 8 + 9)	-113.8 dBm	-102.2 dBm
11	Signal/noise ratio (6 – 10)	15.8 dB	18.0 dB

In this example the signal/noise ratio of the active array is about 2 dB below that of the passive array, because the thermal noise of the amplifiers is comparable with the external noise; a little more amplifier gain, or a lower noise figure, would make the system externally noise limited.

This view of the function of the amplifier leads directly to a criterion for optimum gain of the amplifier. This must be large enough to ensure that the overall noise figure of the receiving system is lowered far enough to allow external noise to dominate internal noise despite the very small effective height of the energy-collecting element which precedes it. Too little gain or too high a noise figure will require a large input signal and will in turn make severe demands on intermodulation performance. Excessive gain will make adequate dynamic range difficult to achieve and will not continue to reduce the level of input signal which is needed, because the noise figure of the system does not improve appreciably once a sensible optimum gain has been reached. The fundamental lower limit to the size of the passive energy-collecting element is the thermal noise (kTB) at the amplifier input terminals. The lowest signal which it is required to receive (presumably only a little above the external noise level) must exceed the sum of thermal and amplifier noise.

The example above shows the method of calculation and the variables which must be defined. There is no single set of optimum performance parameters; the best values in a particular case depend on the noise levels at the receiving location, the receiver noise figure and IP performance, the effective height v. frequency characteristic of the passive antenna element and the performance trade-offs which are available from practical amplifiers. Table 1 shows a comparison of active and passive antennas.

Table 1: Comparison of active and passive antennas

Frequency (MHz)	Passive			Active			
	Output power (dBm)	3rd-order IP (relative dB)	Effective height (m)	Output power (dBm)	Input power (dBm)	3rd-order IP, antenna (dB down)	3rd-order IP, receiver (dB down)
<i>Comparison of a single loop with a quarter-wave monopole</i>							
3	+15.3	-27	0.25	-19	-35	-74	-94
7	+8.1	-40	1.0	-7	-23	-50	-70
15	+1.3	-54	2.5	1	-15	-31	-51
30	-4.7	-64	0.45	-5	-30	-65	-85
<i>Comparison of an 8-loop array with a log-periodic dipole array</i>							
3	+23	10	0.25	-10	-35	-74	-76
7	15.9	26	1.0	+2	-23	-50	-52
15	+9.2	37	2.5	+10	-15	-31	-33
30	+3.2	48	0.45	-5	-30	-65	-67

COMMENTS

It is interesting to see how well an amplifier with a good noise figure and moderate IMP performance appears to perform in an active antenna system. The amplifier may be regarded as a low-noise preamplifier which increases the threshold sensitivity of the receiving system and permits operation at lower levels than normal.

PRACTICAL RESULTS

A large number of arrays of the active antennas described in this paper have been assessed by a variety of users. In each test the criterion for assessment has been signal-to-noise ratio, which has been measured by a variety of methods. Comparisons have been made with various conventional antennas including rhombics, log-periodics, Beverage antennas and simple cones and whips. Linear arrays of four or eight loops have been used for most trials.

Trials conducted in the HF band, for which the active antennas were designed, have been very satisfactory. Once users have accustomed themselves to the low signal output level of the array they find that the signal/noise ratio provided by the active array approaches or even exceeds that of a much larger conventional array. Great care has been taken in comparison tests to make sure that both the active antenna and that with which it is being compared have been properly chosen for the propagation path on which tests are to be conducted. Only in tests conducted in the MF band has the active system shown itself to be internally noise limited, as would be expected from its very small effective height in this band.

No performance limitations due to intermodulation products have been reported although they have been carefully sought. References to signals being ‘cleaner’ or ‘crisper’ with the active array suggest that operators could profitably use more RF attenuation when using conventional antennas, or that conventional passive antennas do make a significant contribution to IPs.

The very low level of secondary lobes from an array of active loops results in lower levels of interfering signals than provided by most conventional antennas. A set of results from one comparative trial is shown in Table 2.

SYSTEM PLANNING

When considering the proper criteria for performance it is important to define carefully the function of the system.

Communication systems must be designed to operate not just in average conditions but in conditions which prevail for just 1% or perhaps 10% of operating time. It is system performance in times of unusually high ambient noise which is critical and for which the system must be planned. At times of low external noise it is of little consequence whether the system noise performance is determined by external or internal noise. By contrast a receiving system which is intended for intelligence gathering should always remain externally noise limited, so that full advantage may be taken of unusually quiet conditions to acquire signals which are normally masked by noise. The optimum amplifier characteristics for these two tasks may be different; the fixed system may have a co-located transmitter antenna and an optimum amplifier must have excellent intermodulation performance combined with a modest gain and noise figure. The antenna for a surveillance system needs an amplifier with lower noise figure and high gain, but intermodulation performance may not be so critical.

Table 2: Comparison of a 4-element array of active loops with a Beverage antenna 3 m high $\times$ 792 m long, a conical monopole and a single active whip over path lengths of 100–4500 km

Antenna	Number of times preferred		Number of times least preferred	
	HF band	MF band	HF band	MF band
4-loop array	13	0	0	3
Beverage	4	5	1	0
Cone	0	1	4	2
Whip	1	0	4	1

CONCLUSION

A large number of the parameters of an active system are interrelated. It has been shown that using a low-noise amplifier and a small pickup element the demands made of the amplifier are not unduly stringent when the antenna is used in a typical receiving station location. The specification of active antennas must be defined in terms of the performance of the whole receiving system.

REFERENCES

1. Collins, B. S.: “Loop antennas for HF reception”, *Communications '74*, Conference proceedings, Brighton, England, 1974.
2. *CCIR Report No. 252-2*, 1970, New Delhi (since replaced by ITU-R P.372-9: Noise).

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