A Broadband Low-Noise Active Antenna

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Tuned active receiving monopoles are investigated with Q's in the range 10-100. These antennas exhibit low noise-figures and relatively narrow bandwidths. A broadband antenna composed of a cluster of such active monopoles is proposed to provide the advantages of small size, wide bandwidth and low noise, well suited to operation in the VLF-UHF range.

1. INTRODUCTION

The properties most sought after in active antennas are size reduction and broadband operation, which are not simultaneously obtainable in corresponding passive antennas. However, in the active antenna, these characteristics are achieved at the expense of the noise performance.

The active dipole/monopole antenna frequency response and noise figure are critically dependent on the impedance matching conditions at the interface between the antenna element and the electronic circuitry [1]. Investigation of the efficiency of the signal transfer shows that the small electrical length of the antenna element results in a large impedance mismatch at the interface of the antenna element and the electronic circuitry, especially when wideband operation is required. The mismatch reduces the signal power transferred to the electronic circuitry and results in an increase in the active antenna noise figure. This agrees with the analysis of Sainati [2] which shows that the performance of an active antenna is limited by its low radiation resistance.

The noise figure of the active dipole/monopole antenna can be improved with suitable impedance matching conditions at the antenna/electronics interface, but the improvement is obtained at the expense of reduced bandwidth. The tuned active monopole [3], shown in Figure 1, has the required impedance transformation carried out by the combined effects of the parameters of the passive antenna element, the tuned circuit and the active electronic circuit. It is structurally simple, occupies a small volume and is suitable for practical engineering applications. It offers low-noise performance and a large signal output, compared with a similar wideband untuned active antenna.

The bandwidth deficiency of the tuned active monopole can be overcome by making a compact active antenna cluster consisting of several such narrow-band antennas, each tuned to a slightly different centre frequency. This antenna cluster provides the advantages of wide operational bandwidth, high sensitivity and small size.

2. TUNED ACTIVE MONOPOLE

The frequency response of a tuned active monopole antenna, such as shown in Figure 1 has been analysed [3] using a three-component lumped-parameter equivalent circuit for the passive antenna element. This circuit exhibits a bandpass filter characteristic with a distinctive tuning peak for $Q > 1$. A Q in the range 10-100 is used for the antenna structures reported here.

2.1 Noise Performance

The equivalent circuit in Figure 2 is used to analyse the noise performance. v_{ni} and i_{ni} are respectively the amplifier equivalent input noise voltage and current. v_{nl} is associated with the resistance of the inductor and v_{na} is the antenna noise voltage.

The equivalent total noise voltage, v_n, referred to the input of the amplifier is given by

$$v_n^2 = v_{ni}^2 + v_{na}^2 \left| \frac{Z_i//Z_L//R}{Z_i//Z_L//R+Z_a} \right|^2 + v_{nl}^2 \left| \frac{Z_i//Z_a//R}{Z_i//Z_a//R+Z_L} \right|^2 + v_{nr}^2 \left| \frac{Z_i//Z_a//Z_L}{Z_i//Z_a//Z_L+R} \right|^2 + i_{ni}^2 \left| Z_i//Z_L//R//Z_a \right|^2$$

where z_i is the input impedance of the amplifier
z_a the antenna impedance
z_L the inductor impedance

Figure 3(a) gives the equivalent total noise voltage and its constituents of an active antenna tuned to 30MHz. At the tuned resonant frequency, the antenna noise (v_{na}) dominates, resulting in an external noise limited system. This is a desirable feature in low-noise active antenna designs. Above and below the resonant frequency, the contribution from the amplifier noise voltage (v_{ni}) becomes significant.

The corresponding noise figure of the antenna is calculated from the expression

$$F = 1 + \frac{\text{excess noise}}{GN_i}$$

which gives for this circuit.

$$F = 1 + \frac{v_{ni}^2}{v_{na}^2} \left| \frac{Z_i//Z_L//R+Z_a}{Z_i//Z_L//R} \right|^2 + \frac{v_{nl}^2}{v_{na}^2} \left| \frac{Z_i//Z_a//R}{Z_i//Z_L//R} \; \frac{Z_i//Z_L//R+Z_a}{Z_i//Z_a//R+Z_L} \right|^2 + \frac{v_{nr}^2}{v_{na}^2} \left| \frac{Z_i//Z_a//Z_L}{Z_i//Z_L//R} \; \frac{Z_i//Z_L//R+Z_a}{Z_i//Z_L//Z_a+R} \right|^2 + \frac{i_{ni}^2}{v_{na}^2} \left| Z_i//Z_L//R//Z_a \right|^2 \left| \frac{Z_i//Z_L//R+Z_a}{Z_i//Z_L//R} \right|^2$$

This is plotted in Figure 3(b) for $Q = 10$ and shows that the minimum noise figure occurs at the resonant frequency. For larger Q's the minima of curves (a) (b) and (c) go to 1dB or less at the resonant frequency.

2.2 Experimental Results

The calculated and measured output noise voltages of a 15MHz tuned active antenna (Figure 1) are given in Figure 4. The experimental results were measured in a 2mx2mx2m shielded room and confirmed the theoretical model used.

3. ACTIVE ANTENNA CLUSTER

A wideband active antenna can be obtained by grouping together a number of the narrowband tuned active monopoles with slightly different centre frequencies and combining the outputs in a summing amplifier. The distance between any two antennas in such a cluster must be carefully selected in order to minimize the effect of mutual coupling. An analysis of the scattered E fields of an electrically small (<0.05λ) passive receiving antenna element shows that the mutual coupling effects are negligible for distances down to about 0.01λ. Thus a number of active antenna elements can be located in a confined space.

3.1 Theory

If $\alpha_i = v_{oi}/v_{ai}$ is the frequency response of the ith bandpass antenna in the antenna cluster, the output of the summing amplifier, v , is

$$v_o = \sum_{i=1}^{N} \alpha_i v_{ai} k_i e^{j\theta_i}$$

where k_i and $e^{j\theta_i}$ provide for amplitude and phase control for the ith element; N is the number of antennas in the cluster. Since each antenna is tuned to a different frequency, the combined result will have a bandwidth greater than that of a single tuned active monopole.

A simple cluster consisting of two tuned antennas is used as an example. The coefficients k_i and $e^{j\theta_i}$ are assumed to be unity, i.e., the signals are not conditioned. One of the antennas is tuned to 14.6MHz. For the investigation the other antenna element was successively tuned to 14.8, 15.0, 15.2 and 15.4 MHz. The calculated frequency response for the 15.0MHz case is shown in Figure 5.

For the other cases it was observed that the 3dB frequency bandwidth decreased as the two centre frequencies are brought together and that the trough of the ripple in the frequency response deepens as they are spread apart. In the extreme case when the two frequencies are far apart, two disjointed peaks are obtained.

3.2 Experimental Results

A two-element active antenna cluster was constructed using two identical tuned active monopoles 870mm long, with $Q = 30$ at 15MHz. The separation between the antennas was 200mm (0.01λ). The outputs were simply combined in a 50 ohm load. One of the antennas was tuned to 14.6MHz which the other was successively tuned to frequencies of 14.8, 15.0 and 15.2 MHz. Figure 6 shows the results for the 15.0MHz case which were measured in the open laboratory, outside the shielded room, over the frequency range 0 to 45 MHz. It can be seen from Figure 6 that the combined response of the two antennas (top trace) produces a wider bandwidth than the isolated 14.6MHz tuned active monopole (bottom trace). The observed bandwidths confirmed the theoretical results for the other cases also. It is noted that the magnitude of the combined output is reduced because the antenna outputs were not isolated in a summing amplifier.

The measured noise output voltage of the above active antenna cluster displays characteristics similar to those of the frequency responses. Two distinct noise peaks are observed when the centre frequencies are far apart. The antenna is thus external noise limited in these regions.

4. CONCLUSIONS

A wideband low-noise active antenna composed of a cluster of narrowband tuned active monopoles is proposed. This antenna cluster has the combined advantages of small size, wide-bandwidth and low noise, compared with either passive antennas or wideband untuned active antennas. Its wideband property has been confirmed experimentally for a two-element cluster over the 14.6 to 15.2 MHz frequency range. The active antenna elements used are each 870mm high and separated by 200mm. It is concluded that 7 such antennas arranged in a cylindrical volume 0.5m diameter and 1m long would cover a 10MHz bandwidth in the HF band.

The experiments were carried out in the HF region because of the availability of commercial buffer amplifiers suitable for the designs. The design principles are applicable to higher frequencies in the VHF-UHF regions, but suitable amplifiers using microwave transistors would be required for that range. There is no restriction in designing at lower frequencies down to the VLF region, provided low-noise amplifiers are used.

It is shown that the performance of a tuned active monopole and a wideband active antenna cluster is external noise limited in the HF region. This compares favourably with a wideband untuned active antenna in which the amplifier noise adversely affects the noise figure.

A number of such active antenna clusters can be used in an antenna array to which conventional radiation pattern control procedures can be applied. It is concluded that this broadband active antenna offers significant advantages for use in VLF-UHF receiving locations which require physically small antennas.

5. REFERENCES

[1] T. Tang and M.W. Gunn, "Signal transfer characteristics of an active receiving antenna", IREECON Digest, pp.26-8, 1981.

[2] R.A. Sainati, "Active antenna performance limitation", IEEE Trans. Antennas Propagat., Vol.AP-36, pp.1265-7, November 1982.

[3] T. Tang and M.W. Gunn, "On the gain factor of a tuned electrically short monopole", IREECON Digest, pp.201-3, 1983.

6. ACKNOWLEDGEMENT

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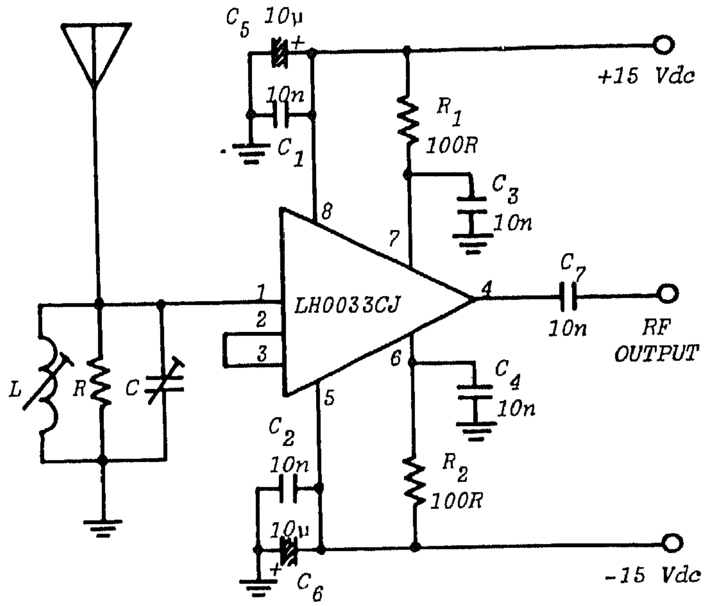

Figure 1 Tuned HF Active Antenna

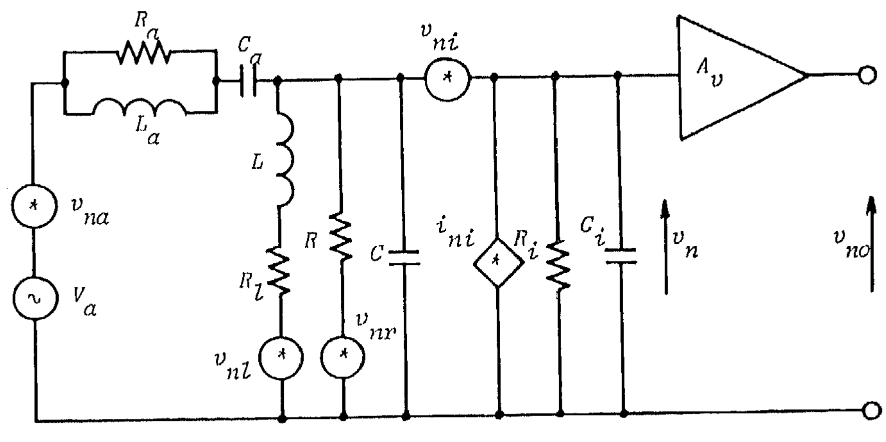

Figure 2 Equivalent Circuit of Tuned Active Antenna

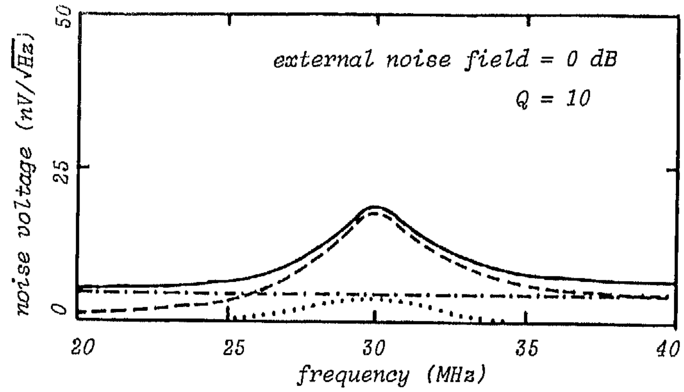

Figure 3(a) Noise Voltages of Band-Pass Tuned Active Antenna

——— total equivalent input noise voltage (v_n)

------ contribution of antenna noise voltage (v_{na})

-·-·-·- contribution of amplifier noise voltage (v_{ni})

········ contribution of resistance noise voltage (v_{nr})

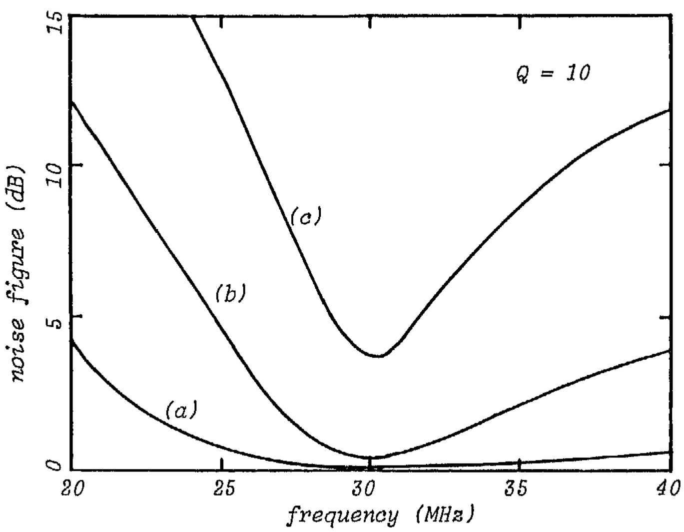

Figure 3(b) Noise Figure of a Band-Pass Tuned Active Antenna When External Noise Field Strength is (a) +10dB, (b) 0dB, (c) -10dB.

0dB is referred to 1 μV/m in 6kHz bandwidth.

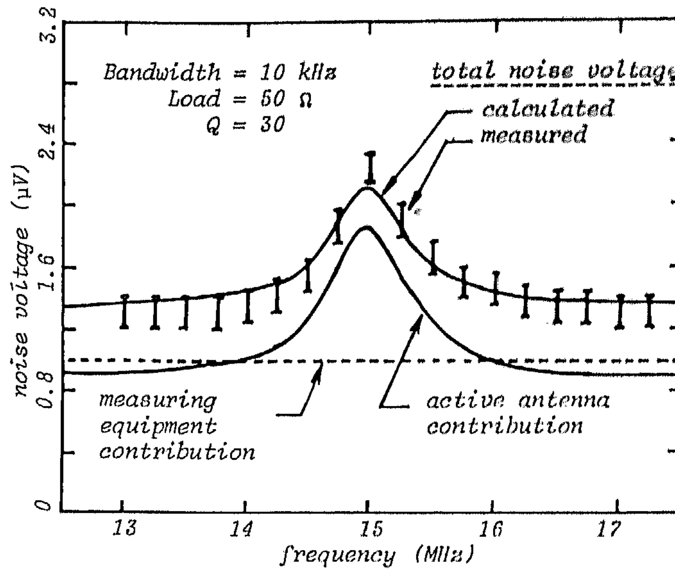

Figure 4 Measured and Calculated Output Noise Voltages for 15MHz Tuned Active Antenna.

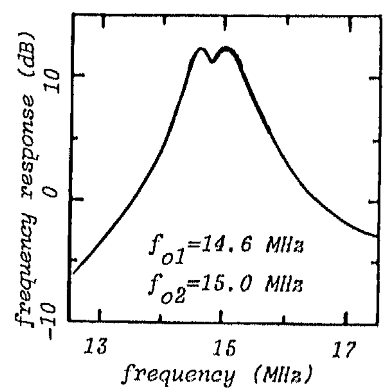

Figure 5 Theoretical Frequency Response of a Two-Element Cluster with Centre Frequencies 14.6MHz, 15.0MHz.

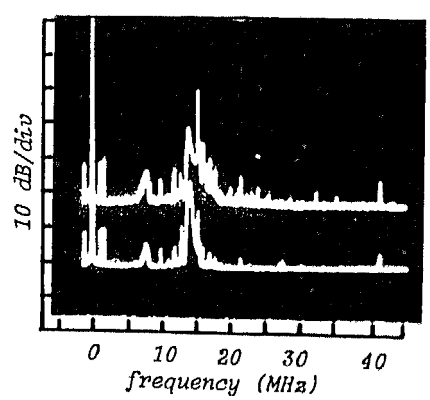

Figure 6 Measured Outputs of Tuned Active Antennas.

top trace: combined output of two-element cluster with centre frequencies 14.6MHz, 15.0MHz.

bottom trace: output of single 14.6MHz tuned antenna.