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February 1979

EFFECT OF MULTIPLE RECEIVING ANTENNAS ON THE RESPONSE OF AN R.F. INTRUSION SENSOR

J. Leon Poirier

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A phenomenological theory was developed to analyze the response of an RF intrusion detection system. The system consisted of a loop of leaky coax cable which acted as a distributed transmitting antenna and one or more receiving monopoles located inside the loop. The variation in received signal power was computed for two system configurations. The first used a single arbitrarily located receiving antenna; the second used two receiving antennas.

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20. Abstract (Continued)

The results showed an increase in system response in the sector where the receiving antenna was nearest the leaky coax cable. It was also shown that the local phase constant which controls the period of the interference pattern varies as the position of the intruder changes. The same characteristics were present in the response of a two antenna system. However, the amplitude of the variation varied over a wider range because of the interference between the two received intruder signals.

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Illustrations

Dist.

Effect of Multiple Receiving Antennas on the Response of an R. F. Intrusion Sensor

1. INTRODUCTION

In a previous report,[1] the variation in received signal power as an intruder moved along the perimeter of the sensor cable of an R. F. Intrusion Sensor was computed. The analysis considered the system configuration to be a centrally located receiving antenna surrounded by a square or circular loop of leaky coaxial cable. This report extends these calculations to cases where the receiving element is not centered and where multiple receiving antennas are employed.

For the purpose of these calculations, the intruder is assumed to follow a path around the perimeter of a circular loop. His principal effect is to scatter some energy out of the field surrounding the leaky coax cable. This scattered field produces a voltage V_1 at the terminals of the receiving antenna of the form

$$V_I = A\, v_o\, P \left\{ e^{(-\alpha_1 + j\beta_1)z} + C_2\, e^{(-\alpha_2 + j\beta_2)\, z} \right\} \tag{1}$$

where A accounts for the scattering amplitude of the intruder and the gain of the receiving antenna, v_o and C_2 are constants which depend on cable properties, P

(Received for publication 13 February 1979)

1. Poirier, J. Leon, Kushner, Martin (1978) Analysis of the Response of an R. F. Intruder Protection System, RADC-TR-79-17.

is a propagation factor, α_1 and β_1 are the attenuation and phase factors associated with the coaxial mode, and α_2 and β_2 are the attenuation and phase factors for the surface wave mode. The phase factors are $\beta_1 = 2\pi f/v_1$ and $\beta_2 = 2\pi f/v_2$ where f is the operating frequency and v_1 and v_2 are the propagation velocities. In the absence of an intruder, a voltage V of the form

$$V = B\, e^{j\phi} \tag{2}$$

exists at the antenna terminals. The constants B and ϕ can be related to the cable characteristics and operating frequency.

The variation in received power is found from the sum of V and V_I and is proportional to

$$V_T V_T^* = VV^* + V_I V_I^* + 2 \text{ Re } VV_I^* \tag{3}$$

where * indicates complex conjugate, and Re means the real part of.

Equation 3 will be applied to a system configuration with a single off-center receiving element and then to one where two separate receiving antennas are used. It will be shown that in the former case, the response is generally greatest the shorter the distance from the intruder to the antenna. For the latter case, the interference between the signals at the two antennas breaks up the pattern of the response and produces wide variations in output signal.

2. SINGLE OFF-CENTER RECEIVING ANTENNA

The geometry of the system configuration is sketched in Figure 1. In this case, the propagation factor P appearing in Eq. (1) takes the form

$$P = \frac{e^{j\beta_3\left[r_o^2 + R_o^2 - 2r_o R_o \cos(\psi - \theta)\right]^{1/2}}}{\left[r_o^2 + R_o^2 - 2r_o R_o \cos(\psi - \theta)\right]^{1/2}} \tag{4}$$

where $\beta_3 = 2\pi f/c$, c is the speed of light, R_o the loop radius, $r_o = [a^2 + b^2]^{1/2}$, and the angles ψ and θ are defined in Figure 1. In addition, the distance z which determines the location of the intruder is equal to $z = R_o\theta$.

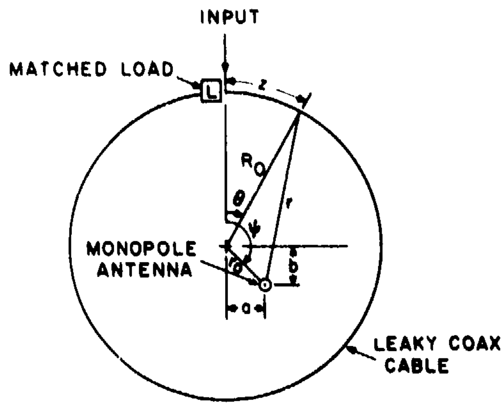

Figure 1. Sketch of Single Off-Center Antenna System Layout

From Eq. (1)

$$V_I V_I^* = A^2 \frac{|v_o|^2}{r^2} \{e^{-2\alpha_1 R_o \theta} + 2C_2 e^{(-\alpha_1 - \alpha_2) R_o \theta} \cos (\beta_1 - \beta_2) R_o \theta + C_2^2 e^{-2\alpha_2 R_o}\} \quad , \qquad (5)$$

and from Eq. (2), $VV^* = B^2$. The cross term is found to be

$$2\mathrm{Re}\, VV_I^* = \frac{2AB|v_o|}{r} \{e^{-\alpha_1 R_o \theta} \cos (\beta_1 R_o \theta + \beta_3 r + \delta - \phi) + C_2 e^{-\alpha_2 R_o \theta} \cos (\beta_2 R_o \theta + \beta_3 r + \delta - \phi)\} \qquad (6)$$

where δ is the phase angle associated with v_o^*.

Equations (4), (5) and (6) are used in Eq. (3) to find the relative change P_Q in received signal during a circumferential walk. This quantity is

$$P_Q = 10 \,\mathrm{Log} \left(\frac{V_T V_T^*}{VV^*} \right) \quad . \qquad (7)$$

Equation (7) was evaluated for a centrally located receiving antenna so that $r = R_o$ and $r_o = 0$. The results are shown in Figure 2 and can be used as a reference to gauge the effect of antenna position. For convenience it was assumed that

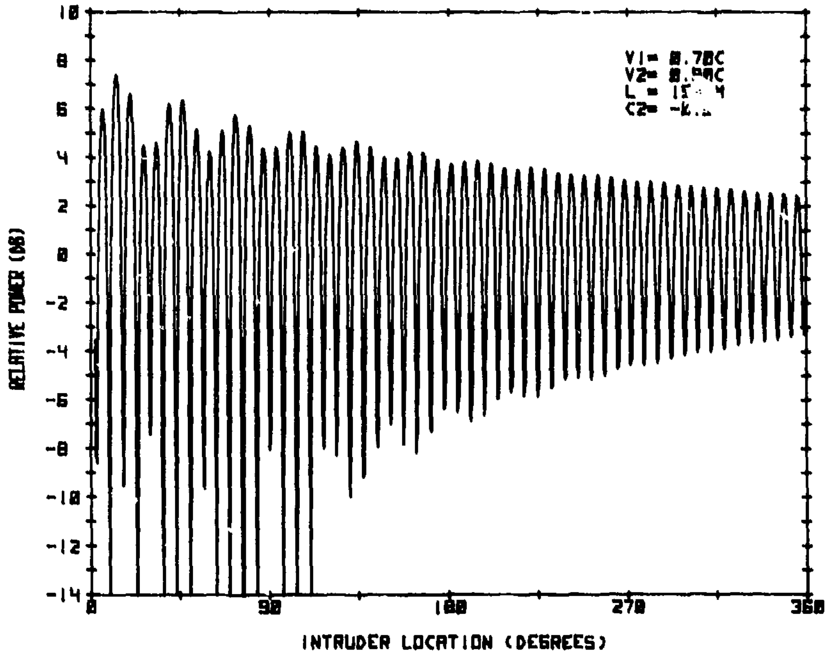

Figure 2. Variation in Received Power for Centrally Located Antenna. $\alpha_1 = 7.5 \times 10^{-3}$ neper/m, $\alpha_2 = 3.77 \times 10^{-2}$ neper/m, $B = |v_0| A R_0$, $a = b = \phi = \delta = 0$

$B = |v_0| A/R_0$, and $\phi = \delta = 0$. Inspection of the curve shows the typical decrease in overall response produced by the cable attenuation. The slower oscillations are a result of the interaction of the surface wave and coaxial wave which travel at different velocities along the cable. The decreasing degree of this interaction is a result of the greater surface wave attenuation. The visibility of the response as a function of intruder position depends on the particular conditions considered. However, the character of the response is always similar to that shown in the figure.

The variation computed when the antenna was moved to a new location $r_0 = 10$ m and $\psi = \pi$ is shown in Figure 3. There are two major differences in this curve worth discussing. The first and more obvious one is the marked increase in response at an azimuth of 180°. At this point, the intruder is as close to the antenna as he will get and V_I is greatest. This behavior has been observed in measurements in conjunction with a parked B52.[2] Thus by intentionally locating

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2. Poirier, J., Karas, N.V., Antonnucci, J.A., and Szczytko, M. (1977) VHF Intrusion Detection: A Technique for Parked Aircraft, RADC-TR-77-384.

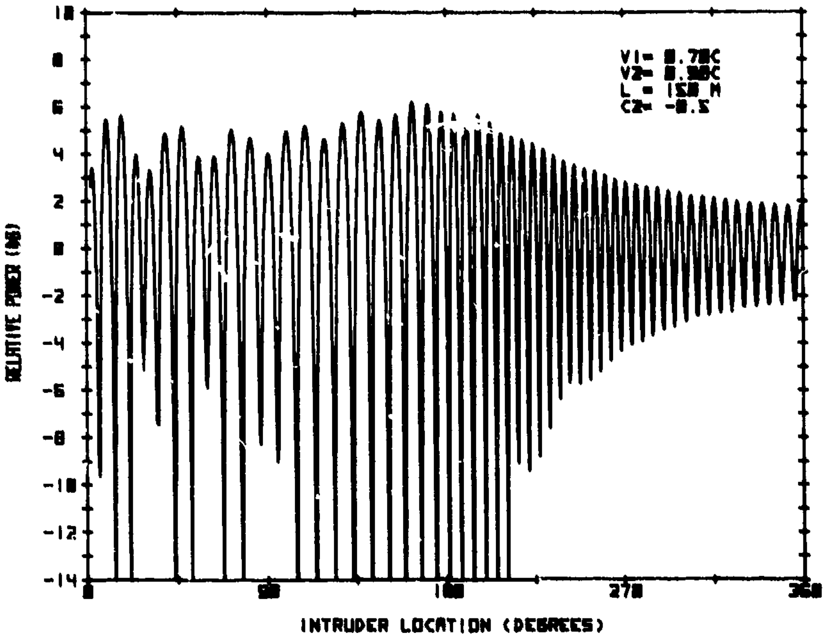

Figure 3. Variation in Received Power for Single Off-Center Antenna, $\alpha_1 = 7.5 \times 10^{-3}$ neper/m, $\alpha_2 = 3.77 \times 10^{-2}$ neper/m, $B = |v_o| A R_o$, $a = \phi = \delta = 0$, $b = 10$ m, $\psi = \pi$

the antenna off center, it is possible to adjust system sensitivity to compensate for abnormal propagation losses in a sector.

The second distinguishing feature of Figure 3 is that the local phase constant varies with the intruders position. If the surface wave contribution is small, the effective phase constant β is found from the cross term, Eq. (6) to be

$$\beta = \beta_1 - \beta_3 \frac{r_o \sin(\psi - \theta)}{[R_o^2 + r_o^2 - 2 r_o R_o \cos(\psi - \theta)]^{1/2}} \tag{8}$$

Inspection of this equation shows that $\beta = \beta_1$, the value for the centrally located antenna, when $\psi - \theta = 0$ and π.

The excursion of β from its β_1 value is plotted in Figure 4 as a function of $(\psi - \theta)$. Inspection of this curve shows that $\beta < \beta_1$ for $0 < \psi - \theta < \pi$ and $\beta > \beta_1$ for $\pi < \psi - \theta < 2\pi$.

The changing phase constant seen above is characteristic of a system configuration where the range from the intruder to the antenna changes with intruder location. The effect is particularly evident for a square loop where the straight

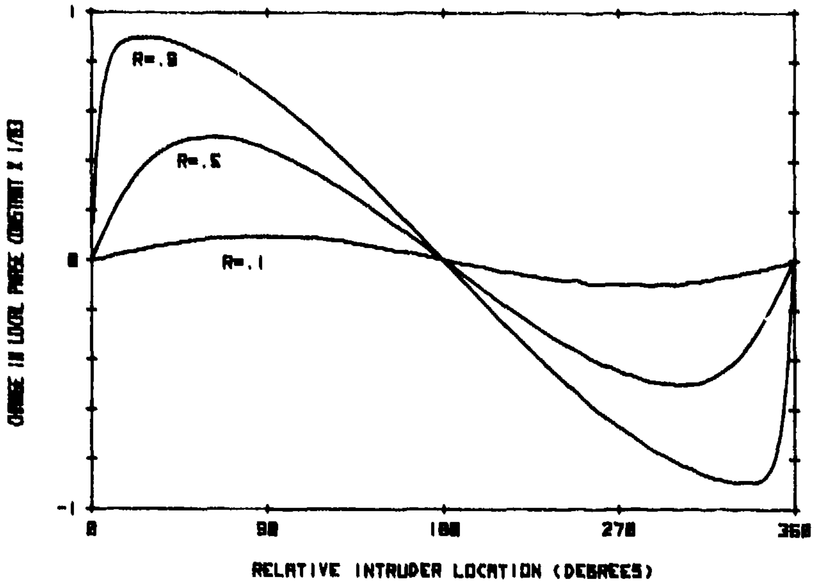

Figure 4. Excursion of Local Phase Constant With Intruder Location. $R = r_o/R_o$

sides maximize the excursion of β. This phenomenum has been observed in many experiments.[3]

The effect of moving the antenna off the $0 - \pi$ diameter is shown in Figure 5. The curves show the characteristics discussed in connection with Figure 3. The peak responses now occur at $3\pi/4$ and $5\pi/4$, the azimuths of the two antenna locations. The change in local phase constant is again evident in the curves.

For certain applications,[4] where the use of one antenna may not be practical, it has been suggested that two or more antennas be used. The response of a system with two antennas will be analyzed in the next section.

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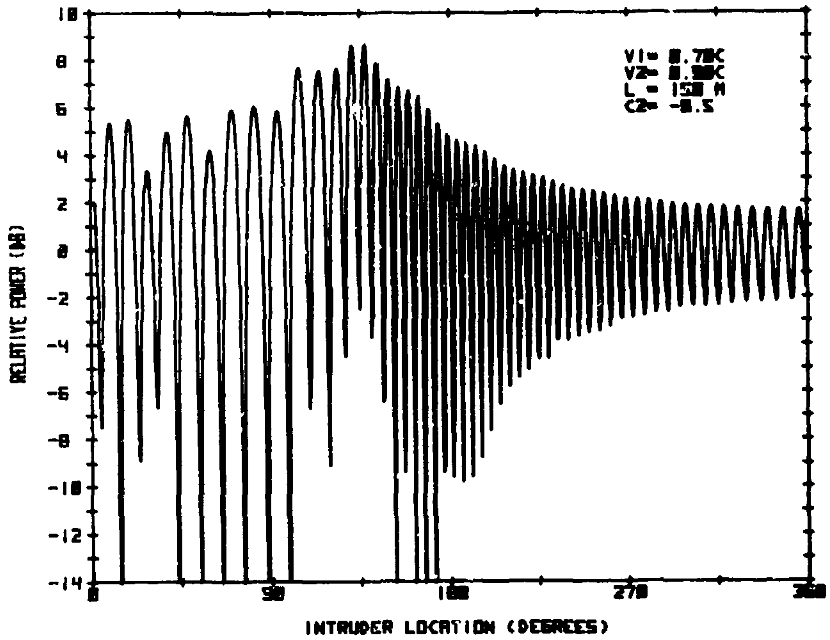
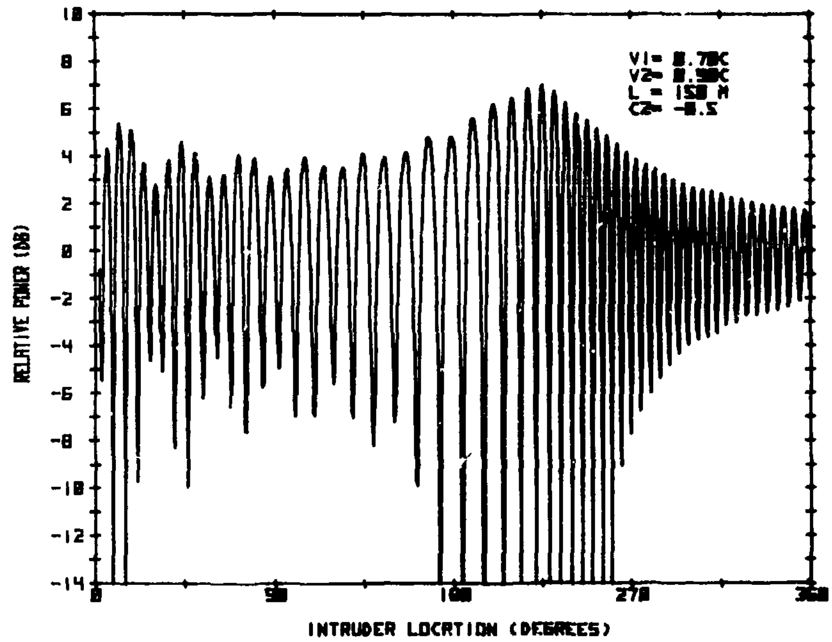
3. Karas, N.V., Poirier, J. Leon, Antonnucci, John A., and Szczytkc, M. (1978) A VHF Intrusion Detection Technique for Isolated Resources, RADC-TR-78-177.

4. Karas, N., Antonnucci, J., and Szczytko, M. (1978) A VHF Intruder Detection System: Tests on a C-5A Aircraft, RADC-TR-78-230.



a. $\psi = 3\pi/4$



b. $\psi = 5\pi/4$

Figure 5. Power Variation for Off-center Antenna. $\alpha_1 = 7.5 \times 10^{-3}$ neper/m, $\alpha_2 = 3.77 \times 10^{-2}$ neper/m; $B = |v_o| A R_o$, a = 10 m, b = 10 m, $\phi = \delta = 0$

3. DUAL RECEIVING ANTENNAS

Analysis of the system response with two antennas is only slightly more complicated. The sketch shown in Figure 6 shows the system geometry with two antennas symmetrically located about the center line. In this case, the total voltage is the sum of three terms $V_{I1,}$ V_{I2}, and V. The received power is thus proportional to

$$V_T V_T^* = VV^* + V_{I1}^* V_{I1} + V_{I2} V_{I2}^* + 2 \text{ Re } \{VV_{I1}^* + VV_{I2}^* + V_{I1} V_{I2}^*\} \quad . \tag{9}$$

The second and third terms can be written as before by applying the subscripts 1 and 2 in turn to A and r to distinguish V_{I1} from V_{I2}. The first two cross terms can be written from Eq. (6) as

$$2 \text{ Re } VV^*_{I1,2} = \frac{2 A_{1,2} B|v_o|}{r_{1,2}} \{e^{-\alpha_1 R_o \theta} \cos (\beta_1 R_o \theta + \beta_3 r_{1,2} + \delta + \zeta_{1,2} - \phi)$$

$$+ C_2 e^{-\alpha_2 R_o \theta} \cos (\beta_2 R_o \theta + \beta_3 r_{1,2} + \delta + \zeta_{1,2} - \phi)\} \tag{10}$$

where

$$r_{1,2} = [r_o^2 + R_o^2 - 2 r_o R_o \cos (\psi \mp \theta)]^{1/2} \quad . \tag{11}$$

The phase angles $\zeta_{1,2}$ are associated with the cables connecting the two antennas to the summing junction. The final term of Eq. (9) can be written as

$$2 \text{ Re } V_{I1} V_{I2}^* = \frac{2 A_1 A_2 |v_o|^2}{r_1 r_2} \cos [\beta_3 (r_- - r_2) + \zeta_1 - \zeta_2]$$

$$\{e^{-2\alpha_1 z} + 2 C_2 e^{(-\alpha_1 - \alpha_2) z} \cos (\beta_1 - \beta_2) + C_2^2 e^{-2\alpha_2 z}\} \quad . \tag{12}$$

The six terms in Eq. (9) are collected and divided by VV^* to obtain P_Q as before. The results, in dB, are plotted in Figure 7. The very complex structure seen is due to the interference among the terms in Eq. (9). The variation in local phase constant is apparent. Compared to the responses shown in Figure 5 for the two antennas used separately, the present response exhibits a much greater variation. The greater amplitude regions are contrasted by narrow sectors where the amplitude is small.

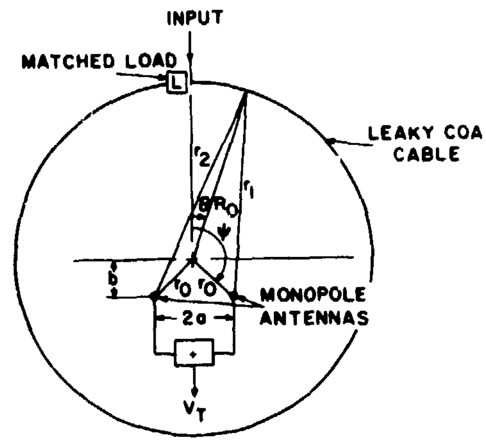


Figure 6. Sketch of Dual Antenna System Layout

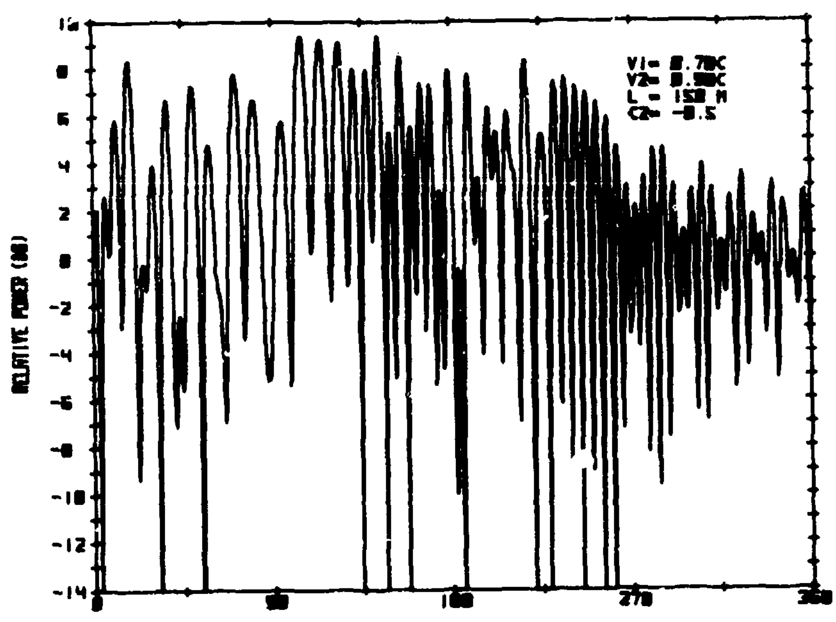


Figure 7. Received Signal Variation for Two-antenna System. $\alpha_1 = 7.5 \times 10^{-3}$ neper/m, $\alpha_2 = 3.77 \times 10^{-2}$ neper/m, $B = |v_0| A/R_0$, $a = b = 10$ m, $\psi = 3\pi/4$ and $5\pi/4$, $\phi = \delta = \zeta_1 = \zeta_2 = 0$

4. DISCUSSION

Three main points can be made about the results obtained for the off-center antenna and dual antenna systems. The first is that the intruder signal is maximum at his point-of-closest-approach. The behavior is not surprising and could be used to advantage in certain situations. For example, the judicious placement of the antenna could compensate for a low sensitivity sector.

The second feature, which is always observed whenever the range to the intruder changes with his position, is the variation in the local phase constant. This characteristic is very evident and its effect is to modify the doppler frequency of the intruder signal as he moves within the zone of detection. This would be an additional factor to consider in the design of the signal processor to be used with the system.

The third characteristic is the large and chaotic variation in signal power observed with the dual antenna system. The very complex structure came about as the result of the two intruder signals and the quiescent signal interferring. The difficulty here is that an ideal system should have a uniform response at all points of the sensor cable. However, the processing gain must be adjusted to achieve adequate detection in the low response regions. Thus the high response regions will be excessively sensitive and contribute to false or nuisance alarms. Dual receiving antennas should be used with care and only when a single antenna is not adequate.

References

1. Poirier, J. Leon, Kushner, Martin (1978) Analysis of the Response of an R. F. Intruder Protection System, RADC-TR-79-17.
2. Poirier, J., Karas, N.V., Antonnucci, J.A., and Szczytko, M. (1977) VHF Intrusion Detection: A Technique for Parked Aircraft, RADC-TR-77-384.
3. Karas, N.V., Poirier, J. Leon, Antonnucci, John A., and Szczytko, M. (1978) A VHF Intrusion Detection Technique for Isolated Resources, RADC-TR-78-177.
4. Karas, N., Antonnucci, J., and Szczytko, M. (1978) A VHF Intruder Detection System: Tests on a C-5A Aircraft, RADC-TR-78-230.