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Spatial Combining of Multiple Microwave Noise Radiators

By Jiri Polivka
Spacek Labs Inc.

This article reports on experiments to increase the noise temperature of a test system by combining individual radiators in a two-dimensional matrix

Noise generators are used to measure noise figure in receivers, to test system health in built-in test (BIT) circuits, in jamming, and in testing digital data transmission systems bit error rate (BER).

Combining a noise generator with an antenna creates a noise radiator [1]. Such a noise radiator generates a random (non-coherent) noise field in which near-field interference is not observed. A noise field can be utilized in various experiments: field distribution in waveguides, antennas and other structures, testing the properties of moving objects, etc.

This paper discusses experiments to increase the noise temperature or power density by the spatial combination of noise sources. The experiments were done to evaluate this method as an alternative to using microwave amplifiers. The results confirm the independence of individual noise sources and the possibility of increasing the noise temperature as well, as possible focusing by adapting the form of the noise source matrix.

The Noise Radiator

The simplest noise radiator was described in [1]. It is a half-wave dipole with a noise diode in it, plus a DC bias inserting circuit as shown in Figure 1. In [2] more noise radiators were described and compared. Their important parameters are:

Excess Noise Ratio, the noise output referred to a matched load under the ambient temperature, ~290K. Usually, ENR ~30 dB when avalanche noise diodes are used.

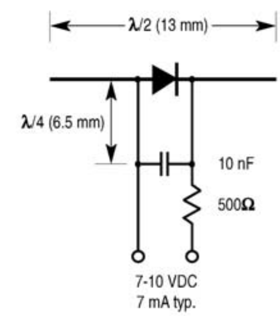

Figure 1 · Photograph and diagram and of a noise radiator with DC bias circuit (diode is the e-b junction of a SMD transistor).

For a matched resistor, the noise power P_n is traditionally defined as

$$P_n = kTB \tag{1}$$

Where P_n is measured in watts, k is Boltzmann's constant, 1.38 × 10^{-23} joules/Kelvin, T is the (ambient) temperature in Kelvins and B is the bandwidth in Hertz.

A more practical formula is for P_n measured in dBm is:

$$P_n(\text{dBm}) = -174(\text{dBm/Hz}) + 10\log B(\text{Hz}) \tag{2}$$

Finally, the ENR in dB is simply added to the above equation to estimate the real power level that a well-matched noise source delivers into a matched load

The noise bandwidth is usually determined by the power meter (receiver). For example, we can take B ~500 MHz, and ENR ~30 dB as before. 10 log(500E8) is +87 dB, so $P_n = -174 + 87 + 30 = -57$ dBm.

Polarization Ratio (PR), the ratio of noise power density for copolar and orthopolar orientation of the receiving antenna with respect to noise radiator.

DC bias is required to generate noise by diode avalanche breakdown. Usually, noise diodes break down with 6-10V reverse voltage, and the current is adjusted to obtain the required noise spectrum. Usually 5-10 mA is best. Two such noise radiators were used slightly separated, to simulate Young's experiment that established the wave concept in optics [3]. The noise temperature detected by a remote (20-40 cm) radiometer with antenna increased by factor of two when both noise radiators were biased. Varying the distance between the two noise radiators resulted in a smooth decrease from the maximum indicated noise temperature, but no interference effects were observed..

Noise Radiator Matrix

In antenna technology, antennas can be arranged in arrays to improve directional concentration of the transmitted energy. Radiation parameters of antenna arrays are mathematically determinable, with sizes and distances are referenced to the radiated wavelength [4]. This is valid for coherent signal combination, where mutual coupling and relative phase is important in all array element radiators.

With noise radiators, it was determined by experiments [2] that they radiate a random noise field, with the power density determined by ENR, and the radiation pattern roughly corresponding to that of the dipole, with a maximum radiation corresponding to the wavelength of the radiator dipole. The spectral function of a noise radiator was investigated [1] by direct tests at different frequencies, and by measuring the coherence radius.

The question addressed by these experiments was: While the noise power density should grow with the number of noise radiators in a matrix, how the radiation diagram and polarization ratio will be affected?

Radiometric Approach

Figure 2 illustrates the radiometry principle, As long as the viewing angle of a target is smaller than the receiving antenna beam width, the radiometer connected to that antenna will read antenna noise temperature equal to the target temperature, diminished by the ratio of these solid angles:

$$T_a = T_s\,(\Theta_s/\Theta_a) \;\sim\; T_s\,(\theta_s/\theta_a)^2 \tag{3}$$

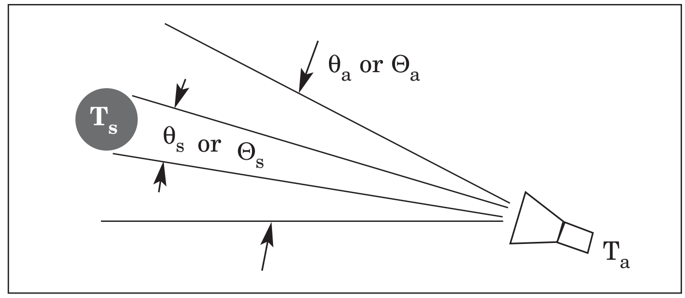

Figure 2 · Radiometry principle.

Where T_a and T_s are in Kelvins, Θ_s and Θ_a in steradians, θ_s and θ_a in degrees. The square approximation holds for axially symmetric geometry.

In the described experiment the noise radiator or matrix was positioned at ~40 cm distance from the radiometer antenna, the single noise radiator used a half-wave dipole ~13 mm long while the nine-dipole matrix was ~48 mm long.

Determining the viewing angle of the dipole is not easy as the ratios in Eq. (3) refer to antenna apertures. The aperture of a half-wave dipole is often defined as an ellipse, with the longer axis ~one wavelength, the shorter, ~one half-wavelength. In the matrix, these ellipses overlap, so the viewing solid angles are somewhat larger than the radiator mechanical size (see Figure 3). The solid angle of the single dipole over 40 cm distance will be:

$$\theta_{sV} \times \theta_{sH} \sim 3.5 \times 1.8 = 6.26 \text{ sterad}$$

For the matrix (Figure 4), we obtain:

$$\theta_{sV} \times \theta_{sH} \sim 10.3 \times 6.77 = 69.7 \text{ sterad}$$

The ratio of those solid angles indicates the possible ratio of the detectable noise temperatures:

$$T_m/T_d = 69.7/6.26 = 11.1 \text{ times}$$

where T_m is the noise temperature received from the matrix, and T_d is that detected from the single dipole. Obviously, one would expect that the noise temperature should increase nine-fold—the sum of the nine noise

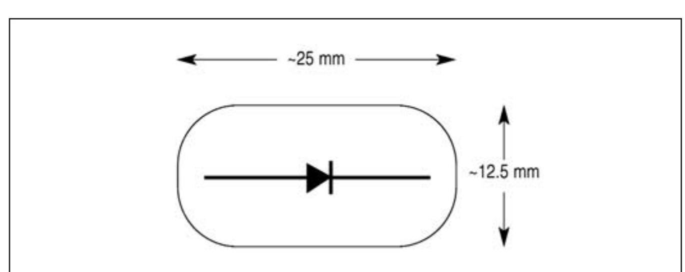

Figure 3 · Approximate aperture of the dipole noise radiator.

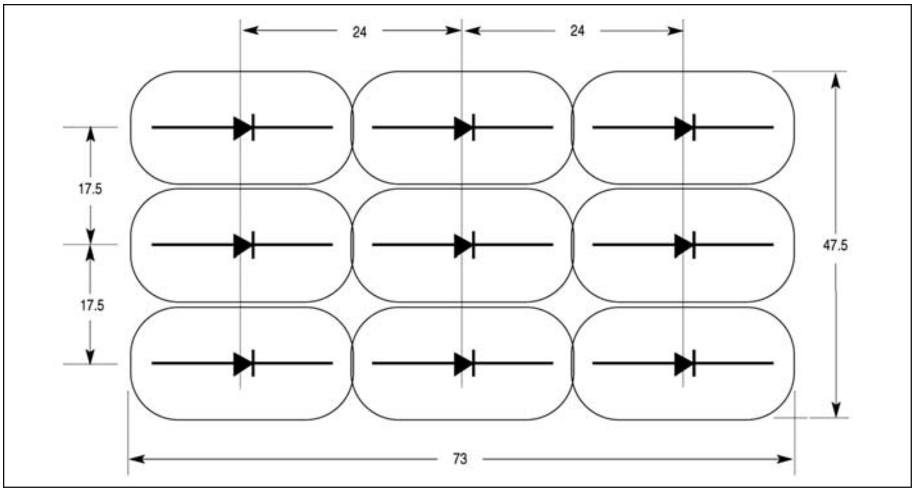

Figure 4 · Equivalent aperture of the 3 × 3 element noise dipole matrix.

radiators that comprise the matrix.

The results of the experiment, however, gave T_m/T_d as approximately five times instead of nine times greater.

Still, the result is a significant increase, and can be accepted as confirming the possibility of augmenting the noise temperature by the spatial combination of noise radiators. So far, the efficiency of the matrix can only be estimated.

Note that the LNB input horn antenna used in the radiometer has a beam width of ~86 degrees, therefore, the detected noise temperature will be not affected by it, per Eq. (3).

The Experiments

The experiment measured the radiation of one noise radiator, three noise radiators in line, and the matrix of nine noise radiators, in a 3 × 3 two-dimensional arrangement (see Figures 5 and 6).

The receiver was a 11 GHz radiometer, with a 0.4 dB LNB. The distance between receiver antenna and the tested radiators was 40 cm.

Figure 7 presents the results of tests, with the measured radiation patterns compared on a single plot. The red trace is the result for one noise radiator (as described in [3]). Its radiation pattern was like that of a dipole, and its copolar/orthopolar ratio (PR) was >20 dB.

Next, three inline radiators were tested with their diodes were connected in series. The directivity of the array was similar to that of the single dipole was observed, as shown in the Green trace, however, the PR was poorer due to inexact mechanical alignment.

In the nine-element matrix, the noise radiators were mounted in a block of polyethylene foam, and the three triplets were biased in parallel. ~50 V, ~21 mA was necessary for the complete matrix. The blue trace in Figure 6 shows the results—again a slight directivity above the single noise radiator was observed, but only ~7 dB PR, obviously due to the mechanical deviations. The excess

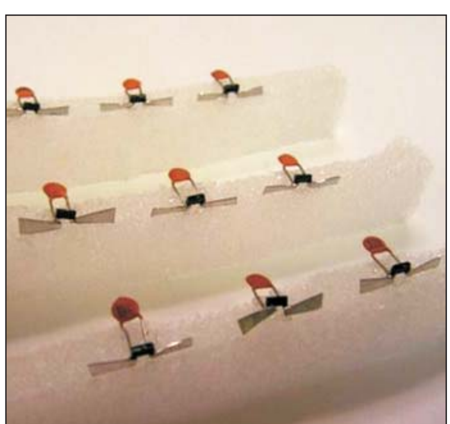

Figure 5 · Photo of the assembled 9 × 9 noise dipole matrix.

noise temperature on-axis, however, increased only ~5 times only. With a conductive reflector added about one wavelength behind the matrix, the on-axis noise temperature increase, was observed to be ~8 times.

Following the method presented first in [1], the coherence radius (CR) of both noise radiators was determined; both CRs were 9.5-10 cm, from any point on axis to the noise temperature dropping to one-half.

The spectrum bandwidth can be calculated by [1]:

$$BW = 0.605\, c/CR \tag{4}$$

where BW is the spectrum bandwidth in Hz, c is the speed of light, 3E8 m/s, and CR is the coherence radius measured on-axis from one noise temperature value to its half value, by increasing the distance from the radiator to radiometer antenna. From this equation, the noise spectrum bandwidth is ~1.8 GHz with a center at ~11 GHz.

Conclusions

The experiment with a 3x3 array of noise radiators confirmed that:

- Combining several noise radiators in a 2-D matrix combines the resulting on-axis noise temperature by less than the sum of individual radiator contributions, although the combining efficiency is only estimated.
- The directional radiation pattern is mostly unaffected by using the matrix as compared to a single noise radiator, as expected from no-coherent sources.
- The copolar/orthopolar (PR) ratio has deteriorated, due to imperfect planarity of the dipoles, due to the presence of bias lines, etc.
- No interference effects were observed; the rotation and movement of the matrix under bias always produced a smooth response. It is confirmed that all array noise radiators remain non-coherent and independent, and no coupling among the individual radiators occurs.

As an alternative to using wide-band high-gain amplifiers, the spatial array combination of noise radiators offers to multiply the on-axis noise power density or noise temperature.

By curving the face of the matrix, or by using reflectors, it is expected that the radiation pattern can be shaped and possibly focused.

All described experiments were done on a laboratory bench. No anechoic arrangement was necessary as no interference field was created.

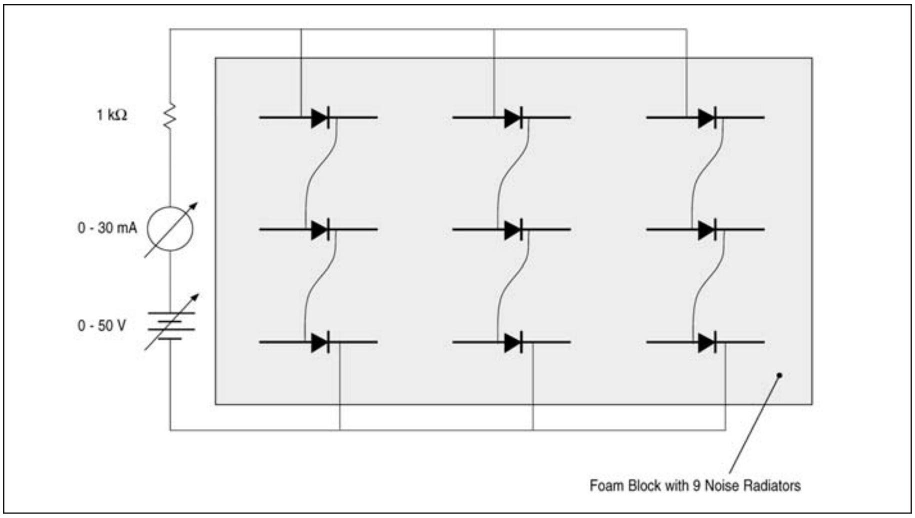

Figure 6 · Layout and biasing arrangement for the 9 × 9 matrix.

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Author Information

Dr. Jiri Polivka is Chief Scientist at Spacek Labs Inc., 212 East Gutierrez St., Santa Barbara, CA 93101. He can be reached by telephone at 805-564-4404 or by e-mail at polivka@spaceklabs.com.

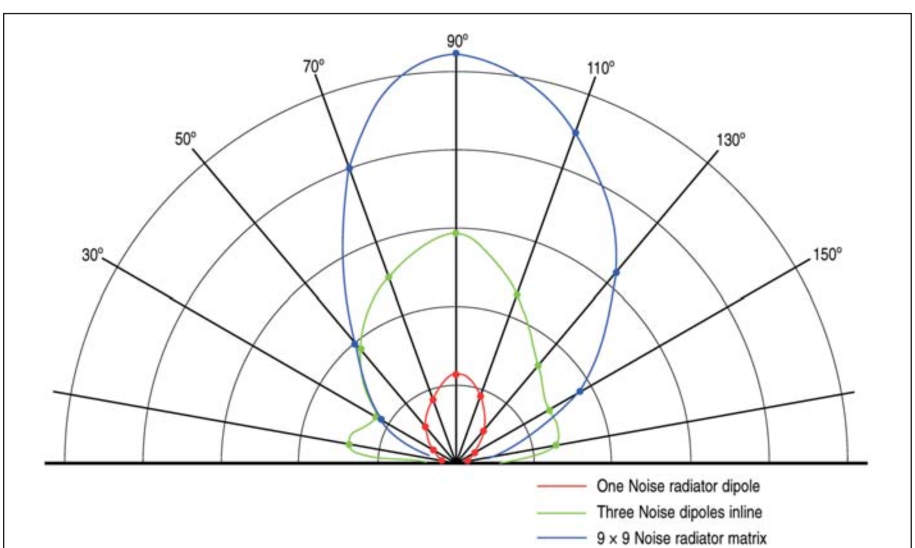

Figure 7 · Measured radiation patterns for the three configurations: single noise dipole (red), three dipoles inline (green), and the 9 × 9 matrix (blue).