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A STABILIZED BROADBAND CORRELATOR FOR MEDICAL MICROWAVE THERMOGRAPHY

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ABSTRACT

A stabilized broadband summing microwave correlator is presented that has particular application to medical microwave thermography. A dual IF is employed to minimize long-term drifts resulting from antenna-source mismatch, RF amplifier gain drifts, and changes in uncorrelated background radiation. The correlation of the source is generated by means of a digital line stretcher, rather than antenna-source movement. Preliminary measurements using a low-temperature thermal source in air are presented.

INTRODUCTION

In previously published work, both in radio astronomy [1,2,3] and in medical microwave thermography [4], relative movement of the source and the antennas has been employed to measure either the temporal coherence function or the spatial frequency components of the source distribution. Such movement is not convenient in medical microwave thermography since it is desirable that the antennas should be in direct contact with the tissue to maximize the coupling of the desired signal and minimize scattered radiation from the air-tissue interface as the tissue is illuminated by its surroundings. To eliminate movement, the correlation function of the source distribution is measured by means of a digital line stretcher in one arm of the correlator [5].

Coherence theory [6] and its application to radiometry [7,8] has been discussed extensively and the advantages of broadband microwave radiometry will be described in a separate publication [9]. This paper is restricted to a discussion of the measurement apparatus.

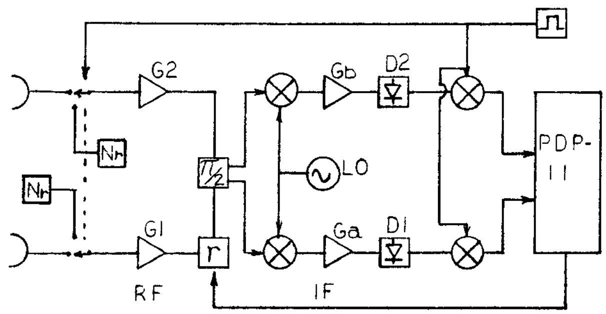
THEORY OF OPERATION

Figure 1 is a schematic of the dual IF correlator under discussion. IF correlation was employed rather than envelope correlation [10] because of the greater sensitivity [11] of the former. From Figure 2, the voltage components at the input of each chopper stabilized amplifier can be expressed as the sum of correlated terms, S, and uncorrelated terms, N:

(1) $V = [S_s+S_i+N_b+N_m]d - [N_r]\,(1-d)$
$= S + N$

where S_s=correlated source radiation
S_i=correlated illuminating radiation
N_m=uncorrelated mismatch radiation
N_b=uncorrelated reflected radiation
N_r=uncorrelated reference radiation
d =duty ratio of square wave modulation

FIGURE 1:
SCHEMATIC OF A DUAL IF CORRELATOR



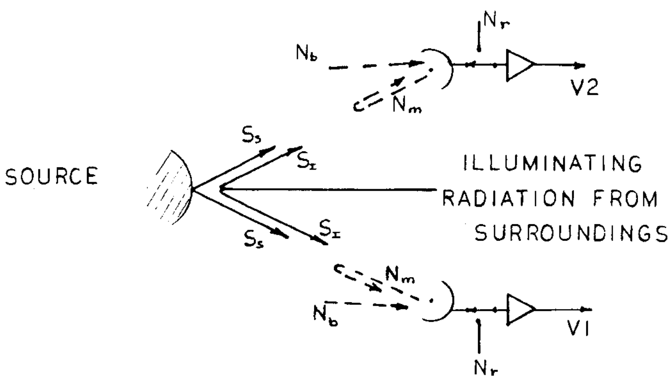


FIGURE 2: VOLTAGE COMPONENTS AT INPUT OF CORRELATOR

Amplitude modulation of the RF signal was employed rather than phase modulation [3]. Si represents thermal radiation from the surroundings of the experiment (chamber, antennas, etc.) that illuminates the source and is reflected back to both antennas; this also includes mutual illumination of the antennas. Since this radiation is correlated, it is indistinguishable from the thermal radiation of the source. The IF voltages at the input to the detectors D1 and D2 are:

$$(2) \quad Va = GaG1(S1+N1)V1(wt+wr+\pi/2)+GaG2(S2+N2)V2(wt)$$

$$(3) \quad Vb = GbG1(S1+N1)V1(wt+wr)+GbG2(S2+N2)V2(wt+\pi/2)$$

The Gs refer to the gains of the various stages (cf Figure 1).

The transfer function of a square law detector and a low pass filter is:

$$(4) \quad V = \langle v(t)v^*(t+r)\rangle = \lim_{T\to\infty} 1/T \int v(t)v^*(t+r)dt = C(r)$$

This is the definition of the correlation of two voltages as a function of the relative delay r. The detector output voltages are:

$$(5) \quad Va' = Ga^2\{G1^2(S1+N1)^2 + G2^2(S2+N2)^2 + 2G1G2S1S2C(r)\}$$

$$(6) \quad Vb' = Gb^2\{G1^2(S1+N1)^2 + G^2(S2+N2)^2 - 2G1G2S1S2C(r)\}$$

Although the terms (S+N) can be set to zero by appropriately adjusting Nr, any minor change in the components of (1) will add substantial errors to the desired signal Ss. These components (typically 300 to 900°K) are 2 to 3 orders of magnitude greater than the desired resolution of Ss, which is much less than 1°K. This error can be reduced by taking the difference of (5) and (6). For equal IF and RF gains:

$$(7) \quad Vo = 4(dG1Ga)^2(Ss^2 + Si^2)C(r) = Va' - Vb'$$

This improvement in long-term stability is obtained without resorting to noise introduction [12] or gain feedback control [13]. The detailed shape of the correlation function C(r) can be calculated from (4). For 0.5 duty modulation, unity gain, Si=0, frequency response from f1 to f2 and a single point source, we have:

$$(8) \quad C(r) = \cos\{\pi(f1+f2)r\} \ \mathrm{sinc}\ (\pi(f1-f2)r)$$

This normalized correlation is plotted in Figure 3 as a function of bandwidth for a center frequency of 2.0 GHz. The reduction in observed coherence time as bandwidth is increased is apparent.

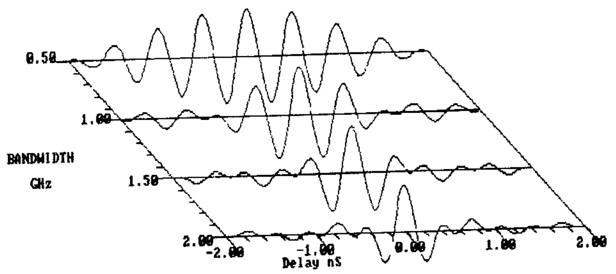


FIGURE 3: CORRELATION VS BANDWIDTH FOR A POINT SOURCE. CENTER FREQUENCY = 2.0 GHZ

MEASUREMENTS

An experiment was designed with the specifications listed in Table I to verify the improved performance of the correlator. Calibration was performed by connecting a 1.15°K coaxial source to both RF amplifiers to simulate a correlated source. The digitally filtered output of both detectors and their difference, Vo, is plotted in Figure 4. As can be seen, the 1°K drift in both Va' and Vb' was eliminated.

A thermal source, .25 by 2.0 inches (.64 by 5.1 cm), fabricated from carbon impregnated cloth [14] was mounted 2.5 inches (6.35 cm) from the antennas, parallel to the E-polarization of the TE_{10} mode of the waveguide. A source approximately one-half of a wavelength long was used to ensure reasonable radiation characteristics. Figure 5 is the digitally filtered data of the change in the correlation as the source was heated first to 3°C and then to 9°C by applying a DC current; recording the change in correlation eliminated the mutual illumination of the antennas. The minimum detectable source temperature change in these preliminary measurements was approximately .7°K for a source area of 0.5 square inches. The minimum detectable system temperature change was 0.04°K, which includes gain errors of the line stretcher during the 30 minutes of the experiment. The minimum observable source temperature is reasonable when compared to the minimum system temperature since the source was less than a tenth of the common viewing area of the antennas.

TABLE I

INPUT NOISE FIGURE:	3.5	dB
MINIMUM RESOLUTION (Measured):	.04	°K
FREQUENCY RF:	2.6-3.4	GHz
IF:	10-400	MHz
DELAY TOTAL:	2.17	nS
NUMBER OF BITS:	7	
INCREMENTS:	.017	nS
MODULATING FREQUENCY:	5.0	KHz
DUTY RATIO:	0.5	
INTEGRATION TIME:	3.0	sec
ANTENNA APERTURE:	1.34 x 2.84	in
	(3.40 x 7.21)	cm
SPACING (On Center):	3.0	in
	(7.62)	cm

CONCLUSION

We have described an improved microwave correlator that will permit measurement of the correlation of a thermal source near room temperature without movement of the antennas relative to the source. With the dual IF, a system sensitivity of 0.04°K was achieved as a total of 256 time-delay (line stretcher) elements were introduced during the 30 minutes of the experiment. Preliminary data for a small cross-section thermal source was presented which illustrates that a temperature resolu- of at least 0.7°K is achievable at room temperatures using a correlation radiometer.

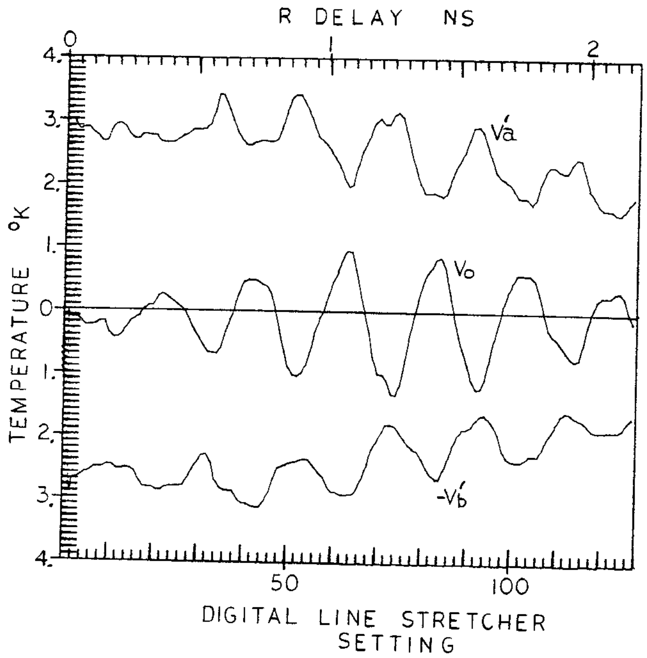


FIGURE 4: CORRELATION OF A 1.15°K NOISE SOURCE SHOWING INDIVIDUAL DETECTOR VOLTAGES AND DIFFERENCE VOLTAGE WITH REDUCED DRIFT

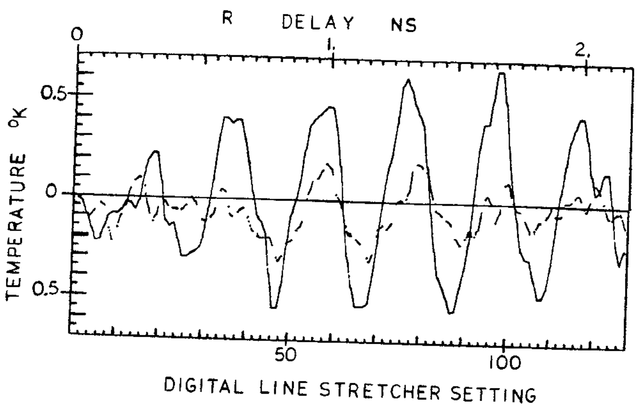


FIGURE 5: CORRELATION OF A THERMAL SOURCE AT 3° AND 9°C ABOVE ROOM TEMPERATURE

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