A Microstrip Parallel Delay-Line Circuit for an Autocorrelation Radiometer

William A. Teso, *Senior Member, IEEE,* Peter W. Gaiser, *Student Member, IEEE,* Calvin T. Swift, *Fellow, IEEE,* and Robert E. McIntosh, *Fellow, IEEE*

Abstract—**A microstrip circuit used to measure the autocorrelation function is presented. The circuit will be part of an autocorrelation radiometer (CORRAD) that directly measures the autocorrelation of downwelling atmospheric thermal emission. A discussion of the CORRAD hardware is included. The microstrip network receives two C-band signals as inputs. The circuit generates eight parallel time-delays and combines the two signals which are then multiplied and averaged to yield the autocorrelation function. The introduction of this circuit to CORRAD will reduce the data acquisition time by a factor of sixteen, while degrading the frequency resolution by a factor of two.**

I. Introduction

THE autocorrelation function has been defined and used in recent years for the processing of complex, wide-sense stationary processes. This function is particularly useful to reduce data that is corrupted with noise. However, the physical measurement of the autocorrelation function can be difficult due to problems with the implementation of the time delays. Methods used in the past to achieve the variable time delay include "trombone waveguides," switching through a series of variable-length transmission lines, or specialized processing of data from two radiometers viewing the same scene. This paper describes a microstrip circuit that provides parallel time-delays and combines two signals that are then averaged to yield an autocorrelation function. The idea of the circuit was suggested in the early stages of the development of an autocorrelation radiometer called CORRAD [1]. However, the available technology and the cost at that time made the project infeasible. Therefore, CORRAD was built in 1986 using variable-length transmission lines to incorporate the time-delays.

II. Motivation

Autocorrelation radiometry seeks to measure the brightness temperature spectrum of a scene indirectly by measuring the autocorrelation of the emission of the scene. Recall that the autocorrelation function of a wide-sense stationary random process is defined as follows [2]:

$$R_x(\tau) = < x^*(t) \cdot x(t+\tau) >,$$

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W. A. Teso is with the Department of Electrical Engineering, University of Hartford, 200 Bloomfield, Ave., West Hartford, CT 06117.
C. T. Swift, R. E. McIntosh, and P. W. Gaiser are with the Department of Electrical and Computer Engineering, University of Massachusetts at Amherst, Knowles Engineering Building, Amherst, MA 01003.
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where $< \cdot >$ denotes ensemble average, and $*$ denotes the complex conjugate.

The Weiner–Khinchin theorem relates the autocorrelation function to the power spectrum as follows,

$$<x^*(t) \cdot x(t+\tau)> \equiv R(\tau) = \int_{-\infty}^{\infty} S_X(f) \cdot e^{j2\pi f\tau} df,$$

where $S_x(f)$ = the power spectral density of the process. Thus, Fourier transforming the autocorrelation function produces the power spectrum, which is proportional to the brightness temperature spectrum.

CORRAD is a K-band radiometer that profiles tropospheric water vapor by measuring the autocorrelation of the received thermal radiation of the atmosphere across a 3.0-GHz bandwidth centered near the 22.235-GHz water-vapor resonance. Radiation enters CORRAD through a single antenna, is divided into two channels, and downconverted to 4.5–7.5 GHz. One of the channels goes directly to a power combiner, while the other goes through a variable time delay. The two channels are multiplied together and averaged, yielding an autocorrelation function which is Fourier transformed in software to produce a brightness temperature spectrum from 20.5–23.5 GHz with 100-MHz resolution. The water-vapor profiling performance of CORRAD, in its present configuration, has been reported elsewhere [3]. CORRAD generates time delays with sixteen nondispersive coaxial transmission lines and four single-pole eight-throw switches yielding sixty-four delay lines with 0.1-nanosecond steps. To switch through all sixty-four of these lines requires nearly six minutes; this time results from the integration time, switch settling time, and system monitoring. The parallel delay line circuit described here will reduce the data acquisition time by a factor of approximately sixteen, enabling CORRAD to be used as a scanning water-vapor profiler.

III. Design and Fabrication

Fig. 1 depicts the schematic form of the circuit. Two parallel microstrip transmission lines lie near the upper and lower edges of a substrate board. One line is excited at port one, while the other is excited at port three. A series of Wilkinson power combiners [4] lie between the two parallel transmission lines. The combiners are fed from directional couplers on the two lines. The difference between the path length from port one to a given power combiner and the path length from port three to the same combiner determines the time delay.

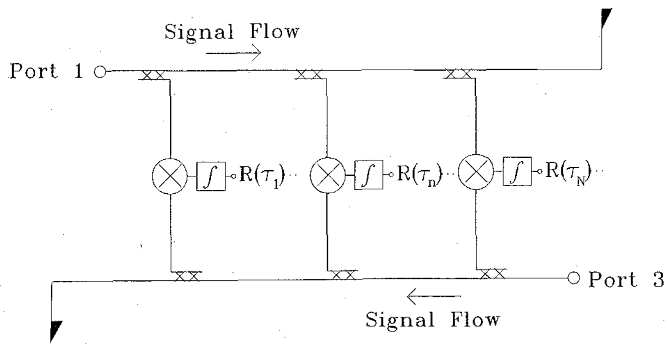

Fig. 1. Schematic of the parallel delay line circuit.

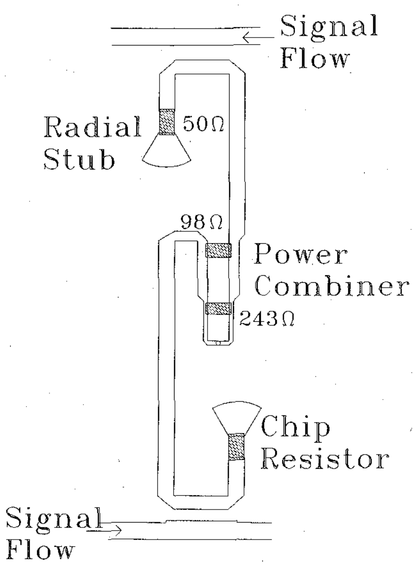

Fig. 2. Detail of a single tap-cell.

First, we fabricated a single tap-cell consisting of two directional couplers and a modified Wilkinson power combiner. We chose RT/duroid 6010.5 ceramic ($\epsilon_r = 10.5$) as the substrate. Fig. 2 shows one tap-cell between the parallel microstrip lines. The power combiner is fed by directional couplers on the two transmission lines. The directional coupler termination consists of a 50 Ω chip-resistor and a radial stub [5], [6]. The radial stub was not resonant at the correct frequency when fabricated according to the design equations of [5] and [6]. Trimming the stub at the outside radius by about two millimeters effected the optimal match in the 4.5–7.5-GHz range. The power combiner is a conventional microstrip design using quarter-wave chamfered lines at 6.0 GHz with chip resistors of 243 Ω and 98 Ω.

After optimizing the performance of a single tap-cell, a series of eight side-by-side tap-cells was developed. The sampling theorem restricted the choice of spacings between adjacent cells. CORRAD measures both the in-phase and quadrature components of the signal; hence, the bandwidth used to compute the Nyquist rate is the actual signal bandwidth as opposed to the highest frequency component of the band-pass signal [7]. This technique, known as quadrature sampling, is possible when both the real and imaginary components

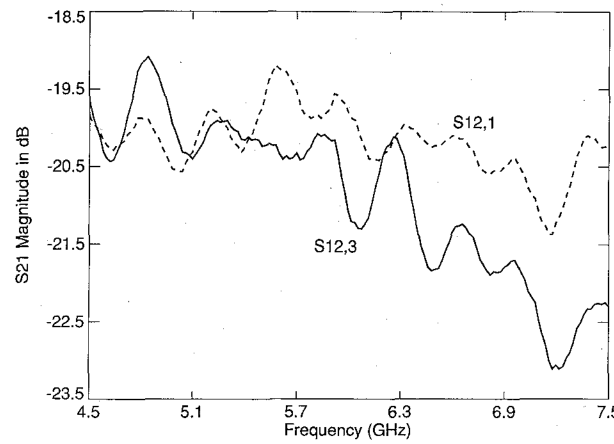

Fig. 3. Comparison of $S21$-frequency response of eight port when fed from ports one and three.

of the complex pre-envelope of a signal are sampled at half the Nyquist rate of the original signal. This results in two effectively independent channels that can be combined coherently to negate aliasing [8].

Since the circuit has a 3.0-GHz bandwidth, the sampling period is given by

$$T_s = (\frac{1}{2}B) = 0.167 \text{ nanoseconds.}$$

In order for the sampled time delay, $\Delta\tau$, to be less than T_s, the one-way time delay (the time required for a signal to travel from cell n to cell $n+1$) must be less than $T_s/2$. This time delay requirement forced the cells to be very close physically, causing significant mutual coupling between adjacent cells.

If the tap-cells are spaced greater than $T_s/2$ apart, serial lines can be added to satisfy the sampling requirements. Consider a circuit with cells spaced $\Delta\tau = T_s$ apart. A set of measurements would yield the following samples of the $R(\tau)$:

$$\{R(t), R(t+2\Delta\tau), \cdots, R(t+14\Delta\tau)\}.$$

Adding a serial line of length Dt to port, one yields the following set:

$$\{R(t+\Delta\tau), R(t+3\Delta\tau), \cdots, R(t+15\Delta\tau)\}.$$

The union of these two sets is an autocorrelation function sampled every $\Delta\tau$ seconds.

Several circuits were built to determine the best compromise with regard to bandwidth, coupling factor, and signal power level. Testing revealed that reflections along the line caused a prominent resonance in S_{11} and S_{33} in the middle of the passband. Simulation of the circuit using SUPERCOMPACT demonstrated that the location of the resonance in the passband depended on the tap-cell spacing. An optimal spacing of 1.25 cm (making $\Delta\tau = 0.125$ nanoseconds) moved the resonance outside the passband. Fig. 3 shows the passband response of the last tap-cell, port 12, when excited at port one and when excited at port three. When this circuit is integrated in CORRAD, system calibration will correct for variations in the passband response.

The next phase of the project is the integration of the circuit into CORRAD. When completed, CORRAD will have a combination of four serial and eight parallel delay lines, enabling CORRAD to make a complete autocorrelation measurement in approximately twenty seconds. By having thirty-two delays instead of sixty-four, the maximum time delay will be one-half its current value; consequently, the frequency resolution will decrease to 200 MHz. This is acceptable since CORRAD will still offer much better resolution than conventional atmospheric profiling radiometers.

IV. Conclusion

This letter has described a microstrip circuit that provides eight parallel time-delays necessary for autocorrelation measurements. The integration of this circuit into the CORRAD system will enable CORRAD to measure autocorrelation functions sixteen times faster than before, while degrading the frequency resolution by a factor of only two.

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