THREE-LEVEL 1 GS/s DIGITAL CORRELATOR FOR WIDEBAND POLARIMETRIC RADIOMETRY

J. R. Piepmeier and A. J. Gasiewski

School of Electrical and Computer Engineering
Georgia Institute of Technology, MS 0250, Atlanta, GA 30332-0250

ABSTRACT

A 500-MHz bandwidth, three-level (1.6 bit) digital correlator operating at 1 GS/s was designed and fabricated. The digital circuit is comprised of discrete high-speed silicon emitter-coupled logic components. The use of digital microwave design techniques was necessary to accomplish proper clock distribution, impedance matching, and asynchronous signal propagation. The correlator is to be part of a fully polarimetric radiometer for airborne application. Experimental results from a 400 MS/s prototype polarimetric radiometer are presented.

INTRODUCTION

Wideband high-speed digital correlators have applications in radiometric polarimetry, synthetic-aperture interferometric radiometry, and autocorrelation spectroscopy. Previously, such correlators were fabricated using either VLSI or standard ECL and operated at sampling rates $\lesssim$ 256 MS/s [1], [2]. The correlator described herein uses discrete high-speed ECL components to achieve a significantly faster sampling rate and wider bandwidth. Digital microwave design techniques were applied in the developement to attain proper operation of the correlator at up to 1 GS/s clock rates.

DIGITAL CORRELATOR

The digital correlator is comprised of three basic components: high-speed analog-to-digital converters (ADC), three-level multipliers, and ripple accumulators. The input signals are assumed to be jointly Gaussian with zero mean and unit variance. The signals are sampled and quantitized into three levels at 10^9 samples-per-second. The effective 1.6-bit ($\log_2 3 = 1.6$) ADCs are comprised of latched dual comparators clocked at $\sim$ 1 GS/s. The digitized data takes on values of +1, 0, or -1 depending on the level of the input signal with respect to positive and negative DC threshold levels. The samples are multiplied using a total of six AND/NAND gates and results are accumulated in 24-bit ripple counters. The counter value after 2^{24} samples provides an estimate of the correlation coefficient of the two signals. This estimate is converted into a corresponding analog correlation coefficient using methods presented in [3]. With the appropriate threshold levels, the

0-7803-3246-6/96/$5.00 © IEEE

three level correlator achieves a sensitivity of 0.81 relative to a perfect analog correlator [4].

DESIGN TECHNIQUES

Use of digital microwave design techniques preserves the integrity and timing of the high-speed digital signals. The high-speed ECL signals exhibit transition times of $\lesssim 250$ ps; therefore, the digital signals have spectral content $\gtrsim 4$ GHz. The circuit is fabricated on low-loss woven PTFE double-sided copper-clad circuit board. All high-speed components (both passive and active) are surface mount devices. Interconnections are made using microstrip transmission lines with terminating resistors to eliminate ringing and minimize transition time.

A differential clock is distributed via coupled microstrip transmission line pairs operating in the odd-impedance mode. Programmable time delay ICs are used to compensate for small path length differences, thus synchronizing the clock, ADC latch, and digitized data signals. The use of such "wavefront processing" design techniques, the arrival times of all signals are adequately maintained.

APPLICATION AND DEMONSTRATION

The digital correlator will be part of a fully polarimetric radiometer for airborne application (Figure 1). The radiometer directly measures the four modified Stokes' parameters [5]:

$$T_v \sim < |E_v|^2 >$$

$$T_h \sim < |E_h|^2 >$$

$$T_U \sim 2\text{Re} < E_v E_h^* >$$

$$T_V \sim 2\text{Im} < E_v E_h^* >$$

where E_v and E_h are the vertically and horizontally polarized incident electric fields and $< \cdot >$ denotes ensemble averaging. The input signals are downconverted using a pair of superheterodyne receivers driven by a common local oscillator (LO). The voltages at the receiver outputs, $v_v(t)$ and $v_h(t)$, correspond to the received signals in the vertical and horizontal polarizations, respectively.

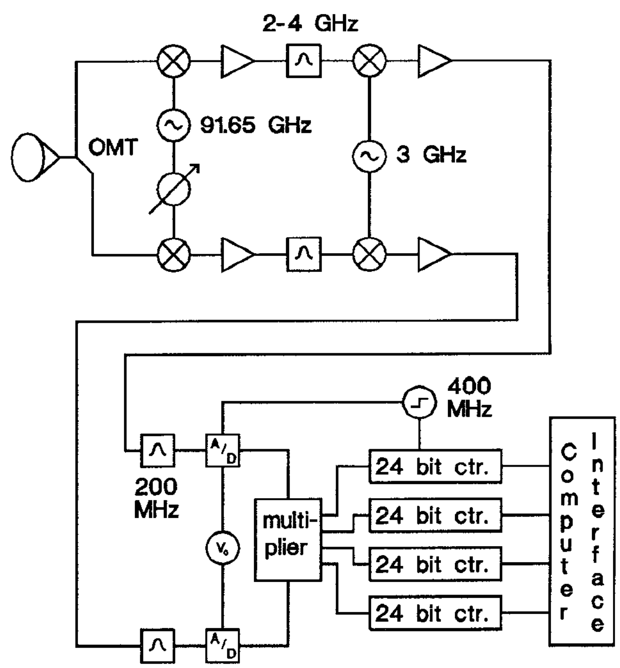

Figure 1. Digital correlator connected to a polarimetric radiometer in the polarization correlating mode.

To measure the third or fourth Stokes' parameter the correlation coefficient of the time-varying voltages ρ must be estimated by the digital correlator. These Stokes' parameters are subsequently found by:

$$T_\alpha = 2\rho_\alpha \sqrt{T_{v,sys} T_{h,sys}}$$

where $T_{v,sys}$ and $T_{h,sys}$ are the calibrated thermal temperatures of the two receivers (referred to the inputs) and $\alpha = U$ or V. If the LO signal is in-phase at each of the receivers, T_U is measured; however, if T_V is desired, the LO signals are adjusted to be in quadrature-phase.

An experiment connecting a prototype digital correlator operating at 400 MS/s to a 91.65 GHz polarimetric radiometer was carried out. The radiometer was calibrated using the non-polarized hot and cold blackbody technique. A polarized blackbody described by [6] was used to generate a known input Stokes' field. Rotation of the polarized load resulted in brightness temperature variations in all three measured Stokes' parameters T_A, T_B, and T_U. Digital measurements are converted to brightness temperatures and presented in Figure 2. As expected, the T_U variations are in phase-quadrature with those of T_A and T_B. In addition, the amplitude of the T_U variations are nearly equal to the amplitude of the T_A and T_B variations. These two features are anticipated consequences of the Stokes' parameter rotational transform [7].

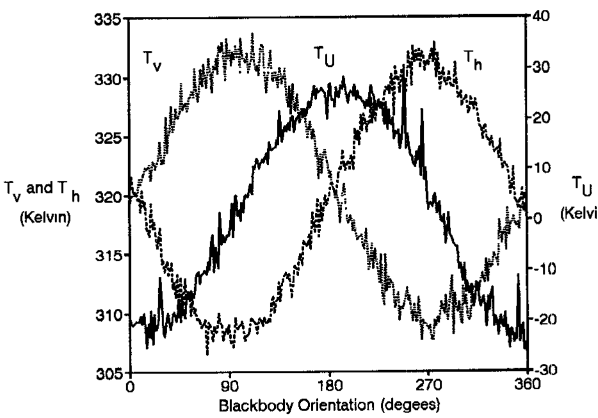

Figure 2: Brightness temperature variations for T_v, T_h, and T_U for continous rotation of the polarized blackbody.

CONCLUSION

A wideband digital correlator operating at 1GS/s has been designed and built. Digital microwave design techniques were used to insure satisfactory performance. A prototype correlator operating at 400 MS/s was demonstrated in the application of wideband radiometric polarimetry.

REFERENCES

[1] S. Padin, *et. al.*, "High-speed digital correlator for radio astronomy," *IEEE Trans. Instr. Measure.*, vol. 42, pp. 793–798, August 1993.

[2] J. Canaris, "NASA CERC digital correlator projects," in *Fourth NASA Symposium on VLSI Design*, no. N94-21708, (Idaho Univ.), 1992.

[3] S. R. Kulkarni and C. Heiles, "How to obtain the true correlation from a 3-level digital correlator," *The Astronomical Journal*, vol. 85, pp. 1413–1420, October 1980.

[4] B. F. C. Cooper, "Correlators with two-bit quantization," *Aust. J. Phys.*, vol. 23, pp. 521–527, 1970.

[5] Y.-Q. Jin, *Electromagnetic Scattering Modelling for Quantitative Remote Sensing.* New Jersey: World Scientific, 1993.

[6] A. J. Gasiewski and D. B. Kunkee, "Calibration and applications of polarization-correlating radiometers," *IEEE Trans. Microwave Theory Tech.*, vol. 41, pp. 767–773, May 1993.

[7] S. Chandrasekhar, *Radiative Transfer.* New York: Dover Publications, 1960.