A NOVEL CONTINUOUSLY VARIABLE DELAY LINE

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Abstract

A novel scheme for producing continuously variable time delay is proposed. The scheme makes use of two dispersive delay lines and spectral inversion to achieve dispersionless variable delay. Experimental results obtained at 1 to 2 GHz are presented.

Introduction

The proposed scheme for producing continuously variable non-dispersive delay is shown in Figure 1. The principle of operation is as follows.

The two local oscillator signals are mixed and the products are fed to a diplexer. One local oscillator frequency is fixed at the midband frequency, f_1, of the signal band of interest and serves to translate the signal band to the operating band of the dispersive delay lines. The frequency of the other local oscillator, f_2, controls the amount of delay through the system and must lie within the operating band of the dispersive delay lines.

From the diplexer, the lower sideband, $f_1 - f_2$, is sent to the mixers preceding and following the first dispersive delay line, and the upper sideband, $f_1 + f_2$, is sent to the mixers preceding and following the second dispersive delay line. The difference between the signal frequency, $f_1 \pm \Delta f$, and the lower sideband produces an IF frequency, $f_2 \pm \Delta f$, in the first dispersive delay line. At the mixer following the first delay line the sum of the lower sideband and the IF frequency recreates the signal frequency, $f_1 \pm \Delta f$.

At the mixer preceding the second delay line the difference between the upper sideband and the signal frequency again produces an IF frequency that lies within the passband of the dispersive delay line. However this time the signal spectrum is inverted. The final mixing process at the output of the second delay line produces the difference between the upper sideband and the IF frequency, which again is the signal frequency with its spectrum re-inverted.

Discussion

A typical delay line dispersion characteristic is shown in Figure 2. It is clear from the figure that the amount of delay is controlled by the frequency f_2 that passes through the delay line. In addition, if the dispersion characteristics of the two delay lines are linear and identical the net delay of the signal after passing through both delay lines is the same for all the spectral components of the signal. To understand this, consider the Maclaurin expansion of the delay vs. frequency characteristic:

$$\tau = a_0 + a_1 f + a_2 f^2 + \ldots , \qquad (1)$$

where τ is the time delay and f is the frequency. The total time delay through the system is the sum of the delays through the two delay lines, i.e.,

$$\begin{aligned} \tau &= \tau' + \tau'' \\ &= a_0' + a_1'(f_2 \pm \Delta f) + a_2'(f_2 \pm \Delta f)^2 + \ldots \qquad (2) \\ &+ a_0'' + a_1''(f_2 \mp \Delta f) + a_2''(f_2 \mp \Delta f)^2 + \ldots . \end{aligned}$$

Expanding Eq. (2) one obtains

$$\begin{aligned} \tau &= a_0' + a_0'' + (a_1' + a_1'')f_2 \pm (a_1' - a_1'')\Delta f \\ &+ (a_2' + a_2'')f_2^2 \pm (a_2' - a_2'')af_2\Delta f \qquad (3) \\ &+ (a_2' + a_2'')(\Delta f)^2 + \ldots . \end{aligned}$$

In order that the delay depend only on the control frequency f_2 and not the signal frequency, all terms in Eq. (3) that contain Δf must go to zero. The only way for this to occur is if

$$a_1' = a_1'' \qquad (4a)$$

and

$$a_i' = a_i'' = 0 \quad ; \quad i = 2, 3, \ldots . \qquad (4b)$$

Thus, the delay lines must have linear dispersion characteristics and be identical (in the sense that the slope of their dispersion characteristics is the same).

If the delay lines are linearly dispersive over some bandwidth, B, then the amount of variable delay that can be obtained from this delay line scheme is determined by the signal bandwidth, $2\Delta f_{max}$. From Figure 2 it can be seen that the maximum excursion of the control frequency, f_2, is equal to $B - 2\Delta f_{max}$, and that the delay can be varied from $2\tau_0$ to $2\tau_0 + 2\Delta\tau$.

Experimental Results

An experiment was conducted to demonstrate that the variable delay scheme discussed in the last section actually performs in the way that has been described. The experimental arrangement is shown in Figure 3. The general scheme shown in Figure 1 was modified slightly in order to allow the use of available equipments and to simplify the experiment. However, the arrangement of Figure 3 still retains the basic features of the general scheme, namely, continuously variable time delay and no dispersion.

A dispersive delay line of the meander-line type[1] was available that provided approximately a linear dispersion of about 50 nsec over a frequency range of 1 to 2 GHz. Thus the input signal frequency was chosen to lie in this range to eliminate the requirement for a mixer at the input. A high-frequency switch connected the output of the delay line to ground. The switch served to spectrally invert the signal and to send it back through the delay line. Thus no second delay line was required and the two delay-line dispersion characteristics involved in the process were guaranteed to be identical. In fact, this technique could probably be used in a fully developed version of this scheme.

No appropriate diplexer was readily available, so a tunable bandpass filter was used to separate the input signal from the spectrally-inverted difference-frequency signal. Rather than add the complication of another local oscillator and mixer to convert back to the signal frequency, the difference frequency was displayed and used to measure the characteristics of the variable delay scheme.

Figure 4 shows the measured variation of time delay as a function of control frequency for a fixed input signal frequency of 1.1 GHz. The total variation of time delay shown in the figure is about 45 nsec, although about twice as much delay variation could have been obtained with the delay line that was used. Some variation in the dispersion of the pulse is noted. However, this was found to be entirely attributable to the dispersion in the tunable bandpass filter.

Figure 5 shows the measured variation of time delay as a function of control frequency for two different input signal frequencies. The fact that the measured points for these two frequencies fall on top of or very near to each other illustrates that the system is relatively free of dispersion (the dispersion due to the bandpass filter has been calibrated out). The small amount of dispersion that is apparent is attributed to non-linearities in the dispersion characteristics of the particular delay line that was used.

Conclusion

It has been shown that two identical delay lines (each with N nanoseconds of delay variation) can be combined so as to give practically no dispersion of the signal which is being delayed (and with a total of almost 2N nanoseconds of electrically controlled delay variation). The use of identical delay lines is an advantage over other systems known to us,[2] because, one, these devices could be fabricated simultaneously, and two, no matching of complementary delay characteristics is required.

References

1. H.S. Hewitt, "A Computer Designed, 720 to 1 Microwave Compression Filter," IEEE Trans. on Microwave Theory and Techniques, Vol. MTT-15, pp. 687-694 (December 1967).

2. A.J. Kelly, "Electronically Variable Time-Delay Network for Broad-Band Phased-Array Steering," IEEE Trans. on Aerospace and Electronic Systems, Vol. AES-4, pp. 837-844 (November 1968).

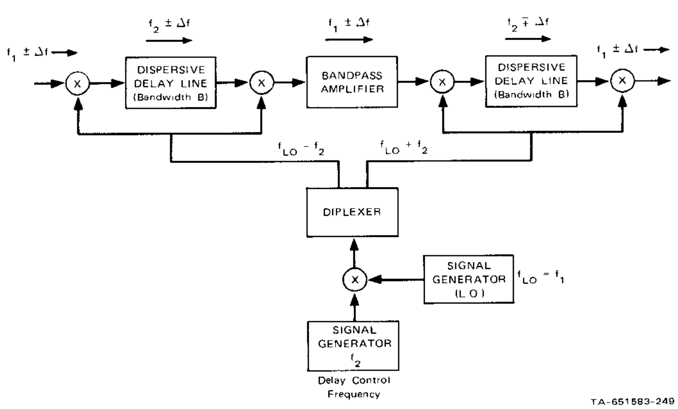

FIGURE 1 SCHEMATIC DIAGRAM OF SYSTEM FOR PRODUCING CONTINUOUSLY VARIABLE DELAY

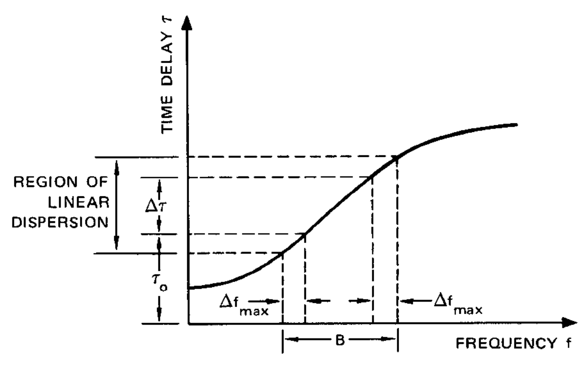

FIGURE 2 DELAY VERSUS FREQUENCY CHARACTERISTIC OF ONE DISPERSIVE DELAY LINE SHOWN IN FIGURE 1

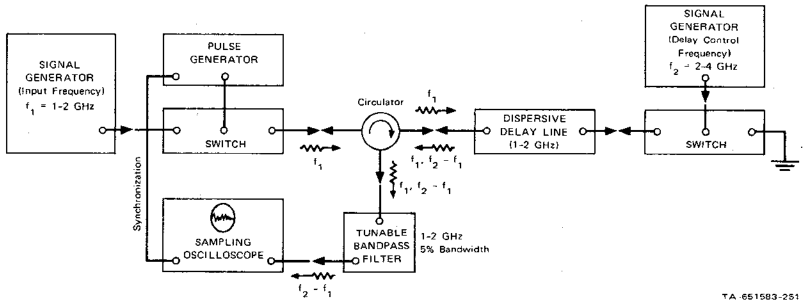

FIGURE 3 SCHEMATIC DIAGRAM OF EXPERIMENTAL ARRANGEMENT USED TO DEMONSTRATE CONTINUOUSLY VARIABLE DELAY

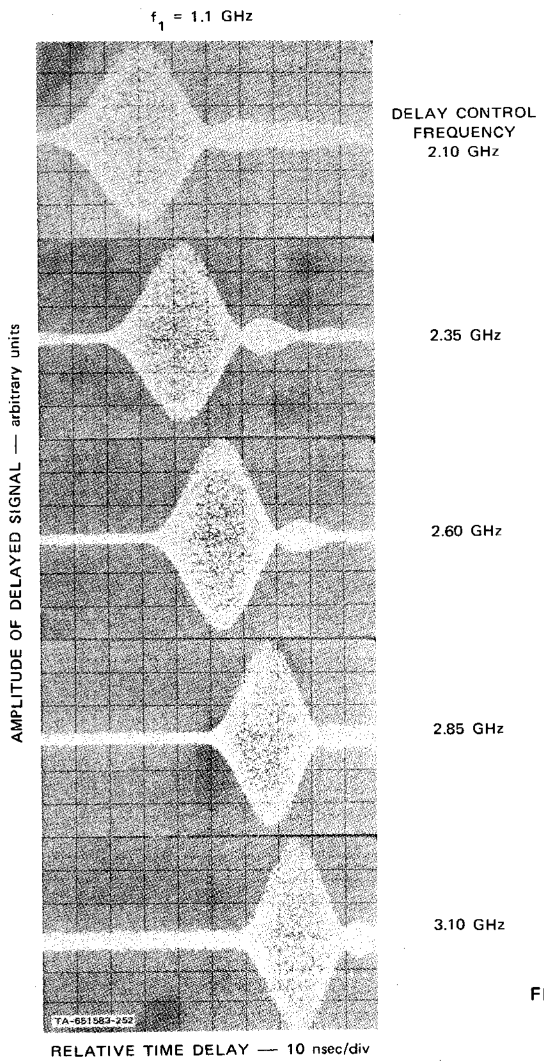

FIGURE 4 OSCILLOSCOPE PHOTOGRAPHS SHOWING VARIATION OF TIME DELAY WITH CONTROL FREQUENCY

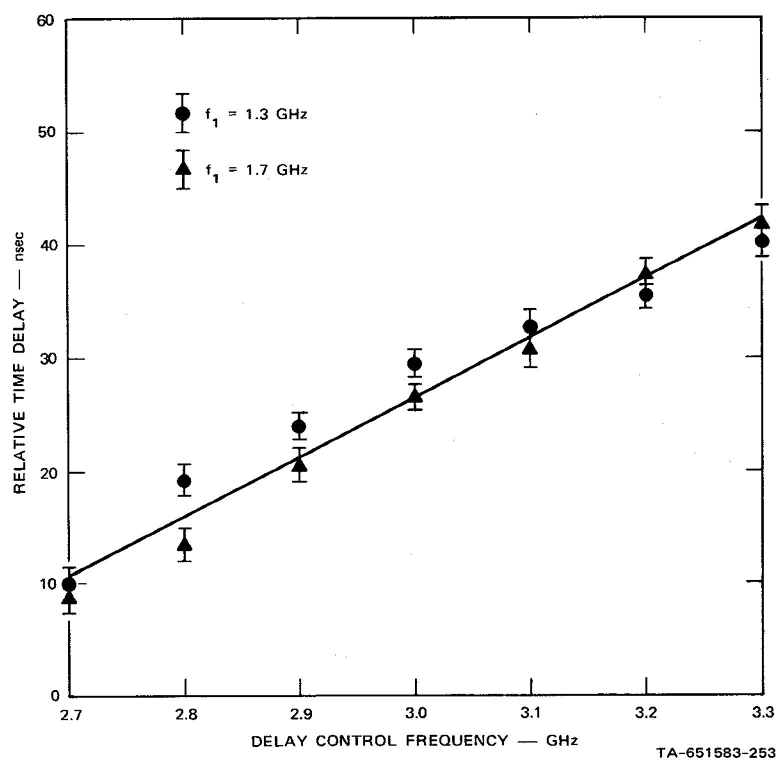

FIGURE 5 MEASURED VARIATION OF TIME DELAY WITH CONTROL FREQUENCY FOR TWO DIFFERENT INPUT FREQUENCIES