# DPSK MODULATION AND DEMODULATION USING BULK ACOUSTIC WAVE (BAW) DELAY ELEMENTS

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## ABSTRACT

DPSK modulation and demodulation are usually based on logical selection of the difference phase before modulation and the recovery sum phase after detection. Here, we describe an analogue procedure done directly on the PSK'd I-F. BAW delay elements are used in arrangements of feed-forward for difference modulation and of feedback for demodulation.

Characteristics are described, and results of laboratory implementation tests for data rate and carrier frequency variations are given. An I-F of 60 MHz and a bit rate of 200 kHz were used as nominal values. Robust performance is indicated.

## INTRODUCTION

We discuss here a conceptual approach to generating DPSK and recovering the PSK using bulk acoustic wave (BAW) delay elements. Performance evaluation of DPSK versus other modulation methods is not intended, being, of itself, an extensive subject. DPSK error rates for certain constraints are found in References (1) and (2). These references also depict particular forms of DPSK modulators and demodulators for systems analysis, which are based on digital logic approaches. Such approaches use data differencing and summing logic, respectively, before and after carrier phase modulation and demodulation.

To set a basis for comparison to our approach, we show a usual procedure in symbolic form in Figures 1 and 2. In a sense, the differencing modulation is offset by a following summing process after detection. Should differentially coherent DPSK be desired, phase synchronous timing of the data and carriers would be required, as by use of a common generating clock or frequency synthesizer.

An alternate to the demodulator shown in Figure 2 employs baseband quadrature circuits, so that the I and Q components of each received bit are obtained.(1) The bit value decision results from the scalar product with the prior bit components. In either case, the differential demodulation occurs after detection. The approach we describe uses BAW delay elements operating at I-F, 60 MHz, to produce the differential modulation and demodulation.

We first describe the modulation and demodulation processes using binary data. A laboratory circuit implementation for experimental evaluation is then described.

## DPSK MODULATION AND DEMODULATION

The primary modulation is binary PSK. Modulation is conversion of the PSK to DPSK, and demodulation is the recovery of the PSK. A feed-forward circuit is used for modulation; a feedback circuit is used for demodulation.

### Modulation

A feed-forward circuit is used as shown in Figure 3. Parameters in Figure 3 are defined as follows:

$\omega_o$ = carrier radian frequency

$\phi_m$ = PSK phase for $m^{th}$ bit

$\tau_1$ = delay of feed-forward branch

$\tau_b$ = 1 PSK bit duration

$G_1$ = gain (or loss) of feed-forward branch

$\alpha_1$ = Mixing loss of the I-F converter

$$\theta_m = \phi_m + \phi_{m-1} - \omega_o \tau_1 \qquad (1)$$

$$\phi_m = \phi\,(t - m\tau_b) \qquad (2)$$

$$\phi_{m-1} = \phi\,(t - (m - {}_{1})\tau_b) \qquad (3)$$

The PSK input is

$$V_1\,(t) = \cos(\omega_o t + \phi_m) \tag{4}$$

The DPSK'd output is

$$V_2\,(t) = \alpha_1 G_1 \cos(2\omega_o t + \theta_m) \tag{5}$$

Note the doubling of the I-F. The DPSK phase modulation is $(\phi_m + \phi_{m-1})$ mod2$\pi$ for our example.

If the delay $\tau_1$ does not match the bit period $\tau_b$, then some intersymbol interference occurs as well as a loss of modulation efficiency. The phase transitions of the delayed bit train are no longer coincident with the undelayed train.

We can represent the differential phase durations by

$$\begin{aligned}&(\phi_m + \phi_{m-1})\ \mathrm{rect}\ \frac{t - m\tau_b - \Delta/2}{[(\tau_b - \Delta) = \tau_1]}\\ &+ (\phi_m + \phi_{m+1})\ \mathrm{rect}\ \frac{t - (m-1)\tau_b - \tau_b/2 - \tau_1 - \Delta/2}{\Delta}\end{aligned} \tag{6}$$

where

$$\Delta = \tau_b - \tau_1 \tag{7}$$

and

$$\mathrm{rect}\ \frac{t}{\Delta} \to 0 \text{ as } \Delta \to 0 \tag{8}$$

These two rect functions are contiguous in delay and disjoint. Intersymbol interference would occur on modulation when $\phi_{m-1}$ and $\phi_{m+1}$ differ. We do not include an analysis of this loss. Now, we consider demodulation.

## Demodulation

The demodulation circuit uses feedback as shown in Figure 4.

The output solution for $V_3(t)$, after substituting for $\theta_m$ from (1) is

$$V_3(t) = \alpha_2 G_2 \cos(2\omega t + \theta_m) \cos\left(\omega t - \omega\tau_2 + \phi_{m-1} + \frac{\omega\tau_2}{2} - \frac{\omega_o\tau_1}{2}\right), \tag{9}$$

where we have substituted an “assumed” solution in the feedback loop.

$$\begin{aligned} V_3(t) &= \alpha_2 G_2 \cos\left(2\omega t + \phi_m + \phi_{m-1} - \omega_o\tau_1 - \omega t + \omega\tau_2 - \phi_{m-1} + \frac{\omega_o\tau_1}{2} - \frac{\omega\tau_2}{2}\right) \\ &= \cos\left(\omega t + \phi_m - \frac{\omega_o\tau_1}{2} + \frac{\omega\tau_2}{2}\right) \end{aligned} \tag{10}$$

Only the difference frequency of the conversion process passes back through the loop. The result, Equation (10), checks our assumed solution (after delay through the BAW).

For PSK bit detection, we can now use the detection scheme of Figure 2, except now our input is the recovered PSK’d carrier, and the data bits are used directly out of the phase detector. The remaining fixed phase term in Equation (10) is removed by use of this self-synchronous detection method. Alternatively, we can use the “I-Q” baseband component process.(1)

Frequency shifts caused by local oscillators, Doppler, and the like do not affect performance as long as they remain in the loop passband. Doppler frequency shifts are caused by time-scale expansion and contraction, and so induce a slight change in the duration of the data bit, which is ordinarily insignificant. The time scale expansion ratio is $v/f_o$, where v is the Doppler and $f_o$ is the un-Dopplered carrier. Hence, an original data bit of duration $\tau_b$ would extend to $\tau_b(1 + \frac{\nu}{f_o})$. Since $\nu/f_o \approx \frac{V}{c}$, V is relative velocity or Doppler inducing velocity and c is velocity of light, the bit duration change will be insignificant; a small change in bit duration has nil effect, in any event.

## LABORATORY CIRCUIT IMPLEMENTATION

A simple arrangement was used for initial laboratory experiments, particularly to eliminate data recovery circuitry. By using a single, matched RF source, we could provide scope observable data “detection” by adding phase coherent prime source I-F to the output from the DPSK demodulator. That is, bit synchronous amplitude modulation results, permitting direct observation of the 60 MHz bit structure. This arrangement is shown in Figure 5.

The BAW elements have a nominal 1-bit delay of 5 µsec, corresponding to a bit rate of 200,000 bps. By our previous notation, $\tau_1 = \tau_2 = 5$ µsec. Variations of >±20 percent in bit rate were essentially unobservable in performance effect.

As mentioned earlier, the BAW delay elements also act as bandpass filters. A measured response is shown in Figure 6. The response width will accept I-F shifts of 10 to 20 MHz while providing excellent rejection at twice I-F.

An example of observed DPSK'd I-F from the DPSK modulator appears in Figure 7. The data rate was 200 kHz. The lower word generator trace corroborates the DPSK'd data.

The demodulated DPSK of Figure 7 is shown in Figure 8. A 1-bit delay in the recovered data results because the data were taken from the BAW filtered output of Figure 4. An alternating data sequence of two "1's" and three "0's" is shown in Figure 9, as recovered from the filtered BAW output of the DPSK demodulator.

## CONCLUDING REMARKS

We have described an experimental arrangement for using BAW delay elements for differential modulation and demodulation of the PSK'd I-F. An I-F of 60 MHz and a bit rate of 200 kHz were used. A BAW delay of 5 μsec corresponds with the bit rate. Laboratory operation was robustly insensitive to carrier frequency and data rate variations.

## REFERENCES

1. Winters, Jack H. "Differential Detection with Intersymbol Interference and Frequency Uncertainty," IEEE, Vol. COM-32, No. 1, Jan 1984, pp. 25-33.

2. Ekanayake, Nimal. "DPSK Signaling Over Hard Limiting Channel in the Presence of Intersymbol Interference," IEEE, Vol. COM-32, No. 5, May 1984, pp. 503-510.

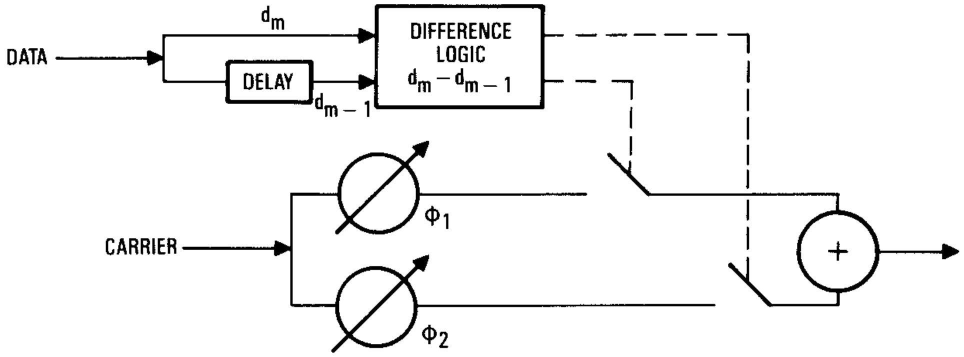

**Figure 1. Symbolic Binary Differential Modulator; Extendable to M-ary. Difference Logic Occurs Before Carrier Phase Modulation.**

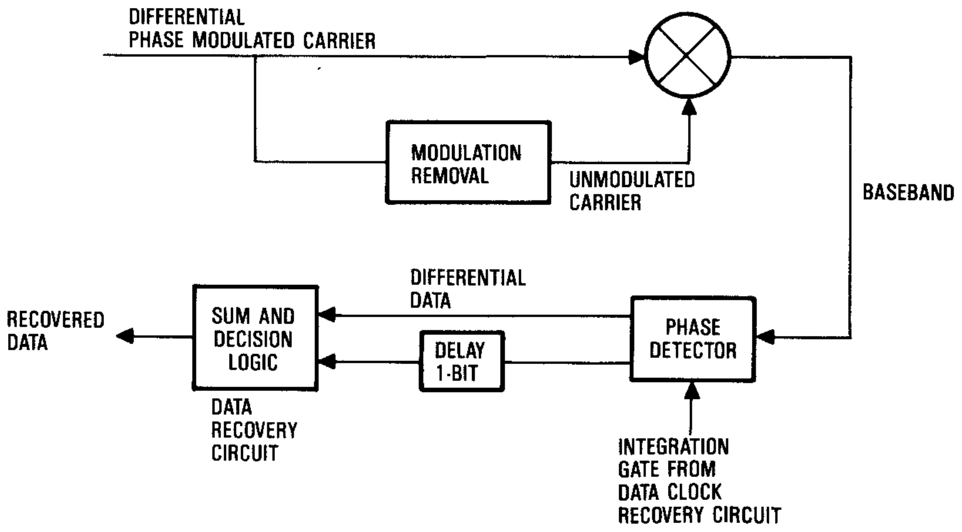

Figure 2. Symbolic Binary Differential Demodulator; Use of Data Period Gating on the Detector Integrator Reduces Intersymbol Interference. Sum Logic Occurs After Carrier Phase Demodulation.

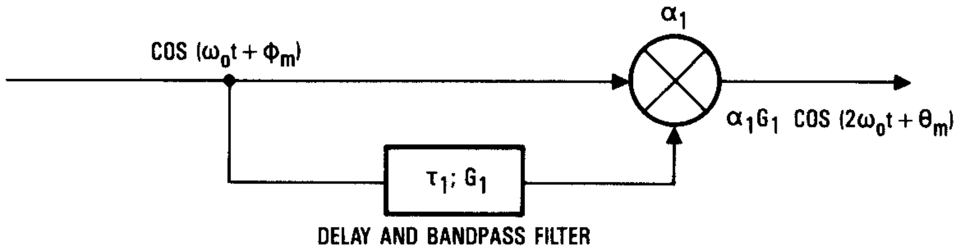

Figure 3. Feedforward DPSK Modulator; the Delay Element Has Delay $\tau_1$, Gain (or Loss) $G_1$; Ideally, $\tau_1 = \tau_b$. Only Frequencies About $\omega_o$ Are Passed in the Feed-Forward Branch.

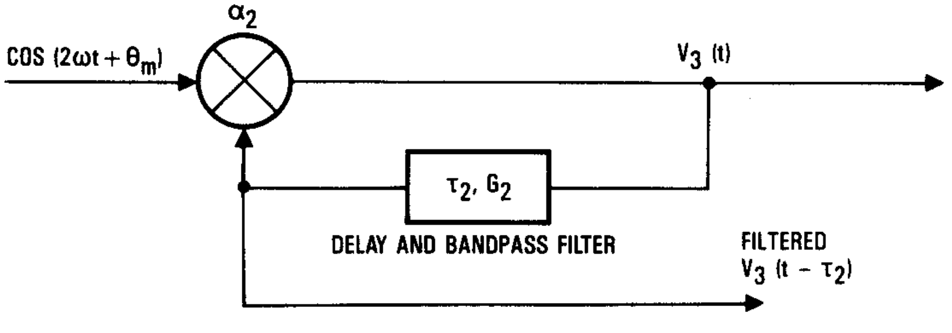

Figure 4. Feedback DPSK Demodulator; the Delay Element Has Delay $\tau_2$, and Gain (or Loss) $G_2$. The Delay Element Passes Frequencies About $\omega$ Only. Ideally $\tau_2 = \tau_b$.

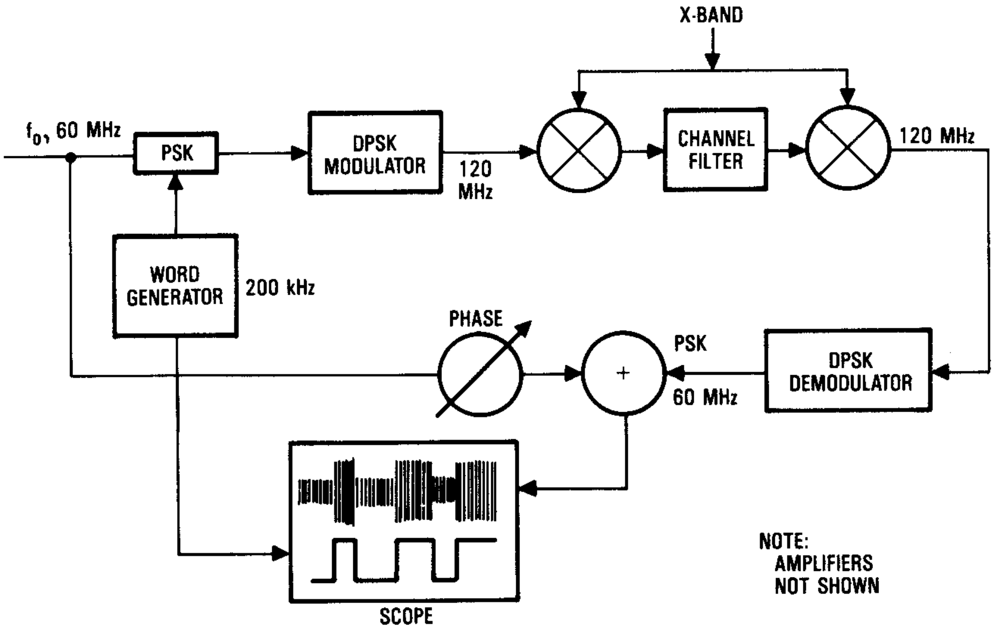

Figure 5. Experimental Laboratory Circuit Arrangement; Direct Observation of the Recovered PSK'd I-F Results From Adding Synchronous I-F to Yield Amplitude Modulation.

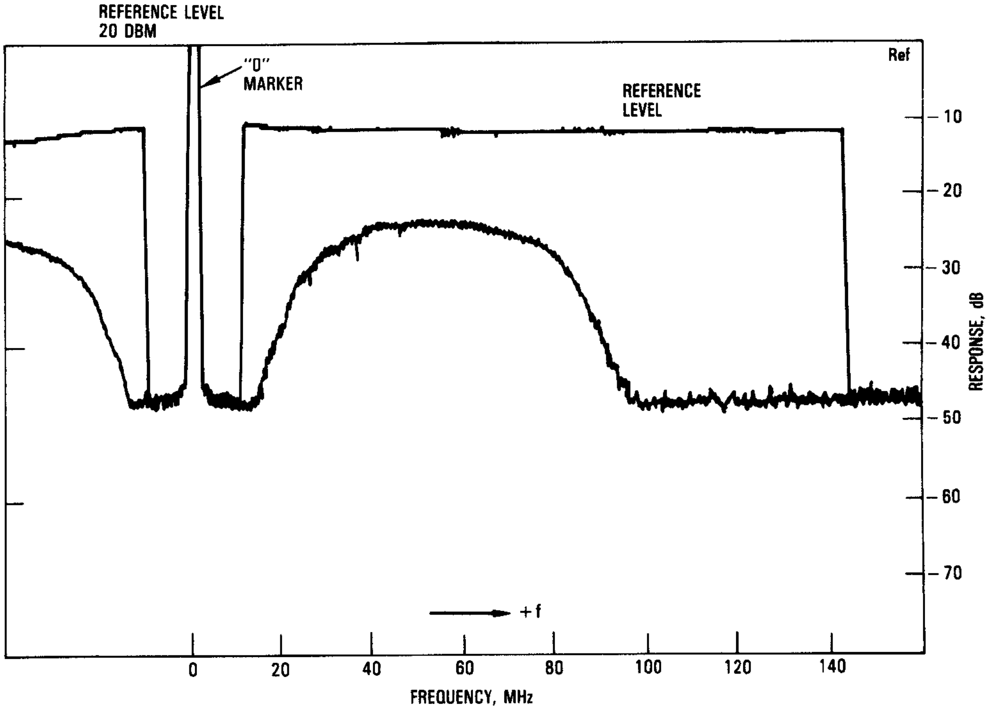

Figure 6. Bandpass Characteristic of a BAW Delay Element.

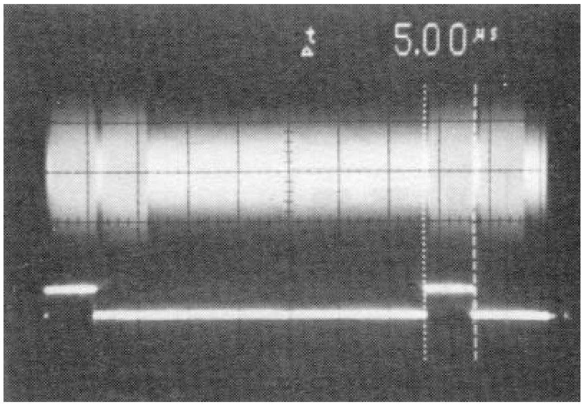

Figure 7. Observed DPSK'd I-F From the DPSK Modulator. The Lower Trace Is the 200 kHz Word. Differential Phase Transitions Occur After Rise and Fall of the "1"-bit.

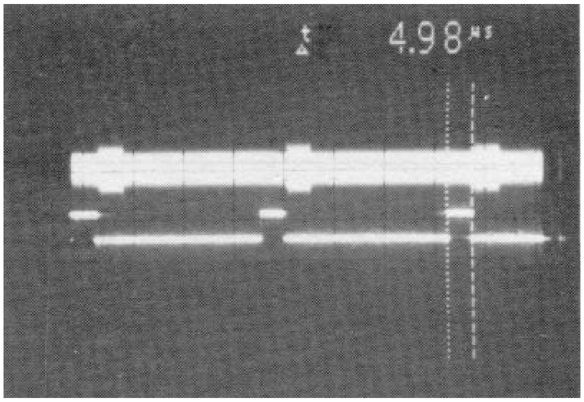

Figure 8. Observed, Recovered PSK'd I-F From the DPSK Demodulator, Taken at the 1-bit Delayed BAW Filter Output

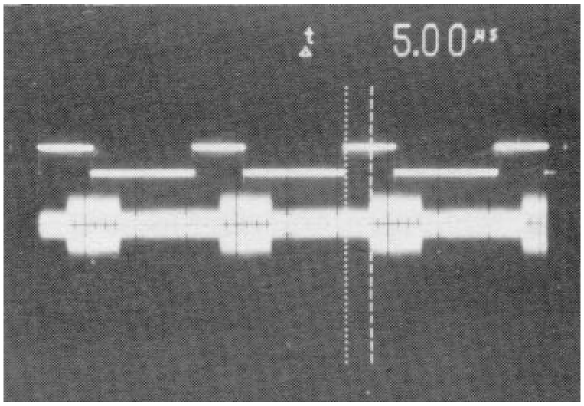

Figure 9. Observed, Recovered PSK'd I-F From the DPSK Demodulator Taken at the 1-bit Delayed BAW Filtered Output. Alternating Two "1's", Three "0's" Word