A SIMPLE MODULATOR AND MIXER FOR DIRECTIONAL DOPPLER SIGNALS

F. S. Schlindwein[1], P. I. J. Keeton[1] and D. J. Dryden[1]

ABSTRACT -- This technical note describes the design of a simple instrument that conveniently modulates and mixes the forward and reverse components outputs from a Doppler velocimeter. The output is a single signal around a programmable carrier frequency. A graphical explanation of the way the circuit works is provided, as well as the complete circuit diagram. The instrument is extremely simple to build and is a very useful tool in a vascular laboratory.

Key words: Doppler Velocimeters, Ultrasound, Directional Doppler, Blood flow, Instrumentation, Modulator

INTRODUCTION

The radio frequency signal received by a Doppler velocimeter contains information of velocities towards the probe and away from the probe. Without sacrificing generality this kind of signal can be written as

$$S(t) = A_0 \cos(\omega_0 t + \phi_0) + A_f \cos(\omega_0 t + \omega_f t + \phi_f) + A_r \cos(\omega_0 t - \omega_r t + \phi_r) \qquad (1)$$

where the subscripts refer to the transmitted base frequency (0), the forward component (f) and the reverse component (r). The transmitted frequency $f_0 = \omega_0 / 2\pi$ is of the order of 2 to 20 MHz. Let us consider a signal with forward and reverse components whose amplitude spectral density is that shown in Figure 1, where the lower hump corresponds to the components ω_r.

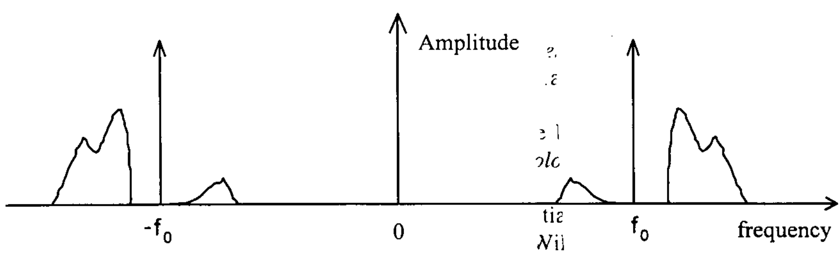

Figure 1. Radio frequency signal received by a CW Doppler velocimeter.

[1] University of Leicester, Department of Engineering, University Road, Leicester LE1 7RH, England, UK, e-mail: fss1@le.ac.uk

// Trabalho recebido em 10/abr/96 e aceito em 29/nov/96 //

In the past, a simple coherent demodulator using the same angular frequency ω_0 from the master oscillator was applied to shift the signal S(t) down in frequency and produce an audio signal output, but this does not differentiate between movements towards and away from the transducer assembly because upper and lower sidebands of the forward and reverse components are brought to the same base audio band as seen in Figure 2 (Wells, 1969).

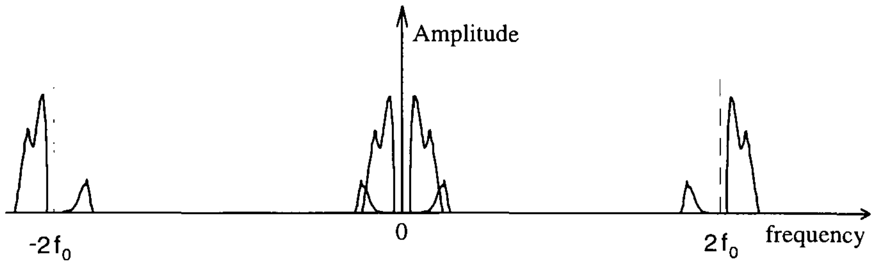

Figure 2. A simple coherent demodulator does not produce directional information because the upper and lower side bands are brought to the same base frequency band.

Nowadays most Doppler velocimeters are directional, that is, they provide separate information about forward flow and reverse flow. The most widely used technique of directional demodulation is quadrature phase detection, which results in two output audio signals, D(t)' and Q(t)' that contain the directional information in the relative phase between them. For a situation where flow is only towards the probe the direct signal D(t)' lags the quadrature signal Q(t)' by $\pi/2$, while for flow that is only receding from the probe it is the quadrature signal that lags the direct signal by $\pi/2$ (Evans et al., 1989). Quadrature phase detection may be followed by phase domain processing (still in the Doppler velocimeter) resulting in the complete separation of the forward and reverse components into two separate signals F(t) and R(t) as shown in Figure 3.

Directional Doppler velocimeters produce outputs either in phase quadrature form (as the Parks 806A does) or completely separated as a forward and a reverse component (as the Dopplex II does). Although these two kinds of output are mathematically equivalent and one can be transformed into the other, the best kind of output to handle is the one that uses separate forward and reverse signals because it can be recorded onto magnetic tape directly. This is not straightforward with quadrature signals because the process of recording and playing back the signal introduces different phase shifts to the two channels, corrupting or even completely destroying the directional information contained in quadrature signals.

The digital processing of the Doppler signals either in quadrature form or in the forward and reverse form requires two analogue to digital channels capable of sampling the signals at a frequencies up to around 40 kHz. In the case of quadrature signals the traditional multiplex-sample/hold-A/D converter architecture of most commercial A/D boards for personal computers is not convenient. Simultaneous sampling is much preferred because the alternative procedure of dealing with the known phase shift introduced by the multiplexed sampling in the post-processing stage is quite awkward. Analogue to digital converter boards that allow simultaneous sampling are much more expensive than the traditional ones.

A single channel output is particularly well suited to spectral analysis since only one A/D channel and one spectrum analyser are required to deal with bidirectional flow. The instrument described here achieves exactly this. The design goal is: We want to mix the forward and reverse components around a programmable carrier of angular frequency ω_c, subtracting the undesired side bands, to produce a single analogue signal that contains the forward spectrum at frequencies above the carrier, say at $(\omega_c + \omega_f)$ for an individual component of angular frequency ω_f and the reverse spectrum at frequencies below the carrier, say at $(\omega_c - \omega_r)$ for a reverse component of angular frequency ω_r, as explained below.

DESIGN CHARACTERISTICS - A GRAPHICAL APPROACH

The description of the circuit can be entirely derived from a very simple graphical analysis of the frequency representation of the input signals and the required output. It follows.

The forward and reverse signals can be represented as in Figure 3 while the required output is as in Figure 4. The procedure to obtain that is easily followed referring to Figures 5 and 6. First, both the forward component signal, F(t), and the reverse signal, R(t), are modulated by the carrier,

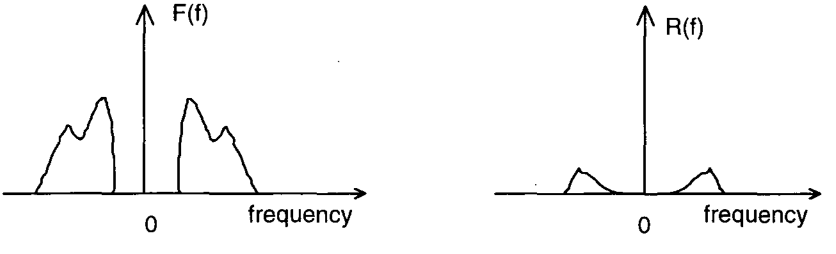

Figure 3. The frequency representation of the forward and reverse spectra.

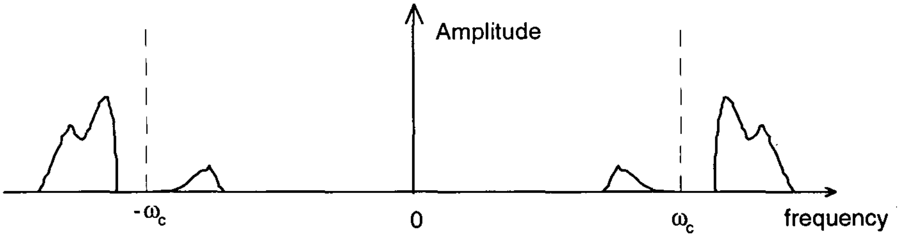

Figure 4. The required output from the instrument: Forward and reverse components modulated about a programmable carrier frequency ω_c and mixed to produce a single signal.

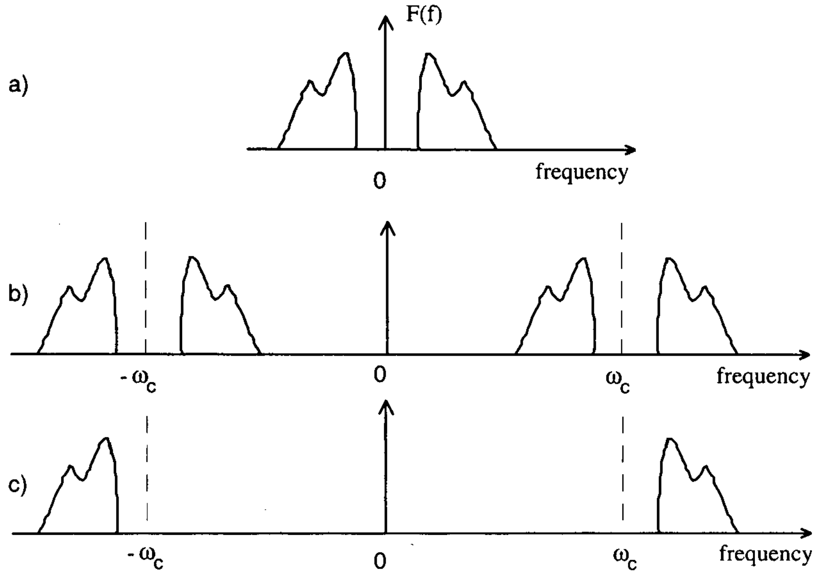

Figure 5. The forward component (a) is modulated (b) and then high-pass filtered (c).

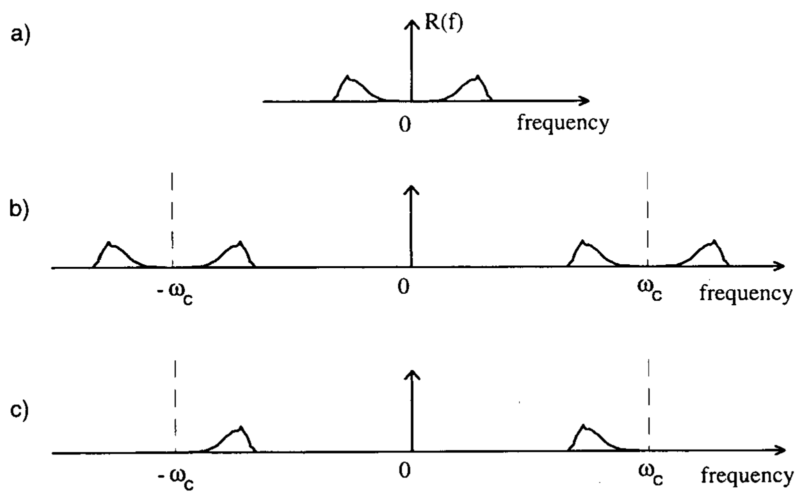

Figure 6. The reverse component (a) is modulated (b) and then low-pass filtered (c).

$H(t) = \cos(\omega_c t)$. The complete circuit of the crystal controlled sine wave generator that produces the carrier signal is shown in Figure 9. The resulting signal from the modulation of the forward component is high-pass filtered to remove the lower side band, while the signal resulting from the modulation of the reverse component is low-pass filtered to remove the upper side band. Finally the filtered signals are added producing the required output. The diagram with the modulators, filters and adder is shown in Figure 7 and the complete circuit in figure 10.

The result of adding the signals represented in Figure 5c and 6c is obviously the required signal of Figure 4.

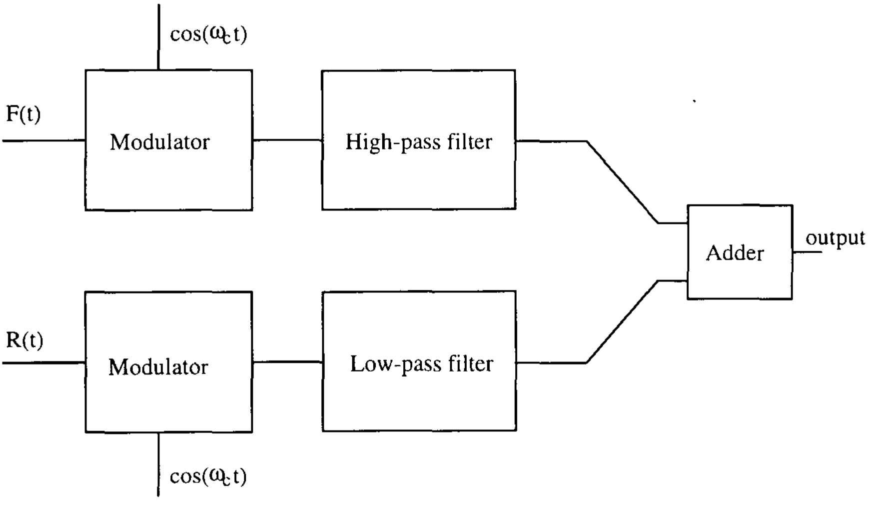

Figure 7. Block diagram of the independent modulator and mixer.

The frequency of the carrier signal is programmable via a 3-bit BCD switch to be 500 Hz, 1, 2, 4, or 8 kHz. The setting of this BCD switch is read by an IBM-compatible personal computer using the parallel printer port programmed as an input. The frequency selection switch, represented by T1, T3 and T4 in Figure 9, produces the six input bits labeled 'FREQ' after the EPROM 2732. These are used as input codes to the filters. Both the high-pass and the low-pass filters are implemented using switched capacitor filter IC chips - two 7th order Elliptical modules in cascade for each, the low-pass implemented using the American Megatrends Incorporated S3528 and the high-pass, the S3529 as shown in Figure 10. For the IC filters the specified pass band ripple is only 0.05 (typ.) per stage, the stop band attenuation is better than 51 dB per stage (102 dB total) for frequencies higher (for the low-pass) than 1.3 times the cut-off frequency. The phase is non-linear around the cut-off frequency - and therefore the group delay is not flat, but this is of little consequence for the kind of processing we perform on the Doppler signals: We are interested in the amplitude spectrum only; phase distortion is not relevant. The choice of the carrier frequency automatically reprograms the cut-off frequencies of both filters. It is left to the operator to ensure that the carrier frequency is larger than the maximum frequency component contained in the reverse signal.

CONCLUSION

The circuit described performs its function well and produces a clean signal as shown in the amplitude sonogram of Figure 8. It has been in use in our research laboratory for over two years. We feel that the graphical description given here is of value for teaching the subject and might even help designers with similar problems. The full diagram of the circuit is given in Figures 9 and 10. A critical part of the adjustments for the circuit is the carrier suppression. This was performed using a spectrum analyser, measuring the output of the modulators IC2 and IC9 (Motorola MC1496) and carefully adjusting the multi-turn potentiometers VR1 and VR2 of the circuit of Figure 10.

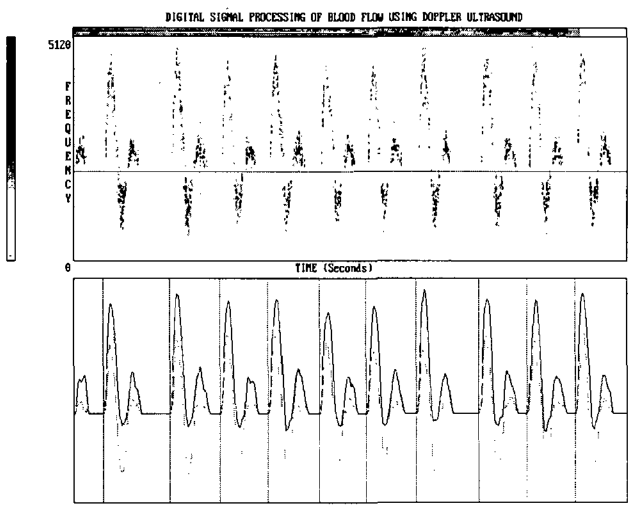

Figure 8. The sonogram of a bidirectional Doppler signal processed by the instrument together with the results of the detection of the individual heart beats. The grey-scale for the amplitude sonogram is linear.

REFERENCES

EVANS, D. H., McDICKEN, W. N., SKIDMORE, R. and WOODCOCK, J. P. (1989). *Doppler Ultrasound.* Chichester: John Wiley & Sons.

WELLS, P. N. T. (1969). *Physical Principles of Ultrasonic Diagnosis.* London: Academic Press".

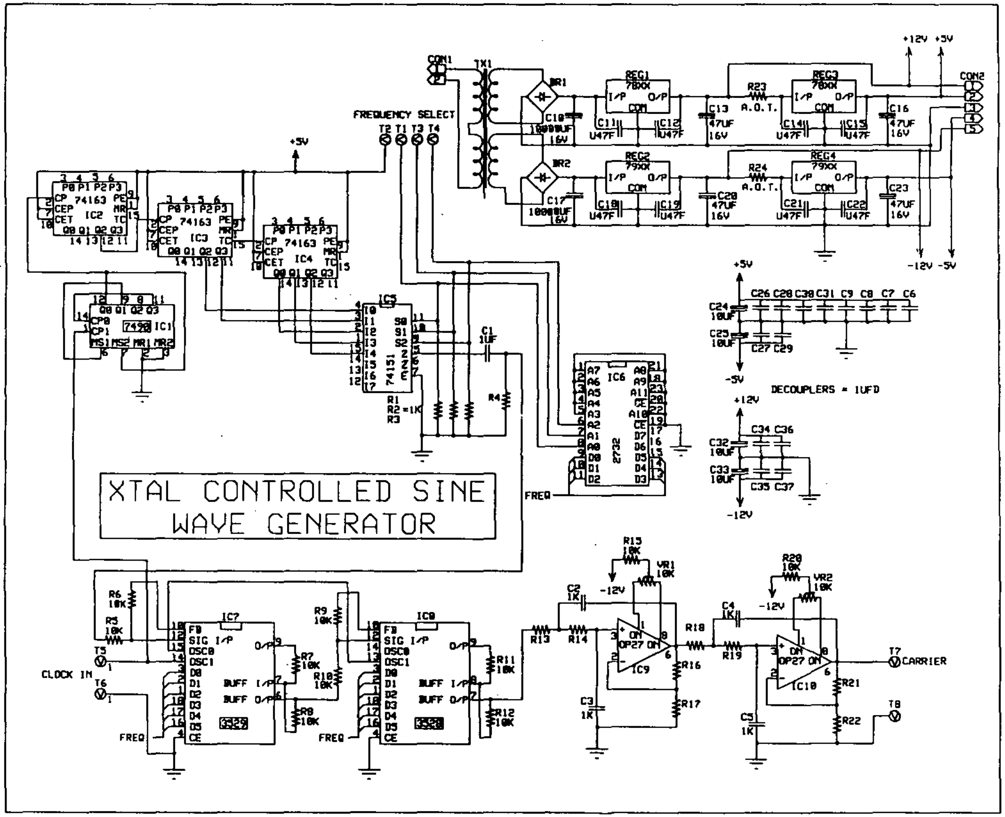

Figure 9. The crystal controlled carrier generator. Only the fundamental frequency goes through the band pass filter to produce the carrier signal.

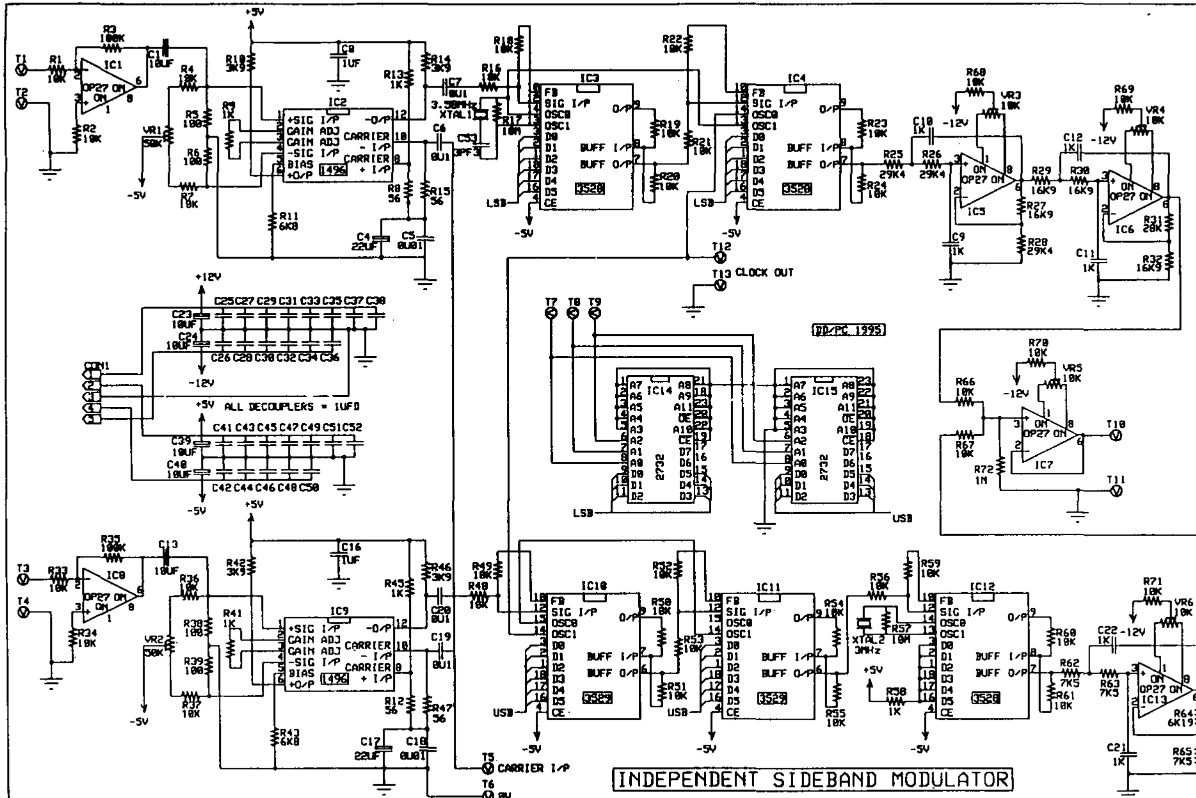

Figure 10. Complete circuit diagram for the modulator, filters and adder.

UM MODULADOR E MISTURADOR SIMPLES PARA SINAIS DOPPLER DIRECIONAIS

F. S. Schlindwein[1], P. I. J. Keeton[1] and D. J. Dryden[1]

RESUMO -- Esta nota técnica descreve um processador analógico (modulador) que mistura as componentes de fluxo direto e reverso de um velocímetro Doppler gerando um sinal único em volta de uma portadora com freqüência programável. Uma explicação gráfica do funcionamento do circuito é apresentada, bem como o diagrama completo do circuito. O instrumento é de construção simples e é um aparelho muito útil em um laboratório vascular.

Palavras-chave: Velocímetros Doppler, Ultra-som, Doppler Direcional, Fluxo Sangüíneo, Instrumentação, Modulador.

[1] University of Leicester, Department of Engineering, University Road, Leicester LE1 7RH, England, UK, e-mail: fss1@le.ac.uk