Meas. Sci. Technol. **8** (1997) 673–675. Printed in the UK PII: S0957-0233(97)81523-8

DESIGN NOTE

Quadrature phase shifter for audio frequency sinewaves

Luca Callegaro and Vincenzo D'Elia

Istituto Elettrotecnico Nazionale Galileo Ferraris, Electrical Metrology Department, Strada delle Cacce, 91-10135 Torino, Italy

Received 4 February 1997, accepted for publication 21 February 1997

Abstract. A quadrature phase shifter for sinusoidal signals is presented. The circuit provides 90° phase delay (within 1°) and unity gain (within 6%) in the frequency range 100 Hz to 10 kHz. It consists of a second-order lowpass current-controlled filter; the cutoff frequency is mantained equal to the input frequency with a frequency to current converter. In this way, the filter provides a 90° phase delay between input and output. The main feature of the phase shifter is the absence of internal feedback; this avoids the introduction of long settling time constants when the phase shifter is part of control loops and gives almost instantaneous (within a period) resettling of the 90° phase delay when amplitude or phase variations of the input signal occur.

1. Introduction

Many applications require a circuit which produces, given an input sinusoidal signal of amplitude A and frequency f, $V_{in} = A\sin(2\pi ft)$, a sinusoidal output of the same amplitude and frequency but with a 90° phase delay with respect to input, $V_{out} = A\cos(2\pi ft)$. A number of active and passive networks have been proposed [1] which, given an input, provide two outputs whose phase difference is 90°; only a few circuits have been reported which give the quadrature relation directly between input and output [2] and they suffer from a very limited working frequency range. A very good quadrature and amplitude precision can be accomplished [3, 4] with a feedback control. These feedbacks require, for good precision and noise rejection, long settling time constants (several seconds for audio frequencies). This feature becomes a serious drawback when the phase shifter itself is part of a control loop; examples of this employ can be found in synchronous vector compensators for automatic bridges [5, 6].

The circuit presented here permits one to obtain acceptable amplitude and phase quadrature precision in a wide frequency range, without internal feedback control loops. Phase and amplitude response is almost instantaneous (within a period of the input frequency); response to frequency variations depend on the precision requested and in the present circuit the time constant is around 1 s. The frequency range can be easily extended if one accepts a loss of precision or a switch for different ranges.

2. Working principle

The principle of operation is indicated by the block diagram of figure 1. The two current-controlled filters (ICFs) are single-pole, lowpass filters with a transfer function

$$G(\omega) = \sqrt{2}\Big/\left(1 + j\frac{\omega}{2\pi f_{cut}}\right) \qquad (1)$$

where f_{cut} can be controlled by a current $I_{control}$.

The remainder of the circuit is a frequency to current converter (with two outputs for the two filters); it is made with a square shaper, a frequency to voltage (F/V) converter and two voltage to current converters, and is tuned in a way to mantain $f_{cut} = f$. For this condition, the transfer function (1) gives for the ICF:

$$G = 1 \qquad \arg(G) = 45^\circ$$

i.e. unit gain and a 45° phase shift.
For a series of two ICFs, we have $G_{series} = 1$ and $\arg(G_{series}) = 90^\circ(ret)$.

3. Circuit details

The circuit diagram is shown in figure 2. The sinusoidal input voltage V_{in} is squared in a comparator U_1 (CMP01) and fed, through AC coupling, into a F/V converter constructed around U_2 (AD650). The output goes through voltage to current converters which are formed by an instrumentation amplifier $U_{3/5}$ (AD624) and a sensing resistor $R_{sense1/2}$, whose signal is fed back to $U_{3/5}$ by

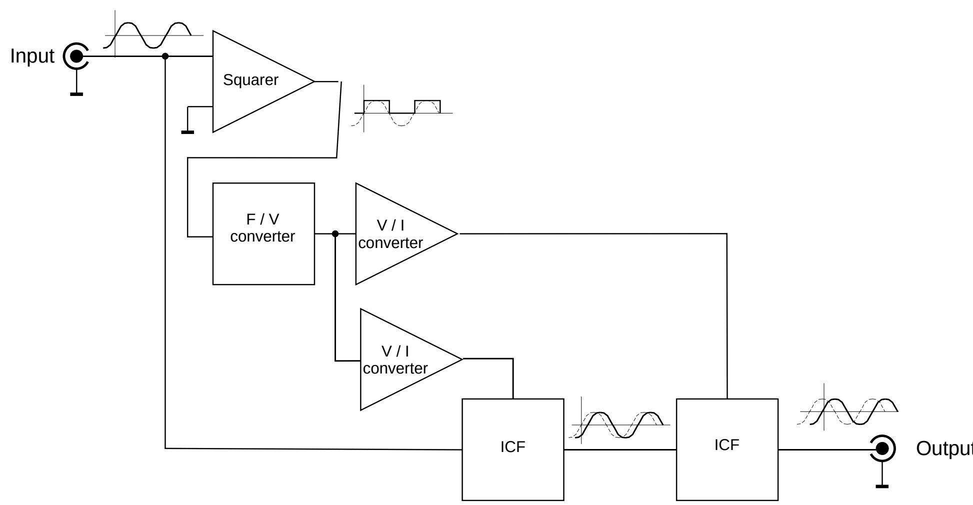

Figure 1. Block diagram of the phase shifter. ICF represents the current-controlled lowpass filter.

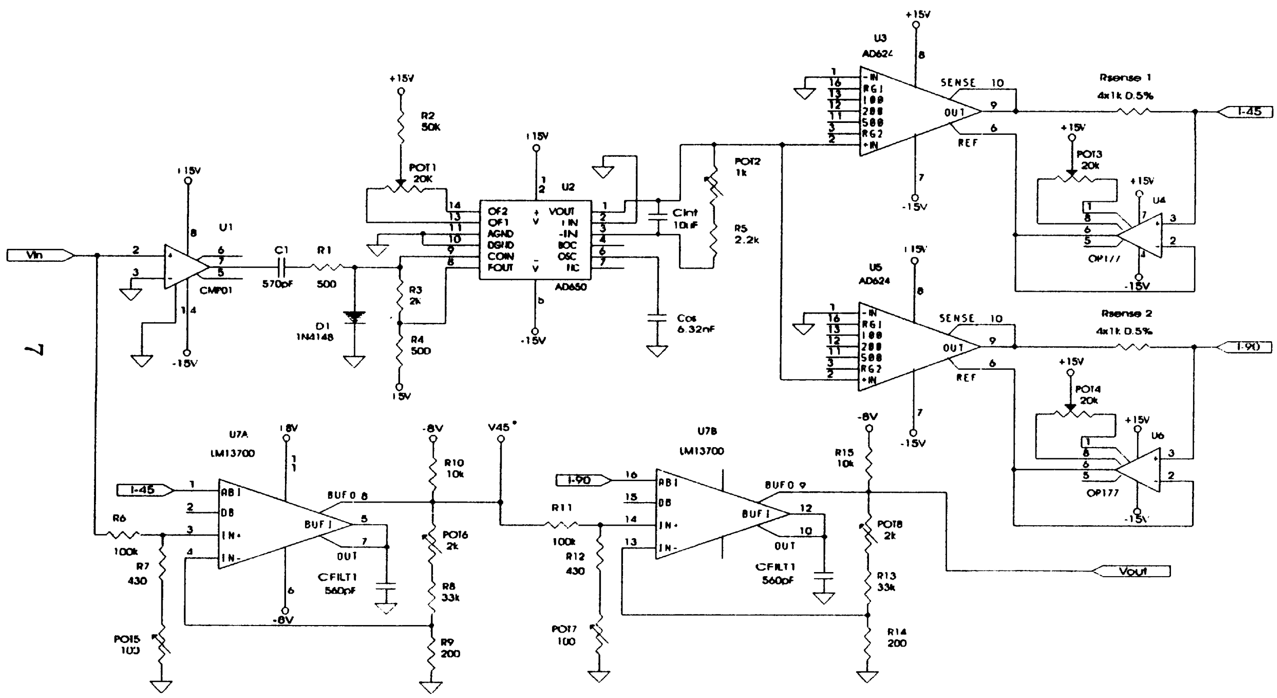

Figure 2. The complete circuit diagram of the phase shifter.

a low-offset buffer $U_{4/6}$ (OP177). The current $I_{-45/90^\circ}$ drives a lowpass filter [7] constructed around $U_{7A/B}$ (the two independent sections of LM13700) which acts as an active filter whose cut frequency depends on $C_{filt1/2}$ and the driving current $I_{-45/90^\circ}$. The output V_{out} must be collected with an AC coupler (not present in the diagram).

The circuit is designed for a maximum working frequency $f_{max} = 20$ kHz, and $I_{-45/90^\circ}(f_{max}) = 1.25$ mA. The choice of values of the lowpass filters is made following a formula from the National Semiconductor Corp. [7]. This can be easily altered.

The circuit requires five power supply voltages (+5 V, ±8 V, ±15 V), easily obtained with standard regulators (e.g. 7805, 7808, 7908, 7815, 7915) not shown in the diagram.

4. Regulations

- Trim the offset of U_2 (with R_2), $U_{4/6}$ (with $POT_{3/4}$).
- Apply a signal f_{max} at V_{in}, trim POT_2 to have the correct current $I_{-45/90^\circ}$ (the voltage drop on $R_{sense1/2}$ must be 5 V).
- Applying a signal f_{trim} (select the frequency where the minimum error is desired), trim POT_5 (gain) and POT_6 (phase) to achieve unity gain and 45° phase delay at V_{45°

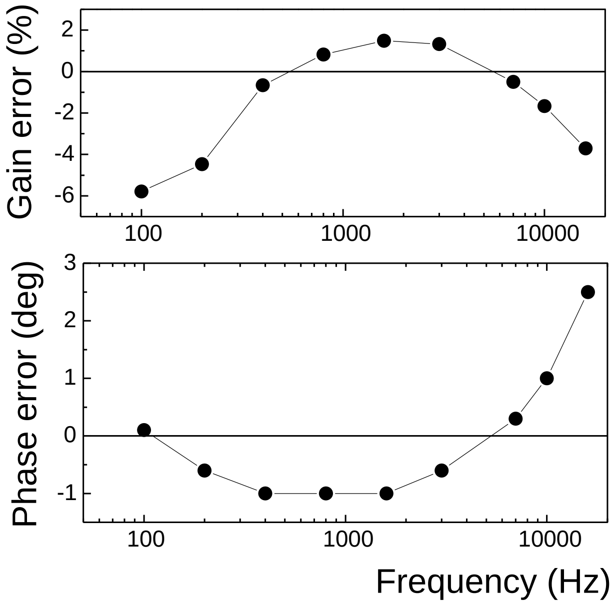

Figure 3. Deviations of the transfer function of the phase shifter with respect to the perfect case (gain = 1, phase delay = 90°).

auxiliary output. Repeat the procedure at POT_7 (gain) and POT_8 (phase) to maintain unity gain and 90° phase delay at V_{out}.

Better precision at low frequencies can be obtained with slight adjustments of the offsets (R_2, $POT_{3/4}$).

5. Test results

Test results have been obtained using a synthesized sine generator (SRS DS345) as source and a two-channel lock-in amplifier (EG&G 5210) as vector voltmeter.

The transfer function of the phase shifter is shown in figure 3.

To test the recovery time of the quadrature phase delay between input and output after a phase or amplitude jump of the input wave, we modulated in phase or amplitude the synthesized generator with a square wave. The time response to a phase change is shown in figure 4, which

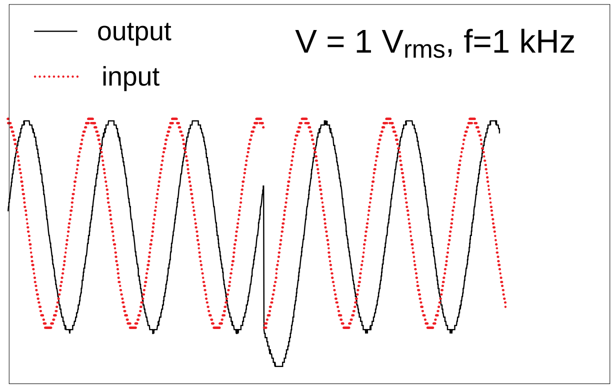

Figure 4. Time domain measurements of the response of the phase shifter. The dotted curve is the input sinewave from a synthesized generator; (the full curve is the) output of the phase shifter. A phase jump of the input is provoked by phase modulation of the generator; the resettling time of the 90° phase delay occurs after less than a period.

shows that, as expected from a second-order lowpass filter, quadrature is recovered after a delay of the period of the input wave. A similar response was obtained with an amplitude modulation.

References

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[4] See also schematics of lock-in amplifiers e.g. the reference manual of EC&G 5210 lock-in amplifier.

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