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High-stability function generator

L. Bruschi, R. Storti, and G. Torzo

Istituto di Fisica, Università di Padova, Italy, and Gruppo Nazionale Struttura della Materia, Padova, Italy

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We describe a voltage-controlled function generator that works in the audio frequency range and gives a sinusoidal signal with an amplitude stable within ±50 ppm. An internal phase shifter, frequency independent, gives eight square wave reference signals, where phase angles are integer multiples of $\pi/4$ with respect to the sine wave.

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INTRODUCTION

Recent experiments performed in our laboratory[1] required the use of sinusoidal voltage with a great amplitude stability. The required stability is within ±100 ppm over a time of several days.

The frequency of the sinusoidal generator must also be voltage controlled, and there must be reference signals available with phase angle equal to integer multiples of $\pi/4$, with respect to the sine wave signal.

Commercial instruments do not offer the required characteristics, so we have built an instrument suitable for our purposes.

The function generator here described works in frequency range 20 Hz–20 K Hz, and its construction requires only easily available commercial components.

I. CIRCUIT DESCRIPTION

The block diagram is a standard one for function generators, and it does not need particular explanations. It is shown in Fig. 1. Figure 2 shows the complete electrical circuit. The work frequency ν is determined by the square wave peak-to-peak amplitude V_s, by the time constant RC of the integrator, and by the reference voltage V_0 through the relation

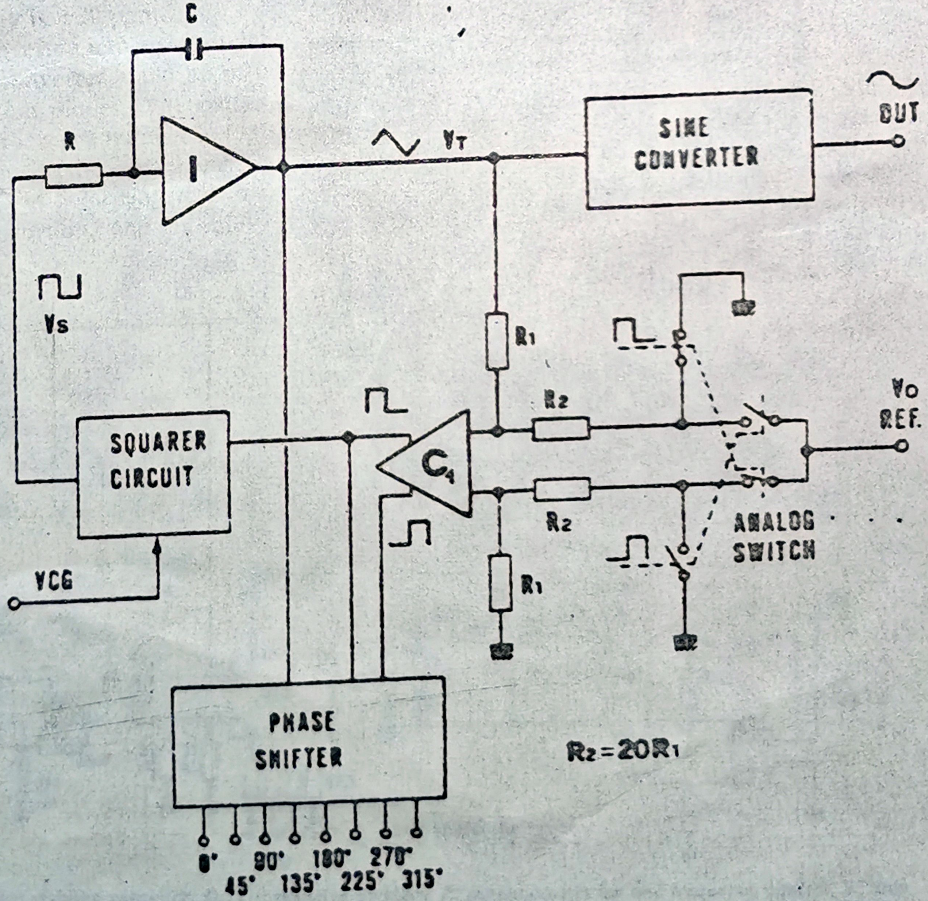

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FIG. 1. Block diagram—I: integrator, C_1: comparator. The double channel analog switch is driven by the comparator output and it switches the voltage reference V_0 alternatively at the two inputs of the comparator.

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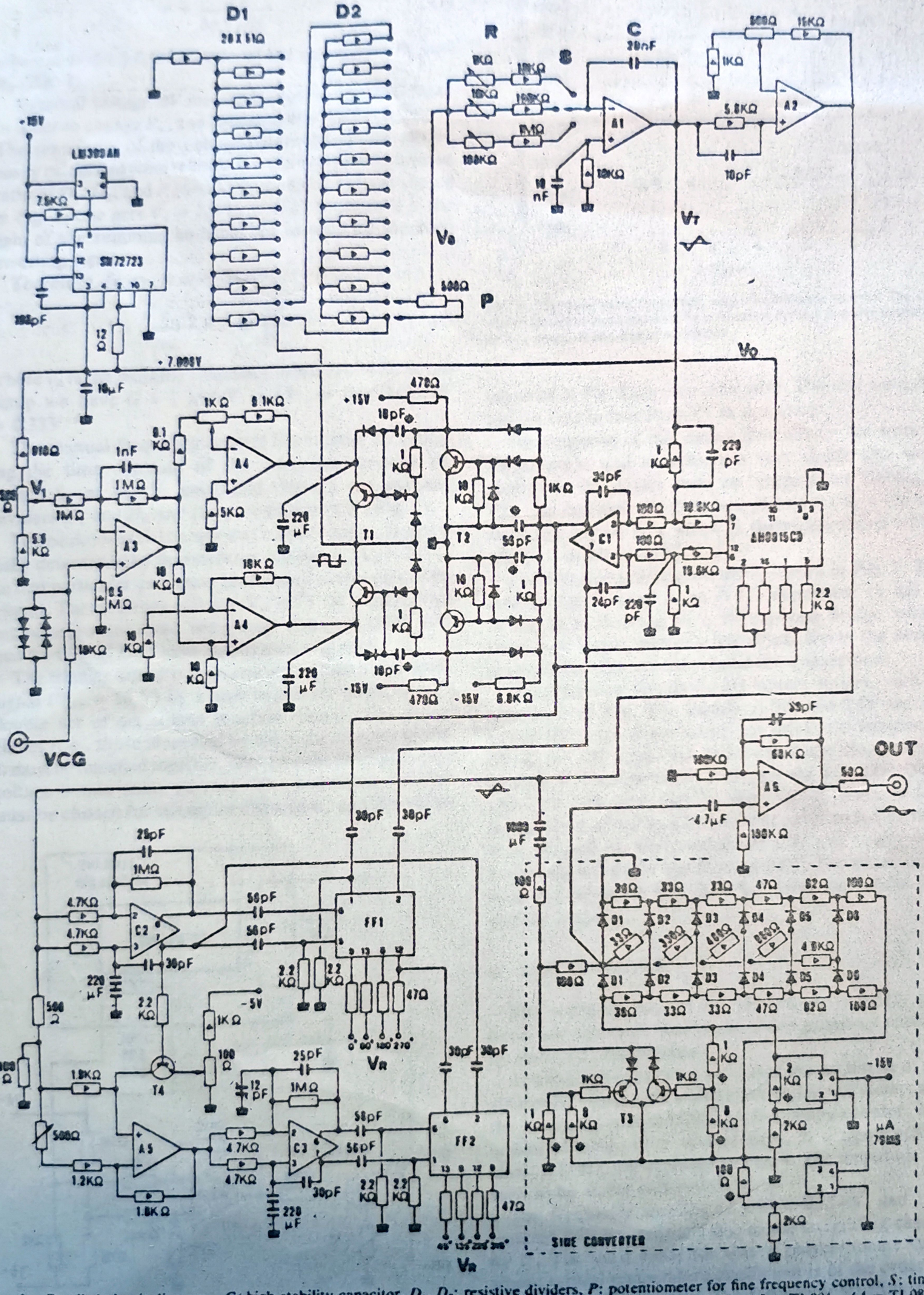

FIG. 2. Detailed circuit diagram—*C*: high stability capacitor, D_1, D_2: resistive dividers, *P*: potentiometer for fine frequency control, *S*: time constant selector, T_1, T_2 = BFX81, *T3* = MD6003, *T4* = BSX27, *A1* = *A5* = *A6* = LF356, *A2* = LF357, *A3* = TL081, *A4* = TL083, *C1* = *C2* = *C3* = LM360, *FF1* = *FF2* = SN7473. All diodes are 1N4148. The values of the starred components are merely indicative, and they must be properly chosen for minimum distortion and for frequency compensation. The resistors distinguished with a triangle are 2% metal film resistors.

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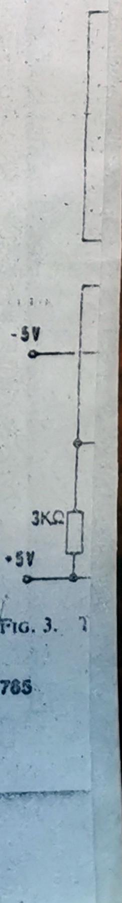

FIG. 3.

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$$\nu = \frac{V_s}{2\alpha V_0 RC}, \tag{1}$$

where α is the partition ratio of the resistances R_1 and R_2 (Fig. 1).

External voltage ΔV may be applied to the VCG input in order to change V_s, and consequently the frequency ν. The sensitivity of the voltage-controlled circuit can be easily calculated from relation (1). If β is the total partition ratio of D_1, D_2, and P, and V_1 is the fixed voltage shown in Fig. 2, one gets $V_s = 2\beta(V_1 - G\Delta V)$, where G is the gain of the summing amplifier $A3$ as seen by the noninverting input.

Therefore, from (1) one obtains

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$$\frac{\nu - \nu_0}{\nu_0} = -G\frac{\Delta V}{V_1}, \tag{2}$$

where ν_0 is the working frequency when $\Delta V = 0$. In our setup we have $G = 2$ and $V_1 \simeq 6V$, so that $\Delta\nu/\nu_0\Delta V = 0.33V^{-1}$.

The manual frequency control is obtained by changing the time constant of the integrator through the switch S, or the V_s amplitude through the resistive dividers D_1 and D_2 and the potentiometer P (Fig. 2).

The peak-to-peak triangle wave amplitude V_T is essentially determined by the reference voltage V_0 ($V_T = 2\alpha V_0$), so that particular care must be devoted to this part of the circuit. The reference voltage ($V_0 = 7V$) is supplied by a temperature-stabilized integrated circuit LM399 AH, and its typical long term stability is ±20 ppm.

The triangle signal is then converted into a sinusoidal signal ($V_{pp} = 10$ V) by a sine converter made up of a double set of six silicon junction diodes. The paired diodes (i.e., those identified by the same number in Fig. 2) must be matched together, choosing the same threshold voltage within some percent. The polarizing resistors must be chosen for minimum distortion,[2] and the values reported in Fig. 2 are only indicative. The sine wave distortion results less than 3% in our setup.

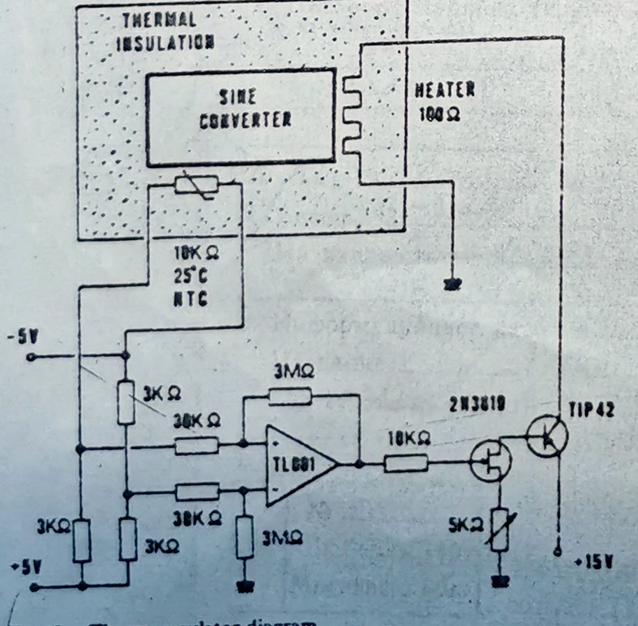

FIG. 3. Thermoregulator diagram.

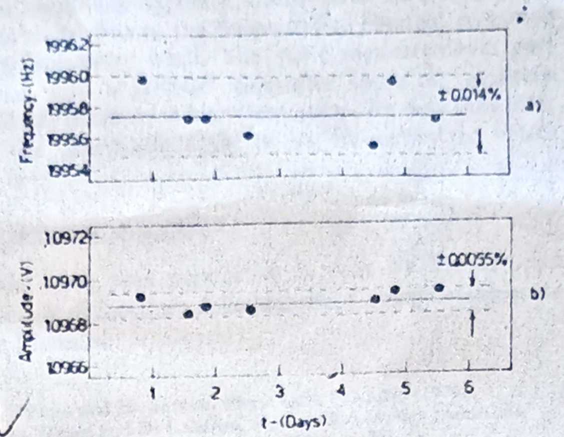

FIG. 4. (a) Sine wave frequency, and (b) amplitude vs time. The sine wave signal has been reduced by a resistive divider in order to use the proper range of the digital voltmeter.

The response of this circuit depends on the working temperature, and to achieve a very stable sine wave amplitude the circuit must be temperature stabilized. The sine converter is therefore placed inside a thermal insulated copper box which is thermoregulated within ±0.05 °C at about 50 °C.

The thermoregulating circuit is shown in Fig. 3. The temperature sensor is an NTC thermistor (3 kΩ at 50 °C): it is inserted in a Wheatstone bridge whose unbalance signal, properly amplified, drives the heater (constantan wire wound around the copper box).

The reference signals V_R are square waves, with an amplitude of 4 V. The signals at 90° and 270° are obtained from the square wave that drives the integrator. The 0° and 180° signals are derived from the triangle wave through the comparator $C2$. To get the 45°, 135°, 225°, and 315° reference signals, the triangle wave is first frequency doubled by a full wave rectifier ($A5$, $T4$), then it is squared by the comparator $C3$, and finally it is frequency halved by the flip-flop $FF2$. The phase error is estimated to be less than 0.5° over the whole frequency range.

II. PERFORMANCE

The warm-up time of the instrument is nearly one hour, and after this time the function generator reaches its standard performance.

At a fixed frequency we measured the amplitude of the sinusoidal signal with a HP3450A digital voltmeter, and the frequency with a HP5327A frequency counter. The results obtained over several days, at a frequency of about 2 K Hz, are reported in Fig. 4. The amplitude results to be stable within 0.005%.

The frequency stability is within 0.014%, and this residual drift is essentially due to the integrating capacity C. The used capacitor was a polycarbonate type whose typical temperature coefficient is of the order of 100 ppm/°C. To improve the frequency stability one

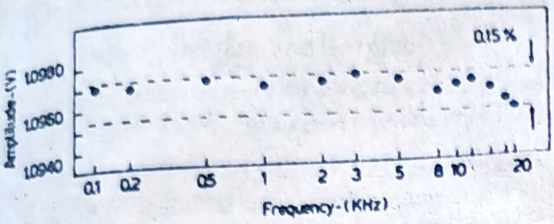

FIG. 5. Sine wave amplitude vs frequency. The sine wave signal has been reduced by a resistive divider in order to use the proper range of the digital voltmeter.

might thermoregulate the capacitor, or use a temperature-compensated capacitor.

The sinusoidal output is quite flat over the whole frequency range: the amplitude does change less than 0.15% from 20 Hz to 20 KHz, as shown in Fig. 5.

The amplitude decrease, observed at high frequency, seems to be due to the frequency-dependent response of the voltmeter itself. The same measurements performed with a HP3465 voltmeter show an apparent amplitude increase at high frequency. We may thus infer that the amplitude stability vs frequency is better than 0.15%.

ACKNOWLEDGMENT

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[1] L. Bruschi and M. Santini, Phys. Lett. 73A, 395 (1979).

[2] H. de Waard and D. Lazarus, *Modern Electronics* (Addison-Wesley, Reading, Massachusetts, 1966), p. 261.