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Stable, Inexpensive, Low Frequency Sine Wave Generator Using Digital Techniques

By

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Abstract

Presented is a circuit for the generation of low frequency (.001 Hz to 63 KHz) sine waves possessing stable amplitude and frequency characteristics using digital techniques. The circuit produces a 32 step approximation to a sine wave at a frequency 1/32nd of the selected digital time base frequency. Also presented are a crystal controlled time base to drive the generator and an active filter, whose selectable cutoff frequencies match the time base frequencies, for removing the high order harmonics produced by the generator. Advantages of the digital sine wave generator over analog oscillator techniques are described.

I. Introduction

Although the generation of sinusoidal waveforms by analog oscillators is widely used, this method has several drawbacks in the low frequency region. First these oscillators require large valued capacitors or inductors, which are generally costly, and whose values are affected by temperature, age, etc. Second they may require some time after adjustment of their frequency to settle down to their final frequency and amplitude. Third their frequency may be difficult to measure accurately, or at least be time consuming, as several seconds to several hours may be required to accumulate enough cycles in a counter to characterize the frequency. Lastly, the harmonic distortion of the oscillator is difficult to assess, as generally it will be a function of frequency and non-ideal characteristics of the circuit elements.

The digital sine wave generator overcomes these low frequency problems. Since the frequency is set only by the digital clock frequency, temperature and aging of analog components have little effect upon it. By starting with a reasonably high clock frequency and dividing it down by a known factor, sine wave frequencies in the millihertz region may be measured in seconds. Also the frequency and amplitude change within fractions of a cycle after they are adjusted, rather than many cycles. The amplitude of the sine wave is set by a reference voltage and a resistor string, and so is independent of frequency, as is the harmonic distortion, which is primarily due to resistor string mismatch.

II. Digital Sine Wave Generator

The method of digital sine wave generation by nonrecursive filtering of a binary waveform was first described by A. C. Davies.[1] Basically it involves sending a binary waveform into a series of n shift registers, which are shifted 2n times per cycle, to produce n delayed versions of the input waveform, and then taking a weighted sum of the first n-1 available waveforms in such a way that the closest possible approximation to a sinusoidal waveform, equal in frequency to the binary waveform, is produced. By proper feedback the shift register series can both produce and delay the binary waveform in the required way. Thus the generator produces a square wave and nonrecursively filters out as many of the harmonics as possible, leaving only the fundamental and several high order harmonics. The remaining components are given by the formulas:[1]

$$\frac{1}{(2kn-1)}\sin(2kn-1)w_o t \qquad \frac{1}{(2kn+1)}\sin(2kn+1)w_o t$$

The feedback shift register described here consists of four 4018 CMOS Divide by N circuits connected together in such a way that they form a 16 stage shift register, Fig. 1. By feeding the inverted output of the last stage into the data input terminal (pin 1) of the first stage, a twisted ring counter results which produces a binary waveform at $\overline{Q}_1$ with a frequency $\frac{1}{2n}$ times the clock frequency and 15 versions of it, each successively delayed by one clock period, Fig. 2. To avoid undesired sequences from developing in the registers, a RST reset pulse is produced by differentiating the positive going edge of the $\overline{Q}_{16}$ output so that all stages are forced clear ($\overline{Q}$'s set high) at the time when this condition would normally occur in the proper sequence.

The proper weighting coefficients for each of the n-1 outputs used to give minimum harmonic distortion are given by the formula:[1]

$$W_i = \sin(\frac{i\pi}{n}) \qquad i = 1, n-1$$

where in this case n = 16. From this formula relative conductances for the summing resistors are calculated, followed by relative resistances. In order to lightly load the CMOS shift register outputs so that they will swing to within millivolts of the supply voltage and thus yield a stable output amplitude, the smallest relative resistance was set equal to 21.5 KΩ, which then determines the value of the rest of the resistors. By setting the value of feedback resistor equal to the parallel resistance of the summing resistors, the peak to peak amplitude of the waveform coming out of the summing amplifier equals the shift register supply voltage (about 15 volts). An adjustable positive voltage is applied to the non-inverting input of the summing amplifier so that the output waveform can be centered around zero volts. The waveform is then sent to a variable attenuator, followed by a voltage follower buffer. The waveform is now ready to be used, as is, or to be filtered further to remove the remaining harmonics (see Sec. IV.) A representation of the unfiltered waveform is shown in Figure 3.

III. Crystal Controlled Time Base

The generator described above can be driven by any CMOS compatible time base from d.c. to several Megahertz. The one described here, Fig. 4, was designed for use as an excitation source for a molecular modulation spectrometer.[2] This method involves measuring the chemical lifetime of a gas phase radical produced in a photochemically driven reaction sequence by measuring the phase shift of the radical concentration with respect to the modulated light source as a function of modulation frequency. For this application a sine wave generator capable of stable operation below 1 Hz and with half-octave frequency settings was required.

The time base starts with a 20 MHz crystal oscillator (Motorola K1100A). Its output goes through a programmable divider, which divides the oscillator frequency either by 10 or 14 (switch selectable). Since 1.4 is very nearly equal to $2^{1/2}$, switching from the ÷10 to the ÷14 mode allows the output frequency to be shifted downward by half an octave. Next the output of the programmable divider is sent to a series of 4 decade counters, which allow the user to scale the output frequency by factors of 10, from ÷1 to ÷10000, by means of the decade switch. From the decade section the selected clock frequency is sent to a series of binary counters, where the user may scale the clock frequency further by factors of 2, from ÷1 to ÷2048, by means of the binary switch. Finally the clock frequency is sent to the generator, which produces a sine wave at 1/32 the clock frequency. Thus the span of frequencies of the sine wave generator using this time base is 62.5 KHz to 2.18 milliHertz.

IV. Active Filter

Since the first harmonics produced by the generator are the 31st and 33rd, analog filtering to remove them without allowing the fundamental amplitude to be dependent on filter components is straightforward. A two pole Butterworth filter[3] was constructed, Fig. 5, with switch selectable cut off frequency. The selectable R and C values were arranged so that there would be a one to one correspondence between available time base frequencies (excluding half-octave shifts) and filter frequencies. The design criterion decided upon for the filter cut off frequency was that it be 4 times the sine wave frequency it was filtering. This means the fundamental is only attenuated by a factor of .998, whereas the 31st harmonic is attenuated by .017. Use of this filter makes the generator output look indistinguishable from a pure sine wave.

V. Acknowledgements

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References

1. A. C. Davies, IEEE Trans. on Inst. and Meas., Vol. IM-18, No. 2, pp. 97-105 (1969).
2. H. S. Johnston, G. E. McGraw, T. T. Paukert, L. W. Richards and J. Van den Bogaerde, Proc. Natl. Acad. Sci., 57, 1146 (1967).
3. D. Lancaster, Active Filter Cookbook (Howard Sams, Indianapolis, 1975).

Figures

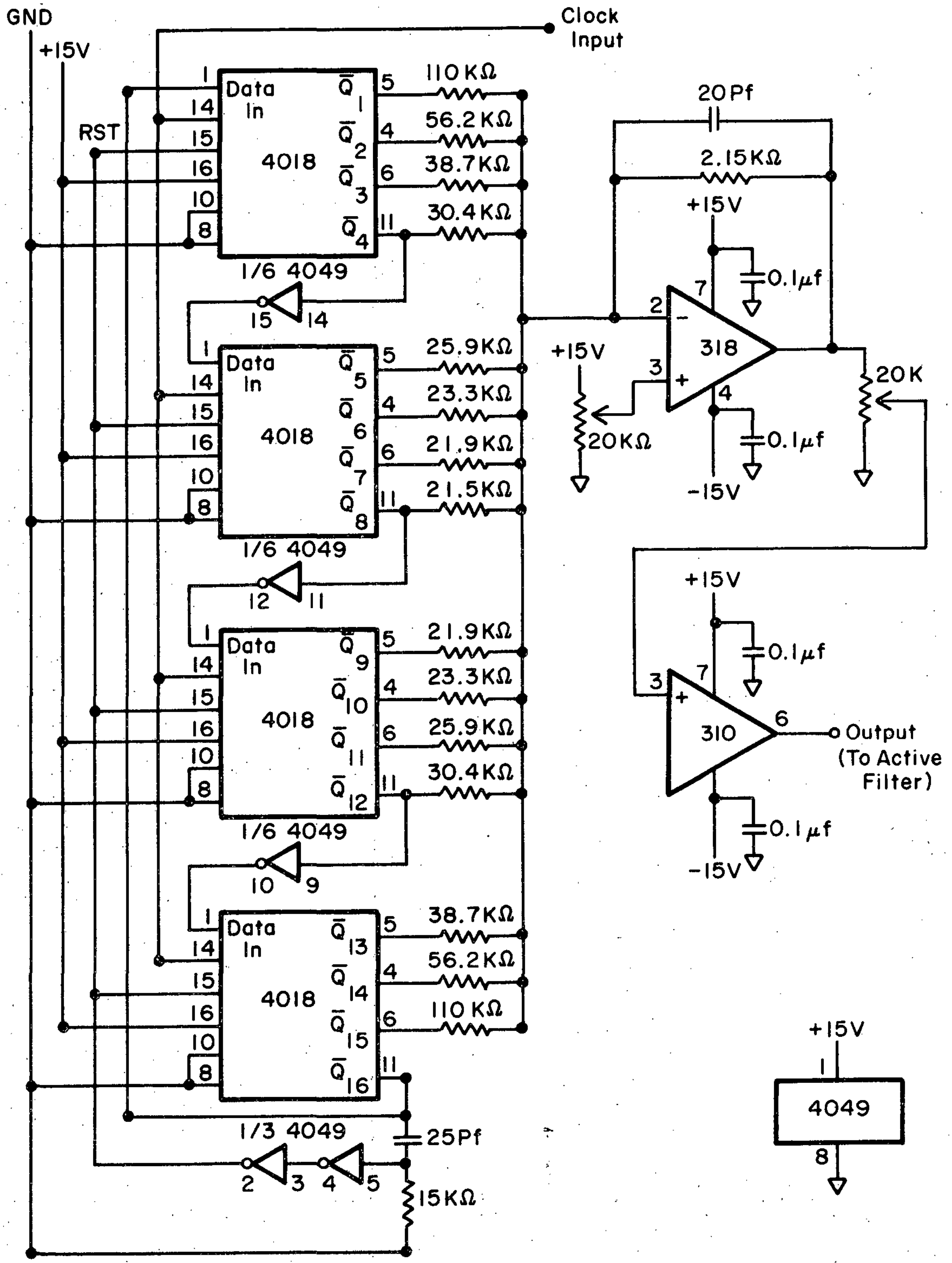
Figure 1. Circuit diagram for the 16 stage digital sine wave generator.

Figure 2. Timing diagram for the $\overline{Q}$ outputs of the twisted ring counter during normal operation. Notice RST reset pulse occurs at the point in the sequence when all Q outputs should be low ($\overline{Q}$ outputs are high).

Figure 3. Unfiltered output waveform of the digital sine wave generator.

Figure 4. Circuit diagram for wide range digital timebase with half-octave resolution.

Figure 5. Circuit diagram for two pole low pass Butterworth active filter with switch selectable cutoff frequency.


GND
+15V
RST
Clock Input
Data In
4018
1/6 4049
1/3 4049
$\bar{Q}_1$
$\bar{Q}_2$
$\bar{Q}_3$
$\bar{Q}_4$
$\bar{Q}_5$
$\bar{Q}_6$
$\bar{Q}_7$
$\bar{Q}_8$
$\bar{Q}_9$
$\bar{Q}_{10}$
$\bar{Q}_{11}$
$\bar{Q}_{12}$
$\bar{Q}_{13}$
$\bar{Q}_{14}$
$\bar{Q}_{15}$
$\bar{Q}_{16}$
110 KΩ
56.2 KΩ
38.7 KΩ
30.4 KΩ
25.9 KΩ
23.3 KΩ
21.9 KΩ
21.5 KΩ
21.9 KΩ
23.3 KΩ
25.9 KΩ
30.4 KΩ
38.7 KΩ
56.2 KΩ
110 KΩ
25Pf
15KΩ
20Pf
2.15KΩ
+15V
-15V
0.1μf
318
20KΩ
20K
310
Output (To Active Filter)
4049

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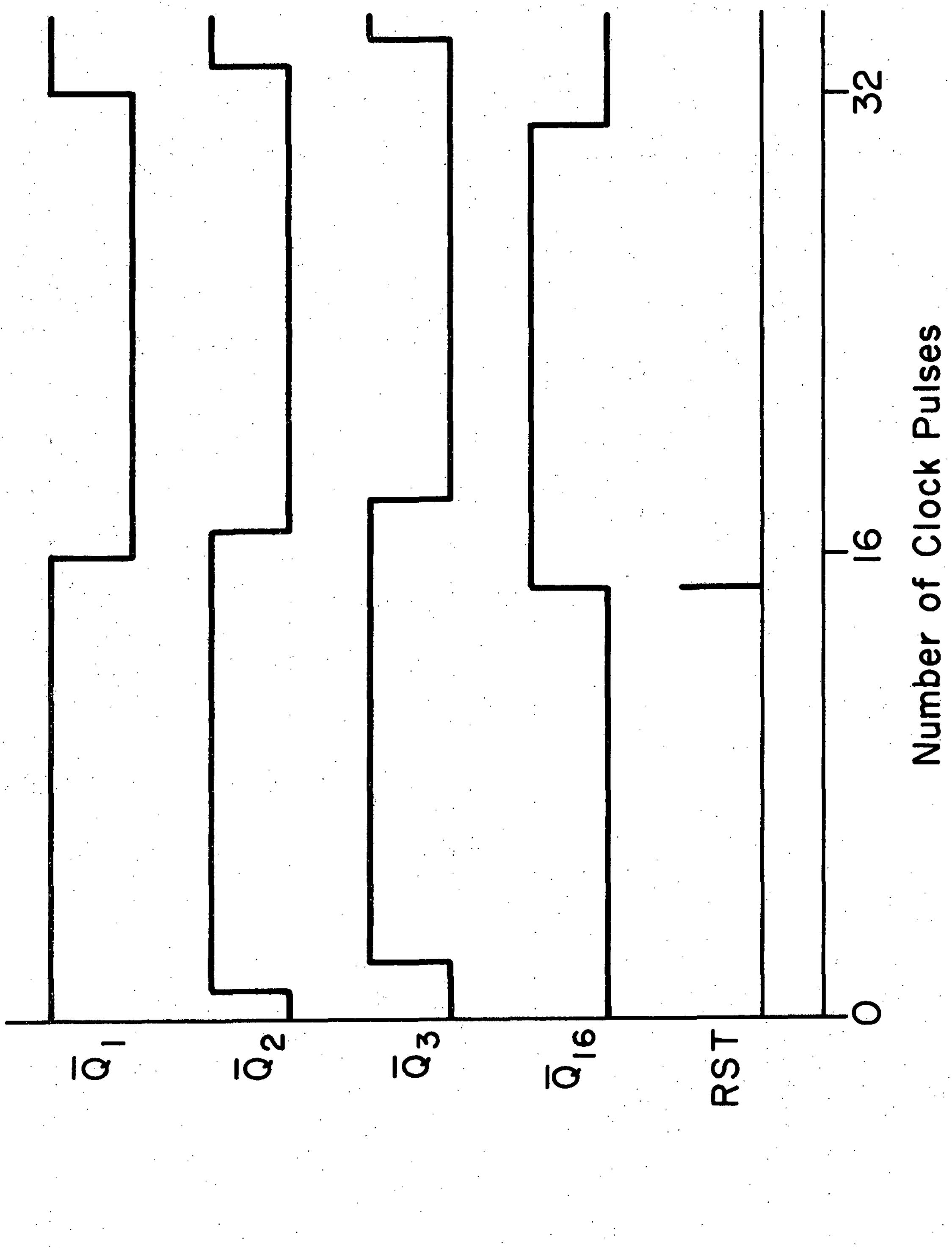

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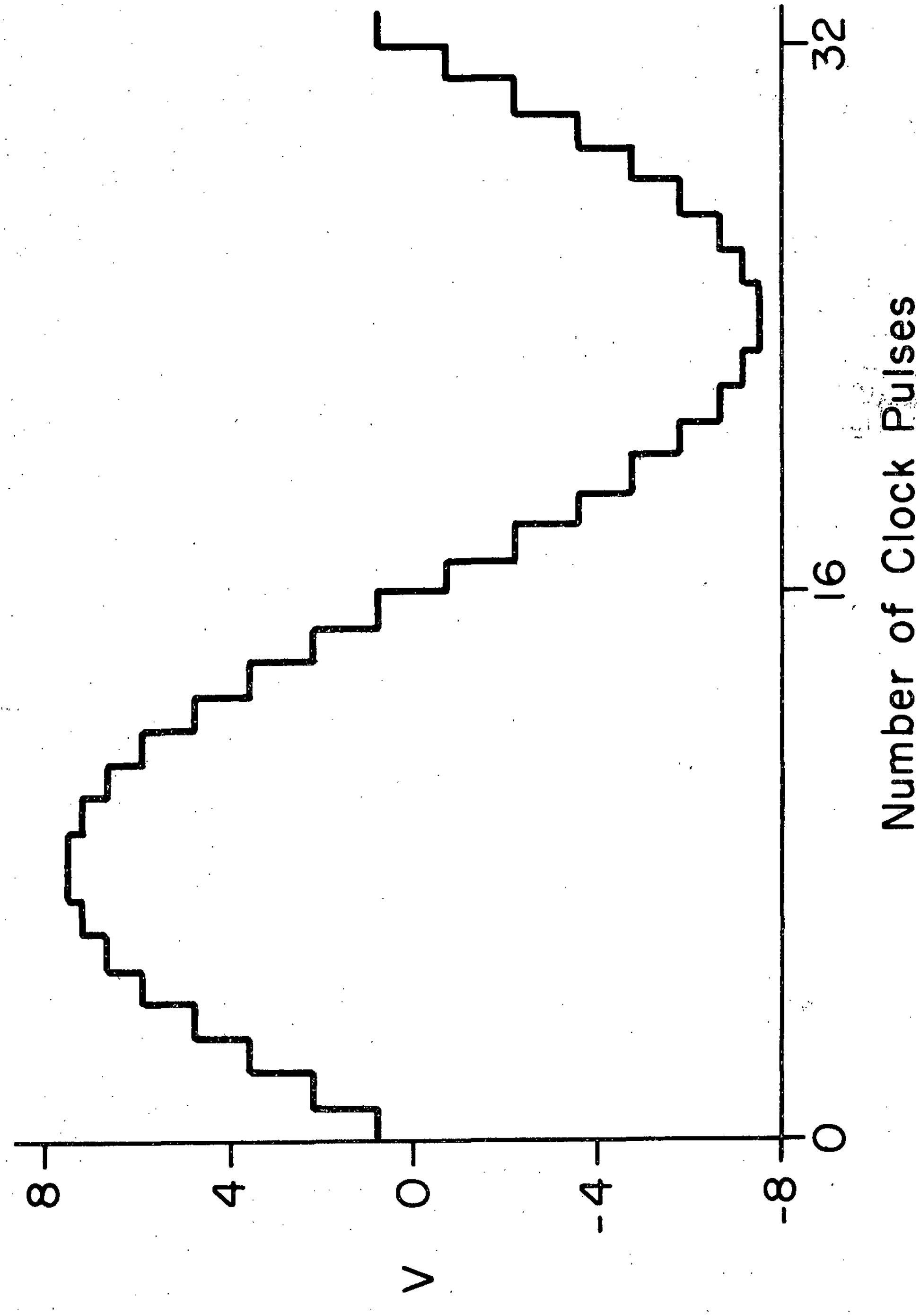
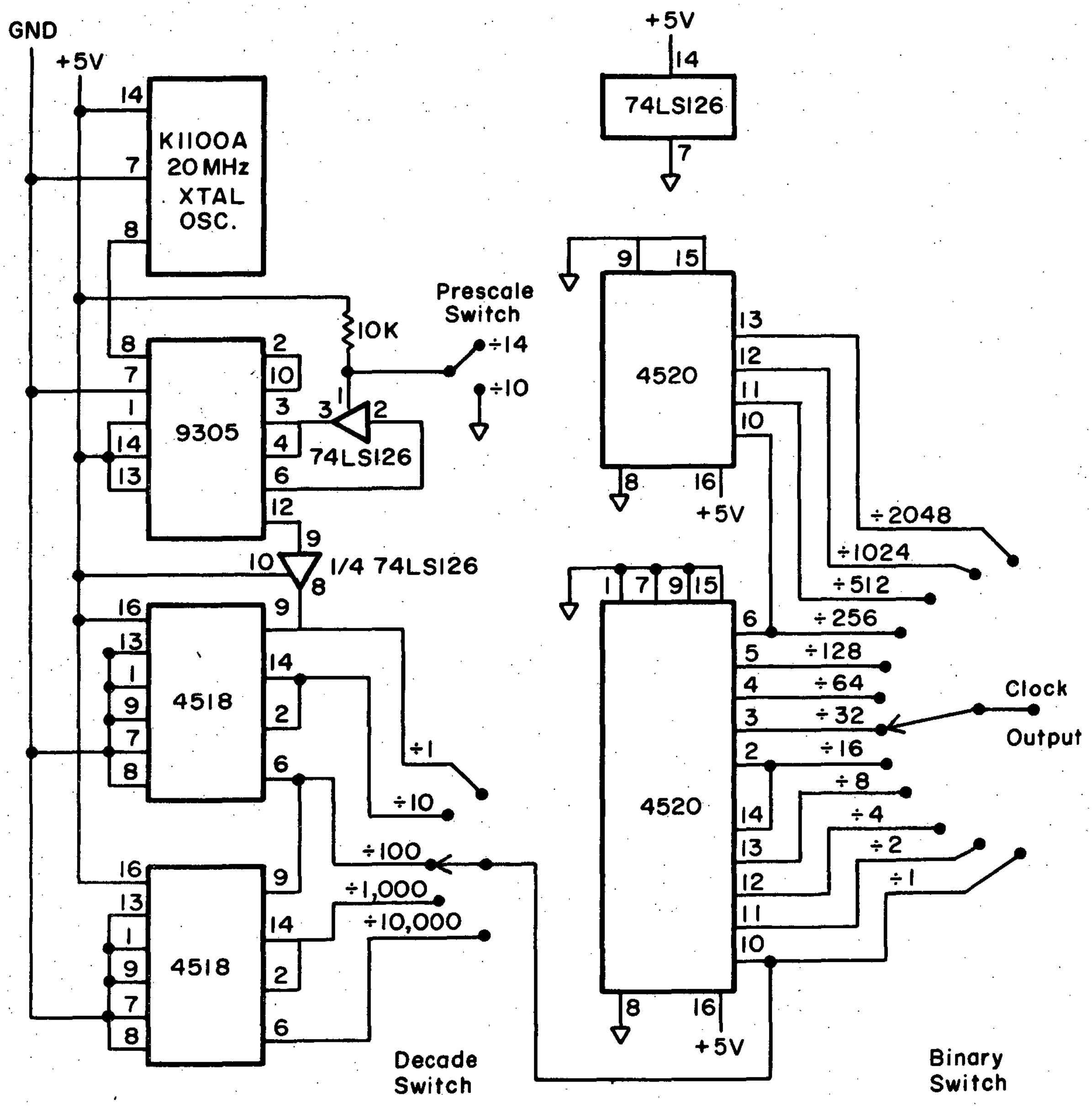
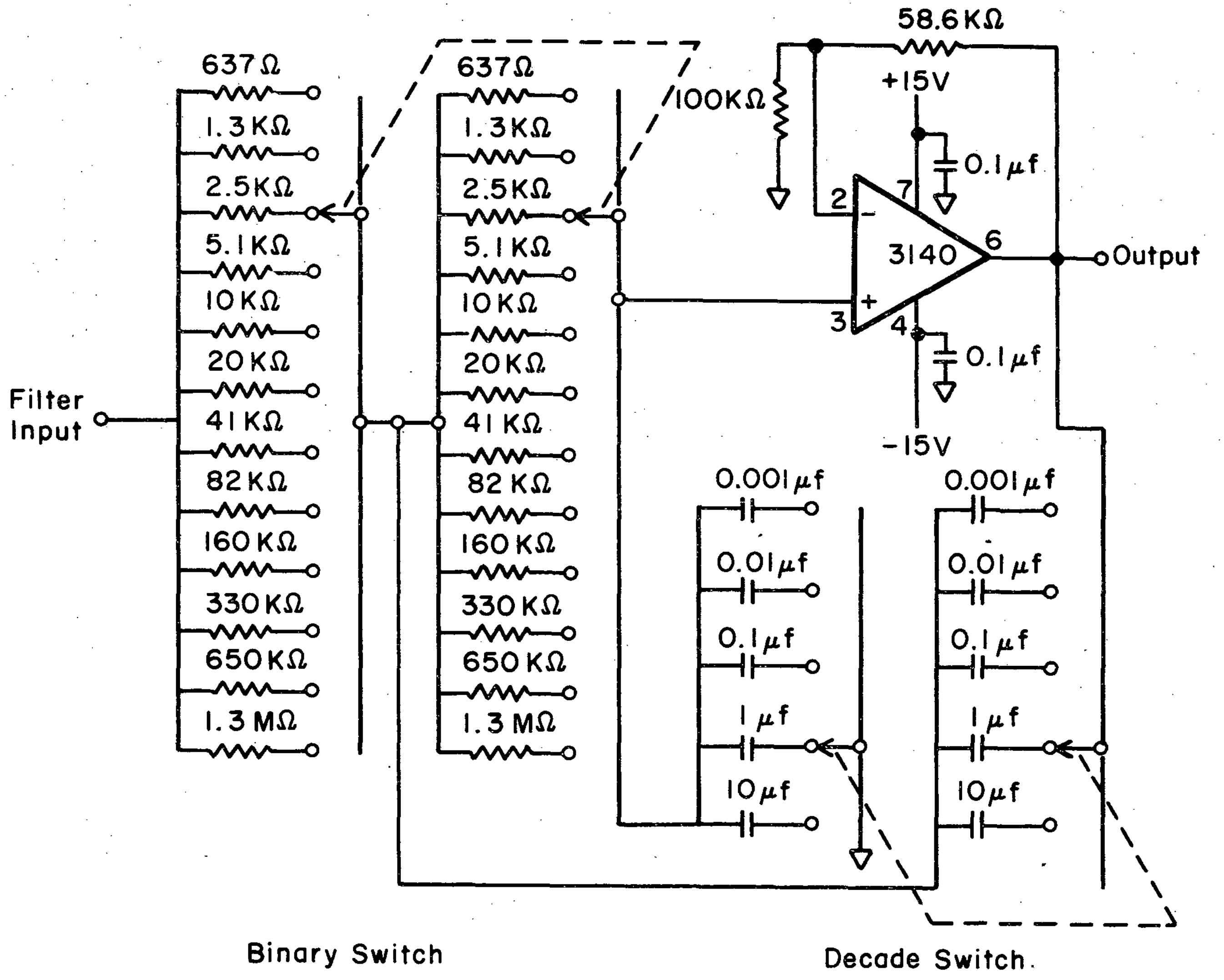


XBL 791-7668


GND
+5V
K1100A
20 MHz
XTAL
OSC.
9305
74LS126
1/4 74LS126
10K
Prescale
Switch
÷14
÷10
4518
4518
÷1
÷10
÷100
÷1,000
÷10,000
Decade
Switch
4520
4520
÷2048
÷1024
÷512
÷256
÷128
÷64
÷32
÷16
÷8
÷4
÷2
÷1
Clock
Output
Binary
Switch

XBL 791-7669



Filter Input
637Ω
1.3KΩ
2.5KΩ
5.1KΩ
10KΩ
20KΩ
41KΩ
82KΩ
160KΩ
330KΩ
650KΩ
1.3MΩ
58.6KΩ
100KΩ
+15V
0.1μf
2
7
3140
6
3
4
0.1μf
-15V
Output
0.001μf
0.01μf
0.1μf
1μf
10μf
Binary Switch
Decade Switch.

XBL 791-7670

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