Marshall

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D C 20546

REPLY TO ATTN OF: GP

OCT 12 1973

TO: KSI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code KSI, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,760,248

Government or Corporate Employee : Government

Supplementary Corporate Source (if applicable) : ——

NASA Patent Case No. : MFS-21,465-1

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:
Yes [ ] No [X]

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words ". . . with respect to an invention of . . ."

Elizabeth A. Carter

Elizabeth A. Carter
Enclosure
Copy of Patent cited above

NASA-HQ

United States Patent [19]

Nola et al.

[11] 3,760,248

[45] Sept. 18, 1973

[54] INDUCTION MOTOR CONTROL SYSTEM WITH VOLTAGE CONTROLLED OSCILLATOR CIRCUIT

[75] Inventors: Frank J. Nola; James R. Currie; Harry Reid, Jr., all of Huntsville, Ala.

[73] Assignee: The United States of America as represented by the Administrator of the National Aeronautics and Space Administration

[22] Filed: Jan. 19, 1972

[21] Appl. No.: 218,965

[52] U.S. Cl. 318/230, 307/271, 318/231, 318/341, 331/135

[51] Int. Cl. H02p 5/34

[58] Field of Search 318/227, 230, 231, 318/341, 307/228, 261, 271, 331/135, 136, 108 C, 108 D, 328/150

[56] **References Cited**

UNITED STATES PATENTS

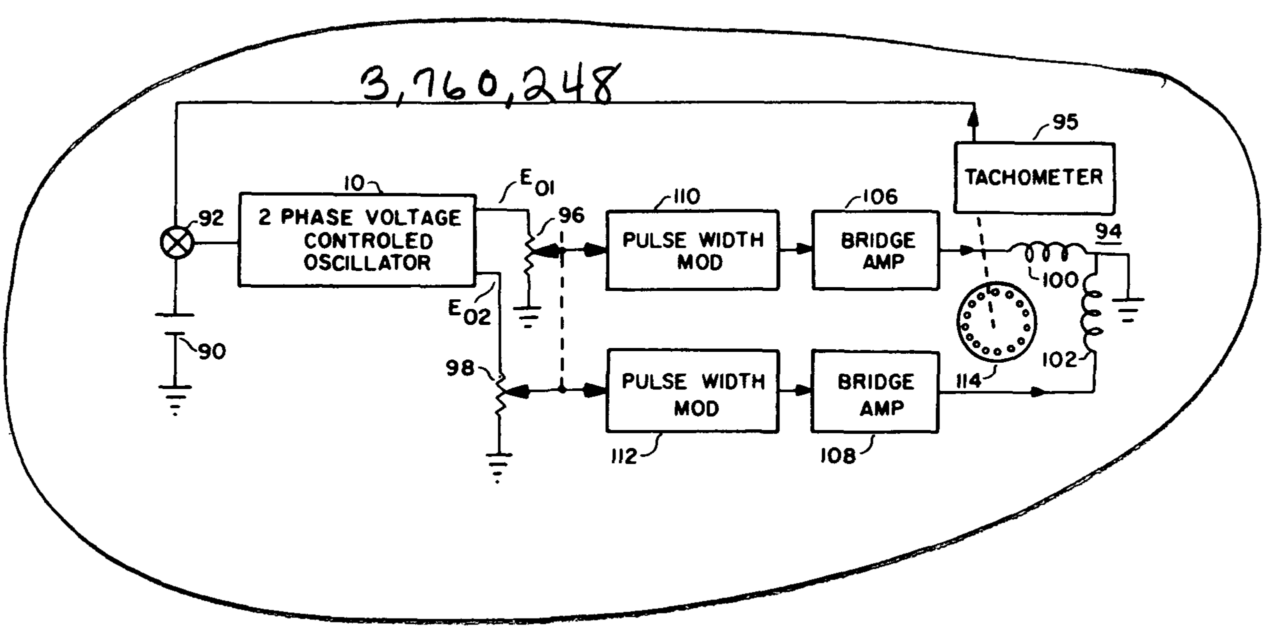
3,662,247	5/1972	Schieman	318/227 X
3,529,223	9/1970	Vergez, Jr	318/230
3,649,845	3/1972	Foch	307/228
3,594,649	7/1971	Rauch	307/271
3,659,168	4/1972	Salihi et al	318/227
3,482,116	2/1969	James	307/228 X
3,278,737	10/1966	Germain	307/261 X

Primary Examiner—J D Miller
Assistant Examiner—H Huberfeld
Attorney—L D Wofford, Jr et al

[57] **ABSTRACT**

A voltage controlled oscillator circuit, single or two phased, in which there is employed a first and second differential amplifier, the first differential amplifier being employed as an integrator for developing equal and opposite slopes proportional to an input voltage, and the second differential amplifier functioning as a comparator to detect equal amplitude positive and negative selected limits and providing switching signals which gate a transistor switch which switches the integrating differential amplifier between charging and discharging modes, whereby there is provided an output of the first differential amplifier which is triangular and which upon the application of wave shaping provides a substantially sinusoidal output signal. A two phased version, adds a second, like, integrator which is switched between charging and discharging modes by a zero crossing detector responsive to the output of the first integrator to provide a second, 90° phase shifted, output

5 Claims, 3 Drawing Figures



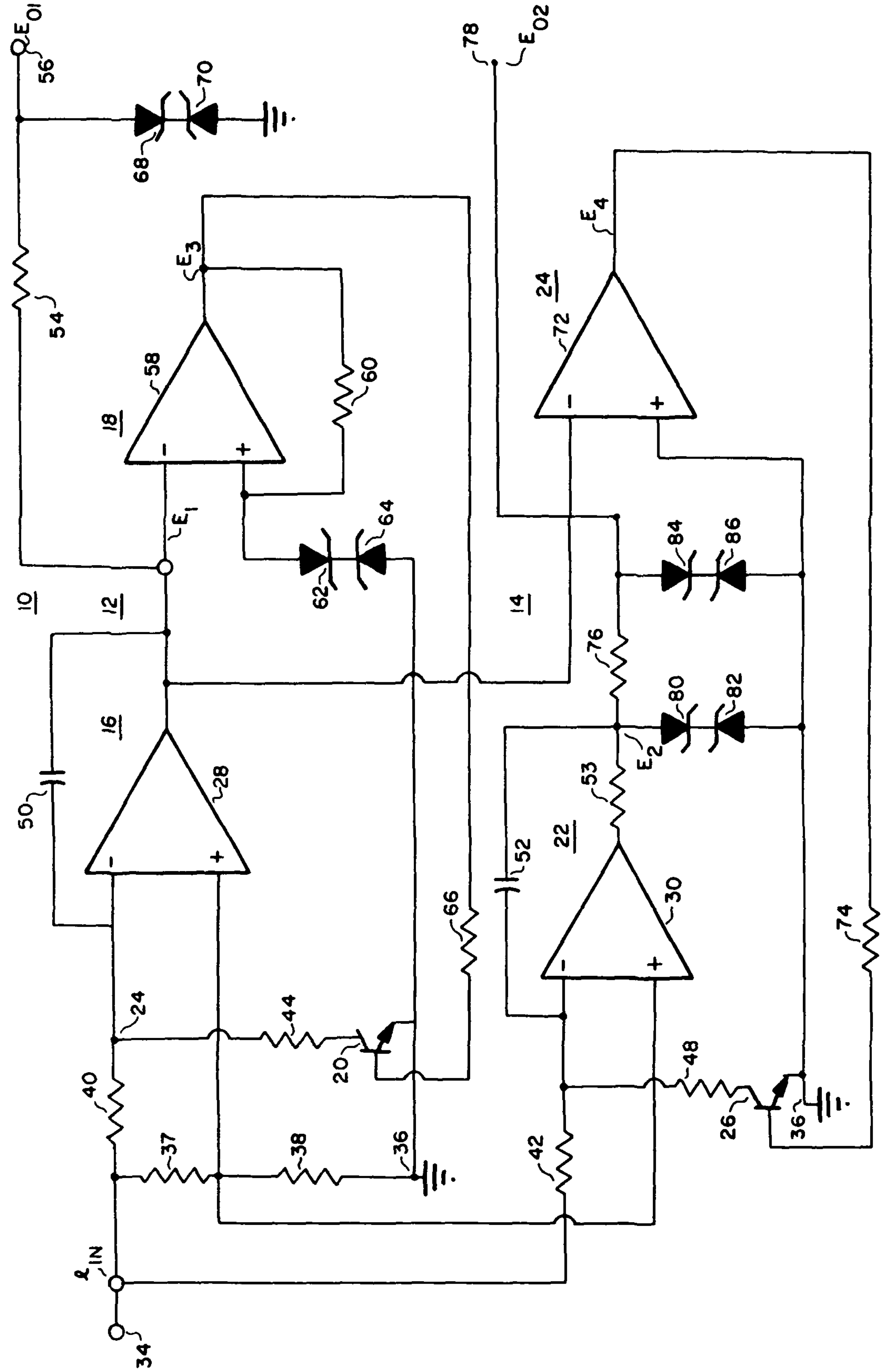

E01
56
68
70
54
E3
58
18
60
E1
62
64
10
12
16
50
28
24
44
20
66
40
37
38
36
ℓIN
34
78
E02
E4
24
72
14
84
86
76
80
82
E2
53
22
52
30
74
48
26
36
42

FIG 1

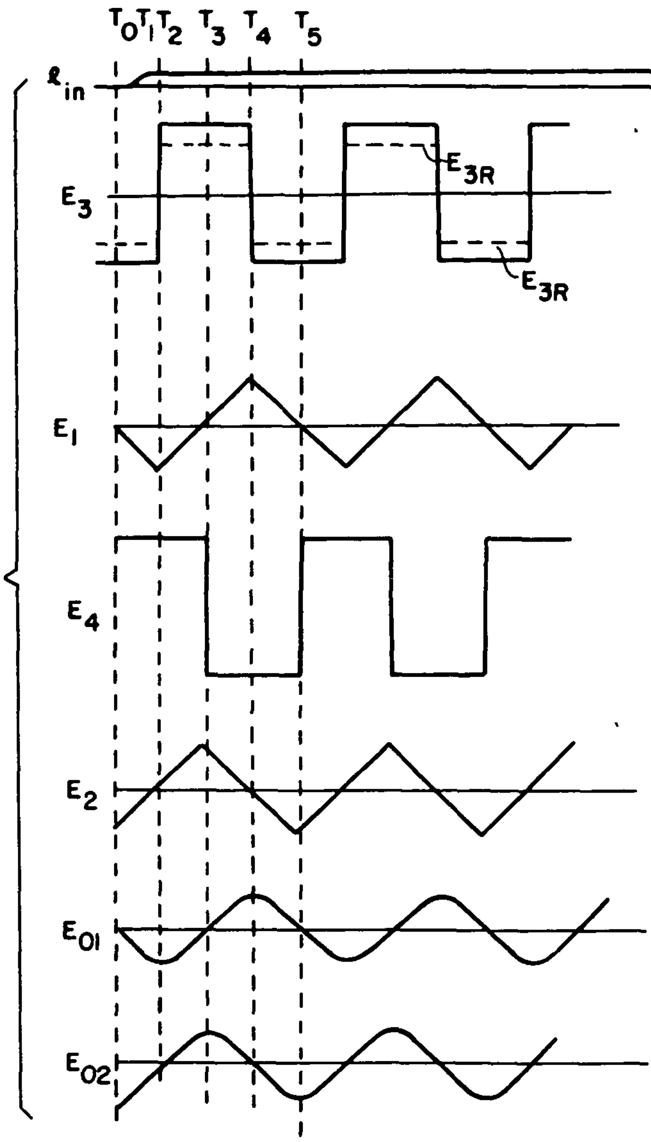

T0 T1 T2 T3 T4 T5
ℓin
E3
E3R
E3R
E1
E4
E2
E01
E02

FIG 2

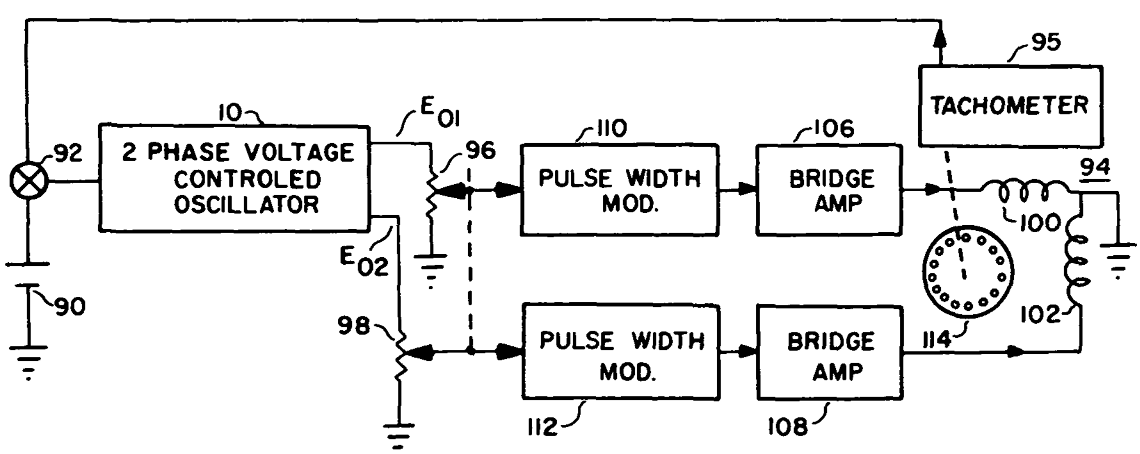

2 PHASE VOLTAGE CONTROLED OSCILLATOR
10
92
90
E01
E02
96
98
PULSE WIDTH MOD.
110
PULSE WIDTH MOD.
112
BRIDGE AMP
106
BRIDGE AMP
108
TACHOMETER
95
94
100
102
114

FIG. 3

INDUCTION MOTOR CONTROL SYSTEM WITH VOLTAGE CONTROLLED OSCILLATOR CIRCUIT

ORIGIN OF THE INVENTION

The invention described herein was made by employees of the United States and may be manufactured and used by or for the Government of the United States of America for Governmental purposes without the payment of any royalties thereon or therefor

BACKGROUND OF THE INVENTION

This invention relates to voltage controlled oscillator circuits and particularly to an improved such circuit which is readily adaptable to the generation of dual outputs displaced 90° in phase, and such as, for example, employed in the construction of two-phase motor control circuits

GENERAL DESCRIPTION OF THE PRIOR ART

Heretofore the generation of two 90° phase displaced signals at frequencies varying as a function of a control voltage has generally involved one or two approaches In one, a conventional voltage controlled oscillator (V C ( ) employs a variable reactance controlled resonant circuit to convert a D C signal to a varying frequency A C signal A second signal, displaced 90° in phase, is then derived from the first signal by means of a reactance network The difficulty with this approach is that reactance networks are frequency sensitive and provide only an accurate 90° phase shift for a limited range of frequencies The second approach is to square the sine wave output of the V C O and employ logic circuitry to obtain two timed square waves which are related in phase by 90°. These square waves are then subjected to wave shaping techniques to provide an output approximating two sinusoidal waveforms, differing in phase by 90°. The difficulty of this approach is that it requires fairly complex circuitry and is expensive

SUMMARY OF THE INVENTION

Accordingly, it is an object of this invention to provide an improved voltage controlled oscillator and control circuits employing same, of improved accuracy, of low cost, of excellent efficiency and of extreme reliability

In accordance with the invention a voltage controlled oscillator is constructed of a dual sloped integrator, a comparator, and a switch wherein the comparator detects equal and opposite selected excursions of the output of the integrator and controls the switch which in turn switches the integrator between rising slope modes and descending slope modes As a further feature of the invention a zero crossing detector, a second integrator and a second switch are added. The zero crossing detector is driven by the output of the first integrator and applies switching signals to the second switch to cause it to switch slope modes of the second integrator coincident with a crossing of the origin of the output of the first integrator With these additions a two phased voltage controlled oscillator is provided wherein the first phase voltage is available at the output of the first integrator and the second, 90° displaced phase, voltage is available at the output of the second integrator As a still further feature of the invention the two phased version of the invention is included in a motor control circuit wherein an AC induction motor is controlled as a function of slip frequency

BRIEF DESCRIPTION OF THE DRAWINGS

FIG 1 is an electrical schematic diagram of a two-phase voltage controlled oscillator embodying the invention

FIG 2 is a graphical representation of waveforms pertinent to the operation of the invention

FIG 3 is an electrical block diagram of an induction motor speed control system embodying the invention

DESCRIPTION OF THE PREFERRED EMBODIMENT

Oscillator circuit **10** consists basically of reference phase oscillator **12** and 90° shifted phase oscillator **14.** Reference oscillator **12** in turn basically consists of integrator **16**, comparator **18** and transistor switch **20.** Oscillator **14** basically consists of integrator **22**, zero crossing detector, or squaring circuit, **24** and transistor switch **26.** Integrators **16** and **22** are identical, having like differential amplifiers **28** and **30** fed from common input terminals **34** and **36** (ground)

The input voltage e_{in} to the circuit (FIG 2) is equally divided by equal value resistors **37** and **38** connected across input terminals **34** and **36** with the full input voltage being applied through like value resistors **40** and **42** to the minus or inverting inputs of differential amplifiers **28** and **30**, respectively One half of the input voltage, appearing at the intersection of resistors **37** and **38** is applied to the plus or non-inverting inputs of both differential amplifiers **28** and **30.** Resistor **44** is connected between the inverting input of differential amplifiers **28** through transistor switch **20** to reference potential ground terminal **36** and resistor **48** is connected from the inverting input of amplifier **30** through transistor switch **26** to ground terminal **36.** Integrating capacitors **50** and **52** are of equal value, capacitor **50** being connected between the output and inverting input of differential amplifier **28** and capacitor **52** being connected through output current limiting resistor **53** between the output and inverting input of differential amplifier **30.** The output E_1 of differential amplifier **28**, and thus of integrator **16**, provides the reference phase output through current limiting resistor **54** to output terminal **56** and inputs to comparator **18** and zero crossing detector **24.**

Comparator **18** employs differential amplifier **58**, to which positive feedback resistor **60** is connected between the output and non-inverting input Back-to-back Zener diodes **62** and **64** are connected between the non-inverting input of differential amplifier **58** and ground and function as a bi-polarity voltage regulator

The input to differential amplifier **58** is applied to the inverting input and the output is applied through resistor **66** to the base input of transistor switch **20.** Back-to-back Zener diodes **68** and **70** are connected between output terminal **56** and ground and function to truncate the otherwise triangular wave output E_{01} of integrator **16.**

Zero crossing detector **24** employs differential amplifier **72** with its input applied on its inverting input terminal and its output being applied through resistor **74** to the base input of transistor switch **26.** The non-inverting input of differential amplifier **72** is grounded The output E_{02} of 90° shifted phase oscillator **14** is supplied from the output of differential amplifier **30** through resistor 53 and resistor 76 to output terminal 78.

Back-to-back Zener diodes 80 and 82, connected between the output of integrator 22, at the intersection of resistor 53 and 76, and ground are of the same value as Zener diodes 62 and 64 and thus provide the same stable voltage limits on the output signal from differential amplifier 30 as provided from the output of differential amplifier 28. Resistor 53 functions to provide a desired current level to Zener diodes 80 and 82 and thus provide the same stable voltage limits of the output signal E_2 from differential amplifier 30 as provided by the output E_1 of differential amplifier 28. Resistor 76 functions to provide a desired current level to Zener diodes 84 and 86 which function as do Zener diodes 68 and 70 to truncate the output signal E_{02} In the illustrated example, Zener diodes 62 and 64 and 80 and 82 set slope switching voltage to nine volts and Zener diodes 68 and 70 and 84 and 86 cut off or truncate the output voltages at six volts

Differential amplifiers 28, 30, 58 and 72 are standard operational amplifiers wherein the output voltage

$$e_o = -e_{in} Z_f/Z_i \qquad 1$$

where Z_f is the feedback transfer impedance, Z_i is the input transfer impedance and e_{in} is the voltage applied to the input terminal to which the input impedance Z_i is connected and the input terminal is the inverting (−) terminal of the operational amplifier For voltages applied directly to the non-inverting (+) input terminal, the output may be represented as

$$e_o = e_{in} (1 + Z_f/Z_i) \qquad 2$$

Differential amplifier 58 of comparator 18 has a relatively high gain and its output is either fully positive or fully negative depending upon the voltage level and polarity of voltage of the E_1 output of differential amplifier 28, which is applied to the inverting input of differential amplifier 58. The output voltage E_3 of differential amplifier 58 provides through resistor 60 and Zener diodes 62 and 64 a maximum, plus or minus, voltage of nine volts at its non-inverting input As explained above, the function of differential amplifier 58 is to turn transistor switch 20 off or on If E_1 applied to the inverting input of differential amplifier 58 is greater than the fixed nine volt reference level at the non-inverting input, then the output of the differential amplifier switches to a maximum minus voltage and turns off transistor switch 20. If E_1 falls below the reference level at the non-inverting input of differential amplifier 58, then the output switches to a positive value and a "turn on" current flows through resistor 66 to transistor switch 20 causing it to effectively ground the lower end of resistor 44 and cause integrator 16 to switch slopes of integrating mode as will be further explained below

The equations for determining the output of differential amplifier 28 are as follows First, assuming that switch 20 is turned off, the feedback and input transfer impedances of differential amplifier 28 are computed as follows

$$Z_f = 1/CS \qquad 3$$

where S is the LaPlace operator

$$Z_{in} = 2R_1 \qquad 4$$

Where R_1 is the value of resistor 40.

Referring to Equations 1 and 2

$$E_1 = -e_{in}\, 1/2R_1CS + e_{in}/2\ (1 + 1/2R_1CS) \qquad 5$$

simplifying

$$E_1 = -e_{in}/4R_1CS + e_{in}/2$$

with transistor switch turned on

$$Z_f = 1/CS \qquad 7$$

Z_{in} with respect to the inverting input is $2R_1$ Since resistor 44 is now at ground, the transfer impedance with respect to the non-inverting input is.

$$Z_{in} = (2R_1 \times R_1/R_1 + 2R_1) = 2/3\ R_1 \qquad 8$$

$$E_1 = -e_{in}\, 1/2R_1CS + e_{in}/2\ (1 + 3/2R_1CS) \qquad 9$$

simplifying

$$E_1 = e_{in}/4R_1CS + e_{in}/2 \qquad 10$$

the output frequency f is then by the equation

$$f = 1/t = e_{in}/16V_zR_1C \qquad 11$$

where V_z is the voltage reference established by Zener diodes 62 and 64, R_1 is resistor 44 and resistor 40 is double the value of resistor 44 and thus indicated above as $2R_1$

It is to be noted that the slope of the frequency dependent term in Equation No 6 applied when transistor switch 20 is turned off and the frequency dependent term in Equation 10 applied when transistor switch 20 is on and that the terms are equal but opposite in sine The term $e_{in}/2$ is an initial condition and has no effect on the steady state operation of the circuit

The operation of the circuit is as follows Assume initially that at time T_0 (FIG. 2) the input e_{in} is zero, that the output of differential amplifier 58, E_3, is negative and that transistor switch 20 is turned off Assume next that at time T_1 e_{in} is raised to a positive value This will cause the output E_1 of differential amplifier 28 to integrate downward When, at time T_2, this voltage, applied to the inverting input of differential amplifier 58 becomes more negative than the nine volt reference level, E_{3R} established by Zener diodes 62 and 64 the output of differential amplifier 58 switches positive which then turns on transistor switch 20 and connects resistor 44 to ground As shown by the above equations, this causes the gain seen by the non-inverting input of differential amplifier **28** to be significantly greater than that seen by the inverting input and causes the output of differential amplifier **28** to integrate upward with a slope equal in magnitude to the previous negative going slope When the output of differential amplifier **28** reaches the positive level of nine volts established by Zener diodes **62** and **64**, at time T_4, the output of differential amplifier **58** switches negative and the process repeats

It can be seen that the rate of integration and hence the frequency is proportional to the voltage level e_{in} The resulting triangular wave output E_1 of differential amplifier **28** is truncated by a limiting circuit consisting of resistor **54** and Zener diodes **68** and **70** to provide the waveform E_{01} with a plus and minus amplitude of approximately six volts The resultant waveform produced in this manner has a low harmonic content and approaches a sinusoid The approximation to a sinusoid is enhanced by the soft clipping features of Zener diodes **68** and **70.**

It should be observed at this point that the circuit thus far described has application as a voltage controlled oscillator with square wave, triangular wave or pseudo-sinusoidal output In addition, it has application as a simple, accurate analog to digital convertor

The remainder of the circuit generates a second pseudo-sinusoidal output E_{02} at terminal **78** locked in frequency to the basic signal E_{01} appearing at terminal **56** but shifted in phase 90 electrical degrees Differential amplifier **30** of integrator **22** operates similarly to that of differential amplifier **28** and is driven from the same input e_{in} voltage across resistors **37** and **38** and has the same time constant The difference is that transistor switch **26**, the on-off condition of which determines the polarity of the slope of the output of differential amplifier **30**, is driven by differential amplifier **72** in turn driven by the output E_1 of differential amplifier **28.** The output of differential amplifier **72** is thus a square wave output E_4 with trailing and leading edges at times T_3 and T_5 corresponding to the midpoints of the slopes of triangular wave E_1 The output circuit of differential amplifier **30** includes current limiting resistor **53** and Zener diodes **80** and **82** which are of the same characteristic as Zener diodes **62** and **64** and thus establish a stable peak-to-peak level for the voltage excursions from differential amplifier **30**, being approximately nine volts peak-to-peak Truncation of the output of differential amplifier **30** is achieved through current limiting resistor **76** and Zener diodes **84** and **86** which have the same characteristic as Zener diodes **68** and **70** to provide a truncated output level of approximately six volts as shown in waveform E_{02} There is thus provided a second pseudo-sinusoid output locked in frequency to the first and shifted 90°. The amplitudes of the two tinusoid outputs are independent of frequency.

FIG 3 illustrates a two phase induction motor control system in which a two-phase voltage controlled oscillator **10**, shown in FIG. **1**, is employed to develop alternating current signals of appropriate frequency, phase and amplitude to drive a two phase induction motor under load conditions which do not permit rapid increases in speed or high input currents D C source **90** provides a reference voltage input to adder **92** representative of a voltage which if alone applied to two-phase voltage control oscillator **10** would provide, as an output, 90° displaced voltages of a frequency representative of the characteristic slip frequency of two phase induction motor **94** which produces maximum torque Tachometer **95** driven by the shaft of motor **94** provides a second input to adder **92** to provide an input D.C voltage proportional to actual speed of motor **94.** Thus adder **92** provides a direct current output apropriate to cause two phase voltage control oscillator **10** to provide output signals of a frequency equal to actual speed of motor **94** plus a slip frequency In order to regulate or adjust the actual input current to motor **94** to accommodate a particular rate of acceleration to a desired speed, the phased outputs E_{01} and E_{02} of oscillator **10** are passed through ganged potentiometers **96** and **98.** As shown here, the actual inputs to the two phased windings **100** and **102** of motor **94** are supplied power from bridge amplifiers **106** and **108** which are in turn controlled by pulse width modulators **110** and **112** in accordance with signals from potentiometers **96** and **98.** Pulse width modulators **110** and **112** are typically of a type disclosed in U S Pat No 3,523,228, and bridge amplifiers **106** and **108** are typically of a type disclosed in U S Pat No 3,260,912

To consider operation of the speed control circuit and with motor **94** initially stalled, a selected input voltage is provided by source **90** through adder **92** to the input of oscillator **10.** The resulting frequency out of oscillator **10** to potentiometers **96** and **98** is a slip frequency at which motor **94** is designed to develop maximum torque The outputs of potentiometers **96** and **98** are converted to variable width pulses in pulse modulators **110** and **112** which in turn control bridge amplifiers **106** and **108** to drive windings **100** and **102** of motor **94.** As motor **94** begins to turn, tachometer **95** applies a D C voltage proportional to speed to an input of adder **92** and the sum voltage (source **90** + speed signal) is then fed as the control input to oscillator **10.** As motor **94** increases in speed, the drive frequency generated by oscillator **10** increases and pulls the rotor **114** of motor **94** to a higher speed This allows the motor to always operate at the frequency at which it develops its maximum torque. Current limiting is accomplished by adjusting potentiometers **96** and **98** for a maximum output and by summing this output with a feedback voltage which is proportional to motor current In order to automatically facilitate the variable voltage inputs to pulse width modulators **110** and **112** for applications where variable torque and speed are required, potentiometers **96** and **98** may be replaced by multipliers which multiply the variable frequency A C signal with a D.C control signal which increases in accordance with a selected function of speed. The output of the multipliers would then be an A C signal with an amplitude proportional to the D.C speed signal

It is believed that this invention provides an improved voltage controlled oscillator which may be employed in a variety of applications as outlined above It is constructed of few and relatively inexpensive components thus providing a substantial improvement for such type devices As a convertor of a D.C voltage to an A.C. voltage, with frequency as a function of voltage, it is capable of producing an output linear to a figure of 0 1 percent or better As a source of 90° displaced A C signals it has not only excellent accuracy but requires only slightly more components than a single phase oscillator Further, it enables the determination of an improved motor control system for the control of A C. induction motors in those applications where it is required to develop high torque over the entire speed range of the motor.

What is claimed is:

1. A voltage controlled oscillator circuit comprising integrating means including a single electrical integrator responsive to an input electrical potential applied with respect to a circuit reference potential point for providing an output having a slope of a magnitude in a first polarity direction proportional to said input potential and including switching means responsive to a switching signal for causing said slope of said output to assume a slope of like magnitude but of opposite polarity direction, and

comparator means responsive to a fixed reference potential and selected equal-amplitude but opposite-polarity outputs of said integrating means for providing said switching signals to said switching means whereby each said slope is caused to be of equal length and wherein an alternating current output is available from said output of said integrating means which varies in frequency directly with said electrical input potential,

whereby an alternating current signal is provided at the output of said single electrical integrator with respect to said circuit reference potential point.

2. A voltage controlled oscillator circuit as set forth in claim 1 further comprising:

second integrating means including a second single electrical integrator responsive to said input electrical potential for providing an output having a slope of a magnitude proportional to said electrical input potential in a first polarity direction and including second switching means responsive to a switching signal for causing said last named slope of said last named output to assume a slope of like magnitude but of opposite polarity direction, and

zero crossing detection means responsive to the output of said first named electrical integrator for providing switching signals to said second switching means whereby each said slope of said output of said second single electrical integrator is of equal length and wherein an alternating current output is available from the output of said second integrator which is of like frequency and amplitude to that of the output of said first integrator but is displaced in phase by 90°.

3. A voltage controlled oscillator circuit as set forth in claim 1 wherein said comparator means comprises

a differential amplifier,

a feedback path from the output to the non-inverting input of said differential amplifier, and

a bi-potential voltage regulator connected between the non-inverting input of said differential amplifier and said circuit reference potential point, and

means for connecting the output of said single electrical integrator to the inverting input of said differential amplifier and the output of said differential amplifier to said switching means.

4. A voltage controlled oscillator circuit as set forth in claim 3 wherein said single electrical integrator comprises

a second differential amplifier,

a capacitor connected between the output and inverting input of said second differential amplifier,

a first resistor connected in series with the inverting input of said differential amplifier,

a second resistor connected in series with said first resistor between the inverting input and the non-inverting input of said second differential amplifier and a third resistor of like value to said second resistor being connected between said last named inverting input and said circuit reference potential point, and

said switching means comprises a transistor switch and a fourth resistor, said fourth resistor being connected in series with the output circuit of said transistor switch between the inverting input of said second differential amplifier and said circuit reference potential point, and said switching signals are applied to the input of said transistor switch.

5. In a motor control system in which an induction motor is controlled in speed by a voltage controlled two-phased oscillator, and said system comprising

reference voltage means for providing a selected direct current voltage representative of an optimum slip frequency at a maximum torque for a said motor,

rate means connected to the output of said motor for providing a direct current output voltage proportional to the speed of said motor,

summing means proportional to the output of said rate means and said reference voltage means for providing an output proportional to the sum of the output of said rate means and said reference voltage means,

first integrating means including a first single electrical integrator responsive to the output of said summing means for providing an output having a slope of a magnitude in a first polarity direction proportional to its input and including switching means responsive to a switching signal for causing said slope of said output to assume a slope of like magnitude of opposite polarity direction, and

comparator means responsive to a fixed reference potential and and selected equal-amplitude but opposite-polarity outputs of said first integrating means for providing said switching signals to said switching means whereby each said slope is caused to be of equal length and wherein an alternating current output is provided at the output of said first integration means which varies in frequency directly with said output of said summing means,

second integrating means including a second single electrical integrator responsive to said output of said summing means for providing an output having a slope and a magnitude proportional to its input in a first polarity direction and including second switching means responsive to a switching signal for causing said last named slope of said last named output to assume a slope of like magnitude but of opposite polarity direction; and

zero crossing detection means responsive to the output of said first single electrical integrator for providing switching signals to said second switching means whereby each said slope of said output of said second single electrical integrator is of equal length and wherein an alternating current output is provided from the output of said second integrator which is of like frequency and amplitude to that of the output of said first integrator but is displaced in phase by 90°.

* * * * *