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Wehmeier

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(54) **SINE-COSINE MODULATOR**

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PCT Pub. Date: **Mar. 13, 2014**

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(51) **Int. Cl.**
H03C 3/02 (2006.01)
H03F 3/217 (2006.01)

(52) **U.S. Cl.**
CPC ***H03C 3/02*** (2013.01); ***H03F 3/217*** (2013.01); ***H03F 3/2171*** (2013.01)

(58) **Field of Classification Search**
CPC H03K 7/08; H02M 3/338; H02M 3/156; H03F 3/217; H03F 3/2171
USPC 327/336, 172, 129; 323/284; 363/13, 363/18; 330/251, 260
See application file for complete search history.

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Jun Yu et al.: "A Dual-Feedforward Carrier Modulated Second-Order Class-D Amplifier with Improved THD", IEEE Transactions on Circuits and Systems II: Epress Briefs, IEEE, US, vol. 59, No. 1, Jan. 1, 2012, pp. 35-39, XP011397557, ISSN: 1549-7747, DOI: 10.1109/TCSII.2011.2173973, Figure 3.

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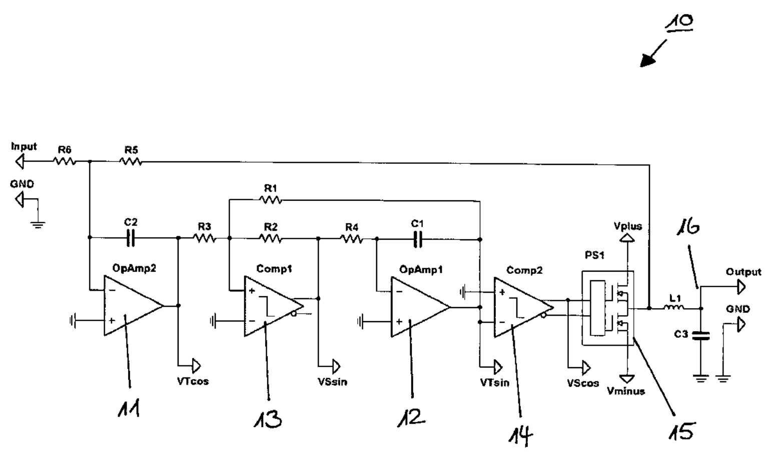
(57) **ABSTRACT**

The invention relates to a self-oscillating pulse-width modulation amplifier in the form of a sine-cosine modulator (**10**) comprising at least two comparators (**13**, **14**), two integrators (**11**, **12**), a power switching stage (**15**), and negative feedback coupling with a low-frequency signal input and output. To achieve a maximum modulation factor, there are provisions with the aid of the comparators (**13**, **14**) and integrators (**11**, **12**) for the generation of sine- and cosine-square-wave voltages and sine- and co-sine-triangle-wave voltages that drive the power switching stage (**15**) in part, wherein the output of the power switching stage (**15**) combined with an LC low-pass filter (**16**) forms the low-frequency signal output. This brings about a situation in which a stable natural frequency exists and the modulation factor can be increased to nearly 100%. At the same time, a very low level of distortion is achieved and no distortion components higher than K3 arise, so there is a significant improvement vis-a-vis the known pulse-width modulation amplifiers.

9 Claims, 16 Drawing Sheets



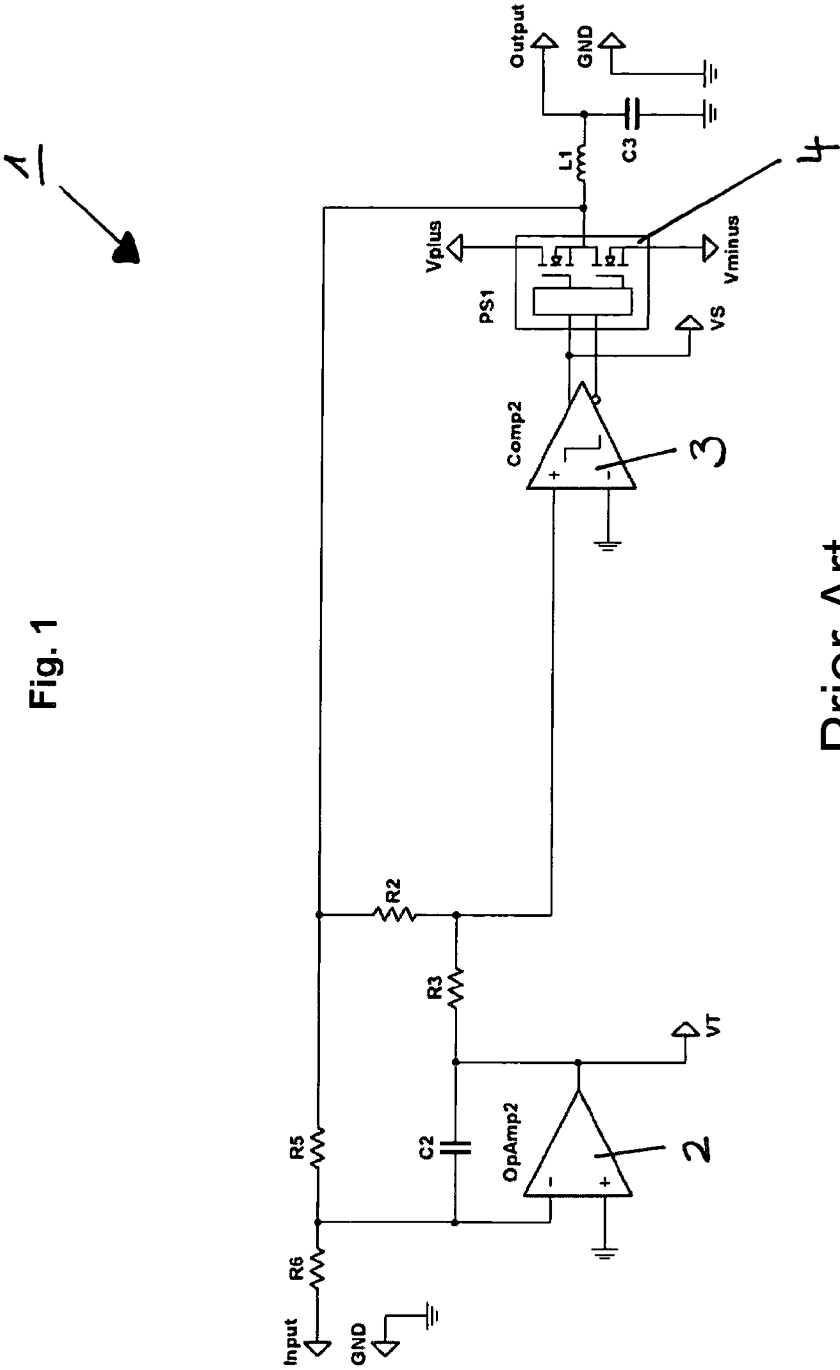
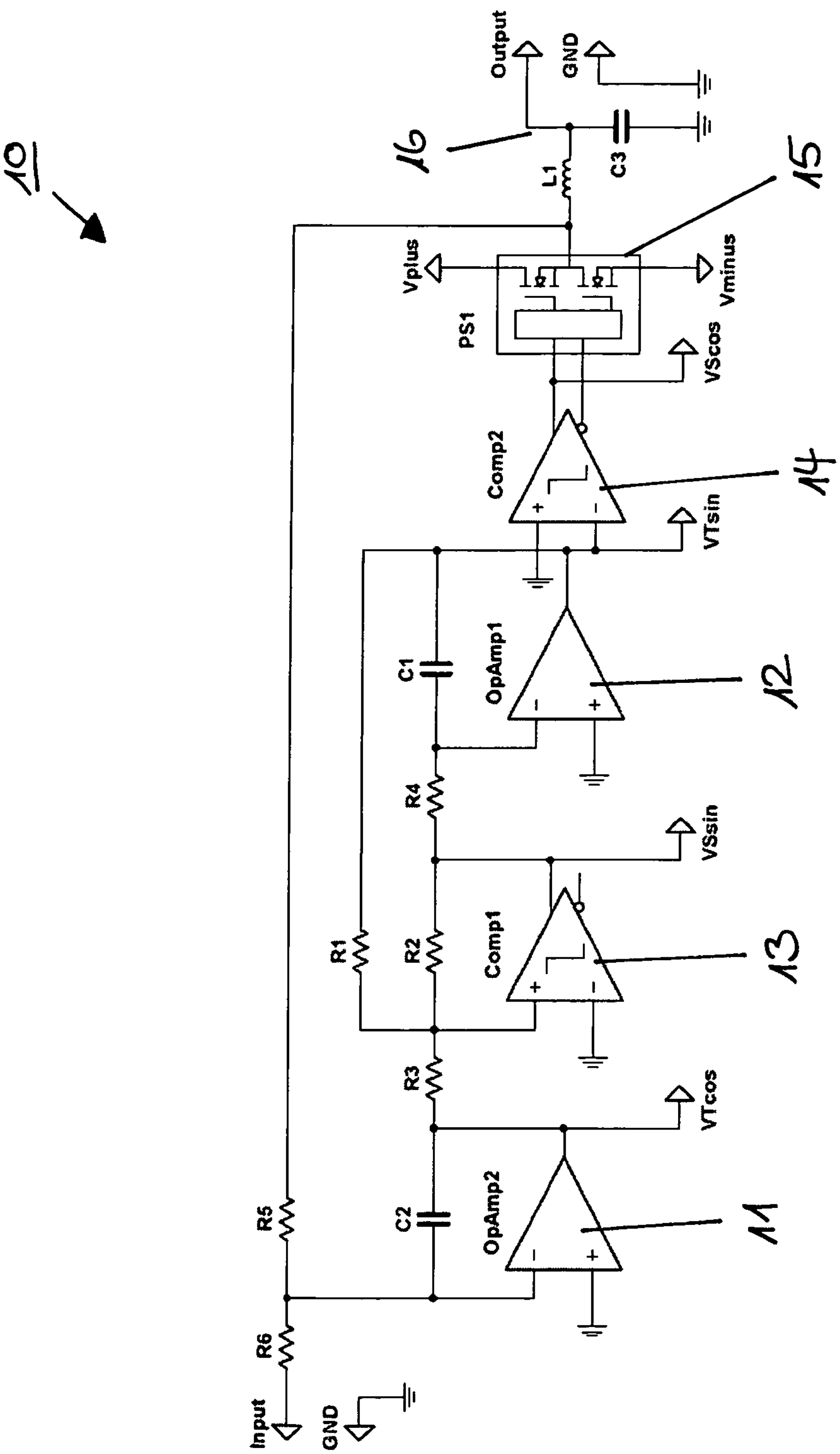


Fig. 1

Prior Art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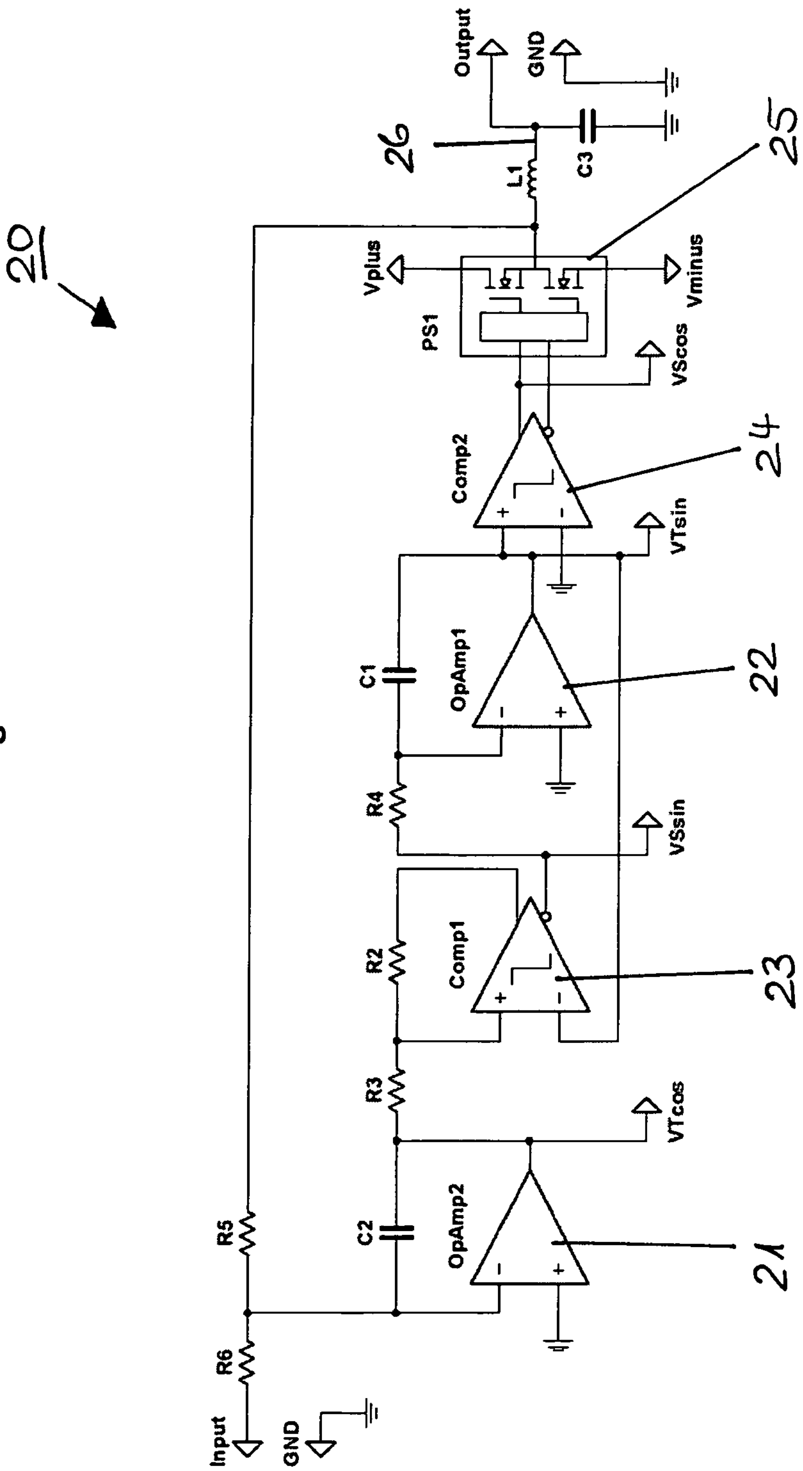
Output
GND
16
L1
C3
15
Vplus
Vminus
PS1
VScos
Comp2
14
VTsin
C1
OpAmp1
12
R4
VSsin
R1
R2
Comp1
13
R3
VTcos
R5
C2
OpAmp2
11
R6
Input
GND

Fig. 2

Fig. 3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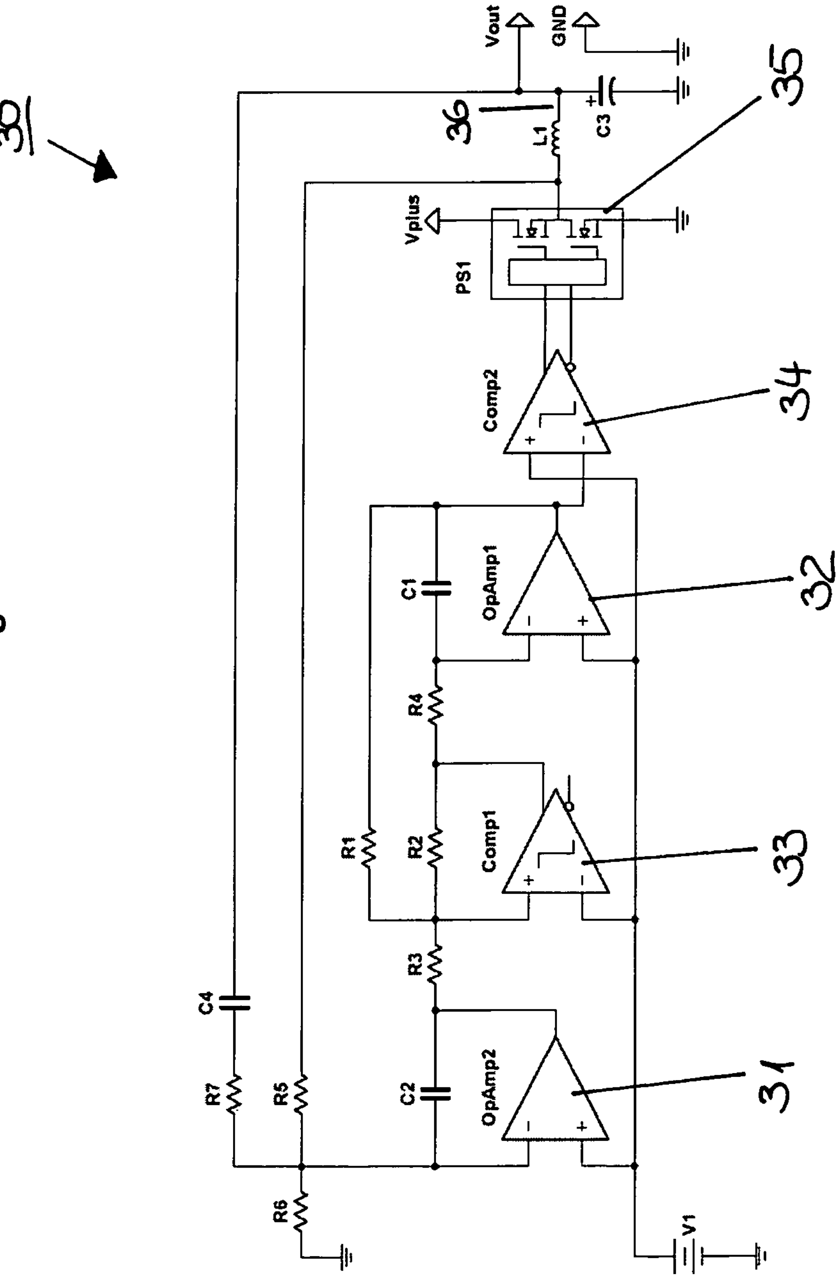
Output
GND
26
L1
C3
25
Vplus
Vminus
PS1
VScos
Comp2
24
VTsin
C1
OpAmp1
22
R4
VSsin
R2
Comp1
23
R3
VTcos
R5
C2
OpAmp2
21
R6
Input
GND

Fig. 4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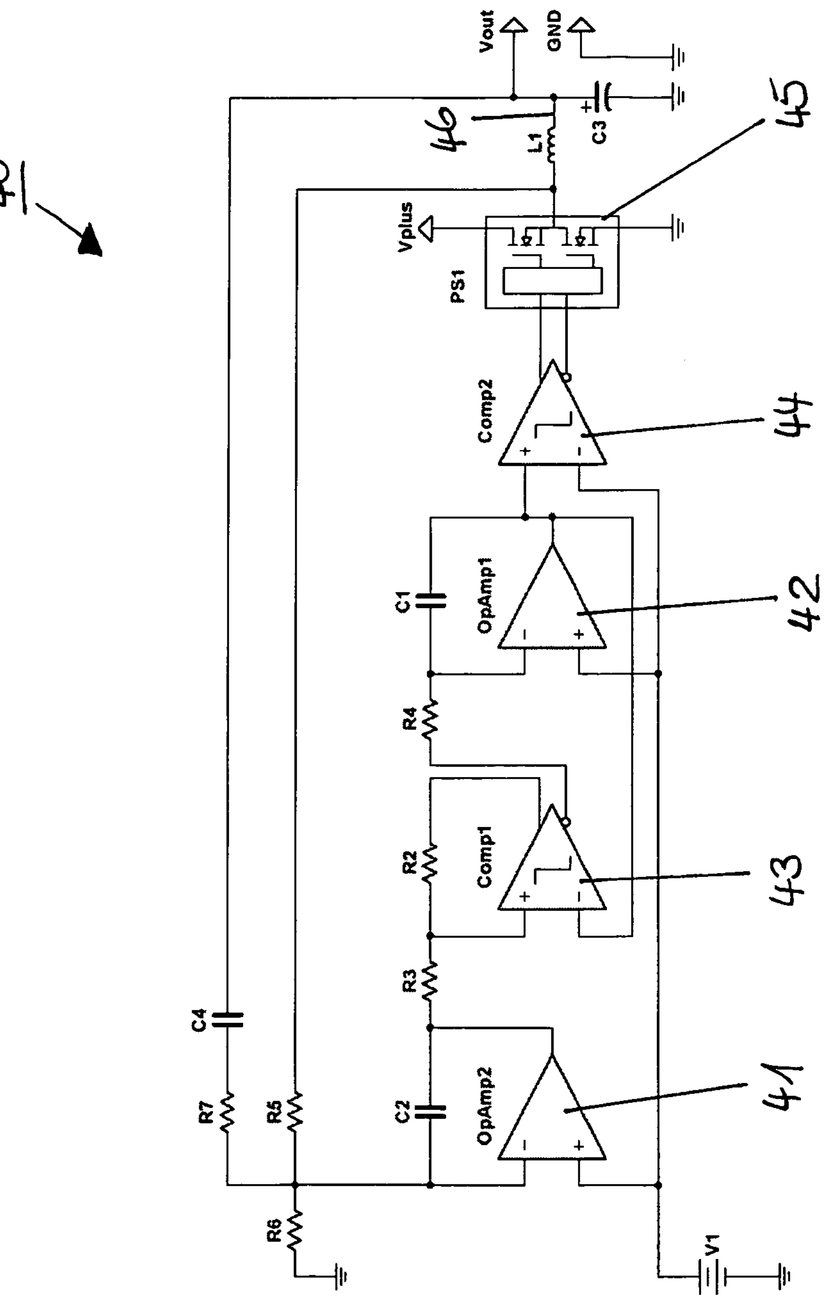
Vout
GND
36
35
L1
C3
Vplus
PS1
Comp2
34
C1
OpAmp1
32
R4
R1
R2
Comp1
33
R3
C4
R7
R5
C2
OpAmp2
31
R6
V1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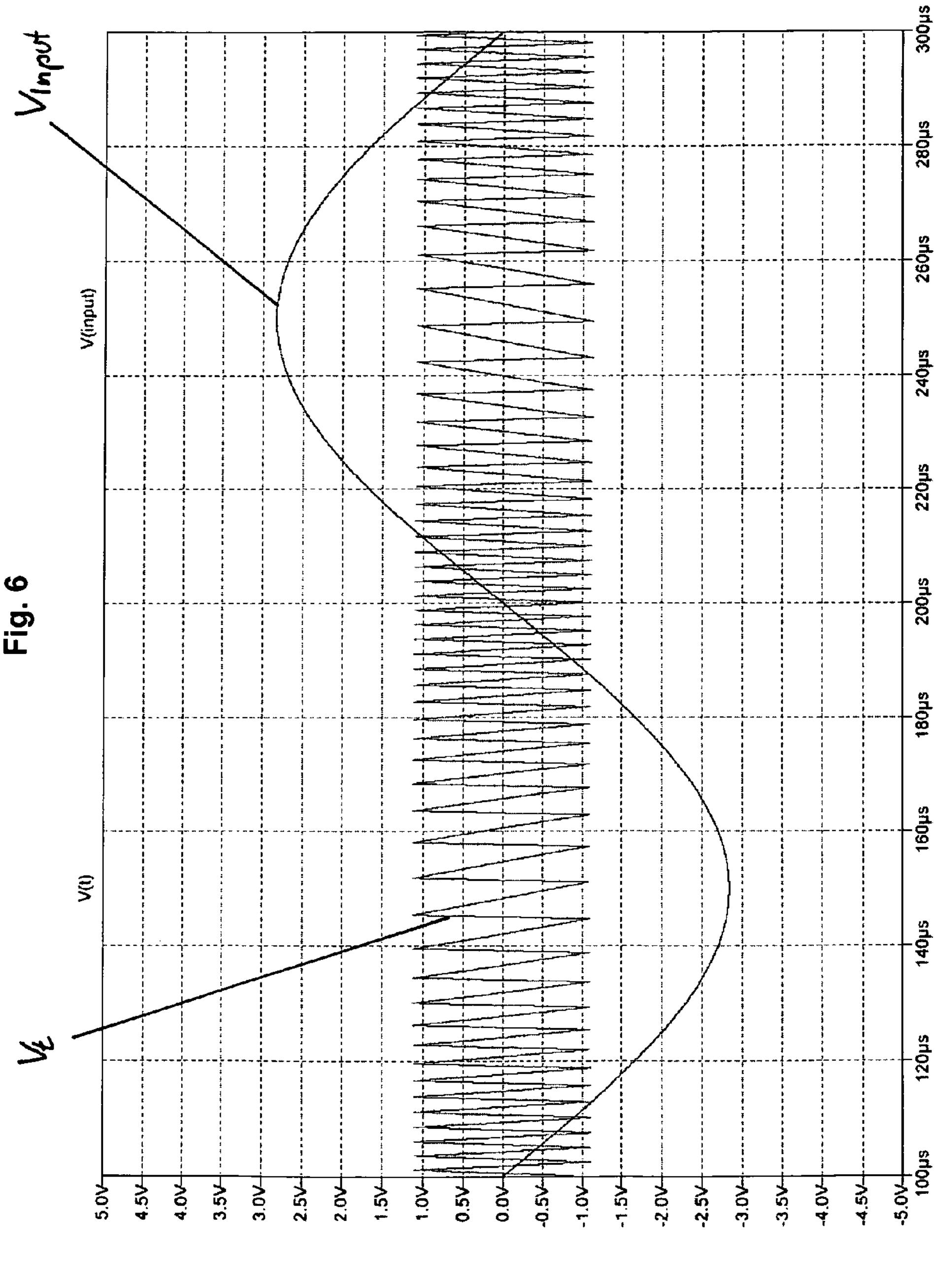
Vout
GND
C3
45
46
L1
Vplus
PS1
Comp2
44
OpAmp1
C1
42
R4
R2
Comp1
43
R3
C4
R7
R5
C2
OpAmp2
41
R6
V1

Fig. 5

Fig. 6



V(t)
V(input)
V_L
V_{Input}
5.0V
4.5V
4.0V
3.5V
3.0V
2.5V
2.0V
1.5V
1.0V
0.5V
0.0V
-0.5V
-1.0V
-1.5V
-2.0V
-2.5V
-3.0V
-3.5V
-4.0V
-4.5V
-5.0V
100µs
120µs
140µs
160µs
180µs
200µs
220µs
240µs
260µs
280µs
300µs

Fig. 7

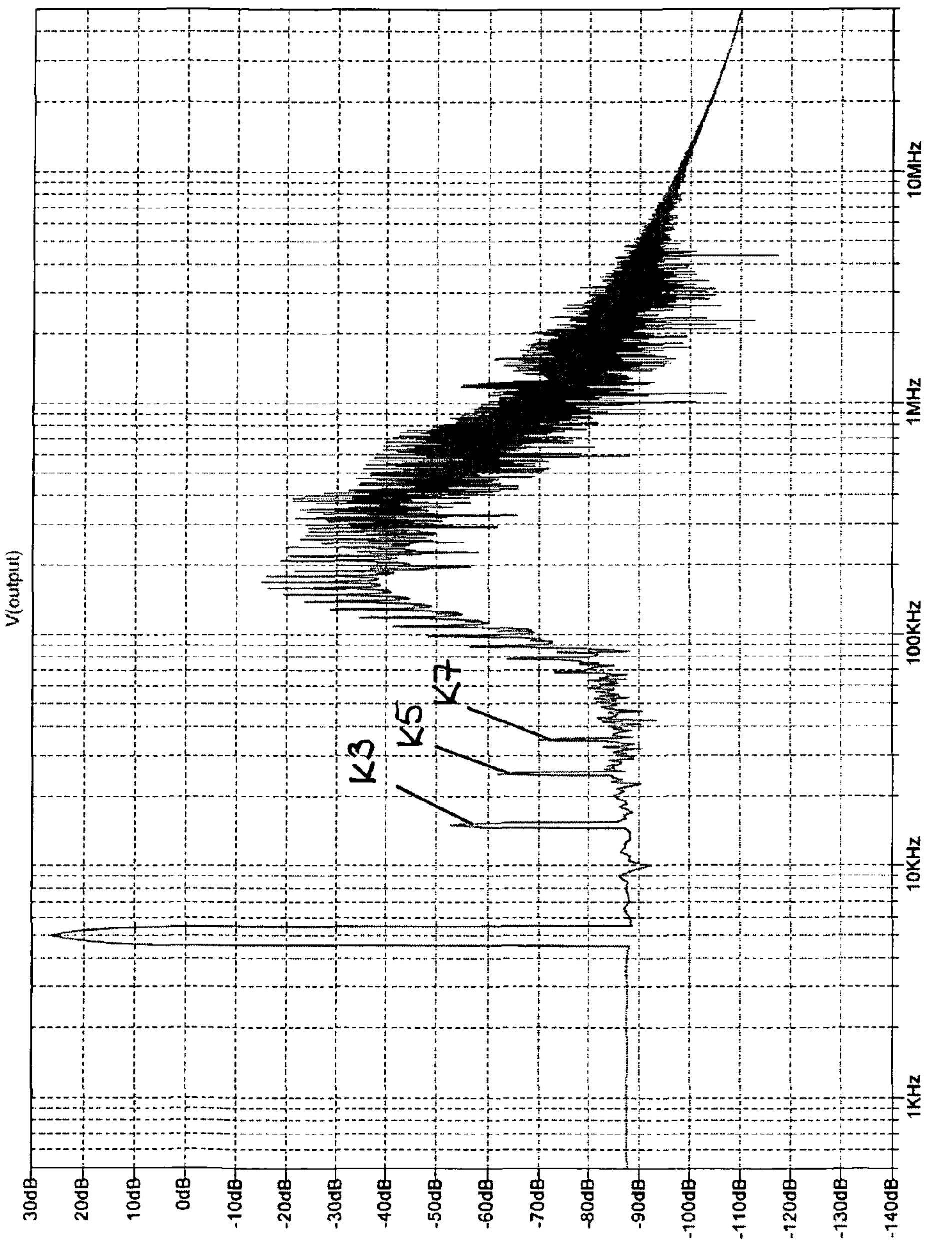

V(output)
30dB
20dB
10dB
0dB
-10dB
-20dB
-30dB
-40dB
-50dB
-60dB
-70dB
-80dB
-90dB
-100dB
-110dB
-120dB
-130dB
-140dB
1KHz
10KHz
100KHz
1MHz
10MHz
K3
K5
K7

Fig. 8

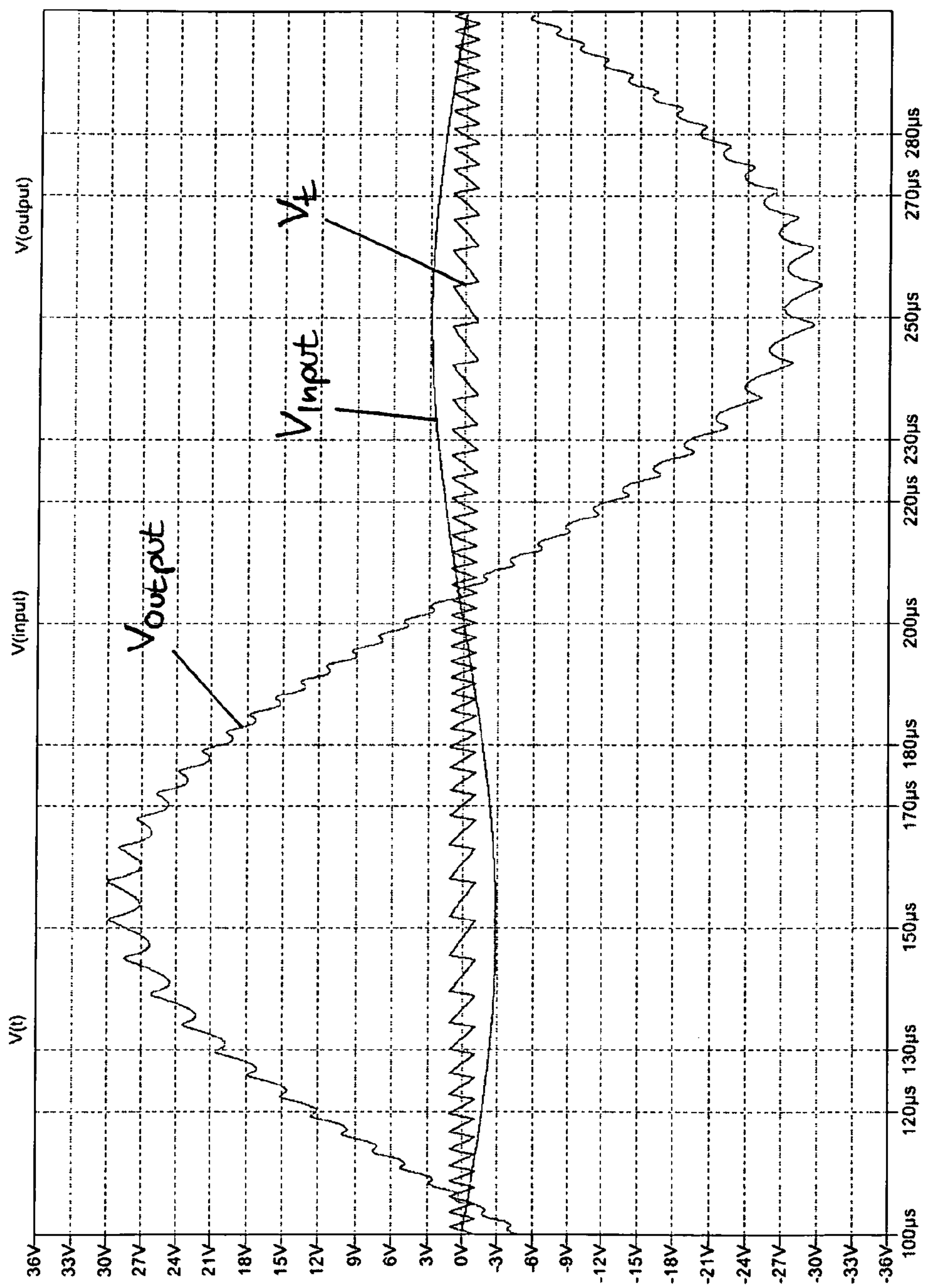

V(t)
V(input)
V(output)
V output
V Input
V t
36V
33V
30V
27V
24V
21V
18V
15V
12V
9V
6V
3V
0V
-3V
-6V
-9V
-12V
-15V
-18V
-21V
-24V
-27V
-30V
-33V
-36V
100µs
120µs
130µs
150µs
170µs
180µs
200µs
220µs
230µs
250µs
270µs
280µs

Fig. 9

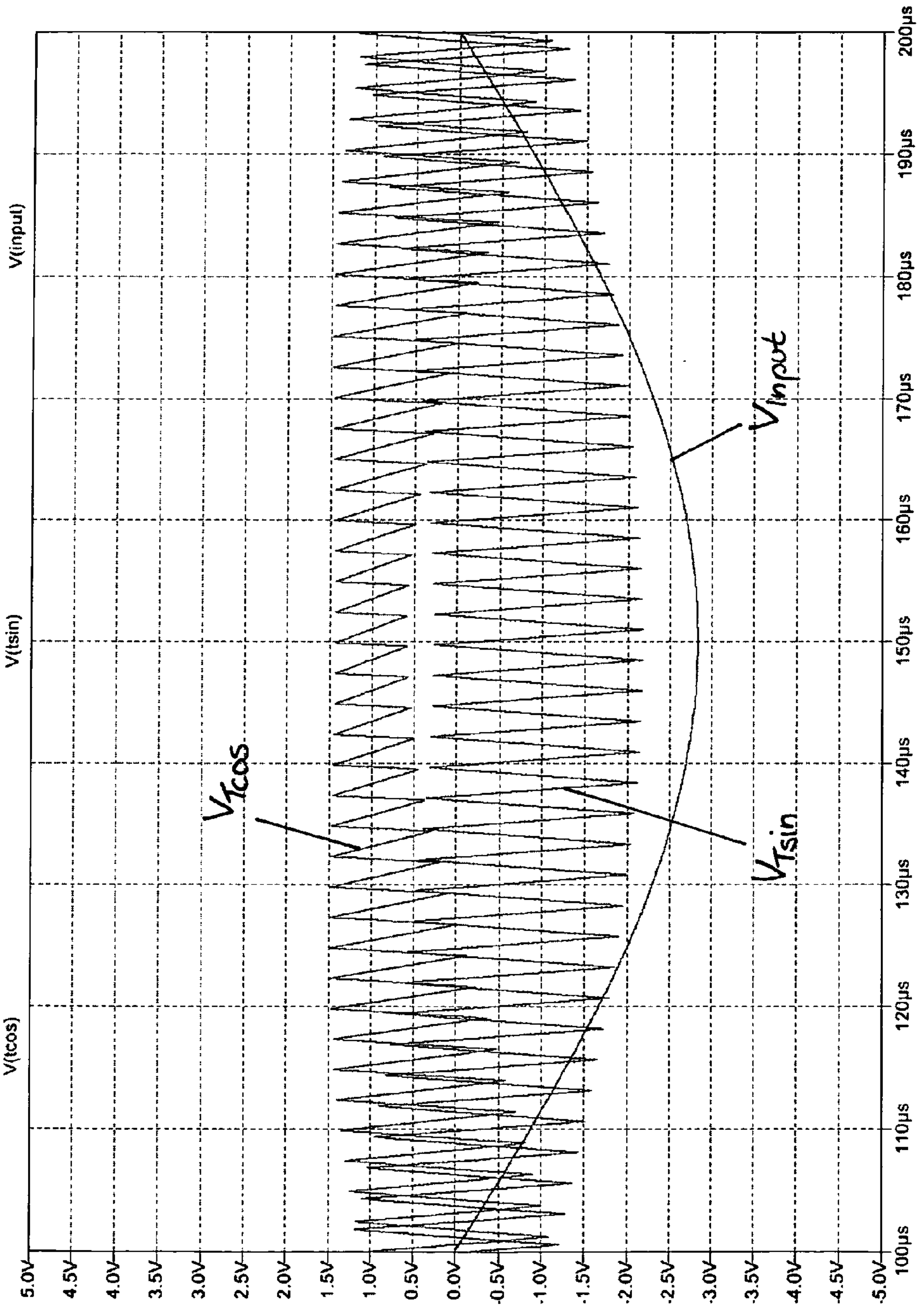

V(tcos)
V(tsin)
V(input)
5.0V
4.5V
4.0V
3.5V
3.0V
2.5V
2.0V
1.5V
1.0V
0.5V
0.0V
-0.5V
-1.0V
-1.5V
-2.0V
-2.5V
-3.0V
-3.5V
-4.0V
-4.5V
-5.0V
100µs
110µs
120µs
130µs
140µs
150µs
160µs
170µs
180µs
190µs
200µs
VTcos
VTsin
Vinput

Fig. 10

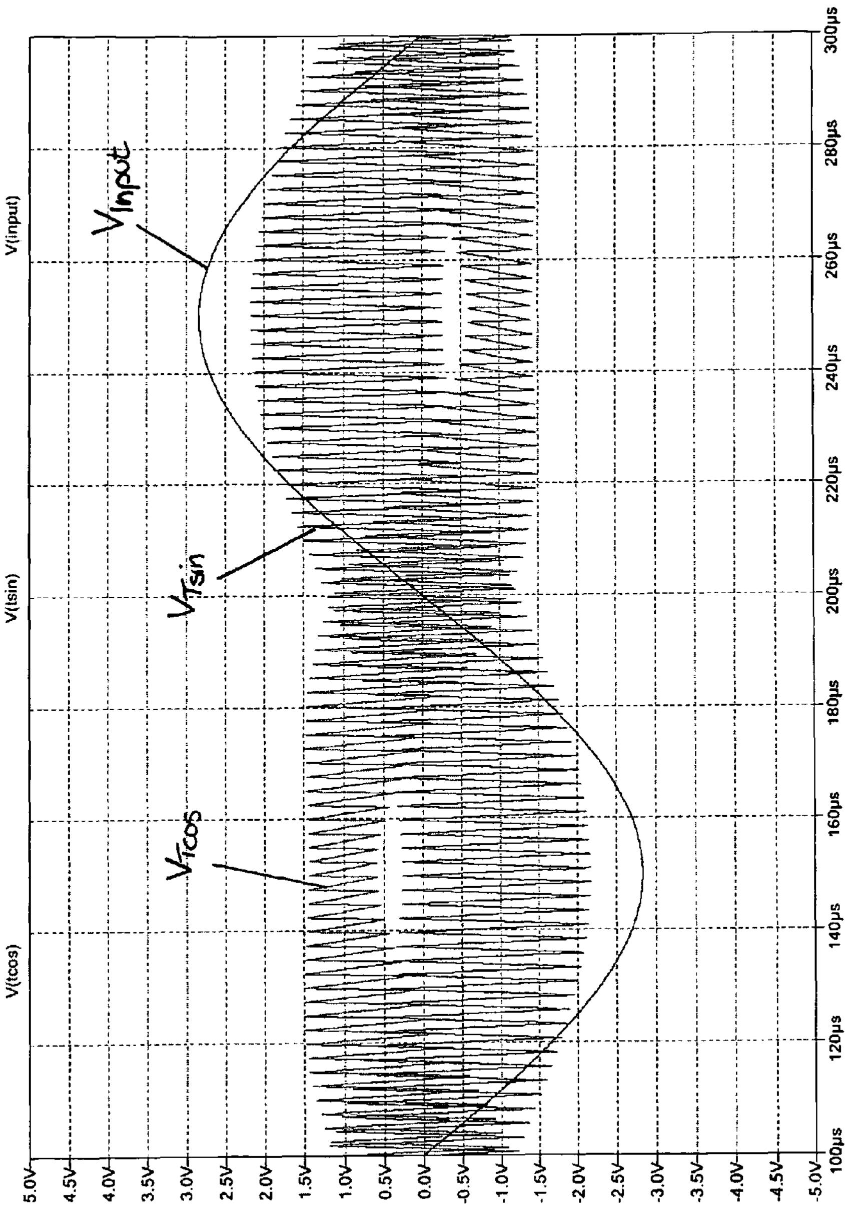

V(tcos)
V(tsin)
V(input)
V_Input
V_Tsin
V_Tcos
5.0V
4.5V
4.0V
3.5V
3.0V
2.5V
2.0V
1.5V
1.0V
0.5V
0.0V
-0.5V
-1.0V
-1.5V
-2.0V
-2.5V
-3.0V
-3.5V
-4.0V
-4.5V
-5.0V
100µs
120µs
140µs
160µs
180µs
200µs
220µs
240µs
260µs
280µs
300µs

Fig. 11

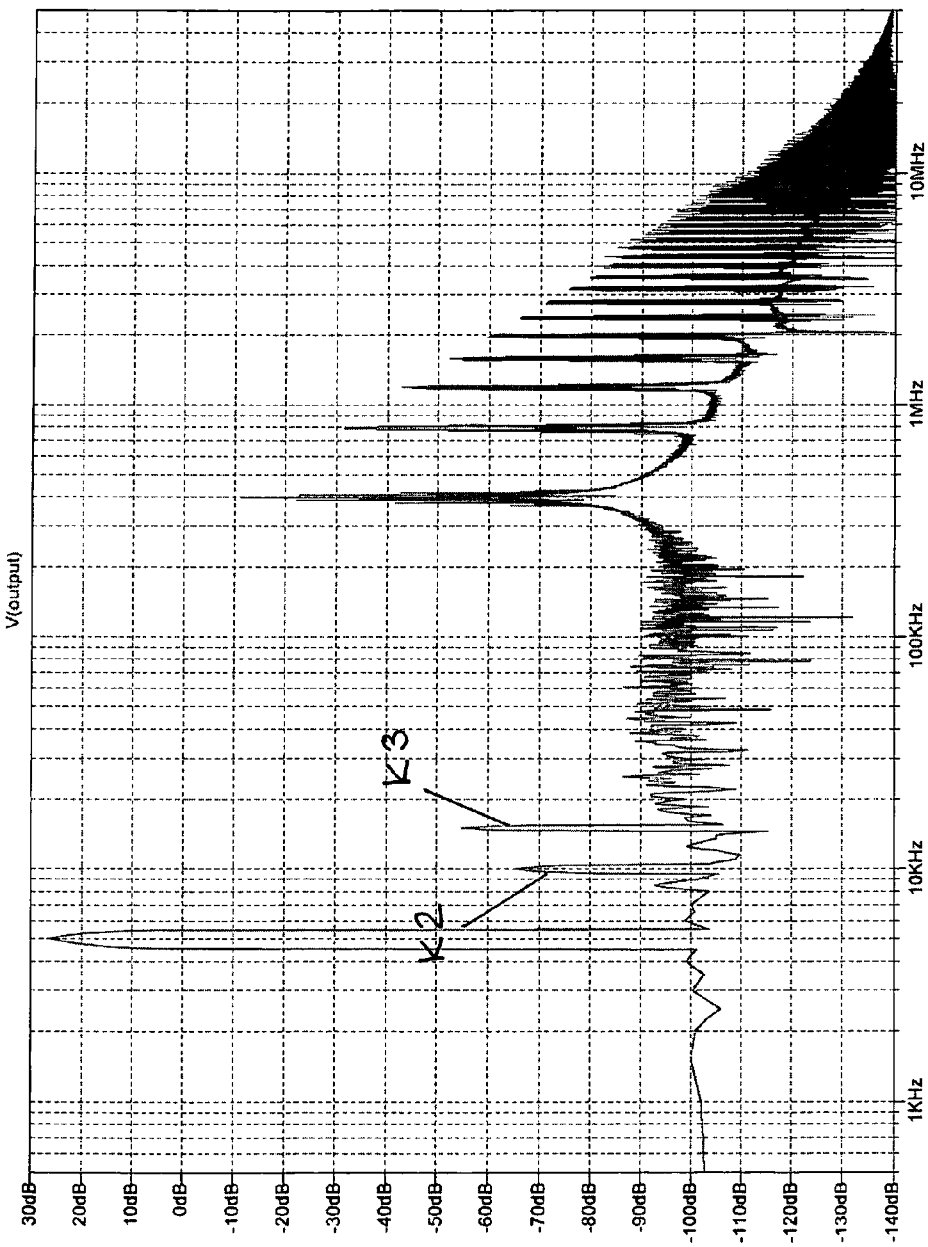

V(output)
30dB
20dB
10dB
0dB
-10dB
-20dB
-30dB
-40dB
-50dB
-60dB
-70dB
-80dB
-90dB
-100dB
-110dB
-120dB
-130dB
-140dB
1KHz
10KHz
100KHz
1MHz
10MHz
K2
K3

Fig. 12

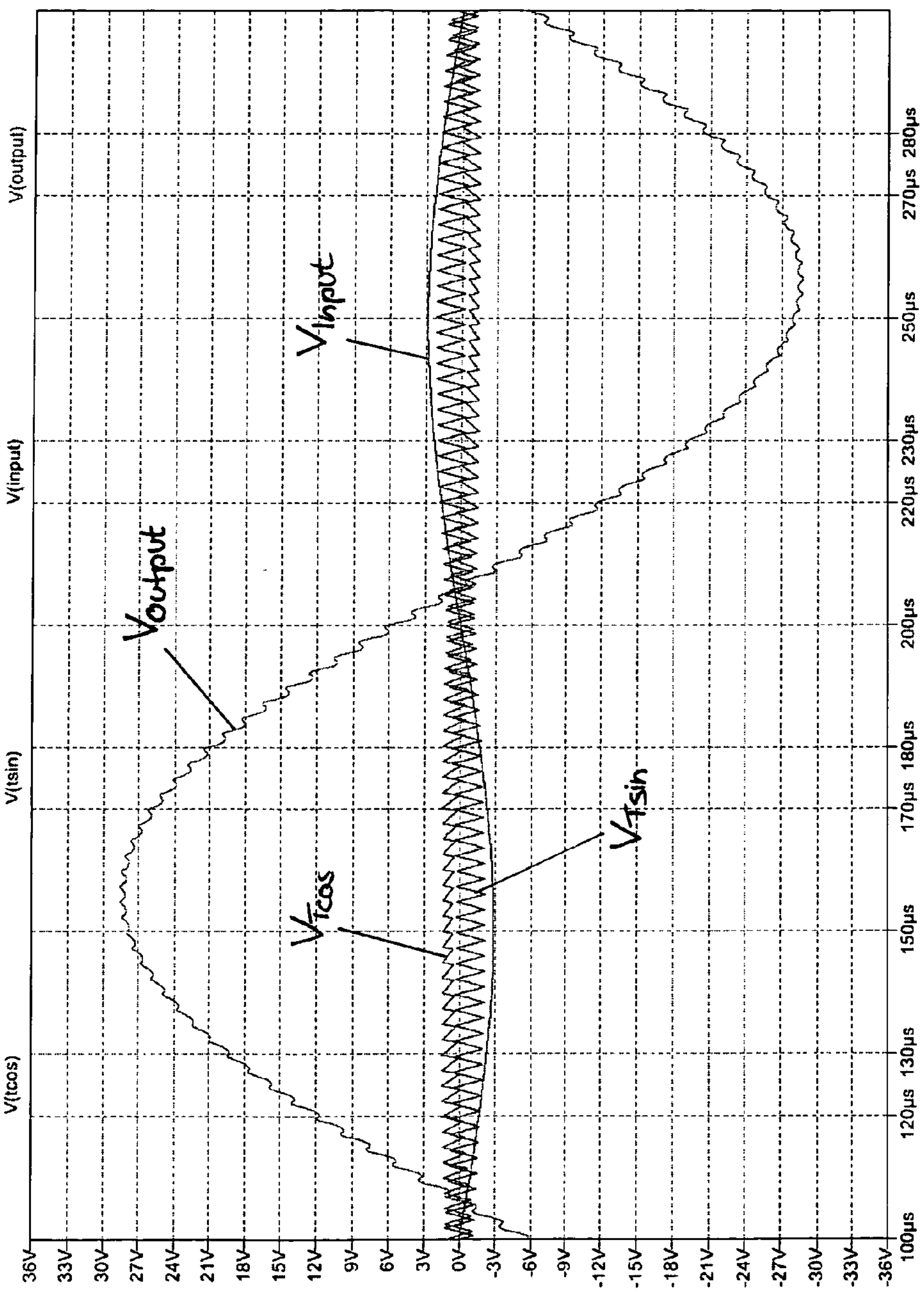

V(tcos)
V(tsin)
V(input)
V(output)
36V
33V
30V
27V
24V
21V
18V
15V
12V
9V
6V
3V
0V
-3V
-6V
-9V
-12V
-15V
-18V
-21V
-24V
-27V
-30V
-33V
-36V
100μs
120μs
130μs
150μs
170μs
180μs
200μs
220μs
230μs
250μs
270μs
280μs
V_{output}
V_{input}
V_{tcos}
V_{tsin}

Fig. 13

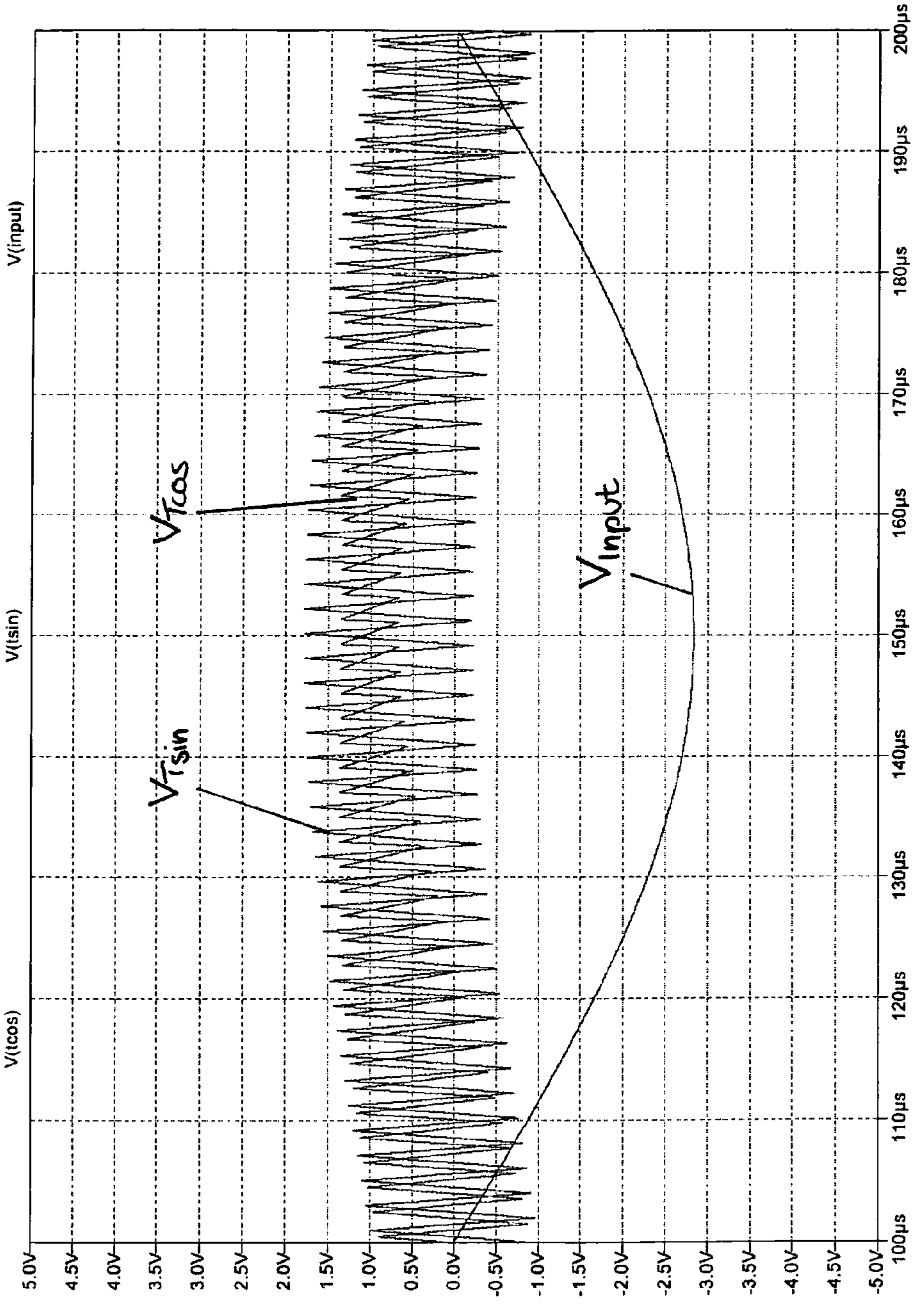

V(tcos)
V(tsin)
V(input)
5.0V
4.5V
4.0V
3.5V
3.0V
2.5V
2.0V
1.5V
1.0V
0.5V
0.0V
-0.5V
-1.0V
-1.5V
-2.0V
-2.5V
-3.0V
-3.5V
-4.0V
-4.5V
-5.0V
100µs
110µs
120µs
130µs
140µs
150µs
160µs
170µs
180µs
190µs
200µs
V_{Tcos}
V_{Tsin}
V_{Input}

Fig. 14

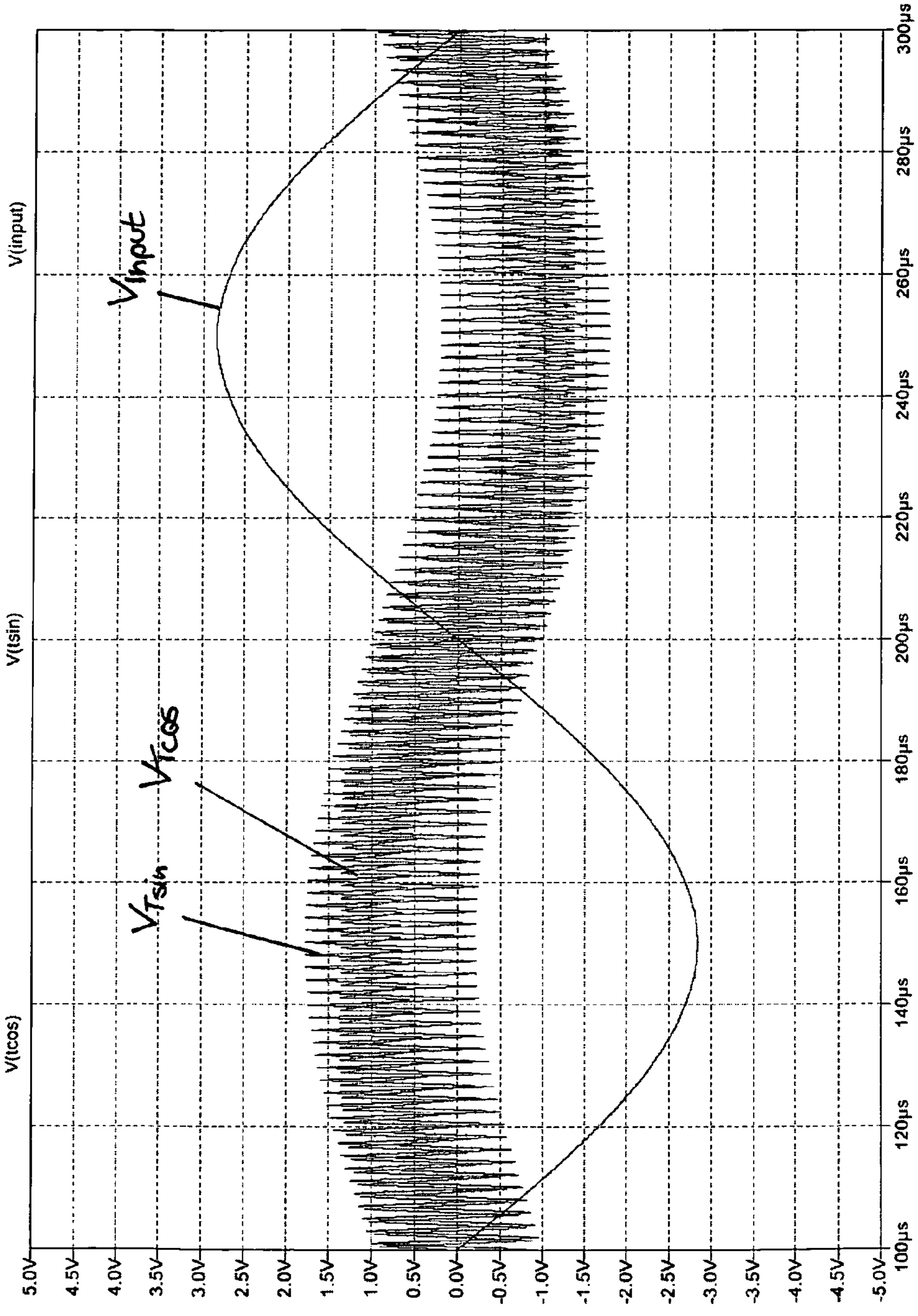

V(tcos)
V(tsin)
V(input)
V_{input}
V_{Tcos}
V_{Tsin}
5.0V
4.5V
4.0V
3.5V
3.0V
2.5V
2.0V
1.5V
1.0V
0.5V
0.0V
-0.5V
-1.0V
-1.5V
-2.0V
-2.5V
-3.0V
-3.5V
-4.0V
-4.5V
-5.0V
100µs
120µs
140µs
160µs
180µs
200µs
220µs
240µs
260µs
280µs
300µs

Fig. 15

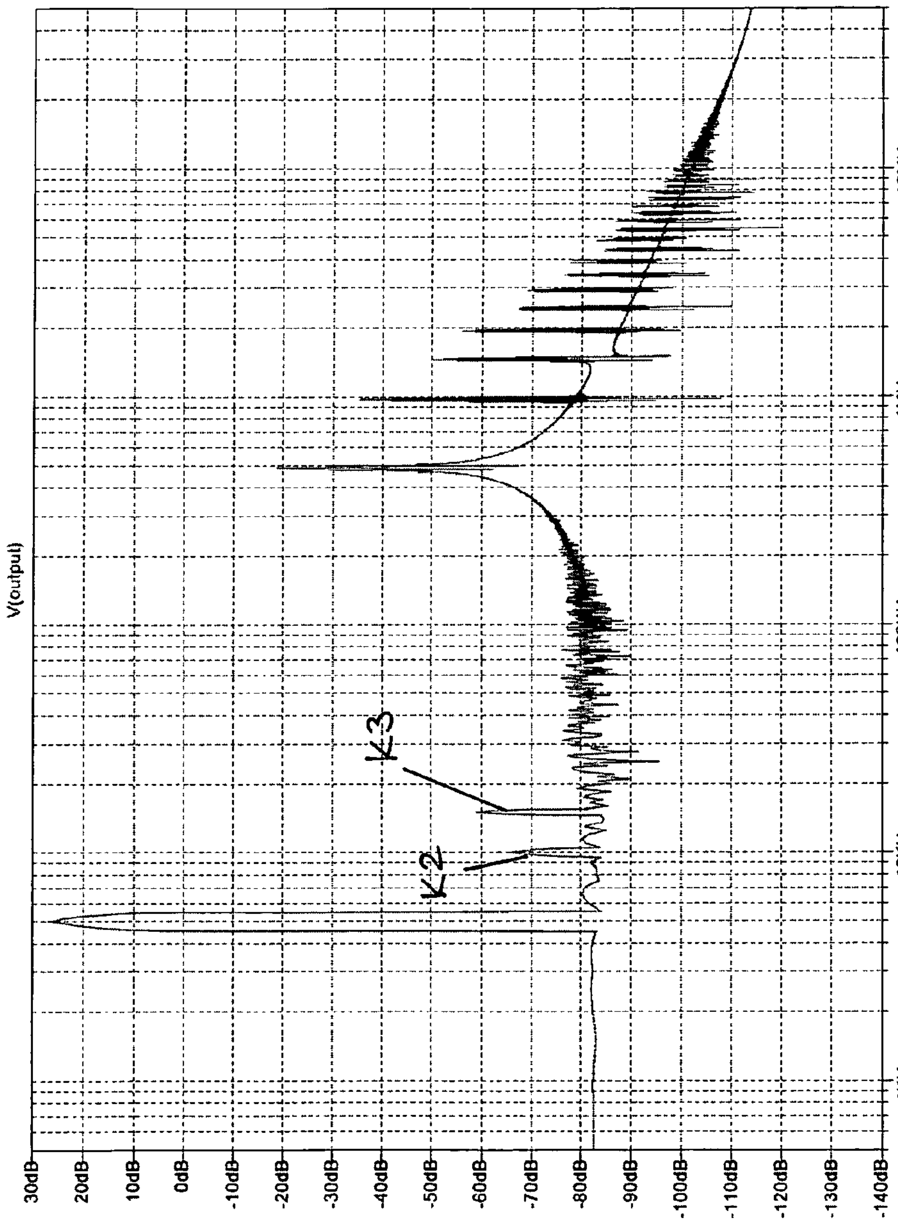
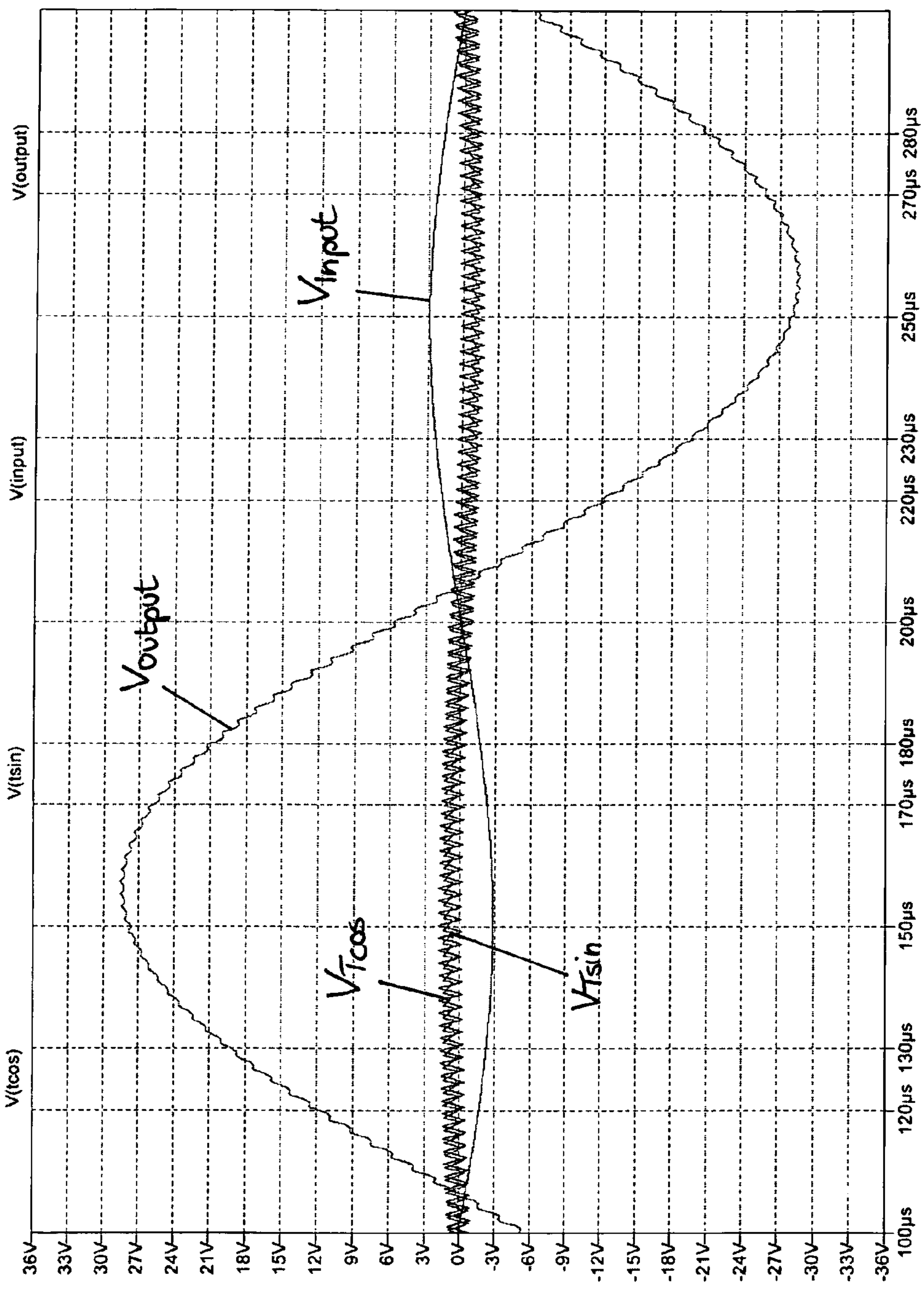

V(output)
30dB
20dB
10dB
0dB
-10dB
-20dB
-30dB
-40dB
-50dB
-60dB
-70dB
-80dB
-90dB
-100dB
-110dB
-120dB
-130dB
-140dB
1KHz
10KHz
100KHz
1MHz
10MHz
K2
K3

Fig. 16


V(tcos)
V(tsin)
V(input)
V(output)
V_{output}
V_{input}
V_{Tcos}
V_{Tsin}
36V
33V
30V
27V
24V
21V
18V
15V
12V
9V
6V
3V
0V
-3V
-6V
-9V
-12V
-15V
-18V
-21V
-24V
-27V
-30V
-33V
-36V
100µs
120µs
130µs
150µs
170µs
180µs
200µs
220µs
230µs
250µs
270µs
280µs

SINE-COSINE MODULATOR

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is the U.S. national stage of International Application No. PCT/EP2012/003689 filed on Sep. 4, 2012, and claims the benefit thereof.

BACKGROUND

The invention relates to a sine-cosine modulator comprising at least two comparators, two integrators, a power switching stage, an LC low-pass filter, and a low-frequency signal input or control-voltage input and a low-frequency signal output or DC voltage output.

Analog power amplifiers for low-frequency AC voltages in the audio-frequency range or voltage stabilizers are replaced in a number of applications in the prior art with pulse-width modulation amplifiers or switched-mode voltage converters that have a significantly higher level of thermal efficiency vis-a-vis the analog circuits. Self-oscillating pulse-width modulation amplifiers have better signal-processing or sound quality than clocked pulse-width modulation amplifiers that are driven by an external oscillator.

A self-oscillating pulse-width modulation amplifier of this type that not only has a significantly higher level of thermal efficiency vis-a-vis analog power amplifiers, but also better sound quality, is described in DE 198 38 765 A1 ("Selbstschwingender Digitalverstärker" ["Self-Oscillating Digital Feedback Amplifier"]). A drawback is that the natural frequency f is dependent upon the modulation factor with the relationship $f=f_0*(1-M^2)$. The modulation factor or excitation factor is consequently limited to approx. 60% in practice.

SUMMARY

The invention relates to a self-oscillating pulse-width modulation amplifier in the form of a sine-cosine modulator **10** comprising at least two comparators **13**, **14**, two integrators **11**, **12**, a power switching stage **15**, and negative feedback coupling with a low-frequency signal input and output. To achieve a maximum modulation factor, there are provisions with the aid of the comparators **13**, **14** and integrators **11**, **12** for the generation of sine- and cosine-square-wave voltages and sine- and cosine-triangle-wave voltages that drive the power switching stage **15** in part, wherein the output of the power switching stage **15** combined with an LC low-pass filter **16** forms the low-frequency signal output. This brings about a situation in which a stable natural frequency exists and the modulation factor can be increased to nearly 100%. At the same time, a very low level of distortion is achieved and no distortion components higher than K3 arise, so there is a significant improvement vis-a-vis the known pulse-width modulation amplifiers.

DETAILED DESCRIPTION

The task of the present invention is to make the natural frequency f of a self-oscillating pulse-width modulation amplifier independent of the modulation factor M and to therefore increase the maximum modulation factor or excitation factor to nearly 100% and to simultaneously further improve the sound quality.

The problem is solved in accordance with the invention by setting up a function generator for the simultaneous generation of sine- and cosine-oscillations with two comparators and two integrators that generate sine- and cosine-square-wave and sine- and cosine-triangle-wave voltages, which drive the power switching stage in part; the output of the power switching stage combined with an LC low-pass filter forms the low-frequency signal output or the DC voltage output. Further advantageous design forms can be found in the sub-claims.

The sine-cosine modulator is comprised, in a tried-and-tested form, of a function generator for the simultaneous generation of sine- and cosine-oscillations. The problem-free amplitude stabilization of the function generator can be used in connection with this. Starting with a triangle-wave signal of an arbitrary function generator, the course of the algebraic sign is determined with a comparator and phase-shifted by 90 degrees vis-a-vis the square-wave signal. This square-wave signal can be transformed into a second triangle-wave signal, which is then likewise phase-shifted by 90 degrees, with the aid of a second integrator. Starting with this possibility of the function generator, a power switching stage is driven by the function generator, wherein the output of the power switching stage combined with an LC low-pass filter forms the low-frequency signal output.

The comparators and integrators are used to generate the square-wave or triangle-wave voltages; the first comparator is used to generate a sine-square-wave voltage and the first integrator is used to generate a sine-triangle-wave voltage, whereas the second comparator is used to generate a cosine-square-wave voltage and the second integrator is used to generate a cosine-triangle-wave voltage. The second comparator for generating the cosine-square-wave voltage is preferably used for driving the power switching stage in connection with this. The sine-cosine modulator has negative feedback coupling here via a resistor from the output of the power switching stage to the input of the second integrator for generating a cosine-triangle-wave voltage. The low-frequency signal input is connected via a resistor with the input of the second integrator for generating a cosine-triangle-wave voltage, whereas the LC low-pass filter is connected to the output of the power switching stage and constitutes the low-frequency signal output.

In a further design form of the invention, there are provisions for the low-frequency output to be connected via a series RC element with the input of the second integrator for generating a cosine-triangle-wave voltage, in order to make the damping factor of the LC low-pass filter independent of the load connected to the low-frequency output.

A situation is achieved with the aid of the procedure that was described in which the sine-cosine modulator operates with a constant natural frequency of 400 kHz, for instance, so a maximum modulation factor or excitation factor of nearly 100% is achieved and only very slight nonlinear distortion arises. K2 and K3 remain in the inaudible range, whereas the higher distortion components K5 and K7 no longer arise in contrast to the prior art according to DE 198 38 765 A1.

The sine-cosine modulator can, as an example, be used with a low-frequency signal input and a low-frequency signal output as a pulse-width modulation amplifier. The natural frequency f of the sine-cosine modulator is kept constant independently of the modulation factor M via an "internal" square-triangle generator comprising a first integrator and a first comparator. At the same time, a second integrator that drives via the "internal" square-triangle generator a second comparator, which in turn drives the power switching stage, forms, together with the second comparator and the power switching stage, an "external" square-triangle generator that has negative feedback coupling via a resistor R5 from the output of the power switching stage to the input of the second integrator, whereas, on the other hand, a resistor R**6** is provided as the input resistance for the low-frequency signal voltage V_{Input} at the input of the second integrator. The output signal V_{Output} is picked up after an LC low-pass filter in connection with this. The voltage amplification V_{Output} divided by V_{Input} is determined by the resistance ratio −R**5**/R**6** here.

Alternatively, the possibility exists of using the sine-cosine modulator as a switched-mode voltage converter; control takes place via a control-voltage input, and the desired output voltage is available at a DC voltage output. This involves the advantage that there is additional negative feedback coupling via a resistor and a capacitor, in order to make the damping factor of the LC output filter independent of the load that is connected. This combination of "internal" negative feedback coupling via a resistor and "external" negative feedback coupling via a resistor and a capacitor leads to very quick control behavior.

The invention consequently involves a sine-cosine modulator, wherein sine- and cosine-square-wave voltages and sine- and cosine-triangle-wave voltages are generated with the aid of the comparators and integrators, driving the power switching stage in part, wherein the output of the power switching stage combined with an LC low-pass filter constitutes the low-frequency signal output and wherein the second comparator for generating the cosine-square-wave voltage drives the power switching stage and the sine-cosine modulator has negative feedback coupling via a resistor from the output of the power switching stage to the input of the second integrator for generating a cosine-triangle-wave voltage and the low-frequency signal input is connected via a resistor to the input of the second integrator for generating a cosine-triangle-wave voltage.

This circuit distinguishes itself by especially low nonlinear distortion; the natural frequency f is independent of the modulation factor M, so a maximum modulation factor or excitation factor of nearly 100% is achieved. The sine-cosine modulator consequently represents a significant improvement vis-a-vis prior pulse-width modulation amplifiers.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is explained once again below with the aid of the figures:

FIG. **1** shows a self-oscillating pulse-width modulator according to the prior art,

FIG. **2** shows a sine-cosine modulator in the form of a self-oscillating pulse-width modulation amplifier with a constant natural frequency independent of the modulation factor,

FIG. **3** shows a circuit variant of a sine-cosine modulator in accordance with FIG. **2** for a first comparator with two complementary outputs,

FIG. **4** shows a sine-cosine modulator in accordance with FIG. **2** in the form of a switched-mode voltage converter with additional feedback,

FIG. **5** shows a sine-cosine modulator in accordance with FIG. **3** in the form of a switched-mode voltage converter with additional feedback,

FIG. **6** shows the oscillation behavior of the self-oscillating pulse-width modulator according to the prior art at M_{max}=0.79 over the period of a 5 kHz input sinusoidal signal,

FIG. **7** shows the frequency spectrum of the self-oscillating pulse-width modulator according to the prior art behind the LC low-pass filter,

FIG. **8** shows the oscillation behavior of the self-oscillating pulse-width modulator according to the prior art with V_{Input} and V_{Output},

FIG. **9** shows the oscillation behavior of the sine-cosine modulator as per the invention in accordance with FIG. **2** at M_{max}=0.79 over a half period of a 5 kHz input sinusoidal signal,

FIG. **10** shows the oscillation behavior of the sine-cosine modulator as per the invention in accordance with FIG. **2** at M_{max}=0.79 over a full period of a 5 kHz input sinusoidal signal,

FIG. **11** shows the frequency spectrum of the sine-cosine modulator as per the invention in accordance with FIG. **2** behind the LC low-pass filter,

FIG. **12** shows the oscillation behavior of the sine-cosine modulator as per the invention in accordance with FIG. **2** with V_{Input} and V_{Output},

FIG. **13** shows the oscillation behavior of the sine-cosine modulator as per the invention in accordance with FIG. **3** at M_{max}=0.79 over a half period of a 5 kHz input sinusoidal signal,

FIG. **14** shows the frequency spectrum of the sine-cosine modulator as per the invention in accordance with FIG. **3** at M_{max}=0.79 over a full period of a 5 kHz input sinusoidal signal,

FIG. **15** shows the frequency spectrum of the sine-cosine modulator as per the invention in accordance with FIG. **3** behind the LC low-pass filter and

FIG. **16** shows the oscillation behavior of the sine-cosine modulator as per the invention in accordance with FIG. **3** with V_{Input} and V_{Output}.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** shows a circuit diagram of a self-oscillating pulse-width modulator **1** in the form of a pulse-width modulation amplifier. The pulse-width modulator **1** comprises an integrator **2** and a comparator **3** in this case; the comparator **3** is provided to drive the power switching stage **4**. An example that is known in the prior art is involved in this case. The pulse-width modulator **1** serves to simultaneously generate triangle- and square-wave oscillations and was extended with a power switching stage **4**, negative feedback coupling, a low-frequency signal input, an LC low-pass filter and a low-frequency signal output; this is called a "self-oscillating digital feedback amplifier" below, SODFA for short, in order to illustrate the advantages of the sine-cosine modulator vis-a-vis the prior art.

FIG. **2** shows an example of a sine-cosine modulator **10** in the form of a pulse-width modulation amplifier with two integrators **11**, **12** and two comparators **13**, **14**, as well as a power switching stage **15**. The integrator **12** generates the signal $V_{T\,sin}$ and forms, together with the comparator **13** that generates the signal $V_{S\,sin}$, an "internal" square-triangle-wave generator that holds the natural frequency f of the sine-cosine modulator constant independently of the modulation factor M. At the same time, the integrator **11** that generates the signal $V_{T\,cos}$ and that drives via the "internal" square-triangle-wave generator the comparator **14**, which generates the signal $V_{S\,cos}$ and which drives the power switching stages **15**, forms, together with the comparator **14** and the power switching stage **15**, an "external" square-triangle-wave generator that has negative feedback coupling via a resistor R**5** from the output of the power switching stage **15** to the input of the integrator **11**, while a resistor R**6** is provided as an input resistor, on the other hand, for the low-frequency signal voltage V_{Input}. The output signal V_{Output} is picked up after an LC low-pass filter **16** in connection with this. The voltage amplification V_{Output} divided by V_{Input} is −R**5** divided by R**6**.

FIG. **3** shows an alternative circuit example of a sine-cosine modulator **20** in the form of a pulse-width modulation amplifier with two integrators **21**, **22** and two comparators **23**, **24**, as well as a power switching stage **25**. A first comparator **23** with two complementary outputs is used in this circuit variant; an output for feedback and the complementary output for generating the signal $V_{S\ sin}$ and for driving the integrator **22**, which generates the signal $V_{T\ sin}$, are provided.

FIG. **4** shows an example of a sine-cosine modulator **30** in the form of a regulated switched-mode voltage converter (synchronous buck regulator) that is once again operated with two integrators **31**, **32** and two comparators **33**, **34**, as well as a power switching stage **35**. Compared with the design variant in accordance with FIG. **2**, additional negative feedback coupling is provided in this case via a resistor R**7** and a capacitor C**4** in order to make the damping factor of the LC output filter independent of the load that is connected. This combination of "internal" negative feedback coupling via R**5** and "external" negative feedback coupling via R**7** and C**4** leads to very quick control behavior (integral-derivative controller) that is superior to the regulation behavior of conventional PID (proportional-integral-derivative) controllers with only one instance of negative feedback coupling. The following applies to the regulated output voltage: $V_{out}=V1*(1+R5/R6)$

FIG. **5** shows an alternative circuit example of a sine-cosine modulator **40** in the form of a regulated switched-mode voltage converter that is operated based on the embodiment in accordance with FIG. **3** with two integrators **41**, **42** and two comparators **43**, **44**, as well as a power switching stage **45**. Additional negative feedback coupling is also provided in this case with a series RC element via a resistor R**7** and a capacitor C**4**. In this design variant, the comparator **43** with two complementary outputs is used; one output is provided for feedback once again, whereas the complementary output generates the voltage $V_{S\ sin}$ and drives the integrator **42**, which generates the signal $V_{T\ sin}$. The control behavior is also significantly improved vis-a-vis conventional PID controllers in this case, and the following applies to the regulated output voltage: $V_{out}=V1*(1+R5/R6)$

FIG. **6** shows the signal shapes V_{Input} and V_T of the self-oscillating pulse-width modulator **1** (SODFA) at a natural frequency $f=400\ kHz*(1-M^2)$ and $M_{max}=0.79$ over the period of a 5 kHz input sinusoidal signal.

FIG. **7** shows the frequency spectrum of the output signal of the SODFA behind the LC low-pass filter. The natural frequency of the SODFA "blurs" between 150 kHz and 400 kHz, and additional distortion components K5 and K7 arise.

FIG. **8** shows the oscillation behavior of the SODFA at a maximum modulation factor of 0.79. The triangle-wave control signal V_T remains centered around the zero point, whereas the natural frequency drops to the minimum value of $f_{min}=400\ kHz*(1-0.79^2)=150\ kHz$. The significantly increased ripple voltage at the output of the SODFA at the peaks of the sinusoidal wave of V_{Output} can be recognized here because of the periodic drop of the natural frequency f_0 to $f_{min}=150$ kHz.

FIG. **9** shows the oscillation behavior of the sine-cosine modulator **10** as per the invention in accordance with FIG. **2** with the signals $V_{T\ sin}$, $V_{T\ cos}$ and V_{Input} at $M_{max}=0.79$ over a half period of a 5 kHz input sinusoidal signal. The control signal $V_{T\ cos}$ is shifted around the zero point in phase opposition to V_{Input} and reduced in amplitude in proportion with M, as well as pulse-width modulated, whereas the control signal $V_{T\ sin}$ is shifted around the zero point in phase with V_{Input} and remains constant with regard to amplitude and symmetry. The natural frequency f remains constant at 400 kHz independently of the modulation factor M.

FIG. **10** shows the oscillation behavior of the sine-cosine modulator **10** as per the invention in accordance with FIG. **2** with the signals $V_{T\ sin}$, $V_{T\ cos}$ and V_{Input} at $M_{max}=0.79$ to illustrate the operational process over the full period of a 5 kHz input sinusoidal signal.

FIG. **11** shows the frequency spectrum of the sine-cosine modulator **10** as per the invention in accordance with FIG. **2** behind the LC low-pass filter. The natural frequency f remains at a constant 400 kHz independently of the modulation factor, and no additional distortion components K5 and K7 arise.

FIG. **12** shows the oscillation behavior of the sine-cosine modulator **10** as per the invention in accordance with FIG. **2** with the signals V_{Input}, $V_{T\ sin}$, $V_{T\ cos}$ and V_{Output} with sinusoidal modulation at $M_{max}=0.79$ without a drop in the natural frequency f and therefore with a significantly less ripple voltage.

FIG. **13** shows the oscillation behavior of the sine-cosine modulator **20** as per the invention in accordance with FIG. **3** with the signals $V_{T\ sin}$, $V_{T\ cos}$ and V_{Input} at $M_{max}=0.79$ over a half period of a 5 kHz input sinusoidal signal. The control signal $V_{T\ cos}$ is shifted around the zero point in phase opposition to V_{Input} and reduced in amplitude in proportion with M, as well as pulse-width modulated, whereas the control signal $V_{T\ sin}$ is shifted around the zero point, likewise in phase opposition to V_{Input}, and once again remains constant with regard to amplitude and symmetry. The natural frequency f remains constant at 400 kHz independently of the modulation factor M.

FIG. **14** shows the oscillation behavior of the sine-cosine modulator **20** as per the invention in accordance with FIG. **3** with the signals $V_{T\ sin}$, $V_{T\ cos}$ and V_{Input} at $M_{max}=0.79$ to illustrate the operational process over the full period of a 5 kHz input sinusoidal signal.

FIG. **15** shows the frequency spectrum of the sine-cosine modulator **20** as per the invention in accordance with FIG. **3** behind the LC low-pass filter. The natural frequency f remains at a constant 400 kHz independently of the modulation factor, and no additional distortion components K5 and K7 arise.

FIG. **16** shows the oscillation behavior of the sine-cosine modulator **20** as per the invention in accordance with FIG. **3** with the signals V_{Input}, $V_{T\ sin}$, $V_{T\ cos}$ and V_{Output} with sinusoidal modulation at $M_{max}=0.79$ without a drop in the natural frequency f and therefore with a significantly less ripple voltage vis-a-vis the SODFA.

LIST OF REFERENCE NUMERALS

1 Pulse-width modulator
2 Integrator
3 Comparator
4 Power switching stage
10 Sine-cosine modulator
11 Integrator
12 Integrator
13 Comparator
14 Comparator
15 Power switching stage
16 LC low-pass filter
20 Sine-cosine modulator
21 Integrator
22 Integrator
23 Comparator
24 Comparator
25 Power switching stage
26 LC low-pass filter
30 Sine-cosine modulator
31 Integrator

32 Integrator
33 Comparator
34 Comparator
35 Power switching stage
36 LC low-pass filter
40 Sine-cosine modulator
41 Integrator
42 Integrator
43 Comparator
44 Comparator
45 Power switching stage
46 LC low-pass filter

The invention claimed is:

1. Sine-cosine modulator comprising a first integrator, a first comparator, a second integrator and a second comparator connected in series, said integrators and comparators also serving to create a phase shift of 90° with respect to their input signal, a power switching stage, an LC low-pass filter, as well as a low-frequency signal input or control-voltage input and a low-frequency signal output or DC voltage output,

wherein

a function generator for the simultaneous generation of sine- and cosine-oscillations through the first integrator, the first comparator, the second integrator and the second comparator is set up that generates sine- and cosine-square-wave voltages and sine- and cosine-triangle-wave voltages that drive the power switching stage in part, wherein the output of the power switching stage combined with an LC low-pass filter forms the low-frequency signal output or DC voltage output.

2. Sine-cosine modulator according to claim **1**,

wherein

the first comparator is provided to generate a sine-square-wave voltage and the first integrator is provided to generate a sine-triangle-wave voltage, whereas the second comparator is provided to generate a cosine-square-wave voltage and the second integrator is provided to generate a cosine-triangle-wave voltage.

3. Sine-cosine modulator according to claim **1**,

wherein

the second comparator for generating the cosine-square-wave voltage drives the power switching stage.

4. Sine-cosine modulator according to claim **1**,

wherein

the sine-cosine modulator has negative feedback coupling via a resistor from the output of the power switching stage to the input of the second integrator for generating a cosine-triangle-wave voltage.

5. Sine-cosine modulator according to claim **1**,

wherein

the low-frequency signal input is connected via a resistor to the input of the second integrator for generating a cosine-triangle-wave voltage.

6. Sine-cosine modulator according to claim **1**,

wherein

the low-frequency signal output or DC voltage output is connected via a series RC element to the input of the second integrator for generating a cosine-triangle-wave voltage.

7. Sine-cosine modulator according to claim **1**,

wherein

it has a low-frequency signal input and a low-frequency signal output in the form of a pulse-width modulation amplifier.

8. Sine-cosine modulator according to claim **1**,

wherein

it has a control-voltage input and a DC voltage output in the form of a switched-mode voltage converter.

9. Sine-cosine modulator according to claim **1**,

wherein

sine- and cosine-square-wave voltages and sine- and cosine-triangle-wave voltages are generated with the aid of the first and second comparators and first and second integrators, driving the power switching stage in part, that constitute a function generator for the simultaneous generation of sine- and cosine-oscillations, wherein the output of the power switching stage combined with an LC low-pass filter constitutes the low-frequency signal output and wherein the second comparator for generating the cosine-square-wave voltage drives the power switching stage and the sine-cosine modulator has negative feedback coupling via a resistor from the output of the power switching stage to the input of the second integrator for generating a cosine-triangle-wave voltage and the low-frequency signal input is connected via a resistor to the input of the second integrator for generating a cosine-triangle-wave voltage.

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