BURR-BROWN®

APPLICATION NOTE

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CURRENT OR VOLTAGE FEEDBACK: THE CHOICE IS YOURS WITH THE NEW, FLEXIBLE, WIDE-BAND OPERATIONAL AMPLIFIER OPA622.

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With the recently introduced wide-band op amp OPA622, Burr-Brown has reached a new height in op amp design. In the past, engineers designing a circuit with feedback had to choose between voltage and current feedback according to the requirements of their particular applications. Both feedback types involve a trade-off. The current-feedback structures available up to now use their symmetrical circuit design and short feedback loop to process wide-band analog signals, while the traditional voltage-feedback amplifiers provide more optimized DC performance but slow down the signal processing rate. But with the OPA622, an IC is available that can be configured for both modes. The first voltage-feedback op amp manufactured using a complementary circuit technique, the OPA622 achieves bandwidths and slew rates previously attainable only with current-feedback amplifiers, while also offering two identical high-impedance inputs, improved common-mode rejection, and external adjustment of the open-loop gain and quiescent current. The OPA622's extremely flexible pin configuration lets the user assemble it as a voltage-feedback op amp, a fast comparator, an AGC amplifier, an open-loop or direct-feedback amplifier, and even a 350MHz current-feedback amplifier. Its powerful output stage can easily drive 50Ω and 75Ω transmission systems and operates stably on capacitive load resistors. This application note will present the internal circuit configuration, specifications, and frequency response alignment of the OPA622 and will also describe its diverse applications.

CLASSICAL CIRCUIT TECHNIQUES

As shown in Figure 1, a classical op amp consists of a differential or transconductance amplifier (TA) with high-impedance output, followed by a buffer amp as impedance converter. Between these two components are a resistor and a capacitor to determine the open-loop gain, slew rate, and bandwidth. The differential amplifier charges the capacitor, C, with quiescent current for rising and falling signals so that the slew rate can be determined as follows:

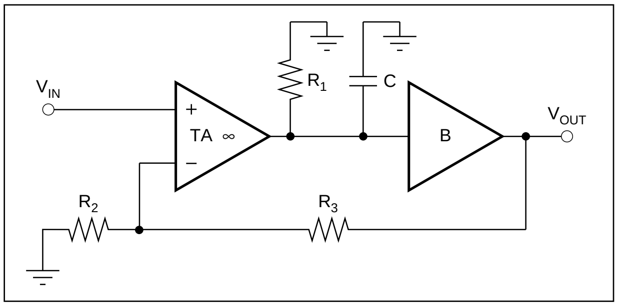


FIGURE 1. Operational Amplifier Consisting of a Transconductance Amplifier (TA) and Buffer (B).

$$SR_{MAX} = \frac{\Delta V}{\Delta t} = \frac{I}{C}\left[\frac{V}{S}\right]$$

Usually, a sine-wave signal is applied to an op amp to determine its –3dB bandwidth. Since sine-shaped signals have the largest signal variation at the zero crossing point, the –3dB bandwidth of the op amp can be calculated by the following equation:

$$f_{-3dB} = \frac{\sqrt{2}}{2\pi} \cdot SR/Vp0$$

Internally compensated amplifiers, which include most classical amplifiers, use an integrated capacitor for the worst case or smallest closed-loop gain. This compensation capacitor reduces the maximum open-loop gain to –6dB per octave starting at very low frequencies but ensures sufficient phase margin for stable operation even at gain +1. This method of frequency response adjustment is not at all suitable for wide-band amplifiers, since the compensation capacitor allows neither slew rates over 1000V/µs nor large-signal bandwidths over 100MHz.

CURRENT-FEEDBACK CONFIGURATION: THE ALTERNATIVE OF THE 80s

About ten years ago, current-feedback amplifiers were developed as an alternative to conventional op amps. They consist of a transconductance amplifier in Diamond structure and an output stage made up of complementary emitter followers as shown in Figure 2. The feedback loop connects the output of the amplifier to the low-impedance input, thus transforming the usual voltage feedback into current feedback. The current-feedback method not only allows optimal frequency response adjustment using the parallel impedance of the feedback network (which also influences the open-loop gain) but also eliminates the need for an internal compensation capacitor. The design does have one parasitic capacitor at the high-impedance OTA output, but its capacitance is much smaller than that of compensation capacitors in classical configurations, and the improvement in capacitor charging (10 to 20 times I_Q) produces slew rates of up to

2000V/µs and large-signal bandwidths of up to 250MHz. The current-feedback configuration does, however, have drawbacks such as asymmetrical inputs, reduced common-mode rejection, and relatively high input voltage offset compared to state-of-the-art conventional op amps.

THE WHOLE WORKS: CURRENT AND VOLTAGE FEEDBACK IN ONE

The OPA622 combines the speed of a current-feedback design with the precision of a voltage-feedback design using two identical high-impedance inputs. As shown in Figure 3, the OPA622 comprises an OTA, a feedback buffer, and a ±70mA output stage. The differential input stage with high-impedance inputs is made up of two identical complementary buffers so that the only input offset voltage is the difference between their offset voltages. Both buffer outputs are connected to package pins and to each other via the resistor R_{OG}. This resistor functions like the emitter degeneration resistor of a classical 2-transistor differential stage and allows external open-loop gain adjustment. Figure 4 shows the frequency response of the open-loop gain at various R_{OG} values. When the input voltage is differential, a current flows through the R_{OG}. The current mirror in the OTA reflects this current to its high-impedance output, which is decoupled by the output stage and functions practically in open-loop mode. The feedback loop connects the output to the input of the feedback buffer (FB), which when inserted switches the circuit from current-feedback to voltage-feedback mode.

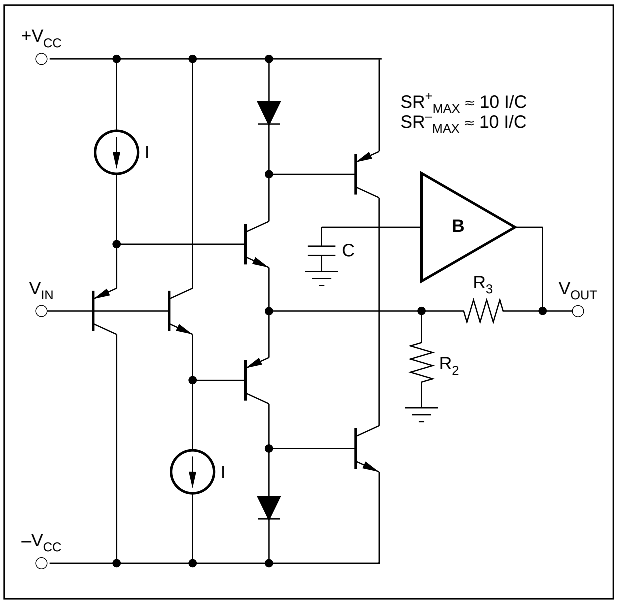
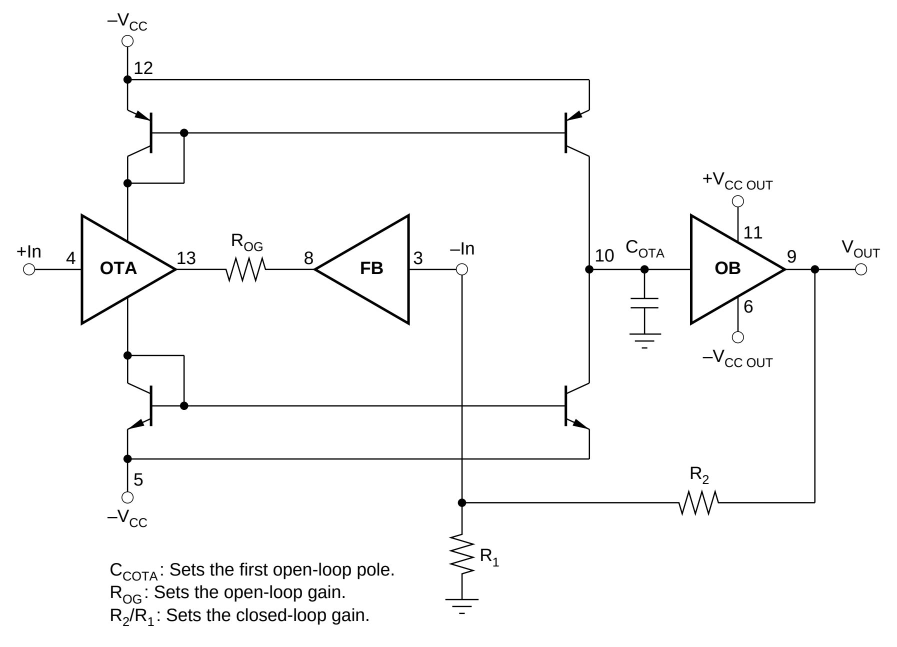


FIGURE 2. Current-Feedback Amplifier in Diamond Structure.

FLEXIBILITY

When defining a product, engineers always face a conflict between ensuring pinout compatibility, providing the smallest possible package, and guaranteeing circuit flexibility. Only with a flexible configuration is it possible for engineers to adapt an IC to their particular applications or to implement functions that are impossible or extremely difficult to achieve with standard op amps. The OPA622 makes it easy for users to customize the configuration to their particular needs and allows multiple access points to the inputs and outputs of the individual circuit parts. The compromise for the OPA622's flexibility is its slightly reduced AC performance, as its multiple pin-to-pin connections generate a longer delay time in the feedback loop. For optimum AC



C_{COTA}: Sets the first open-loop pole.
R_{OG}: Sets the open-loop gain.
R_2/R_1: Sets the closed-loop gain.

FIGURE 3. Voltage-Feedback Amplifier in Diamond Structure.

performance and for standard circuit functions, the OPA623 and the planned 8-pin standard pinout voltage-feedback amplifier series OPA655/6/7/8 are the better choice.

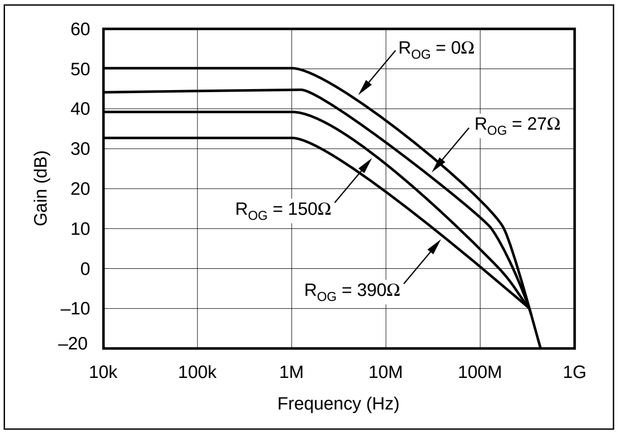


FIGURE 4. Open-Loop Gain at Various R_{OG} Values.

Figure 5 shows the pin configuration of the OPA622, and Table I describes the function of the individual pins. The OPA622 is available in a 14-pin DIL or SO package and is specified over the industrial temperature range from –40°C to +85°C. The internal power supply provides the quiescent current, which rises with temperature to maintain constant AC performance. In addition, the external resistor, R_Q, allows the user to vary the total quiescent current consumption between ±3mA and ±8mA. The quiescent current is specified at ±5mA using a quiescent current resistance (R_Q) of 430Ω. R_Q is connected to Pin 5 and the negative supply voltage (–5V). In normal operation, a negative current flows at Pin 2. If the user forces a positive current by using an external current source, the OPA622 is switched off and requires practically no current. Figure 6 shows the OPA622 as a current-feedback amplifier, which offers 350MHz bandwidth at 2.8Vp-p and a slew rate of over 2000V/µs. The feedback buffer is not necessary for the current-feedback configuration so it can be used for other applications. Since the output stage of the feedback buffer is purposely small to ensure a short delay time, and since it may not be overloaded, the load resistance at the maximum output signal should not exceed 500Ω.

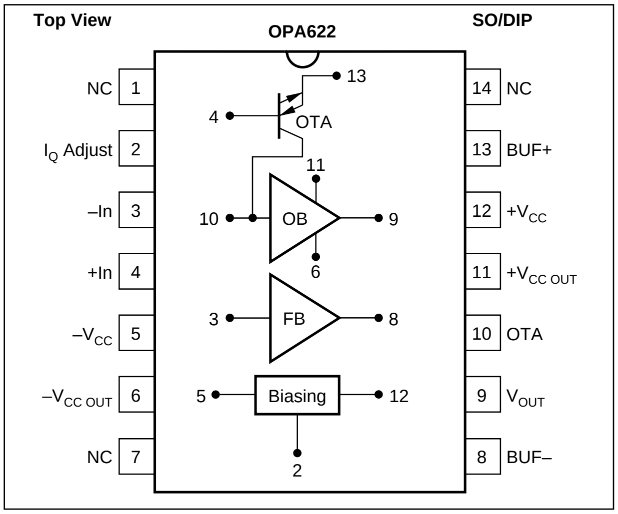


FIGURE 5. Pin Configuration.

PIN NO.	DESCRIPTION	FUNCTION
2	I_Q Adjust	Quiescent Current Adjustment: typ 3-8mA
3	–In	Inverting Analog Input
4	+In	Noninverting Analog Input
5	$–V_{CC}$	Negative Supply Voltage: typ –5VDC
6	$–V_{CC\ OUT}$	Negative Supply Voltage Output Buffer: typ –5VDC
8	BUF–	Analog Output Feedback Buffer
9	V_{OUT}	Analog Output
10	OTA	Analog Output OTA
11	$+V_{CC\ OUT}$	Positive Supply Voltage Output Buffer: typ +5VDC
12	$+V_{CC}$	Positive Supply Voltage: typ +5VDC
13	BUF+	Analog Output/Input

TABLE I. Functional Description of the Pin Configuration.

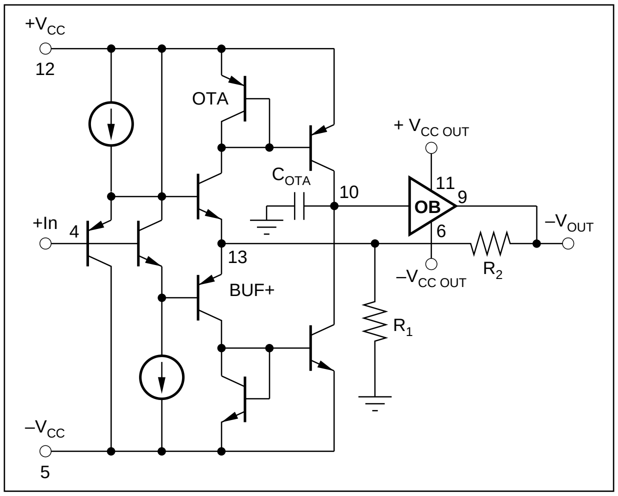


FIGURE 6. OPA622 as a Current-Feedback Amplifier.

One special feature of the OPA622 is its separate supply pins for the differential amp and the output buffer, which is capable of driving the ±70mA output stage. The separate supply decouples the differential amplifier from the output stage, through which large charge currents must flow at 200MHz large-signal bandwidth, and also improves the pulse response and allows various power supply sensing techniques for higher output voltage swings. In addition, it is possible to limit the current consumption to protect the output stage from overload.

Figure 7 shows inverting and noninverting versions of the OPA622 in current- and voltage-feedback modes.

OPTIMIZING THE FREQUENCY RESPONSE ADJUSTMENT

Analyses of various op amp configurations have proven that the frequency response is optimally flat when the following equation holds:

$$C/gm = 2k_O \cdot T_D,\ G_{CL} = \frac{1}{k_O}$$

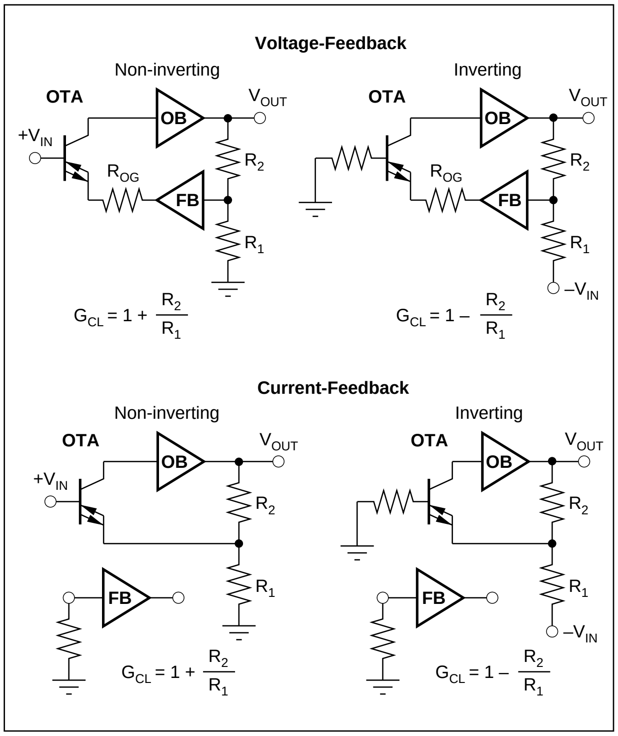


FIGURE 7. Overview of the Various Op Amp Configurations Possible with the OPA622.

Thus the ratio of the capacitance, C, at the high-impedance OTA output to the internal OTA transconductance is equal to the closed-loop gain times the delay time (T_D) times 2. Adjusting the open-loop gain externally to produce optimal frequency response is the best way to guarantee that wide-band amplifiers will function stably in feedback mode. As already shown in Figure 4, raising R_{OG} lowers the open-loop gain while simultaneously maintaining sufficient phase margin. What's important for wide-band amplifiers is that the bandwidth does not decrease with open-loop gain—thus the gain-bandwidth product rule, stating that the gain bandwidth of internally compensated op amps decreases with increasing closed-loop gain while the product of the gain times the bandwidth remains constant, no longer applies. Figure 8 shows that the OPA622 is quite successful in putting these theoretical analyses into practice. At a gain range of –2 to +10 and output voltage of 1.4Vp-p, the –3dB bandwidth varies from 110MHz to 230MHz while R_{OG} varies from 10Ω to 390Ω. The differences between the theoretical and real measurements are due to parasitic capacitances and other minor influences. Figure 9 shows the effect of varying R_{OG} at constant closed-loop gain. The frequency response is optimally aligned at a gain of +2 and R_{OG} of 150Ω. Increasing the R_{OG} flattens the frequency response curve, while decreasing R_{OG} produces a rise in frequency response at the end of the bandwidth. In some applications, slight peaking is useful; while increasing overshooting, it also expands the –3dB bandwidth and lowers the pulse slew rates.

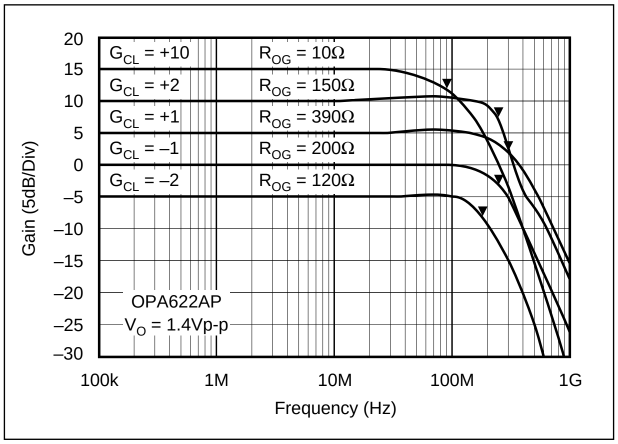


FIGURE 8. Frequency Response at Various Gains.

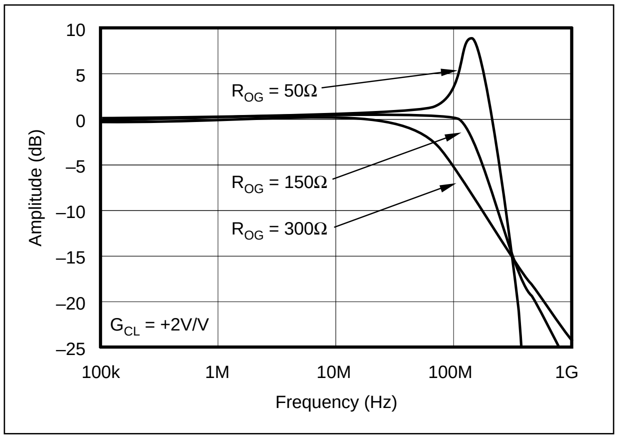


FIGURE 9. Effect of R_{OG} on the Frequency Response Curve.

The ability to adjust the open-loop gain externally lets users adapt the frequency response to capacitive load resistances to a certain extent. Figure 10 shows the flat frequency response attained at gain +2 for three different load capacitances.

To put the finishing touches on the general presentation of the OPA622, Figures 11, 12, and 13 show the bandwidth at different output signals, the pulse response at 5Vp-p, and the group delay time, respectively.

The broad range of applications for the OPA622 impressively demonstrates the flexibility of its individual circuit parts and pin configuration. The OPA622's specifications, which are shown in Table II, fulfill requirements for applications in high-speed analog and digital communications, broadcasting and video, test and instrumentation, fiber optic transmission, and data acquisition equipment. Typical applications include an input differential amplifier for test equipment and monitors, a line driver for analog and digital systems, an ADC input and DAC output amp, a multiplier output amp, and a magnetic head driver when combined with a discrete current source. The following discussion presents several applications in more detail.

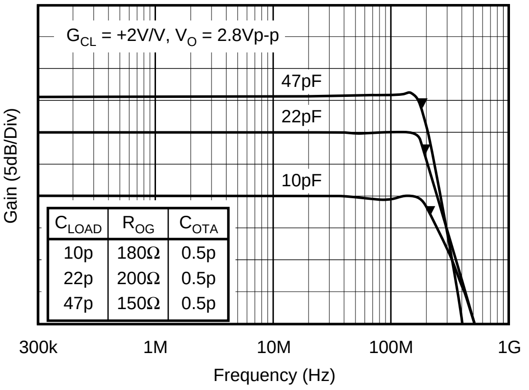


FIGURE 10. OPA622 Bandwidth at Various Capacitive Load Resistances.

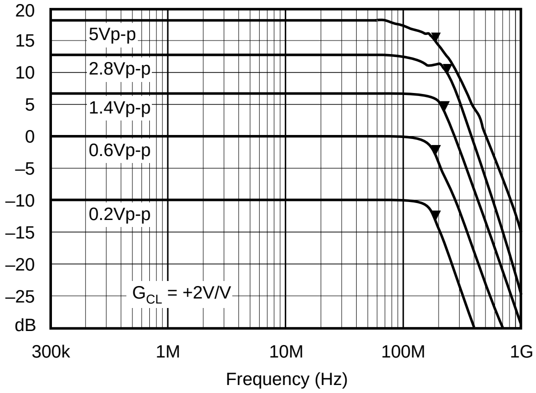


FIGURE 11. OPA622 Bandwidth at Various Output Signals.

Large Signal Bandwidth (5Vp-p)	1700V/µs (SOIC)
Slew Rate	200MHz (SOIC)
Gain Deviation: DC to 30MHz	0.12dB
DC to 100MHz	0.3dB
Quiescent Current Consumption	±5mA
Input Bias Current	–1.2µA
Output Current	±70mA
Offset Voltage	100µV
Common-Mode Rejection	78dB

TABLE II. Typical Parameters of the OPA622 as a Voltage-Feedback Amplifier.

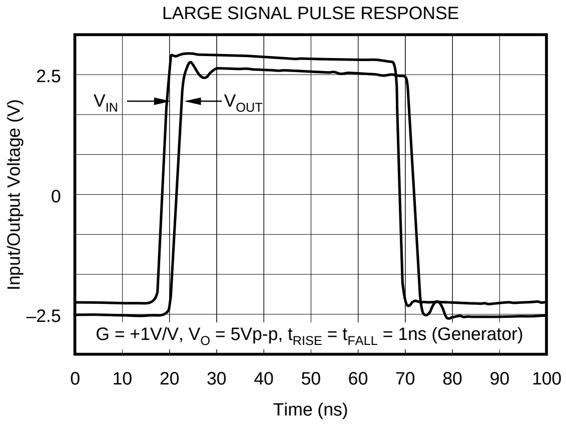


FIGURE 12. Pulse Response at 5Vp-p.

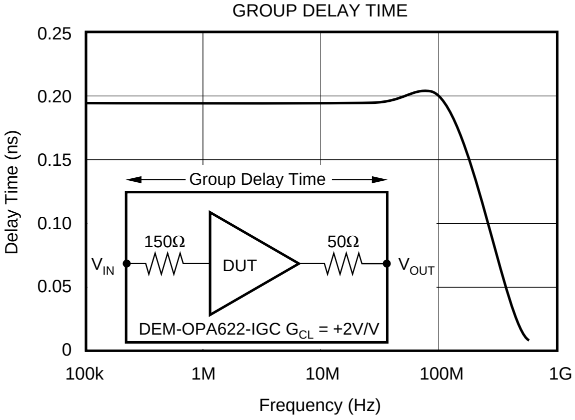


FIGURE 13. Group Delay Time.

A TRUE DIFFERENTIAL AMPLIFIER FOR WIDE-BAND MULTIPLIERS

Four-quadrant, wide-band multipliers produce differential output currents to achieve the high bandwidth required by their applications. A multiplier's differential open collector outputs are undesirable, however, in applications in which the multiplication should produce a voltage referred to ground. Since current-feedback amplifiers have asymmetrical inputs, they require complex discrete circuitry to be used as output amplifiers for wide-band multipliers. Another possibility is to use an RF transmitter with a sender tap and corresponding winding ratio to achieve the required output impedance matching. In the application shown in Figure 14, the OPA622 with its high-impedance inputs converts the complementary output currents of the multiplier into an asymmetrical output voltage. The low-impedance output can be adapted to 50Ω or 75Ω systems by inserting a series resistor. In this way, the OPA622 can be used as a true differential amplifier.

For the multiplier to function perfectly, both open collector outputs have to have a potential of more than the positive supply voltage to prevent saturation of the output transistors. Additional resistors (R_3 and R_4) are located in series to the multiplier supply pins so that no extra power supply is necessary. These resistors reduce the supply voltage of the multiplier to less than that required by the output amplifier. We recommend raising the supply voltage from typically 5V to 6V to expand the common-mode output range of the OPA622 and to improve the multiplier's dynamic performance.

Using the multiplier, it is possible to multiply wide-band signals of up to 100MHz with little distortion. Other typical

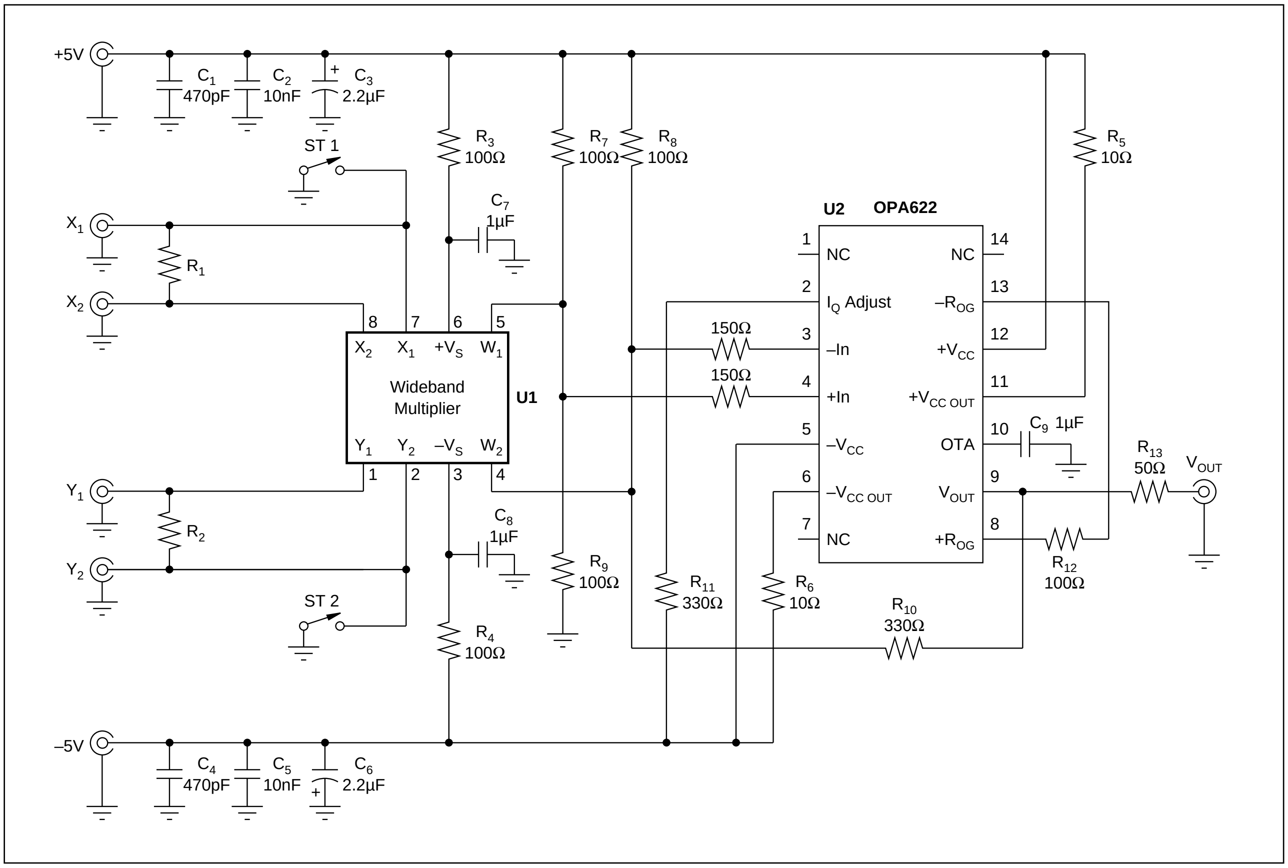


FIGURE 14. Output Amplifier for Wide-Band Multipliers.

multiplier applications include modulation, demodulation, signal control, mixing, phase detection, and fast video switching and keying.

EXPANDING THE OPEN-LOOP AMPLIFIER

Amplifiers with no external feedback loop deliver bandwidths and slew rates that are unattainable using current- and voltage-feedback op amps. They can not, however, provide the benefits of a feedback loop, such as improvement in linearity, reduction in output impedance, performance adjustment using the feedback network, and reduced sensitivity to parameter and temperature variations and aging effects. The OPA622, however, provides a solution combining the advantages of both methods. As shown in Figure 15, the OPA622 functions like a discrete common emitter circuit. Its working points are internally fixed and the transconductance of the OTA can be adjusted by varying R_Q. The transconductance remains constant over the input voltage range, which is the basic prerequisite for distortion-free signal transmission in nonfeedback mode. Inserting the feedback buffer lowers the input offset voltage to 100µV, and the output stage then decouples the amplifier stage. Unlike that of feedback op amps, the output impedance is not in the mΩs, but rather between 4Ω and 10Ω depending upon the quiescent current. It remains, however, extremely constant over frequency. The gain can be adjusted using the resistors R_1 and R_2. Signal excitation at Pin 4 produces noninverting mode, while excitation at Pin 3 produces inverting mode.

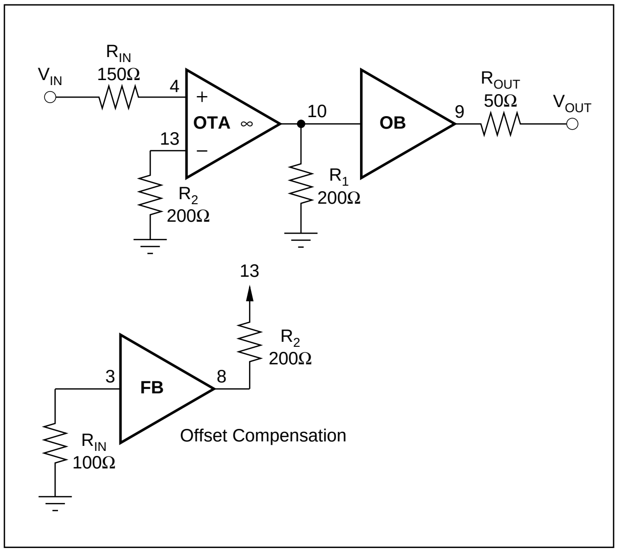


FIGURE 15. Open-Loop Amplifier Common Emitter Circuit.

AGC AMPLIFIER OR AMPLITUDE MODULATOR

Near the zero point (V_{DS} ~ mV), a FET functions like a linear resistor controlled by V_{GS} ($r_{DS} = dV_{DS}/d_{ID}$). As shown in Figure 16, this property of a FET can be used to control the amplitude of an RF signal by the DC voltage, V_{GS}, according to the equation in the figure. In this configuration, the OPA622 functions as an open-loop amplifier with offset compensation. The signal excitation can take place either at the inverting or at the noninverting input. The only components lacking for a complete AGC circuit are a peak detector to measure the output voltage and a control amplifier, which can also be used to linearize the FET.

It's easy to convert an AGC amplifier into an amplitude modulator. The carrier frequency is applied to the input of the OPA622, and the FET modulates the carrier frequency amplitude in tact with the LF signal voltage.

DIRECT-FEEDBACK AMPLIFIER

It has already been mentioned that a short delay time in the feedback loop is important to provide large bandwidth. As indicated by its name, the direct-feedback amplifier, shown in Figure 17, uses a direct, short feedback loop. The output signal at the OTA is transferred via R_2 to the inverting input. Since the currents at the OTA output and the inverting input have the same polarity, they combine to counteract the voltage at the noninverting input. As already shown using the OPA660 direct-feedback amplifiers can deliver bandwidths of up to 500MHz and excellent pulse behavior at slew rates of up to 2ns.

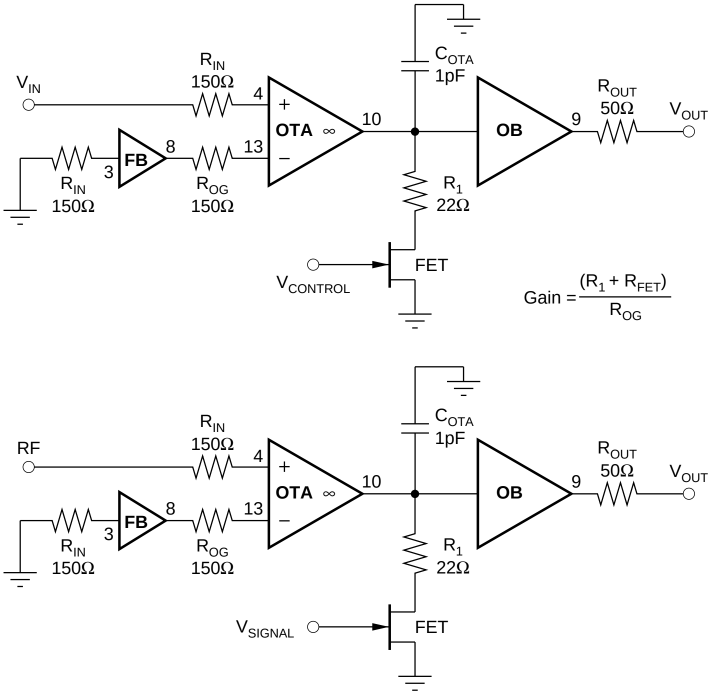


FIGURE 16. AGC Amplifier and Amplitude Modulator.

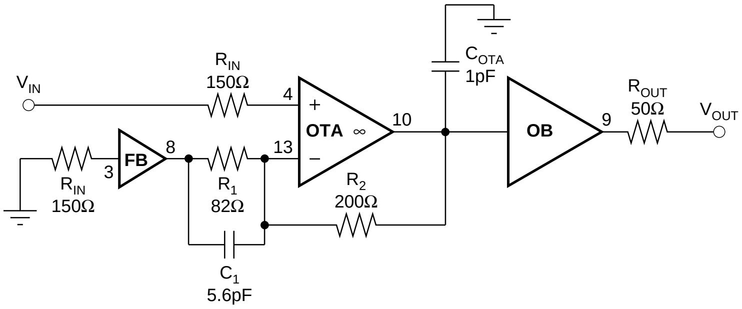


FIGURE 17. Direct-Feedback Amplifier with Offset Compensation.

VOLTAGE-FEEDBACK AMPLIFIER WITH OUTPUT VOLTAGE LIMITATION

Some integrated circuits such as very fast ADCs react extremely sensitively to overdrive at the input. In such cases, overdrive protection is vital to prevent damage to the converters. Unlike circuits offering external protection for sensitive inputs, the circuit shown in Figure 18 limits the maximum output voltage from a TV camera or production mixer that can go into a broadcast distribution system. The high-impedance OTA output functions linearly only up to the positive or negative limits determined by the limitation circuitry.

LOW JITTER COMPARATOR

Integrated circuits with good pulse behavior and a short recovery time after overdrive make excellent comparators. Figure 19 shows a comparator using the OPA622. This configuration might appear unusual at first glance, but it offers a comparator with jitter of approximately 20ps at a signal frequency of 10MHz. The OPA622 compares the voltages at its two inputs and changes the output according to the difference between these input voltages. The two antiparallel GaAs diodes limit the output voltage and keep the OPA622 in the linear range. A configuration using R_1 and C_1 produces positive feedback from the OTA output to the positive input and works like a Schmitt trigger, accelerating the output voltage change during the reversal phase of the comparator. The positive feedback with R_1 increases the open-loop gain of the comparator at low frequencies, while C_1 increases the overall open-loop gain over frequency.

DESIGN TOOLS

To enable users to test the parameters and applications of the OPA622 for themselves, Burr-Brown offers a completely assembled demo board and two PSpice® models. The demo board gives important tips for layout design, as well as facilitating the test phase. Since almost all pulse and bandwidth parameters specified in the PDS were determined using this demo board, it is guaranteed to deliver comprehensible results. As can be seen in Figure 20, the noninverting variation can be tested using voltage feedback and a gain of +2. The board uses SMA RF connectors as an interface to the test devices. For users who wish to reassemble the pins, Table III lists recommended component values for various gains.

Another way to sample the OPA622 is by simulation using the PSpice® circuit simulator program. The two PSpice® macromodels for the OPA622 feature differing accuracy and simulation times. Both models are part of a shell, which makes it easier for the user to run the simulations and compare simulation results. The disk also contains completely dimensioned application circuits for the most common applications, which can be displayed immediately after installation.

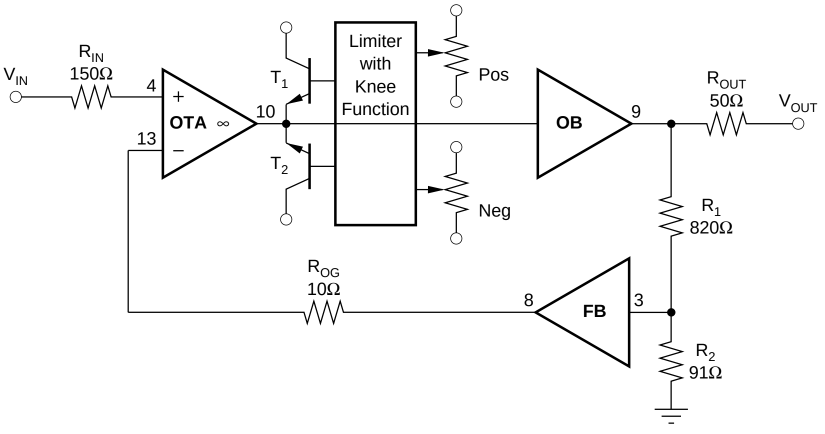


FIGURE 18. Operational Amplifier with Output Voltage Limitation.

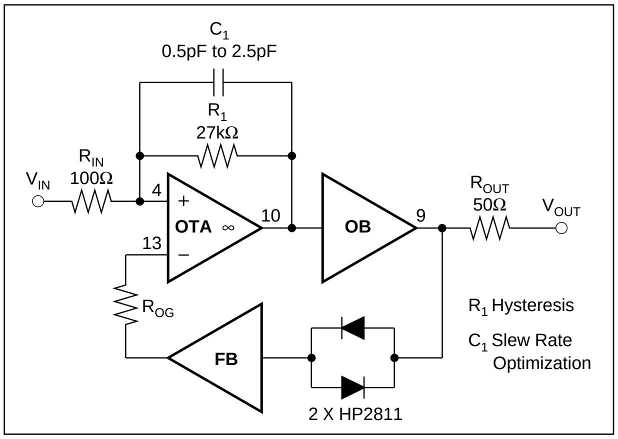


FIGURE 19. Comparator with Voltage Feedback.

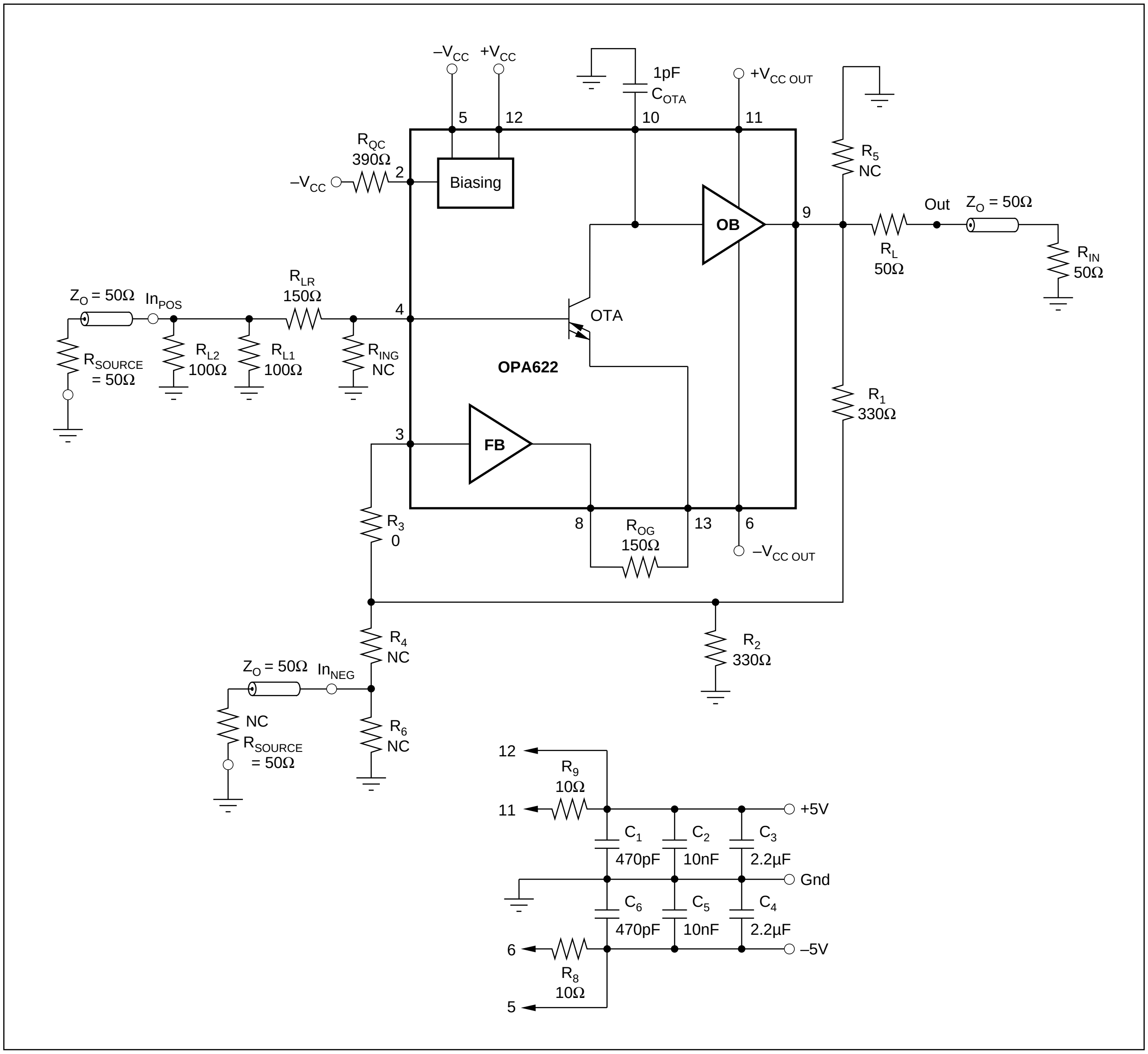


FIGURE 20. Circuit Schematic Demo and Board DEM-OPA622-1GC.

OPA622AP		**I_Q = 5mA**		**R_{QC} = 430Ω**			
G_{CL}	**+1**	**+2**	**+5**	**+10**	**–1**	**–2**	**UNITS**
R_1	0	330	620	1,600	390	470	Ω
R_2	—	330	160	180	—	—	Ω
R_3	220	0	0	0	0	0	Ω
R_{OG}	330	150	56	10	200	150	Ω
C_{OTA}	2.2	1	—	—	1	1	pF
R_{LR}	150	150	150	150	150	150	Ω
R_4	—	—	—	—	390	240	Ω
R_5	—	—	—	—	62	62	Ω
Ring	—	—	—	—	150	150	Ω
Bandwidth:							
V_{OUT} = 0.2Vp-p	170	160	140	110	135	125	MHz
V_{OUT} = 2.8Vp-p	220	200	170	110	150	150	MHz

OPA622AU		**I_Q = 5mA**		**R_{QC} = 430Ω**			
G_{CL}	**+1**	**+2**	**+5**	**+10**	**–1**	**–2**	**UNITS**
R_1	150	240	470	820	240	300	Ω
R_2	—	240	120	91	—	—	Ω
R_3	0	0	0	0	0	0	Ω
R_{OG}	270	150	47	10	160	100	Ω
C_{OTA}	2.2	1	—	—	1	1	pF
R_{LR}	200	150	200	200	150	150	Ω
R_4	—	—	—	—	240	150	Ω
R_5	—	—	—	—	68	68	Ω
Ring	—	—	—	—	150	150	Ω
Bandwidth:							
V_{OUT} = 0.2Vp-p	200	170	160	100	180	175	MHz
V_{OUT} = 2.8Vp-p	250	240	230	100	250	240	MHz

TABLE III. Typical Parameters of the OPA622 as a Voltage-Feedback Amplifier.

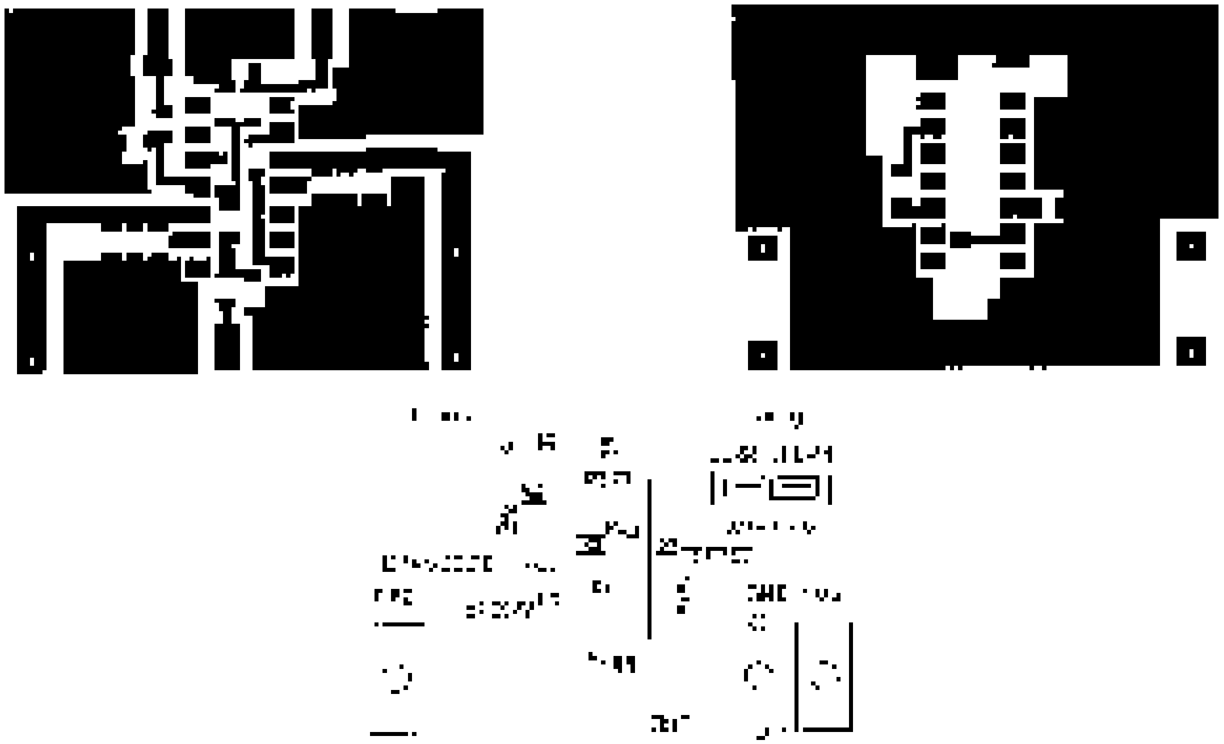


FIGURE 21. Layout and Silkscreen of the Demo Board.