A homebrew two-telephone intercom

The design described in this paper differs in three ways from many other two-telephone intercoms described on the internet, including the original "Link Telephone Intercom" designs.

1. This design uses a so-called "dry" telecom transformer, in which DC current is not allowed to flow through the coils of the transformer. "Wet" transformers are easier to use, but they are bigger, more expensive and harder to find.

2. Each telephone has its own power supply, being a 12Vdc 1A wall wart. This allows the telephones to be placed farther apart. In my application, the two telephones are located about 200 feet apart on opposite sides of an industrial building.

3. The two telephones are connected by only four wires. Some other designs require up to seven wires for the connection.

Like most other designs, though, this one uses a 12Vdc buzzer to announce an incoming call. This means that the circuit does not need to produce the 90Vac sine wave which is used in normal telephony for the ring signal.

Circuit description

U3 and U4 are 555 timer chips wired in astable mode. When the Reset line (pin 4) is high, U3 produces a 320 Hz square wave and U4 produces a 1.5 second on – 1.5 second off square wave. Both square waves have approximately a 50% duty cycle. These waveforms are used to power the buzzer at the receiving end of a call and to generate the ringback tone in the earpiece of the initiating telephone.

The calculations for the 320 Hz timer are as follows:

R1 = 4.7K
R2 = 100K
C1 = 0.022μF
Time on = 0.693 × (R1 + R2) × C1 = 1.596 ms
Time off = 0.693 × R2 × C1 = 1.525 ms
Period = Time on + Time off = 3.121 ms → Frequency = 320 Hz
Duty cycle = Time on ÷ Period = 51.1%

The calculations for the three second timer are as follows:

R3 = 4.7K
R4 = 100K
C2 = 22μF
Time on = 0.693 × (R3 + R4) × C2 = 1.596 sec
Time off = 0.693 × R4 × C2 = 1.525 sec
Period = Time on + Time off = 3.121 sec
Duty cycle = Time on ÷ Period = 51.1%

I chose these component values so that the pitch of the ringback tone and cadence of the ring pulses were pleasant to the ear.

A series circuit comprised of the infrared LED in optocoupler U5, resistor R5 and the telephone is used to determine the status of the telephone. When the handset is on-hook, the resistance across the telephone, between pins 1 and 2 of connector J1, is extremely high. No current flows through the series circuit, so the LED is dark. The output transistor of the optocoupler is therefore cut off and the output line (pin 6) is pulled high by resistor R6. When the handset is picked up, the telephone's resistance drops to a few hundred Ohms. DC current now flows through the series circuit, lighting up the LED. The glow acts like current flowing into the base of the output transistor, which becomes active. Actually, the transistor is driven into saturation, and the collector (pin 6 once again) is pulled low. Thus it is that the pin 6 line gives us direct knowledge about whether the handset is on-hook (voltage is high) or off-hook (voltage is low). This line is one of the four which connect the two telephones in the intercom. Connector J2 is a four-terminal connector, and is the endpoint of the connecting cable. In the schematic, the pin 6 line of this telephone is labelled "This phone". The other telephone has a similar circuit, of course, and its "This phone" line is connected to the "Other phone" terminal of this telephone's J2 connector.

I selected the value of resistor R5 to ensure that about 15 mA of DC current flows through the telephone when it is taken off hook. This will be enough to light up the LED. The calculations are as follows:

Telephone's off-hook resistance = 300Ω (This is an assumption)
Voltage drop over LED when lit = 1.5V (This is another assumption)
Series resistance of R5 and telephone = 330Ω + 300Ω = 630Ω
Voltage drop over R5 and telephone = 12V – 1.5V = 10.5V
DC current through series circuit = V ÷ R = 10.5V ÷ 630Ω = 16.7 mA

When this telephone is off-hook, the DC voltage drop over the telephone will be 16.7 mA × 300Ω = 5.0V. That is well inside the range of suitable DC voltages for operating a standard telephone. When both telephones are off-hook, the audio signal is passed through a fairly big capacitor (C6 = 10μF) and onto the "Audio" line of the connecting cable.

Capacitor C5 is a blocking capacitor which prevents the DC current in the series circuit from flowing through the primary coil of transformer T1. T1 is a 600Ω-to-600Ω telecom transformer, through which the ringback signal is passed to the earpiece of the initiating telephone. (The purpose of the ringback signal is to assure the calling party that the telephone at the other end is ringing.)

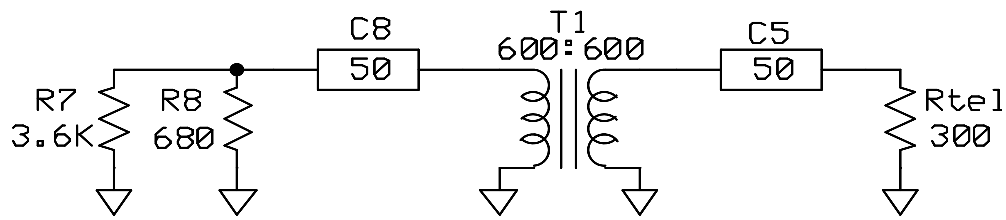
Two quad gate chips take care of the control logic. Both are CMOS chips which can handle the 12V power supply. U1 is a quad two-input NAND. U2 is a quad 2-input NOR. They are wired into three sub-circuits.

Logic circuit #1

This sub-circuit generates the ringback signal. It begins by inverting the "This phone" line. That inverted signal is then NANDed with the "Other phone" line. The output pin 11 of NAND U1 is usually high, and goes low only in the special circumstance that "This phone" is off-hook and "Other phone" is on-hook. When the output pin 11 of NAND U1 is high, it overrides the other input of the following NOR gate, which is kept low. Only in the special circumstances just described will NOR input pin 1 go low, turning control of this NOR gate over to input pin 2. Input pin 2 is a combination of the 320 Hz and three second square waves. What appears at the NOR's output pin 3 is an alternating pattern of 1.5 seconds of 320 Hz followed by 1.5 seconds of "silence". Because capacitor C8 blocks the flow of DC through the secondary coil of transformer T1, "silence" occurs when the output pin 3 is held at a constant voltage. It does not matter whether this constant voltage is high or low, so long as it is constant.

When it's active, the output signal at pin 3 is a 12V square wave. This is much too high a peak-to-peak amplitude to be fed directly onto a telephone line. The audio signals (that is, the AC waveforms) in normal telephony typically have a peak-to-peak voltage of 0.7V or so. Resistors R7 and R8 form a voltage divider which provides the appropriate scaling. The peak input voltage (12V) is scaled down by the fraction R8 ÷ (R7 + R8) = 0.159 to 12V × 0.159 = 1.9V. The AC waveform after passage through capacitor C8 will be approximately 1.9V peak-to-peak. I set it to more than 0.7V because not all of the

1.9V will find its way through to the earpiece. I selected the value of resistor R8 to provide some degree of impedance matching through the transformer. Note that the capacitive reactance of capacitors C5 and C8, at the ringback frequency of 320 Hz, is $X_C = 1 \div (2\pi \times 320 \times 10\mu) = 49.7\Omega$. The essentials of the AC circuit through the transformer can be illustrated as follows:



The calculations are as follows:

Equivalent resistance of R7 and R8 = (3.6K × 680) ÷ (3.6K + 680) = 572Ω
Reactance to left of T1 = $\text{sqrt}(572^2 + 50^2)$ = 574Ω
Reactance to right of T1 = $\text{sqrt}(50^2 + 300^2)$ = 304Ω

This is close enough for my purpose. In any event, one does not have any control over the characteristics of the telephone. I assumed above that it has a DC resistance of 300Ω. That does not mean that its AC resistance/reactance is the same; it may well be closer to 600Ω.

Logic circuit #2
This sub-circuit controls the buzzer. It begins by NANDing together the "This phone" line and the three second square wave. It operates in the specific circumstance that "This phone" is on-hook (so the voltage at pin 1 of NAND U1 is high) and "other phone" is off-hook (so the voltage at pin 13 of NOR U2 is low). Only in this special circumstance will the three second square wave pass through to output pin 11 of NOR U1. Transistor Q1 is a small signal NPN. The value of resistor R9 (1KΩ) was chosen so that Q1 will operate either in cutoff or saturation. The value of resistor R10 was chosen to reduce the loudness of the buzzers to an acceptable level.

Note that, unlike many other intercom designs, each end of this intercom powers its own buzzer, not the one at the other end.

Logic circuit #3
This logic circuit combines the "This phone" and "Òther phone" signals to achieve a more subtle purpose. When both telephones are on-hook (voltage high), output pin 4 of the NOR gate will be low. Capacitor C10 will discharge through resistor R11, and the output pin of the NAND gate will go high. This will set the Reset lines of both 555 timers, activating the timers and causing them to produce their square waves. This state of affairs will continue even when one handset is taken off hook, since the output pin of the NOR gate will remain low so long as at least one handset is on-hook.

Things get interesting only when both handsets are taken off-hook and a conversation is underway. Capacitor C10 will charge up through resistor R11. The output pin of the NAND gate will go low, and the 555 timers will be reset. They will stop generating their square waves. Since the two parties are talking with each other, there is no need for the buzzers or ringback tones.

Think ahead to the end of the conversation when the parties hang up. Both parties will not hang up at exactly the same instant. There will always be some period of time between their placing the handsets back on-hook. The interval might be short, but it might not be short if one party fumbles his handset or holds it to his ear while writing a final note. This state of affairs – with one handset off-hook and the other on-hook – is, unfortunately, exactly the same circumstance for which we designed the ringback and buzzer controls. However, we don't want these controls to operate at the end of a call, but only at the beginning.

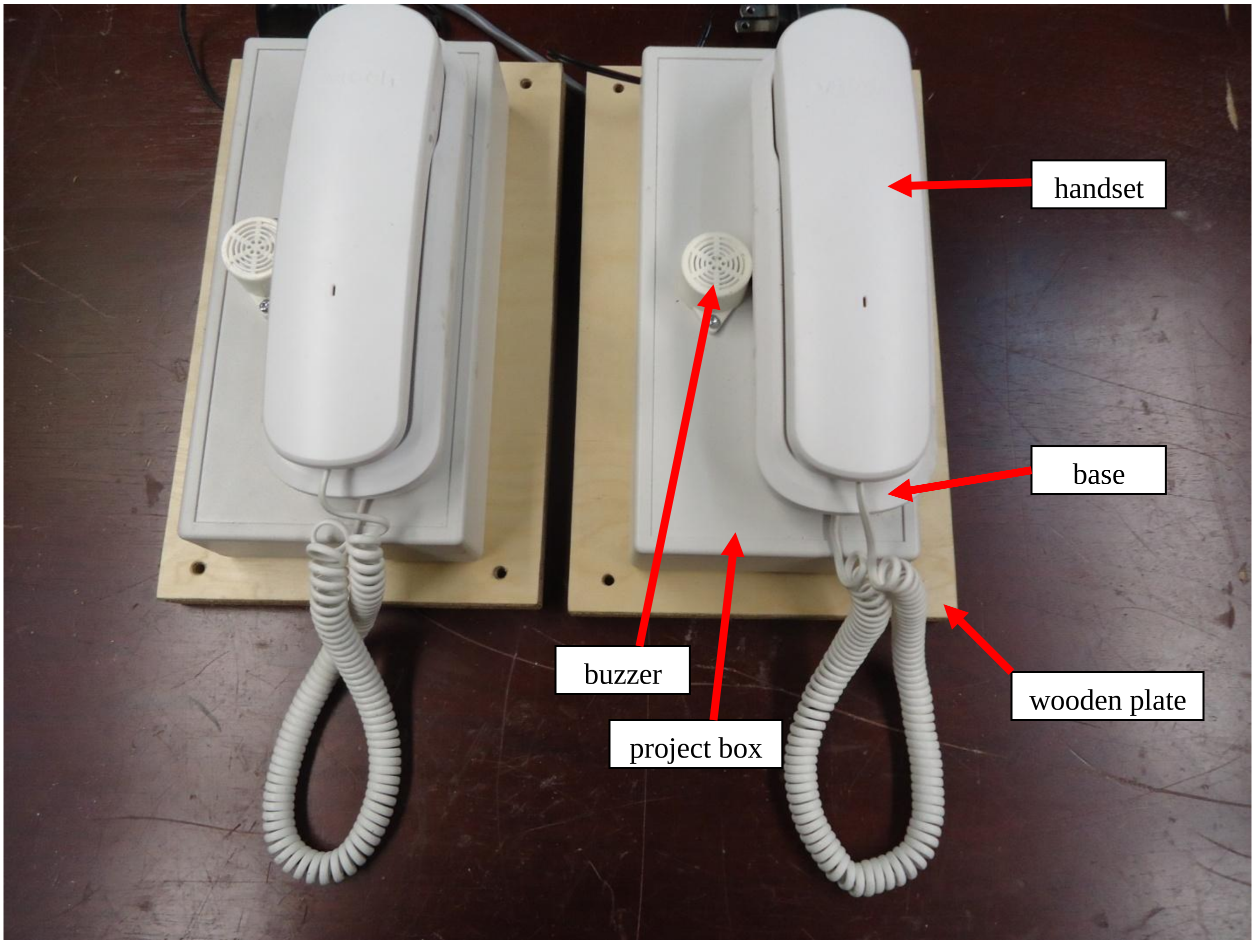
The two gates, and the capacitor and resistor, enable us to distinguish between the start and the end of a call. The time constant of the resistor-capacitor pair is quite long, being $\tau = R11 \times C10 = 47K \times 100\mu = 4.7$ seconds. This means that there will be a noticeable delay between the instant when the output of the NOR gate changes state and the output of the NAND gate changes state. The delay will be approximately one-half of one time constant, or a couple of seconds.

The result is that, at the end of a conversation, there will be a grace period of a couple of seconds before the 555 timers begin to generate their square waves and the phones start ringing.

Note that the time constant causes the same delay at the start of a conversation. It will take a couple of seconds after both handsets are taken off-hook before capacitor C10 has charged up enough to bring the Reset lines low.

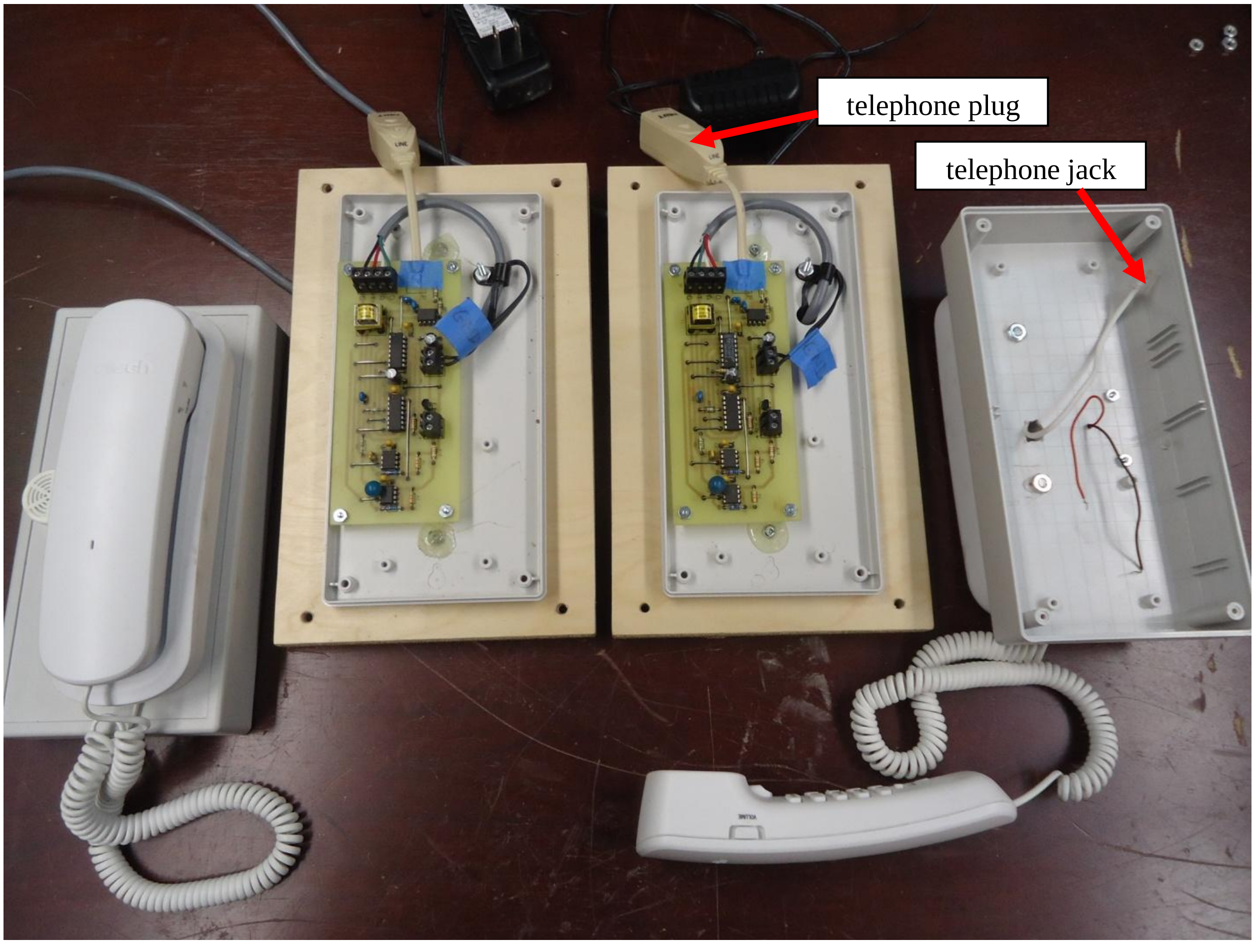
Construction

I used inexpensive wall-mount telephones, costing less than $20. I found to my dismay that I could not get access to the inside of either the handset or the base. The shells were each made of two pieces of moulded plastic snapped together. But certain components had been bathed in glue before the pieces were snapped together. Separating the two pieces completely destroys the handset or base. My remedy was to mount the telephones, untouched, on top of project boxes containing the circuit boards. The project boxes (which do not having mounting flanges) were then secured with internal screws to wooden plates. The following photograph shows the two completed units.



The power cord from the wall wart and the four-wire telephone cable are routed through a hole cut through the bottom of the project box and through the wooden plate below it. When the wooden plate is screwed into the wall, none of the wiring is accessible.

The following photograph shows the insides of the units. A single-sided PC board is sufficient. The only item of interest is the telephone plug. The wires in the cord of the telephones I used were incredibly thin. I simply could not strip the insulation off without cutting through the copper strands. (I conducted this bit of research on the same telephone whose plastic shells I ruined.) My solution was to leave the cord alone, with the jack on the end. To enable conncetion to the terminal strip on the PC board, I used the female end of a telephone extension cord whose wires were large enough to strip.



I have attached copies of the schematic diagram, the PC board and the silkscreen layer. The PC board is single-sided copper. The jumper wires which connect copper traces are shown as thin black lines on the silkscreen layer.

Jim Hawley
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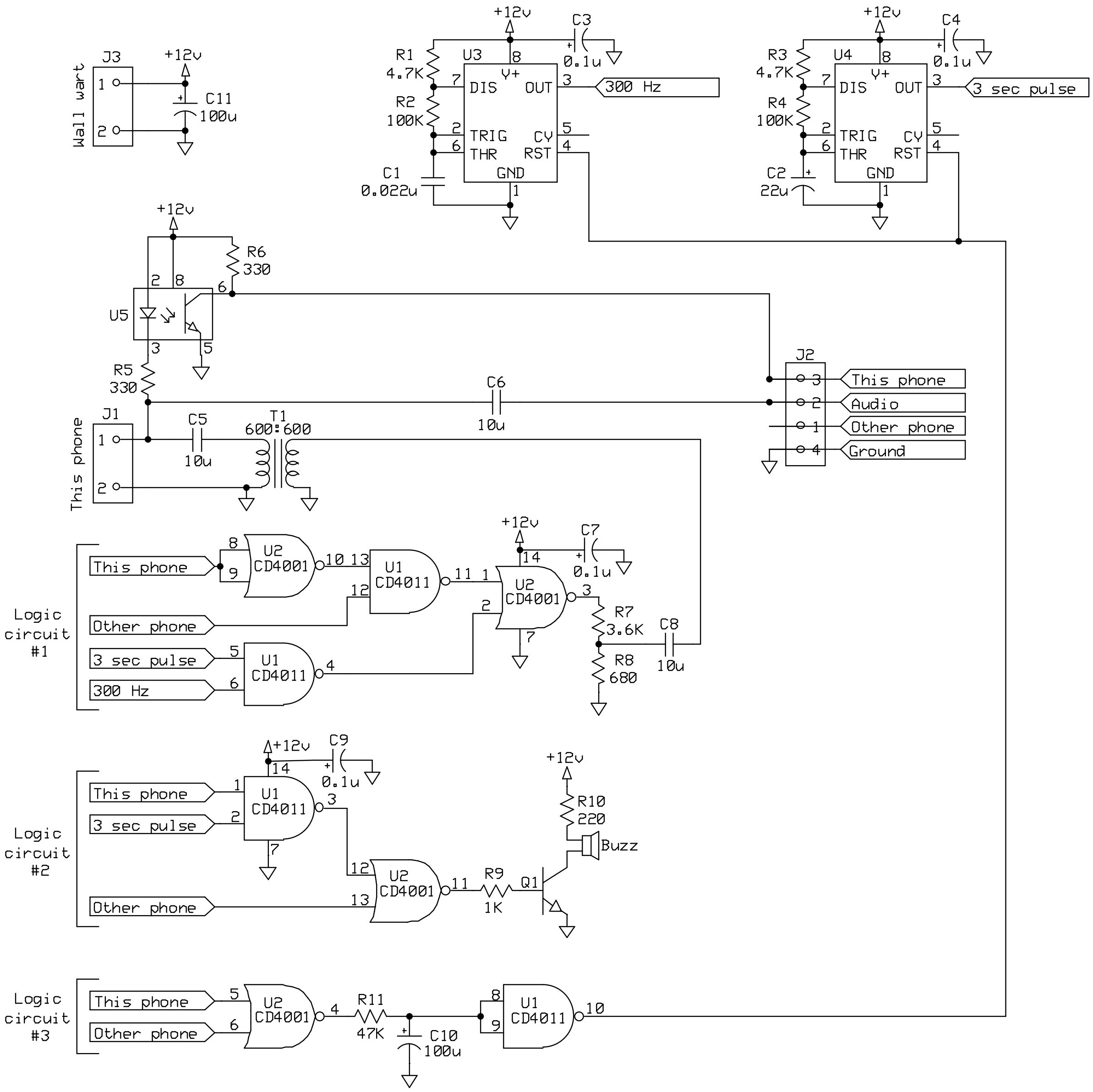
(An e-mail describing errors or omissions would be appreciated.)



Digikey part numbers
U1 CD4011BCN-ND quad CMOS NAND
U2 CD4001BCN-ND quad CMOS NOR
U3,U4 LM555CNFS-ND 555 timer
U5 HCPL2601QT-ND optocoupler
Q1 2N2222ACS-ND general purpose NPN transistor

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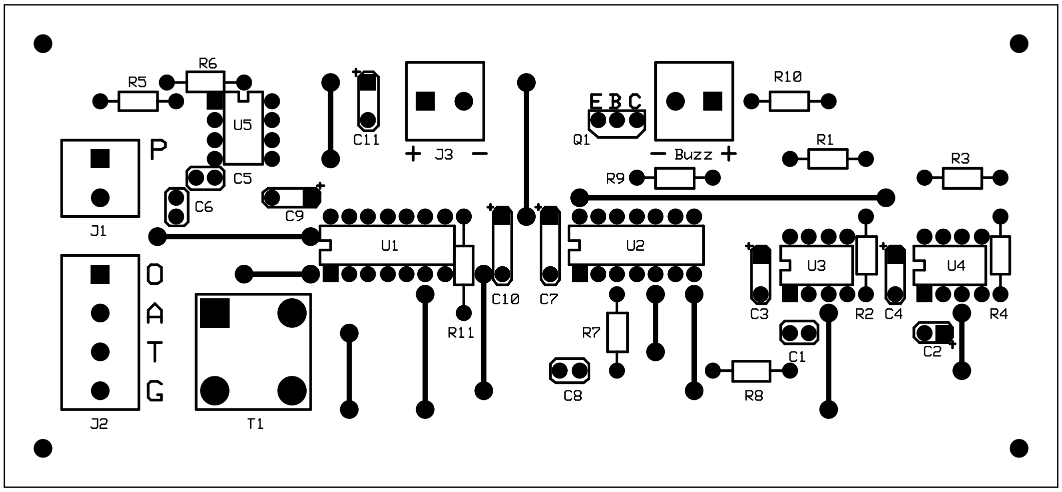
The circuit board is 5½ inches wide and 2½ inches high. The following images of the silkscreen layer and the copper trace layer are very close to real size.



The single-letter identifying labels of the terminal screws are:

- P = incoming tip and ring Phone lines (polarity does not matter)
- O = Other telephone
- A = Audio line
- T = This telephone
- G = Ground

"Buzz" is the terminal strip for connecting the buzzer. "J3" is the terminal strip to which the wall wart is connected.