DINESH BHATIA

WIRELESS GUITAR TRANSMIT

TRANSMIT YOUR GUITAR CHORDS through the air to a nearby FM receiver, and get rid of those cords on the floor. Your FM receiver can feed one or more amplifiers if you really want to boost the sound and fill the room with music. Simply plug this transmitter into your guitar's output jack, make a few adjustments, and start playing "wireless" through your FM stereo tuner or a portable FM receiver.

With this Guitar Transmitter, you won't have to plug in cables, hook up guitar-effects pedals, and turn on a lot of different power sources. Moreover, you can build your own transmitter for a lot less money than you would pay for a factory-built unit—and you'll end up with a better product. The parts for the Guitar Transmitter described here cost less than $40. This transmitter has a built-in distortion effects unit, so you won't have to fumble with an effects pedals every time you play your guitar.

Today many professional guitar players have their own wireless guitar transmitters. Why doesn't every guitar player have one? Probably because of price. Until now it has just been a lot less expensive to plug your guitar into your amplifier with a patch cord.

Commercial wireless guitar transmitters have available since the late 1960's, but those early units were either too noisy or too expensive for most amateurs. It seemed that only rock stars could afford them. However, integrated circuitry cut the cost of transmitters and led to significant improvements in signal-to-noise (S/N) ratio over the earlier models.

However, recent "affordable" IC-based transmitters have usually included some form of *companding* to reduce background noise. Companding is a technique for compressing the signal's dynamic range at the transmitter and then expanding it back to its original range at the receiver. Dynamic range is the difference in volume between the lowest and highest audio levels.

Companding usually works well as a noise-reduction technique, but it has drawbacks: the most common of these is a response known as "breathing—" the background noise gets softer and louder as

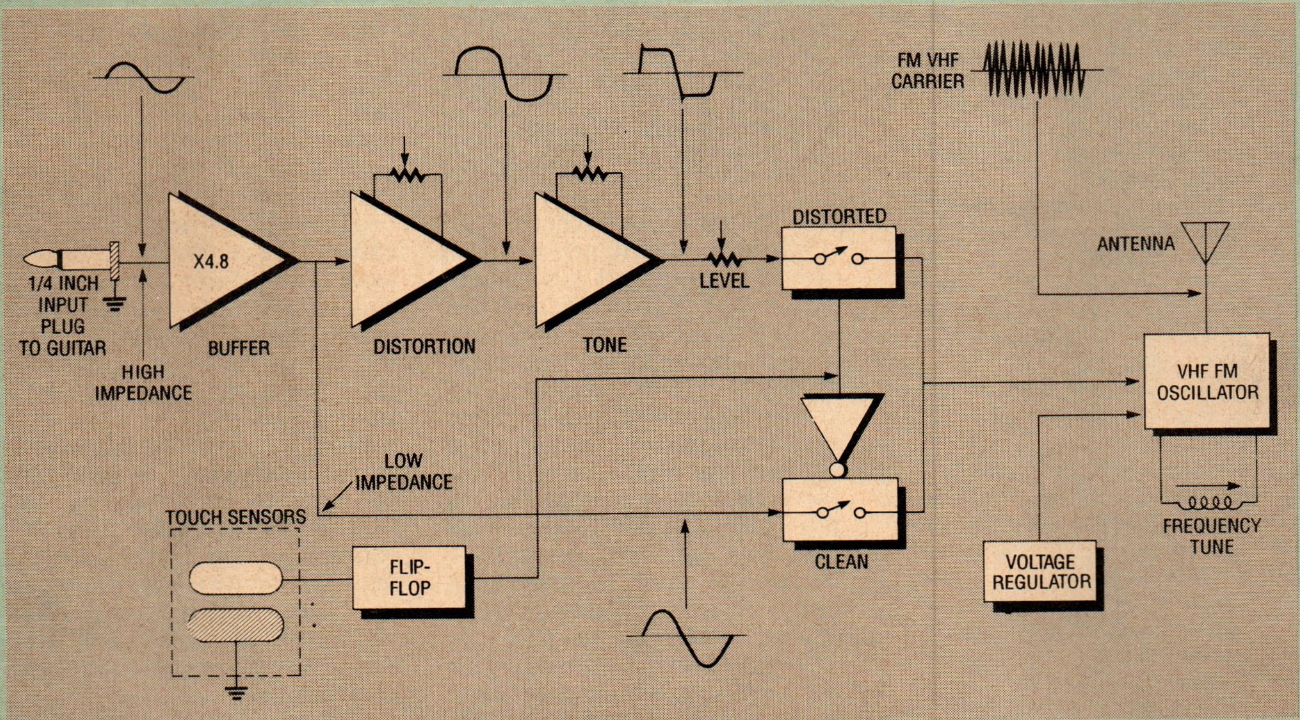
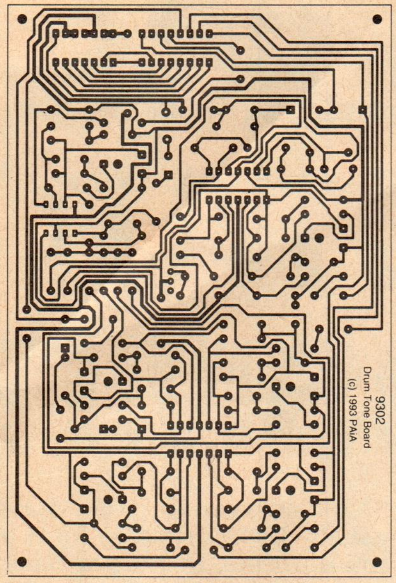


FIG. 1—BLOCK DIAGRAM OF THE WIRELESS GUITAR TRANSMITTER showing the separate channels for the distorted and clean sound and the VHF FM oscillator.



TONE BOARD foil pattern.

(and a snare drum is nothing but a tom-tom with snares), diode D5 couples the tom-tom oscillator to the snare trigger so that it rings when the snare pad is hit. Diode D5 also prevents the snare from sounding when

Note: The following items are available from PAiA Electronics, Inc., 3200 Teakwood Lane, Edmond, OK 73013, Phone (405) 340-6300, Fax (405) 430-6378:

- **Sensor PC board only (item # 9301pc)—$16.50**
- **MIDI PC board only (item # 9201pc)—$27.25**
- **Tone PC board only (item # 9302pc)—$19.25**
- **Sensor board kit (item # 9301k, includes PC board and parts)—$54.25**
- **MIDI computer kit (item # 9201k, includes PC board, DIN jacks, and PROM with firmware)—$89.50**
- **Tone board kit (item # 9302k, includes PC board and parts)—$34.75**
- **Complete MIDI ThumbDrum kit (item # 9300m, includes case, PC board, all parts, and firmware in PROM)—$165.00**
- **Complete audio ThumbDrum kit (item # 9300a, includes case, PC board, and all parts)—$99.00**
- **Case only (item # 9300c, includes wood side panels)—$28.50**

TONE BOARD PARTS LIST

All resistors are ¼-watt, 10%.
R1—1000 ohms
R2, R5, R9, R16, R23, R31—10,000 ohms
R3, R4, R10, R11, R13, R17, R18, R24, R25, R32, R33, R39, R47, R6, R20, R27, R35—3.9 megohms
R7, R14, R21, R28, R36, R51—100,000 ohms, trimmer potentiometers
R8, R15, R45, R60—330 ohms
R12—15,000 ohms
R19—68,000 ohms
R22, R30—33,000 ohms
R26, R29, R44—1 megohm
R34—39,000 ohms
R37, R43—680,000 ohms
R38—2200 ohms
R40–R42, R46, R48, R50—2.2 megohms
R49, R52–R57—47,000 ohms
R58, R59—22,000 ohms
R61—10,000 ohms, potentiometer

Capacitors
C1, C13, C18, C26, C9—0.01 µF, ceramic disc
C2, C6, C10, C14, C19, C22—0.01 µF, Mylar
C5—0.05 µF, Ceramic
C7, C8—4700 pF, Mylar
C3, C4, C11, C12, C15, C16, C20, C21—0.001 µF, Mylar
C17—0.22 µF, Mylar
C23, C24, C27–C29—560 pF, Mylar
C25—0.1 µF, Mylar
C30—0.005 µF, Ceramic
C31—10 µF, 15 volts, electrolytic

Semiconductors
IC1, IC2—LM324 quad op-amp
IC3—5532 dual low-noise op-amp
D1–D5—1N914 diode
Q1—NPN silicon transistor (selected for noise, see text)

Other components
J1—14-pin input connector
J2—16-pin DIP socket
J3—¼-inch phone jack
Miscellaneous: PC board, ribbon cable, solder

only the tom-tom trigger is hit.

Whereas all the other drum circuits operate at a constant pitch, the SynthDrum built around IC1-c is a little different. It slides down in pitch as it decays. The circuit is a ringing oscillator like the others, but here the frequency can be adjusted by varying the current flow through diodes D1 and D2. It's not typical to see diodes used that way, but as current flow through a diode increases, its equivalent impedance goes down. Diodes D1 and D2 are "controlled" by the current flow through R29, which is a trigger pulse stretched by D3 and C1. The "control" is done by the

MIDI COMPUTER PARTS LIST

All resistors are ¼-watt, 10%.
R1—4700 ohms R2, R3, R6, R9—220 ohms
R4, R13—680 ohms
R5, R8—3300 ohms
R7, R10, R11—100,000 ohms
R12—3900 ohms

Capacitors
C1, C2—33 pF, ceramic disc
C3—10 µF, electrolytic
C4–C11—0.1 µF, Mylar
C12—1 µF, electrolytic
C13—100 pF, ceramic disc
C14—100 µF, electrolytic
C15–C19—0.01 µF, ceramic disc

Semiconductors
IC1—7805 5-volt regulator
IC2—74HC373 octal latch
IC3—8031 8-bit microcontroller
IC4—2764 EPROM
IC5—6116 static RAM
IC6—74HC04 hex inverter
IC7, IC9—TIL111 optolsolator
IC8—74HC138 1-of-8 decoder
IC10—74HC02 quad NAND gate
IC11—ADC0809 8-input ADC
D1—not used
D2,D3—1N914 diode
LED1, LED2—red light-emitting diode

Other components
J1—optional expansion header
J2–J4—5-pin DIN (MIDI) socket
S1—8-position DIP switch
S2—normally open pushbutton switch
XTAL1—12 MHz chrystal
Miscellaneous: PC board, ribbon cable, solder

notch frequency of the filter network (R24–R26, and C14–C16). A pulse raises the frequency which then glides down as the charge on C1 drains away.

While the input triggering pulse coupled by C13 and R22 knocks the circuit into oscillation and provides the percussive edge, the circuit would oscillate spontaneously just because of the change in impedance of the diodes. The result is that this drum is capable of much longer "sustains" than the others because as the trigger decays it effectively turns the tone off.

Finally, the audio outputs of all the drum circuits are mixed by the summing amplifier built from IC3-a and R52–R59, AC-coupled by C31 to the level potentiometer R61, and appear at the audio-output jack J3. The 5532 dual low-noise amplifier can directly drive high-efficiency headphones.

That's all we have room for. Next month we'll finish up. Ω

Build a wireless FM guitar transmitter that is better than what you can purchase —and save money.

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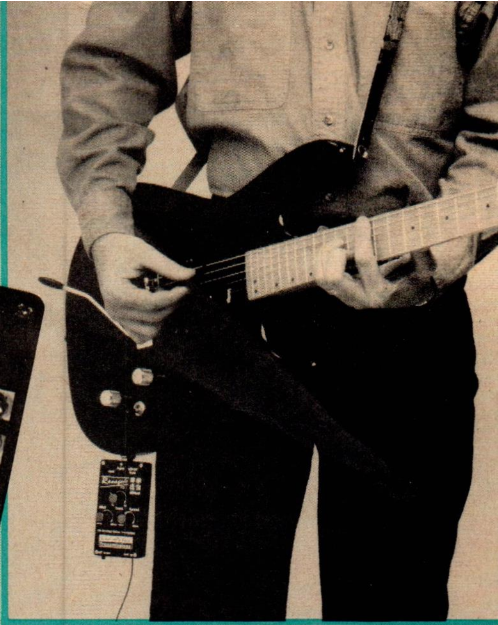


the guitar is played. The latest commercial wireless guitar transmitters include modifications of companding that reduce background noise and suppress "breathing," but that improvement has increased their price.

A transmitter must have a high signal-to-noise ratio (S/N) if it is to be used with a distortion-effect unit because it is essentially a high-gain audio amplifier. Therefore, if the distortion effect is inserted after the receiver (as in typical wireless guitar transmitters), *all* sound including background noise will be amplified. The result is a lower overall S/N ratio.

Typical S/N ratios for wireless transmitters rarely exceed 70 dB unless some form of companding is present. However, if you assume that a commercial wireless transmission system has an S/N of 100 dB and a distortion effects unit is inserted between the receiver and amplifier, the overall S/N will drop to about 54 dB. This is based on the assumption that voltage gain is 200, therefore:

S/N reduction = 20 log (200) = 46 dB

The Guitar Transmitter differs from the latest commercial products because it has a distortion-effects unit which precedes its transmitter. As a result, the effects unit amplifies *only* the pure guitar signal and not the background transmission noise. Therefore, noise is reduced, component cost is lower because no companding circuity is required, and you can expect a consistent 60-dB overall S/N.

Figure 1 is a block diagram of the Guitar Transmitter with typical waveforms shown at various stages of signal processing. Notice that the complete transmitter has three functional circuits: distortion, touch switch, and VHF FM voltage-controlled oscillator (VCO).

How it works

Figure 2 is the schematic diagram for the Guitar Transmitter. The plus and minus signs on the schematic near the potentiometer symbols indicate that clockwise rotation is from the minus sign towards the plus sign.

This circuit will produce both undistorted and distorted audio output. The undistorted output is produced by non-inverting amplifier IC1-*d* with a gain of:

R4/R5 + 1 = 68K/18K + 1 = 4.8.

Capacitor C1 blocks the DC components of the input signal, and resistors R2 and R3 form a voltage divider to bias the input of an LM324 operational amplifier IC1 at about half of its supply voltage of 9 volts. Resistor R1 sets the input impedance of the circuit to 1 megohm.

Capacitor C2 attenuates unwanted ultrasonic frequencies, while capacitor C3 lowers the impedance of the bias voltage at audio frequencies to yield a cleaner bias-voltage supply. Capacitor C4 performs the same function on the supply voltage for IC1.

The clean signal is then routed to IC2, a CD4066 CMOS quad bilateral switch, and is also amplified from 1 to 214 times by IC1-*a*, depending on the setting of DISTORTION control potentiometer R7. Resistor R6 and capacitor C5 establish a low-frequency roll-off (i.e., attenuation of low frequencies) of approximately 160 Hz.

To produce a distorted signal from IC1-*a*, three 1N4148 diodes, D1, D2, and D3 clip the amplified voltage at asymmetric levels of about Ø.7 volt and -1.4 volts, producing a distortion similar to that obtained with an overdriven vacuum-tube amplifier.

The distorted signal is then sent to the tone-control section centered around IC1-*b* where frequencies above about 1KHz are attenuated when TONE control potentiometer R10 is set full counter-clockwise (i.e., the wiper is at the non-inverting input of IC1-*b*. This stage amplifies frequencies above 1KHz when R10 is fully clockwise.

Resistor R8 and capacitor C6 form a low-pass filter that attenuates the high-frequency components of the clipped

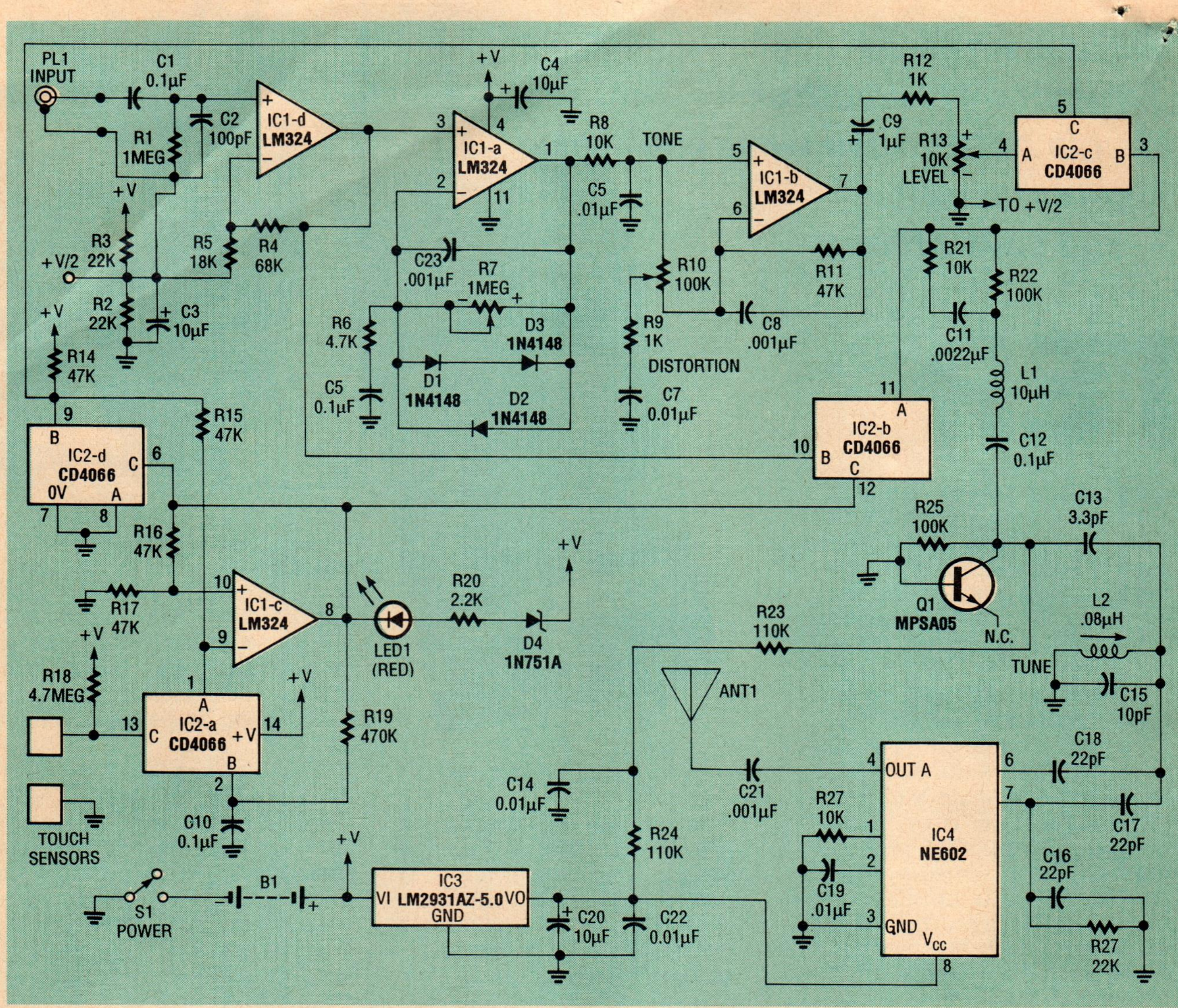


FIG. 2—SCHEMATIC FOR THE WIRELESS GUITAR TRANSMITTER. The touch sensors permit fingertip control of the sound.

waveform produced by IC-*a*. High-frequency roll-off for IC1-*b* is set by C8 and R11. The AC voltage gain is determined by resistors R9, R10 and R11.

The output level from IC1*b* is controlled by LEVEL control potentiometer R13. Capacitor C9 AC-couples R13 from the output of IC-*b*. Resistor R12 limits the maximum output voltage to prevent overmodulation of the transmitted carrier.

Touch control:

Two sections of IC2 switch between the clean and distorted signals. Sections *a* and *b* of IC2 are operated as complementary switches by the touch-control section of the transmitter. Operational amplifier IC1-*c* forms a voltage comparator with hysteresis produced by positive feedback resistor R16. The reference for this voltage comparator is set slightly higher than half the supply voltage by R16 and R17.

The entire comparator circuit performs a flip-flop function by combining an inverter IC2-*d* and R14 with low-pass filter R19 and C10. That filter has a time constant of 47 milliseconds to prevent false triggering and high- frequency oscillations.

To understand the operation of this flip-flop, assume that C10 is initially discharged, IC2-*a* is open, and IC1-*c* is in its true state (the voltage at the inverting input is less than at the non-inverting input; thus its output is at supply-voltage level. Capacitor C10 charges through R19 to a value higher than the reference voltage.

Now, if IC2-*a* were closed momentarily (pins 1 and 2 shorted), IC1-*c* would change state (i.e., output drops to zero volts). Resistor R15 provides the inverse of the output level of IC1-*c* from IC2-*d*, keeping IC1-*c* in static equilibrium. Then C10 discharges through R19 and once discharged, IC2-*a* closes momentarily, causing IC1-*c* to change state again.

This process causes a "push-pull" action, thus forming a "touch-on/touch-off" switch.In practice, the touch sensors will be shorted by a finger tip, causing control input pin 13 of IC2-*a* to be grounded, opening the switch.

The EFFECT/BATTERY LED1 lights only when the distorted sound channel is selected. Zener diode D4, resistor R20, and LED1 form a measuring circuit to indicate when battery voltage falls below about 7 volts. Replace the 9-volt battery if the *effect/battery* LED dims when the distorted sound channel is selected.

VHF FM oscillator:

The clean or distorted audio signal is fed into the VHF FM oscillator section of the transmitter. Resistors R21 and R22 and capacitor C11 form a preemphasis network to complement the de-emphasis network found in most FM receivers. The values chosen for this network attenuate frequencies below about 700 Hz to produce a "brighter" sound with a lot of "edge."

Low-power VHF mixer/oscillator forms an oscillator with an operating frequency of about 100 MHz, a frequency that can be adjusted across most of the FM broadcast band of 88 to 108 MHz by tuning variable coil L2.

Caution: It is unlawful to broadcast above or below the FM band with this transmitter. The oscillator is frequency modulated by using transistor Q1 as a varactor diode. The transistor's collector-to-base junction capacitance varies directly with the applied audio voltage.

The output of voltage regulator IC3 powers IC4 and supplies a stable DC bias for transistor Q1 through resistors R23, R24, and R25. Capacitor C14 and resistors R23 and R24 form a low-pass filter that prevents unwanted RF from affecting the DC bias supply. Capacitor C13 limits the capacitance change of transistor Q1 as seen by the inductor-capacitor tank tuning section made up of variable coil inductor L2 and capacitor C15.

The tank limits the frequency deviation of the FM carrier to a maximum of ± 75 kHz in accordance with the Canadian Department of Communications (DOC) and the U.S. Federal Communication Commission (FCC) regulations. The VHF FM sinewave is generated by the inductive-capacitive tank section, and amplified and buffered by IC4. This signal is then AC coupled to the antenna by capacitor C21, which also helps to minimize antenna loading effects on IC4.

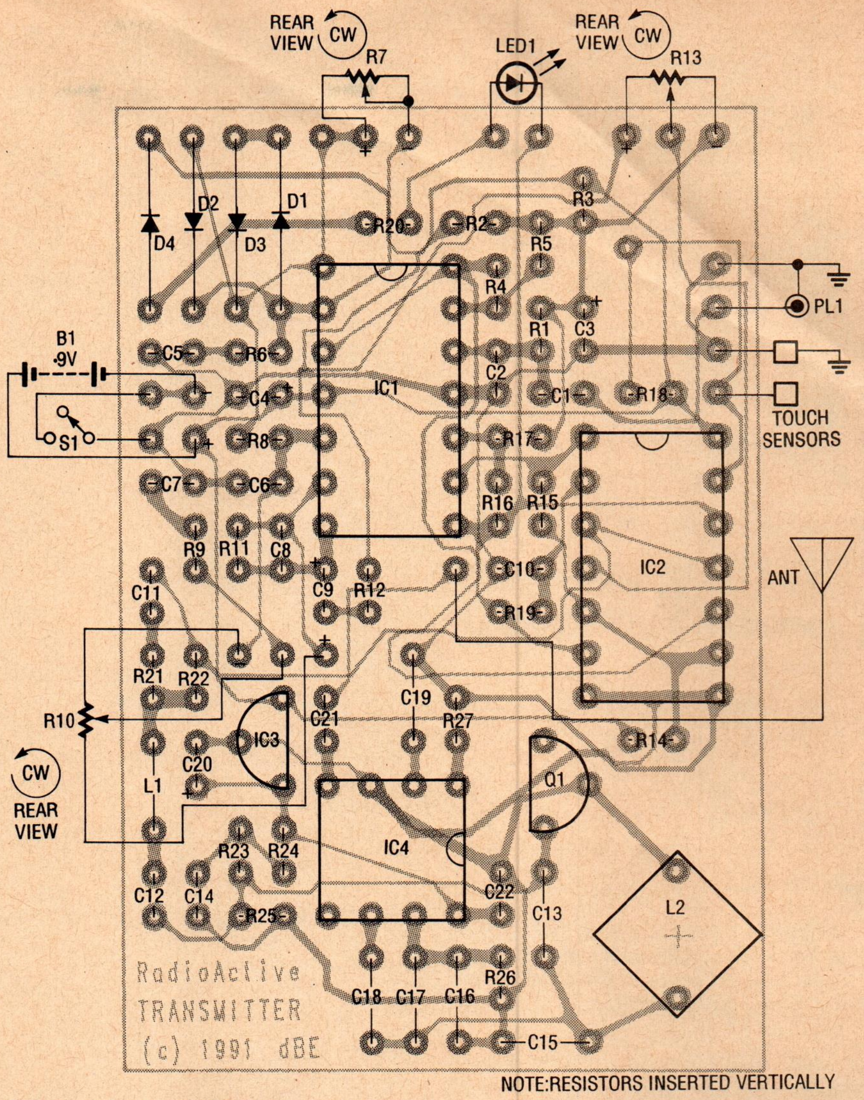
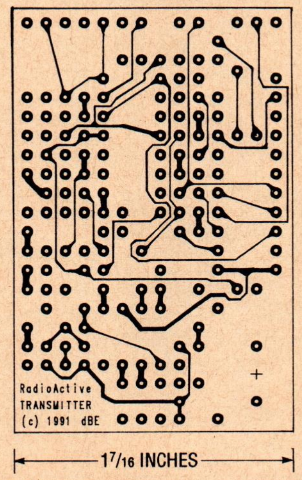
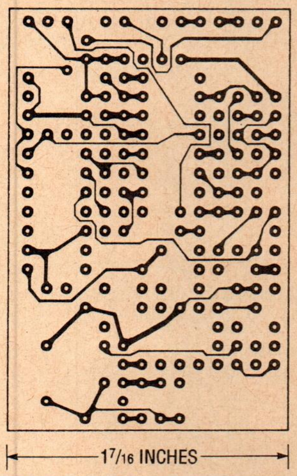


FIG. 3—PARTS PLACEMENT DIAGRAM for the wireless guitar transmitter. Three control potentiometers, the LED, and touch sensors are located on the case cover.



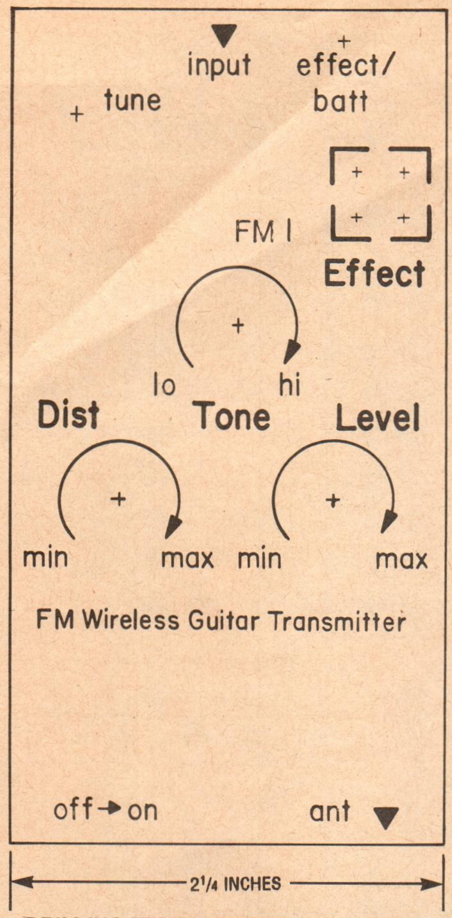
COMPONENT-SIDE FOIL PATTERN for the two-sided circuit board of the guitar transmitter.



SOLDER-SIDE FOIL PATTERN for the two-sided circuit board of the guitar transmitter.

Building the transmitter

Most of the components in the Guitar Transmitter are stan-



DRILLING TEMPLATE FOR THE COVER of the wireless guitar transmitter. Holes must also be made in the case for the input plug and the switch.

PARTS LIST

All resistors are ⅛-watt, 5%, unless otherwise specified.

R1—1 megohm
R2, R3, R26—22,000 ohms
R4—68,000 ohms
R5—18,000 ohms
R6—4,700 ohms
R7—1 megohm miniature potentiometer
R8—10,000 ohms
R9—1000 ohms
R10—100,000 ohms miniature potentiometer
R11, R14, R15, R16, R17—47,000 ohms
R13—10,000 ohms miniature potentiometer
R12—1000 ohms
R18—4.7 megohms
R19—470,000
R20—2,200
R21, R27—10,000 ohms
R22, R25—100,000 ohms
R23, R24—110,000 ohms

Semiconductors

IC1—LM324N quad low-power operational amplifiers, Motorola or equivalent
IC2—CD4066BCMOS quad bilateral switch, Harris or equivalent
IC3—LM2931Z-5.0 low-dropout voltage regulator, 5-volt, Motorola or equivalent
IC4—NE602Nlow-power VHF mixer/oscillator, Signetics or equivalent
Q1—MPSA05 NPN transistor National or equivalent
D1, D2, D3—1N4148 fast-switching diode
D4—1N751A Zener diode, 5.1-volt, 500 mW
LED1—light-emitting diode, general purpose, T1 case size, red,

Capacitors

C1, C5, C10, C12—0.1 µF ceramic monolithic , radial-leaded, 10%
C2—100 pF, ceramic disc, 10%
C3, C4, C20—10 µF, tantalum, solid dip, 10%, 10 volts
C6, C7, C14, C19, C22—0.01 µF ceramic monolithic, 10%,
C8, C21, C23—0.001 µF ceramic monolithic, radial leaded, 10%
C9—1 µF tantalum, solid dip, 10%, 10 volts
C11—0.0022 µF, polyester film, 5%
C13—3.3 pF ceramic Philips 09338 or equivalent
C15—10 pf ceramic, Philips 10109 or equivalent
C16, C17, C18—10 pF ceramic, Philips 10229 or eqivalent

Inductors

L1—10 µH, fixed, 5% Toko FL-4 or equivalent
L2—0.08 µH variable molded, Q = 130 @ 100 MHz, Toko MC-120 or equivalent

Other components

B1—battery, 9-volt, alkaline transistor
tr- S1—switch, subminiature slide, SPDT
PL1—input plug, ¼-inch, mono phone

Miscellaneous: double-sided printed circuit board, 9-volt battery clip, plastic project case with cover with inside dimensions of 4 ¼ × 2⅛ × 1⅟16-inch deep, three miniature black knobs, 28 AWG stranded, black-insulated hookup wire, multicolored ribbon cable, plastic coil alignment tool, solder, epoxy cement, RTV silicone adhesive.

Note:The following parts are available from RadioActive Transmissions, P.O. Box 6714, Station "A", Simcoe St., Toronto, Ontario, M5W 1X5 Canada (519) 974-0163, Fax (519) 974-0165.

- **Kit 1—complete kit of all parts including double-sided PC board, plastic coil alignment tool, and screened pre-drilled case —$39.95 plus $5.00 shipping and handling.**
- **Kit 2—silk-screened and pre-drilled case with cover and three knobs—$10.00 plus $2.50 shipping and handling.**
- **Assembled and tested unit $54.95 plus $5.00 shipping and handling. Please send U.S. money order only. Canadian residents please call for prices. Other countries add additional $5.00 for shipping.**

dard, off-the-shelf parts available from electronics retail stores and mail-order distributors. Although not surface-mount, the components were selected to conserve PC board space and miniaturize the circuitry.

All resistors are specified as ⅛-watt, metal-film units because they generally produce less noise in audio circuits than carbon-composition or carbon-film resistors, and they are smaller. Radial-leaded monolithic ceramic capacitors were selected because of their small size, and dipped solid tantalum capacitors were specified in place of aluminum electrolytics for 1-microfarad and 10-microfarad values to save space. Moreover, tantalum capacitors retain their rated capacitance values at higher frequencies better than aluminum electrolytics, and they do a better job of filtering out stray radio frequency (RF) noise from the power supply.

Board assembly:

The Guitar Transmitter will perform better if it is built on the double-sided printed-circuit board designed for it. Both component- and solder-side foils are included in this article if you want to make your own boards. Notice, however, that plated-through holes are recommended so that you do not have to solder leads on both sides of the board to assure a sound solder joint. If you do not want to make the board yourself you can purchase a finished circuit board from the source listed in the Parts List or build the circuit on perforated board.

You can obtain the full performance capabilities of the circuit with perforated board if you are aware of the possible pitfalls in building an RF circuit on that substrate—and take extra care in placing components and dressing wires. Nevertheless, the use of perforated circuit board stock is not recommended.

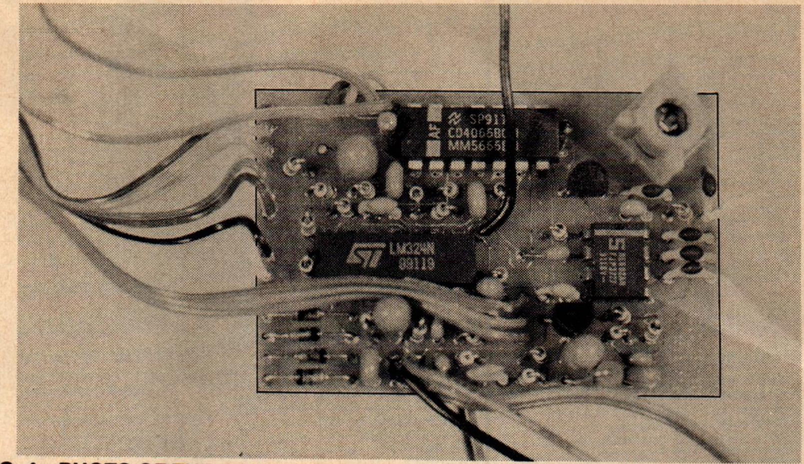


FIG. 4—PHOTO OF THE COMPLETED guitar transmitter circuit board showing wiring to off-board components. Note the star-shaped tuner body.

When building the transmitter, refer to schematic Fig. 2 and Parts Placement diagram Fig. 3. Follow standard practice in inserting the components and soldering them in place. Use a grounded, 15- to 30-watt, pencil-type soldering iron, especially for soldering the semiconductor devices to avoid damaging or destroying the devices with excess heat or electrostatic discharge (ESD).

There is a choice of three different values for capacitor C15 because the tuning coil L2 for this transmitter has a high Q (130 at 100 MHz). The letter Q stands for quality factor—a reference to the ability of the circuit to present a well defined oscillator frequency. The higher the resolution, the smaller the tuning range if the range of the tuning slug is limited to the length of the coil body.

Variable coil L2 specified in the Parts List has a tunable frequency limit of about 15 MHz. Because the FM broadcast band spectrum is 20 MHz wide (from 88 to 108 MHz), select one of three standard values for C15:

- 10 picofarads gives a tuning range 15 MHz wide centered at approximately 98 MHz. (The ends of the FM broadcast band can be obtained with slightly higher or lower values for C15.)
- 12 picofarads permits tuning in the lower end of the band.
- 8.2 picofarads permits tuning in the upper end.

The exact tuning range obtained will vary with each transmitter because of the parasitic capacitance and inductance introduced by the interconnecting wires.

Do not use IC sockets for any of the ICs because all lead lengths must be kept as short as possible. The components can be inserted and soldered in any order, but it is a good idea to check off each part on the Parts List after you insert and solder it.

Observe all polarities shown on the schematic for the diodes and tantalum capacitors. Mount all resistors vertically, and mount all capacitors flush against the circuit board. After soldering, trim all lead lengths as short as possible to reduce stray noise pick-up in the audio-frequency section of the transmitter.

Antenna length

Cut a 38.2 centimeter (15.3-inch) length of black stranded 28 AWG insulated hookup wire for the antenna. Trim one end and solder that end in position as shown in Fig. 3. The Guitar Transmitter operates at 98.00 MHz, so one wavelength equals 3.0612 meters.

Transmitted signal strength is generally proportional to antenna length up to one wavelength, but if its length is more than 76 centimeters (30 inches) the transmitted carrier will exceed the maximum allowable signal strength level specified by the DOC and FCC regulations. That's why the 38.2 centimeter antenna length was selected for this transmitter.

Mechanical assembly

After all of the components are inserted and soldered on the PC board, refer to exploded assembly drawing Fig. 4 as well as the Parts Placement diagram Fig. 3 for the location and orientation of off-board components. If you purchase the case and cover from the source given in the Parts list, all holes will be drilled.

If you elect to provide your own case, use the cover template provided to drill:

- Three control potentiometer mounting holes.
- Four 3/32-inch holes for the touch sensor.
- One 1/16-inch hole for access to tuner L2.
- One 3/32-inch hole for LED1.

Then drill a 0.39-inch diameter hole centered in the end wall of the case for plug PL1, taking care that the plug fits snugly. (The plug will be the sole support for the completed transmitter when it is plugged into the guitar, so it is important that it be rigidly mounted.)

Finally, cut a slot in the opposite end wall of the case for switch S1, and drill one or two holes beside the slot, as necessary, for fastening the switch to the case. With a hacksaw, cut a slot about 1/16-inch deep in the end wall of the case near the switch slot for the antenna wire to permit it to pass under the cover without interference when the cover is closed.

Assemble the touch sensor from four 1/4 inch, No. 4-40 Phillips-head screws with match-

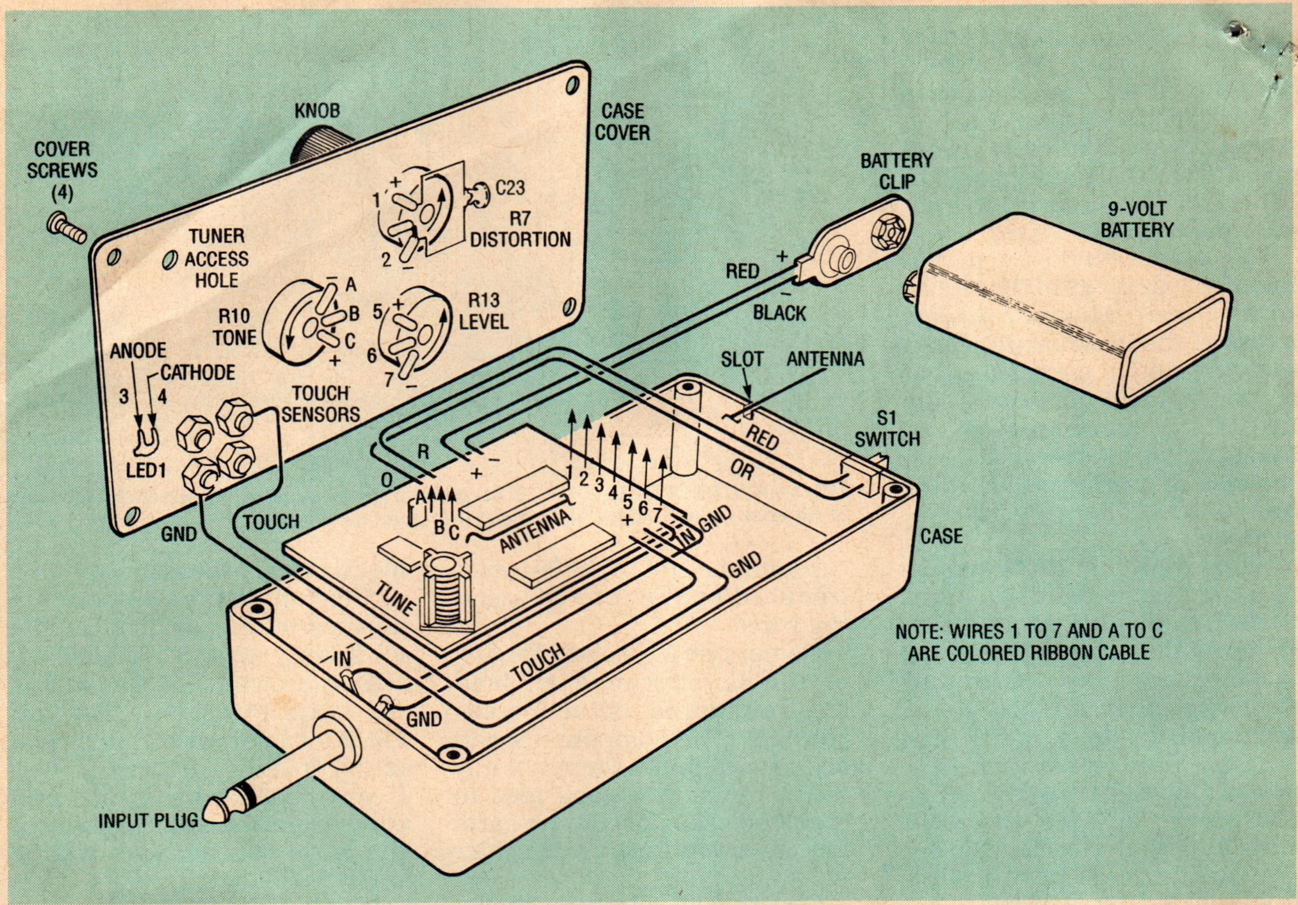


FIG. 5—EXPLODED VIEW OF THE TRANSMITTER showing the locations of the off-board components and wiring. The input plug attaches the transmitter to the guitar.

ing nuts. (Two of the four nut-bolt combinations will be non-functional.) However, be sure that the two to be wired as active sensor elements are electrically isolated.

Assemble the three miniature control potentiometers R7, R10 and R13 to the underside of the cover with the ring nuts provided, orient their terminals as shown as shown in Fig. 4, and tighten the nuts. Insert plug PL1 and secure it in position with its nut. Insert switch S1 in the case and fasten it with one or two rivets or self-tapping screws.

Off-board wiring

Cut 6- to 7-inch lengths of standard multicolored ribbon cable (28 AWG 7×36 stranded tinned copper), strip about 1/16-inch of insulation from the ends, and insert one set of wires in the board and solder them in position. (As many as ten wires can remain bonded together for most of their length if they are separated only near top and bottom to permit making the connections.) Then crimp the bared ends of the off-board wires around the lugs of the potentiometers, and the leads of the LED and plug before soldering:

- The terminal lugs of potentiometers R7, R10, and R13 (as shown in Figs. 3 and 4): 8 wires.
- Light-emitting diode (LED1): 2 wires.
- Input plug PL1: 2 wires.

Insert capacitor C23 between the terminals of potentiometer R7. (It reduces the possibility of audible feedback in the high-gain distortion stage.) Solder all wires to the potentiometer lugs and the leads of LED1.

Loosen two of the touch -sensor nut-bolt combinations, and wind one turn of the bare end of the "ground" wire around one of the screws and one turn of the bare end of the "touch" wire around the other screw. Then tighten both nuts to clamp the wire ends securely in place.

Cut, and strip the ends of about 3-inch lengths of the red and black battery-clip wires, and solder them to the PC board. Bend the leads of LED1 90°, insert the LED in the drilled hole in the cover, and cement it in position with epoxy cement. Carefully check all wiring to be sure that you have made no mistakes, and make any corrections necessary.

Position the circuit board as shown in Fig. 4, being certain that the top of inductor L2 is aligned under the access hole drilled in the cover. Apply one drop of RTV silicone (or other appropriate adhesive) to each of the four corners of the circuit board on the solder side, and position the board correctly in the bottom of the case. Also place a drop of adhesive in the slot for the antenna wire cut in the edge of the case, and position the wire in the slot to keep it in position. Allow time for all adhesives to set.

Snap a fresh 9-volt alkaline transistor battery to the battery clip. Check to see that the EFFECT/BATTERY LED lights when you bridge the screw

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