BLACK MAGIC

TELECOM DESIGN TRICKS

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BLACK MAGIC! TELECOM DESIGN TRICKS FOR THE 1990s

I. INTRODUCTION

With the explosive growth of telecommunications and its integration with computers, engineers new to telecom now often design telecom equipment or interfaces.   In the days of regulated networks, a relatively small community of engineers designed such equipment. Standards in internal technical publications, the arcana, and the industry "tricks," were handed down within the engineering departments of the few firms manufacturing for the operating telecom monopolies.

With today's deregulation, a new generation of engineers unfamiliar with the foundations of the industry is being called upon to design for it.

The telecom industry is conservative, as is apparent from the fact that today's analog ringing signal is the same as that of a century ago and derives directly from the output of a hand-crank magneto generator.

Conservative design practices arose from the industry ideal that devices not only survive but continue to work under almost any conceivable conditions of customer abuse (e.g. dropping), mis-installation or line faults (e.g. crossing telephone with power lines) or environmental stress (e.g. a lightning strike).   Telecom equipment was intended to work trouble-free for a very long time, and it did.

Many telephones are still operating after decades of hard use. This point is worth stressing because few other fields have chosen to design to this ideal, instead planning for obsolescence, limited working lifetimes and a reliability policy of "fix it when it breaks." Those new to telecom design will better appreciate the arcana and the "tricks" if they first understand the ideals of the telecom industry.   Anyone can design telecom equipment.   An engineer who thinks like a traditional telecom professional can design good telecom equipment.

Much of telecom design involves standard engineering principles, but some special aspects are not familiar and others not obvious. The neophyte may waste time learning for himself—from mistakes that fail in prototype or later in customers' hands—principles or practices well known to old hands.

This review of some aspects of telecom design, principally related to power and ringing circuits, is intended to lift this burden from newcomers while suggesting a few new tricks to old hands.   Interested readers are invited to contact Cambridge Electronics Laboratories for related subjects not covered in the following pages or for more detailed information or designs not included here.

The following assumes knowledge of basic telephony circuits. Please refer to the annotated references at the end for elaboration of these basics.

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II. RINGING THEORY

Idle and Talking Condition

An analog telephone circuit may occupy three states: idle, talking, or ringing.   During idle and talking states, a type circuit receives d.c. "talk battery" through a high-impedance balanced inductor or simulated inductor. (Refer to References 1 and 2.) Atypical circuits, operating over short loops not requiring the noise reduction of a balanced feed, may use an unbalanced supply.   (Figure 6 illustrates such an unbalanced battery feed circuit; all other illustrations are designed around balanced feed circuits.) Talk battery voltage is ordinarily dimensioned to supply a minimum of 23 mA through each anticipated terminating device under any anticipated line length and number of off-hook devices.   Higher current is unnecessary and dissipated as heat somewhere in the circuit, unless limited by design—which is a good design practice.

Ringing Condition

Ringing power is dimensioned with a similar goal: to actuate the alerting element of all anticipated devices terminating any anticipated loop length.   Present-day North American ringing power (86 V 20 Hz) is a heritage from the days of magneto telephony, but contemporary design must contemplate three classes of alerting circuits, each having special characteristics and limitations.

Inductive alerters (mechanical bells) have a very high impedance at voice   frequencies since they are permanently bridged across the line.[1] Such devices will ordinarily provide ample sound pressure with only about 35 volts at their terminals.   An 86 V ringing source at the Central Office [hereafter CO] will deliver this minimum voltage over a loop of about 1,300 Ω to five ringers in parallel, anticipating that one subscriber may have up to five telephone sets in his premise.   If the loop is known to be shorter (e.g. subscriber carrier, customer premise equipment, or curb-mounted fiber-optic terminals) then the source voltage may be lower, except where provision must be made for the special requirements of the third type of alerting circuit described below.

Mechanical ringers store energy in their hefty inductors (typically 80 Hy) and capacitors, with two design consequences.   First, provision must be made for high open-circuit potential at the moment when the circuit switches (under relay control) between ringing and idle states.[2]   Should protective provision not be made, this potential may degrade circuit performance (data glitch or system crash) and may well destroy wiring or printed circuit boards through arcing.   Second, stored energy will cause false off-hook indications at the instant the circuit is cadenced from ringing to silent.   This potential false indication must be handled in either hardware or software.[3]

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1 North American ringers operating at 20 Hz have a nominal impedance of 7,000 Ω at 20 Hz; one "Ringer Equivalent Number" [hereafter referred to as REN] may be simulated by a 6930 Ω resistor in series with an 8 μF capacitor.   European ringers often operate at different frequencies and voltages and have different impedances.

2 See Section IV and Figure 5.

3 See Section VI and Figure 12.

Ringer ICs are offered by numerous vendors which convert standard ringing power to operate piezo-electric or dynamic alerters. Such circuits store no energy. Therefore equipment successfully prototyped with a telephone set incorporating such an IC may fail when ringing real-world sets with inductive alerters, unless provision has been made for them.

Zener-clipped ring-detection circuits are now common in devices emulating a telephone set, e.g. facsimile machine, modem, or answering machine, which detect incoming ringing without generating an audible signal. These circuits also store no energy so the above prototyping caution applies. The type ring-detection circuit shown in Figure 1 also occasionally produces difficulties for equipment designers if the zener value is set too high (e.g. 82 volts) in anticipation of seeing the peak of an incoming sine wave. Such a device may not detect ringing from an 86 V square-wave the peak value of which (also 86 V) fails to excite the opto-coupler. (The peak of an 86 V_{rms} sine wave is 121 V.) If production units may encounter such devices, a higher square wave voltage (e.g. 100 V) must be selected.
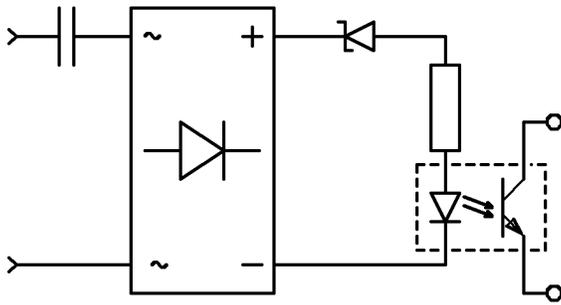
The moral for designers: test prototypes with all classes of alerting circuits and devices. Otherwise your beta testers—or worse, your customers—may encounter unpleasant surprises in faraway places!

Fig. 1: Type Ringing Detection Circuit

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Making Waves: Square, Sine, Shaped

The engineer must consider both economic and engineering factors in design: least cost, highest efficiency, smallest size, lightest weight. Heretofore the basic choices for signaling telephone circuits were square waves and sine waves, but a happy middle way exists: shaped waves.

Filters to shape square waves may easily be designed with a bit of experimentation. A simple RC "L" filter (Figure 2a) may be adequate for many applications; typical starting values for experimentation would be 100 Ω and 0.1 µF. This circuit, good design practice in any event, removes only very high frequency energy present in the sharp wavefront, preventing possible audible clicks in adjacent analog circuits or glitches in digital circuits. The physically larger LC "L" implementation (Figure 2b) can remove energy in the voice band to any desired degree by selecting appropriate filter constants. The inductor must be specified such that under full load it does not saturate, and its resistance does not cause excessive voltage drop.

Typical starting values for experimentation would be 4 Hy and 0.56 µF. Figure 2c illustrates an LC π filter which can be designed with quite a low impedance in constant-k form in a relatively small implementation due to the additional capacitor, thus reducing filter impedance to match a heavier load. The trade-off is increased stress on the ringing generator. Typical starting values for experimentation would be 600 mH and 0.68 µF for each capacitor. (A standard battery-feed inductor can be used for this inductor.)

The circuits in Figures 2b and 2c boost ringing generator idle-current drain (2c substantially), increasing heating and component stress. *Good design will power the ringing generator only when actually calling ringing.*
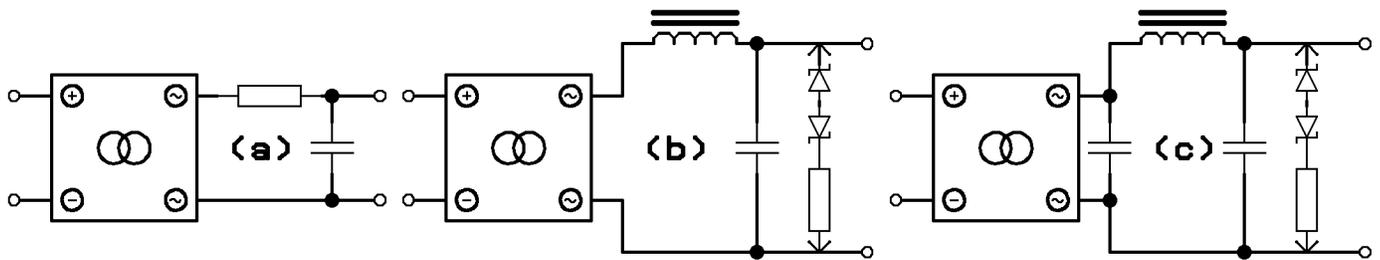
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Fig. 2: Type Wave Shaping Filters

(a) Simple anti-glitch filter removes only sharp edges from wavefront.   Starting values for experimentation:
R ~ 100 Ω   C ~ 0.1 µF 200 V

(b) LC "L" filter, though larger, can remove energy in voiceband as well. Starting values for experimentation:
L ~ 4 Hy   C ~ 0.56 µF 630 V   Optional clamp to reduce resonant peaks: ZD = 150 V   R = 20 kΩ.
This will allow capacitor's rated voltage to decrease to 200 V. (This filter architecture cannot be used
with CEL's MINI model of ringing generator.)

(c) LC "π" architecture filters better in smaller package but stresses ringing generator more.   Starting values
for experimentation: L ~ 600 mH   C ~ 0.68 µF   Suitable inductors are CEL's L/WSN1 or L/WSN4, or
battery feed inductors such as Prem SPT-169 or SPT-179 or coupling transformer SPT-196 wired with
coils in phase. (This filter architecture cannot be used with CEL's MICRO model of ringing generator.)

High-voltage resonant swings into an open circuit, if objectionable, can be damped with the dummy load shown in Figures 2b and 2c.

Filter type and constants can be selected to achieve differing balances between impedance (to match required maximum load), filtering effectiveness, size, equivalent rms output voltage and idle-current drain.   Experimentation will reveal the minimum degree of filtering acceptable, since susceptibility depends on the wiring and printed-circuit-board configuration as well as on the sensitivity of own and connected equipment.

Conclusion.   When signalling over short circuits (e.g. to nearby or co-located equipment), square waves work well, usually with no interference, especially if the filter in Figure 2a is employed. Their generators are always smallest, lightest and least expensive. When signaling over longer circuits on which interference might be a problem, shaped waves offer an excellent alternative. In general they are the best engineering and economic compromise where cost, size and weight are significant, one is not signaling circuits with harmonic ringers, and no arbitrary standard dictates a sine waveform.   Pure sine wave ringing generators are most suited when signaling circuits with harmonic ringers, when so mandated by some arbitrary technical specification, or where cost, size and weight are less severe constraints. In this case the choices are:

- *Linear*:   operate on d.c.; relatively bulky, heavy, and inefficient;

- *Ferro-resonant*: small and inexpensive; operate only on a.c.;

- *Switching*:   efficient; operate on d.c.; more expensive than equivalently
rated linear designs but much smaller and lighter.

SQUARE WAVES

pack more energy for a given peak voltage and ring bells well; square wave generators are relatively small, inexpensive, and efficient. However roughly one-sixth of the energy appears in the first ten odd harmonics (equivalent to a 45 % THD), stretching well into the voice band and possibly causing interference to adjacent analog or digital circuits. Also the d.c. input to a square-wave generator typically has a very spiky current flow, possibly coupling noise via the d.c. bus unless properly conditioned. Zero-crossing ringing injection circuits will not work with square wave generators which are thus best suited to applications signaling co-located devices over short loops or drop wire, where size, cost and efficiency are important design criteria.

SINE WAVES

inherently cause less interference on both input and output due to their slow rate of change, but their generation requires larger, costlier, and more complex devices. Designers occasionally encounter "regulatory requirements" mandating a sine waveform. Such requirements are often ancestral inheritances from the era of hand-crank magnetos and motor-generators, when there was no economic difference between generating sine and square waves. They should be viewed critically in light of contemporary economic and technical alternatives.

SHAPED WAVES

result from passing a square wave through a "wave shaping filter" and are often the best economic and engineering compromise, especially when designers want to move the ringing generator to the board level rather than rely on a single central unit which may fail or be unsuitable for economic space or modularity reasons. Zero-crossing ringing injection circuits can be designed to operate with shaped waves.

The trade-off between these factors is summarized in the following table. (Sine factor is based on switching designs.)

```
     TRADE-OFF OF FEATURES  (expressed as ratio of figure of merit)

       WAVEFORM            SIZE            WEIGHT          COST

        Square             1.0             1.0            1.0

        Shaped             1.3             1.5            1.1

        Sine               2.5             2.3            2.5

     Note: Square wave generator is normalized to 1.0 for comparison
```

Ringing Supply Standards

Frequency and voltage.   Each national network ordinarily has a standard ringing frequency e.g. 20 Hz for North America, 25 Hz for UK, 17 Hz for Australia. Some countries use multi-frequency ringing for party line applications, e.g. North America between 16 and 66.67 Hz.   If tuned ringers may be encountered, ringing frequency tolerance must be quite tight, e.g. ±0.5 %, but if not, then a loose tolerance of ±3 Hz or more may be acceptable.

Minimum   ringing source voltage is determined principally by anticipated   loop length, so as to deliver sufficient energy to all alerting devices over any anticipated loop.   Maximum ringing source voltage is determined by the network owner based on human safety factors and equipment/component characteristics such as lightning protector breakdown voltage.

Thus the selected frequency and voltage will be a result of network constraints (if ringing over a network), safety factors, and the requirements of the signaled equipment.

Waveform.   The guiding principle is not to interfere with adjacent   circuits. In practice this means energy in the voice band may have to be limited by using either a sine wave with low total harmonic distortion [hereafter THD], or a square wave filtered to an acceptable degree.

If ringing over a network, the network owner may specify the waveform characteristic. Typical specifications:

• *Sine wave THD* (often 10 %) is specified in many countries.

• *Crest factor*, a typical North American specification, is defined as the the peak-to-rms voltage ratio of the a.c. component of the alerting signal.   For example, Bellcore Reference TA-TSY-000057 (Digital Loop Carrier Equipment) specifies that the crest factor must be ≥ 1.2 and ≤ 1.6 and should be ≥ 1.35 and ≤ 1.45. (A perfect sine wave would be 1.4142.)   A wave with this crest factor can be made by filtering a square wave.

However when not ringing over a network, the only constraint is the   practical consideration of what will operate the alerter without causing interference.

Required power is determined by the maximum instantaneous load in watts or REN, which may be either absolute or probabilistic. The maximum instantaneous load of some types of equipment such as PABXs in which ringing is under own microprocessor control can be known absolutely. Other types such as T-1 multiplexers where the distant end controls ringing intervals require probabilistic calculation based on CCS tables and load assumptions.

Because alerting is cadenced into ringing and silent intervals, required power capacity of the ringing generator can be reduced by design to service different groups of lines (ring groups) at different times. For example, the standard North American cadencing plan calls for 2 seconds ringing and 4 seconds silent. It is thus possible to establish three ring groups during six seconds. If for example each ring group might simultaneously ring four circuits, and each circuit had only one ringer attached, then a single four-watt ringing generator would support the system.

With careful architecture, reasonable assumptions about calling loads, and possibly limits on number of alerters connected to each line, a twenty-watt ringing generator may support equipment sized up to several hundred ports.

Safety factors. Telecommunication equipment must cause no hazard to humans or property. The hazard inherent in ringing power is limited in three ways:

- Ringing must cease into a low impedance within a limited time; see Section V below.

- The ringing source impedance must have a minimum value, typically 400 Ω, so as to limit current which may cause a fire or human safety hazard.

- The peak voltage is limited; for example Bellcore Technical Reference LSSGR Section 6.2.7.1A specifies in paragraph 3 "As a maximum value, the rms voltage multiplied by the peak-to-rms ratio, and added to the d.c. component, should not exceed 200 volts peak-to-ground or 300 volts peak-to-peak. This limits the ringing voltage to a maximum of 104 V_{rms} for a waveform ratio of 1.4142 with a ring-trip battery voltage of 52.5 Vdc." British standards place different and more complex limits on the alerting signal.

III. RINGING GENERATOR OUTPUT CIRCUITS

The ringing generator output may be passed directly to the load or, if a square wave, after filtering. In almost all applications it will be necessary to bias the a.c. ringing source with a d.c. source, in order to provide for ring trip. (See Section V.) This requires special consideration, since the bias source is often the source of d.c. talk battery which may simultaneously supply other operating circuits. Several considerations ensue:

Filtering of the d.c. bias path may be necessary as shown in Figure 3 if the bias source is also the "quiet battery" supporting other talk circuits which may be in use while ringing. Resistor R may already exist elsewhere in the circuit (e.g. a current-limiting resistor) and simply be moved to this location.
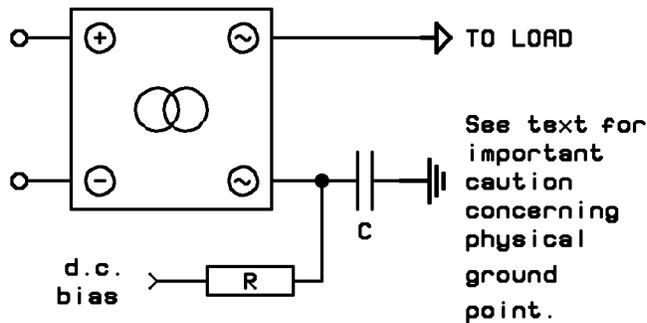

Fig. 3: Filter for d.c. bias source

This filter reduces interference if the d.c. bias source is also the v.f. "quiet battery." It will also protect the ringing generator input from voltage rise at the transition to off-hook status.

R ~ 47-300 Ω depending on d.c. bias source impedance.

C ~ 47-220 μF depending on degree of filtering required.

Observe the d.c. bias source with an oscilloscope while going off hook to select R and C values.   \TRXF03

Protection of ringing generator input is required when the the d.c. bias source is simultaneously the d.c. input to the ringing generator as is often the case. From the inception of off-hook status until the ring-trip circuit cuts ringing (normally ≤ 200 milliseconds but possibly longer under fault conditions), the output of the ringing generator is placed across its own input through the ring-trip circuitry, loop resistance, and the called equipment's d.c. resistance—perhaps only a few hundred ohms in total. Unless the d.c. source is extremely "stiff," the ringing generator's input may rise to destruction. The circuit in Figure 3 will also solve this problem. Observe the ringing generator input with an oscilloscope at the inception of off-hook status to select correct filter constants (if required). Figure 4 illustrates the corresponding modification to the manufacturer's application circuit provided for a Mitel SLIC.

Ground potential rise at the transition to off-hook status may generate serious disruption, due to possible high current flow through the ground point of capacitor C in Figure 3. For example, going off hook at the peak of an 86 V sine wave, biased at 50 V, through a d.c. resistance of 400 Ω, results in current flow of 400 mA! Carefully select the return path for this current to avoid disruptive ground potential rise.

Ringing bus protection, in the event of ringing a shorted line, is normally accomplished by adding a Positive Temperature Coefficient thermistor [hereafter PTC] in each branch off the ringing bus feeding a line circuit. The PTC's cold resistance is about 300 Ω but rises rapidly if ringing a shorted line, so maintaining the bus voltage for other line circuits. This PTC, often shown in application circuits, is unnecessary if the ringing generator supports only one line (rather than a bus) and has internal short-circuit protection.
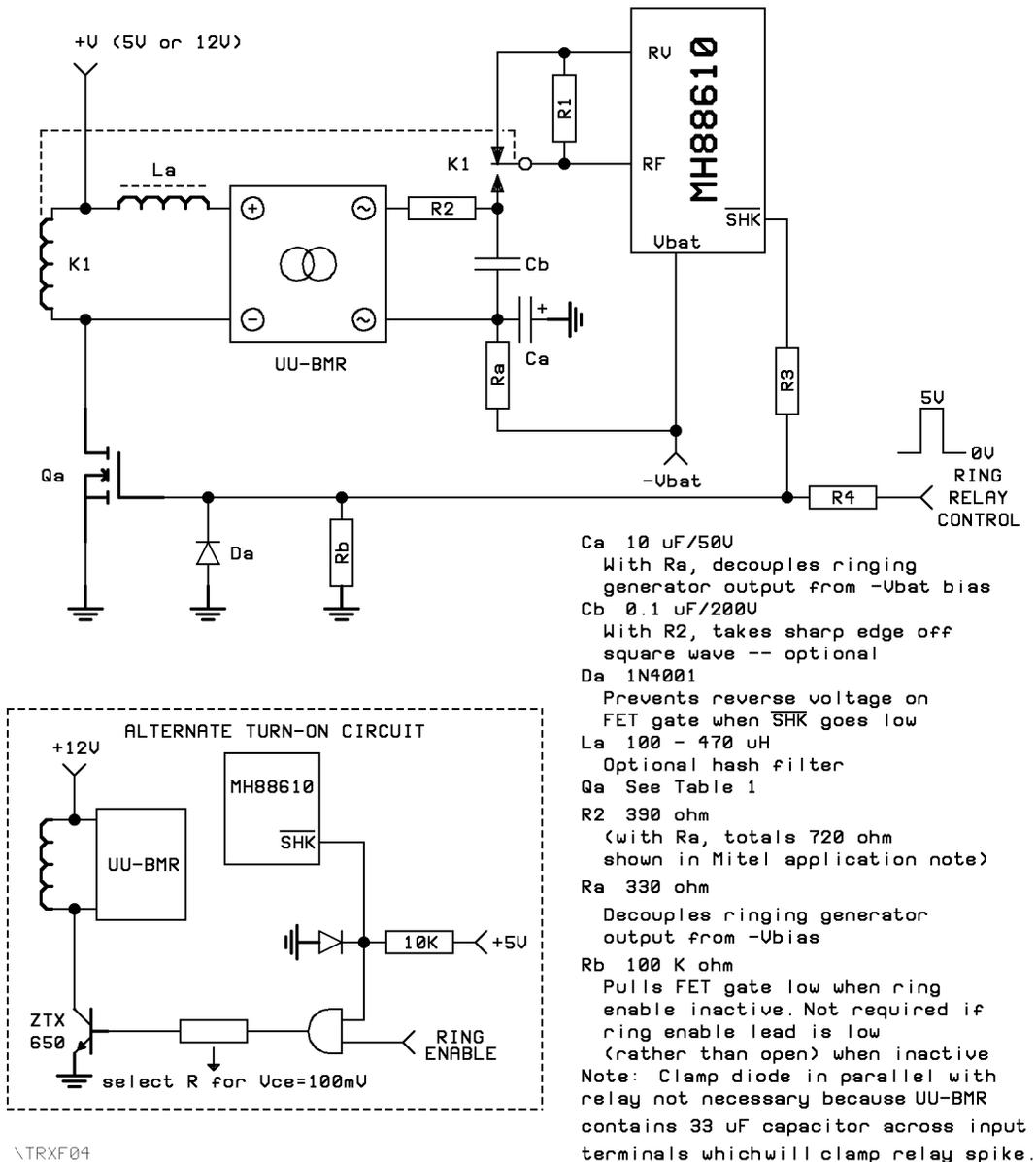
Fig. 4: Adaptation of Mitel Application Circuit for MH88610 SLIC

(Derived from Mitel Analog Communications Handbook 1991 Edition, Page 4-27 Fig. 2)

Ca 10 uF/50V
  With Ra, decouples ringing
  generator output from -Vbat bias
Cb 0.1 uF/200V
  With R2, takes sharp edge off
  square wave -- optional
Da 1N4001
  Prevents reverse voltage on
  FET gate when $\overline{SHK}$ goes low
La 100 - 470 uH
  Optional hash filter
Qa See Table 1

R2 390 ohm
  (with Ra, totals 720 ohm
  shown in Mitel application note)

Ra 330 ohm
  Decouples ringing generator
  output from -Vbias

Rb 100 K ohm
  Pulls FET gate low when ring
  enable inactive. Not required if
  ring enable lead is low
  (rather than open) when inactive
Note: Clamp diode in parallel with
relay not necessary because UU-BMR
contains 33 uF capacitor across input
terminals whichwill clamp relay spike.

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IV. RINGING INJECTION

Theory and Implementation of the General Case

During idle and talking conditions, the loop is connected to the d.c. talk battery. The ringing injection circuit connects the loop to the ringing source and also implements ring cadencing under hardware or software control. There are three type circuits:

Relay injection is simplest and least expensive but some peculiarities must be observed. A type circuit using a DPDT relay is shown in Figure 5. Some circuits (e.g. Harris HC5504 and the Mitel MH88610 shown in Figure 4) use only an SPDT form, continuing to connect the tip[4] lead to the SLIC for off-hook detection. When the equipment calls ringing, it operates the relay and simultaneously powers the ringing generator as shown. *Important caution*: while the relay contacts transition between ringing and conversational positions, the loop is an open circuit. Energy stored in an inductive ringer will raise the potential until an insulation breakdown occurs—possibly carbonization of your pcb! A snubber must be employed with this type circuit; an inexpensive RC circuit is shown but a varistor (typically 130 V) may also be employed. An RC snubber may also be placed across the ringing injection relay contacts (e.g. Harris 550X application circuits).
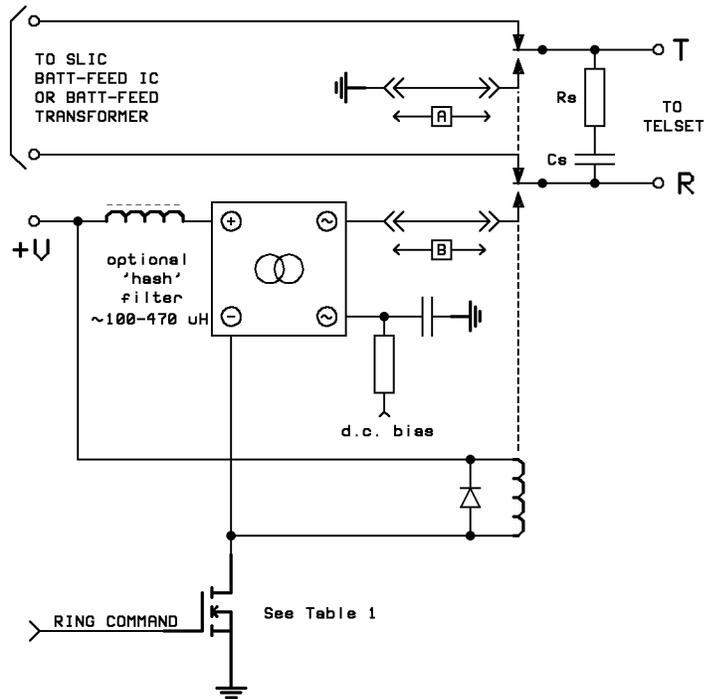
Fig. 5: Type Relay Ringing Injection Circuit

SLICs normally include ringing-interval hook-status detection. If not, or if using a battery-feed IC or transformer, detect hook status by adding the circuit of Fig. 8 at [A] for equipment not referenced to earth ground, or the circuit of Fig. 10 at [B] for equipment referenced to earth ground. Snubber RsCs is required; see text.   \TRXF05

Triac injection employs few and inexpensive components which are also physically small. Motorola provides an application circuit using their MC3419 SLIC; see Telecommunications Device Data Book, 1984, Fig. 15.

Opto-coupled FET injection employs few components as shown in Figure 6. Its greater cost may be justified by its generality of application and small size. The circuit shown injects ringing and detects ringing-interval hook status; contrary to all the other circuits shown, it is for an unbalanced line feed. Such a line feed suits equipment connected over only very short loops e.g. a modular cord or building wiring.

The balanced Motorola circuit mentioned in the previous paragraph could be modified to use an opto-coupled FET such as an LCA110 instead of a triac; this alternative would no longer provide zero-crossing injection but it would allow use of a pure square wave ringing source which the triac solution will not admit. (Due to the high dv/dt of a square wave, ringing will latch on permanently if gated with a triac.)

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4 The North American terms tip and ring correspond to the European terms A and B leads.
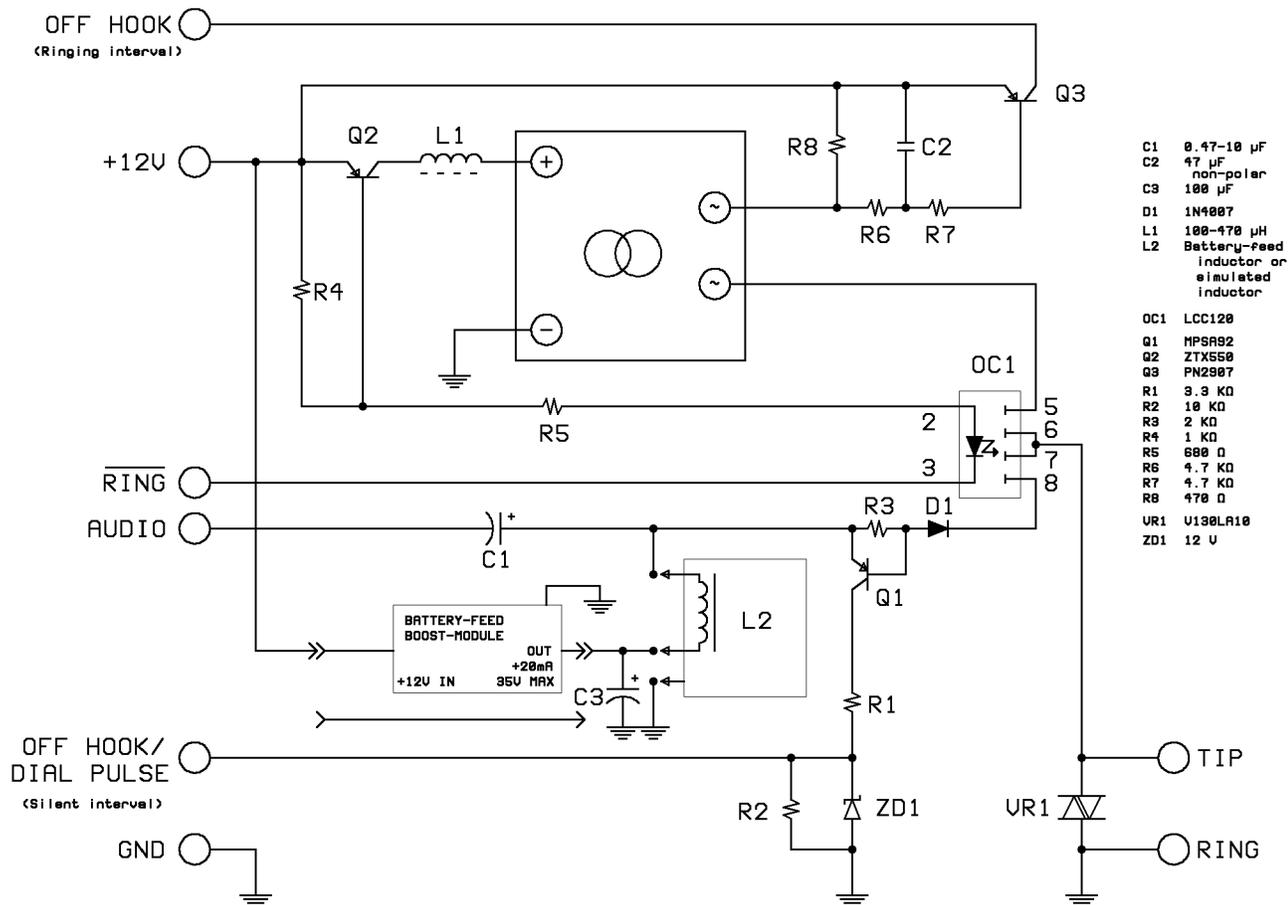
Fig. 6: Type Ringing Injection Circuit Employing Optocoupled FET

Simple basic circuit provides ringing and talk battery to unbalanced telephone line. Size may be reduced substantially by substituting a simulated inductor for L2. Battery feed may be 12 V (strap through as shown) or a constant-current source with higher open-circuit voltage required in some applications. (See footnote 7 on page 17 for explanation.)

Component list (from figure):

Ref	Value
C1	0.47–10 µF
C2	47 µF non-polar
C3	100 µF
D1	1N4007
L1	100–470 µH
L2	Battery-feed inductor or simulated inductor
OC1	LCC120
Q1	MPSA92
Q2	ZTX550
Q3	PN2907
R1	3.3 KΩ
R2	10 KΩ
R3	2 KΩ
R4	1 KΩ
R5	680 Ω
R6	4.7 KΩ
R7	4.7 KΩ
R8	470 Ω
VR1	V130LA10
ZD1	12 V

Zero-crossing Ringing Injection

Ringing   power exceeds voice frequency levels by many orders of magnitude.   To reduce the chance of interference, designers often prefer to employ "zero-crossing" ringing injection circuits.   In theory injecting or interrupting the ringing power at a zero point (variously zero-current or zero-voltage) reduces the chance that energy stored in the load or loop will interfere with low-power voice circuits.

Implementation is often complex and uncertain in effect.   The traditional implementation employs a zero-crossing detector on the ringing generator output to trigger operation of the ringing injection relay.   This method is used with the Ericsson and Harris 550X/5524 Subscriber Line Interface Circuits.   It cannot be used with square waves, and does not work reliably even with sine waves since by the time the relay operates (and its operate time varies with age, manufacturer, temperature and position) the wave will have moved off zero.

Figure 7 shows improved zero-crossing ringing injection circuits usable with both sine and shaped waves which, with proper component values, always inject ringing exactly at zero voltage and remove ringing exactly at zero current without a zero-crossing detector.   Its secret is that the relay only establishes the ringing path, but actual conduction is determined by the zero-crossing triac driver.   Capacitor C_t is chosen together with the relay resistance to hold the relay operated for more than one-half Hertz at the ringing frequency.   When ringing is called, the relay operates immediately to establish the ringing path, but conduction

occurs only at the first zero crossing under triac control.   When ringing ceases to be called, conduction ceases at the first zero crossing, but the relay remains operated slightly longer. Accurate timing demands a tight tolerance on the electrolytic capacitor C_t.   A pulse-stretcher may also be employed to drive the relay, the higher impedance of which would permit a small-value NPO timing capacitor (Fig. 7b).
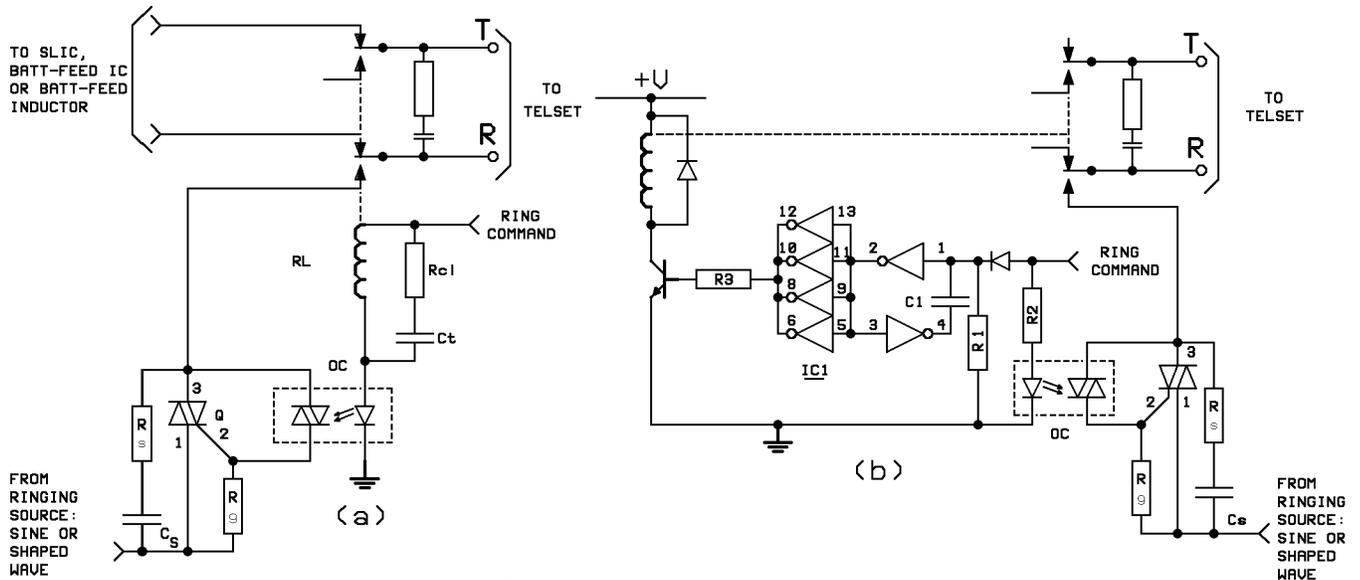
Fig. 7: Improved Zero-Crossing Ringing Injection Circuits

Theory of operation -- see text. (a) Basic circuit   (b) Alternate relay driver   (Values shown for 20 Hz)

C_S	0.01µF		C1	0.02µF NPO 5%
C_t	See text; must have stable, tight tolerance for consistent operation.		Cs	0.01µF
			IC1	CD40106BE
			OC	MOC3032
OC	MOC3032		Q	MAC97A-6, L501E-5
Q	MAC 97A-6, L501E-5		R1	3MΩ for 30 milliseconds
Rcl	~ 22 Ω		R2	390 Ω
Rg	330 Ω		R3	Select for correct base drive
Rs	150 Ω		Rg	330 Ω
Relay	Select lower coil voltage to compensate for drop in OC		Rs	150Ω

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With this modification to the Harris application circuit, there is no need for a zero-crossing detector; tie pin 7 [RING SYNC] of 550X or pin 6 of 5524 [RS] to +5 V. Other manufacturers' comparable devices may be handled similarly.

TABLE 1

MOSFETS SUITABLE FOR GATING RINGING GENERATOR POWER
(Mandatory for 5 V units with heavy current drain)

MANUFACTURER	P/N	PACKAGE	Rds	Vmax	REMARK
Fuji	2SK2018-01S	DPAK	0.10	60	Suitable up to 48 V supply
Harris	RFD3055RLE	DPAK	0.18	60	Suitable up to 48 V supply
International Rectifier	IRFR012	DPAK-SMD	0.30	50	Suitable up to 24 V supply
	IRFR121	DPAK-SMD	0.27	80	Suitable up to 48 V supply
	IRFR111	DPAK-SMD	0.54	80	Suitable up to 48 V supply
	IRFU014	DPAK-leaded	0.20	60	Suitable up to 24 V supply
	IRFU110	DPAK-leaded	0.54	100	Suitable up to 48 V supply
	IRFU120	DPAK-leaded	0.27	100	Suitable up to 48 V supply
	IRLD024	4-pin DIP	0.10	60	Suitable up to 48 V supply
Motorola	MTD3055E1	DPAK-leaded	0.15	60	Suitable up to 48 V supply
	MTD3055E	DPAK-SMD			
	MTD10N05E	DPAK	0.10	50	Suitable up to 24 V supply
	MMDF4N02	SO-8	0.10	20	Parallel dual units to achieve Rds = 0.05 Ω Suitable up to 12 V supply
	MMFT3055EL	SOT-223	0.18	60	Suitable up to 48 V supply Suffix EL denotes Vgs = 5 V
Samsung	[Second source to International Rectifier and Siliconix]				
Siliconix	SI9410DY	SOIC-8	0.05	30	Suitable up to 24 V supply (0.03 Ω if Vgs = 10 V)
	SMD25N05-45L	DPAK	0.045	50	Suitable up to 24 V supply
	SMD30N03-30L	DPAK	0.03	30	Suitable up to 24 V supply

NOTE: All units have 5 V gate threshold
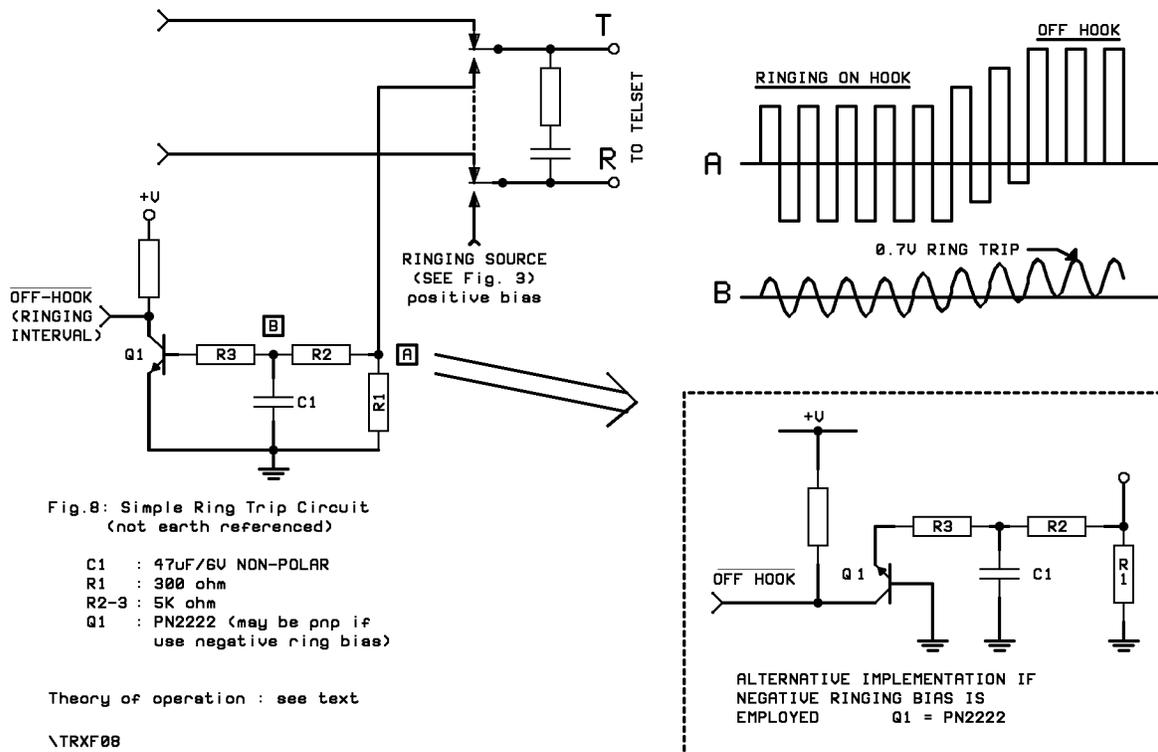
Ring-trip Detection Standards

The following are generally accepted industry standards.

• Ringing must be interrupted within 200 milliseconds after any telephone instrument goes off hook and should be interrupted within 100 milliseconds, to avoid ringing in the earpiece and excessive current drain from the ringing generator.

• If the calling equipment provides a return path from the loop to earth ground, ringing into a lead faulted to earth ground must be tripped.

• Any permitted combination of telephone instruments, over any loop length, must not trip ringing when all are on hook, but any one going off hook must trip ringing.

• Ringing must not be tripped by a d.c. imbalance of ≤ 3 mA (usually caused by non-linear alerters).

These requirements are achieved by placing d.c. bias on the a.c. ringing signal. The telephone instrument's blocking capacitor permits only a.c. current flow in the on-hook state, which is so filtered as not to cause an off-hook indication. Any instrument going off hook permits d.c. current flow which passes through the low-pass filter to give an off-hook indication. The designer must select the filter constants to meet the ring trip specifications under his equipment's conditions of ringing power, d.c. bias, permitted loop lengths, and possible combinations of signaled equipment.

Ring-trip Circuits: Equipment Not Earth-referenced

SLICs may include a ring-trip circuit but if a home-brew battery feed circuit is employed (battery-feed inductor or IC, split-coil coupling transformer) then the designer must make his own ring-trip circuit. Figure 8 illustrates a very low-cost circuit which works with

Fig.8: Simple Ring Trip Circuit (not earth referenced)

C1 : 47uF/6V NON-POLAR
R1 : 300 ohm
R2-3 : 5K ohm
Q1 : PN2222 (may be pnp if use negative ring bias)

Theory of operation : see text

\TRXF08

ALTERNATIVE IMPLEMENTATION IF NEGATIVE RINGING BIAS IS EMPLOYED   Q1 = PN2222

d.c. bias as low as 12 V over short loops. A higher bias will give more reliable operation over long loops but may require tweaking filter constants to achieve the above requirements.

Figure 8 operation is simple but not obvious.   During ringing about 5 V a.c. develops across R_1, centered about 0 V.   The voltage at Q_1's base does not reach turn-on due to the action of the T filter consisting of R_2, R_3 and C_1. When any telephone instrument goes off hook, the resulting d.c. current flow causes point "A" no longer to be centered about 0 V. This d.c. potential passes through the T filter to turn on Q_1. (Polarities may be reversed by changing Q_1 to pnp.)

Figure 9 is a comparable implementation using an operational amplifier, which would be appealing were a spare op-amp section available.

These circuits may be used only for equipment in which the loop floats with respect to earth ground because neither will trip ringing if the ring lead is faulted to earth.

Ring-trip Circuits: Earth-referenced Equipment

Figure 10a illustrates a type ring-trip circuit employed with a central ringing generator. It will trip ringing into a lead faulted to earth ground in an earth-referenced system.

Figure 10b illustrates a simpler type circuit possible when (a) the loop is referenced to the cir-
cuit common; (b) the d.c. bias is positive (so ordinary positive logic can be employed); (c) the ringing generator is specific to the circuit[5] rather than a central ringing supply.
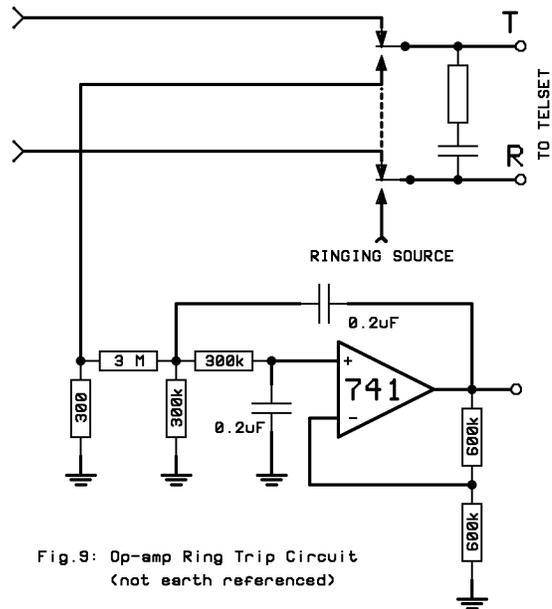
Fig.9: Op-amp Ring Trip Circuit
(not earth referenced)

Set R1-R3 and C to achieve
proper ring trip.   See
Section V.

R1   ~ 470 --> 680 ohm
R2R3 ~ 5K
C   ~ 20 --> 47 uF 6V
          (Non-polar)
R4R5   Select for proper
        ratio to give off-
        hook logic signal
        from +V
ZD   Logic level clamp
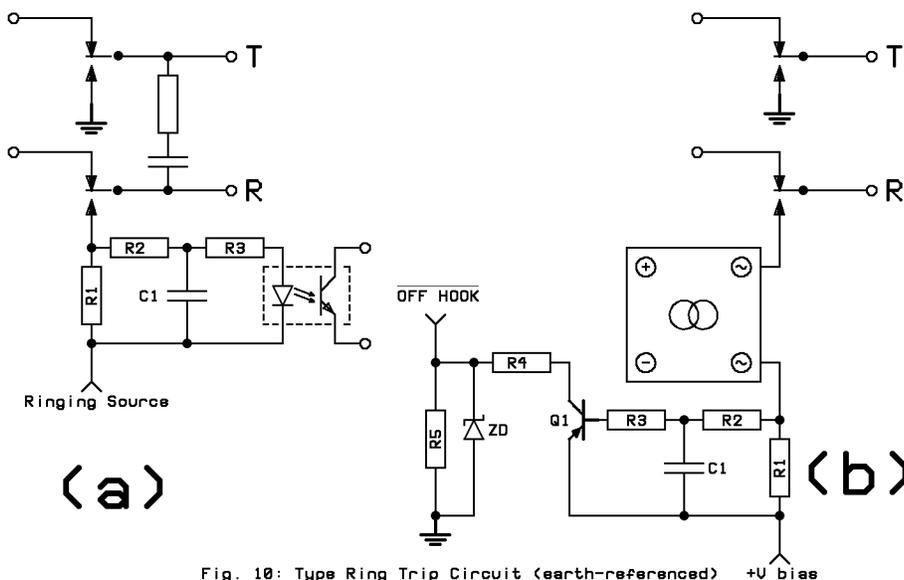
Fig. 10: Type Ring Trip Circuit (earth-referenced)   +V bias

\TRXF10

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5 For example the Cambridge Electronics Laboratories Micro Black Magic Ringing Generator.

VI. TALK BATTERY CIRCUITS

Ringing and talking power intersect at so many points that talking power must be considered.   Important points are that the talk-battery source (1) be noise-free; (2) source sufficient but limited current; and (3) be monitored to detect silent interval hook status.

Talk battery will ordinarily be provided to the ring and tip leads balanced with reference to system common (often earthed), using:

Inductor, transformer, or relay,[6] which permits any d.c. feed voltage even down to 5 V providing sufficient current through short loops.   This method allows varying the d.c. feed voltage according to loop length to maintain constant current, economizing on power, for example, in battery-powered applications[7]. Figure 11a shows how to monitor loop current to detect silent-interval off-hook status.   In devices referenced to earth, better balance may be obtained by the circuit in Figure 11b which employs a balanced current sense relay.   If the d.c. source is too noisy, a capacitance multiplier may be implemented with only a transistor, small capacitor, and resistor.
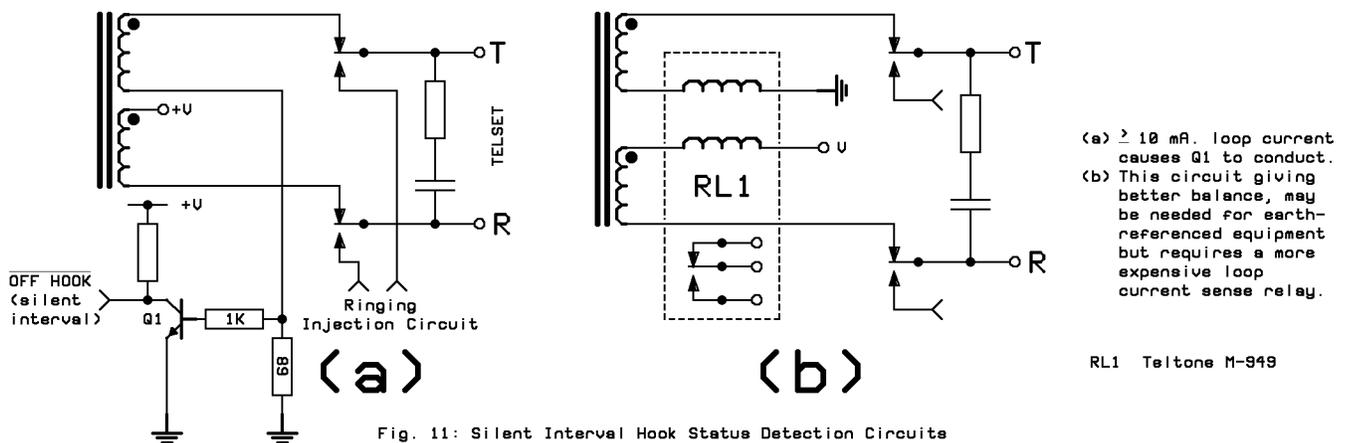
Fig. 11: Silent Interval Hook Status Detection Circuits

Home-brew *simulated inductor* ("gyrator") using an operational   amplifier, or simulated inductor ICs such as A T & T's LB1011AB or LB1012AD.

Subscriber Line Interface Circuits (SLICs), most of which are multi-functional including hook-status detection and 2-wire to 4-wire conversion of the voice path.

A peculiar difficulty arises from the interworking of the ringing injection and silent-interval hook-status detection circuits, because of energy stored in the loop (several microfarads in some cases) and in a telephone instrument's mechanical ringer and blocking capacitor.   This energy will be dumped back into the silent-interval hook-status detection circuit causing a false ring trip indication.   To prevent this false indication, the silent-interval hook-status detection circuit must be blanked for the first 50 milliseconds, in either software

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6 See Reference 4.

7 Cambridge Electronics Laboratories produces an unusual product, the Battery Feed Boost Module, which outputs a constant 25 mA into any load from a 12 V input.   Its 35 V open circuit output drops to 6 V over short loops.   Using PWM control it does not burn up excess power as heat like linear current limiters. Aside from the factor of energy economy, some telecom devices (such as certain brands of facsimile machines) must see an on-hook potential $\geq$ 30 V for proper functioning, even though 25 mA at 5 V is acceptable for the off-hook condition.

or hardware. Figure 12 shows how to modify the circuit in Figure 11a in hardware. As a SLIC example, the Motorola MC3419, sensed on the HSO, RSO and TSO pins, must be blanked in software, or else a filter added (shown as C_{ts} and R_{ts} in the Motorola application notes).

   This point needs stressing because engineers often spend days, without success, "debugging" false off-hook indications, when the answer is simply the above.[8]
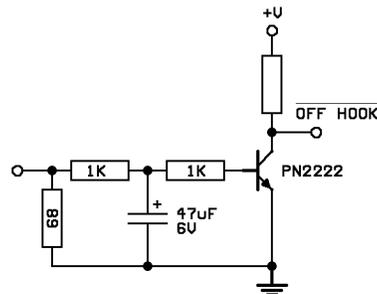
Fig. 12: Blanking False Off Hook
Indication in Hardware

\TRXF12

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8 The actual test from Bellcore Technical Reference TA-TSY-000057 is that off-hook must not be indicated "when an 8 µF capacitor precharged [with +70 V ring to tip or -170 V ring to tip] . . . is abruptly applied to the ring and tip leads . . . " A quick-and-dirty test is to verify that ringing an instrument with an inductive alerter does not give false off-hook indication after a few minutes of cadencing ringing on and off.

VI. RINGING GENERATOR INPUT CIRCUITS

Careful consideration must be given to a ringing generator's input circuit to achieve design goals while not disturbing other circuits or other aspects of circuit operation. Figure 13 highlights the essential points.

First, power the ringing generator only when calling ringing, ordinarily infrequently. This will conserve power, reduce heating, and minimize the possibility of interference. This may be implemented in software (μP control of the generator) or hardware, by ORing the ring command signals from each ringing injection relay. Figure 14 suggests a possible implementation.

Second, filter the ringing generator input as needed to mitigate the effect of the spiky input current which may cause glitches elsewhere on the bus. This is more necessary with square wave and switchmode generators.

Third, employ a solid-state switch, not a relay, to control input power to the ringing generator. A relay will not reliably survive the capacitor input filter found in most ringing generators. Refer to Table 1 for suggested MOSFET devices and vendor names, and the Component Sources section at the end of this publication.

Fourth, where possible employ ringing generators with higher rather than lower input voltages. Lower input current is easier to switch and results in less loss in pcb traces, wiring and connectors.
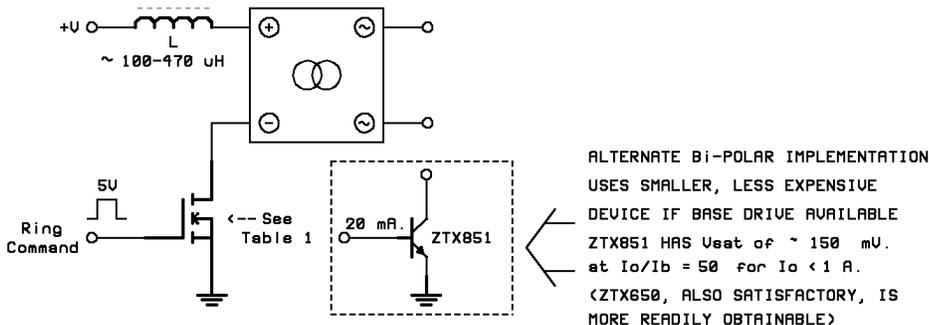
Fig.13: Ringing Generator Power Input Circuit

ALTERNATE Bi-POLAR IMPLEMENTATION USES SMALLER, LESS EXPENSIVE DEVICE IF BASE DRIVE AVAILABLE ZTX851 HAS Vsat of ~ 150 mV. at Io/Ib = 50 for Io < 1 A. (ZTX650, ALSO SATISFACTORY, IS MORE READILY OBTAINABLE)

\TRXF13

ZTX750 if V=12-24; ZTX751 if V > 24

Fig.14: ORing Multiple Ring Command Leads

This circuit powers the ringing generator when any ringing injection relay operates.

\TRXF14

Fig. 15 Failure Detection and Redundancy

	5V	12V	
C1	0.1/200V	0.1/200V	
C2	0.1/25V/X7R	0.1/25V/X7R	
D1-5	1N4001	1N4001	
IC1	TL061	LM741	NOTE: USE RELAY TO SWITCH LOAD
Q1	2N2907	2N2907	TO BACKUP RINGING GENERATOR.
R1	200K	200K	
R2	200K	200K	
R3	560K	560K	IF NOT REQUIRED OMIT RL, D4, AND
R4	2K	2K	FEED D5 TO ALARM BUS.
R5	4.7K	6.8K	
R6	3.3K	5.6K	
R7	2K	2K	
ZD1-2	5.6V	5.6V	\TRXF15
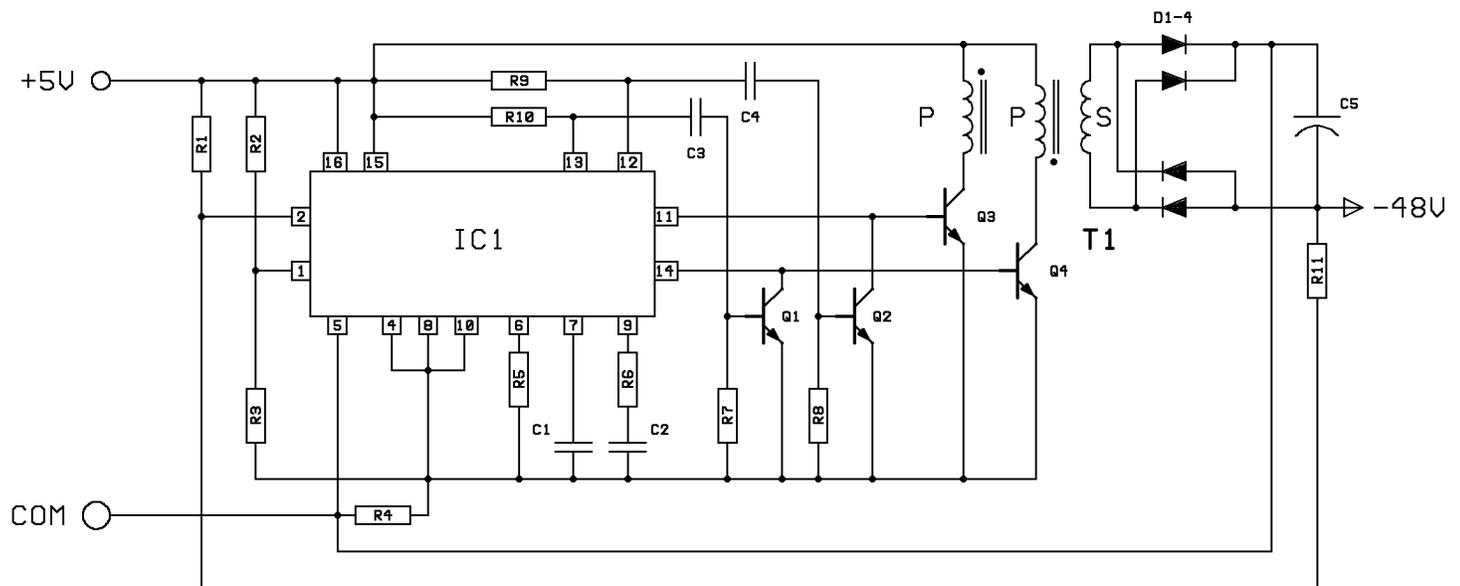
PARTLIST

R1-3	4.7K	C1	0.01µF	IC1	SG3524
R4	0.25Ω	C2	0.1µF		
R5	2K	C3-4	0.01µF		
R6	6.8K	C5	47µF/63V		
R7-8	4.7K	D1-4	1F4		
R9-10	330Ω	T1	1814		
R11	99K		(POT CORE)		
Q1-2	BC337	P=12T//12T			
Q3-4	ZTX650	S=140T			

IMPORTANT CAUTION   DUE TO TYING OF PINS 15-16, THE MAXIMUM INPUT VOLTAGE OF THIS CIRCUIT IS 5.5 V. ALSO NOT ALL MANUFACTURERS' VERSIONS OF THIS IC PERMIT 5 V OPERATION.   CONSULT MANUFACTURER'S DATA SHEET.

Fig. 16: 5 V to -48 V dc/dc converter   \TRXF16

VIII. GENERAL APPLICATION HINTS

The following general hints may prove useful.

Consider establishing a redundant ringing source. Telecom equipment may survive to provide minimal service without some features, but ringing is not one of them.   Where possible provide a backup ringing generator and change-over circuit.   Figure 15 illustrates a type circuit which monitors generator output and provides a signal, should failure occur, to send an alarm and/or to switch to a backup generator.   As an alternative to one large ring-ing generator, consider an architecture dividing the ring groups into two sets.   A primary generator supports each. When either fails, a control circuit sends a minor alarm and switches its load to the survivor.   The survivor should successfully carry the total load under most traffic conditions, if conservative design principles were followed in dimensioning the system.   (Figure 15 can be adapted to perform this function.)

Modularity improves service because it eases troubleshooting and   repair and reduces lifetime costs because only failed components are replaced. Consider decentralizing the ringing supply to board level, using modular ringing supplies, and physically separating the ringing generator modules from the power supply module.   This will also reduce heat pock-ets and exposure of the ringing generator to heat from the main d.c. power supply.

Strive for simplicity of the power supply. Ideally a supply operating on commercial power would output a single voltage and be external to one's equipment.   Such single output sup-plies are inexpensive and readily available from manufacturers' stocks as standard products. And if such a supply is safety rated for the jurisdiction in which one's equipment is to be sold, making it external should eliminate the need for a separate safety approval for the product itself.   "Jelly-bean" dc/dc converters are readily available to and from most standard vol-tages.   The principal exception is 5 V to -48 V.   Figure 16 illustrates such a circuit.

Put the ringing generator on its own card, an excellent means of enhancing modularity. Figure 17 illustrates a type ringing generator card carrying the generator and optional input and output filters and protection circuits.[9]
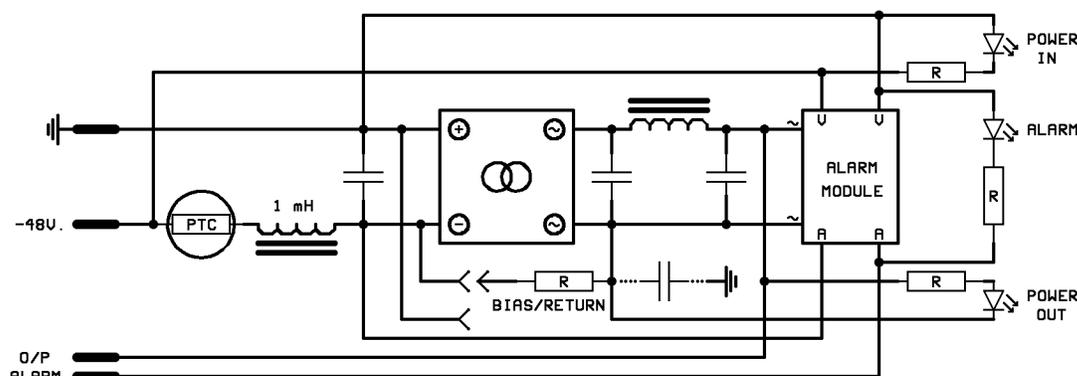
Fig. 17: Type Ringing Generator Card with Alarm

\TRXF17

Strive for commonality of components.   Figure 18 illustrates a type combination FXS/FXO circuit which saves many components by doubling up on functionality.

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9 Cambridge Electronics Laboratories can fabricate complete plug-in cards to customer order e.g. for shelf mounting, carrying CEL's proprietary Black Magic ringing generators and ancillary circuits, and bearing the customer's own logo.

Fig. 18   Combination FXS/FXO Circuit

C9,R9,R13 compose optional capacitance multiplier filter circuit.

D1-4	1N4004
T1	Microtran T9220
T2	Microtran T9220
VR1	V130LA10
ZD1	27 V

C12	47 µF
C13	47 µF
	NON-POLAR
OC1	4N33
OC2	4N33
Q1	ZTX650
Q2	PN2222
Q3	ZTX650

C3	.0082µF
C4	.015 µF
C5	.033 µF
C6	.068 µF
C7	.120 µF
C8	2.15 µF
C9	100 µF
C10	10 µF
C11	0.33 µF

R10	604 Ω
R11	301 Ω
R12	6.8 KΩ
R13	100 Ω
C1	.0022µF
C2	.0039µF

R1	100 Ω
R2	470 Ω
R3	470 Ω
R4	4.7 KΩ
R5	4.7 KΩ
R6	2 KΩ
R7	2 KΩ
R8	2 KΩ
R9	2 KΩ

IX. ISDN APPLICATION HINTS

Despite the aspirations of many for an "ISDN world," analog telephone instruments will dominate usage for the foreseeable future.   During this indeterminate period of technological overlap, many applications demand that ISDN circuits interface with, and ring to, analog devices such as telephone sets, facsimile machines, and answering machines.   For this reason such circuitry must be developed.

Such circuits have four elements:

- the ISDN-facing element;

- the power conversion element;

- the analog-facing element;

- the ringing supply.

Typical applications are ISDN Terminal Adapters (either stand-alone or emplaced in a personal computer), and pair-gain devices.

At least two difficulties ensue:

• ISDN technology is four-wire without d.c. talk-battery feed.   Interfacing to an analog device requires 2W/4W conversion and sourcing talk battery, both of which may be implemented with a SLIC or inductive hybrid as covered in previous sections.

• ISDN technology envisions a piezo-electric alerter powered from the ISDN Terminal Adapter d.c. bus (5 V).   Energy allowance is sufficient for only this small signal.   This is not a problem if local power is continuously available, but if CO power must support the local ringing function, a "trick" must be employed, namely storing CO power for the surge requirements of analog ringing.   Batteries are undesirable due to their inherent short lifespan. A superior solution is charging a "double layer" capacitor (typical value 1.0 F), which can support an instantaneous load of one ampere at 5 V during the brief ringing intervals.   This special type of capacitor is very small, has practically unlimited lifetime, and stays fully charged from the 1 W continuously available over the ISDN copper pair.

Figures 19 and 20 illustrate two types of ISDN-to-analog interfaces.   Current ISDN ICs have the capability to cancel the 2W/4W return signal within the chip using DSP technology. This reduces the burden on the SLIC or inductor hybrid function compared to the purely analog case.
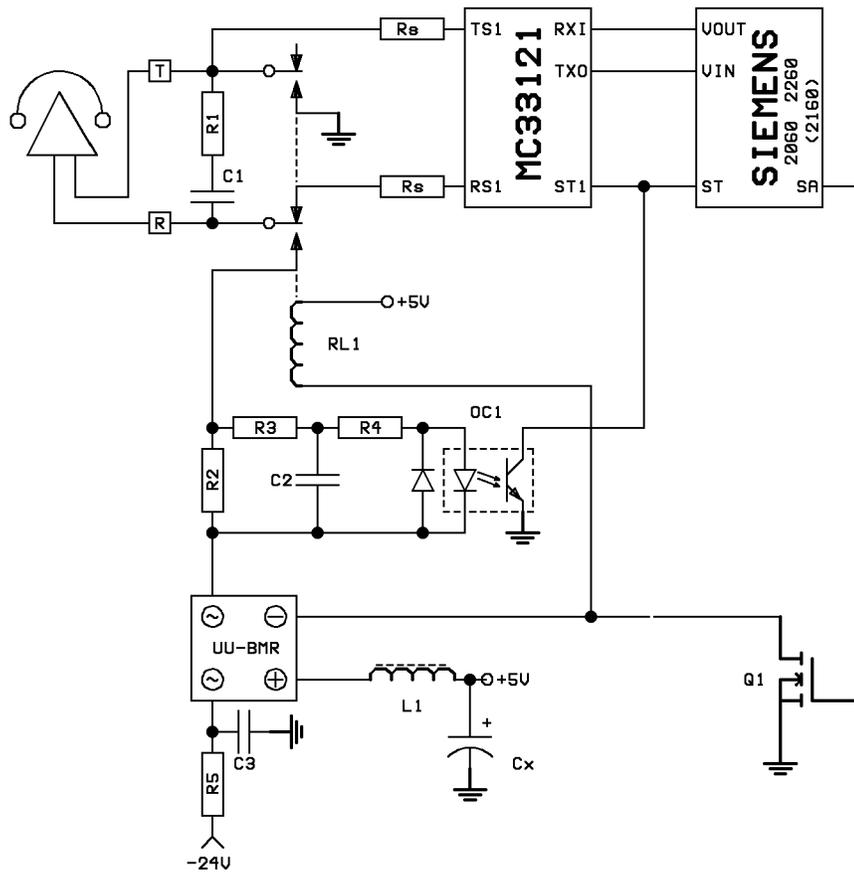
FIG. 19   Type Analog Telset Interface to ISDN Circuit -- SLIC Implementation

```
C1  0.1 uF/250 V       Forms snubber with R1
C2  47 uF / 10 V       Bi-polar/non-polar recommended (instead of polar electrolytic
                        shown in Motorola application note)
C3   47 uF/50 V        See text for important caution about location of
                        physical ground point
L1     125 uH          Optional hash filter e.g. Miller 5252 (125 uH/0.08 Ω)
OC1    PC817A          Four-pin alternative to 4N35
Q1                     See Table 1
R1    10 K ohm         Forms snubber with C1
R2     620 ohm         Per Motorola application note
R3-4   5 K ohm         Per Motorola application note
R5     100 ohm         Decouples noise from 24 V d.c. bus
RL1                    Ringing injection relay
UU-BMR                 Micro Black Magic Telephone Ringing Generator
```

NOTES:

A. DEPENDING ON PHASING OF ENERGY STORED IN INDUCTIVE RINGER IN CALLED TELSET,
    MC33121 MAY GIVE FALSE OFF-HOOK INDICATION AS RINGING IS CADENCED OFF WHILE
    TELSET REMAINS ON HOOK. IT MAY BE NECESSARY TO BLANK ST1 FOR FIRST FEW
    MILLISECONDS IN SOFTWARE, OR ALSO TO MONITOR ST2. ANOTHER POSSIBILITY IS
    TO ADD LOW-PASS FILTER TO ST1 OUTPUT. (THIS WILL DEFEAT ABILITY TO FOLLOW
    DIAL PULSES.)

B. SET SIEMENS ARCOFI/SICOFI SO THAT PIN MARKED "SA" IS HIGH WHEN RINGING IS
    CALLED.

C. TRANSIENT ACROSS RELAY RL1 COIL IS CLAMPED BY 33uF FILTER CAPACITOR INSIDE
    THE BLACK MAGIC RINGING GENERATOR, SO NO CLAMP DIODE IS REQUIRED

D. Cx IS OPTIONAL ENERGY-STORAGE "SUPERCAP."   SEE TEXT PAGE 23.

\TRXF19

Notes:

⟨1⟩ +V talk batt: 5V acceptable for 25 mA. 12V better.
Over 12V wasted power.

⟨2⟩ C1 = 22 uF NON-POLAR 6V.
⟨3⟩ Snubber required -- see text.
⟨4⟩ Set to be: Low=OFF HOOK
⟨5⟩ Set to be: High=RING COMMAND
⟨6⟩ ZD = 24 V 1 W simulating d.c. bias.
⟨7⟩ Optional has filter ~ 100-470 µH
⟨8⟩ Optional "supercap" energy reservoir.
See text page 23.

ALTERNATIVE CIRCUIT

This implementation uses ARCOFI's internal echo cancellation circuitry instead of external hybrid. Requires good transformer.

External hybrid balancing network will give better balance.

See Siemens application literature.

Fig. 20: Type Analog Telset Interface to ISDN Circuit -- Inductor Implementation

Note that this unusual circuit requires only a single low voltage (5 V or 12 V) for operation. Since no SLIC is used, and no d.c. ringing bias is required, there is no need for a high voltage (24 V or 48 V) source. The circuit is suited for short loops.

APPENDIX 1: W-A-R-N-I-N-G ! ! !

SLIC APPLICATION NOTES MAY EASILY BE MISINTERPRETED!

The d.c. bias source for the ringing generator is often shown in the simplified form of an equivalent circuit, as illustrated by these examples:

Figure 5. Typical Application circuit
MITEL MH88600

Application Note
HARRIS HC-5504
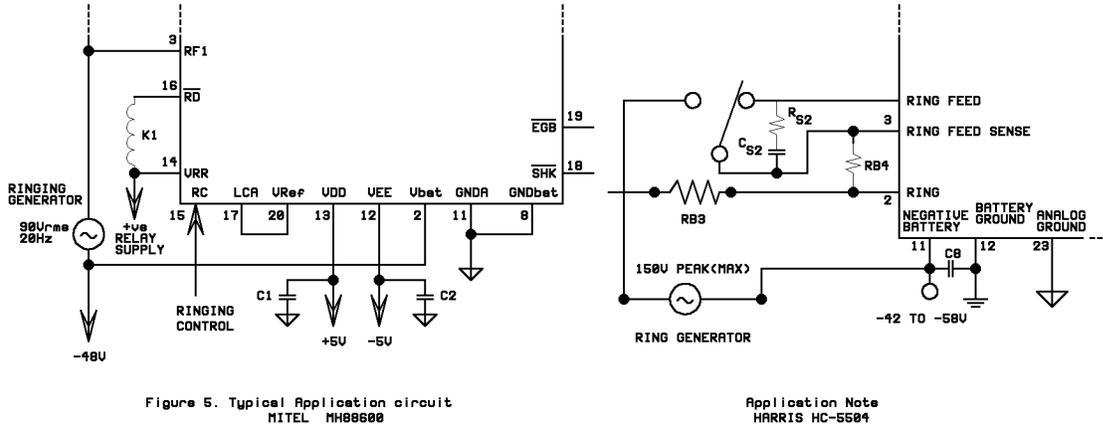
\WARNING1.PIX

Such schematics do not show sufficient detail to guarantee proper operation of the ringing generator portion with the current technology of miniaturized ringing generators and on-board dc/dc converters.   As explained in the text, at the moment when the called telset goes off hook, but before the ring trip circuit terminates ringing, a large current flows through the ringing generator and d.c. bias supply.   If the latter is also the ringing generator's d.c. input (as typically shown in manufacturers' application notes such as the examples shown above), and this supply is, as is often the case, a small dc/dc converter, then the resulting large current may force the d.c. supply into current foldback or shut-down.   Its impedance will rise, and the resulting equivalent circuit is simply the ringing generator output connected to its input through the off-hook telephone and hook-status sensing resistor.   The resulting high voltage across the ringing generator's input may destroy the device.

The solution is the decoupling filter shown.   This is elaborated in Section III of the text, "Protection of ringing generator input," and in Figure 3.   Place an oscilloscope at the point shown and observe the stability of the d.c. voltage source while exercising the circuit through the ringing and transition-to-off-hook-while-ringing functions.   Sufficient filtering must be added to prevent the d.c. supply from excursions dangerous to the ringing genera-tor's input.   If the d.c. supply is also the v.f. "quiet battery," additional filtering may be required.
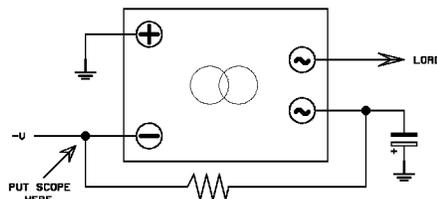
\WARNING2.PIX

APPENDIX 2 :   Designing Wave-Shaping Filters

   1. In designs employing a wave-shaping filter, there is trade-off between efficiency (resulting in higher output voltage to load), size, and cutoff frequency of the resulting filter (which reduces potential for interference the lower is the cutoff frequency). CEL recommends the following procedure:

  a. If possible design the cadencing plan to minimize peak instantaneous load (in numbers of physical ringers) as described in the text.

  b. Knowing the peak instantaneous load, calculate the current (roughly 10 mA per ringer), from which calculate the voltage drop of each of the different wave-shaping inductors.

  c. Determine the additional voltage drop in the loop. If short (e.g. signaled devices are essentially co-located with equipment), this will be zero.

  d. Determine the minimum acceptable voltage across each load to operate it properly. For a telephone set, this will be about 40 volts. For modems and the like, it will be specified in the manual, usually also about 40 volts.

  e. Subtract the minimum voltage required to the signaled devices from 80 Vrms (the rms equivalent to the 86 v square wave output). This is the maximum allowable voltage drop in the inductor and loop. Subtract the voltage drop in the loop (if any). This is the maximum allowable voltage drop in the inductor.   Then identify which inductors qualify, and choose the one best suited to the desired form factor.   (Refer to d.c. resistances shown in the CEL publication "Selecting Ringing Generators from the Black Magic Family.")   Alter this calculation as appropriate if designing to use a ringing generator with a different output voltage.

   2. CEL inductors exhibit the following principal differences:

  a. The L/WSN1 was designed for use with CEL's Micro model and a one-ringer load but may work with up to three ringers on short loops.   It is larger that the L/WSN2 and L/WSN3 but has a higher inductance.

  b. L/WSN2: horizonal mounting; L/WSN3: vertical mounting.

  c. L/WSN4: much lower resistance and inductance, so less voltage drop but higher filter cutoff frequency.   Originally designed for CEL's Mini model ringing generator, but can be used with the Micro model if the architecture is changed to be an L filter rather than a pi filter.   (The design of the Micro model will not accept a capacitive load such as presented by a pi filter.)

  d. L/WSN5: still lower resistance and inductance, suited for loads of more than four REN.

  e. L/WSN6: resistance and inductance similar to the L/WSN5 but in a smaller package. This inductor may saturate in some applications.   In cases where this is unimportant, the saving in space is substantial.

   3. For applications requiring a very low profile on the printed circuit board, a possible alternative is to employ a standard battery feed inductor (L ~ 1 Hy) available from several magnetics vendors.

   4. Another alternative is standard inductors from magnetics vendors, or (for volume applications) custom-wound inductors.

   5. It is best is to get a variety of samples and test actual performance.

APPENDIX 3:   REFERENCES

1. A. Michael Noll, *INTRODUCTION TO TELEPHONES AND TELEPHONE SYSTEMS*, second edition, Artech House, Boston and London, 1991.

   Artech House, 685 Canton Street, Norwood MA 02062.   Telephone +1 617 769-9750

2. "Direct Connection: Interfacing to the Telephone Network," *Application Note 102*, Compliance Engineering, 1990.

   Compliance Engineering Inc., 593 Massachusetts Avenue, Boxborough MA 01719.
   Telephone +1 508 264-4668   Telefax +1 508 263-7086

   Succinct basic description of telephone instruments and interfaces and many important details, with stress on regulatory compliance and safety issues.

3. *TELECOM DESIGN SOLUTIONS*, Teltone Corporation, Issue 1, Fall 1990

   Teltone Inc., 22121 20th Avenue SE, Bothell WA 98021
   Telephone +1 206 487-1515   +1 800 426-3926
   Telefax +1 206 487-2288   Telex 910-449-2862 TELTONE

   See especially Application Note SC-1: "Applications for DTMF and Pulse Telephone Dialing," which provides a comprehensive overview of switched network interface standards, methods, and typical circuits.

4. "Telephone Coupling Transformers for Interconnect of Voice/Data Modem Terminals," *Engineering Application Bulletin F232*, Microtran Company Inc., April 1992.

   Microtran Company Inc., 145 East Mineola Avenue, Valley Stream NY 11582.
   Telephone +1 516 561-6050   Telefax +1 516 561-1117

   General background on interfacing, 2-wire to 4-wire conversion, and battery feed, stressing circuit parameters and use of inductive components.

5. *DESIGNERS GUIDE*, International Science and Technology Inc., periodical.

   International Science & Technology, Inc., Black Hall Road, Epsom NH 03234
   Telephone +1 603 736-8414   Telefax +1 603 736-4506

   Tested design methods, stress on reliability and regulatory compliance.

6. Bell Communications Research Information Operations Center, 60 New England Avenue, Piscataway NJ 08854.

   Telephone +1 201 699-5800   +1 800 521-2673   Telefax +1 201 699-0936

7. Stephen J. Bigelow, *UNDERSTANDING TELEPHONE ELECTRONICS*, 3rd edition, SAMS Computer Publishing Division of Prentice Hall, Carmel, Indiana, 1992.

   Telephone +1 800 428-5331   Telefax: +1 800 448-3804

APPENDIX 4: COMPONENT SOURCES
Note: Information current as of December 1993

CAPACITOR, DOUBLE LAYER ELECTROLYTIC for filtering d.c. bus

 CESIWID Inc., 3245 Hyde Park Blvd, Niagara Falls NY 14302   USA
 Telephone +1 716 286-7600   Telefax +1 716 286-7602

  LF series for low ESR; operating temperature range -40° C to +85° C

 Evans Company, 33 Eastern Avenue, East Providence RI 02914 USA
 Telephone +1 401 434-5600   Telefax +1 401 434-6908

  Values to 1.5 F, voltage to 11.0; operating temperature range -55° C to +85° C

 NEC, 401 Ellis Street, Mountain View CA 94039   USA
 Telephone +1 800 632-3531   Telefax +1 800 729-9288

  Values to 2.2 F, voltage to 11.0; operating temperature range -25°

 Panasonic Industrial Company, 2 Panasonic Way, Secaucus NJ 07094   USA
 Telephone +1 201 348-5206   Telefax +1 201 392-4441

  Values to 10 F

 Philips Components, 2001 West Blue Heron Blvd, Riviera Beach FL 33404   USA
 Telephone +1 800-447-3762   +1 407 881-3200   Telefax +1 407 881-3300

  Model DLC 196

CAPACITOR, FILM, BOX OR DIPPED TYPE, RADIAL LEAD for Wave Shaping Network

 EVOX USA Inc., 100 Tri-State International Suite 100 Lincolnshire IL 60015   USA
 Telephone +1 : 312 948-9511   Telefax +1 312 948-9320   Telex 206997 EVOX

  Series MMK22.5

 Philips Components, 2001 West Blue Heron Blvd, Riviera Beach FL 33404   USA
 Telephone +1 800-447-3762   +1 407 881-3200   Telefax +1 407 881-3300

  Series 719A

CAPACITOR, FILM, OVAL TUBULAR, AXIAL LEAD for Wave Shaping Network

 Can be upended to minimize pcb footprint

 Industrial/Midwec, 4902 Tollview Drive, Rolling Meadows IL 60008   USA
 Telephone +1 708 577-0120   Telex 910-687-3375

  Series 2.5MUMZ

 Philips Components, 2001 West Blue Heron Blvd, Riviera Beach FL 33404   USA
 Telephone +1 800-447-3762   +1 407 881-3200   Telefax +1 407 881-3300

  Series 708A1

CAPACITOR, FILM, ROUND TUBULAR, AXIAL LEADS for Wave Shaping Network

 Can be upended to minimize pcb footprint

 Cornell Dubilier, 1605 E. Rodney French Blvd, New Bedford MA 02744   USA
 Telephone +1 508 996-8561   Telefax +1 508 996-3830   Telex 929419

   Series MTE

CAPACITOR, ORGANIC SEMICONDUCTOR ELECTROLYTE for d.c. bus hash filter

   Organic semiconductor electrolytic capacitors ("OS-CON") have extremely low ESR
   at high frequencies, providing highly effective filtering on the d.c. bus.

 Marcon America Corp., 998 Forest Edge Drive, Vernon Hills IL 60061   USA
 Telephone +1 708 913-9980   Telefax +1 708 913-1150

 Sanyo Video Components (USA) Corporation, 2001 Sanyo Avenue, San Diego CA 92173   USA
 Telephone +1 619 661-6322   Telefax +1 619 661-1055

INDUCTOR AND TRANSFORMER for battery feed inductor and coupling transformer

 Lian Bao Electronics Inc., 4 Jyi An Street, Hsin Ten, Taipei, Taiwan ROC
 Telephone +886 2 211-2081   Telefax +886 2 211-3222

 Microtran Company Inc., 145 East Mineola Avenue, Valley Stream NY 11582 USA
 Telephone +1 516 561-6050   Telefax +1 516 561-1117

 Prem Magnetics Inc., 3521 North Chapel Hill Road, McHenry IL 60050 USA
 Telephone +1 815 385-2700   Telefax +1 815 385-8578

 Silicore Electronics Inc., 228 Shih Chien Road, Keelung, Taiwan ROC
 Telephone +886 2 451-5276   Telefax +886 2 451-3295

INDUCTOR for d.c. bus hash filter

 Inductor Supply Inc., 1849 West Sequoia, Orange CA 92668 USA
 Telephone +1 800 854-1881   +1 714 978-2277   Telefax +1 714 978-2411

   Model LA4S   330 to 470 μH

 Miller Div. of Bell Industries, 306 East Alondra Blvd, Gardena CA 90247 USA
 Telephone +1 310 537-5200   Telefax +1 310 631-4217

   Model 5252   125 μH/0.08 Ω

 Renco Electronics Inc., 60 Jefryn Boulevard East, Deer Park NY 11729 USA
 Telephone +1 516 586-5566   Telefax +1 516 586-5562   Telex 220883

   Model RL-1284   330 to 470 μH

INDUCTOR for Wave Shaping Filter

Cambridge Electronics Laboratories, 20 Chester Street, Somerville MA 02144   USA
Telephone +1 617-629-2805   Telefax +1 617 623-1882   Telex 948580 RACE SOMV UD

Microtran Company Inc., 145 East Mineola Avenue, Valley Stream NY 11582 USA
Telephone +1 516 561-6050   Telefax +1 516 561-1117

    Model T8410 toroid 1 Hy 113 Ω D=1.25" H=0.625"

Prem Magnetics Inc., 3521 North Chapel Hill Road, McHenry IL 60050 USA
Telephone +1 815 385-2700   Telefax +1 815 385-8578

    Model SPT-178 battery feed inductor 0.85 Hy 88 Ω L=1.45" W=1.30" H=0.52"
    Model SPT-192 coupling transformer with windings series-connnected

INTEGRATED CIRCUIT for Battery Feed

AT&T Microelectronics, Dept. 51AL230230, 555 Union Blvd, Allentown PA 18103
Telephone +1 800 372-2447   Telefax +1 215 778-4106

INTEGRATED CIRCUIT for ISDN

Advanced Micro Devices, Communication Products Division,
5900 East Ben White Drive, Austin TX 78741 USA
Telephone +1 512 462-5852   Telefax +1 512 462-5101

Mitel Semiconductor, 360 Legget Drive, Kanata Ontario K2K 1X5 CANADA
Telephone +1 613 592-5630   Telefax +1 613 592-6909   Telex 05-33221

Motorola, PO Box 6000 M/S F8, Austin TX 78762 USA
Telephone +1 512 928-7569   Telefax +1 512 928-7991

Siemens Components Inc., 186 Wood Avenue South, Iselin NJ 08830 USA
Telephone +1 800 888-7730   Telefax +1 908 632-2830   Telex 844891

  Asia: Siemens Components Promotion Office, 47 Ayer Rajah Crescent, Singapore 0513
    Telephone +65 776-0283   Telex 21000

INTEGRATED CIRCUIT for SLIC

Advanced Micro Devices, Communication Products Division
5900 East Ben White Drive, Austin TX 78741 USA
Telephone +1 512 462-5852   Telefax +1 512 462-5101

  795XX series of SLIC can open tip lead for ground-start applications and
  has power-efficient PWM loop-current regulation architecture.

Aptek Technologies Inc., 700 NW 12th Avenue, Deerfield Beach FL 33442 USA
Telephone +1 800 423-8450   +1 305 421-8450   Telefax 305 421-8044 Telex 441020

  SIP configuration, operates to 24 V

INTEGRATED CIRCUIT for SLIC (continued)

Ericsson Components Inc., 403 International Parkway #500, Richardson TX 75085   USA
Telephone +1 214 907-7907   Telefax +1 214 680-1059   Telex 735389 ERICS RCHN

  Several models operate from 24 V and/or have power-efficient loop-current
  regulation architecture.

Harris Semiconductor, 1301 Woody Burke Road, Melbourne FL 32902   USA
Telephone +1 407 724-3739   Telefax +1 407 724-3111

Mitel Semiconductor, 360 Legget Drive, Kanata Ontario K2K 1X5 CANADA
Telephone +1 613 592-5630   Telefax +1 613 592-6909   Telex 05-33221

   SLICs in both DIP and small-footprint SIP package

Motorola Inc., 7402 South Price Road, Tempe AZ 85283   USA
Telephone +1 602 897-3872   Telefax +1 602 893-3392

   Latest products specified to 24 V

National Semiconductor Corp, PO Box 58090, Santa Clara CA 95052   USA
Telephone +1 408 721-7318   +1 800 272-9959
Telefax +1 408 733-0613   Telex 346353

Plessey Semiconductors, Sequoia Research Park
1500 Green Hills Road, Scotts Valley CA 95066   USA
Telephone +1 408 438-2900   Telefax +1 408 438-5576   Telex 4940840

   SL373 includes power-efficient loop current limiting circuit.

SGS-Thomson Microelectronics, 55 Old Bedford Road, Lincoln MA 01773   USA
Telephone +1 617 259-0300   Telefax +1 617 259-4420

 Signetics Inc., 811 East Arques Avenue, Sunnyvale CA 94086   USA
 Telephone +1 408 991-4535

 Texas Instruments, 8360 LBJ Freeway, Dallas TX 75265   USA
 Telephone +1 214 997-3305

OPTO-COUPLED MOSFET

 AT&T Microelectronics, Dept. AL-520404200, 555 Union Blvd, Allentown PA 18103   USA
 Telephone +1 800 372-2447   Telefax +1 215 778-4106

   Model LH1056AT = form A; Model LH1537AT = form C

 Theta-J Div. of C.P. Clare Corp., 107 Audubon Road, Wakefield MA 01880   USA
 Telephone +1 617 246-4000   Telefax +1 617 246-1356

   Model LCA = form A; Model LCB = form B; Model LCC = form C
   TS Series in 8-pin DIP flatpack; height = 0.090 inch

RELAY for Loop Current Sense

Teltone Inc., 22121 20th Avenue SE, Bothell WA 98021 USA Telephone +1 800 426-3926
Telephone +1 206 487-1515   Telefax +1 206 487-2288   Telex 910-449-2862 TELTONE

CP Clare, 3101 W. Pratt Blvd, Chicago IL 60645 USA
Telephone +1 312 262-7700   Telefax +1 312 262-7819   Telex 210075

   Model MLR 22 x 10 x 10

RELAY for Ringing Injection

 Note: All vendors produce telecom relays in industry-standard DIP package.
  Some also produce devices in smaller packages as noted.

 American Zettler, 75 Columbia, Aliso Viejo CA 92656 USA
 Telephone +1 714 831-5000   Telefax +1 714 831-8548   Telex 678472

   MINIATURIZED HORIZ   MINIATURIZED VERT   SMT
                               AZ846 15 x 6.2 x 8.7

 Aromat, 629 Central Avenue, New Providence NJ 07974 USA
 Telephone +1 908 464-3550   Telefax +1 908 464-8513   Telex 710-997-9536

   MINIATURIZED HORIZ   MINIATURIZED VERT   SMT
   TQ 14 x 6.0 x 9.5   TN2E

 CP Clare, 3101 W. Pratt Blvd, Chicago IL 60645 USA
 Telephone +1 312 262-7700   Telefax +1 312 262-7819   Telex 210075

   MINIATURIZED HORIZ   MINIATURIZED VERT   SMT
                               LQ52

 Fujitsu Microelectronics Inc., 3545 North First Street, San Jose CA 95134 USA
 Telephone +1 800 642-7616   +1 408 922-9000   Telefax +1 408 428-0640

   MINIATURIZED HORIZ   MINIATURIZED VERT   SMT
                               FBR10 15 x 6.2 x 8.7

 Hasco, 247 Jericho Turnpike, Bellerose Village NY 11001 USA
 Telephone +1 800 852-5050   +1 516 328-9292   Telefax +1 516 326-9125

   MINIATURIZED HORIZ   MINIATURIZED VERT   SMT
   14 x 8.0 x 5 T

 NEC, 401 Ellis Street, Mountainview CA 94039 USA
 Telephone +1 800 632-3531   Telefax +1 800 729-9288

   Ultra-small EA2 and EC2 models

 Omron, One East Commerce Drive, Schaumburg IL 60195 USA
 Telephone +1 312 843-7900   Telefax +1 312 843-7787   Telex 910-291-0426

   MINIATURIZED HORIZ   MINIATURIZED VERT   SMT
   G6H 15 x 7.0 x 10.5   G6N

RELAY for Ringing Injection (continued)

Original Electric Mfg, 124 Lincoln Blvd, Middlesex NJ 08846   USA
Telephone +1 201 271-5770   Telefax +1 201 271-5774

Takamisawa Electric America Inc., 1134 Tower Lane, Bensenville IL 60106   USA
Telephone +1 708 350-9065   Telefax +1 708 350-8995

    MINIATURIZED HORIZ   MINIATURIZED VERT   SMT
    A12-K 9.0 x 9.0 x 5.0   NA12W-K 14.9 x 7.4 x 9.7   AS12-K 9.0 x 14.0 x 6.5

RINGING GENERATOR

 Cambridge Electronics Laboratories, 20 Chester Street, Somerville MA 02144 USA
 Telephone +1 617 629-2805   Telefax +1 617 623-1882   Telex 948580 RACE SOMV UD

 Commercial Electric Products Corp., 1738 East 30th Street, Cleveland OH 44114   USA
 Telephone +1 216 241-2886   Telefax +1 216 241-1734

 Elgin Electronics, 5533 New Perry Hwy, Erie PA 16509   USA
 Telephone +1 814 866-6000   Telefax +1 814 866-8900

 Farnell International, Jubilee House   Sandbeck Way, Wetherby LS22 4DH   UK
 Telephone +44 1937 61961   Telex 55478 FARINT G

 James Electronics Inc., 4050 North Rockwell Street, Chicago IL 60618   USA
 Telephone +1 312 463-6500   Telefax +1 312 463-1504   Telex 910-221-5034

 Kenton Research Ltd., Europa Trading Estate, Erith Kent DA8 1QL UK
 Telephone +44 13224 41933   Telefax +44 3224 48929   Telex 8954958

 Lorain Products, 1122 F Street, Lorain OH 44052   USA
 Telephone +1 216 288-1122   Telefax +1 216   Telex 980505

 Pylon Electronics Inc., 5020 Fairway Street, Lachine PQ H8T 1B8   CANADA
 Telephone +1 514 633-8787   Telefax +1 514 636-1970   Telex 05-821680

 Tellabs Inc., 4951 Indiana Avenue, Lisle IL 60532   USA
 Telephone +1 708 505-0099   Telex 4330911 TEL UI

THERMISTOR

 Keystone Carbon Co., 1935 State Street, St. Mary's PA 15857   USA
 Telephone +1 814 781-1591   Telefax +1 814 781-7648   Telex 914517

 Raychem, Polyswitch Division, 300 Constitution Drive, Menlo Park CA 94025-1164   USA
 Telephone +1 800 272-9243   +1 415 361-3860
 Telefax +1 415 361-5579   Telex 348316

   Has telecom applications packet for patented "polyswitch" thermistor

TRANSISTOR for gating ringing generator power

Harris Corporation, Semiconductor Products Division, Power Products
724 Route 202, Somerville NJ 08086 USA
Telephone +1 908 685-6000   Telefax +1 908 685-7008

International Rectifier Corporation, 233 Kansas Street, El Segundo CA 90245 USA
Telephone + 1 310 772-2000   Telefax +1 310 772-9028   Telex 910-348-6291

Motorola Semiconductor, 5005 East McDowell Road, Phoenix AZ 85008 USA
Telephone +1 602 244-4391   Telefax +1 602 952-4002   Telex 910-951-1334

Samsung Semiconductor Inc., 3655 North First Street, San Jose CA 95134-1708 USA
Telephone +1 408 954-7000   Telefax +1 408 954-7873

Siliconix Inc., 2201 Laurelwood Road, Santa Clara CA 95054 USA
Telephone +1 408 988-8000   Telefax +1 408 727-5414   Telex 910-338-0227

Zetex, Fields New Road, Chadderton, Oldham OL9 8NP UK
Telephone +44 161 627-5105   Telefax +44 61 627-5467   Telex 668038

  87 Modular Avenue, Commack NY 11725 USA
  Telephone +1 516 543-7100 Telefax +1 516 864-7630

  Also available in the USA from:
    Digi-key, 701 Brooks Avenue South, Thief River Falls MN 56701
    Telephone +1 800 344-4539 Telefax +1 218 681-3380

  3510 Metroplaza Tower 2, Hing Fong Road, Kwai Fong NT, HONG KONG
  Telephone +852 2 610-0611   Telefax +852 2 425-0494

20 Chester Street   Telefax +1 617 623-1882
Somerville MA 02144-3005   Telex 948580 RACE SOMV UD
USA   62075697@eln.attmail.com

=DATABASE REGISTRATION TO RECEIVE CIRCUIT DESIGN APPLICATION LITERATURE=

NAME_____TITLE/POSITION_____

ORGANIZATION_____DEPT_____

ADDRESS_____MAIL STOP/OFFICE SYMBOL_____

CITY_____STATE/PROVINCE_____

COUNTRY_____POSTAL CODE_____

TELEPHONE NETWORK COUNTRY CODE_____CITY CODE_____NUMBER_____

TELEFAX NUMBER_____TELEX/TWX NUMBER_____

INTERNET ADDRESS_____

OTHER ELECTRONIC MAIL ADDRESS_____

MESSAGE-HANDLING BBS NUMBER_____

ORGANIZATION'S PRODUCT OR SERVICE_____

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REGISTRANT'S AREA OF TECHNICAL OR MARKET INTEREST_____

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>> COMPLETE ONE FORM FOR EACH REGISTRANT <<

**SUBMIT COMPLETED PHOTOCOPY BY POST, OR TRANSMIT REQUESTED INFORMATION BY ELECTRONIC MEANS
TO CAMBRIDGE ELECTRONICS LABORATORIES AS ABOVE**