

AN1603

Providing a POTS Phone in an ISDN or Similar Environment

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INTRODUCTION

This circuit is intended to provide an auxiliary circuit for the connection of a POTS phone (or answering machine, fax, etc.) to a digital communication line (ISDN, e.g.). The first two circuits assume there is a 5.0 V supply, a 12 V supply, and a microprocessor or other controlling circuit, although the circuits can also work from 5.0 V only. A single line, and a dual line system are discussed.

The final two circuits described herein provide variations of the Ring Generation portion of the circuits for the purpose of lower cost, but with some compromises.

The MC33121 SLIC provides most of the central office functions to the external POTS phone line – dc loop current, off-hook detection, proper ac and dc impedances, 2-to-4 wire conversion, transhybrid rejection, and high longitudinal balance (>58 dB).

The only functions not provided by the MC33121 are the supplying of the ringing voltage, and off-hook detection during ringing. Those are supplied by the Ring Generator circuit, and the associated Off-Hook Detector. The Telecom Relay switches the phone line between the SLIC and the Ring Generator. In the normal (de-energized) state, the phone line is connected to the MC33121 SLIC.

The MC145484 CODEC provides the A/D and D/A conversions of the voiceband signals between the digital system and the SLIC.

The Single Line System is discussed first.

BLOCK DIAGRAM – SINGLE LINE SYSTEM

Referring to the block diagram (Figure 1), in the standby state (phone on-hook, not ringing), the relay connects the phone line to the SLIC.

When the phone is taken off-hook, the SLIC provides the loop current, and the speech paths between the phone and the CODEC. The HOOK STATUS output (from the SLIC) is provided to the MCU via the Ring Control Logic.

The dc-to-dc converter provides the -24 V (from the 5.0 V supply) necessary to power the SLIC and provide the loop current.

When the phone is on-hook, and ringing is to be applied, the Ring Control Logic (controlled by the MCU) powers the Ring Generator, and switches the relay so as to provide the ringing voltage to the phone line. The Off-Hook Detector informs the logic if the phone is taken off-hook during ringing. The Ring Control Logic then switches the relay to the SLIC.

The RING ENABLE signal, and the CADENCE are supplied from the MCU.

CIRCUIT DETAILS (Refer to Figure 2)

MC33121 SLIC

The MC33121 is powered by -24 V at V_{EE} (to provide the loop current), and 5.0 V at V_{DD} for the logic interface. The circuit consumes ≈ 1.0 mA at V_{EE} when the phone is on-hook, and ≈ 9.0 mA more than the loop current when off-hook. The following functions are provided by this circuit:

- a) *DC Loop Current*: The loop current limit is set by the resistor at Pin 8 (RFO). A 6.98 k Ω resistor sets a current limit of ≈ 30 mA. Using Figure 7 in the data sheet, different resistor values can be picked to set other current limit values in the range of 20 to 40 mA.

NOTE: It is recommended that the loop current not be less than 30 mA as there are many line powered speakerphones on the market which do not work well at lower currents.

- b) *Hook Status*: ST1 (Pin 13) is a logic level output which is high when the phone is on-hook, and low when off-hook. Internally there is an NPN pulldown transistor, and a 15 k Ω pullup resistor to 5.0 V. This output also provides pulse dialing and flash information.

- c) *AC Terminating Impedance*: The 20.3 k Ω resistor between Pins 10 and 11 sets the ac terminating (and source) impedance at 600 Ω to the phone line. See the data sheet (Equation 8) to set different impedances.

- d) *Receive Gain*: The 30.9 k resistor at Pin 10 sets a 0 dB receive gain from the CODEC's output (at its Pin 4) to the phone line, based on a 600 Ω impedance at the phone line. The 0.47 μ F capacitor provides rolloff below 300 Hz. See Equation 12 in the data sheet if the gain is to be changed or different ac impedances are used for the phone line and the MC33121.

- e) *Transmit Gain*: The transmit gain is fixed within the MC33121 from the phone line to TXO (Pin 11) at 0.318 V/V (-10 dB). However, the overall transmit path includes an operational amplifier external to the MC33121, which (in this circuit) is located within the MC145484 CODEC. The 31.6 k Ω resistor at the CODEC's Pins 17 and 18 is the feedback resistor for the operational amplifier. In conjunction with the 10 k resistor at the SLIC's Pin 11, the overall transmit gain is set to 0 dB from the phone line to Pin 17 of the CODEC. If the transmit gain is to be varied, this should be done with the resistor at Pins 17 and 18 of the CODEC (see Equation 15 in the MC33121 data sheet).

- f) *Transhybrid Rejection*: This parameter is a reduction of the amount of a receive signal which reflects back through the transmit path of the SLIC. The network composed of the 604 Ω resistors, the 15.8 k Ω resistor and the 0.005 μ F capacitor provide a cancellation of the reflected signal where this network joins the 10 k resistor. Adjustments to this parameter should be done by varying the 15.8 k Ω resistor, and must be done last, after any of the above parameters are adjusted.
- g) *Connections to the CODEC*: The analog receive signal from the CODEC is available at its Pin 4, the output of a buffer amplifier. The gain of this amplifier, set by the resistors at Pins 2 to 4, can be used to adjust the receive gain to the SLIC, and therefore to the phone line, without affecting the other parameters of the SLIC.

The transmit signal, available at the SLIC's TXO (Pin 11) is fed through the 10 k resistor, through the 1.0 μ F capacitor, and to the transmit amplifier in the CODEC. The 31.6 k Ω resistor at Pins 17 and 18 is the amplifier's feedback resistor, providing a gain of 3.16, or 0 dB from the phone line to the TG pin. The output from the TG pin is available for the MC145436A DTMF decoder, or any other circuit which may need this signal.

NOTE: The MC145480 CODEC may be used instead of the MC145484. The pinouts are the same, except Pin 1 is left open.

MC34063A DC-to-DC Converter

The MC34063A is a switching regulator configured in an inverting mode to provide the -24 V required by the SLIC, the Ring Generator, and the Off-Hook Detector. This design can provide up to 50 mA to the SLIC (40 mA loop current). The capacitor at the regulator's Pin 6 must be low ESR as it supplies the current peaks (>1.0 A).

The 1.5KE27 transient suppressor protects the regulator and SLIC from phone line transients. Transients occur when switching from ringing to non-ringing, during pulse dialing, and when the phone is set on-hook. Additionally, the 1.5KE27 provides a current path for negative transients since the dc-to-dc converter cannot supply current in the opposite direction.

This circuit uses $\approx$ 120 mA from the 5.0 V supply when the phone is on-hook, and $\approx$ 340 mA when the phone is off-hook (loop current = 28 mA).

Ring Generator

The Ring Generator used in this circuit is a Black Magic™ module (model #NU-BMR) from Cambridge Electronics Laboratories. The module requires 12 V at the input, and produces $\approx$ 100 Vrms, 20 Hz at the output. The unit requires $\approx$ 200 mA from the 12 V supply. One output terminal is referenced to the -24 V supply, while the other terminal provides the ringing voltage to the telephone via the 620 Ω resistor.

Off-Hook Detector

Since the MC33121 SLIC must be disconnected from the phone line when ringing is applied, separate provisions are necessary to determine if the phone is taken off-hook during ringing.

When the Ring Generator is powered on, and the relay is energized, the ringing voltage is fed to the Ring lead of the phone through the 620 Ω resistor. As long as the phone is on-hook, the ringing voltage sensed by the first comparator

(through the 1.3 M Ω resistor) is a high enough amplitude to keep the first comparator's output switching high. This keeps the HOOK STATUS line (output of the second comparator) a steady high.

When the phone is taken off-hook, the ringing voltage at the Ring lead is substantially reduced in amplitude. The first comparator's output now stays low steady, allowing the second comparator to change state, pulling low the HOOK STATUS line to the Ring Control Logic. This de-energizes the relay, and provides the Hook Status signal to the MCU.

The third comparator in this circuit ensures the second comparator's output is high when RING ENABLE and the relay are inactive.

Ring Control Logic

The Ring Control Logic consists of the four NOR gates (MC74HC02A), and the transistors at the MCU interface. For the normal (non-ringing) condition, the RING ENABLE input and the CADENCE input are high.

When RING ENABLE is taken low, power is applied to the Ring Generator. The MPSA06 transistor was chosen for the NPN since it has a very low saturation voltage. Alternately, an FET could be used.

Since the Black Magic™ Ring Generator's output does not provide a low impedance dc path when it is de-energized, it is necessary to switch the phone line to the SLIC to provide the silent time of the ringing cadence. Therefore, the CADENCE signal cycles the relay.

The CADENCE input is to be low to apply ringing, and high during the silent time. The normal USA cadence is 2 seconds on, and 4 seconds off, but the cadence may be any other timing if desired. The CADENCE input is ineffective unless RING ENABLE is low.

As long as RING ENABLE is low, the telephone will ring in step with the CADENCE input. The Hook Status indicator to the MCU will be low, indicating on-hook. However, there may be a 20 to 30 ms glitch on the Hook Status output each time the cadence changes from ringing to silent (within 60 ms of this change). This will depend on the type of phone which is connected to this circuit. It is not practical to filter the glitch with hardware as that will affect pulse dialing and Flash timing. Instead the MCU's software should be made to ignore the glitch.

When the telephone is taken off-hook, either the MC33121's ST1, or the Off-Hook detector's output, will switch low, depending on the position of the relay. The logic will then disable the relay, preventing the ringing voltage from being applied to the phone while it is off-hook. The Hook Status indicator will switch high. The MCU should then set the RING ENABLE and CADENCE high.

If the phone is taken off-hook while ringing, the relay, upon being de-energized by the logic, will switch the phone line to the SLIC. During the relay's transition (which takes a few milliseconds), the Off-Hook Detector's output (comparator #2) will turn off, allowing the HOOK STATUS line to ramp up. The 10 μ F capacitor on this line keeps it low during this transition, until the SLIC's ST1 output has a chance to switch low, preventing a re-energizing of the relay, and to minimize glitches on the Hook Status indicator to the MCU.

NOTE: MC74HC02A gates are to be used for the NOR gates. LS and F versions of this gate will not work in this circuit.

CIRCUIT CHARACTERISTICS (Single Line System, Figure 2)

Parameter	Nominal Value	Units
Average Power Supply Current from 5.0 V Supply Non-Ringing, On-Hook Non-Ringing, Off-Hook (Phone = 200 Ω DCR) Ringing, On-Hook	160 385 230	mA
Average Power Supply Current from 12 V Supply while Ringing 1 REN 4 REN	165 280	mA
Timing Ring Cadence to Ring Voltage at Tip and Ring (Figure 3) Phone Taken Off-Hook to Hook Status Indicator while Ringing (Figure 4) Phone Taken Off/On-Hook to Hook Status Indicator while Not Ringing (Figure 5)	t1 5.0 t2 5.0 t3 100 max. t4 7.0 t5 6.0	ms
On-Hook Voltage at Tip and Ring	21.6	Vdc
Loop Current Phone = 200 Ω DC, Phone Line <100 Feet Phone DCR + Phone Line = 490 Ω Phone DCR + Phone Line <100 Ω	27.7 20 30 max.	mA
Ringing Voltage at Tip and Ring 1 REN 4 REN (Using Black Magic™ Ring Generator from Cambridge Electronics Laboratories)	91 72	Vrms

OPERATION FROM 5.0 V ONLY

If a 12 V supply is not available in a particular application, the circuit can be modified to operate from 5.0 V only, as shown in Figure 6. The Ring Generator must be replaced with a 5.0 V model (Cambridge Electronics Labs Model #NU-BMR), and the capacitor at the Ring Generator input is different. It is imperative in this case that an NPN transistor with a very low saturation voltage be used. The MPSA06 is recommended.

The power supply current requirements are as follows:

Parameter	Nominal Value	Units
Average Power Supply Current from 5.0 V Supply Non-Ringing, On-Hook Non-Ringing, Off-Hook (Phone = 200 Ω DCR) Ringing, On-Hook Ring Enable = Low, Off-Hook (Phone = 200 Ω DCR)	160 385 700 600	mA

TWO LINE SYSTEM

Although a two line system (e.g., from a single ISDN line) could be implemented by simply duplicating the above described circuitry, there is a certain amount of commonality which can be employed to minimize cost and component count. Figures 7 and 8 are the Block Diagram, and Schematic, respectively, of a two line system. In those figures, the dc-to-dc converter, Ring Generator, Off-Hook Detector, the microprocessor and logic interface have been changed so as to service both phone lines. Each phone line still requires its own SLIC, CODEC, DTMF Decoder, and relay.

Figure 8 shows the schematic details for one phone line and the common circuitry. The SLIC, relay circuit, CODEC, and DTMF Decoder sections are the same as in Figure 2.

DC-to-DC Converter

This circuit uses the same MC34063 as in the Single Line System, but with the external components modified so as to provide 100 mA at -24 V. This will allow both phones to be off-hook simultaneously.

Ring Generator

A single ring generator can ring both phones if they are rung alternately. Since the typical cadence is 2 seconds on, and 4 seconds off, the alternate ringing cadences can easily be accomplished by the microprocessor.

Off-Hook Detector

A single Off-Hook detector is used for both phone lines. When either phone is taken off-hook during ringing, the output of both #2 comparators will change, indicating off-hook to both Hook Status 1 and Hook Status 2 points at the microprocessor interface. However, since only one phone is ringing at any time, when that phone is taken off-hook during ringing, the logic will quickly de-energize its relay, and then the appropriate MC33121 SLIC will provide the off-hook status to the microprocessor. The other hook status input to the microprocessor will then change back to on-hook, if appropriate.

Ring Control Logic

The Ring Control Logic consists of the microprocessor, the two 4-input NAND gates, and the various inverters and transistors associated with sensing hook status, and driving the relays. To energize either relay (in order to ring either phone) the 4 inputs to its NAND gate must be high.

The four inputs are:

- Phone 1 (or Phone 2) supplied by the microprocessor. This line, when high, enables the phone line for ringing.
- Cadence 1 (or Cadence 2) supplied by the microprocessor. This line supplies the ringing cadence

(2 seconds on, 4 seconds off), and is to be high for the “on” ringing time. If both phones require ringing at the same time, the two Cadence outputs should alternate the ringing of the two phones.

- Ring Enable supplied by the microprocessor. This line, when high, powers the Ring Generator, and provides an additional enable to the NAND gates.
- HOOK STATUS – The output from the Off-Hook Detector and the appropriate MC33121 SLIC are Or’ed together to provide this fourth input. This line is high when on-hook.

As with the single line circuit, there may be a 20 to 30 ms glitch on the Hook Status signal to the microprocessor each time the cadence changes from ringing to silent (within 60 ms of this change). This will depend on the type of phone which is connected to this circuit. It is not practical to filter the glitch with hardware as that will affect pulse dialing and Flash timing. Instead the MCU’s software should be made to ignore the glitch.

When a Hook Status line to the microprocessor goes high, indicating off-hook, then the Phone and Cadence lines for that phone, and the Ring Enable line, should be taken low.

NOTE: HC type gates are specified for the NAND gates and the inverters. LS and F versions of these gates will not work in this circuit.

IF 120 Vac IS AVAILABLE ...

If the end product containing the POTS interface is powered by 120 Vac commercial power, the generation of the ringing voltage can be done differently by making use of the higher available voltage. The Off-Hook detector, and Ring Enable logic is also done differently. Figure 9 is a block diagram/schematic showing this circuitry.

Ring Generator

The generation of the ringing signal, and the cadence, is accomplished with the circuitry at the top of Figure 9. The 120 Vac is applied to a transformer for isolation and UL safety reasons. The 120 Vac secondary is rectified and filtered to provide a –170 V source to the power stage.

Generation of the 20 Hz signal, and the cadence, involves the logic at the top of Figure 9. The 6.3 Vac, 60 Hz output of the transformer is full wave rectified to provide a 120 Hz signal to the NOR gate. The first SN74LS92 counter is configured to divide by 6, and then by 2. This produces a 20 Hz square wave at the Q3 output, and a 10 Hz signal at the Q0 output. The 10 Hz signal is divided down by the SN74LS90 ($\div 10$) to provide a 1.0 Hz signal. This is fed to the second SN74LS92, configured to divide by 6. By applying the input at CP0, and taking the Q2 output, the 1/6 Hz output has a 2:1 duty cycle, thereby providing the “2 seconds on, 4 seconds off” cadence signal. This signal gates the 20 Hz signal via the NOR gate.

The NOR gate output is fed to the MC33201 circuit, configured as a 20 Hz bandpass filter, providing a 20 Hz sinusoid at its output. This signal modulates the Power Stage.

The output of the Power Stage (at the collector of the TIP49), is approximately 60 Vrms, and is fed to the telecom relay through the 500 μ F capacitor in the Off-Hook detector.

Off-Hook Detector

When the phone is taken off-hook (with the relay energized), a dc current will flow from ground through the phone, through the opto-coupler, and the 6.2 k resistor to the Power Stage output. The output of the opto-coupler will then

go low, providing a high signal to the MCU, and disabling the relay through the two series NOR gates.

When the relay has transferred, the MC33121 SLIC will then sense the off-hook phone, and provide a low signal at its ST1 output.

During the relay’s transfer, the 1.0 μ F capacitor at the ST1/opto line will hold it low long enough for the transfer to occur.

Ring Control Logic

The Ring Control Logic consists of two lines at the controlling MCU: The Off-Hook input, and the RING ENABLE output. When ringing is to occur, the RING ENABLE line is taken low to energize the relay, and release the Reset lines on the SN74LS92 counter. (This ensures the ringing will not start in the middle of a cadence cycle.) Unlike the previously described circuits, the MCU need not generate the cadence, and the relay is not cycled. It is held energized until the phone is taken off-hook.

Once the MCU senses that the phone is off-hook, the RING ENABLE output should then be set high.

DC-to-DC Converter

The dc-to-dc converter is not detailed in this example, as it can be done in several ways. The circuits in Figures 2 or 8, using the MC34063A, could be duplicated here, if a 5.0 V supply is available which can supply the nearly 400 mA required by the converter. Alternate methods include powering it from the –170 V line, or from a separate transformer winding. The system design of the end product will likely dictate the most economical approach for this section.

5.0 V Supply

The 6.3 Vac winding on the transformer can be used to power a traditional 5.0 V regulator (MC78L05, or equivalent), which provides power to the logic, the MC33121 SLIC, MC145484 CODEC, the MC145436A DTMF decoder, and other portions of the circuit. As mentioned in the dc-to-dc converter section above, the design of this supply should be done in conjunction with the system design of the end product.

ELIMINATE THE RING GENERATOR, BUT ...

A lower cost POTS interface circuit is possible with the circuit of Figure 10. The main difference between this circuit and the previous ones is that this circuit will not ring the bell in the phone. The Ring Generator and relay have been eliminated, and replaced with an Internal Ringer section. This will provide the ringing sound within this product, rather than at the telephone.

The Internal Ringer uses the MC34017 tone ringer which is commonly used as the ringer in modern telephones. The circuit makes use of the fact that the MC34017 can be operated from a dc voltage (29 V in this case), as well as the standard ac ringing voltage. The MC34017 is continually powered in this application, and is cycled on-off by controlling Pin 5. The current consumption is ≈ 3.0 mA when not ringing, and ≈ 4.5 mA when ringing.

The ringing cadence is controlled by the MCU. The Cadence output is to be cycled 2 seconds high, 4 seconds low to provide the typical cadence. When the phone is taken off-hook, the Cadence line is disabled by the AND gate. The Cadence output is to be held low when ringing is not required.

The SLIC, CODEC, DTMF Decoder, and DC-to-DC Converter sections are the same as in Figure 2.

Note that the MC34017's "ground" line (Pin 7) is an independent, floating ground, and is NOT to be connected to the ground line of the rest of the circuit.

While this circuit has the advantages of lower cost and simpler circuitry, there are two compromises associated with this implementation:

- The phone must be within a reasonable (audible) distance of this circuit since the phone's bell will not ring.
- This circuit cannot be used with fax machines, modems, or answering machines since they respond to the standard ringing voltages on the phone line for their operation.

PC BOARD LAYOUT (Applicable to all above circuits)

Due to the mixing of analog and digital circuits, and because of the high peak currents involved in the dc-to-dc converter and the ring generator, a proper PC board layout is important. A ground plane should be provided wherever possible, except for the power leads to the Ringing Generator module. These should be separate tracks of substantial size. The capacitor at the Ring Generator input should be a low ESR type, and located physically adjacent to the input, to provide the peak current required at the on-hook to off-hook transition. A two-sided board is recommended.

The peak current on the 5.0 V side of the MC34063A is ≈ 1.0 A in Figure 2, and close to 2.0 A in Figure 8. The board traces in the area of Pins 6, 7, 8, and 1, and the inductor must be substantial so as to not create significant IR drops. The capacitor at Pin 6 must be a low ESR type, and located physically adjacent to Pin 6, so that it can provide the peak current. The layout must be neat and compact.

The layout connecting the MC33121 SLIC with the MC145484 CODEC must be done with care so as to prevent digital noise from entering the analog speech paths. The 5.0 V supply must be adequately decoupled at both devices.

For clarity, bypass capacitors are not always shown in the various schematics at the various logic gates. Standard good design practice, however, dictates that the supply lines to all logic gates should be adequately bypassed to help prevent noise from affecting the analog speech sections.

COMPONENT SOURCES

Telecom Relays

Potter & Brumfield
812-386-1000
Model #T83S11D212-05

Aromat Corp.
908-464-3550
Model #TQ2E-5V

Omron Electronics, Inc.
708-843-7900
Model #G5A-234P-FC-DC5

C.P. Clare Corp.
708-797-7000
LX Series

Ring Generator

Cambridge Electronics Laboratories
20 Chester Street
Somerville, MA 02144-3005
617-629-2805
5.0, 12, and 24 V models

CSTS, Inc.
1480 No. Lakeview Ave.
Anaheim, CA 92807-1827
714-777-2787
Custom designs

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REFERENCES

1. Low Voltage Subscriber Loop Interface Circuit, MC33121, Motorola Technical Data, 1992
2. 5 V PCM Codec-Filter, MC145484, Motorola Technical Data
3. Low Power Dual Tone Multiple Frequency Receiver, MC145436A, Motorola Technical Data, 1995
4. DC-DC Converter Control Circuits, MC34063A, Motorola Technical Data, 1996
5. Telephone Tone Ringer, MC34017, Motorola Technical Data, 1996

Figure 1. Block Diagram for Single Line System

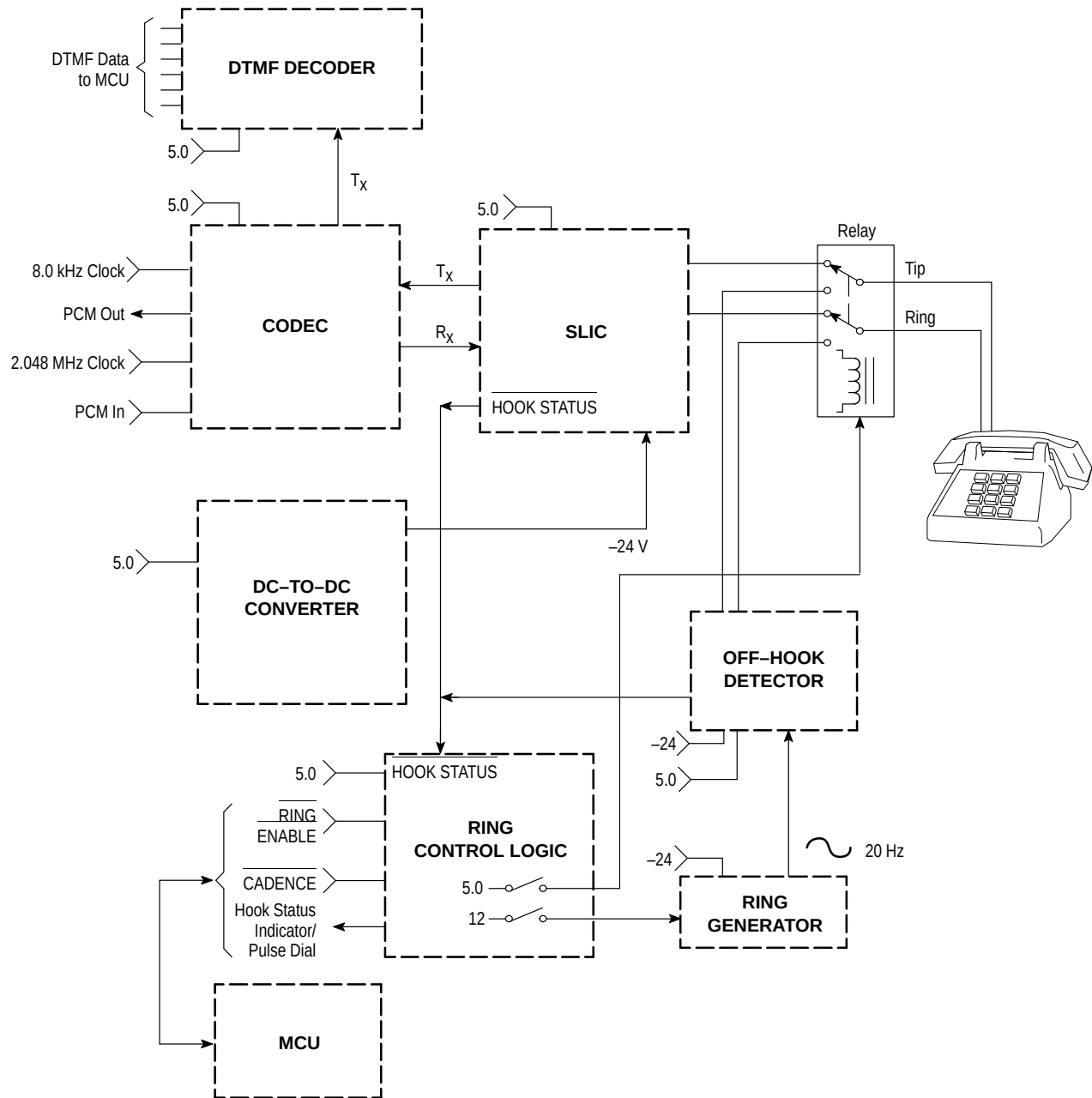
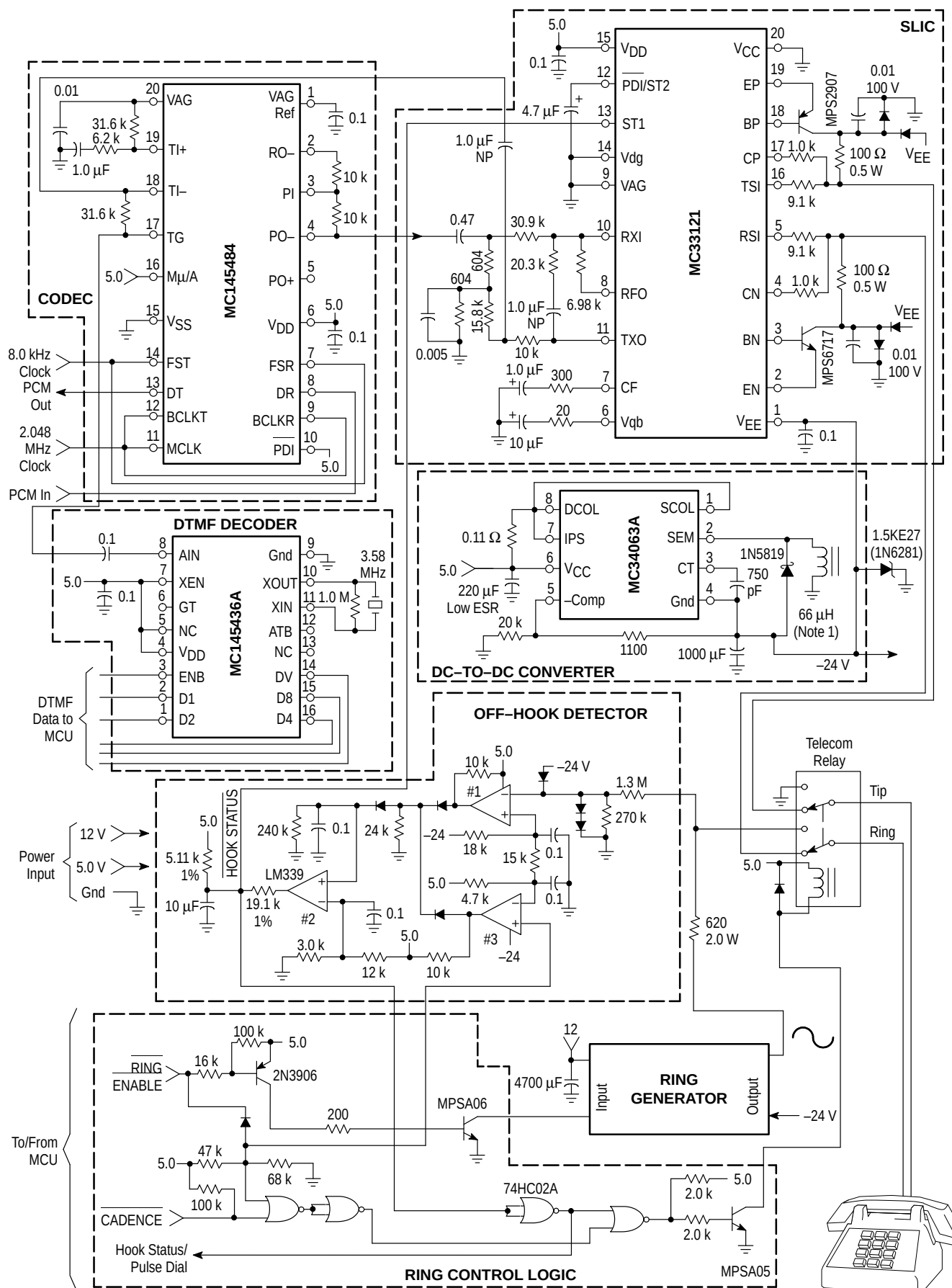


Figure 2. Schematic for Single Line System



NOTES: 1. 32 turns #24 wire on a 55050A2 core from Magnetics Inc.
2. All diodes 1N4002 unless noted.

Figure 3. Ring Cadence Timing

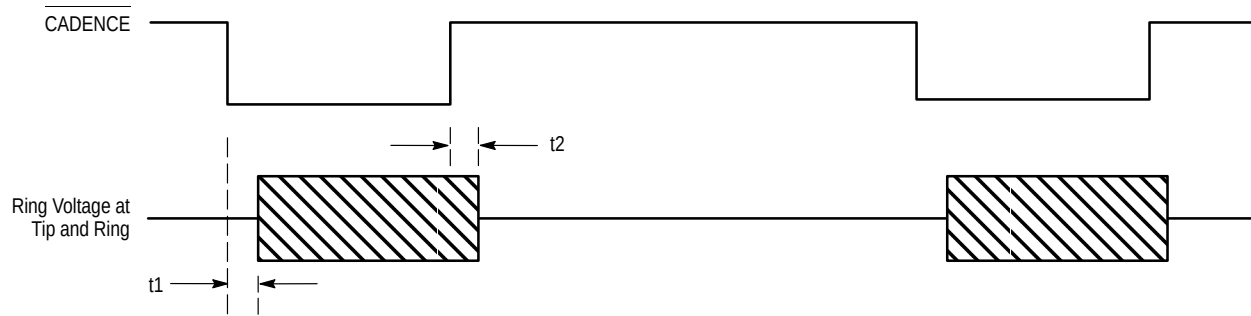


Figure 4. Hook Status Response While Ringing

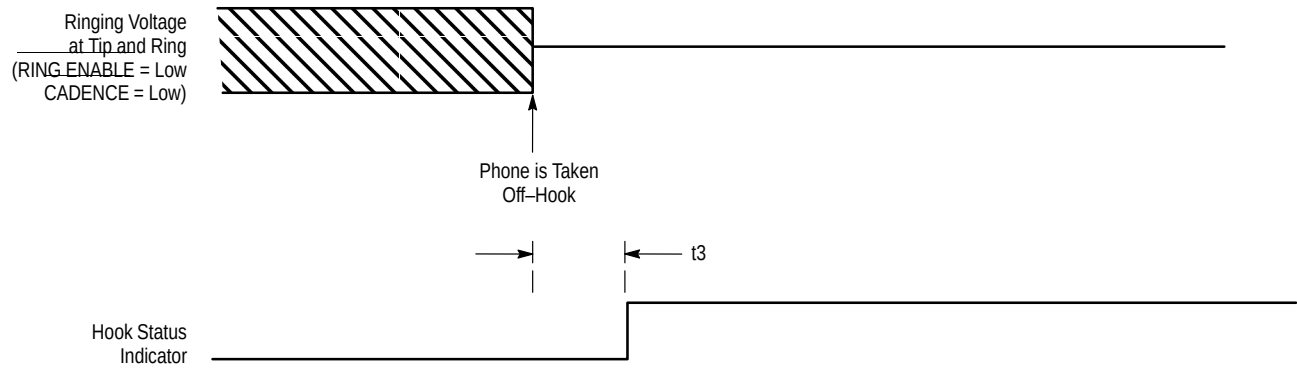


Figure 5. Hook Status Response While Not Ringing

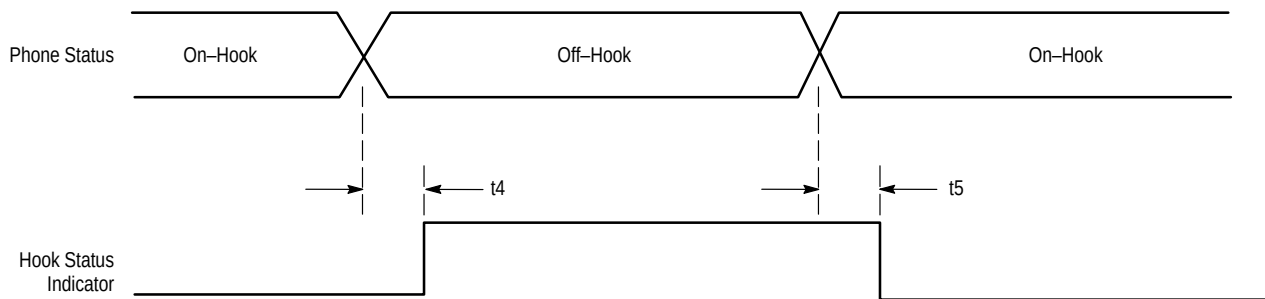


Figure 6. Operation from 5.0 V Only for Single Line System

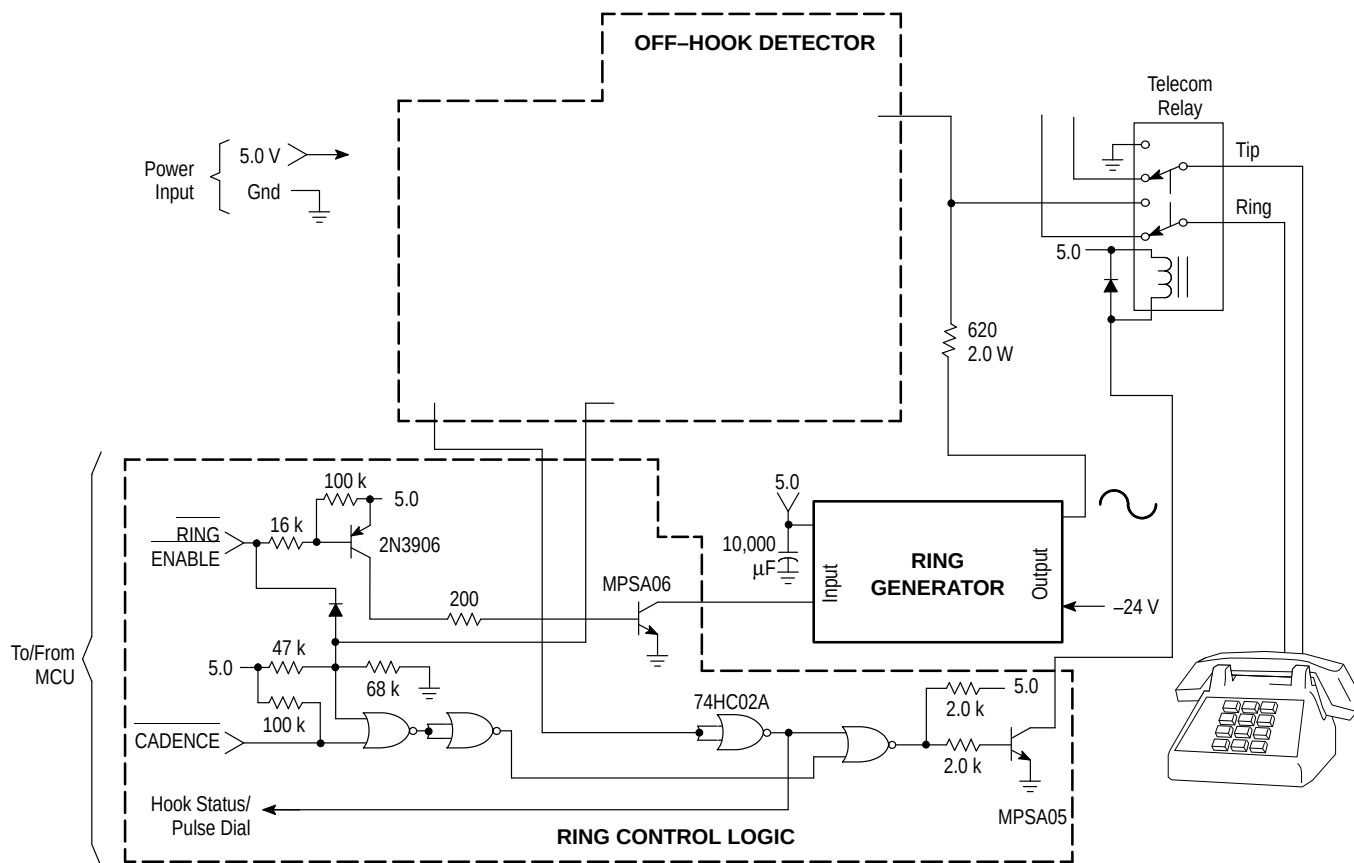
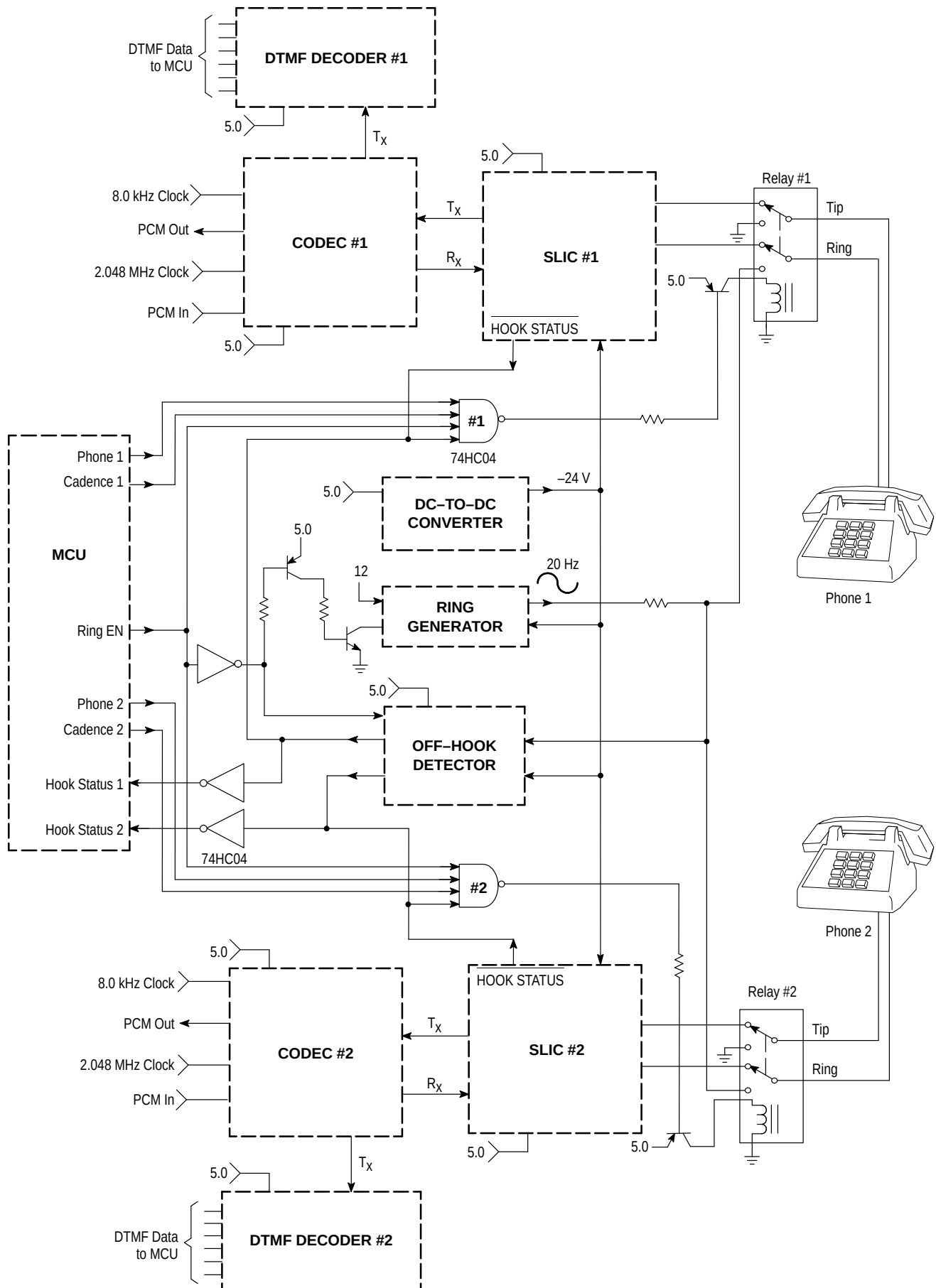


Figure 7. Block Diagram for Two Line System



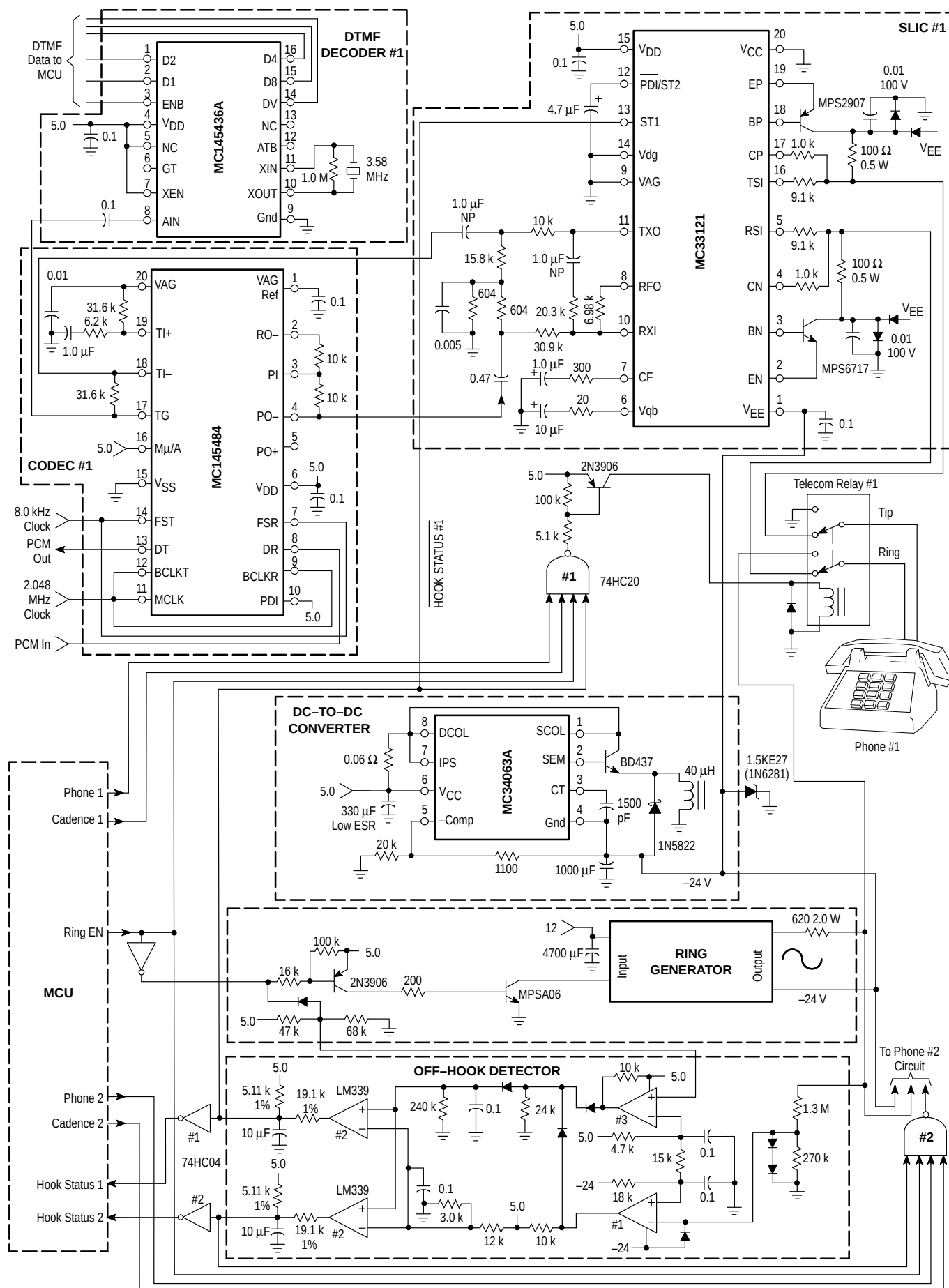
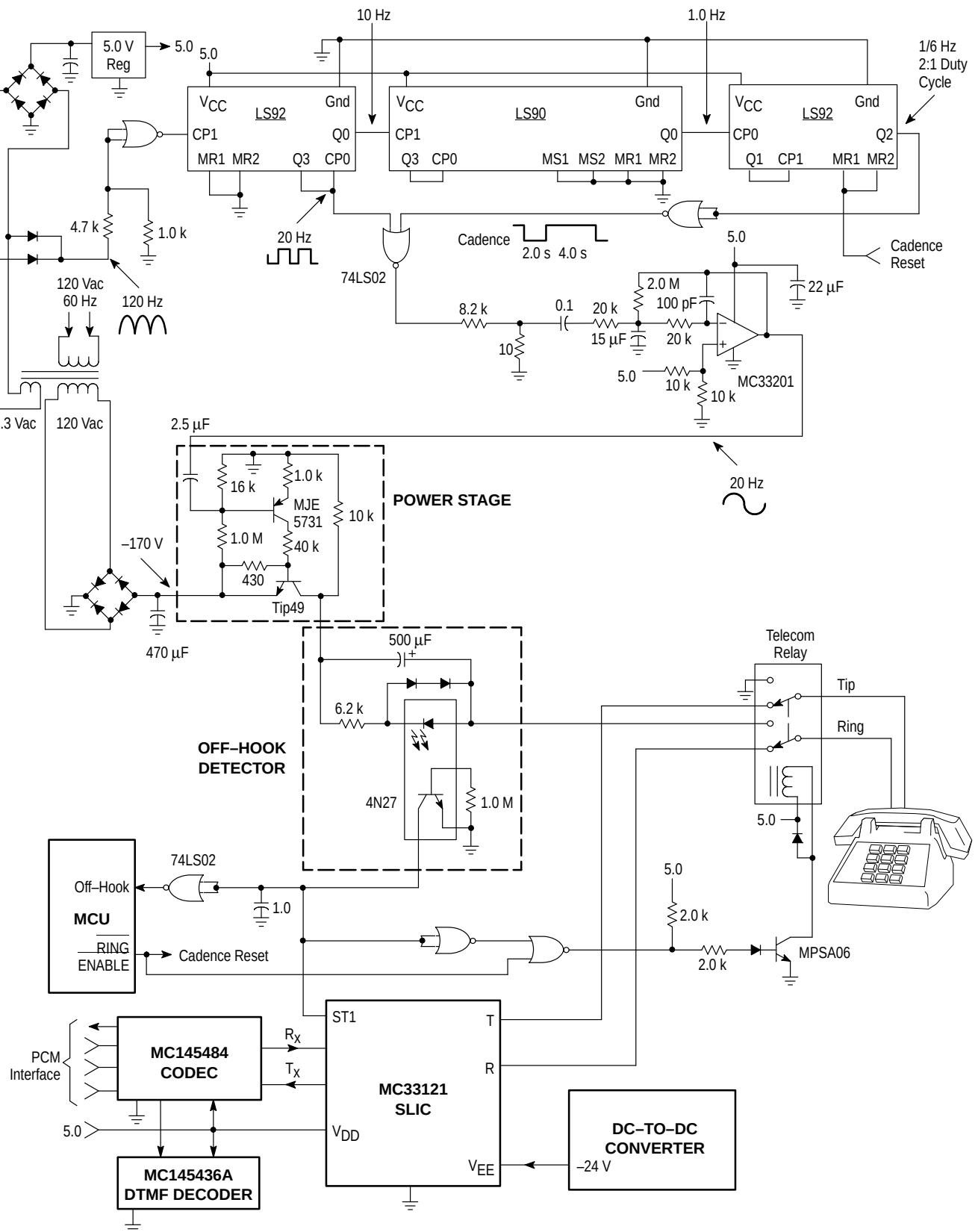


Figure 9. POTS Interface Powered by 120 Vac





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