



TEXAS INSTRUMENTS

99000

**TMS99532 Single-Chip
Bell 103 Compatible MODEM**



MICROPROCESSOR SERIES™

Preliminary Data Manual

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1. INTRODUCTION

1.1 DESCRIPTION

The TMS99532 modem is a telecommunications device that transmits and receives serial, binary data over the switched telephone network using frequency-shift-keyed (FSK) modulation. It is compatible with the Bell 103 series data sets and will communicate at up to 300 bits per second. The TMS99532 provides all the necessary modulation, demodulation and filtering required to implement a serial, asynchronous communications link. It is designed for users not expert in the telecommunications field and is an easily implemented cost-effective alternative to standard discrete modem design. Large scale integration NMOS technology provides the advantages of small size, low power and increased reliability. The TMS99532 modem design assures compatibility with a broad installed base of low-speed modems and acoustic couplers. Applications include interactive terminals, desk-top computers, point-of-sale (POS) terminals and credit verification systems.

1.2 KEY FEATURES

- Bell 103 compatible
- Single LSI chip solution requiring only 1 dual op-amp and 13 discretes
- All filtering, modulation and demodulation on chip
- Simplex, half duplex and full duplex capability
- Originate and answer modes
- Data rates from zero to 300 BPS
- Adjustable carrier detect timing
- Crystal controlled oscillator on chip
- CCITT V.25-compatible answer tone
- Analog loopback test mode
- TTL-compatible digital interface
- N-channel silicon gate process (NSAG)
- Switched capacitor technology
- Housed in space-saving 18-pin DIP

1.3 TMS99532 PIN ASSIGNMENTS AND DESCRIPTION

Figure 1 shows the pin-out for the TMS99532, and Table 1 describes the function of each pin.

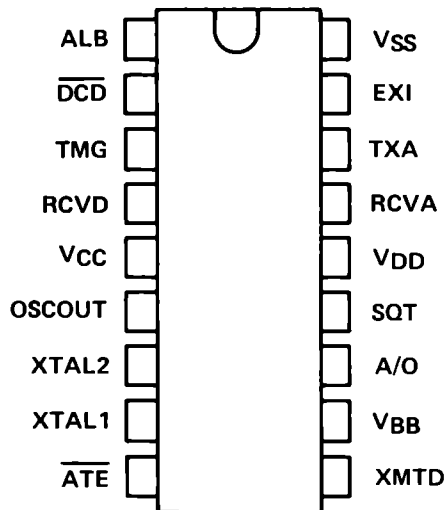


FIGURE 1 – PIN ASSIGNMENTS

TABLE 1 – TMS99532 PIN DESCRIPTION

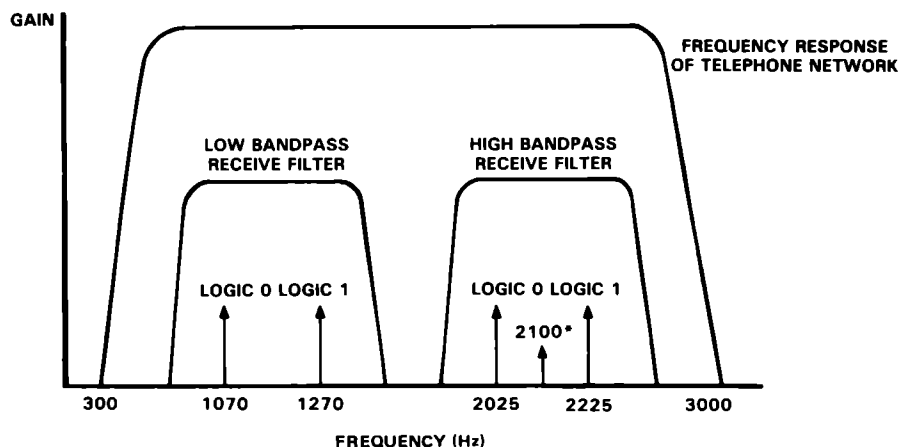
SIGNAL	PIN	I/O	DESCRIPTION
ALB	1	IN	Analog loopback. When active (high), any data sent on the XMTD pin will appear on the RCVD pin.
$\overline{\text{DCD}}$	2	OUT	Data carrier detect. When active (low), a valid carrier signal is being received.
TMG	3		Carrier detect timing. This pin is used to fix the carrier detect turn-on and turn-off times.
RCVD	4	OUT	Received serial data output line.
VCC	5		Supply voltage (+ 5 V nominal).
OSCOUT	6	OUT	Oscillator output. This pin oscillates at the master clock frequency.
XTAL2	7		Crystal connection for the internal oscillator.
XTAL1	8	IN	Crystal connection for the internal oscillator. Also the input from an external clock, if desired.
ATE	9	IN	Answer tone enable. When active (low), the CCITT V.25 answer tone (2100 Hz) is enabled and RCVD is tristated.
XMTD	10	IN	Transmitted serial data input line.
VBB	11		Supply voltage (- 5 V nominal).
A/O	12	IN	Answer/Originate mode select. When active (high), the originate mode is selected. A low input selects the answer mode.
SQT	13	IN	Transmit squelch. When active (high), XMTD is disabled.
VDD	14		Supply voltage (+ 12 V nominal).
RCVA	15	IN	Analog received signal. This pin is the input for the received analog carrier signal from the switched network.
TXA	16	OUT	Analog transmitted signal. This pin is the output for the transmitted analog carrier signal to the switched network.
EXI	17	IN	External input. Any external analog signal to be transmitted is connected to this pin.
VSS	18		Ground reference.

1.4 SPECIFICATION SUMMARY

TABLE 2 – SUMMARY OF TMS99532 MODEM OPERATING CHARACTERISTICS

DATA AND OPERATION MODE CHARACTERISTICS	
Data Format	Serial, Binary, Asynchronous
Data Rate	0-300 BPS
Operating Modes	Simplex, Half Duplex, Full Duplex

Figure 2 illustrates the TMS99532 modem channel and filter assignments.



*2100 Hz – CCITT V.25 ANSWER TONE

FIGURE 2 – TMS99532 MODEM CHANNEL AND FILTER ASSIGNMENTS

1.5 MODEM TERMINOLOGY

Acoustic Coupler: A device that permits the use of a telephone handset as a connection to dial-up telephone lines (rather than a direct connection using a DAA interface) for data transmission by means of sound transducers. Usually implemented for call origination.

Aliasing: Aliasing occurs when high-frequency noise, which is close or higher in frequency to the sampling clock frequency, is "mixed down" (difference frequency) into the frequency band of the received carrier signal (applicable to sampled data). The TMS99532 has antialiasing filters in both the receive and transmit paths.

Analog Loopback Mode: A diagnostic mode whereby the transmitted analog output is internally connected to the analog receiver input so that the chip's entire signal path is under test.

Analog Receiver: The analog receiver accepts the audio signals on the telephone line as an input, determines if the received signal represents a logic one (mark) or a logic zero (space) and outputs the digital result.

Analog Transmitter: The modem transmitter accepts serial data for an input, uses it to modulate an oscillator between two audio frequencies and then transmits the resulting analog signal over the telephone line to the remote receiver.

Audible Ringing Tone: A local loop signal for supervisory purposes from the Central Office (CO) to the calling telephone to indicate that the called phone is ringing.

Answer Tone: A tone returned by the answering modem to the originating modem and the network.

Asynchronous Transmission: A data transmission scheme that handles data on a character-by-character basis without synchronization (a clocking signal). The character code includes a "start" bit to identify the beginning of a data character, a "stop" bit to identify the end of the data character and a "parity" bit to check for errors in transmission.

Attenuation: Decrease of a communication signal's energy during transmission.

Audio Frequencies: Frequencies in the range of human hearing, i. e., 30 to 20,000 cycles per second.

Automatic Calling Unit (ACU): A device that is used to automatically dial a telephone number.

Bandpass Filter: A circuit that outputs a single band of frequencies.

Bandwidth: The frequency range or information-carrying capability of a communications channel. Conventional dial-up telephone lines have a total bandwidth of 300 to 3300 Hz (voice-grade).

Baseband: Digital information that is to be modulated onto the carrier (analog) signal for transmission over the telephone line.

Bias (Asymmetrical) Distortion: Distortion affecting a binary (mark, space) modulation scheme whereby the actual mark or space has a longer or shorter duration than the corresponding theoretical duration. The TMS99532 has built-in mark biasing to compensate for the natural space biasing of the telephone lines.

Bit Error Rate (BER): A measurement of the average number of bits transmitted before an error occurs. Usually expressed as the reciprocal of the average.

Bit Rate (BPS) versus Baud Rate: For modems using voice-grade telephone lines, the bit rate equals the data rate. The baud rate is the actual number of times per second that the transmitted carrier is modulated or changes state. Each modulation may represent multiple bits.

Carrier: An analog signal fixed in amplitude and frequency that can be combined in a modulation process with a second information-bearing signal to produce a signal for transmission.

CCITT (International Telegraph and Telephone Consultative Committee): An international forum for communication system standards.

Central Office (CO): Telephone company building that first switches the telephone lines into the network.

Channel: A one-way communications path.

C-Message Weighting: The Bell System standard weighting network for the evaluation of noise effects on voice-grade data services. Used in bit error rate testing.

Communication Mode: Operational characteristic of a modem relating to reception and transmission. A system may have the following options: simplex, half-duplex, and full-duplex operation. The TMS99532 has pin settings

for call answering, call origination, analog loopback testing and answer tone enable so that the desired communications function may be implemented.

Coupling (To The Telephone Line): Due to technical and safety reasons, it is beneficial to couple the signals to and from the telephone line using a transformer. The transformer provides DC isolation between the telephone line and the modem.

DAA (Data Access Arrangement): Prior to 1976, this equipment had to be leased from the telephone company as protective circuitry for the dial-up (switched) network. Now users may buy or build the necessary circuitry providing it is registered with the FCC according to Part 68 of the FCC's regulations. Also called Registered Protective Circuit.

Data Carrier Detect (DCD) Timing: On the TMS99532, adjusts the turn-on time for carrier detection and turn-off time for carrier loss.

dB (Decibel): The decibel is defined by the ratio of output signal power to input signal power as follows:

$$\text{dB} = 10 \cdot \text{Log}_{10} (\text{Output Power}/\text{Input Power})$$

Note that if the output power is less than the input power, the logarithmic result is negative. In this case, the line is said to have a loss of that many dB.

dBm: Input and output signal power may be related to a specific level called a dBm for reference purposes. Zero dBm ($\log 1 = 0$) equals 1 mW dissipated in 600 ohms impedance. The reference frequency used in most circuits is 1000 Hz. Measurements made relative to reference frequency are expressed in decibels relative to 1 mW as follows:

$$\text{dBm} = 10 \cdot \text{Log}_{10} (\text{Signal Power in mW}/1 \text{ mW})$$

Thus, zero dBm means 1 mW and absolute power levels may be expressed as so many dBm.

dB SPL: In acoustics, the unit commonly utilized to measure sound pressure is decibel sound pressure level or dB SPL. The zero reference for this measurement is 0.0002 dynes per square centimeter.

dBv: Microphone sensitivities are commonly related to a specific level called a dBv for reference purposes. Zero dBv ($\log 1 = 0$) represents one mW dissipated in 1000 ohms impedance. The unit dBv is expressed in terms of the peak voltage of a signal referenced to one volt:

$$\text{dBv} = 20 \cdot \text{Log}_{10} (\text{Peak Voltage of Signal}/1 \text{ Volt})$$

DCE (Data Communication Equipment): Consists of the modem and any other equipment related to the transmission and reception of analog signals over the telephone lines, such as the FCC-approved Registered Protective Circuit.

DDD (Direct Distance Dial): Dial system for North American Telephone.

Demodulator: The modem component that converts the received analog signal into a digital signal.

Dial-Up Telephone Lines: Also referred to as the switched network lines, these lines are used in voice-grade communications. A FCC-approved Registered Protective Circuit (DAA) is required for modem operation.

Direct Connection: Description of a modem connection to the switched network that uses a FCC-approved Registered Protective Circuit (DAA) rather than an acoustic coupler. The modem is physically wired (connected) to the telephone network.

DTE (Data Terminal Equipment): The digital equipment that connects to a modem or to the DCE.

EIA (Electronic Industries Association) RS-232C: Standard interface between a modem and the line controller on the switched network.

Envelope Delay Distortion: Variation of signal delay with frequency in the communications channel bandwidth.

Equalization: Modem circuitry that compensates for the telephone line's electrical characteristics.

FCC (Federal Communications Commission): Government agency that establishes communications standards. Part 68 of the FCC's regulations specifies the conditions for direct connections to the switched telephone network.

Fixed Loop Loss Transmit Level Control: This type of connecting arrangement permits a maximum adjustable level of no greater than -4 dBm. A resistive attenuator is put in the signal path to prevent the transmit level from exceeding -12 dBm at the Central Office (CO). However, the received signal is unnecessarily attenuated.

Frequency-Shift Keying (FSK): Frequency modulation method which varies the carrier frequency to correspond with binary logic (mark/space being equivalent to logic one/zero). The changes in frequency may occur in a continuous manner or by abrupt transitions. The TMS99532 implements a continuous-phase FSK scheme of modulation.

Full Duplex: Provides for simultaneous transmission and reception by both modems.

Gaussian (White) Noise: Background noise which is produced by the normal motion of electrons in conducting material. Used in bit error rate testing.

Half Duplex: Provides for either transmission or reception but each modem may perform only one function at a time.

Handshaking: Interchange of control signals to establish a data communications path.

Impulse Noise or Surge: A type of high-amplitude short-duration interference on communications lines caused by such events as lightning, electrical sparking action or by the make/break action of switching devices. A DAA is required to protect the modem from such voltage surges.

Local Loop: The local loop is defined by the telephone company as the cable that connects the signal switching equipment at the Central Office (CO) to the user's telephone or modem.

Local Loop Current: DC flow in the local loop that indicates to the telephone company that a phone is in use. In telephone company terminology, a phone (or modem) is "on-hook" when no local loop current is flowing and is "off-hook" otherwise.

Long Haul Modem: May be designed for use on the public switched telephone network or for dedicated use on a leased telephone line. The TMS99532 is a long haul modem designed for use on the public switched telephone network.

Mark: Logic one in the frequency-shift-keying (FSK) modulation scheme implemented on the TMS99532.

Microbar: Unit of pressure: one dyne per square centimeter. In acoustics, microphone sensitivities are commonly referenced to the following unit: 1 volt/microbar.

Modem: Device to convert digital data into an analog signal and vice versa so that two electronic devices (such as a computer and a data terminal) may communicate over the telephone system. The word modem is a contraction for modulator/demodulator.

Modulator: The modem component that converts a digital signal input into an analog signal for transmission.

Off-Hook: Telephone terminology for the electrically-connected state of a data transmission system, i. e., current is flowing in the local loop.

On-Hook: Telephone terminology for the electrically-disconnected state of a data transmission system, i. e., current is not flowing in the local loop.

Permissive Transmit Level Control: Arrangement that allows the transmit level of a modem to be fixed at no greater than -9 dBm regardless of loop loss.

Programmable Transmit Level Control: Arrangement that permits the transmit level to be "programmed" in 1 dB steps from 0 to -12 dBm using a programming resistor in the connecting circuitry supplied by the telephone company. The value of this resistor represents the local loop loss and is defined in Part 68 of the FCC's regulations.

Protocol: A set of conventions including handshaking and line control functions for communication processes.

Registered Protective Circuit: Part 68 of the FCC's regulations stipulates that all devices connected to the switched network have Registered Protective Circuits to prevent damage to the telephone company's equipment. Also called DAA.

Signal-To-Noise Ratio (SNR): An expression in decibels of the relative signal and noise power levels present on a communications line. Important for modem diagnostics.

Simplex: Provides for one-way transmission and reception in the following manner: one modem is transmit-only and the other modem is receive-only.

Space: Logic zero in the frequency-shift-keying (FSK) modulation scheme implemented on the TMS99532.

Switched Network Telephone Lines: See Dial-Up Telephone Lines.

Two-To-Four Wire Hybrid (Duplexer): Since the telephone line is a two-wire system that mixes the transmitted and received analog signals, the modem requires a two-to-four wire hybrid to separate these signals. The two telephone wires are normally called "TIP" and "RING". The four wires of the hybrid refer to the transmitter output and ground plus the receiver input and ground.

2. OPERATION

2.1 SYSTEM DESCRIPTION

2.1.1 TMS99532 Block Diagram

A functional description of the TMS99532 FSK modem is presented in the sections that follow. Refer to Figure 3 for the TMS99532 block diagram.

2.1.2 User Mode Description

Table 3 summarizes the various user modes for the TMS99532 modem.

In the Answer and Originate modes, digital data is transmitted and received as follows: the Answer mode allows transmission in the high-band frequencies and reception in the low-band frequencies while the reverse is true for the Originate mode. Answer and Originate are the normal operating modes for the TMS99532.

Transmitted data may be squelched in the Answer and Originate modes by placing a logic one on the SQT pin (thereby disabling TXA). The TMS99532 continues to receive data in this mode.

The Analog Loop Back Test mode is enabled by setting the ALB pin to a logic one. The transmitter operates normally in this mode. However, before the signal reaches the TXA pin, it is routed to the receiver. This allows functional testing of the digital and analog performance of the device by using only digital signals.

The EXI mode is used to enable an external source through the TXA pin. Applications requiring dual tone dialing may implement this mode.

The Answer Tone Enable mode generates a 2100 Hz signal on the TXA pin. Note that this mode is not normally implemented in the USA.

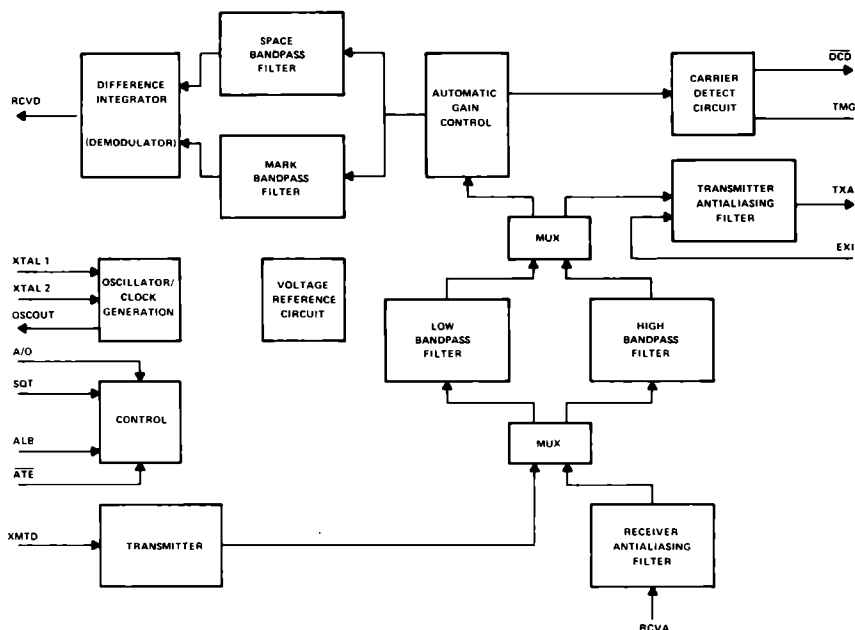


FIGURE 3 – BLOCK DIAGRAM OF TMS99532

TABLE 3 – USER MODES

MODE	MODE CONTROLS	TRANSMITTED DATA		RECEIVED DATA		TOUCH TONES
	SQT ALB A/O ATE (Digital)	XMTD (Digital)	TXA (Analog) Hz	RVCA (Analog) Hz	RCVD (Digital)	EXI (Analog)
Answer	0 0 0 1	Mark = 1 Space = 0	– 2225 – 2025	Mark = 1270 Space = 1070	– 1 – 0	x
Originate	0 0 1 1	Mark = 1 Space = 0	– 1270 – 1070	Mark = 2225 Space = 2025	– 1 – 0	x
Answer, Squelch	1 0 0 1	x	Disabled	Mark = 1270 Space = 1070	– 1 – 0	x
Originate, Squelch	1 0 1 1 –	x	Disabled	Mark = 2225 Space = 2025	– 1 – 0	x
Analog Loop Back, Answer	0 1 0 1	Mark = 1 Space = 0	Disabled	Disabled	1 0	x
Analog Loop Back, Originate	0 1 1 1	Mark = 1 Space = 0	Disabled	Disabled	1 0	x
ALB Test, Answer	1 1 0 1	x	Disabled	Disabled	1	x
ALB Test, Originate	1 1 1 1	x	Disabled	Disabled	1	x
EXI as Input	1 0 1 0	x	Same as EXI, Inverted [†]	x	Three-State HBPF Active [†]	External Tone Source
EXI as Input [§]	1 0 0 0	x	Same as EXI, Inverted [†]	x	Three-State LBPF Active [‡]	External Tone Source
2100 Hz [§] CCITT V.25 Answer Tone	0 0 0 0	x	2100	x	Three-State	x
Note: These states are undefined and should not be used.	0 0 1 0 0 1 0 0 0 1 1 0 1 1 0 0 1 1 1 0	Footnotes: x = Don't Care [†] HBPF = High Bandpass Filter (see Figure 2) [‡] LBPF = Low Bandpass Filter (see Figure 2) [§] Typically not used in USA applications. [¶] Assumes AC coupling at EXI.				

2.2 SYSTEM CLOCK

The TMS99532 modem has an internal parallel resonant oscillator and clock generator that may be controlled by an external crystal. The user may also disable the oscillator and directly inject a frequency source into the chip. If a crystal is implemented, it is connected across XTAL1 and XTAL2, as shown in Figure 4. Note that two capacitors connect XTAL1 and XTAL2 to ground. (See Section 4.4.1.) The crystal should be a fundamental parallel resonant type and the connections to XTAL1 and XTAL2 should be as short as possible.

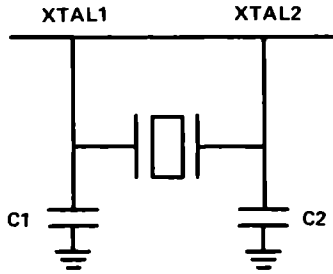


FIGURE 4 – CRYSTAL OSCILLATOR CONNECTION

Figure 5 shows the connection for an external oscillator. Note that XTAL2 must not be connected if an external clock is implemented. Also note that the frequency must be 4.032 MHz plus/minus .01 percent with either a crystal or an external frequency reference. Table 4 gives the 4.032 MHz crystal specifications.

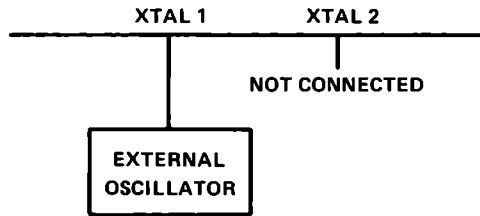


FIGURE 5 – EXTERNAL OSCILLATOR CONNECTION

TABLE 4 – 4.032 MHz CRYSTAL SPECIFICATIONS

PARAMETER	PREFERRED	WORST CASE	UNIT
HOLDER TYPE	HC18/U		
OPERATING TEMPERATURE RANGE	-20 to 70		°C
TEMPERATURE STABILITY (OVER RANGE)	+/- 0.005	+/- 0.01	%
FREQUENCY CALIBRATION TOLERANCE AT 25°C +/- 2°C	+/- 0.005		%
OPERATING MODE	Parallel Resonant		
LOAD CAPACITANCE	22	25	pF
EFFECTIVE SERIES RESISTANCE	70	100	Ω
DRIVE LEVEL	2.0		mW
OSCILLATION MODE	Fundamental		

OSCOUT is a TTL compatible output that oscillates at the master clock frequency. If desired, OSCOUT may be implemented to drive other circuits at the same frequency.

The oscillator is used to generate two different sets of frequencies: one set to sample the analog signals in the switched capacitor circuits and the other set to generate the carrier signals in the transmit modulator.

The clock characteristics and timing requirements for the TMS99532 are described in Sections 4.4 and 4.5.

2.3 FSK MODULATOR

The frequency-shift-keyed (FSK) modulator is phase continuous, i. e., the phase of the signal remains constant during a frequency transition. A square wave is generated at four carrier frequencies when selected by the A/O and XMTD inputs. A fifth frequency, the 2100 Hz CCITT answer tone, is selected by the $\overline{\text{ATE}}$ pin. Note that the modulator is unconditionally disabled by the transmit squelch pin (SQT).

Modulation is achieved by means of a transmitter which divides the master clock to generate the mark and space (logic one and logic zero) frequencies. The signal is then bandpass filtered to eliminate noise from the desired carrier frequencies. Finally, the carrier is passed through the transmitter and antialiasing filters to produce the transmitted, modulated data.

2.4 FSK DEMODULATOR

The demodulation scheme includes an initial antialiasing filter and two narrow bandpass filters centered on the first Bessel side bands of the mark and space frequencies. The outputs of the mark and space filters are full-wave rectified by a difference integrator before an energy comparison is made. If the energy in the mark filter is greater than the energy in the space filter, the result is a logic one (and conversely). Finally, the signal is compared to a reference voltage and limited to become the received demodulated data.

2.5 BANDPASS FILTERS

There are two bandpass filters on the TMS99532: one centered on the low band (1170 Hz) and the other centered on the high band (2125 Hz). These filters reduce out-of-band interference so that the received signal can be easily demodulated. A photograph of the bandpass filter response is shown in Figure 6. Figures 7 and 8 show the ideal amplitude and group delay response of each filter's pass band. These responses are not quite flat because they have been designed to cancel some of the amplitude and phase distortion present in a communications network. Both filters are used at all times with one filter being in the transmit path and the other filter in the receive path. The mode select pins automatically determine how the filters are multiplexed in the circuit.

The TMS99532 has built-in amplitude and group delay equalization as well as intentional mark bias distortion to compensate for the phone lines' natural space bias distortion.

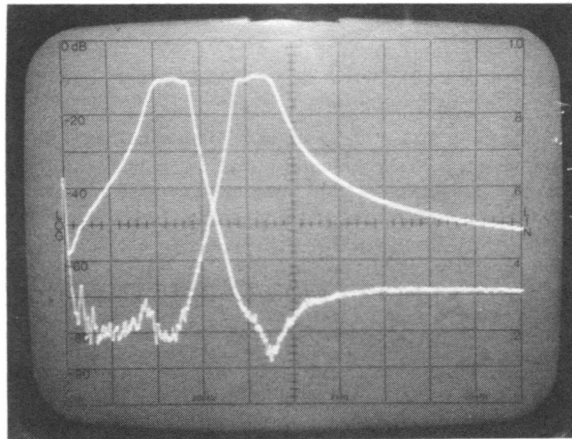


FIGURE 6 – BANDPASS FILTER RESPONSE

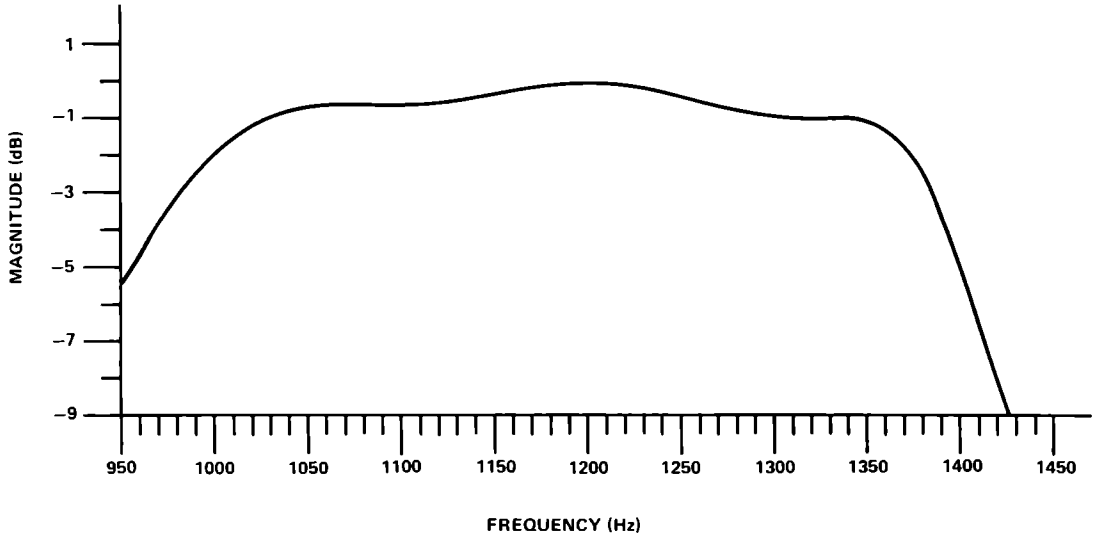


FIGURE 7 - IDEAL LOW-FREQUENCY PASS BAND RESPONSE

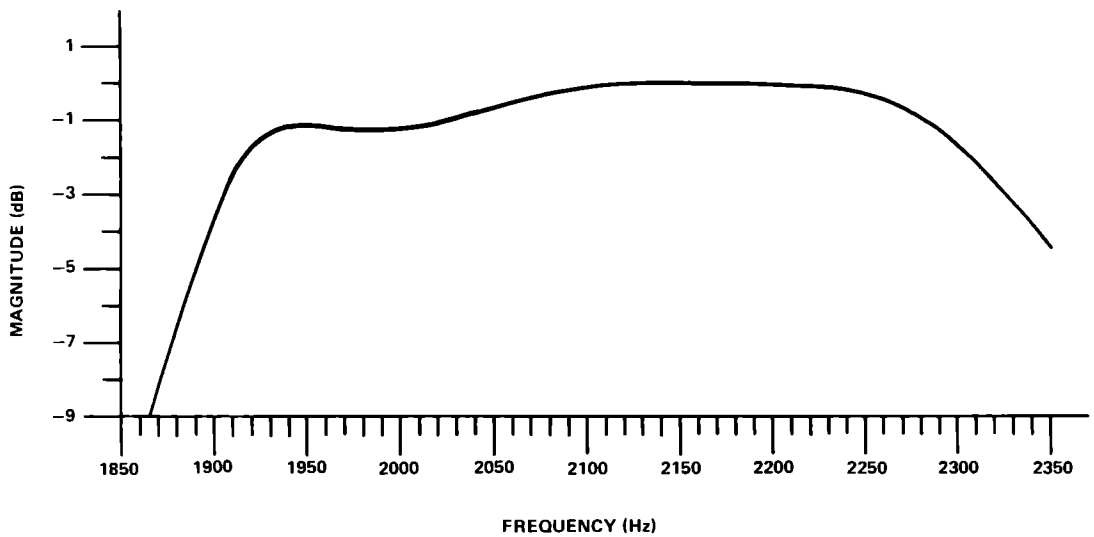


FIGURE 8 - IDEAL HIGH-FREQUENCY PASS BAND RESPONSE

2.6 ANTIALIASING FILTERS

The TMS99532 modem has an antialiasing filter in both the transmit and receive paths so that no external filtering is required.

The antialiasing filter is also in the signal path for the External Tone Input (EXI), thus minimizing the need for antialiasing even with externally generated signals. Figure 9 shows the frequency response of the antialiasing filter.

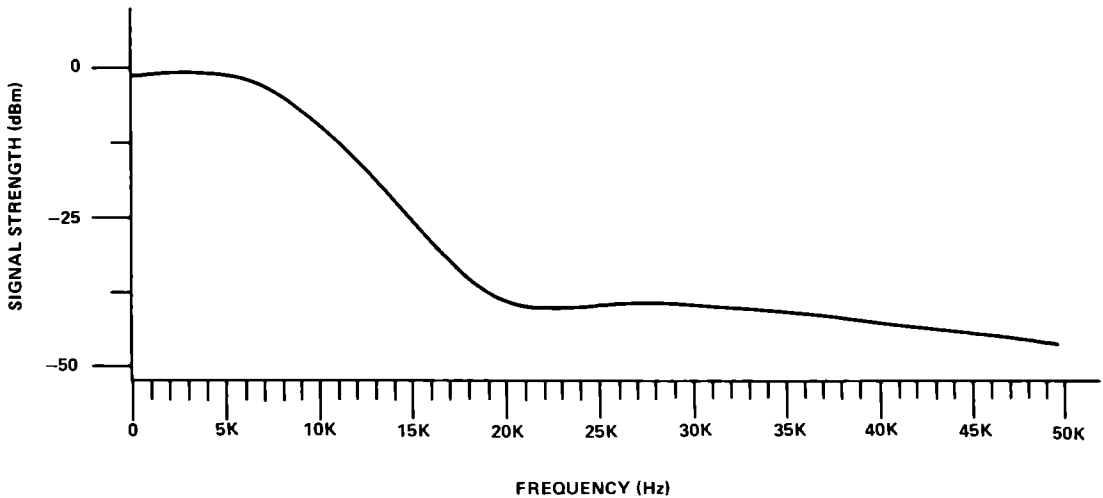


FIGURE 9 – ANTIALIASING FILTER RESPONSE

2.7 AUTOMATIC GAIN CONTROL

The Automatic Gain Control (AGC) circuit adjusts the amplitude of the received, filtered signal for optimum demodulator operation, i.e., the wide dynamic range of the received signal is reduced by the AGC to a very narrow range for the demodulator. The AGC also has a secondary function of providing an energy detector for the carrier detect circuit. (See Section 2.8.) The AGC is a digital, stepped AGC with a step size of six dB that produces an output of constant amplitude within a factor of two.

2.8 CARRIER DETECTION

The carrier detect function is implemented by an energy detector, a signal quality circuit and a carrier detect timing circuit.

The energy detect function is derived from the AGC circuit. If the AGC is in its maximum gain state, then the received signal is less than the carrier detect turn-on level. If the signal is greater than this level, then the AGC indicates to the data carrier detect circuitry that energy is present. After a carrier is detected, the signal must be reduced below the carrier detect turn-off level before the Data Carrier Detect (DCD) output indicates that there is a loss of signal. (See Section 4.7.2.)

The signal quality circuit acts only during the carrier turn-on time since occasional errors due to poor signal quality do not warrant disconnecting the circuit. The TMS99532 must receive a valid mark signal for the duration of the turn-on time. After the $\overline{\text{DCD}}$ pin goes active, any in-band energy will maintain the carrier detect indication. When the carrier detect circuit shows no valid signal, the RCVD pin is always clamped to a mark (logic one) condition.

The timing circuit allows the user to select the turn-on and turn-off times independently by connecting an appropriate resistor and capacitor to the TMG pin. (See Section 3.4)

2.9 CARRIER DETECT TIMING CONNECTION (TMG)

The TMG pin determines the Data Carrier Detect ($\overline{\text{DCD}}$) turn-on and turn-off times. (Refer to Section 3.4 for a more complete description.)

The TMG pin uses a resistor/capacitor timing scheme to independently drive the acquisition and loss times. The circuit is shown in Figure 10.

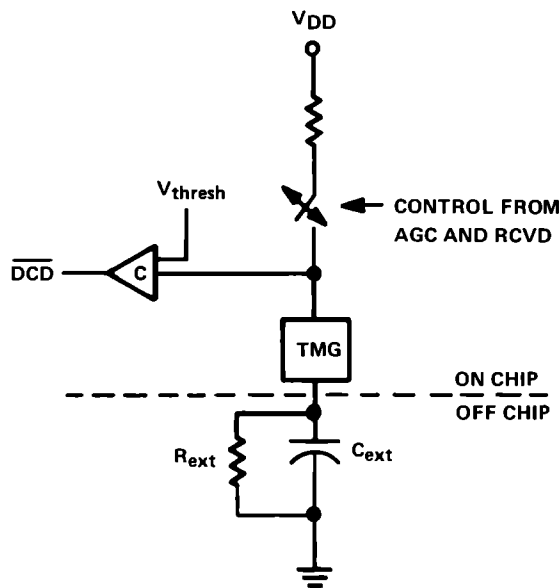


FIGURE 10 – EQUIVALENT CIRCUIT FOR CARRIER DETECT TIMING

There are two relevant times that characterize the carrier detect timing (TMG) circuit: a discharge time which determines the carrier detect turn-on time and a charge time which determines the carrier detect turn-off time. The TMG circuit creates these times by charging C_{ext} to a voltage level greater than that of V_{thresh} and then discharging C_{ext} through R_{ext} so that the voltage on C_{ext} is less than V_{thresh} . \overline{DCD} will be low at power-up until C_{ext} has charged.

2.10 EXTERNAL ANALOG INPUT (EXI)

The EXI pin allows an external analog signal to be passed through the TMS99532. When the EXI mode is enabled, the signal on EXI is sent through the transmitter antialiasing low pass filters and out the TXA pin. (See Section 2.6.) The EXI mode is enabled when $\overline{ATE} = 0$, $SQT = 1$, and $ALB = 0$.

The EXI pin facilitates complete support for touch tone dialing and may also be used for connecting other modems through the TMS99532 to support multiple data set capability.

2.11 ANALOG LOOPBACK

When the Analog Loopback (ALB) function is enabled (active high), the receiver is reconfigured to match the transmitter, as shown in Figure 11. During ALB, the transmitter bandpass filter is circumvented and the transmitted waveform goes directly into the receiver filter. Since the signal path forms an internal loop, all data transmitted at XMTD is received at RCVD. Note that the TXA and RCVA signal pins are disabled, thereby preventing the test carrier signal from being detected on the network.

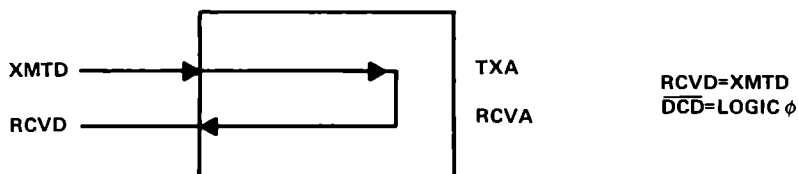


FIGURE 11 – ALB SIGNAL PATH

3. DEVICE APPLICATIONS

3.1 TYPICAL MODEM CONNECTIONS

The TMS99532 modem may be electrically connected to the dial-up or switched telephone network by means of a Registered Protective Circuit or a Data Access Arrangement (DAA). Such a circuit must pass the tests described in Part 68 of the FCC Rules and Regulations AND BE REGISTERED BY THE FCC before connection to the telephone lines. This type of modem arrangement is commonly referred to as a "direct connect" interface to the network and is discussed in Section 3.3.

The TMS99532 modem may also be acoustically connected to the dial-up or switched telephone network through the telephone handset by means of a speaker and a microphone. However, although this technique is convenient and does not require FCC approval, it does have some disadvantages when compared to a direct connection with the telephone line. The acoustic coupler interface is discussed in Section 3.2.

Specifications for interface and control signals between the data terminal equipment (DTE) and the data communications equipment (DCE: TMS99532 modem, FCC-approved Registered Protective Circuit and any other equipment relating to reception and transmission of analog signals on the telephone lines) may be met by implementation of a standard EIA RS-232C interface. This specification has remained popular in spite of the availability of more modern interface standards. The EIA RS-232C interface is discussed in Section 3.3.3.

3.2 ACOUSTIC COUPLER INTERFACE TO NETWORK

The TMS99532 modem may be implemented in an acoustic coupler arrangement when a direct connection is not feasible. In the discussion that follows, factors affecting acoustic coupler performance are presented with suggestions. An example of an acoustic coupler connection is given in Section 3.2.1.

The Central Office (CO) is the telephone company building that first switches the telephone lines into the network. The telephone line that goes from the CO to the user's location is called the local loop. For acoustic applications, the TMS99532 interfaces to the telephone handset's speaker and microphone by means of simple buffer amplifiers that provide gain and impedance matching. The telephone handset itself serves as a hybrid for two-to-four wire conversion between the switched network's local loop and the TMS99532 modem. (The two wires are the telephone line connections normally called "TIP" and "RING". The four wires are the transmitter output (TXA) and ground plus the receiver input (RCVA) and ground.)

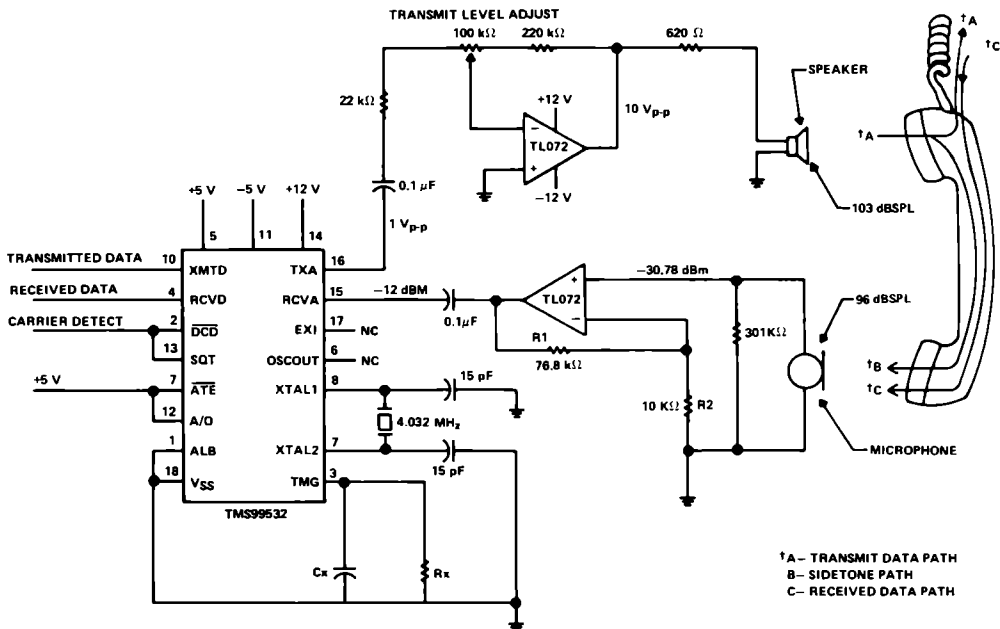


FIGURE 12 - EXAMPLE OF ACOUSTIC COUPLER INTERFACE

The telephone has several characteristics which impair modem performance:

1. Second harmonic distortion coupled with sidetone path
2. Microphone sensitivity to packing, orientation and mechanical vibrations
3. Ambient noise coupling

Second harmonic distortion due to the nonlinear effects of the microphone would not be a problem if there was not sidetone path in the telephone handset. The sidetone path allows any signal transmitted through the microphone to be fed back into the earpiece. This feature is desirable for speech applications because it allows people to hear themselves through the earpiece when they talk through the mouthpiece. However, there is a problem in data communications for an origination mode acoustic coupler since the earpiece is receiving the desired signal plus the second harmonics of its own transmitter (which is applied to the earpiece by the sidetone path). Unfortunately, the transmitter's second harmonics coincide with the receive band since the modem is transmitting in the low band when in the origination mode.

	TRANSMITTER	RECEIVER	TRANSMITTER'S SECOND HARMONICS
MARK (1)	1270	2225	2540 Hz
SPACE (0)	1070	2025	2140 Hz

One obvious way to minimize the second harmonic effects is to lower the transmit level (and therefore the second harmonics) of the origination mode acoustic coupler to the point where the receiver of the answering modem demonstrates an acceptable error rate. Data errors begin to occur when the received signal is in the -35 dBm to -40 dBm range.

The second harmonic problem need not be considered for short communications links. Likewise, the answering modem does not have a second harmonic problem since its receiver has been designed to operate in the low (1070/1270) band and its filters reject out-of-band signals. (The originating modem's filters have likewise been designed to reject out-of-band signals.)

The quality of data communications is lowered when the physical orientation of the telephone handset is such as to cause the carbon granules to become packed. Depending upon the length of time that the handset is maintained in a stationary position, the same sound pressure input produces a decreasing microphone voltage output. This problem may be minimized by rotating the handset several times at the beginning of a call and vertically orienting the microphone, i. e., the handset is off-hook and laying on its side.

The carbon microphone is also sensitive to mechanical vibrations. These vibrations may cause intermodulation between the second harmonic of the transmitter frequency and the frequency of vibration with the result of mixing products at the second harmonic frequency plus/minus the vibration frequency. Proper isolation of the carbon microphone will minimize this problem.

Ambient noise coupling (or external room noise interference) is another factor affecting modem performance. A good design for the rubber or plastic cups that hold the telephone handset should be utilized to insure the quality of data communications.

3.2.1 Design of Acoustic Coupler Interface

This section presents a design (Figure 12) for an acoustic coupler interface utilizing the TMS99532 modem. Specific applications may require changes in circuit component values, depending upon the sensitivity of the selected microphone, speaker efficiency and the properties of the acoustic interface between the telephone handset and the microphone and speaker.

3.2.1.1 Telephone Handset Characteristics

In order to facilitate proper transmitter and receiver design, the relationship between sound pressure and electrical signal level (and conversely) should be determined for the particular handset to be implemented. The unit commonly used to measure sound pressure is decibel sound pressure level (dBSPL). The zero reference for this measurement is 0.0002 dynes per square centimeter. For acoustic coupler transducers and rubber cups used in this example, it was determined that 100 dBSPL applied to the mouthpiece (microphone) of the telephone handset corresponds to -13 dBm when measured across the "TIP" and "RING" connections of the telephone line. It was also determined that a -20 dBm received signal corresponded to 88 dBSPL at the earpiece (speaker) of the telephone handset.

3.2.1.2 Signal Level Requirements

In data communications, it is desirable for the signal level to be -12 dBm when measured at the Central Office (CO). The transmitter should be designed so as not to violate -12 dBm as a maximum for an in-band signal. A conservative transmitter design would assume that there is no attenuation in the local loop and prevent the transmit level from exceeding -12 dBm when measured at the user's end of the local loop. Part 68 of the FCC's regulations, however, does account for attenuation in the local loop and permits signals up to -9 dBm at the user's end of the loop. A -9 dBm transmit level could exceed the level for acceptable performance due to the existence of a sidetone path and second harmonic distortion.

Concerning transmitted energy above the voice frequency band, power in the band from 3995 to 4005 Hz must be 18 dBm below the maximum in-band power level. In addition, the following constraints apply:

1. From 4000 to 10,000 Hz, the signal power level must not exceed -16 dBm.
2. From 10,000 to 25,000 Hz, the signal power level must not exceed -24 dBm.
3. From 25,000 to 40,000 Hz, the signal power level must not exceed -36 dBm.
4. Above 40,000 Hz, the signal power level must not exceed -50 dBm.

The TMS99532 modem has been designed so that all out-of-band signal level requirements are met without external filtering if the user does not set the transmit level above the allowed limits.

3.2.1.3 Receiver Design

In the originate mode, the receiver operates in the high band (1975 to 2275) with received signals in the -12 dBm to -38 dBm range. Note that the in-band signal should be as high as possible without exceeding -12 dBm. In-band signals greater than -12 dBm may cause the bandpass filters to saturate and thus perform unacceptably. As shown in Figure 12, a part of a TL 072 is used as a buffer amplifier to provide the TMS99532 with the proper input signal. A coupling capacitor is necessary since the RCVA pin is referenced at a DC level. The amplifier gain is determined as follows:

1. Determine what sound pressure corresponds to -12 dBm.
 - a. Since -12 dB SPL is 8 dBm greater than the -20 dBm received signal (that was determined to correspond to 88 dB SPL at the earpiece (speaker) of the telephone handset), the output signal level should be 8 dBm greater than 88 dB SPL or 96 dB SPL.
2. Determine the microphone output for the sound pressure in the preceding step. Microphone sensitivities are commonly related to a specific level called a dBv for reference purposes. Zero dBv (Log 1 = 0) represents one milliwatt dissipated in 1000 ohms impedance. The unit dBv is expressed in terms of the peak voltage of a signal referenced to one volt:

$$\text{dBv} = 20 \cdot \text{Log}_{10} (\text{Peak Voltage of Signal} / 1 \text{ Volt})$$

Another unit commonly utilized to reference microphone sensitivities is 1 volt/microbar. A microbar is a unit of pressure: one dyne per square centimeter.

- a. The microphone implemented in this example has a sensitivity of -55 dBv below 1 volt/microbar, i. e., applying a pressure of one dyne per square centimeter to the microphone results in an output of 55 dBv below one volt. Minus 55 dBv is 1.78 mV RMS (antilogarithm of $-55 \text{ dBv} / 20 = 1.78 \text{ mV}$). The reference for dB SPL is 0.0002 dynes per square centimeter. A pressure of one dyne per square centimeter is

$$20 \cdot \text{Log}_{10} (1 / 0.0002) = 74 \text{ dB SPL}$$

which corresponds to 1.78 mV from the microphone or, in dBm, the equivalent expression is

$$20 \cdot \text{Log}_{10} (1.78 / 775) = -52.78 \text{ dBm}$$

(since 0 dBm = 0.775 V). With a 96 dB SPL input to the microphone, an amplifier output of -12 dBm is required. However, since 96 dB SPL is 22 dB SPL greater than the number just calculated for the microphone sensitivity (74 dB SPL), the equivalent dBm expression is

$$-52.78 + 22 = -30.78 \text{ dBm}$$

which is 18.78 dBm less than -12 dBm. Therefore, the microphone amplifier requires a gain of 18.78 dBm or a voltage gain of 8.69 (antilogarithm of $18.78 / 20 = 8.69$). A 0.1 mF capacitor is used to couple the amplifier output to the RCVA input of the TMS99532 modem chip.

3. For the noninverting amplifier configuration utilized in Figure 12, the gain is equal to $1 + (R1/R2)$. Therefore:
 - a. $8.69 = 1 + (R1/R2)$
 - b. $7.69 = (R1/R2)$

NOTE: Let $R2 = 10K$ ohms, then $R1 = 76.9K$ ohms. The nearest 1% value of 76.8K ohms was used.

3.2.1.4 Transmitter Design

As stated previously, the maximum transmit level permitted by this design is -9 dBm. Only a simple buffer amplifier is required to provide variable gain for transmit level calibration and speaker drive capability since the TXA pin of the TMS99532 modem will drive loads of 20K ohms or more. Using an 8-ohm speaker with the 620-ohm series resistor, shown in Figure 12, a 10-volt peak-to-peak drive signal at the output of the TL 072 produced an output sound pressure of 103 dB SPL which in turn produced a -9 dBm signal on the telephone line. To accommodate variations in speaker efficiency, another 3 dBm of gain is required for a total of approximately 14.1 volts peak-to-peak or an output buffer gain of 14.1 volts. The signal level on the TXA pin of the TMS99532 is 1 volt peak-to-peak. The input resistor was chosen to be 22K ohms.

The feedback resistance at maximum output is

$$14.1 * 22K = 310.2K \text{ ohms}$$

The potentiometer configuration, shown in Figure 12, was selected to prevent too low a transmit level and to eliminate coarseness in the transmit level adjustment if a 3/4-turn potentiometer is implemented. Using a 100K ohm potentiometer requires the fixed feedback resistor to be 210K ohms. However, a 220K ohm resistor was chosen since it is the nearest 5% value.

These values give a maximum gain of

$$(220K + 100K)/22K = 14.54 \text{ or } 23.25 \text{ dBm}$$

and minimum gain of

$$(220K)/(100K + 22K) = 1.8 \text{ or } 5.12 \text{ dBm}$$

for an overall adjustment range of over 18 dBm. The transmit level should be calibrated for a -9 dBm maximum.

3.2.1.5 Example of System with Acoustic Coupler

Figure 13 shows a TMS9995 system design with the TMS99532 modem acoustically coupled to the network in the originate mode.

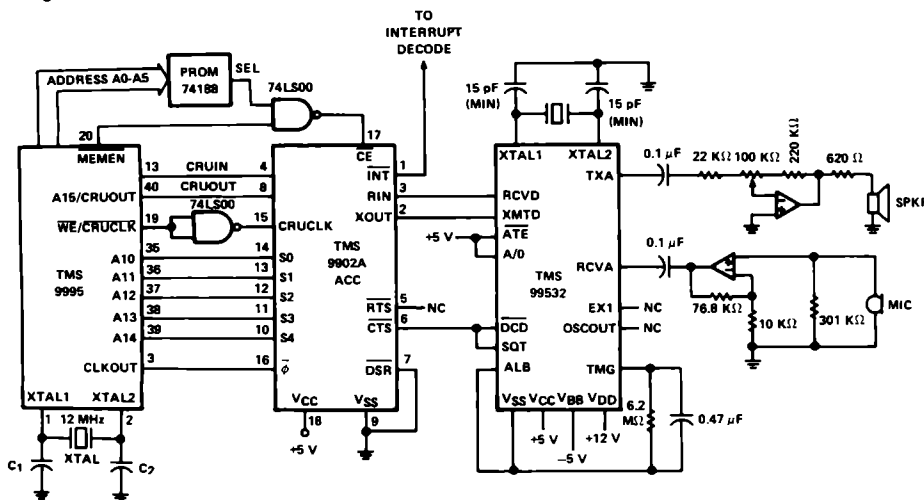


FIGURE 13 – TMS9995 SYSTEM UTILIZING ORIGINATE-MODEM

3.3 DIRECT CONNECT INTERFACE TO NETWORK

Connecting a modem to the switched network by means of a direct connect interface gives the user the best guarantee of reliable performance. This section discusses the design of a direct connect interface in general by means of a block diagram and then gives two design examples: one design with a DAA circuit that has NOT been FCC approved and one design that includes a FCC-approved Registered Protective Circuit.

3.3.1 Block Diagram of Direct Connect Modem

Figure 13 shows a block diagram illustrating the functions necessary for sending and receiving data on the switched telephone network.

1. Analog transmitter (modulator)
2. Analog receiver (demodulator)
3. Analog signal detector ($\overline{\text{DCD}}$)
4. Two-to-four wire hybrid
5. Coupling to telephone line
6. DC loop current control
7. Ring detection (for automatic answer)
8. Line transient and surge protection
9. Control logic

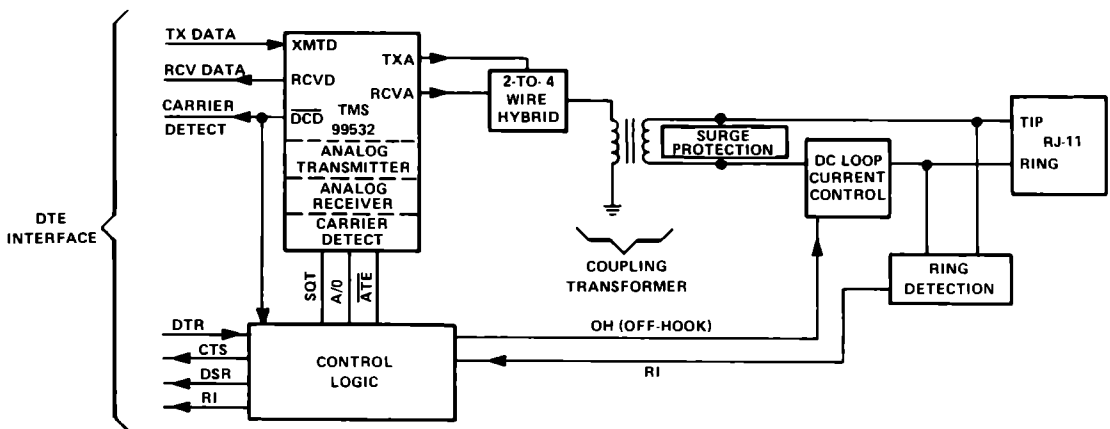


FIGURE 14 - BLOCK DIAGRAM OF DIRECT CONNECT MODEM

3.3.2 Design of Direct Connect Interface

Two designs for a direct connect interface are presented in this section as a guide to the user. The first design directly relates the functions illustrated in the block diagram to a circuit which has NOT been FCC approved. The second design implements a FCC-approved DAA circuit and a standard RS-232C interface.

3.3.2.1 Direct Connect Design without A Registered Protective Circuit

Figure 15 presents a circuit implementing the TMS99532 as a transmitter, receiver and carrier detector. The remaining functions shown in the block diagram are discussed by starting at the telephone line and proceeding back to the control logic block.

DC Loop Current Control

The local loop consists of two wires, "TIP" and "RING," that connect the signal switching equipment to a telephone. DC flow in the local loop is recognized by the telephone switching system as an indication that a phone is in use. In telephone company terminology, a phone (or modem) is "on-hook" when no local loop current is flowing and "off-hook" when local loop current is flowing. The requirements for on-hook and off-hook current are specified in Part 68 of the FCC's regulations. To meet these and the isolation specifications, a relay is typically implemented for on-hook/off-hook control of the modem. This relay is driven by a SN75472 relay driver which receives its input from the control logic. Proper selection of this relay could also provide pulse dialing capability.

Ring Detection

The user interfaces to the telephone company's "TIP" and "RING" signals by means of a RJ-11 jack. In many modem applications, it is necessary to automatically answer a call so that data may be transferred when the data terminal equipment is unattended. The telephone system uses what is known as a "ringing voltage" to ring the bell in a telephone. Figure 15 shows a circuit that can detect the AC ringing signal (typically 17-33 Hz at 40-130 Vrms "on" 2 seconds, "off" 4 seconds) which is superimposed on the on-hook loop voltage (nominal 48 volts DC). The impedance requirements for this circuitry are stated in Part 68 of the FCC's regulations. The circuit components include a high voltage coupling capacitor, a protection diode, a zener diode, a current limiting resistor and an optical coupler. Note that the ring detection circuit in Figure 15 contains a simple analog comparator circuit to integrate the ringing signal so it is valid for the entire two seconds that the ringing voltage is applied.

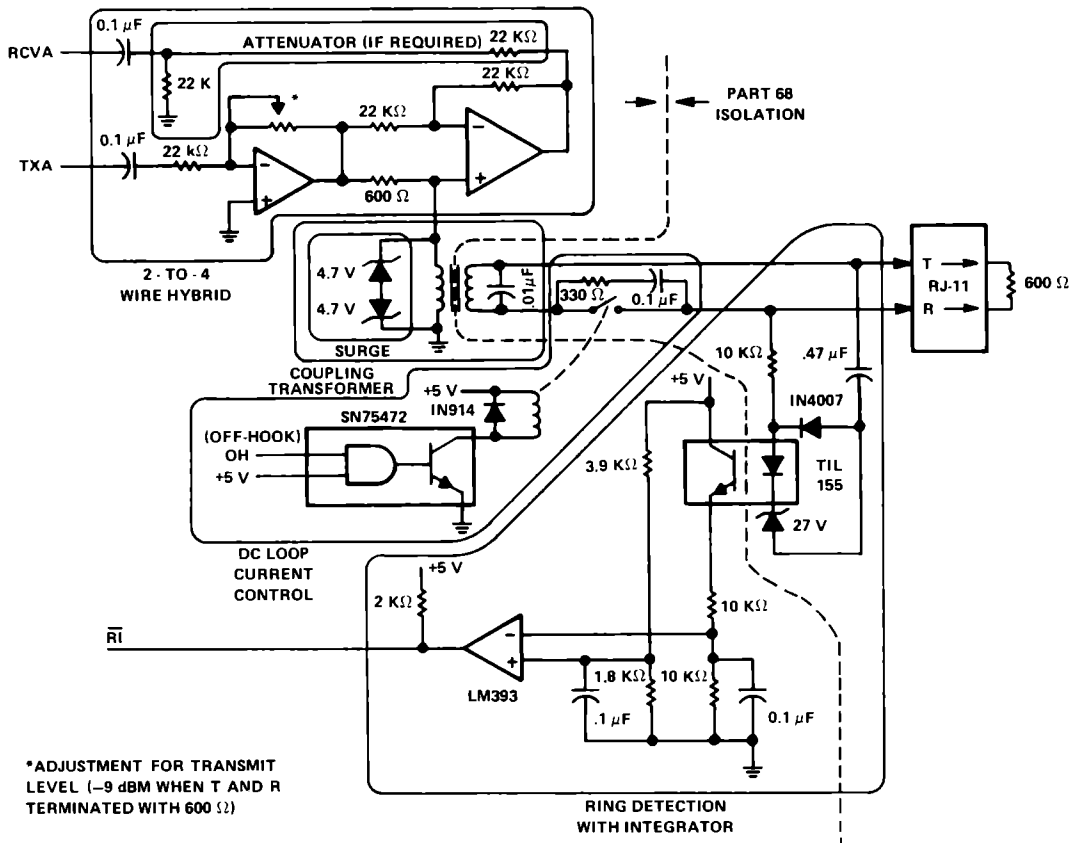


FIGURE 15 - EXAMPLE OF DIRECT CONNECTION (NOT FCC APPROVED)

Line Transient and Surge Protection

This circuitry is utilized to protect the modem from damage caused by excessive voltages (such as lightning) that may appear on a telephone line.

Coupling to the Telephone Line

Part 68 of the FCC's regulations has an isolation requirement between the phone line ("TIP" and "RING") and the modem which is usually satisfied by implementing a transformer for coupling the incoming and outgoing AC analog signals. As shown in Figure 15, this transformer must not introduce signal distortion due to transformer saturation (caused by the flow of DC loop current through the winding). Transformers that meet this requirement are commercially available from a number of manufacturers.

Two-to-Four Wire Hybrid

Since the telephone line is a two wire system that mixes the transmitted and received analog signals, it is necessary for the modem to separate these signals using a two-to-four wire hybrid. Figure 16 isolates this circuitry for the purposes of this discussion. To understand the circuit's operation, assume the telephone line impedance to be 600 ohms resistive and that the transformer is ideal. Figure 17 shows the equivalent circuit for calculating the transfer function from the VT (transmitter) to VL (the telephone line). The relationship is given by:

$$V_L = (V_T \cdot R_R) / (R_L + R_R)$$

The transfer function for VR (receiver input) is:

$$V_R = \left[(V_T \cdot R_R) / (R_1 + R_R) \right] \cdot \left[1 + (R_2 / R_1) \right] - \left[V_T \cdot (R_2 / R_1) \right]$$

If $R_R = R_L$ and $R_1 = R_2$, then the contribution of VT to VR is zero and the transfer function for VR is:

$$V_R = V_L \cdot \left[1 + (R_2 / R_1) \right]$$

If $R_1 = R_2$, then $V_R = 2 \cdot V_L$.

The rejection of the transmitter is not perfect (typically 10 to 12 dB) due to the impedance mismatch of the telephone line and a nonideal transformer. However, this is not a problem for the TMS99532 modem since its internal receiver filters reject the transmitter by at least 65 dB.

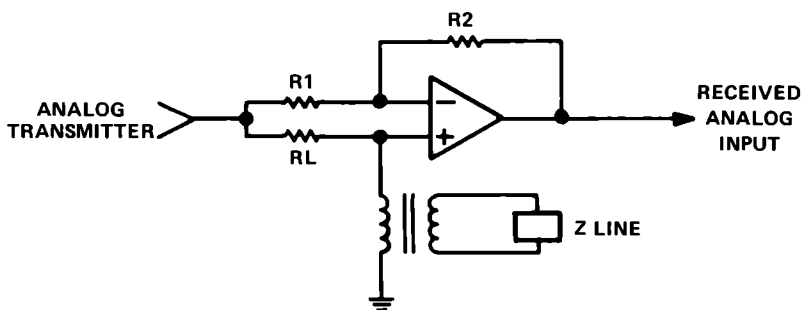


FIGURE 16 - TWO-TO-FOUR WIRE HYBRID

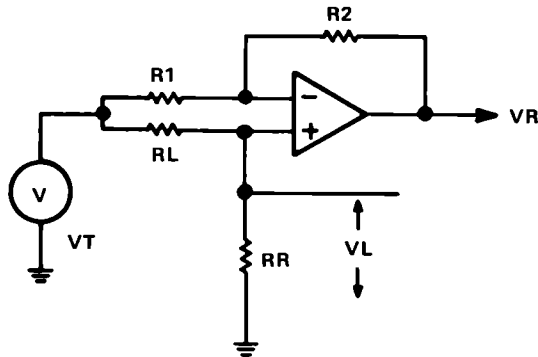


FIGURE 17 – EQUIVALENT CIRCUIT FOR TWO-TO-FOUR WIRE HYBRID

Control Logic

The circuitry that composes this block performs the call establishment “handshake” that occurs between two modems, selects the correct operating mode and generates the Data Set Ready (DSR) and Clear To Send (CTS) signals for a RS-232C standard interface. The control logic may be implemented using various techniques, such as random logic, a single-chip microcomputer, or a memory-mapped microprocessor-based system. Refer to Section 3.5 for further details on modem control.

3.3.2.2 Transmitter Output Level

In data communications, it is desirable for the signal level to be -12 dBm when measured at the Central Office (CO). A conservative design would neglect attenuation in the telephone line and not permit the transmit level to exceed -12 dBm at the user’s end of the local loop. However, Part 68 of FCC’s regulations has taken into account the signal loss due to attenuation and established three methods of transmit level control using different direct connect wiring arrangements:

1. Permissive
2. Programmable
3. Fixed loop loss

Permissive

An arrangement that “permits” the transmit level of a modem to be fixed at no greater than -9 dBm regardless of loop loss.

Programmable

An arrangement that allows the transmit level to be “programmed” in 1 dBm steps from 0 to -12 dBm using a “programming” resistor supplied by the telephone company. The value of this resistor represents the local loop loss and is defined in Part 68 of the FCC’s regulations.

Fixed Loop Loss

An arrangement that permits a maximum adjustable level of no greater than -4 dBm by placing a resistive attenuator in the signal path to prevent the transmit level from exceeding -12 dBm at the Central Office (CO). Unfortunately, the received signal is also unnecessarily attenuated.

The user needs to incorporate some method of transmit level control between the TMS99532 and the transmitter input of the two-to-four wire hybrid that meets the requirements of the direct connect interface selected. Most modems are connected to a permissive or programmable arrangement. The transmitter output signal (TXA) of the

TMS99532 has a DC offset and cannot drive impedances less than 20K ohms. It is necessary to capacitively couple this output to the gain determining stage. It is also possible to use this control stage to compensate for the variations in transmitter output level between devices as well as to compensate for the transformer losses of the hybrid.

3.3.2.3 Receiver Input Level

The two-to-four wire hybrid discussed earlier (Figure 15) has a gain of 6 dBm in the receiver input path. Depending upon the transformer losses and the particular application, it is sometimes necessary to adjust the analog signal level applied to the RCVA pin of the TMS99532 modem so that the -12 dBm maximum received signal level is not exceeded. In most applications, the received signal path is adjusted with a fixed resistive divider. With this device, a -12 dBm received signal at "TIP" and "RING" corresponds to a -12 dBm reading at the RCVA pin of the TMS99532 modem. If the RCVA input signal is too large, the internal filters of the TMS99532 will start to saturate and clip the signal. Therefore, it is necessary to take precautions so that modem performance will not be degraded at large signal levels.

3.3.2.4 Direct Connect Design with Registered Protective Circuit

Figure 18 presents a direct connect design utilizing a FCC-approved Registered Protective Circuit and a RS-232C standard interface. Refer to Section 3.3.3 for details concerning relevant RS-232C signals.

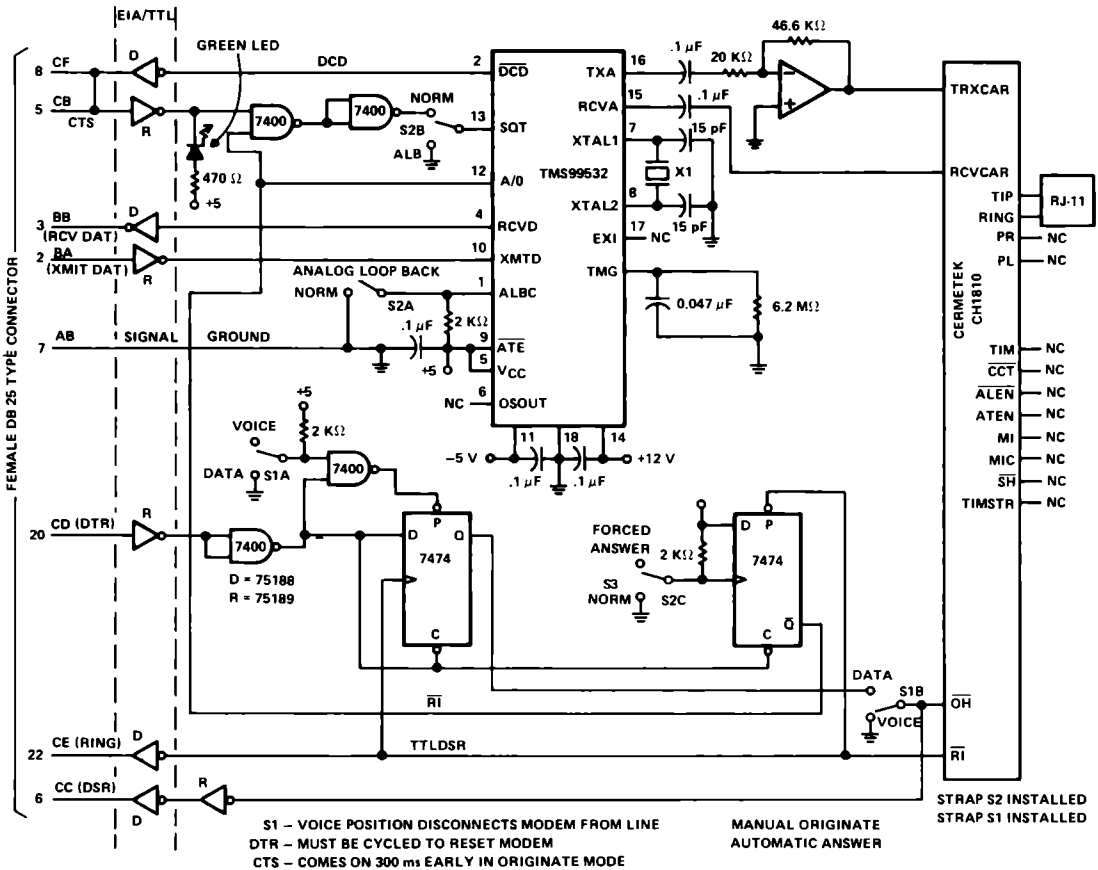


FIGURE 18 - EXAMPLE OF DIRECT CONNECTION WITH REGISTERED PROTECTIVE CIRCUIT

3.3.3 RS-232C Interface

The RS-232C interface is a specification of the Electronic Industries Association (EIA) that determines a standard interconnect scheme between data terminal equipment (DTE) and data communications equipment (DCE). Although the RS-232C has been a popular interface between low speed modems and data terminals, the TMS99532 modem does not directly support this interface because it was designed as part of the DTE rather than as a separate unit of DCE. Therefore only nine of the twenty-one signals in the RS-232C interface are actually required. These signals are described below:

1. CF: Data Carrier Detect – Indicates that a valid carrier has been received from a remote modem.
2. CB: Clear To Send – Indicates that it is alright to send data. (CTS)
3. BB: Received Data Signal Path – Path by which received data that has been demodulated by the modem is transferred to the DTE.
4. BA: Transmitted Data Signal Path – This signal is generated by the DTE so that the modem can modulate the data for transmission.
5. AB: Signal Ground – Provides a common potential reference for the other control signals.
6. CD: Data Terminal Ready – The main signal provided by the terminal to control the connection between the modem and the telecommunications network.
7. CE: Ring Indicator – This signal is provided by the DAA to indicate to the terminal that a ringing signal is being received.
8. CC: Data Set Ready – Indicates that the modem is connected to the telephone line. It does not indicate whether or not there is a valid carrier or if it is "Clear To Send". (DSR)
9. AA: Protective Ground

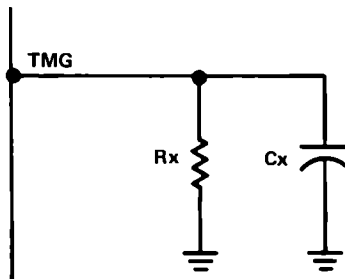
The appropriate timing sequences for these control signals are described in detail in Bell Tech Pub 41106. The RS-232C signals may be implemented with either microcomputer software or discrete logic.

3.4 CARRIER DETECT TIMING

The carrier detect function (as described in Section 2.8) is implemented by an energy detector (provided by the automatic gain control (AGC) circuit), a signal quality circuit and a carrier detect timing circuit (TMG connection). To summarize, three conditions must be met before the TMS99532 modem will acknowledge that it is receiving a valid carrier:

1. There must be in-band energy greater than turn-off energy level. (See Section 4.7.2.)
2. This in-band energy must be present for the duration of the carrier detect turn-on time, i.e., typically 100 milliseconds to 1 second.
3. The TMS99532 must receive a continuous mark signal for the duration of the carrier detect turn-on time so that the modem will not demodulate noise. Once the carrier detect circuit has turned on, any in-band energy greater than the turn-off energy level will maintain its operation. (See Section 4.7.2.)

The carrier detect timing can be set to meet the needs of a particular application by means of a parallel resistor/capacitor timing circuit connected between the TMG pin and ground. Both the carrier detect turn-on and turn-off times may be selected independently by varying the values of the resistor and capacitor shown in Figure 19. For acoustic coupling applications, the turn-on times can be quite long and require minimal accuracy.



NOTE: In all applications, the TMG pin should have a parallel resistor/capacitor connection to ground. In addition, Rx should never be smaller than 4.7 MΩ. The TMS99532 modem will not operate properly if the TMG pin is tied off or left floating.

FIGURE 19 – TMG PIN CONNECTION FOR CARRIER DETECT TIMING

Table 5 gives some representative resistor/capacitor values for obtaining various carrier detect turn-on and turn-off times. These values are for approximation purposes only and may produce times that vary as much as 30% from the times given. The turn-on/turn-off ratio normally varies from 2 to 20. Values from 2 to 10 are preferred in DAA configurations and values from 10 to 20 are normally used in acoustic coupling applications.

If greater accuracy in the carrier detect timing is desired, then the user should choose resistor/capacitor values that set the minimum turn-on and turn-off times. The appropriate values are as follows:

Turn-on = 40 ms
 Turn-off = 25 ms
 $R_x = 4.7 \text{ M}\Omega$
 $C_x = 0.009 \text{ }\mu\text{F}$

An external timer may then be connected to the $\overline{\text{DCD}}$ pin to allow the user to set the carrier detect turn-on and turn-off times to any desired value greater than or equal to these times but not shorter. An example of a simple timer circuit is shown in Figure 20.

TABLE 5 - REPRESENTATIVE RESISTOR/CAPACITOR VALUES FOR CARRIER DETECT TURN-ON/TURN-OFF TIMES*

$C_x (\mu\text{F})$	$R_x (\text{M}\Omega)$				Turn-on	Turn-off	Times (ms)
	4.7	7.2	10.2	12.0			
0.100	320	500	760	920	Turn-on	Times (ms)	
	60	60	60	60	Turn-off		
0.047	150	230	350	420	Turn-on	Times (ms)	
	40	40	40	40	Turn-off		
0.017	60	95	140	160	Turn-on	Times (ms)	
	30	30	30	30	Turn-off		
0.009	40	55	75	90	Turn-on	Times (ms)	
	25	25	25	25	Turn-off		

* These values may vary as much as 30%. If greater accuracy is desired, use the circuit shown in Figure 20.

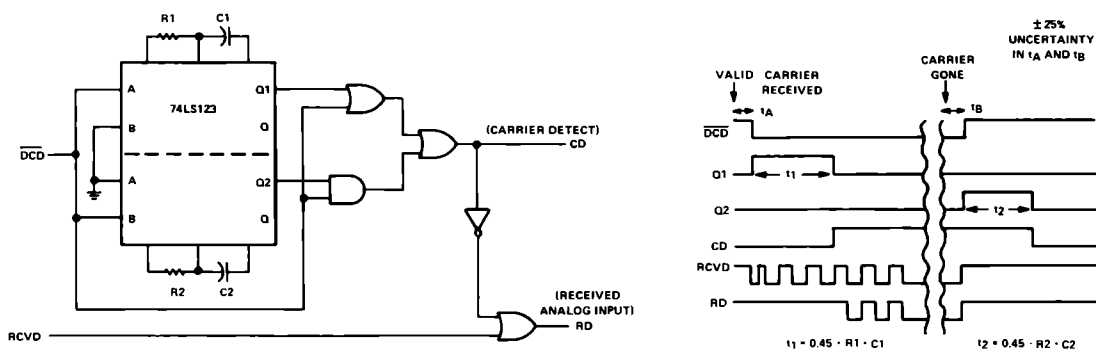


FIGURE 20 - $\overline{\text{DCD}}$ PIN CONNECTION FOR EXTERNAL TIMER CIRCUIT

3.5 MODEM CONTROL

This section discusses the operational sequences for the TMS99532 modem. First, however, a few helpful comments about pin settings will be made.

Pin 10, XMTD, is the serial, digital data input line. If EIA RS-232C signal levels are required, a line receiver such as a SN75189 should be implemented.

Pin 4, RCVD, is the serial data output signal (demodulated data). If EIA RS-232C signal levels are required, a SN75188 line driver should be implemented.

Pin 2, $\overline{\text{DCD}}$, is the data carrier detect signal. If EIA RS-232C signal levels are required, a SN75188 line driver should be implemented.

Pin 13, SQT, is the transmitter squelch. When active (high), the analog transmitter is off and no signal appears on the TXA pin. In the answer mode, SQT must go inactive (low) two seconds after the modem enters the off-hook condition. This is to comply with the two-second billing delay requirement stated in Part 68 of the FCC's regulations. In the originate mode, SQT should go inactive (low) immediately after $\overline{\text{DCD}}$ goes active (low) in order to prevent the transmitter from being turned on before a valid carrier is detected from the remote modem.

Pin 9, $\overline{\text{ATE}}$, is the answer tone enable. It should be connected to a logic one (inactive) since Bell 103 type modems use the 2225-Hz mark frequency as the answer tone.

Pin 12, A/O, selects the answer mode (logic zero) or the originate mode (logic one).

Pin 1, ALB, is the analog loopback test mode. For normal operation, it should be inactive (logic zero).

Pin 17, EX1, is an external analog signal input. It may be implemented with a dialer, such as the TMS99531.

Pin 6, OSCOUT, is the master 4.032-MHz oscillator output. It is not required for normal operation.

Pins 7 and 8, XTAL2 and XTAL1, are for an external crystal connection. The TMS99532 has an internal oscillator and a clock generator that may be controlled by an external crystal. The internal oscillator may be disabled and a frequency source injected directly into the chip. Refer to Section 2.2 for details.

3.5.1 Idle Condition

When the TMS99532 modem is in the idle condition, the following initial conditions permit easy entry into the data mode:

1. The modem should be in the on-hook condition.
2. The SQT input (pin 13) should be at a logic one to squelch the transmitter.
3. The A/O input (pin 12) should be at a logic one (for origination mode).
4. The $\overline{\text{ATE}}$ input (pin 9) should be at a logic one.
5. The ALB input (pin 1) should be at a logic zero.
6. The control logic should have the Data Set Ready (DSR) and the Clear To Send (CTS) output signals in the off or unasserted state.

3.5.2 Call Establishment Sequence

Before data can be transmitted and received, a connection between the two modems must be established through the telephone network. A call may be originated either manually (by a person) or automatically (by an automatic calling unit (ACU)). When an answer is detected by the originating modem, the modem is placed in the data mode. Similarly, a call may be answered either manually or automatically and the modem placed in the data mode at the appropriate time. The call establishment sequence for the TMS99532 modem is illustrated in Figure 21 and described below:

1. Call is placed to the remote modem.
2. Ringing occurs at the answering end.
3. Answering modem is enabled to answer the call by asserting DTR.
4. Answering modem goes off-hook upon completion of ringing.
5. Answering modem waits two seconds for the billing delay (t_{BD}) specified in Part 68 of the FCC's regulations.
6. Answering modem turns on transmitter to send an answering mode mark (2225 Hz).
7. The mark (2225 Hz) answer tone is received by the originating modem and the originating modem is placed in the data mode.
8. The originating modem activates its carrier detect ($\overline{\text{DCD}}$) signal (by a logic zero) after its carrier detect delay (t_{DCD}).

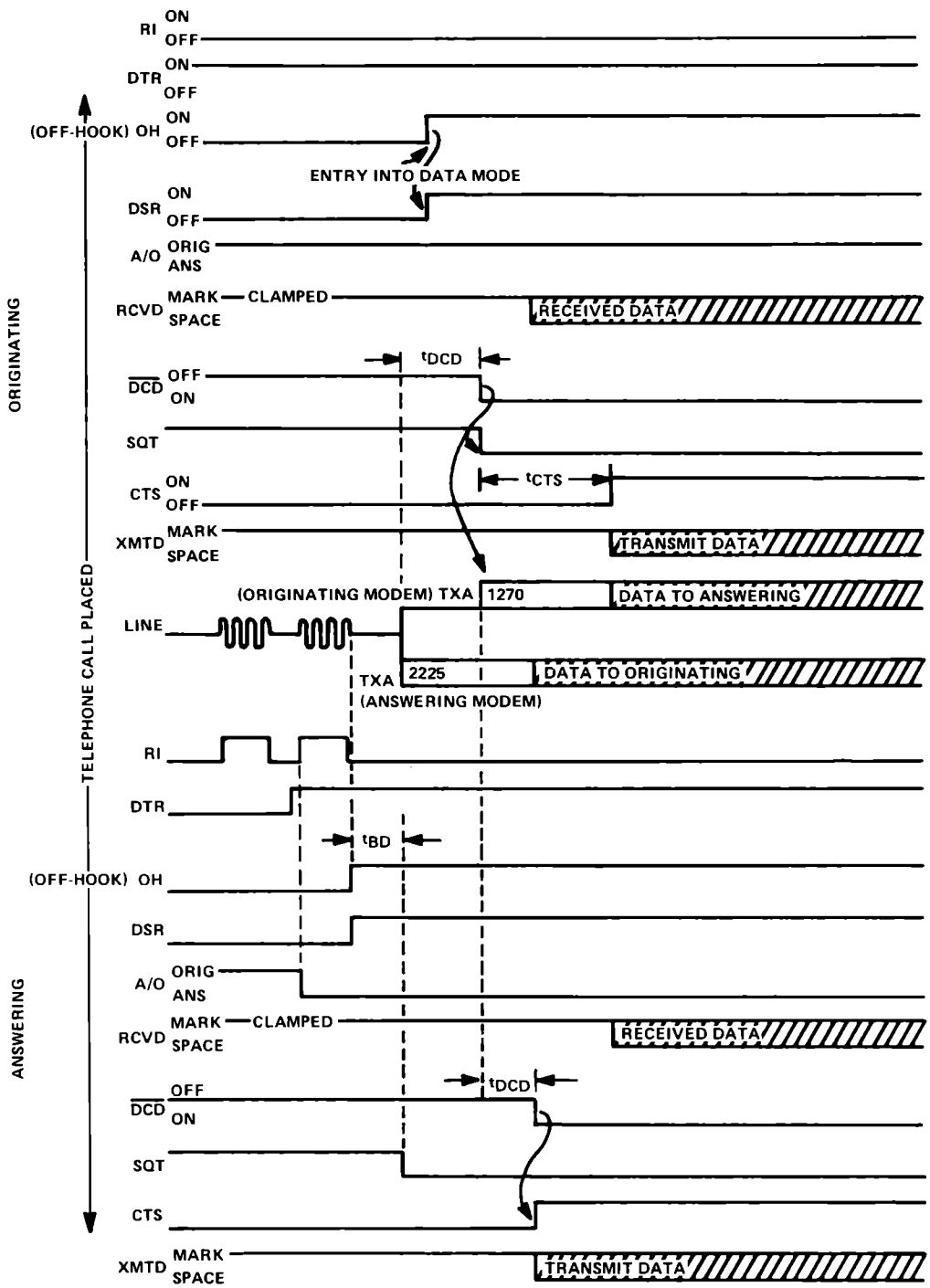


FIGURE 21 - CALL ESTABLISHMENT TIMING DIAGRAM

9. Originating modem unquelsches its transmitter, sends an origination mode mark (1270 Hz) and starts a 200-350 millisecond Clear To Send delay (t_{CTS}).
10. Answering modem receives originate mode mark signal (1270 Hz).
11. Answering modem activates its carrier detect (\overline{DCD}) signal (by a logic zero) after its carrier detect delay (t_{DCD}).
12. Answering modem activates its Clear To Send signal (by a logic one). Answering modem may now start data communication.
13. Clear To Send delay of the originating modem expires. The originating modem may now start data communication.

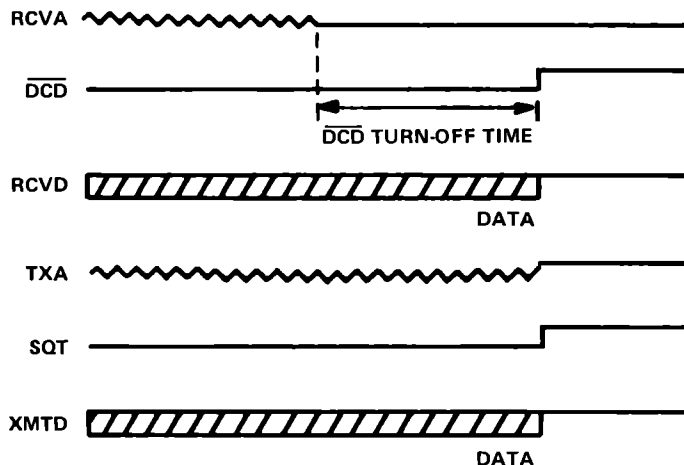
During the call establishment sequence, the logic must control the SQT and A/O pins of the TMS99532 modem, as shown in Figure 21, so that the correct mode is selected and the billing delay requirement is satisfied.

3.5.3 Call Termination Procedures

Depending upon the requirements of the particular application, there are several call termination procedures currently in use. Modem manufacturers offer the user these options by means of jumper wires or switch settings. Four call termination procedures are discussed in this section. The TMS99532 modem requires external logic to implement the Data Terminal Not Ready, Long Space Disconnect, and Abort Disconnect call termination procedures.

3.5.3.1 Loss of Carrier Disconnect

The TMS99532 modem will go on-hook when a loss of received carrier energy is detected. The loss of carrier disconnect sequence begins when the received signal level goes below -48 dBm. Figure 22 shows that the modem begins a carrier detect turn-off time delay that is determined by the values of Rx and Cx (see Section 3.4) on the TMG pin. If the carrier is off longer than the turn-off time delay, then the TMS99532 modem immediately clamps the RCVD signal to a mark and deactivates the \overline{DCD} pin (by a logic one) to show a loss of carrier. When this happens, the SQT pin should be activated (by a logic one) in order to turn-off the transmit carrier. The modem is then normally disconnected from the network.



NOTE: INITIAL CONFIGURATION:

SQT	0
ALB	0
A/O	Any value
ATE	1
XMTD	Any value

FIGURE 22 - CARRIER FAIL DISCONNECT TIMING DIAGRAM

3.5.3.2 Data Terminal Not Ready (DTR Not Activated)

The Data Terminal Ready (DTR) signal must be activated in order for the modem to remain connected to the telephone line. Therefore, by placing the modem on-hook, DTR will not be activated and the telephone connection will be terminated. This disconnection procedure is the only method that the DTE has of terminating a call.

3.5.3.3 Long Space Disconnect

There are receive and transmit long space disconnect options as follows:

Receive

This sequence requires that the received data be monitored for the presence of a spacing condition (logic zero) that is at least 1.7 seconds in duration. After 1.7 seconds of continuous spacing, the modem goes off-hook. The TMS99532 modem requires external logic to monitor RCVD for 1.7 seconds of space before disconnection.

Transmit

This sequence is similar to the Data Terminal Not Ready sequence. When DTR is not activated, the modem transmits a spacing condition (logic zero) for two to four seconds before going to the on-hook condition. The transmitted data going to the TMS99532's XMTD pin must be controlled by logic in order to implement this termination procedure.

3.5.3.4 Abort Disconnect

This sequence is usually not an option and is employed when the Data Set Ready (DSR) signal is activated. If a valid carrier is not received in 10 to 18 seconds, the modem goes to the on-hook condition. This sequence should be implemented on automatic answer modems in case the modem is called by mistake, i. e., the modem will not stay connected to the telephone line in anticipation of a received carrier.

3.5.4 External Tones

The EXI pin facilitates complete support for touch tone dialing. Figure 23 shows the connecting circuitry for implementing the TMS99531 dialer as an external tone input to the TMS99532 modem. The EXI mode is enabled when $\overline{ATE} = 0$, $SQT = 1$, and $ALB = 0$.

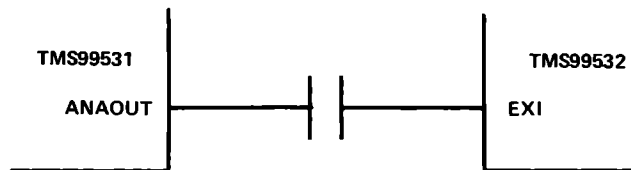


FIGURE 23 – CONNECTION OF TMS99532 MODEM TO TMS99531 DIALER

3.6 MODEM PERFORMANCE

A widely used means of measuring modem performance is a bit error rate (BER) test. Figure 24 shows a test configuration whereby a signal is received by the modem under test at a specific signal level and at a set signal-to-noise ratio (SNR). The bit error rate is the result of the number of bits received in error divided by the total number of bits transmitted. The test system generates a 511-bit pseudo-random bit pattern in order to modulate a standard transmitter. The transmit signal level is set by an attenuator and sent through a telephone line simulator or sent directly to the modem under test for back-to-back simulation. A SEG 3002 line simulator is typically used to distort the signal in a manner similar to a bad telephone line. The signal is then summed with a white noise source of fixed amplitude (by an attenuator) and bandwidth (50 kHz). The transmitter signal level is measured directly by an RMS voltmeter but the noise is filtered through a C-message filter before it is measured. As a result, the noise level is calibrated to voice band energy but the modem must still reject all 50 kHz of noise. The modem's own transmitter is summed into the receive signal path to simulate poor two-to-four wire hybrid performance since a good modem

receiver should completely reject its own transmitter. Finally, the demodulated data is compared to the original transmitted data and the errors are counted. This is a relatively severe test and gives a good comparison of modem performance.

Figure 25 shows the measured bit error rate (BER) of the TMS99532 versus the signal-to-noise ratio (SNR) in dB. For a received signal level of -35 dBm, the TMS99532 was tested in a back-to-back configuration as well as over a SEG 3002 telephone line simulator. The results are shown for both the answer and originate modes of operation. Note that the TMS99532 performs slightly better over a distorted line than in a back-to-back configuration because of built-in equalization (both amplitude and group delay equalization). Also, intentional mark bias distortion has been integrated into the TMS99532 design in order to compensate for the phone lines' natural space bias distortion.

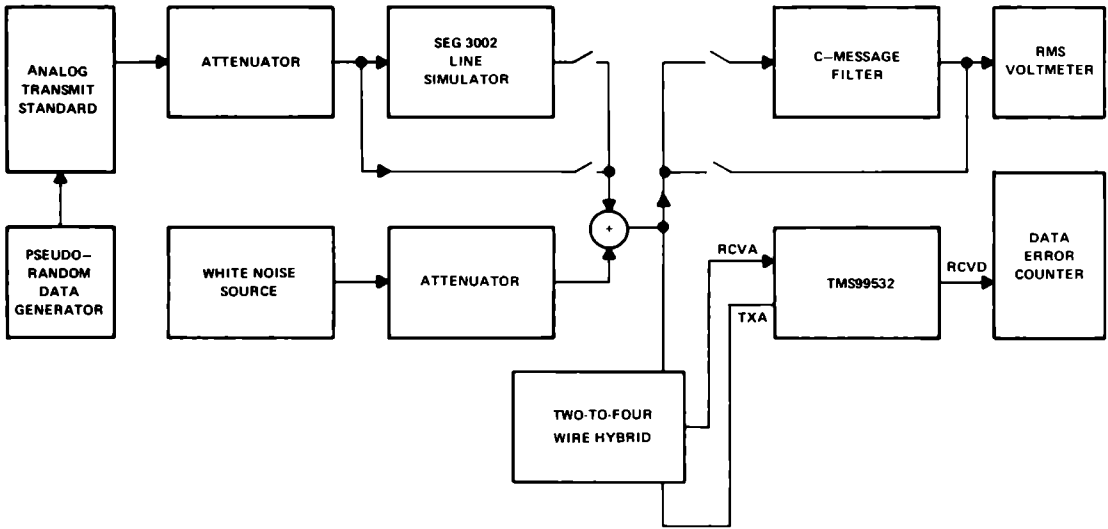


FIGURE 24 - MODEM TEST SET

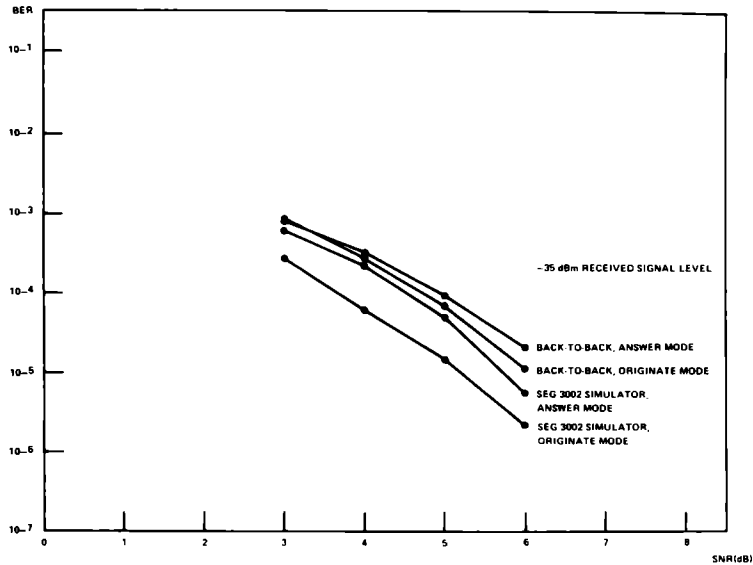


FIGURE 25 - TMS99532 BIT ERROR RATE CURVES (TYPICAL)

4. TMS99532 PRELIMINARY ELECTRICAL SPECIFICATIONS

4.1 ABSOLUTE MAXIMUM RATINGS OVER OPERATING FREE-AIR TEMPERATURE RANGE (UNLESS OTHERWISE NOTED)*

Supply voltage, V_{CC}^{**}	-0.3 to 20 V
Supply voltage, V_{DD}^{**}	-0.3 to 25 V
Supply voltage, V_{SS}^{**}	-0.3 to 20 V
All input voltages	-0.3 to 20 V
Output voltages	-0.3 to 7 V
Continuous power dissipation	350 mW
Operating free-air temperature range	0 °C to 70 °C
Storage temperature range	-55 °C to 125 °C

* Stress beyond these absolute maximum ratings may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions beyond those indicated under "RECOMMENDED OPERATING CONDITIONS" is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect the device reliability.

** Under "ABSOLUTE MAXIMUM RATING", voltage supply values are with respect to the normally most negative supply voltage, V_{BB} (substrate). Throughout the remainder of this data sheet, voltage values are with respect to V_{SS} (ground reference), unless otherwise noted.

4.2 RECOMMENDED OPERATING CONDITIONS

PARAMETER	MIN	NOM	MAX	UNIT
Supply voltage, V_{CC}	4.75	5.00	5.25	V
Supply voltage, V_{DD}	11.40	12.00	12.60	V
Supply voltage, V_{BB}	-5.25	-5.00	-4.75	V
Supply voltage, V_{SS}		0		V
High-level input voltage, V_{IH} (all inputs except XTAL1)	2.0	2.4	V_{CC}	V
High-level input voltage, V_{IHc} (XTAL1)	2.4	3.0	V_{CC}	V
Low-level input voltage, V_{IL} (all inputs)	V_{SS}	0.6	0.8	V
Input clock frequency (+/- 0.01%)		4.032		MHz
Operating free-air temperature, T_A	0	25	70	°C

4.3 ELECTRICAL CHARACTERISTICS (DIGITAL) OVER FULL RANGE OF RECOMMENDED CONDITIONS (UNLESS OTHERWISE NOTED)*

PARAMETER	TEST CONDITION	MIN	NOM	MAX	UNITS
I_{CC} Supply current	$V_{CC} = \text{MAX}$		15.0	20.0	mA
I_{DD} Supply current	$V_{DD} = \text{MAX}$		10.0	20.0	mA
I_{BB} Supply current	$V_{BB} = \text{MAX}$		10.0	25.0	μA
I_I Digital input current	$V_I = V_{SS}$ to V_{CC}	-10		10	μA
X_I XTAL1/CLKIN input current	$V_I = V_{SS}$ to V_{CC}	-50		50	μA
I_{OZ} TXA, RCVD off-state leakage current	$V_I = V_{SS}$ to V_{CC}	-20		20	μA
V_{OH} DCD, RCVD high-level output	$I_{OH} = -400 \mu\text{A}$	2.2		V_{CC}	V
V_{OL} DCD, RCVD low-level output	$I_{OH} = 2.0 \text{ mA}$	V_{SS}		0.6	V
V_{OHC} OSCOUT high-level output	$I_{OH} = -400 \mu\text{A}$	2.0		V_{CC}	V
V_{OLC} OSCOUT low-level output	$I_{OH} = 2.0 \text{ mA}$	V_{SS}		0.6	V

* All typical values are at $T_A = 25^\circ\text{C}$ and nominal voltages.

4.4 CLOCK CHARACTERISTICS AND TIMING REQUIREMENTS OVER FULL RANGE OF RECOMMENDED OPERATING CONDITIONS

The TMS99532 can use either its internal oscillator or an external source for a clock.

4.4.1 Internal Clock Option

The internal oscillator is enabled by connecting a parallel resonant crystal across XTAL1/CLKIN and XTAL2. (See Figure 26). The frequency of OSCOUT is equal to the fundamental crystal frequency.

PARAMETER		MIN	NOM	MAX	UNIT
f_x	Crystal frequency (+/- 0.01% accuracy)		4.0320		MHz
C1	Stabilizing capacitance*	10	15	25	pF
C2	Stabilizing capacitance*	10	15	25	pF

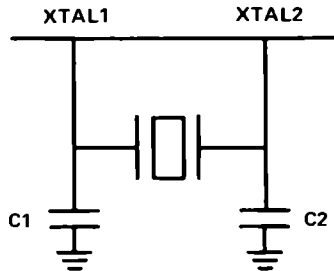


FIGURE 26 – CRYSTAL OSCILLATOR CONNECTION

*C1 and C2 represent the total capacitance on these pins including stray and parasitic.

4.4.2 External Clock Option

An external frequency source may be used by injecting the frequency directly into XTAL1/CLKIN. (See Figure 27.) However, the external frequency must conform to the following specifications. The frequency of OSCOUT is equal to that of the injected signal.

PARAMETER		MIN	NOM	MAX	UNIT
f_{ext}	External source frequency (+/- 0.01%)		4.0320		MHz
t_{R1}	Input oscillator rise time		10	12	ns
t_{wh1}	Input oscillator pulse width high	100	124	148	ns
t_f1	Input oscillator fall time		10	12	ns
t_{wl1}	Input oscillator pulse width low	100	124	148	ns

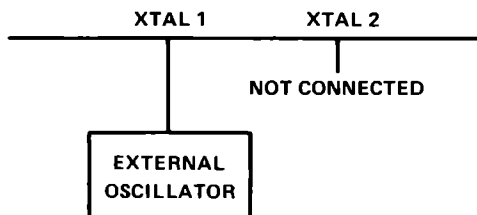


FIGURE 27 – EXTERNAL OSCILLATOR CONNECTION

4.5 TIMING REQUIREMENTS AND SWITCHING CHARACTERISTICS OVER RECOMMENDED OPERATING CONDITIONS

4.5.1 Digital Switching Characteristics Over Recommended Operating Conditions

PARAMETER		MIN	NOM	MAX	UNIT
t _{D1}	Delay time, CLKIN to OSCOUT	0		90	ns
t _{C2}	OSCOUT CYCLE TIME: External clock source Internal oscillator XTAL FREQ = f _x	f _{ext}	f _{ext}	f _{ext}	MHz
		f _x	f _x	f _x	MHz
t _{r2}	OSCOUT rise time		20	40	ns
t _{wh2}	OSCOUT pulse width high		104		ns
t _{f2}	OSCOUT fall time		10	40	ns
t _{wl2}	OSCOUT pulse width low		104		ns

4.6 TRANSMITTER SPECIFICATIONS

4.6.1 Transmitter Input Requirements Over Full Range of Operating Conditions

PARAMETER		MIN	NOM	MAX	UNITS
t _w (XMTD MARK)	XMTD High-level width		3.33		ms
t _w (XMTD SPACE)	XMTD Low-level width		3.33		ms
f _{EXI}	EXI Frequency		3.0		kHz
V _I (EXI)	EXI Voltage level		1.40		V _{p-p}

4.6.2 Transmitter Characteristics at Nominal Operating Conditions

PARAMETER		MIN	NOM	MAX	UNIT
TXA Frequency:					
f _(TOM)	Originate mark frequency (Note 1)	1268	1270	1272	Hz
f _(TOS)	Originate space frequency (Note 1)	1068	1070	1072	Hz
f _(TAM)	Answer mark frequency (Note 1)	2222	2225	2228	Hz
f _(TAS)	Answer space frequency (Note 1)	2022	2025	2028	Hz
f _(ATE)	Answer tone enable (Note 1)	2097	2100	2103	Hz
TXA Output voltage levels:					
V _{dc} (TXA)	TXA DC offset voltage (Note 1)		5.5		V
V _{ac} (TXA)	TXA carrier voltage (Note 2)	0.6	1.0	1.3	V _{p-p}
TXA 2nd Harmonic energy (down from fundamental)			-50		dB

NOTE 1. The following table is used to generate the carrier frequencies when ALB=0 and SQT=0:

MODE	XMTD	A/O	ATE	FREQUENCY
ANSWER	0	0	0	2025 Hz
	1	0	0	2225 Hz
ORIGINATE	0	1	0	1070 Hz
	1	1	0	1270 Hz
ATE	X	0	1	2100 Hz

The voltage levels are measured at all frequencies with the loading shown in Figure 28.

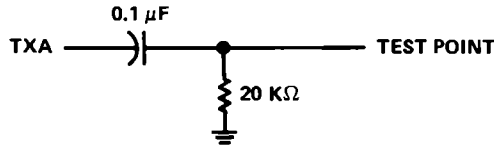


FIGURE 28 – LOADING FOR VOLTAGE LEVEL MEASUREMENT

NOTE 2. The TXA carrier voltage levels are specified in volts peak-to-peak. The typical nomenclature for these values is in dBm, i.e., the energy of the signal given a 600 ohm loading. With a given loading, there is a one-to-one correspondence between voltage levels and dBm. The specification is given in volts because the TMS99532 does not present a 600 ohm load and, strictly speaking, there is not a correspondence with dBm values. However, with an impedance matching circuit (with a voltage gain of 1), a correspondence does exist. The equation to convert the peak-to-peak voltage levels to dBm energy levels is:

$$P(\text{dBm}) = 20 \cdot \text{Log}_{10} ((0.3535 \cdot \text{Volt(p-p)})/0.774597).$$

This equation assumes very low distortion of the carrier sine wave.

4.7 RECEIVER SPECIFICATIONS

4.7.1 Receiver Input Requirements Over Full Range of Operating Conditions

PARAMETER		MIN	TYP	MAX	UNITS
RCVA Input Frequencies:					
f(ROM)	Originate mark frequency		2225		Hz
f(ROS)	Originate space frequency		2025		Hz
f(RAM)	Answer mark frequency		1270		Hz
f(RAS)	Answer space frequency		1070		Hz
V _I (RCVA)	RCVA Carrier voltage level (Note 3)	400	700		mV _{p-p}

4.7.2 Receiver Characteristics Over Nominal Operating Conditions

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNIT
D _I (BDO) Receiver bias distortion (originate mode high level)	(Note 4)	0.0	7.0	17	%
D(BDO) Receiver bias distortion (originate mode low level)	(Note 4)	0.0	10	17	%
D(BDA) Receiver bias distortion (answer mode high level)	(Note 4)	-5	4.0	15	%
D(BDA) Receiver bias distortion (answer mode low level)	(Note 4)	-5	8.0	15	%
Receiver Isochronous distortion (high level)	(Note 4)	0.0	5.0	9.0	%
Receiver Isochronous distortion (low level)	(Note 4)	0.0	8.0	11	%
Carrier detect turn-on level	(Note 3)		25		mV _{p-p}
Carrier detect turn-off level	(Note 3)		9.0		mV _{p-p}
Carrier detect turn-on time	(Note 5)		45		ms
Carrier detect turn-off time	(Note 5)		25		ms

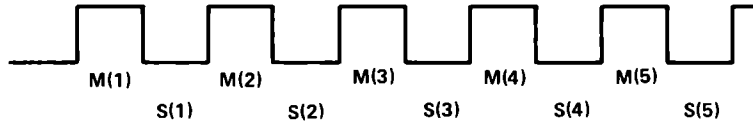
NOTE 3. The RCVA carrier voltage levels are specified in volts peak-to-peak. The typical nomenclature for these values is in dBm, i.e., the energy of the signal given a 600-ohm loading. With a given loading, there is a one-to-one correspondence between voltage levels and dBm. The specification is given in volts because the TMS99532 does not present a 600-ohm load and, strictly speaking, there is not a correspondence with dBm values. However, with an impedance matching circuit (with a voltage gain of 1), a correspondence does exist. The equation to convert the peak-to-peak voltage levels to dBm energy levels is:

$$P(\text{dBm}) = 20 \cdot \text{Log}_{10} ((0.3535 \cdot \text{Volt(p-p)})/0.774597).$$

This equation assumes very low distortion of the carrier sine wave.

NOTE 4. The distortion tests are made under the following conditions:

- 1) The received signal levels are at 0.70 V_{p-p} (-10 dBm) and at 0.070 V_{p-p} (-30 dBm).
- 2) The received signal is a "back-to-back" signal. No distortion is added to the signal.
- 3) An alternating pattern of marks and spaces is applied to the device. The mark and space pulse widths are accurately measured on 10 bits of data. The distortion measurements are then calculated using the following equations:



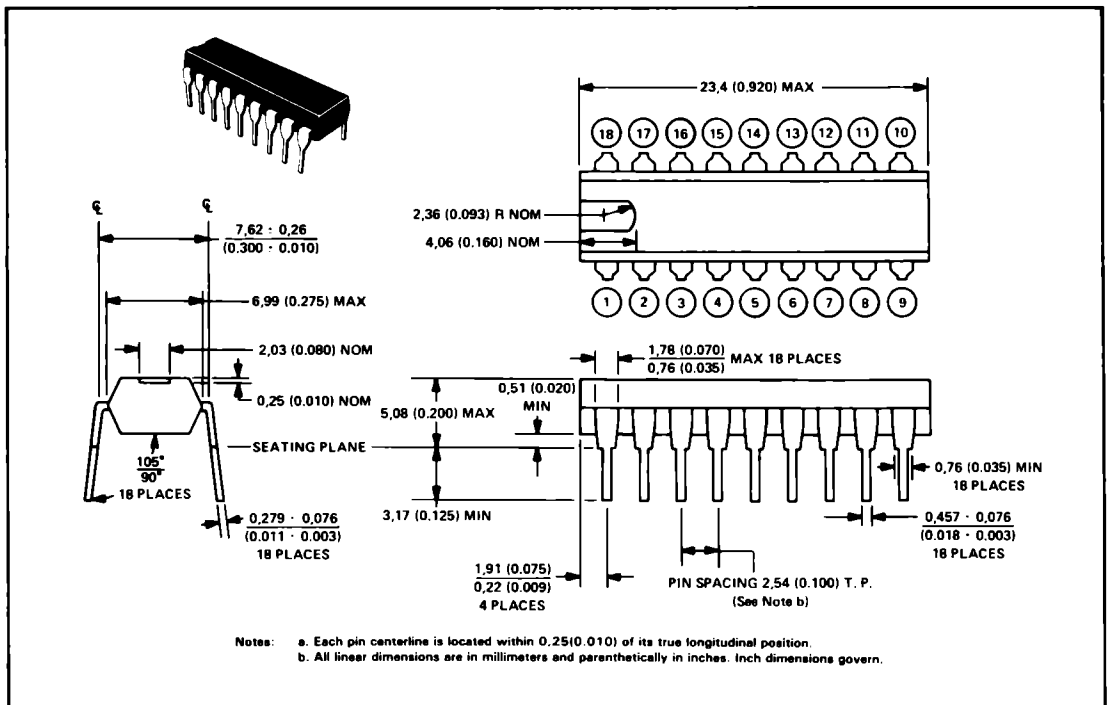
$$\begin{aligned}
 \text{MTOT} &= \text{M}(1) + \text{M}(2) + \text{M}(3) + \text{M}(4) + \text{M}(5) \\
 \text{STOT} &= \text{S}(1) + \text{S}(2) + \text{S}(3) + \text{S}(4) + \text{S}(5) \\
 \text{M(AVE)} &= \text{MTOT}/5 \\
 \text{S(AVE)} &= \text{STOT}/5 \\
 \text{W(AVE)} &= \text{M(AVE)} + \text{S(AVE)} \\
 \text{A} &= (\text{S}(1) \cdot \cdot 2) + (\text{S}(2) \cdot \cdot 2) + (\text{S}(3) \cdot \cdot 2) + (\text{S}(4) \cdot \cdot 2) + (\text{S}(5) \cdot \cdot 2) \\
 \text{B} &= (\text{STOT} \cdot \cdot 2)/5 \\
 \text{DEV} &= 2 \cdot \text{SQRT}[(\text{A}-\text{B})/5] \\
 \text{Bias distortion} &= [\text{M(AVE)} - \text{S(AVE)}]/2 \cdot \text{W(AVE)} \\
 \text{Isochronous distortion} &= (2 \cdot \text{DEV})/\text{W(AVE)}
 \end{aligned}$$

NOTE 5. These measurements are made with $R_{\text{ext}} = 4.7$ megohms and $C_{\text{ext}} = 0.009 \mu\text{F}$.

5. MECHANICAL SPECIFICATIONS

18 pin plastic packages

TMS99532 NL



TI Sales Offices

ALABAMA: *Huntsville*, 500 Wynn Drive, Suite 514 Huntsville AL 35805 (205) 837-7530

ARIZONA: *Phoenix*, P.O. Box 35160, 8102 N 23rd Ave, Suite B Phoenix AZ 85021 (602) 995-1007

CALIFORNIA: *El Segundo*, 831 S. Douglas St. El Segundo CA 90245 (213) 973-2571. *Irvine*, 17891 Cartwright Rd Irvine CA 92714 (714) 660-1200. *Sacramento*, 1900 Point West Way, Suite 171 Sacramento CA 95815 (916) 929-1521. *San Diego*, 4333 View Ridge Ave., Suite B, San Diego, CA 92123 (714) 278-9600. *Santa Clara*, 5353 Betsy Ross Dr Santa Clara CA 95054 (408) 980-9000. *Woodland Hills*, 21220 Erwin St. Woodland Hills CA 91367 (213) 704-7759

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GEORGIA: *Atlanta*, 3300 Northeast Expwy Building 9 Atlanta GA 30341 (404) 452-4600

ILLINOIS: *Arlington Heights*, 515 W Algonquin Arlington Heights IL 60005 (312) 640-2934

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MARYLAND: *Baltimore*, 1 Rutherford Pl., 7133 Rutherford Rd Baltimore MD 21207 (301) 944-8600

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MICHIGAN: *Farmington Hills*, 33737 W 12 Mile Rd Farmington Hills MI 48018 (313) 553-1500

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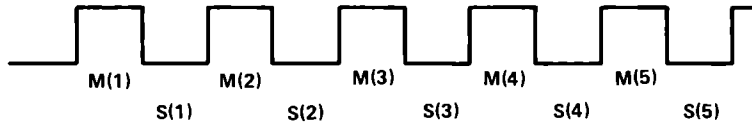
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TEXAS INSTRUMENTS



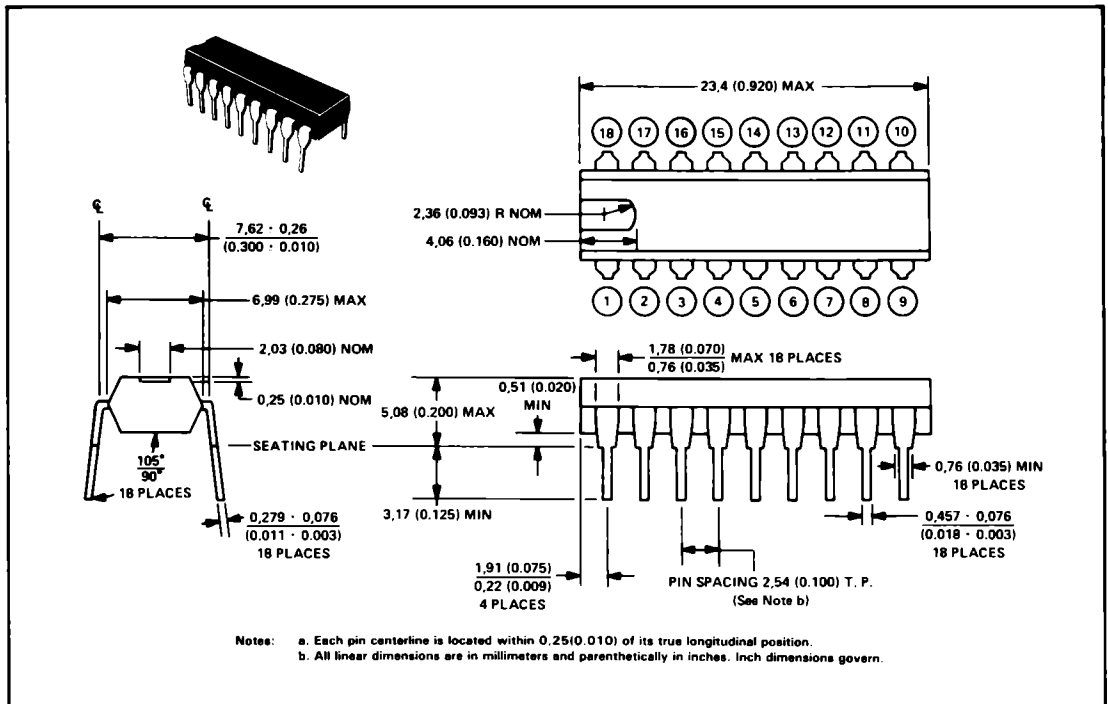
$$\begin{aligned}
 \text{MTOT} &= \text{M}(1) + \text{M}(2) + \text{M}(3) + \text{M}(4) + \text{M}(5) \\
 \text{STOT} &= \text{S}(1) + \text{S}(2) + \text{S}(3) + \text{S}(4) + \text{S}(5) \\
 \text{M(AVE)} &= \text{MTOT}/5 \\
 \text{S(AVE)} &= \text{STOT}/5 \\
 \text{W(AVE)} &= \text{M(AVE)} + \text{S(AVE)} \\
 \text{A} &= (\text{S}(1) \cdot \cdot 2) + (\text{S}(2) \cdot \cdot 2) + (\text{S}(3) \cdot \cdot 2) + (\text{S}(4) \cdot \cdot 2) + (\text{S}(5) \cdot \cdot 2) \\
 \text{B} &= (\text{STOT} \cdot \cdot 2)/5 \\
 \text{DEV} &= 2 \cdot \text{SQRT}[(\text{A}-\text{B})/5] \\
 \text{Bias distortion} &= |\text{M(AVE)} - \text{S(AVE)}|/2 \cdot \text{W(AVE)} \\
 \text{Isochronous distortion} &= (2 \cdot \text{DEV})/\text{W(AVE)}
 \end{aligned}$$

NOTE 5. These measurements are made with $R_{\text{ext}} = 4.7$ megohms and $C_{\text{ext}} = 0.009 \mu\text{F}$.

5. MECHANICAL SPECIFICATIONS

18 pin plastic packages

TMS99532 NL



TEXAS
INSTRUMENTS

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Semiconductor Group

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