X-10® POWERHOUSE ™

NUMBER ONE IN HOME AUTOMATION

TECHNICAL NOTE

The X-10 POWERHOUSE Power Line Interface Model # PL513 and Two-Way Power Line Interface Model # TW523

(for use with the RR501 Two-Way Transceiver Appliance Module)

Revision 2.4
Dave Rye

PL513/TW523
Power Line Interfaces

Introduction

The X-10 code format is the "De Facto" standard for Power Line Carrier (P.L.C.) transmission. The code format was first introduced in 1978 for the Sears Home Control System and the Radio Shack Plug 'n Power System. Since then, X-10 has developed and manufactured O.E.M.* versions of its Home Control System for many companies including Leviton Manufacturing Co., General Electric, C & K Systems, Schlage Lock Co., Stanley and Heath/Zenith Co. We also distribute the system in Canada and have manufactured O.E.M. versions of the system for Germany, Holland, France, Switzerland, Japan and Australia.

All of these systems use the X-10 code format, all are compatible and virtually all P.L.C. Home Automation Systems currently available in the USA use *X-10 POWER-HOUSE* ™ Modules developed and manufactured by X-10. It is therefore advantageous for any Home Automation System to be compatible with the X-10 standard. This enables any O.E.M. to take advantage of the very large installed base of X-10 customers as well as having access to the extensive array of different types of *X-10 POWERHOUSE* Modules available.

The X-10 code format is patented

However, in order to encourage others to take advantage of the large installed base of *X-10 POWERHOUSE* Modules and develop their own systems to control these Modules, the PL513 and TW523 Power Line Interfaces are offered as cost effective ways of coupling X-10 compatible signals onto the AC power line. Permission to transmit the X-10 code format is granted to purchasers of the PL513 and TW523 Power Line Interfaces.

The PL513 is a transmitter and the TW523 is a transmitter-receiver. Both plug into regular AC outlets and connect to the O.E.M. product via a modular RJ11 telephone jack.

Both interfaces provide an opto-coupled 60Hz. square wave, synchronized to the zero crossing point of the AC line. The O.E.M. generates X-10 compatible codes synchronized to this zero crossing point. The PL513 and TW523 then couple the X-10 codes onto the AC line. Thus all patent related criteria are satisfied within the interfaces.

This also relieves the O.E.M. of any U.L. or C.S.A. considerations as all power line connections are taken care of by the interfaces and all connections between the interfaces and the O.E.M. product are opto-coupled.

Two-Way transmission available

The TW523 is similar is concept and design to the PL513 but provides a means to transmit **and receive** X-10 codes. Any O.E.M. product designed to receive X-10 codes MUST use the TW523. X-10 will not grant permission to receive X-10 codes by any other method.

The TW523 enables an O.E.M. to develop a system to control X-10 Modules, and receive X-10 signals from remote sensors (P.I.R. motion detectors for example).

The TW523 lets the O.E.M. transmit a "polling" code to the RR501 2-Way Transceiver Appliance Module. The RR501 responds by transmitting a specific code to indicate its status (on or off). The TW523 then receives this code. When used with the RR501, the TW523 gives the O.E.M. the ability to implement a full 2-Way system with collision detection and contention resolution.

X-10 Code Transmission (PL513 and TW523)

To transmit X-10 signals the O.E.M. must supply 1 ms "envelopes" to the TX input of the interface with respect to common. These envelopes must be as close as possible to the zero crossing point of the AC line (see timing diagrams). An opto-coupled output representing the zero crossing point of the power line is provided for the O.E.M. to which X-10 codes are to be synchronized.

* O.E.M. = Original Equipment Manufacturer.

X-10 Code Reception (TW523 only)

The TW523 uses a custom proprietary I.C. to read X-10 codes from the power line. This takes a lot of burden off the microprocessor in the O.E.M. product as the O.E.M. microprocessor does not have to continuously monitor the power line and check all incoming signals (and noise) for validity. Any signals applied to the O.E.M. product are error-checked, valid X-10 codes. When a valid X-10 code is received, it is stored in the custom I.C. and applied (in envelope form) to the O.E.M. product. This output is coincident with the second X-10 transmission. (X-10 codes are always transmitted in groups of two, except for Bright and Dim see note 3, page 5).

Data sent to the O.E.M. product is valid X-10 data. The Start Code (1110) can be used to alert the O.E.M. product that an X-10 code will follow. A "1" bit from the TW523 appears as a negative going pulse 1.1 ms long, beginning approximately 100 μs after zero crossing. The O.E.M. should sample this data between 500 and 700 μs after zero crossing.

The L.E.D. on the TW523 gives a visual indication that X-10 codes are being received. The L.E.D. is illuminated when AC power is applied to the TW523, and blinks off when X-10 codes are received. The TW523 will also receive the codes it transmits, therefore the L.E.D. will also give an indication of codes being transmitted.

The ability to read X-10 codes from its own output also allows the O.E.M. to incorporate data collision detection. If the code received differs from the code transmitted, the code can be assumed to have been corrupted by noise (or another transmission) on the power line.

The Line Monitor capability of the TW523 allows the O.E.M. to ensure that the power line is free from X-10 signals before starting a transmission. This means that in a multi-transmitter system the O.E.M. can minimize contention between transmitters. For example, if after detecting that the line is free, a transmitter waits for a random number of power line half cycles before transmitting, the chance of collision is reduced. A different priority can be assigned to each transmitter by including a fixed delay before the random delay. The shorter the fixed delay, the higher the priority.

Important Safety Notice

> 0V in this product is directly connected to one side of the AC line. Therefore, for safety, an ISOLATING power transformer MUST be used when attempting any internal measurements.

The power supplies in the PL513 and TW523 are capacitively derived from, and directly referenced to, the 120V AC power line. Care should be taken when monitoring any internal circuitry with an oscilloscope, as **the 0V reference in the PL513 and TW523 are NOT isolated from 120 volts.**
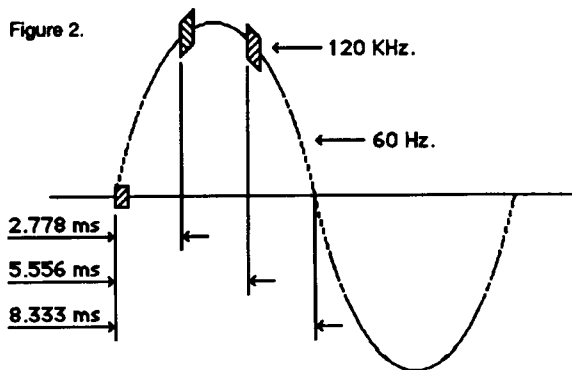
Transmission Theory

X-10 transmissions are synchronized to the zero crossing point of the AC power line. The design goal should be to transmit as close to the zero crossing point as possible but certainly within 200 microseconds of the zero crossing point. The PL513 and TW523 provide a 60 Hz. square wave with a max. delay of 100 μsec from the zero crossing point of the AC power line. The maximum delay between signal envelope input and 120 KHz. output bursts is 50 μsec. Therefore, it should be arranged that outputs to the PL513 and TW523 be within 50 μs of this 60 Hz. zero crossing reference square wave.

A Binary 1 is represented by a 1 millisecond burst of 120 KHz. at the zero crossing point and a Binary 0 by the absence of 120 KHz. The PL513 and TW523 modulate their inputs (from the O.E.M.) with 120KHz., therefore only the 1 ms "envelope" need be applied to their inputs. These 1 millisecond bursts should actually be transmitted three times to coincide with the zero crossing points of all three phases in a three phase distribution system. Figure 1 shows the timing relationship of these bursts relative to zero crossing.

Figure 1.

60 Hz.

120 KHz.

1 ms
2.778 ms
5.556 ms
8.333 ms
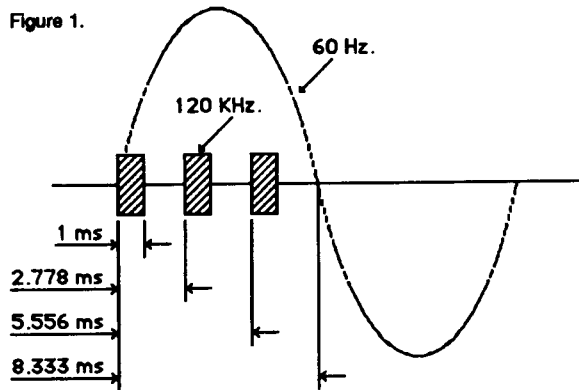
Note. - For clarity, the signals in figure 1 are shown as they would be seen through a high pass filter. The 60 Hz. waveform is only shown for reference. In reality the signals are actually superimposed on the 60Hz. waveform and look more like that shown in figure 2.

Figure 2.

120 KHz.

60 Hz.

2.778 ms
5.556 ms
8.333 ms

A complete code transmission encompasses eleven cycles of the power line. The first two cycles represent a Start Code. The next four cycles represent the House Code and the last five cycles represent either a Number Code (1 thru 16) or a Function Code (On, Off etc.). This complete block, (Start Code, House Code, Key Code) should always be transmitted in groups of 2 with 3 power line cycles between each group of 2 codes. Bright and dim are exceptions to this rule and should be transmitted continuously (at least twice) with NO gaps between codes. See figure 3.
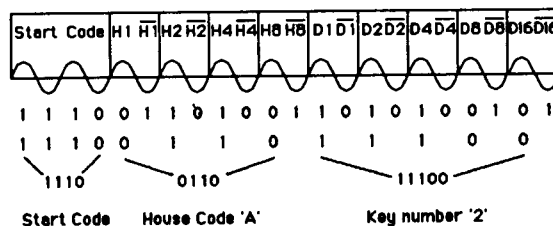
Power Line Cycles

	11		2	4	5
Start Code	House Code	Number Code	Start Code	House Code	Number Code
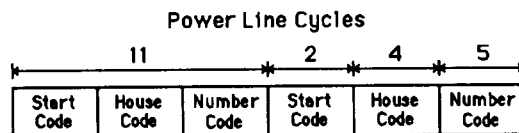
Code transmitted when a **number** button is pressed

Start Code	House Code	Function Code	Start Code	House Code	Function Code
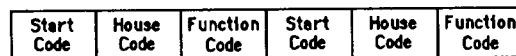
Code transmitted when a **Function** button is pressed

Figure 3.

Within each block of data, each four or five bit code should be transmitted in true and complement form on alternate half cycles of the power line. I.E if a 1 millisecond burst of signal is transmitted on one half cycle, (binary 1) then no signal should be transmitted on the next half cycle, (binary 0). See Figure 4 below.

Start Code	H1 H̄1	H2 H̄2	H4 H̄4	H8 H̄8	D1 D̄1	D2 D̄2	D4 D̄4	D8 D̄8	D16 D̄16

1 1 1 0 0 1 1 0 1 0 0 1 1 0 1 0 1 0 0 1 0 1
1 1 1 0 0   1   1   0   1   1   1   0   0

1110   0110   11100

Start Code   House Code 'A'   Key number '2'

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The Tables in figure 5. show the Binary Codes to be transmitted for each House Code and Key Code. The Start Code is Always 1110 which is a unique code and is the only code which does not follow the true-complement relationship on alternate half cycles.

Figure 5.
House Code and Key Code Tables.

	H1	H2	H4	H8		D1	D2	D4	D8	D16
House Codes					**Key Codes**					
A	0	1	1	0	1	0	1	1	0	0
B	1	1	1	0	2	1	1	1	0	0
C	0	0	1	0	3	0	0	1	0	0
D	1	0	1	0	4	1	0	1	0	0
E	0	0	0	1	5	0	0	0	1	0
F	1	0	0	1	6	1	0	0	1	0
G	0	1	0	1	7	0	1	0	1	0
H	1	1	0	1	8	1	1	0	1	0
I	0	1	1	1	9	0	1	1	1	0
J	1	1	1	1	10	1	1	1	1	0
K	0	0	1	1	11	0	0	1	1	0
L	1	0	1	1	12	1	0	1	1	0
M	0	0	0	0	13	0	0	0	0	0
N	1	0	0	0	14	1	0	0	0	0
O	0	1	0	0	15	0	1	0	0	0
P	1	1	0	0	16	1	1	0	0	0
					All Units Off	0	0	0	0	1
					All Lights On	0	0	0	1	1
					On	0	0	1	0	1
					Off	0	0	1	1	1
					Dim	0	1	0	0	1
					Bright	0	1	0	1	1
					All *Lights* Off	0	1	1	0	1
					Extended Code	0	1	1	1	1
					Hail Request	1	0	0	0	1 ①
					Hail Acknowledge	1	0	0	1	1
					Pre-Set Dim	1	0	1	X	1 ②
					Extended Data (analog)	1	1	0	0	1 ③
					Status = on	1	1	0	1	1
					Status = off	1	1	1	0	1
					Status Request	1	1	1	1	1

① Hail Request is transmitted to see if there are any other X-10 transmitters within listening range. This allows the O.E.M. to assign a different Housecode if a "Hail Acknowledge" is received.

② In a Pre-Set Dim instruction, the D8 bit represents the Most Significant Bit of the level and H1, H2, H4 and H8 bits represent the 4 Least Significant Bits.

③ The Extended Data code is followed by 8 bit bytes which can represent Analog Data (after A to D conversion). There should be no gaps between the Extended Data code and the actual data, and no gaps between data bytes. The first 8 bit byte can be used to say how many bytes of data will follow. If gaps are left between data bytes, these codes could be received by X-10 Modules causing erroneous operation.

Extended Code is similar to Extended Data: 8 Bit bytes which follow Extended Code (**with no gaps**) can represent additional codes. This allows the designer to expand beyond the 256 codes presently available.

IMPORTANT NOTES

NOTE 1. X-10 Receiver Modules require a "silence" of at least 3 power line cycles between each pair of 11 bit code transmissions (no gaps between each pair). The one exception to this rule is **bright and dim** codes. These are transmitted **continuously** with no gaps between each 11 bit dim code or 11 bit bright code. A 3 cycle gap is necessary between different codes, i.e between bright and dim, or 1 and dim, or on and bright etc.

NOTE 2. The TW523 Two-Way Power Line Interface cannot receive Extended Code or Extended Data because these codes have no gaps between them. The TW523 can only receive standard "pairs" of 11 bit X-10 codes with 3 power line cycle gaps between each pair.

NOTE 3. The TW523 can receive dim and bright codes but the output will represent the first dim or bright code received, followed by every third code received. i.e. the output from the TW523 will not be a continuous stream of dim or bright codes like the codes which were transmitted.

Transmission Timing Diagrams.

A square wave representing zero crossing detect is provided by the PL513/TW523 and is within 100 μs of the zero crossing point of the AC power line. The output signal envelope from the O.E.M. should be within 50 μs of this zero crossing detect. The signal envelope should be 1 ms (-50μs +100μs). See Figure 6.
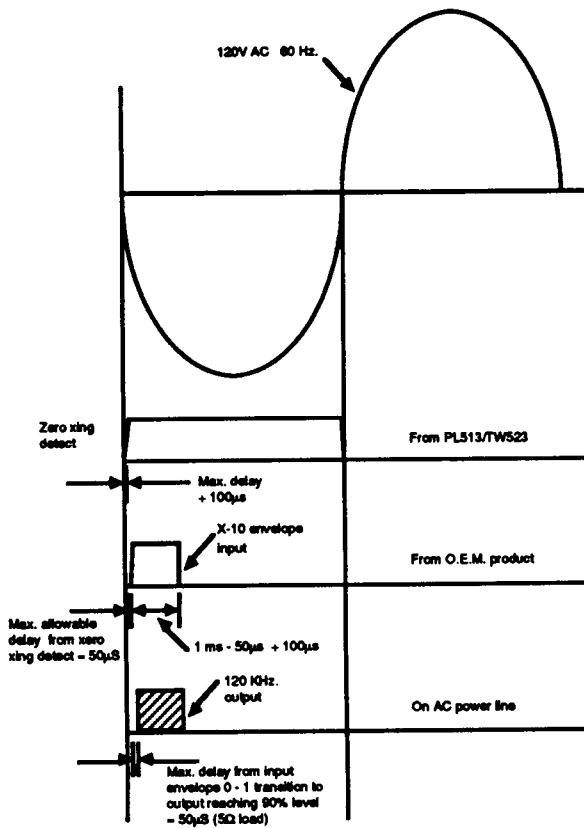
Figure 6. Transmit Timing Diagrams.

Opto-Coupled 60 Hz. reference output
(*from* the PL513/TW523)

Transmissions are to be synchronized to the zero crossing point of the AC power line and should be as close to true zero crossing as possible. The PL513 and TW523 are designed to be interfaced to other microprocessor circuitry which outputs X-10 codes synchronized to the zero crossing point of the AC power line. It is therefore necessary to provide a zero crossing reference for the O.E.M. microprocessor.

It is likely that this microprocessor will have its own "isolated" power supply. It is necessary to maintain this isolation, therefore the trigger circuit normally used in *X-10 POWERHOUSE* controllers is **not** desirable as this would reference the O.E.M. power supply to the AC power line. It is also **not** desirable to take the trigger from the secondary side of the power supply transformer as some phase shift is likely to occur. It is therefore neces-

sary to provide an opto-coupled 60 Hz. reference.

An opto-coupled 60 Hz. square wave is provided at the output of the PL513 and TW523. X-10 codes generated by the O.E.M. product are to be synchronized to this zero crossing reference. The X-10 code envelope generated by the O.E.M. is applied to the PL513 or TW523 which modulates the envelope with 120 KHz. and capacitively couples it to the AC power line.

Opto-Coupled Signal Input
(*to* the PL513/TW523)

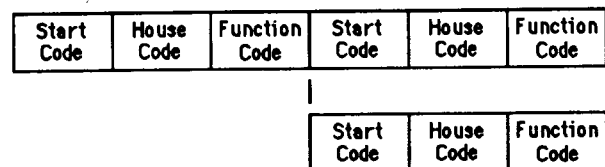The input signal required from the O.E.M. product is the signal "envelope" of the X-10 code format, i.e.

High for 1 ms. coincident with zero crossing represents a binary "1" and gates the 120 KHz. oscillator through to the output drive circuit thus transmitting 120 KHz. onto the AC power line for 1 ms.

Low for 1 ms. coincident with the zero crossing point represents a binary "0" and turns the 120 KHz. oscillator/output circuit off for the duration of the 1 ms input.

Opto-Coupled Signal Output
(*from* the TW523)

The "X-10 received" output from the TW523 coincides with the second half of each X-10 transmission. This output is the envelope of the bursts of 120 KHz. received. Only the envelope corresponding to the first burst of each group of 3 bursts is available at the output of the TW523. See figures 7, 8 and 9.

X-10 code received from the AC power line.

Start Code	House Code	Function Code	Start Code	House Code	Function Code

			Start Code	House Code	Function Code

"X-10 received" output from TW523

Figure 7.

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Receive Timing Diagrams

Figure 8.

Start Code | First Transmission Address A 1 | Start Code | Second Transmission Address A 1

X-10 code on AC power line

"X-10 received" output from TW523

Figure 9.

Zero Crossing from TW523
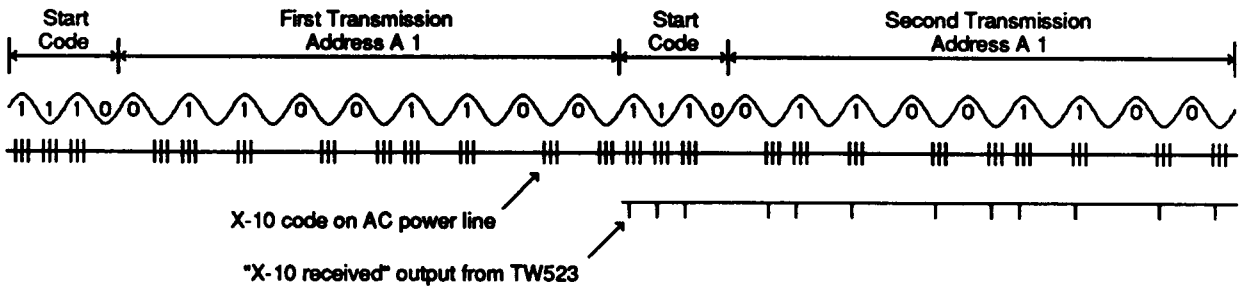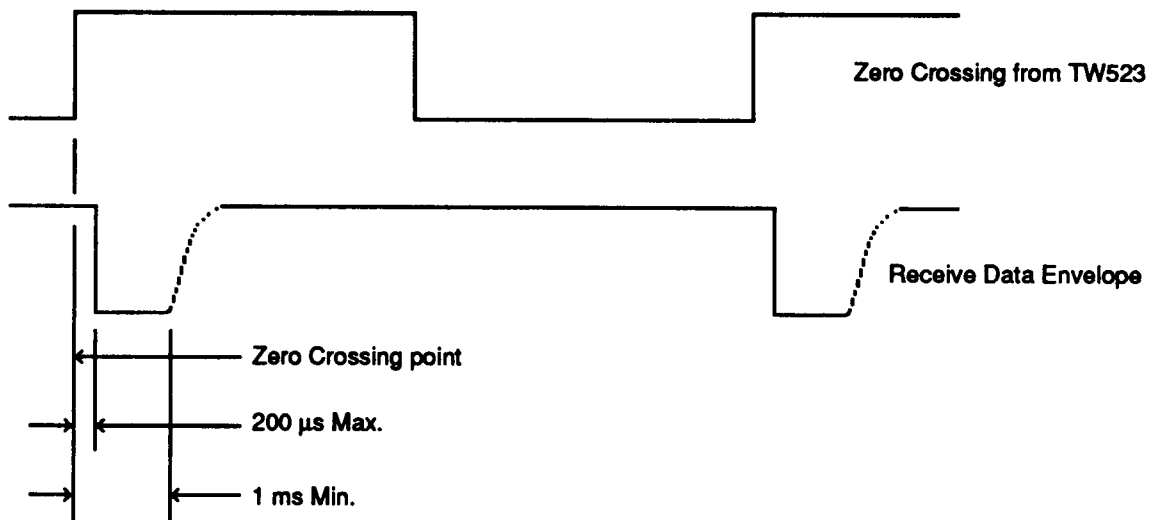
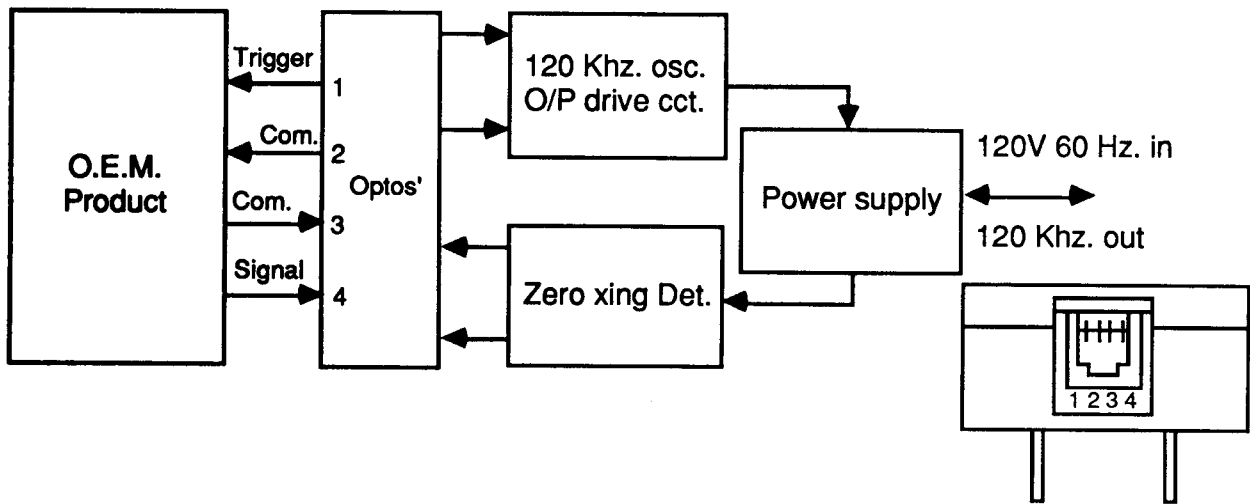Receive Data Envelope

Zero Crossing point

200 µs Max.

1 ms Min.

PL513 Block Diagram

Connection between the O.E.M. product is via a standard modular phone jack, the connections for which are as follows:

1. **B** Zero crossing detect **output** (with respect to 2).
2. **R** Zero crossing detect common.
3. **G** X-10 transmit envelope common.
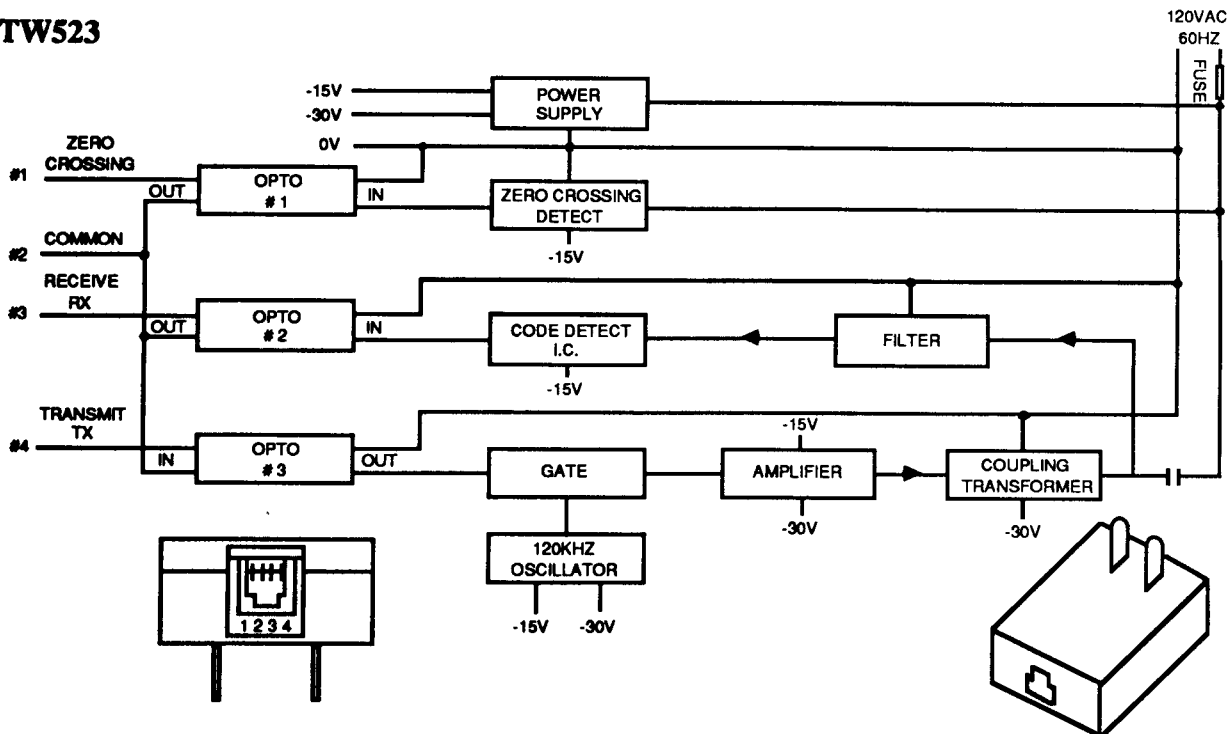4. **Y** X-10 transmit envelope **input** (with respect to 3).

TW523 Block Diagram

Connection between the O.E.M. product is via a standard modular phone jack, the connections for which are as follows:

1. **B** Zero crossing detect **output** (with respect to 2).
2. **R** Common.
3. **G** "X-10 received" envelope **output** (with respect to 2).
4. **Y** X-10 transmit envelope **input** (with respect to 2).

PL513

TW523

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PL513 Electrical Characteristics at 25° C

AC input voltage.   100 - 130VAC 60Hz
Max. voltage between any terminals (1, 2, 3, and 4)
                                     +/- 50V
Storage temperature.   - 40 to + 70 ° C
Operating temperature.   - 10 to + 50 ° C

DC characteristics

Serial data input

Min. Logic '1'   4V   input will sink approx 2.5 mA
Max. Logic '1'   20V input will sink approx 18 mA
Max. Logic '0'   0.8V input will sink approx 0.1 mA

(Voltages and currents with respect to terminal 3).

Zero crossing detect output.

Logic '1' Leakage output.   10 μA max. at 5V

Logic '0' Sink current.   1 mA min. at 0.8V

(Voltages and currents with respect to terminal 2).

Note: This output is an open collector transistor. Therefore, the logic '1' voltage is quoted as a reference for defining the output leakage current. An output pullup resistor is required to generate a logic level. The pullup can be returned to any voltage up to + 20V with respect to terminal 2.

AC characteristics

RF output to AC power line.	60 mW average into a 5 Ω load (5V pk-pk instantaneous).
Carrier frequency.	120 KHz. +/- 2 KHz.
Max. phase delay between zero crossing point of AC power line and zero crossing detect output (either transition).	100 μsec.
Max. allowable delay between transitions on zero crossing detect output and serial data input '0' - '1' transition.	50 μsec.
Max. delay between serial input envelope '0' - '1' transition and carrier burst reaching 90% level.	50 μsec.
Width of X-10 envelope	1 ms + 100μs - 50μs
Isolation voltage	2500V r.m.s. 60 Hz. for 1 min.

TW523 Electrical Characteristics at 25° C

AC input voltage.   100 - 130VAC 60Hz
Max. voltage between any terminals (1, 2, 3, and 4)
                                     +/- 20V
Storage temperature.   - 40 to + 70 ° C
Operating temperature.   - 10 to + 50 ° C

DC characteristics

Serial data input

Min. Logic '1'   4V   input will sink approx 2.5 mA
Max. Logic '1'   20V input will sink approx 18 mA
Max. Logic '0'   0.8V input will sink approx 0.1 mA

(Voltages and currents with respect to terminal 2).

Zero crossing detect output and receive output.

Logic '1' Leakage output.   10 μA max. at 5V
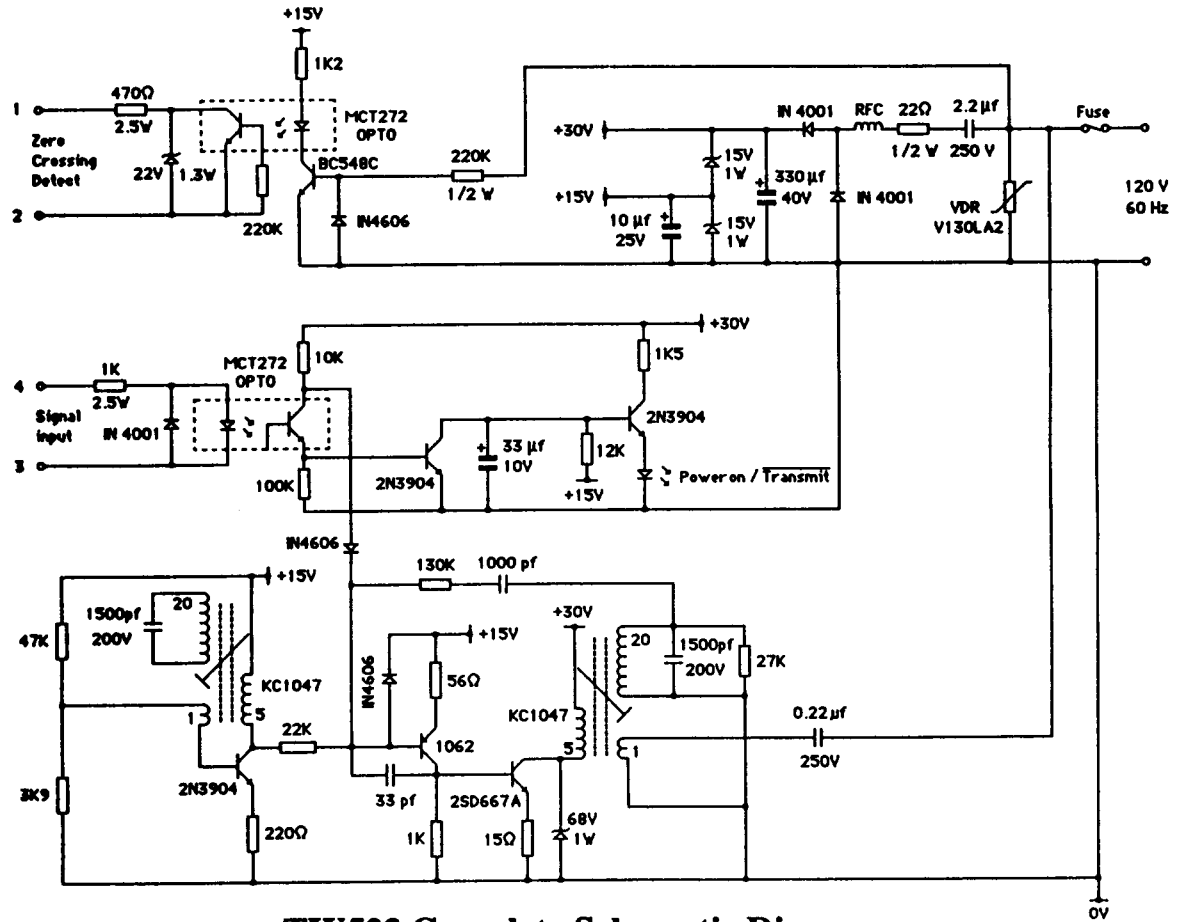
Logic '0' Sink current.   1 mA min. at 0.8V

(Voltages and currents with respect to terminal 2).

Note: This output is an open collector transistor. Therefore, the logic '1' voltage is quoted as a reference for defining the output leakage current. An output pullup resistor is required to generate a logic level. The pullup can be returned to any voltage up to + 20V with respect to terminal 2.
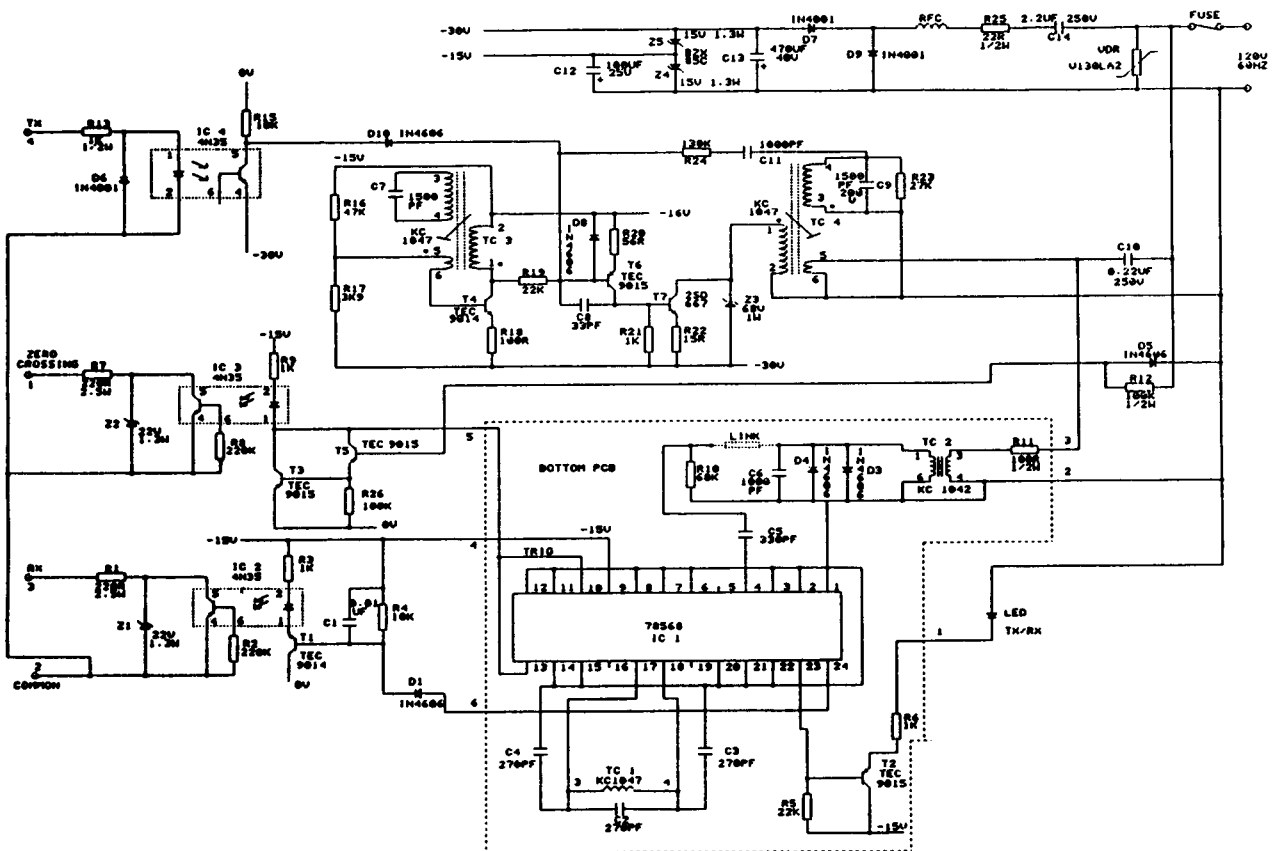
AC characteristics

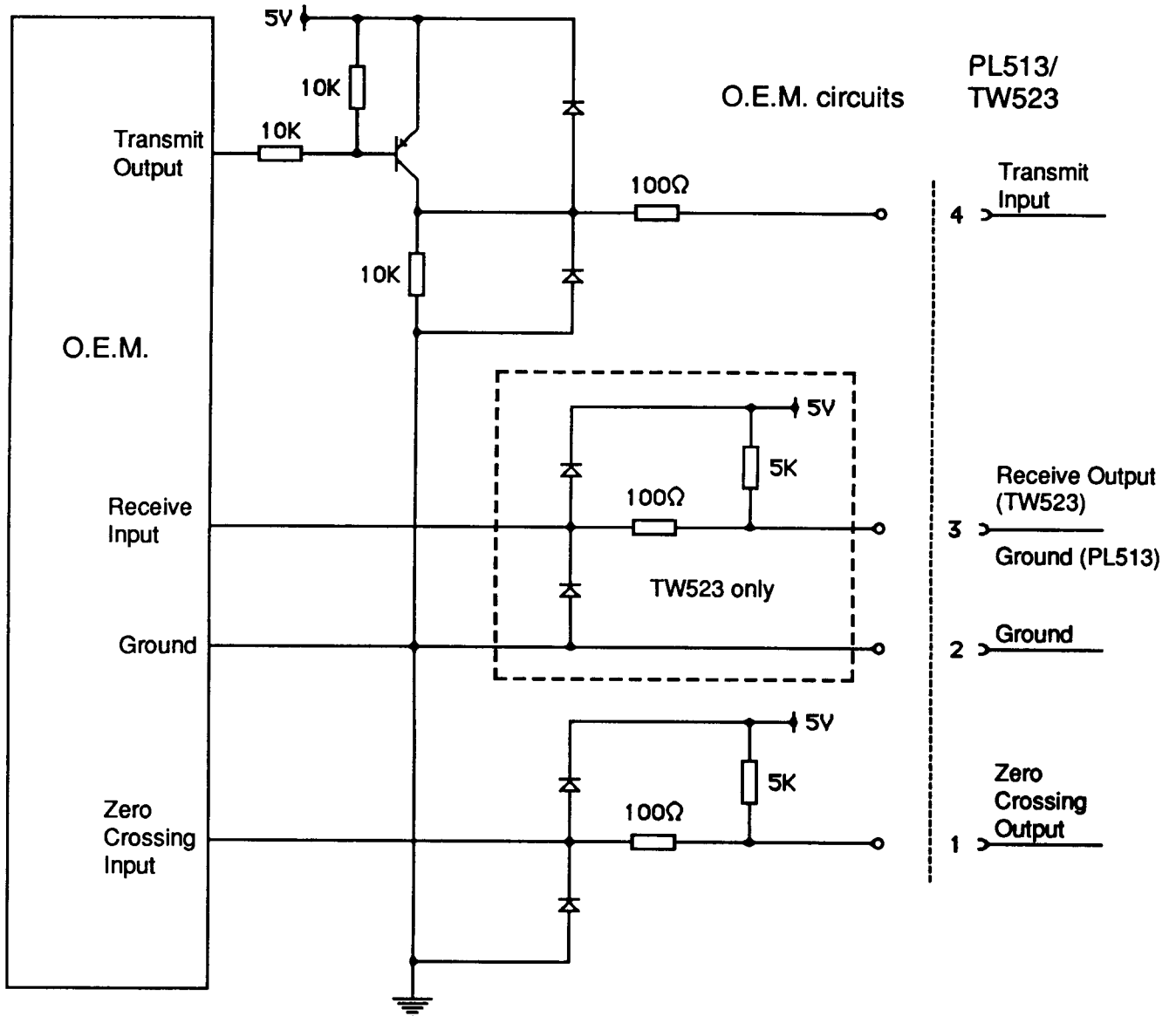|	
RF output to AC power line.	60 mW average into a 5 Ω load (5V pk-pk instantaneous).
Carrier frequency.	120 KHz. +/- 2 KHz.
Max. phase delay between zero crossing point of AC power line and zero crossing detect output (either transition).	100 μsec.
Max. allowable delay between transitions on zero crossing detect output and serial data input '0' - '1' transition.	50 μsec.
Max. delay between serial input envelope '0' - '1' transition and carrier burst reaching 90%.	50 μsec.
Width of X-10 envelope	1 ms + 100μs - 50μs
Isolation voltage	2500V r.m.s. 60 Hz. for 1 min.

PL513 Complete Schematic Diagram.

TW523 Complete Schematic Diagram.

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Typical O.E.M. Connection Diagram

O.E.M.

Transmit Output

Receive Input

Ground

Zero Crossing Input

10K

10K

10K

5V

100Ω

5V

5K

100Ω

TW523 only

5V

5K

100Ω

O.E.M. circuits

PL513/
TW523

Transmit Input   4

Receive Output
(TW523)   3

Ground (PL513)

Ground   2

Zero
Crossing
Output   1

X-10 ® Compatible Home Automation/Security Systems

The systems listed below (in alphabetical order) use *X-10 POWERHOUSE* ™ Modules developed, manufactured and supplied by X-10, and use Controllers which transmit signals compatible with the X-10 standard. The systems marked with an * use Modules *and* Controllers developed, manufactured and supplied by X-10.

Advanced Control Technologies,		Leviton, Decora ™ Electronic Controls.*	(718) 631-6555.
Powerline Control Components.	(317) 248-2640.	L ● Phant ™ Home Automation System.	(813) 593-1590.
AES, Pool & Spa Control.	(904) 454-1630.	Magic Mansions, System 2000.	(312) 364-5257.
American Products, Pool Control.	(805) 523-2400.	Mastervoice,	
Amway, Home Control System /		Butler in a Box. ™ (voice control).	(213) 594-6581.
Amgard II. ™	(616) 676-6000.	Medical Equipment Distributors,	
Apex, Security Alarm.	(919) 876-0010.	(Env. Controls for the disabled).	(806) 793-8421.
Aquadyne, Pool Control System.	(213) 722-1755.	Micromint Inc., Home Run ™ System.	(203) 871-6170.
Aquatherm, Series 3000 Spa System.	(805) 388-1094.	MRL, Security System.	(703) 669-0195.
Baran-Harper Group, software for PL513	(416) 294-6473.	Murray & Sons Co. Inc.,	
Blue Earth Research,		Billiard Control Panel.	(213) 323-1752.
BEaR-1FB Progammable Controller.	(507) 387-4001.	National Energy Consultants,	
C & K Systems,		Multi-Zone Control Panel.	(319) 364-8805.
Big Switch ™ P.I.R. Light Control.	(408) 434-1149.	NuTone, Remote Intercom Systems.	(800) 543-8687.
Capricorn, Wireless Security System.	(704) 428-3451.	Nynex, PhoneWatch Security System.	(914) 644-3797.
CB Enterprises, Billiard Control Panel.	(800) 628-7339.	Pal-Tech, Chicken-House Control.	(800) 328-8842.
Chardonnay, Pool Control System.	(818) 787-7779.	Prentke Romich Co.,	
CompuAbility, EZRA (E.C.S.)	(800) 433-8872.	(Env. Controls for the disabled).	(216) 262-1984.
Covox Inc., Voice Master.™	(503) 342-1271.	Radio Shack, plug 'n power ™ System.*	(817) 390-3232.
Crimeguard, Apex 5.	(919) 362-4200.	Radio Shack,	
Cyberlynx, Smarthome ™ System.	(303) 444-7733.	plug 'n power ™ Homeminder. ™ *	(817) 390-3232.
DEK Research Co., Multi-user software		Rollins Protective Services,	
for the CP290 (uses THEOS O.S.)	(719) 635-3732.	Security System.	(404) 888-2940.
Dolphin, Billiard Management Software.	(714) 240-6297.	Safko International, (voice control).	(602) 479-1987.
Dynamark, Security System.	(301) 797-2124.	Schlage, Keepsafer ™ Security System.	(415) 467-1100.
Enerlogic, System 1400.	(603) 880-4000.	Sears, Home Control System. *	(312) 875-2500.
G. E. Marshall, Tel-A-Control,		Shasta, Pool Control System.	(602) 258-8981.
(telephone control system).	(416) 240-1770.	Silent Knight Securty Systems.	(612) 493-6400.
G.E., Homeminder. ™ *	-	Solus Systems Inc., H. A. Panel.	(503) 635-3966.
Gencor Software for the PL513.	(519) 542-8863.	Sonitrol, Security System.	(407) 859-3350.
Group Three Technologies Inc,		Stanley Home Automation,	
SAMANTHA ™ H. A. System.	(805) 582-4410.	*LightMaker* ™ Garage Door Opener.	(313) 344-0070.
Heath/Zenith, Reflex ™ Home Controls.	(616) 982-5642.	Stanley Home Automation,	
Home Automation Inc., Model 1530.	(504) 833-7256.	*LightMaker* ™ Home Controls. *	(313) 344-0070.
Hydrus, PoolMinder ™ System.	(214) 350-8766.	Ultratec, Super Signal System ™	
Hypertek, Homebrain. ™	(201) 534-9700.	(for the hearing impaired).	(608) 273-0707.
Intelligent Devices Inc.,		Unity Systems, Home Manager. ™	(415) 369-3233.
Sophi Home Control System.	(504) 734-7069.	Universal Electronics Inc., One-For-All ™	
ITI, Caretaker ™ System.	(612) 777-2690.	Infrared Control System.*	(800) 872-2682.
JDS, Telecommand System 100.	(619) 487-8787.	Westec, 5000 Alarm Panel.	(800) 877-3287.
KY Enterprises,		*X-10 POWERHOUSE* ™ System,	
(Env. Controls for the disabled).	(213) 433-5244.	(formerly BSR System X-10). *	(201) 784-9700.