A Modern Link Trainer Telegon Oscillator to Facilitate Testing

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Linktrainer.net

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Caution:

The Telegon oscillator described herein contains dangerously high AC and DC voltages that could cause severe injury and possibly death.

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Background

The restoration of any Link Trainer that incorporates a Telegon remote transmitter/indicator system involves testing of the associated transmitters and indicators. Testing a Telegon instrument requires an excitation that would normally be provided by the original equipment Telegon Oscillator and a driving source to "steer" the remote instrument under test. There are some disadvantages to using the original equipment Telegon oscillator, (1) The Telegon oscillator is designed to only provide proper voltage and sinusoidal waveform when connected to the entire Telegon system load, (2) The output voltage of the Telegon Oscillator, while adjustable, is not easy (nor is it advisable) to adjust while operating, and (3) There is a warm up time associated with the vacuum tubes used in the Telegon Oscillator. Given these limitations of the original Telegon Oscillator a need was born to build a solid state version that could be utilized to operate the entire Telegon system (3 transmitters and 6 remote indicators) or allow for testing of one or two indicating instruments.

The Telegon System

The Telegon system of remote sensing and indicating is similar to that of a Synchro (also known as selsyn and autosyn) based system in that it has a sending unit that senses a mechanical position (Telegon transmitter) input and a receiving unit that replicates the position of the indicator remotely through a set of electrical connections. In a typical Link trainer there are typically one sending unit and two indicators for each instrument type that utilizes the Telegon system. Airspeed, Vertical Speed, and Altitude are the three parameters conveyed by this system with the one of the two indicators being located on the instrument panel and the other in the instrument cluster at the instructor's desk. The three Telegon sensors are located in the trainer directly behind the student's seat. Both the Telegon transmitters and indicators are the same device from an electrical stand point, the difference being that the transmitters are mechanically driven and the indicators reflect the position of the transmitter.

There are similarities and differences between a Synchro system and the Telegon system. A Synchro system has three stator windings and thus three amplitude modulated outputs that are isolated from the input excitation signal. The output of each winding is measured relative to the other and is an amplitude modulated signal that varies as a function of the sine of the input shaft angle with a 120º difference between each output as defined by the equations and Figures below. Unlike a Sychro system, the Telegon system utilizes two phases and actually has more in common with Resolver signals in that the two amplitude modulated outputs (Phase 1 and Phase 2) vary as the sine and cosine of the shaft angle. However, unlike a typical resolver which is not designed to receive and replicate a mechanical position, the Telegon system is able to utilize these sine and cosine amplitude modulated signals to position a shaft to which an pointer is attached. In fact, the Telegon electro-mechanics does not utilize any brushes to conduct signals, which is one of the reasons it is highly reliable and maintenance free. Each Telegon unit uses jeweled bears and produces very little torque. Paul Kollsman patented this system as documented in US patent 2239790 in 1938 and later refined it under US patent 2303285 in 1940 in a disclosure that bears a great similarity to the Telegon units utilized in the Link Trainer.

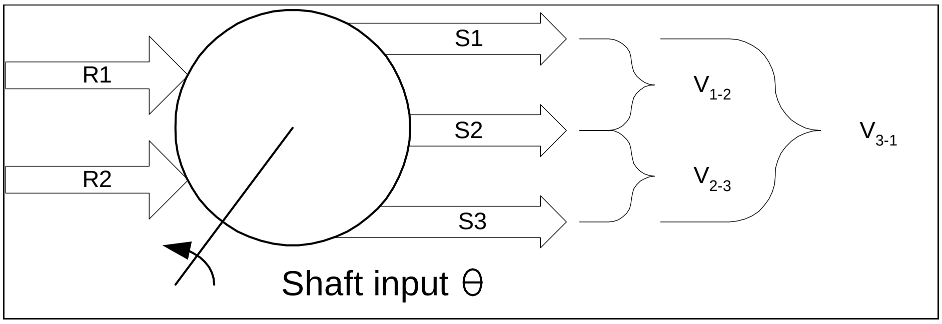

Figure 1 Representation of a Synchro device

The equations that accompany Figure 1 for a Synchro system are:

$$V_{3-1} = K_1 \sin\theta \sin(\omega t)$$

$$V_{2-3} = K_2 \sin(\theta + 120°) \sin(\omega t)$$

$$V_{1-2} = K_2 \sin(\theta - 120°) \sin(\omega t)$$

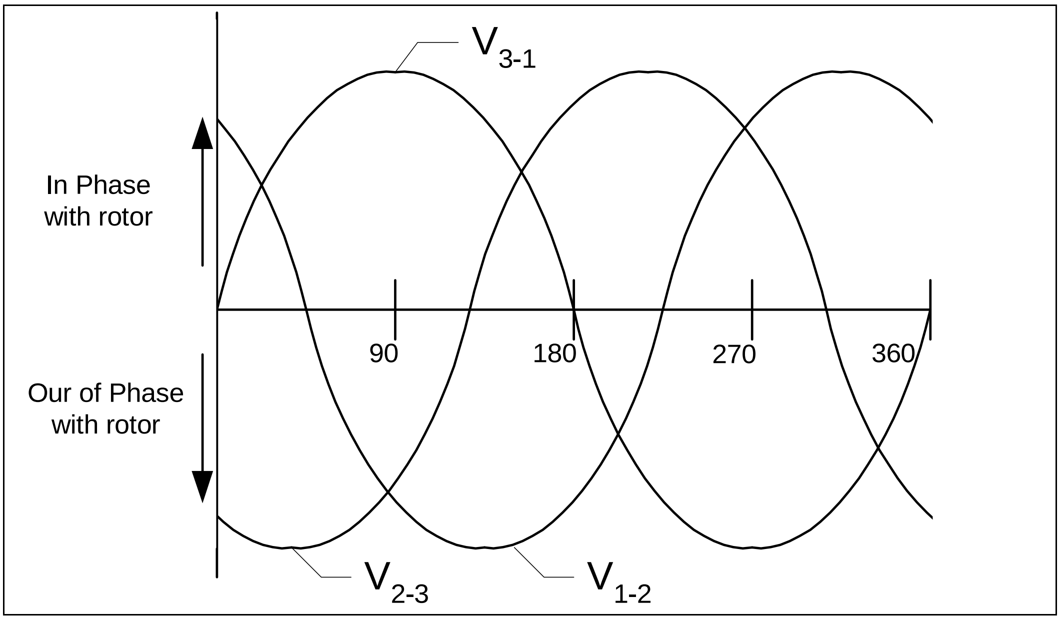

Figure 2 Synchro voltage magnitudes as a function of rotor angle in degrees

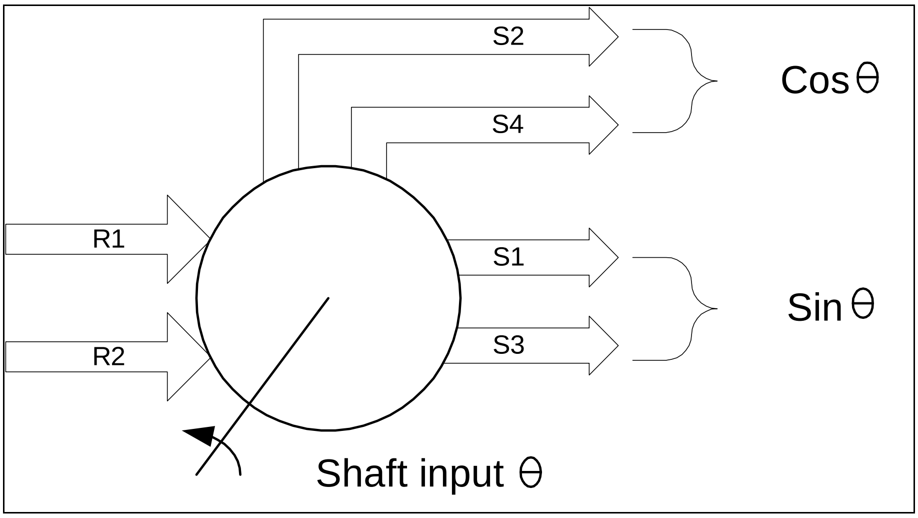

Figure 3 Resolver and Telegon device representation

The equations that accompany Figure 3 for a Telegon system are:

$V_x = Kx \sin\theta \sin(\omega t)$

$V_y = Ky \cos\theta \sin(\omega t)$

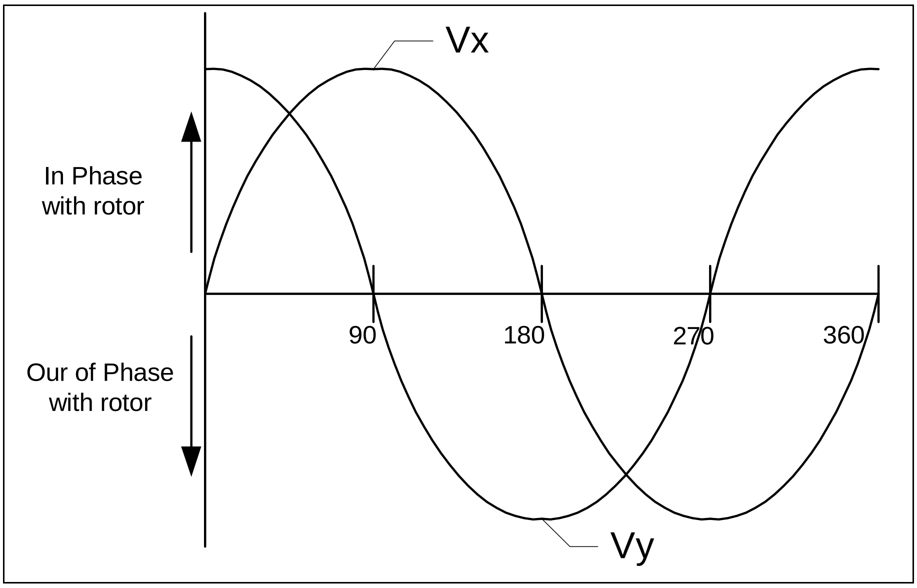

Figure 4 Resolver and Telegon voltages as a function of shaft angle

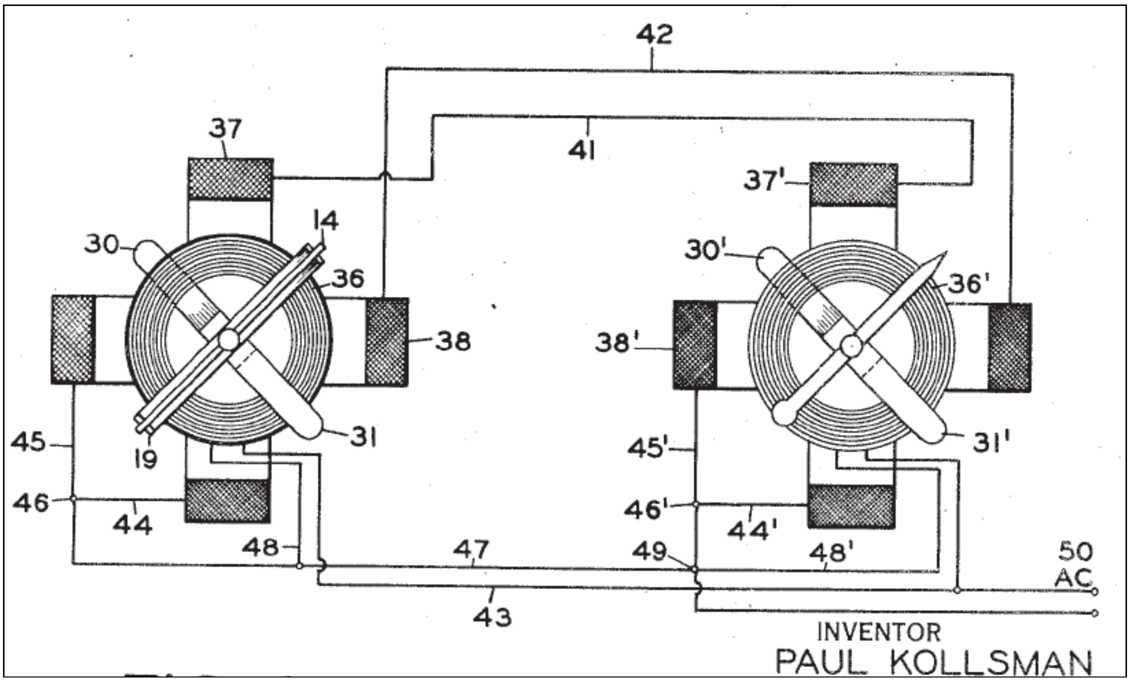

Figure 5 Illustration from Patent number 2303285 showing a Telegon system

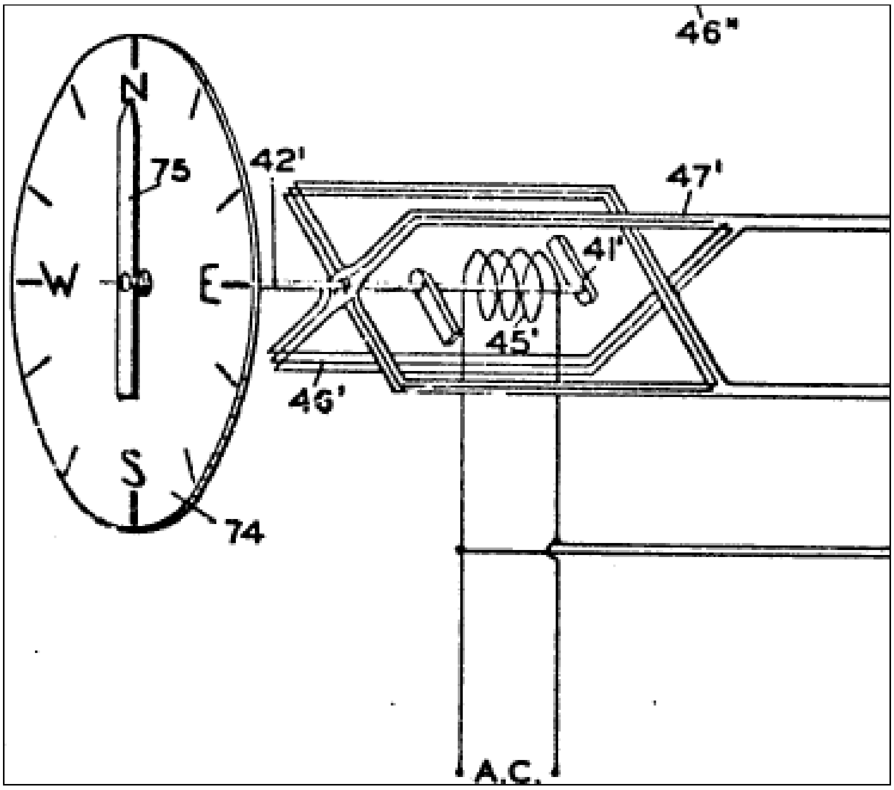

Figure 6 Isometric view of the Telegon unit showing the orthogonal windings and "Z" armature (41) as disclosed in US Patent 2316873 from April 1943

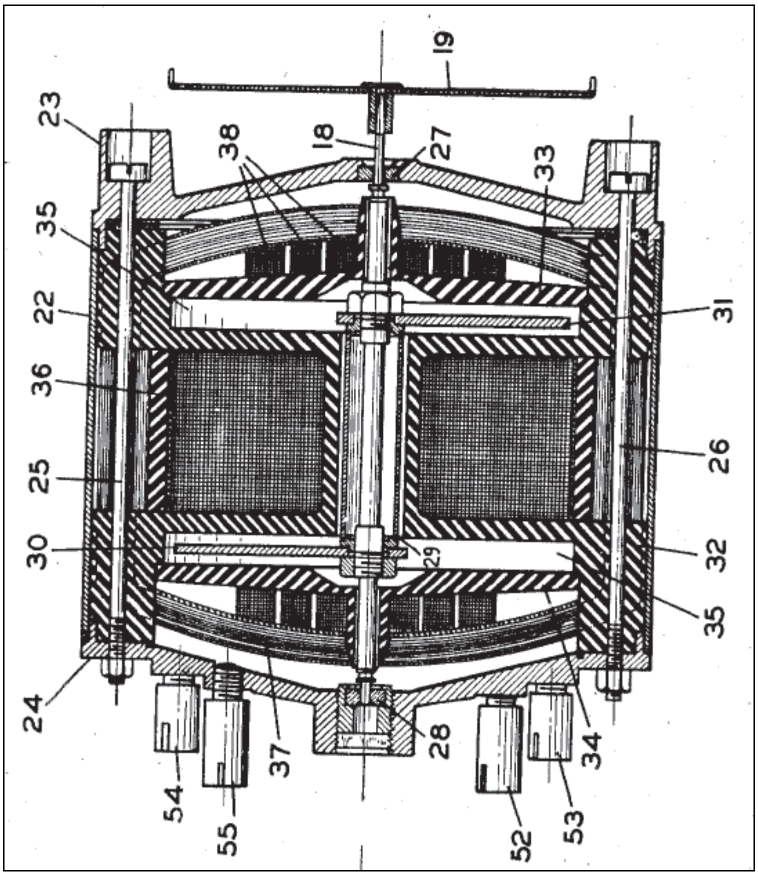

Figure 7 A cross section of a Telegon device as depicted in Patent 2303285

Output signals

Figure 2 and Figure 4 depict the output voltage of a Synchro and Resolver/Telegon unit as a function of shaft angle. These diagrams can be a bit confusing in that it might seem to depict that the outputs of the signals have a phase relationship at either 120º relative to each other (Synchro) or 90 º to each other (Resolver/Telegon). In reality all output voltages are in phase with the input signal that is applied to the rotor with the exception that the phase can be opposite (180º out of phase). The amplitude and polarity of each output will vary with the shaft angle such that the outputs are amplitude modulated as a function of the rotor shaft angle. This can be a bit confusing but an example may help. Refer to Figure 4 and you will note that at 0 degrees of shaft input angle the cosine signal output, Vx, will have an maximum amplitude in phase with and at same frequency of the rotor input (recall that the cos(0º) = 1 which is the maximum value). Likewise, under a 0º shaft input the sine signal output, Vy, will have a minimum or near zero output amplitude (recall that the sin(0º) = 0). At 180 degrees the cosine output, Vx, will again be a maximum but the phase will be inverted 180 degrees from that of the rotor input (cos(180º)=-1). Likewise the sine output signal, Vy, will again be a minimum or near zero output amplitude.

The Telegon Oscillator replacement

The prior discussion does not directly relate to the design and construction of a Telegon oscillator replacement but an understanding of the Telegon device and its Synchro cousin is beneficial for understanding the role that the Telegon oscillator plays from an overall system perspective. It should be noted that the Link trainer does make use of true Synchro units in the wind drift and recorder devices as well as the Automatic Direction Finder (ADF) system, however, these devices are operated from line power that is stepped down to 36 volts at 60Hz and are independent of the Telegon oscillator. Much literature is available on the internet that provides information about Synchro and resolver devices and the reference section identifies some useful sources for further reading.

Block diagram

A block diagram of the Telegon test oscillator is shown in Figure 8. The architecture is similar to the original Telegon oscillator in that the output relies on a resonant circuit consisting of the transformer output windings, output capacitors, and the inductance of the load which in this case is either the Link Trainer Telegon system (a total of 9 Telegon devices) or a test system which consists of only two or three Telegon devices under test. The ability to support these different loads requires a change in capacitance to maintain the same resonant frequency which is why one may observe a second capacitor in the output section that is engaged via a SPST switch. When operating with the Trainer's Telegon load (9 Telegon units) the switch is closed, when operating with two or three Telegon loads the switch is open. Each condition requires a different capacitance to tune the resonance to 780 Hz. 780 Hz was selected as this was the optimum frequency observed for the authors' Link trainer Telegon system. Link Trainer literature describing the Telegon oscillator indicates that it generates a frequency in the 700 to 800 Hz range at 85 volts rms.

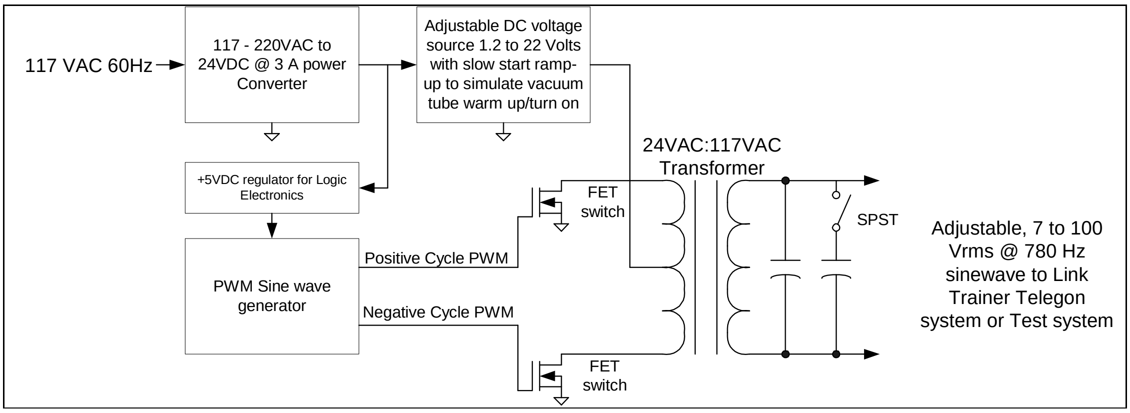

Figure 8 Telegon Test oscillator block diagram

Sine wave generation

In order to make the test oscillator efficient and minimize the need for cooling of the FET power transistors it was decided to use switching techniques and avoid linear biasing of the power transistors. A common method utilized in sine wave output inverter circuits is to generate a Pulse Width Modulated (PWM) version of a sine wave that is used to switch voltages that are 180º out of phase on the outer taps of a center tapped transformer where the center tap is supplied with a voltage. The Sine wave PWM function is generated by a PIC microcontroller that incorporates hardware designed to facilitate PWM generation. A higher frequency clock is used and the sine wave period is sliced into 40 segments that vary in width throughout the sine wave cycle. Actually, only 20 values are used and are repeated twice, once for the positive sine cycle, and once for the negative sine cycle. Figure 9 provides some insight as to how a PWM signal can be used along with filtering to generate a sinusoidal function. The PWM representation of the sine wave is subsequently smoothed by the filter action of the resonate circuit formed by the output transformer, output capacitance and the load inductance of the Telegon devices. The depiction of the PWM in Figure 9 is only for illustration and is not the actual PWM utilized as the number of PWM cycles shown is 25 slices versus the actual 40 used in this design.

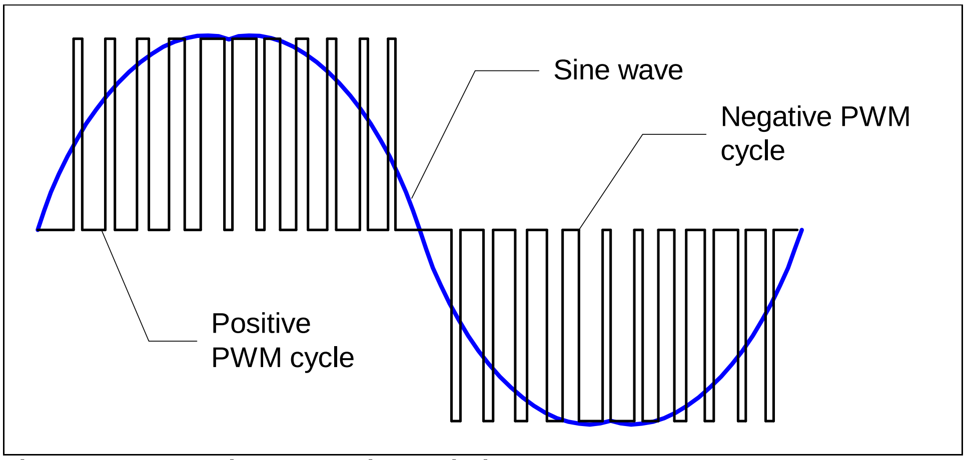

Figure 9 PWM to sine generation technique

Power Switching and step-up voltage transformation

The power switching is performed by two N channel Field Effect Transistor (FET) devices. One switches the positive sine PWM cycle, the other the negative sine PWM cycle. Each switch is located on the “Secondary” outermost connections of a center-tapped transformer. The transformer is actually a step-down power transformer operated in a reverse manner in that instead of stepping down 117 VAC to 24 VAC the switching waveforms and supply voltage are applied to the “secondary” such that the switching action of the FET devices increased the voltage. In this mode the transformer winding ratio is 1 to 4.875. Which implies that a 1Vrms voltage applied to the “secondary” would result in 4.875 Vrms at the output of the “primary”. The ability to reverse the voltage transformation direction is one of the unique features of a transformer.

The transformer is a 117 VAC to 24 VAC center tapped type. This means that the 24 VAC step down voltage is developed across the outer connections of the secondary winding. The voltage measured between the secondary center tap and either output connections would be ½ of 24V or 12 VAC. It should also be noted that this transformer is rated to operate at 60Hz as opposed to the 780Hz it is subjected to for this application, however, this transformer operates reasonably well at the higher than rated frequency. The transformer selected for this design is rated to deliver 4A at 24 VAC at 60Hz (96VA). The Telegon Test Oscillator delivers 90 mA at 90V rms into 3 Telegon loads and about 270 mA at 90V into a complete Telegon System which equates to 24.3VA, the point being that the transformer is not overstressed although the 96VA rating is probably somewhat lower at 780Hz.

Schematic

Figure 10 displays the schematic diagram of the Telegon test oscillator. A PIC microcontroller, U2, is clocked at a 20MHz frequency by crystal oscillator module U3. The PIC generates three signals, the PWM output that represents the sine wave and the signals POL N and POL P which through the logic formed by NAND gates U5 applies the PWM signal to Q2 for the positive portion of the sine wave and to Q3 for the negative portion. Q2 and Q3 operate in a complimentary mode, meaning that when Q2 is applying the positive portion of the PWM sine wave to transformer T1, Q3 is inactive or open circuit. Likewise when Q3 is applying the negative PWM sine wave to transformer T1, Q2 is inactive.

The center tap voltage supplied to T1 is provided by adjustable voltage regulator U4 via the adjustment potentiometer R7 which is user accessible. U4 is rated to deliver 3A of current and is housed in a metal TO-3 style package that is attached to a heat sink and provided with airflow from a fan installed in the enclosure. It is the adjustment of this voltage that varies the voltage on the output side of the transformer. A soft start feature for the output of U4 is provided by the action of Q1, R4 and C11. This soft start circuit gradually increases the output voltage from approximately 8 volts to the voltage setting defined by variable resistor R7. This feature was added to mimic the gradual voltage increase that a vacuum tube based Telegon oscillator delivers to the Telegon system. The time constant formed by R4 and C11 provides for a gradual increase from 8 volts to 85 volts (as set by R7) over a four (4) second time interval. It should be noted that a vacuum tube Telegon oscillator requires more than four seconds to initiate operation from a cold turn on, but once the filaments have reached a certain operating temperature the output voltage increases to the final value in about 4 to 5 seconds.

The voltage to operate U4 is provided by a PSA065M 24VDC 65 watt switching power supply that will operate from either 117 or 220 VAC 50 or 60 Hz making it a universal input type power supply. Power to the 5V logic for the PIC micro, U5 NAND gate and U1 RS-232 transceiver is provided by voltage regulator U6 which is provided a 24VDC input by the PSA065M power supply. Likewise, voltage regulator U7, a 12 VDC regulator that provides power to a 12V fan is also supplied with 24V from the PSA065M power supply. A brief note regarding the power derivation is worth mentioning – the decision to use the aforementioned linear regulators as opposed to a more efficient switching type was made due to the simplicity in implementation and the inherent ability to sink and cool the linear regulators based upon the enclosure selected (a former ATX PC power supply). Early in the design process it was decided to use a linear regulator to provide voltage to the center tap of T1 to facilitate adjustment of the final output voltage which drove the selection of a device capable of handing up to 3A at reasonably high wattage. L1 is a 20uH toroidal ferrite based inductor consisting of 16 turns of 18 gauge wire on an Amadon FT-82-61 core.

U4 dissipates up to 6 watts of power and is attached to a heat sink that is subjected to forced airflow. Since the airflow was already present it was beneficial to also sink the 5V linear regulator and place it in the airflow path. Linear regulator U7 provides the power to the 12VDC fan and was physically attached to the chassis of the enclosure and did not require any additional sinking other than what the enclosure could provide.

The output of T1, in concert with capacitors C13 (and C14 when switch S2 is closed), form a resonant tank which is further modified when the Telegon system inductance of 42.5mH is attached. When these inductances and capacitances are present a resonant frequency near 780 Hz is observed which results in a near sinusoidal waveform that is adjustable to nearly 100 Vrms. When testing two or three Telegon loads an inductance of 130 to 190 mH is presented and thus less capacitance is required to achieve the resonant frequency of 780 Hz. In the “test” mode switch S2 is placed into the open position so that proper resonance and waveform voltage is realized.

Construction

The circuitry shown in the schematic was built using experimenter’s perf-board with a generic copper pattern etching and point to point wiring. The design was split into two boards, the first consisting of the microprocessor related circuitry and the second consisting of the power devices including the switching FETs and voltage regulators. A purchased 117 VAC to 24VDC power converter was utilized as the 24 volt source used to power the unit. It was convenient to utilize a failed ATX style PC power supply as a chassis to house the electronics after removing the original circuit boards.

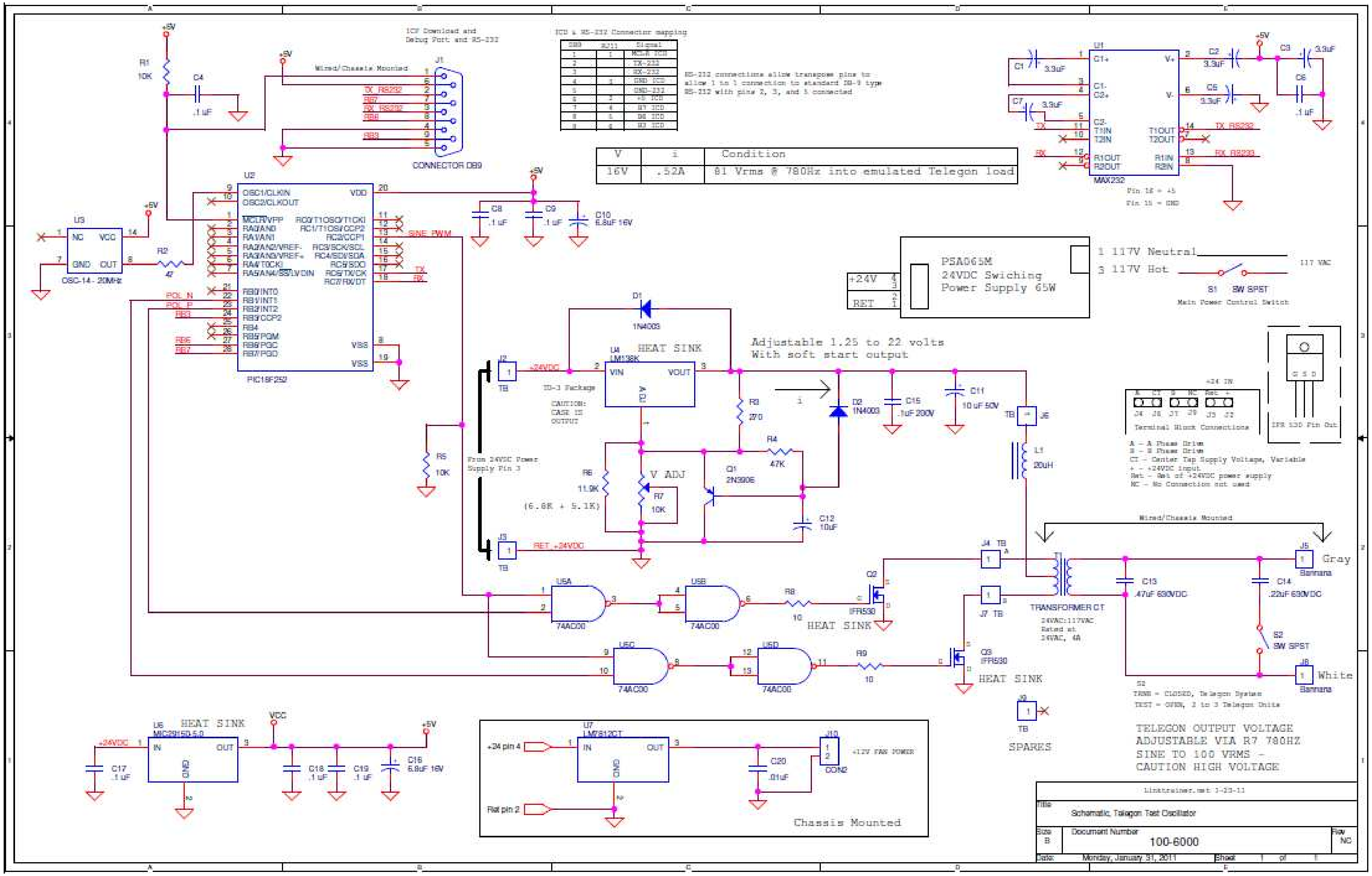

Figure 10 Schematic diagram of the Telegon test oscillator

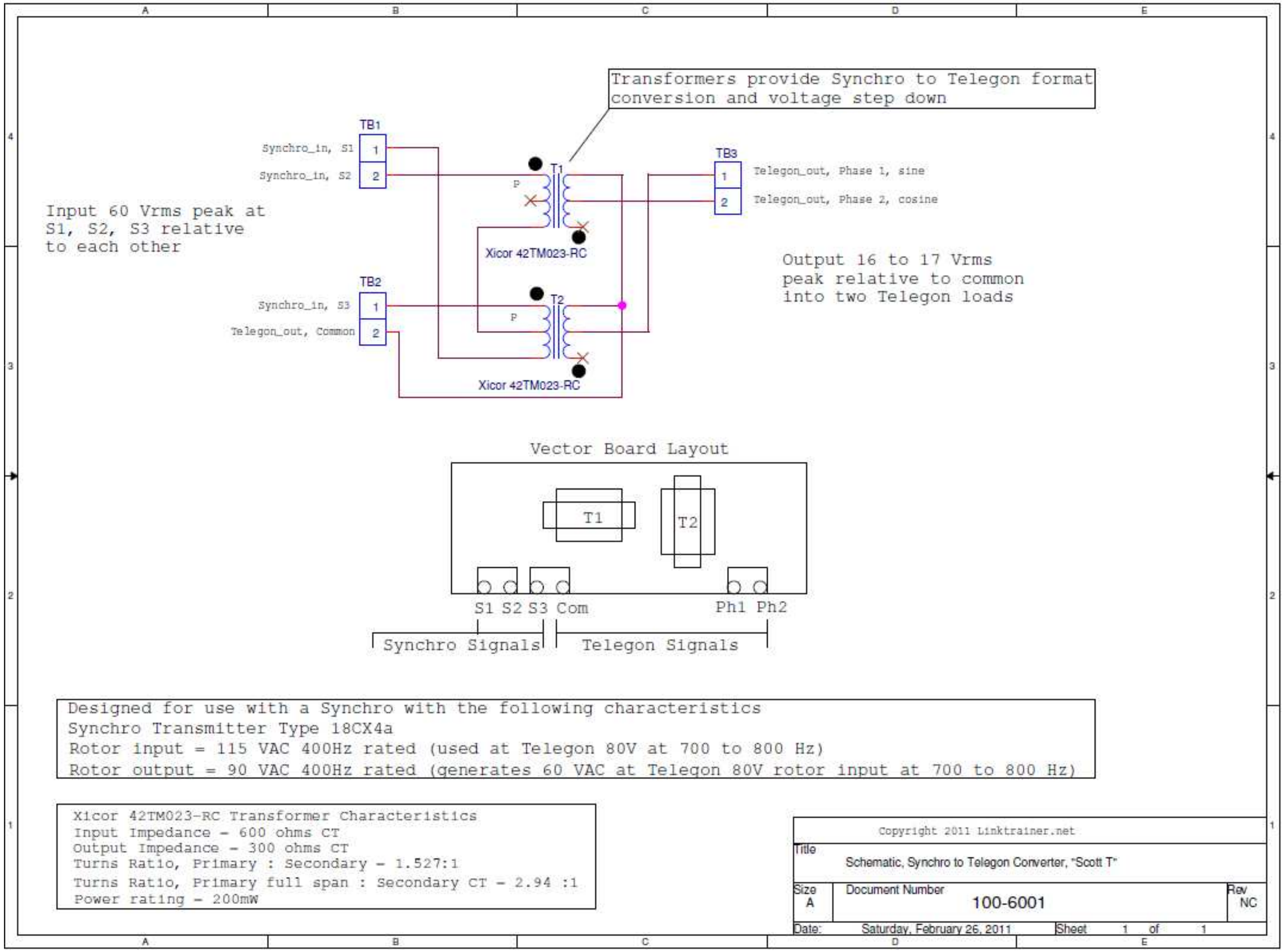

Figure 11 Synchro to Telegon format converter

The former ATX power supply chassis provided a ready made power entry for the 117 VAC and a cooling fan. Figure 12 Figure 13 and Figure 14 display the interior of the completed unit and Figure 15 the front panel.

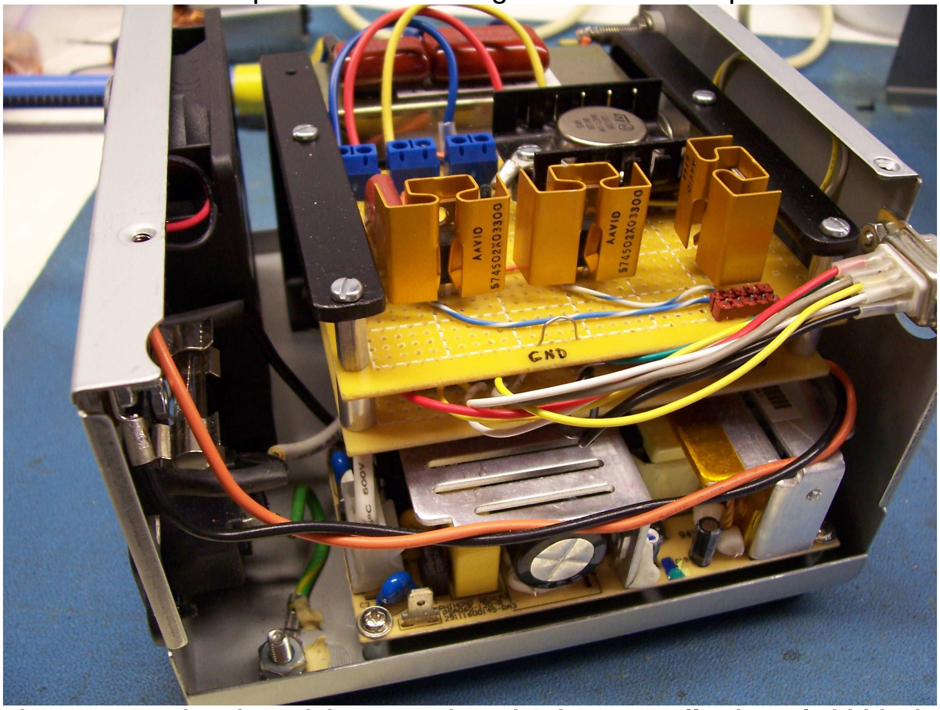

Figure 12 Interior view of the power board, microcontroller (mostly hidden) & 24 V power supply (bottom)

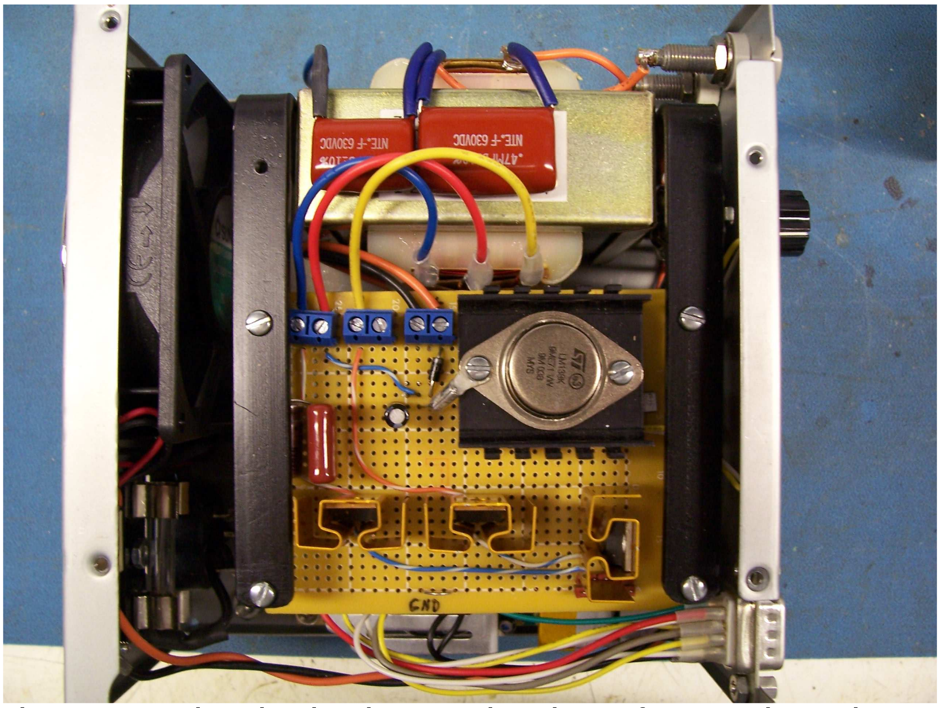

Figure 13 Top view showing the power board, transformer and capacitors

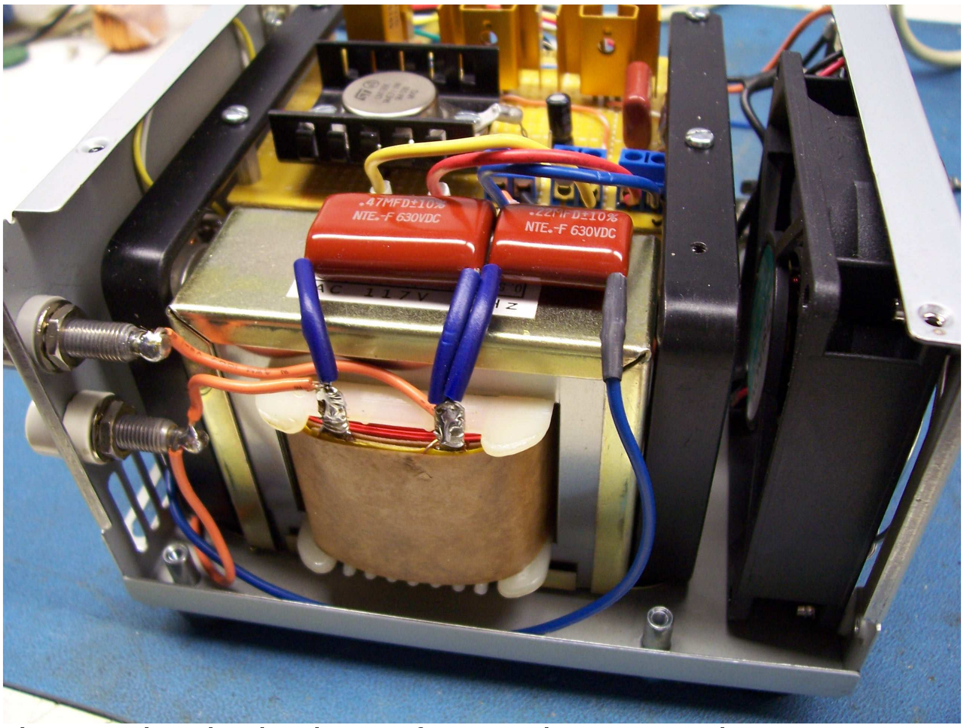

Figure 14 View showing the transformer and output capacitors

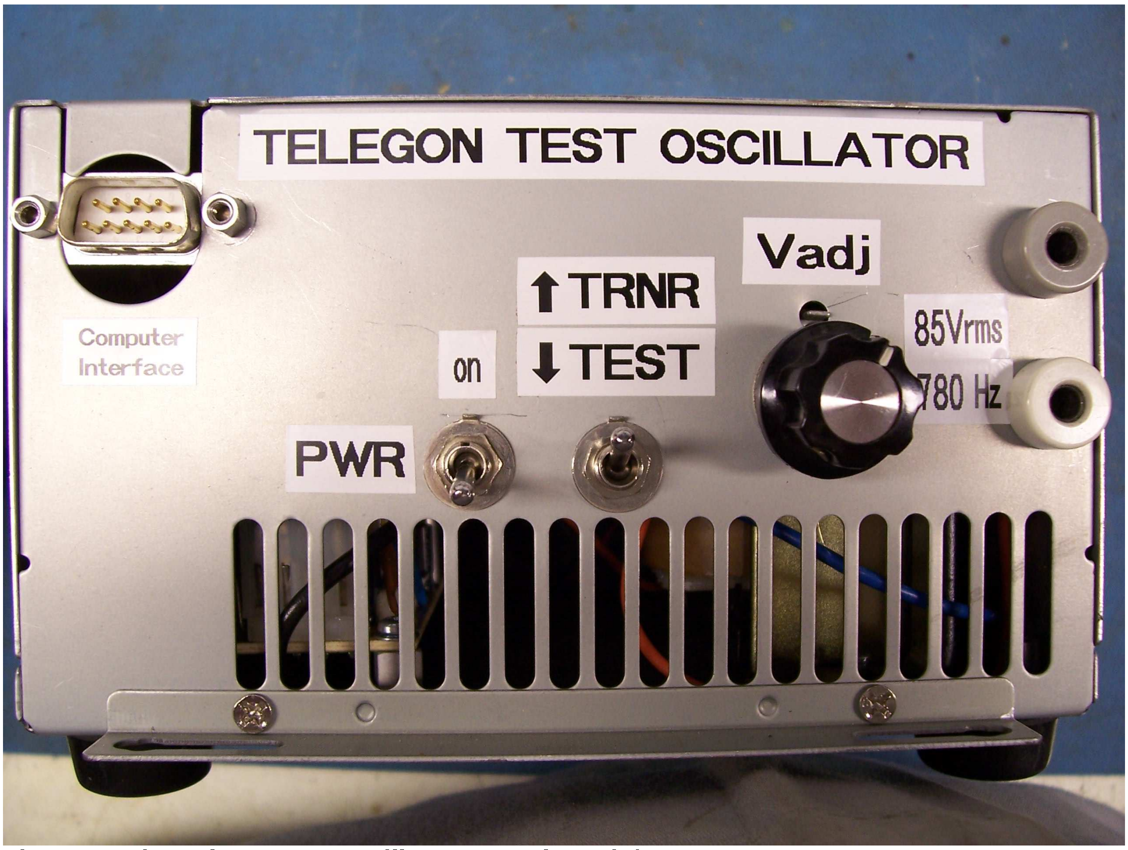

Figure 15 The Telegon test oscillator controls and I/O

Software/Firmware

The software to generate the PWM sine wave was written in C using an integrated development system and compiler sold by CCS (Custom Computer Services). The source code listing appears in Appendix A. The software uses a look-up table that is designed to produce a frequency of 780Hz. This frequency was selected since it was within the 700 to 800 Hz range provided by the original Telegon Oscillator and proved to be the optimum resonant frequency of the Author's Link Trainer Telegon system. Within the source listing you will also find additional look up tables for different frequencies that have been commented out yet remained within the source code as examples of other frequencies. The sine PWM values within the look up table were computed using an Excel spread sheet and entering the appropriate equations. An interrupt driven routine is used to read a value from the look up table and update the PWM value at

Operation

When substituted for the original oscillator the results were found to be very good. Figure 16 displays the waveform obtained with the Test Telegon Oscillator connected to the Link Trainer Telegon system. The waveform was stable and a reasonable sinusoid.

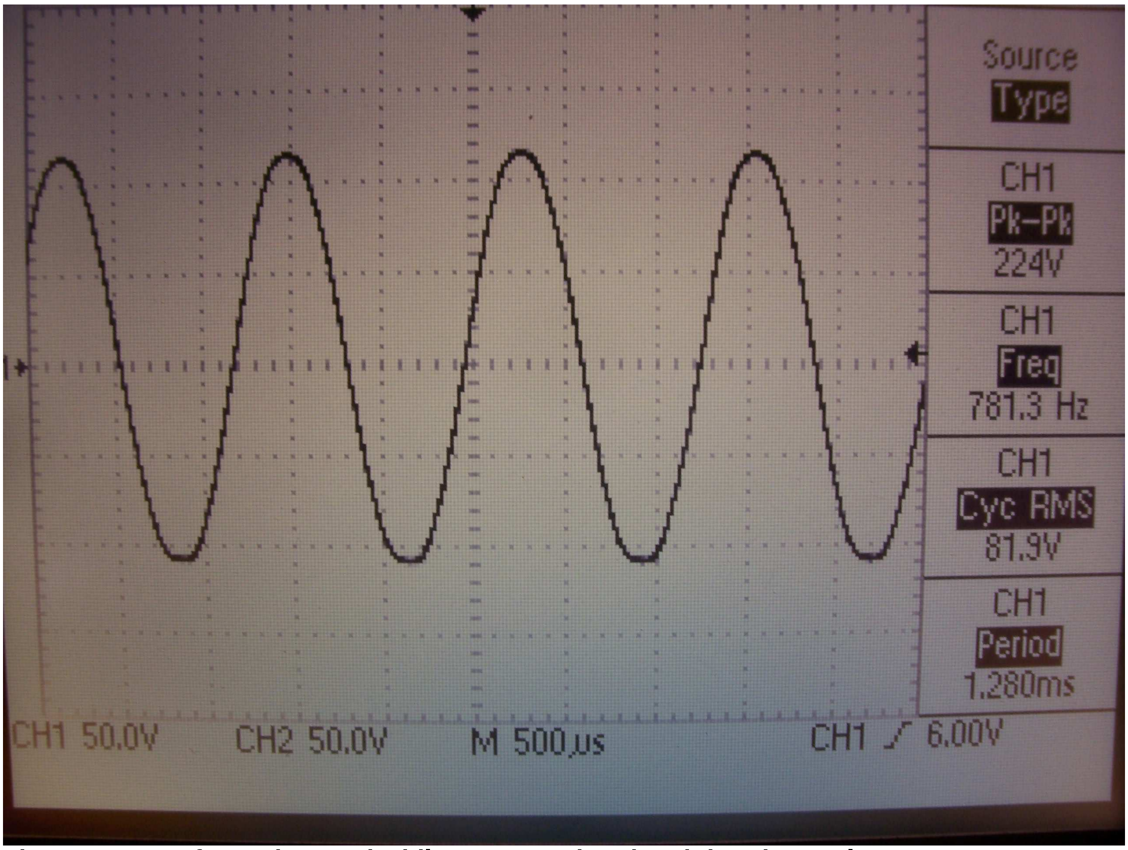

Figure 16 Waveform observed while connected to the Link trainer Telegon system

Telegon instrument testing

The ability to test Telegon based instruments independent of the transmitting Telegon does offer some advantages in terms of ease of test and the ability to compare instrument pointer values amongst paired instruments to ensure common alignment. There are several means to generate a Telegon signal, the easiest being to utilize a Telegon instrument as a driving source. Of the three types of Telegon instruments available the altimeter makes a good candidate as a driving source.

The Telegon unit within the Altimeter is magnetically coupled to the altimeter clockwork hands. This magnetic coupling allows an externally placed magnet situated near the face of the altimeter to drive the altimeter Telegon unit and have it act as a transmitter. A relatively simple device consisting of a very strong rare earth magnet and circular insert can be made to drive the altimeter. The construction of such a device is shown in Appendix B. This technique is not as smooth or predictable as a mechanically driven type and may at times flip magnetic poles. Also, the pressure setting will influence the relative pointer position on the Telegon units following the Altimeter so while useful, it is not as precise as the Synchro based system described in the following section.

Alternatives to the simple magnetic coupled drive via an Altimeter or Synchro based system would be to extract a Telegon unit from a instrument and use it in place of the a Synchro in which case a Scott T conversion is not necessary. Another possibility would be the use of a resolver to generate Telegon signals so long as the input voltage to the resolver could be scaled to accommodate the drive level of a Telegon Oscillator output (80 to 90 VAC rms) and generate the phase 1 and 2 output levels required (16 to 17 VAC rms at peak values). Not having a resolver available the Author has not attempted this technique.

Of the two techniques utilized by the Author, the first being the aforementioned magnetic drive Altimeter method and the second an adaptation of a Synchro transmitter with a Scott-T type transformer arrangement to convert the Synchro signals into the format required by the Telegon system the latter has proven to work very well.

A Synchro based test system

The Author purchased a small number of used surplus Synchro transmitters that were rated for operation on 115VAC at 400Hz. After disassembly and cleaning of the contact brushes and cleaning and lubricating the bearings the transmitter was mounted into a custom built transmitting unit with a 360 degree dial attached to the shaft of the Synchro and a means to adjust the dial. The electrical “0” of the Synchro was confirmed and the shaft position indicator set to zero. A “Scott T” transformer arrangement was constructed and attached to the output of the Synchro in order to create Telegon compatible signals.

The Telegon signals used for the “Primary” winding of a Telegon unit are typically excited with 80 VAC rms at 700 to 800 Hz. The Phase 1 and Phase 2 signals are relatively low in amplitude and vary from 0 to 15-17 VAC rms amplitude as a function of shaft/pointer angle. The Synchro purchased was well suited to handle the 80 VAC input voltage but generated an output voltage that was near a maximum of 60 VAC which is much too high in amplitude for a Telegon receiver/indicator.

The difficulty of driving a Telegon receiver with a Synchro relates to the Synchro’s three 120º oriented windings versus the two 90º oriented windings used in the Telegon. Fortunately both issues can be resolved (no pun intended) using a relatively simple technique incorporating two off-the-shelf audio transformers connected in what is known as a “Scott-T” configuration. Normally Scott T transformers are manufactured as matched pairs to exacting specifications and are used to converter between Synchro and Resolver signal formats (they are also very expensive). Through measurement and experimentation, the Author found that two low cost 600 to 300 ohm audio impedance matching transformers connected in a Scott T configuration were sufficient to perform the Synchro to Telegon (resolver) conversion with the added benefit of stepping down the Synchro output voltage from a maximum of 60 VAC to 16-18 VAC. While not 100% accurate the maximum error between driven angle and indicated was found to be less than 4% which seemed like a good trade-off given that the cost of the two transformers was less than $5.00.

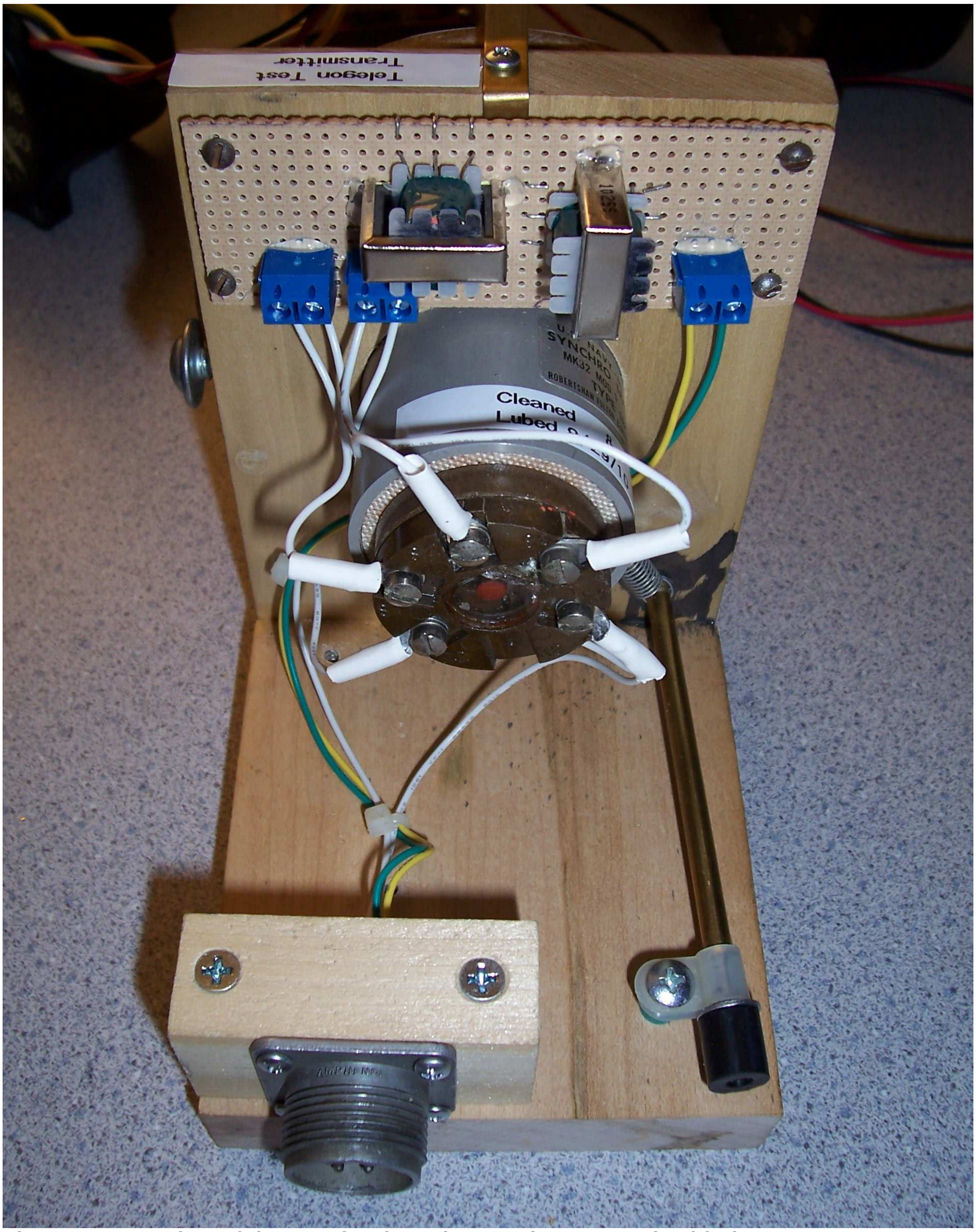

Figure 17 Rear view of the Synchro based transmitter test unit with the "Scott T" transformer board used to convert and step down the Synchro voltages to those compatible with the Telegon indicators

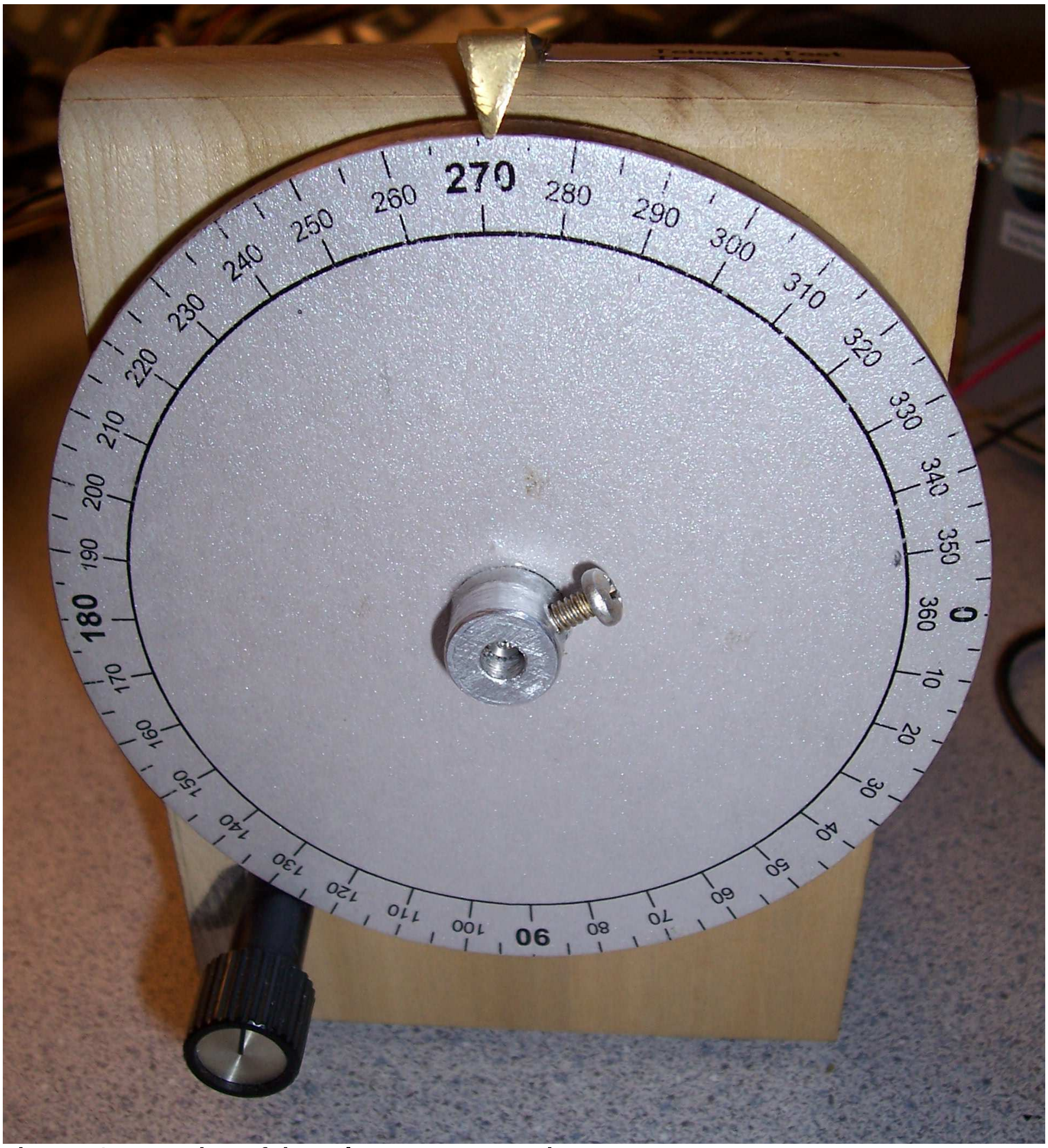

Figure 18 Front view of the Telegon test transmitter

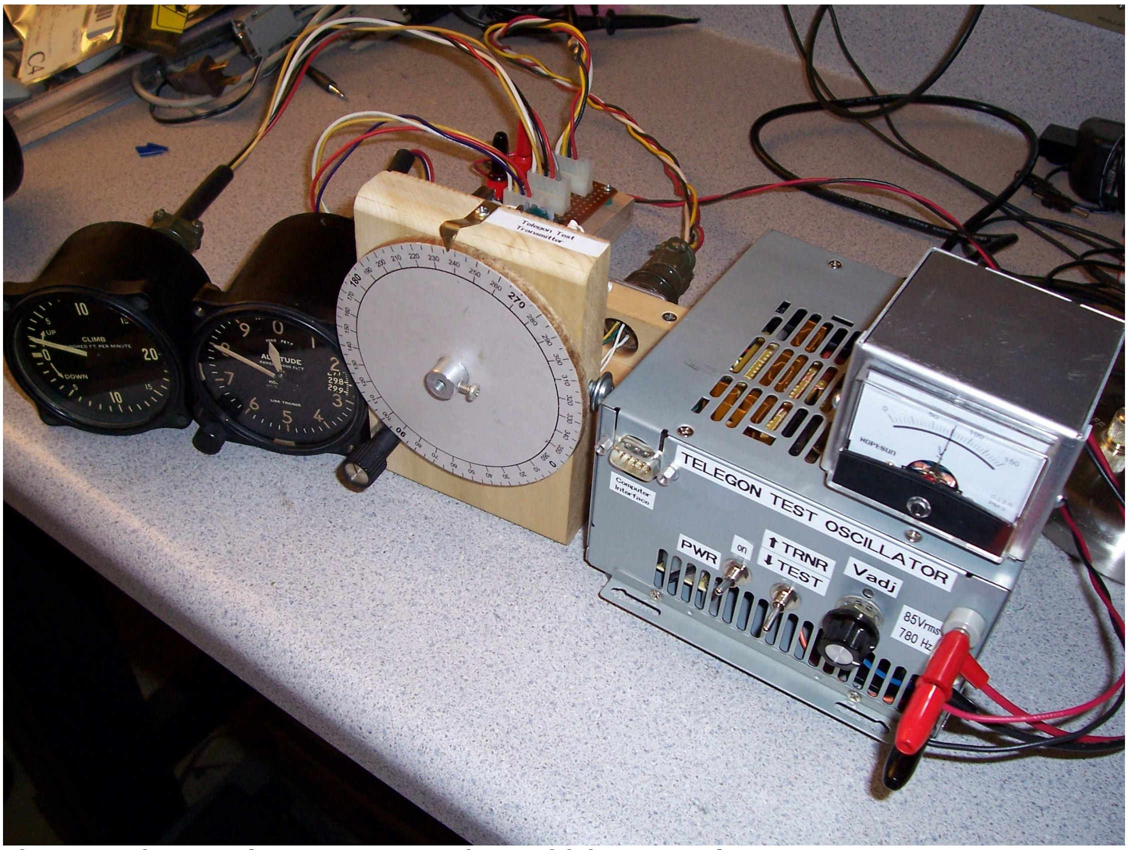

Figure 19 The complete test system shown driving two Telegon Instruments.

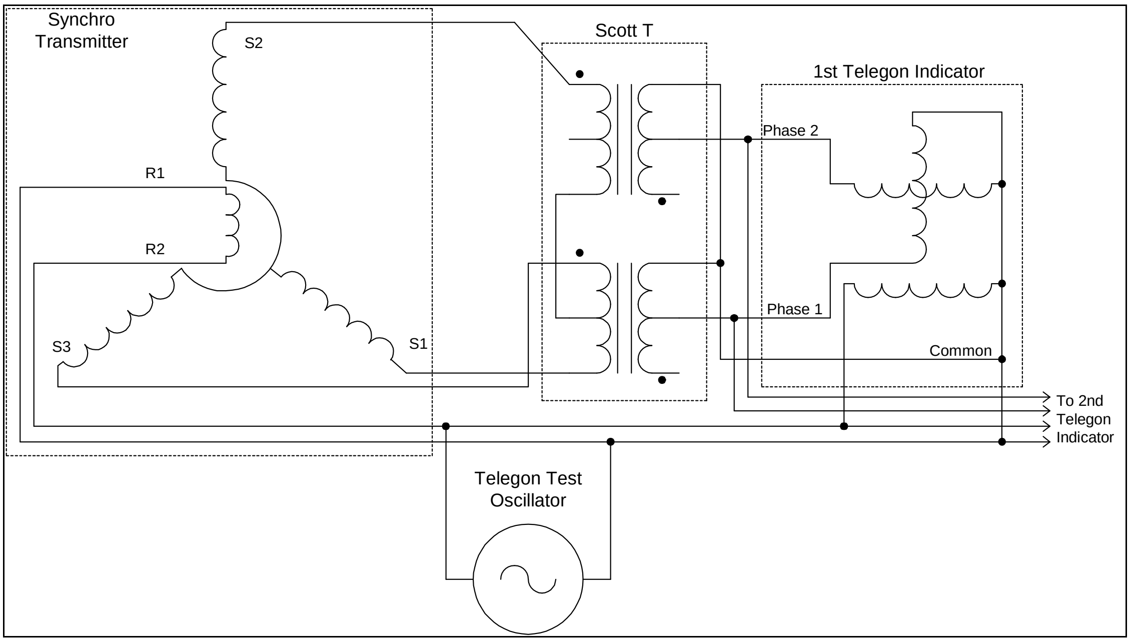

Figure 20 The electrical schematic of the Synchro based Telegon Test system

The question of indicator pointer position

The signal generated by each Telegon transmitter is sent to two identical indicators. It is important that the indicator mounted in the trainer's instrument panel be in agreement with the corresponding indicator located on the instructor's desk. Thus the two receiving indicators must be synchronized to report the same position for the same electrical signal input. Furthermore, the indication must properly correspond to a minimum and maximum indication as set by the transmitter and reflected in the Telegon phase 1 and 2 signal amplitudes. Each Telegon transmitter provides a degree of adjustment but the Link Manuals are not completely clear as to what is considered to be the correct pointer position to correlate with the transmitter min/max settings.

Both Synchro and resolver devices have a defined electrical "zero" point that can be determined based on measurements of the output signals as monitored on a multi-channel oscilloscope. The synchro based test transmitter described above was calibrated so that the indicated angular reading is in accordance with a resolver based quadrature signal structure. While it is unclear if such a relationship was fully established within the framework of the Telegon system one would expect that Link/Kollsman had to establish one in order to mass produce the quantity of instruments built. Measurements of the Author's Link trainer are shown below for the three types of Telegon instruments.

Table 1 Pointer position vs test system shaft angles for three Telegon instruments

Instrument	Instrument Reading	Shaft Angle	Comments
Vertical Speed	0 fpm	250º	
	-500 fpm	200º	
	-1000 fpm	242º	
	+500 fpm	207º	
	-1000 fpm	165º	
Altimeter	0 ft	355º	Altimeter set to 29.80 inches of Mercury
	500 ft	175º	
Airspeed	0 mph	250º	
	40 mph	232º	
	60 mph	205º	
	80 mph	197º	
	100 mph	166º	
	120 mph	140º	
	140 mph	103º	
	160 mph	65º	
	180 mph	31º	
	200 mph	357º	
	250 mph	275º	

The Altimeter can be easily adjusted to meet "zero" by following the instructions provided in the Link Manual. This adjustment is accomplished by turning the barometric adjustment knob to adjust the altitude to the desired setting, and then backing out the captive screw next to the knob and shifting the screw outward so that the barometric adjustment knob can be pulled toward the user and rotated which allows setting of the barometric pressure window without moving the altimeter's hands. Once set, the knob is pushed back toward the instrument and the captive screw reinstalled. The vertical and airspeed instruments, if not synchronized, require that the hands be removed and repositioned. This requires the use of a clock hand removal type tool and some very careful manipulation. The test system described in this paper does allow both indicators to receive the same electrical signals and thus be synchronized, however, such synchronization would typically require that the instrument be powered and operating so as to maintain the Telegon indicator shaft position while the pointer is affixed.

A Caution about Radium Dials

It should be mentioned that some of the instruments used in the Link Trainer were equipped with indicator hands and dial markings produced with Radium based paint. The purpose of the Radium was to provide a luminous dial without the need for much additional lighting, although most trainers did have flood type lighting as well as fluorescent with black light filters to create luminescent instrument dials. In any case, the Radium based instrument dials are radioactive and should be handled very carefully. While this Author does not recommend disassembly of radium equipped instruments if attempted, proper protection through the use of gloves and respiration devices should be worn to prevent the ingestion or inhaling of any particles. Radium has a half-life of approximately 1600 years so the radioactive nature of these indicators will be present for a long time. It is best to obtain a sensitive Geiger counter to determine if the instrument is radioactive.

References

1. Synchro/Resolver Conversion Handbook, Fourth Edition, Electronic Version, Data Device Corporation, 1974, 1999, www.ddc-web.com

2. Navy Electricity and Electronics Training Series (NEETS), Module 15, Principles of Synchros, Servos and Gyros, September 1998

3. Kollsman Manual for Link Trainer Instruments, Kollsman Instrument Division of Square D Company, circa 1940.

4. Link Instrument and Radio Trainer Type C-3 Handbook, Link Aviation Devices, Inc. Binghamton New York, 1941.

Appendix A

PIC Microcontroller C source code listing

```
#include <18F252.h>
#FUSES NOWDT              //No Watch Dog Timer
#FUSES HS                 //High speed Osc (> 4mhz for PCM/PCH) (>10mhz for PCD)
#FUSES PUT                //Power Up Timer
#FUSES PROTECT            //Code protected from reads
#FUSES NODEBUG            //No Debug mode for ICD
#FUSES NOBROWNOUT  //No brownout reset
#FUSES NOLVP              //No low voltage prgming, B3(PIC16) or B5(PIC18) used for I/O
#FUSES NOCPD              //No EE protection
#FUSES NOWRT              //Program memory not write protected

#use delay(clock=20000000)

#define Polarity PIN_B1       //Provides positive cycle FET logic control signal to port B bit 1
#define Polarity_N PIN_B2  //Provides negative cycle FET logic control signal to port B bit 2

int i=0;              // i defines which duty cycle look up entry is used

//The following look up table defines the duty cycle for two "rectified" sine waves.  This is not the most
//efficient table usage from a memory perspective but it made the generation of the FET polarity control bit
//simpler by merely examining the value of i since the "upper" FET conducts on one half sine cycle and
//the "lower" FET conducts on the other.  The control of "i" is interrupt driven and entered into every 62.4
//microseconds when Timer 2 reaches a count of 78d.  The maximum duty cycle supported in this timing
//scheme is 312 which is why the maximum table entry is 312 which occurs at the peak of the  sine wave

// for 400 Hz use the following look up table
//long duty_cycle[40]={0,49,96,141,183,220,252,278,297,308,312,308,297,278,252,220,183,141,
96,49,0,49,96,141,183,220,252,278,297,308,312,308,297,252,220,183,141,96,49,0};

//for 750 hz use the following look up table
//long duty_cycle[40]={0,26,52,76,98,118,135,149,159,165,167,165,159,149,135,118,98,76,52,26,26,52,
76,98,118,135,149,159,165,167,165,159,149,135,118,98,76,52,26,0};

//for 780 hz use the following look up table
long
duty_cycle[40]={0,25,50,73,94,113,130,143,152,158,160,158,152,143,130,113,94,73,50,25,0,25,50,73,94,
113,130,143,152,158,160,158,152,143,130,113,94,73,50,25};

#int_TIMER2

void  TIMER2_isr(void)          //Timer 2 interrupt routine
{

   i++;                        // Increment i

   set_pwm1_duty(duty_cycle[i]); // Output PWM LUT entry for the current sample

   if(i >=21)              // if table entry element >= 22 polarity = 1, otherwise polarity = 0 (i count starts at 0)
    {
    output_high(Polarity);
    output_low(Polarity_N);
    }
```

```
    else
    {
      output_low(Polarity);
      output_high(Polarity_N);
    }

    if(i == 39)                   // Check to see if sample = 39, if so reset i to equal 0, otherwise don't change i
    {
    i = 0;
    }
    else
    {
    i = i;
    }

}                                       // End of Timer 2 interrupt

void main()                   // Main loop
{

   setup_adc_ports(NO_ANALOGS);
   setup_adc(ADC_OFF);
   setup_spi(SPI_SS_DISABLED);
   setup_timer_0(RTCC_INTERNAL|RTCC_DIV_1);
   setup_timer_1(T1_DISABLED);

   output_high(Polarity);     // Initialize FET Drive Polarities to known start values
   output_low(Polarity_N);

// The next statement is an important to the proper operation of this system. Timer 2 is used for two items
// (1) It sets up the interrupt interval to 32.1 microseconds (32.1.4E-6s) and
// (2) It defines the divisor for the PWM counter.  In this case the "T2_DIV_BY_4" gives the PWM counter
// a 200 ns period clock
// The 200 ns is derived as follows: 20MHz/4 = 5MHz, the period of 5MHz is 1/5,000,000 = 200 ns (200E-
// 9s). Thus the PWM duty cycle for this
// configuration is (Table entry value)*200E-9/32.1E-6.  Example, the Duty cycle of the 143 value (element
// 7)in the table is 143*(200E-9)/32.1E-6 = .890, now
// multiply this by 100 to get the duty cycle in percent (.890) * 100 = 89.0%.

// Use the following timer set up for 400 Hz
// setup_timer_2(T2_DIV_BY_4,78,1);

// Use the following timer set up for 750 Hz
// setup_timer_2(T2_DIV_BY_4,42,1);

// Use the following timer set up for 780 Hz - this is the one to be used
   setup_timer_2(T2_DIV_BY_4,40,1);

   setup_ccp1(CCP_PWM);
   set_pwm1_duty(0);             // Set PWM output to 0 for initialization purposes

   enable_interrupts(INT_TIMER2);
   enable_interrupts(GLOBAL);

   while(1);                     // Execute this routine forever
}
```

Appendix B

A magnetic drive wheel to convert an altimeter to a Telegon drive source

Figure 21 Two rare earth magnets extracted from a failed hard drive stacked together setting on top of a 2.75 inch diameter disk cut from foam board – foam with paper on each side

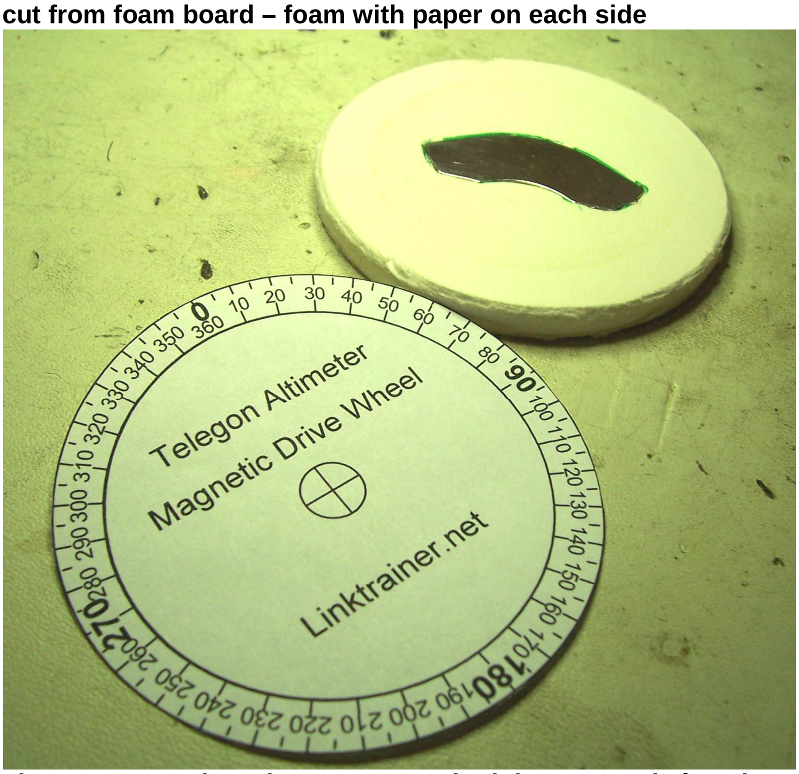

Figure 22 Foam board was cut to embed the magnet below the surface – the magnet must be below the surface otherwise it may scratch the altimeter glass – the magnet is secured using glue – hot melt in this case – the paper overlay is shown and will be glued to the side opposite the magnet.

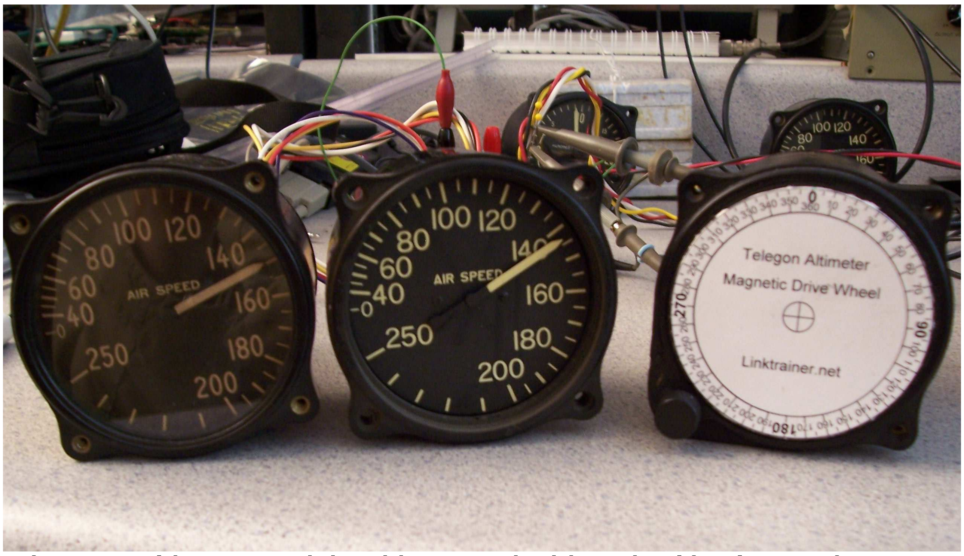

Figure 23 Altimeter on right with magnetic drive wheel in place and two airspeed indicators on left, note small discrepancy in pointer values.

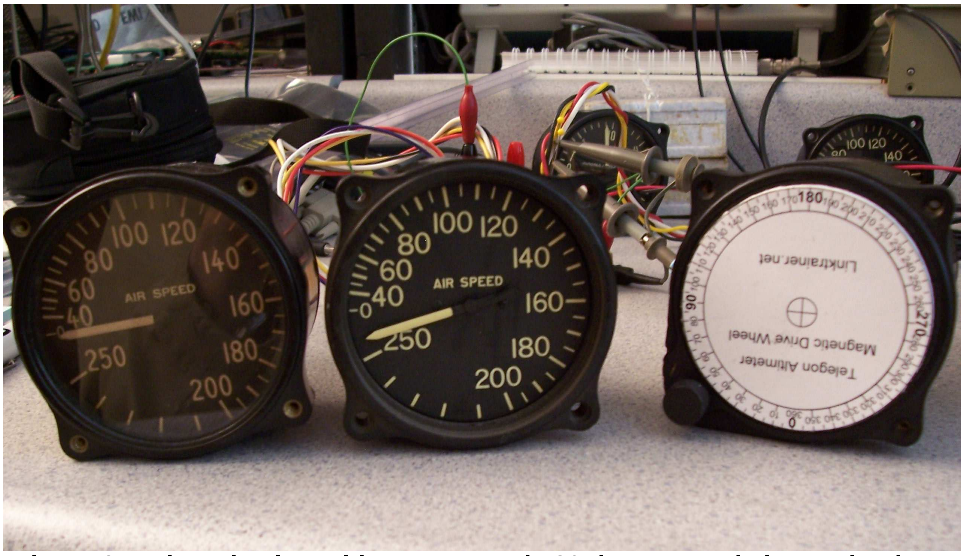

Figure 24 Drive wheel on altimeter rotated 180 degrees and airspeed pointers are shown to follow

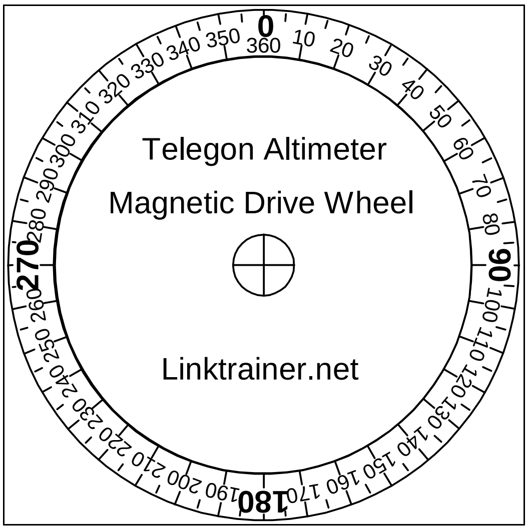

Figure 25 Full size drive wheel rosette template the degree indicators are for reference only and do not necessarily represent truth.

Revision information

August 21, 2014 Incorrectly listed Kollsman patent as 230285, was corrected to 2303285.