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APPLICATION NOTE #G-SA1

DRIVING SYNCHRO LOADS

With Synchro Amplifiers and Converters

Synchro Torque (Producing) **Receivers**

When driving Synchro Torque Recievers, power is pulled from and against the 2 following sources:

1) The Torque Reciever itself: Via 26 or 115VAC on it's rotor coil, R1 & R2 rotor coil.

----------- AND -----------

2) The Power Amplifiers 3 wire synchro outputs, S1, S2 and S3 stator coils.

Torque recievers provide torque as a result of the interaction of the two magnetic fields introduced through these coils within the torque reciever itself.

The torque reciever is considered an active load in that it works against the opposing stator coil inputs, thereby loading them to produce the torque required of its shaft.

Torque is produced whenever the torque recievers shaft angle differs from the angle dictated by it's 3 wire stator input. The angular difference is reflected as a voltage gradient that develops circulating currents in the stators, working against the rotors magnetic field.

These opposing stator currents provide the magnetomotive force against the rotors magnetic field, to move the rotor shaft.

Theoretically, when the shaft angle is positioned exactly to the angle dictated by it's 3 wire synchro input (respective of the phasing of it's rotor input); the load impedence is infinite, the shaft is nulled and the load is null.

In practice however, the amplifiers outputs must still accomodate the load incurred by virtue of both the voltage and phase differentials existing between the amplifier outputs and the actual characteristics of the torque recievers imperfect stator coils. These differential effects are significant, and must be considered when specifiing appropriate amplifiers for a given application.

Driving Synchro Torque (Producing) **Receivers**

When driving torque recievers: the amplifier must be able to handle both: the peak transient power required to be able to drive the torque reciever to a null (close the loop), in addition to being able to supply enough steady state, continuous power to maintain the torque reciever at null, accomodating the circulating currents at the null resulting from phase shift and voltage differentials in the driven synchro, the amplifier, and the D-S converter or other synchro driving the amp.

When driving a Torque Receiver, like driving a servo, we are constantly attempting to null the circuit to achieve any desired position, to null a 3 wire synchro consider the voltage required at null in a 3 wire synchro format as:

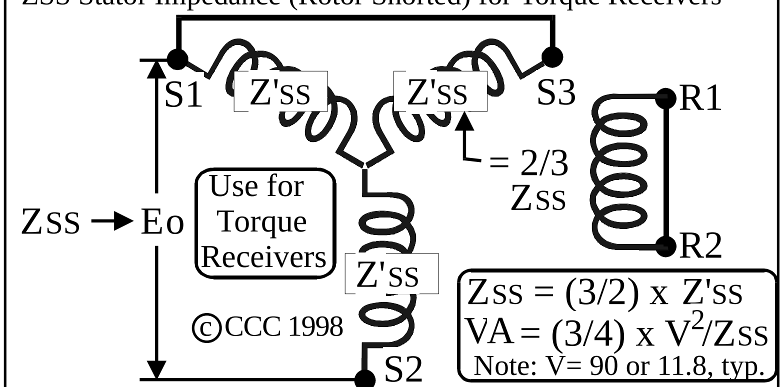
$\sin(120^{o})(Vm)$ Vm = voltage magnitude

Vm for a 115V/90V L-L synchro: (.866)(90V.L-L) = 78 V. L-L

Vm for a 26V/11.8V L-L synchro: (.866)(11.8) = 10.2 V. L-L

This Vm (Voltage magnitude) is the voltage that will be measured with two stator legs shorted accross the remaining winding. See the following illustration "Zss":

ZSS Stator Impedance (Rotor Shorted) for Torque Receivers



Driving 90V L-L Torque Receivers use VA = 6100/ZSS

Driving 11.8V L-L Torque Receivers use VA = 104/ZSS

Fig. Zss, Driving Torque Receiver Loads

The power amplifier's Zss (output impedence) must be low enough to drive the combined Zss of all the Torque receivers being driven, (plus the Zso of all the CT's and CDX's being driven off the same load (less if these are tuned)), to accomodate the peak transient power required to be able to drive the torque reciever/'s shaft to a null (close the loop).

Additionally, the Synchro Amplifier **must be able to provide enough continuous power to accomodate the circulating currents respective of the phase shift and voltage missmatch (Vmm), required just to maintain a null.**

Calculating Load Impedances Required to Maintain a Null

(To maintain desired position, minimum continuous current flow)

The criteria used to determine the effective load impedence at null, or effectively how much power will be required just to maintain a constant position, we must consider the voltage mismatch and phase shift respective of the components used in the system.

1) Line to line **voltage** difference between the amplifiers outputs and the torque recievers stator, (differential voltage, **mismatch** or magnitude error, = Vmm).

--------------- **AND** ---------------------

2) Phase Shift: Line to line **phase-shift differential** between the amplifiers outputs and the torque recievers stator.

The active load calculations derived by these two variable differentials may be referred to as the "null wattage" or the "VA @ null required", the power exhibited as circulating currents flowing just to maintain a null (any constant position), which is lost wattage above and in addition to the VA required of the amplifier to produce any torque.

Calculating line to line "Voltage Missmatch" @ null

A) When driven from a digital to synchro converter, that part's "Transformation Ratio Accuracy" is the criteria required, it is not usually specified on D-S converters which normally only specify accuracy with respect to the ratio accuracy. For standard CCC D-S

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converters this is typically +/-2%, and may be trimmed to +/-1% on request. It is benificial to source both the Amp and the converters from the same source and request they be matched interchangeably, this will minimize the voltage missmatch.

B) The Scale factor accuracy specified of a good Reference Powered Synchro Amplifier is +/-1%.
On conventional DC powered (non-pulsating) amplifiers this absolute scale factor accuracy may be as much as +/- 8%.

The Transformation Ratio (Input to Output) tolerance of most synchro's is typically +/-2%:

*Amplifier Scale Factor accuracy,	+/-1.%
Synchro Transformation Ratio:	+/- 2.%
Total Voltage missmatch:	+/-3.%.

* Amplifier Reference Powered type with D-S converters trimmed to match where any combined represents +/-1%.

+/-3.0% voltage differential (or missmatch) can be used for nominal calculations, with 1 synchro TR and any of CCC's Reference Powered Synchro Amplifiers.

When driving a Torque Receiver, like driving a servo, we are constantly attempting to null the circuit to achieve any desired position, to null a 3 wire synchro consider the voltage required at null in a 3 wire synchro format as:

$$\sin(120^{O})(V.L\text{-}L)$$

for a **115V/90V** L-L **synchro**: (.866)(90V.L-L) **= 78 V. L-L**
for a **26V/11.8V** L-L **synchro**: (.866)(11.8) = **10.2 V. L-L**

When driving a synchro Torque Reciever using **115VAC** reference and 90 V.L-L stators, anticipate this 3.% in synchro system tolerances, will yield a **Voltage Missmatch** of 2.34V.

78V.L-L (.03 System Tolerance) **= 2.34V.L-L = Vmm**,

The following figure further illustrates the power required at null (actually to satisfy the circulating currents that will be flowing) attributed to the voltage differential (magnitude error, or component missmatch) in the synchro system driving a T.R..

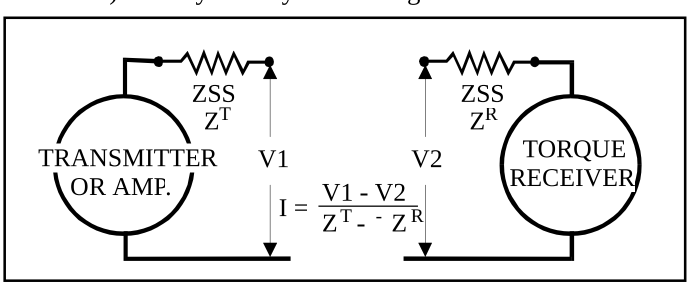

Fig. Vmm, voltage mismatch currents @ null

Take the magnitude of the voltage missmatcth (V1 -V2) over the total impedence of the circuit (output impedence of the transmitter or amplifier (ZSS = Z^T) - the impedence of the Receiver (ZSS = Z^R).

This current times the nominal voltage (78V. for 115/90V systems) represents the power flowing at null in VA or watts, just to satisfy the voltage mismatch..

If multiple synchro's are being driven, only the impedence of the receivers side needs to be changed, calculate like adding resistors in parallel:

$$\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} = \frac{1}{Total} = ZSS = Z^R.$$

Voltage Mismatch and Amplifier Headroom:

The voltage mismatch must also be considered with respect to the negative potential of the missmatch verses the amplifiers voltage envelope, to insure there is sufficient headroom such that the negative flowing currents do not try to backfeed or buck the amplifier outputs, possibly causing damage to the amplifier.

This is explained in greater detail in the following section regarding large phase shifts, and includes both the tolerance of different synchro amplifiers, and the means to increase the headroom and ZSS in the system, and at the synchro amplifier itself.

Calculating line to line phase-shift differential @ null:
(between the amplifiers outputs and the torque recievers stators)

When reference powered amplifiers are used, the 3 wire synchro outputs are in phase with the reference input, the phase shift specified of the Torque Reciever being driven provides the line to line phase-shift differential.

Theoretically, when driving only one synchro this effect can be minimized by adding a phase shift compensation RC (Resistor Capacitor Network) in series with the rotor input of and at the source of each synchro being driven, on many preinstalled synchro applications this luxury is usually not a practical expectation.

Alternatively, adding a large capacitor in series with the Reference input of the Synchro Amplifier can be considered, but this also requires a RC phase lead/lag network be added to the synchro or D-S converter driving the amplifier itself.

Large Phase Shift Effects:

Most installations specify power sufficient to accomodate the increased load required to maintain a null, respective of both the phase shift and voltage mismatch differentials required of the synchro's employed, but the voltage tolerance especially with respect to the phase shift should be calculated to insure there is enough voltage mismatch headroom, that the negative flowing currents do not try to backfeed or buck the amplifier outputs, possibly causing damage to the amplifier.

Phase shift differentials can be significant, example: a typical 15TRX6a has a 20 degree phase shift, a 23TR6 is 9.1 degrees, also consider the phase shift tolerence between like manufactured synchro's is approx. +/-20% of that nominally specified. This is further complicated when driving multiples of differing synchro's off of one common amplifier.

When Reference Powered Synchro Amplifiers are used to drive synchro Torque Receivers having large phase shifts, the phase shift limits the peak voltages available from the pulsating power supplies, this is because the pulsating power supplies' peak voltages are full-wave rectified, and in phase with, the reference (power)

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input. The peak magnitude of the voltage seen as phase shifted away from the reference is less.
This makes the amplifiers effective output voltage envelope smaller, limiting or reducing the peak amplitude available on the outputs with respect to the synchro's desired phasing.

The more undesireable effect (from phase shift) is when the synchro stator signals being driven by the amp., exhibit a higher voltage (by virtue of the induced rotor voltage coupling working against the stators) than the peak voltages being produced by the amplifier. This results in a **negative voltage mismatch** which, if significant enough **will try to backfeed or buck the synchro amplifiers output stages**.

Phase Shift Measurements, and effect:

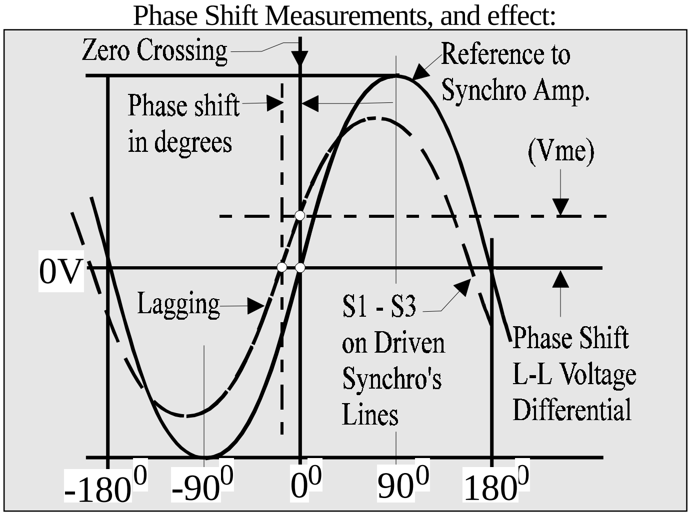


Fig. PS-(Vme), Phase Shift Voltage Magnitude Error

Calculations for the effects of Phase Shift on Synchro Amp.

To calculate the circulating currents that will be flowing at null attributed to phase-shift, first calculate the Voltage magnitude error, (or the voltage offset) incurred by the phaseshift, over the total impedence of the circuit (output impedence of the transmitter or amplifier ZSS = Z^T) + the impedence of the Receiver (ZSS = Z^R):

$$\frac{\text{Sine (phase shift in degrees) (Vm)} = \text{Vme}}{Z^T + Z^R} = I$$

To calculate the power that will be lost to phase shift to simply maintain a null: I (Vm) = VA

Where Vm = Voltage magnitude used to Drive Synchro,
Vm = for 115/90 Systems use 78V,
Vm = for 26/11.8V Systems use 10.2V

Vme = Voltage Magnitude Error, this voltage will be present on the driven synchro's leads, fighting against the power amplifiers outputs, at the zero-crossings of the reference input sine wave, when the reference input is providing no instantaneous power, and likewise, the dynamic pulsating supply has no instantaneous power to transfer; at the instant of these (reference/power input) zero crossings; the amplifier is essentially driving 0V, 0 current (less mismatch), while the driven synchro inductively applies to the same signal lines its phase shifted voltage potentials.

The difference between the voltage seen from the driven synchro, at the zero-crossings of the pulsating supply; must fit into the headroom tolerated by the amp.

If the phase shift line to line voltage plus the mismatch exceeds the voltage missmatch headroom tolerated by the amp.: the phase shift must be compensated for, or external resistors must be used, on the stator lines to increase the headroom, or both.

Synchro Amplifier Headroom:

The negative voltage missmatch that CCC's Reference Powered Synchro Amp's. are designed to tolerate for 115V/90V. units are as follows, (this is your headroom tolerance):

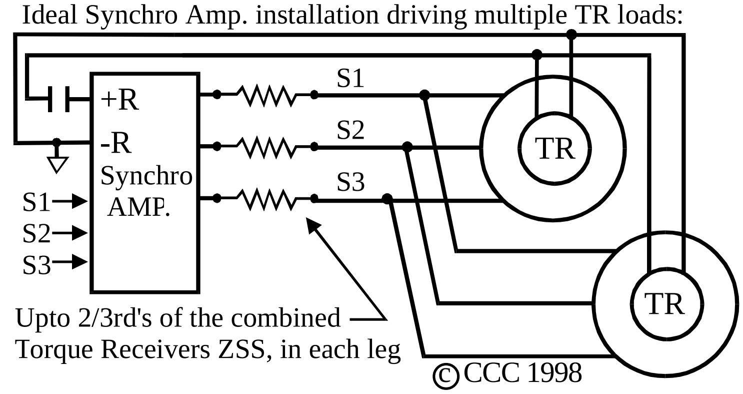
25 VA unit: 6.7 Volts/leg, (2) = 13.4 Volts across winding
50 VA unit: 2.45 Volts/leg, (2) = 4.9 Volts across winding
100 VA unit: 1.73 Volts/leg, (2) = 3.46 Volts across winding

Techniques used to increase the Synchro Amplifier Headroom:

1) Adding Load Balancing Resistors (illustrated in figure LBR)

To increase the amount of negative voltage mismatch tolerated by the amp. without shutting down the outputs, the user can add large (10 - 20) watt resistors in series with the amplifiers synchro outputs representing upto 2/3rd's of the synchro load being driven (represented as the ZSS "Stator impedence rotor shorted", specified for the synchro (or synchro's) being driven in each leg.

Ideal Synchro Amp. installation driving multiple TR loads:



Load Balancing Resistors & Phase Shift added to Synchro Amp.

The added resistors will effect the current flow through the synchro, the synchro signals however will still read 90 V.L-L. The higher the total line impedences, the lower the current flow at null.

Though this will certainly help minimize the voltage at null, and lower the current flow. There may be a slight reduction in peak torque available on the synchro's output shaft (when driving very large shaft loads). **When driving multiple synchro loads, load sharing effects' can and will minimize loss of torque**.

Occasionally, when driving several different Torque Receivers with large shaft loads, compromise may be required, and the user may have to try a couple of different load balancing resistors, or phase shift capacitors to the amp's. reference input to optimize driving the loads.

When driving multiple synchro Torque Recievers, the phase shift should be apportioned respective of the ZSS rating of each synchro verses its phase shift, the larger that synchros load (the lower its

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ZSS impedence), the more its effect of phase shift will burden the system.

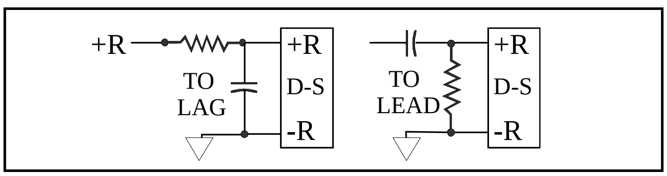
Adding Lead/Lag RC networks for phase shift compensation:

If the phase shift is large, the user may add (or order with internal) a phase shift lead/lag RC (resistor/capacitor) network on the D-S converters reference input lines, and, use a large capacitor on the reference input of the synchro amplifier to compensate for the average phase shift of the load driven.

If a 115V, 60 Hz. synchro system is being used, start with a 10 Uf. 400V cap. in series with RH on the synchro amp., simply measure phase shift between S1-S3 out verses the RH-RL in , when loaded, on a dual-trace scope.

The formula used to calculate the phase shift for the D-S are as follows: $\tan\varphi = \frac{X_C}{R}$ Where φ = the phase shift in degrees.

$X_C = \frac{1}{2\pi f c}$ Where: f = frequency, c = capacitance



Phase Shift Lead/Lag RC placement on D-S Converters
Fig. PSL/L

The input impedence of the reference input specified for the D-S converter is required as part of "R" resistor component (see Data Sheets). CCC converters are available with internal phase shift.

Control Transformer CT's and CDX type Synchro's

CT's are relatively high impedence rotary transformers that provide a single phase AC rotor output representing the sine of the difference between the absolute shaft angle of it's rotor and it's 3 wire stator (command) inputs. CT's are typically coupled directly on the apparatus being controlled, providing instantaneous position feedback and control, it's output is typically amplified to drive a servo motor direct, thus the motor automatically nulls it's shaft to the command angle dictated by the CT's 3 wire input.

CT's' are typically driven from a CX (control transmitter) or CDX (control differential transmitters).

CDX's (control differential transformers) have a 3 wire primary input, a physical rotor shaft angle input, and a 3 wire secondary output used to drive CT's other CDX's or even TR (Torque Receiver) inputs.

The CDX output is a 3 wire synchro format representing the angular difference between the absolute shaft angle of it's rotor input and the shaft angle command determined by it's 3 wire synchro input. Because the CDX is used to drive other synchro's, it's load must be added to the loads required of all the synchro's connected to it's outputs, to determine the full magnitude of the load burden that will be required of it's inputs.

CDX's are typically driven from a CX (control transmitter) or another CDX, the are used as active offsets in a synchro chain to bias their synchro inputs by the shaft angle of their rotor..

Driving CT's and CDX's

When driving CT's or CDX's the amplifier must be able to supply enough steady state, continuous power to drive the Zso of the load.

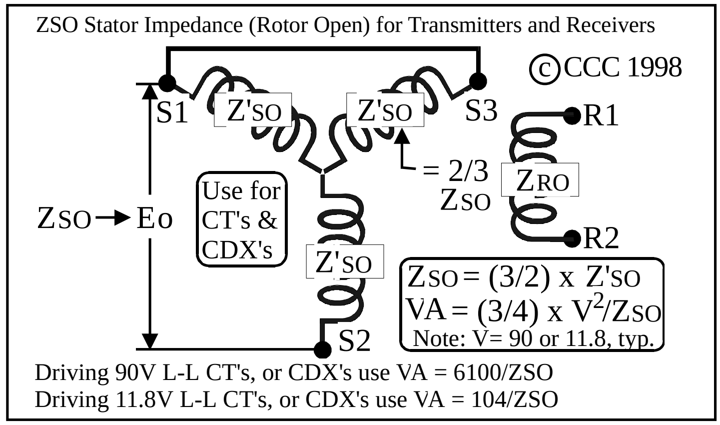


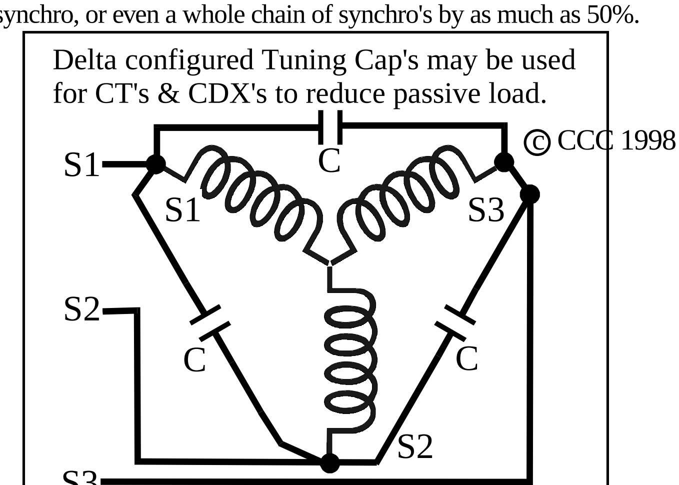
Fig. Zss, Driving Control Transformer (CT) and CDX Loads

Power Factor Correction by Tuning CT's and CDX's

Unlike the more resistive load requirements of Torque Receivers; CT's and CDX's are primarily inductive loads, whereby power factor correction can be achieved to reduce the reactive component by simply tuning the loads.

CT's and CDX's may be tuned by adding good grade, unpolarized, poly-type, high voltage tuning capacitors in a delta configuration, in parallel with the stator inputs (see illustration, use 400V. min. capacitors for 90 V. L-L signals).

The use tuning capacitors can reduce the load burden to the synchro, or even a whole chain of synchro's by as much as 50%.



$$C = \frac{X_L}{4\pi f(R^2 + X_L^2)}$$

4 pi f

Where:
C = Capacitance in Farads,
f = Frequency in Hertz,
Zso: 23CT6 example Zso is rated as 1250 +j3980,
R = 1250 this is the "Real" (resistive) component,
Z_L= j3980 is the "Reactive" (inductive) component

Fig. TC, Adding Tuning Capacitors for CT Type Loads