TP3077SW HyBal™ Software Manual Optimization Program for COMBO®II TP3070/71/72 Programmable PCM CODEC/Filter

National Semiconductor
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HYBRID BALANCE FILTER

The COMBO II TP3070/71/72 has an on-chip programmable Hybrid Balance Filter (HyBal™ Network) for echo cancellation. It consists of a second-order section (HyBal1), followed by a first-order section (HyBal2), a programmable attenuator, and a selectable phase inverter. The hybrid balancing works on the principle of impedance matching, with the HyBal Network trying to replicate the frequency response of the echo signal. Its range is designed to cover the frequency response of the echo signal that would result from a wide range of test networks terminating the subscriber line.

Each of the filter sections is controlled by an 8-bit control word, thus forming 64k possible filter combinations. HyBal1 is intended to balance low frequency signals across a transformer-based SLIC. HyBal2 is intended to balance midrange to higher frequency signals in the voice band, and is particularly useful if the test balance impedance includes a capacitor of 100 nF or less, such as the loaded and nonloaded loop testing networks used in the United States. Each of the filter sections can be bypassed if only one is required to achieve good echo cancellation.

Once a combination of the filter is chosen to replicate the frequency response of the echo signal, the programmable attenuator can be used to correct for the absolute magnitude. It has a correction range of -2.5 dB to -8.5 dB for echo signals at VFxI relative to VFrO, with a resolution of 0.25 dB per step.

For those SLIC interfaces that have the echo signal inverted relative to VFrO, a selectable 180 degree inverting stage is included on-chip for proper balancing.

Figure 1 shows a simplified diagram for the Hybrid Balance Filter, with a transformer SLIC interface. The local echo signal, measured at VFxI relative to VFrO, is a function of the driving impedance ZT, the hybrid transformer, and test network ZR terminating the line. If the impedance reflected into the transformer secondary winding at the CO side is expressed as ZL′, then the transfer function of the echo signal from VFrO to VFxI is given by:

$$E'(w) = ZL'/(ZT + ZL')$$

If there exists a combination of the HyBal Network that perfectly replicates the echo signal in magnitude and phase over the voice band, that is:

$$H(w) = -E(w) = -G \times E'(w)$$

where,

$H(w) =$ HyBal1 $\times$ HyBal2 $\times$ Attenuator $\times$ (± 1)

$G =$ Voltage Gain Introduced into the Echo Path by TP3070/71/72

Then the output voltage from the summing amplifier is zero, resulting in perfect cancellation.

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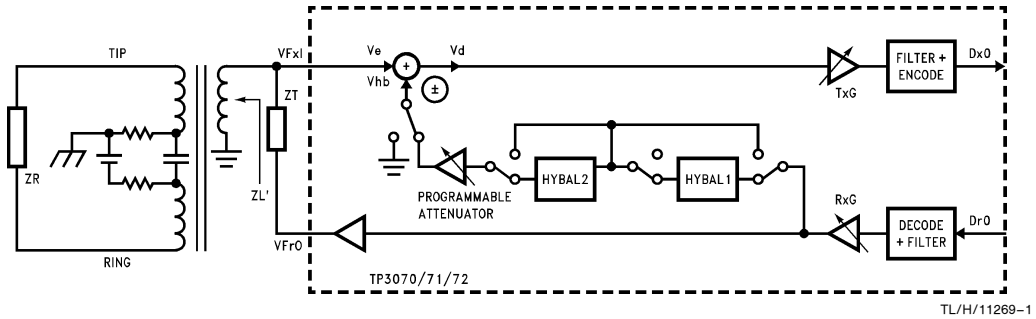

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FIGURE 1. Simplified Diagram of HyBal Network

RANGE OF THE HYBAL NETWORK

The range of the HyBal Network is designed to replicate most echo frequency responses that may result from a wide range of hybrid balance test networks terminating the line, and with a wide range of transformer-based and electronic SLIC interfaces. HyBal1 can be configured as a second-order section, most suitable for balancing interfaces with transformers having low to medium inductance. It can also be configured as a simple first-order section to deal with larger transformers. HyBal2 is used to provide additional phase and amplitude correction for mid and higher frequency signals. *Figure 2a* and *2b* show the range of HyBal1 in magnitude and phase, normalized at 3500 Hz., while *Figures 3a* and *3b* show the range of HyBal2 normalized at 200 Hz.

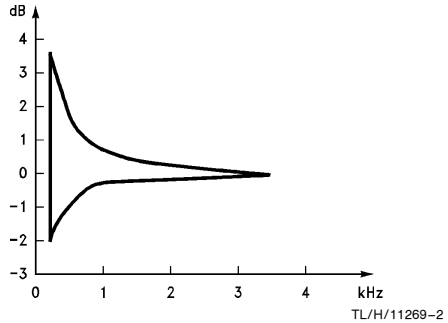

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FIGURE 2a. HyBal1 Magnitude Normalized at 3500 Hz

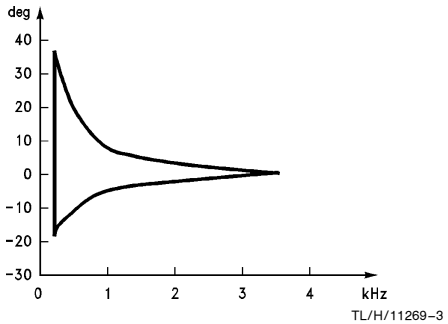

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FIGURE 2b. HyBal1 Phase Normalized at 3500 Hz

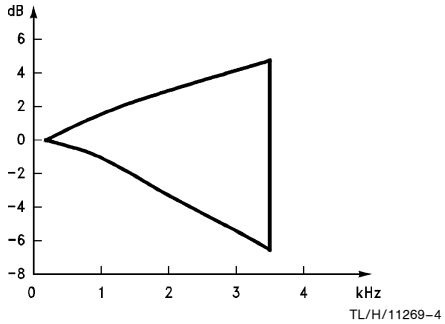

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FIGURE 3a. HyBal2 Magnitude Normalized at 200 Hz

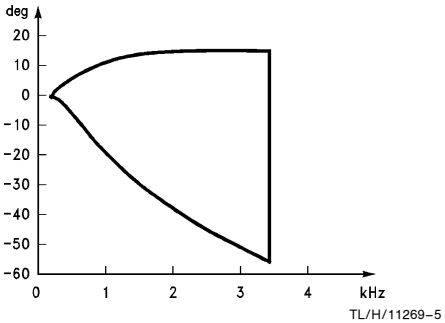

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FIGURE 3b. HyBal2 Phase Normalized at 200 Hz

The programmable attenuator is used to correct the absolute magnitude of the cancellation signal to match with that of the echo signal. It has a correction range of −2.5 dB to −8.5 dB for echo signals at VFxI relative to VFrO, with a resolution of 0.25 dB per step. *Figure 4* shows the absolute magnitude of the echo signal at VFxI that the HyBal Network can handle.

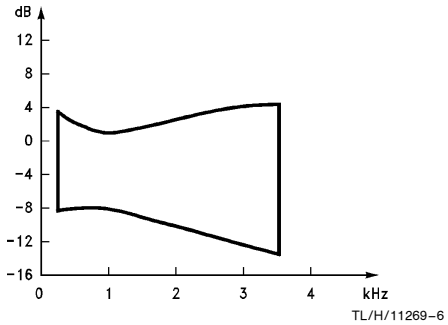

FIGURE 4. Attenuator x HyBal1 x HyBal2

Tolerance of the HyBal Network

Referring back to *Figure 1*, the degree of transhybrid loss obtained by the programmable HyBal Network can be measured from the PCM digital input Dr0 (or Dr1) to the PCM digital output, Dx0 (or Dx1), either by digital test signal analysis or by conversion back to analog via the use of another PCM CODEC/Filter. If the Transmit Programmable Gain is set to have a gain of TxG dB, and the Receive Programmable Gain is set to have an attenuation of RxG dB, then the Transhybrid Loss in dB is given by:

$$THL = 20 \times \text{Log}\,|(H(w) - E(w))| + TxG - RxG$$

If a combination of HyBal Network is chosen such that it closely matches that of the echo signal, then $E(w) \approx H(w)$. Any variations in magnitude or phase of either the echo signal or the HyBal Network characteristics will upset the balance and produce an impact on the echo cancellation performance.

The HyBal Network of COMBO II TP3070/71/72 is implemented by advanced switched capacitor techniques with tight control over process and temperature. Depending on whether one or both HyBal1 and HyBal2 filter sections are used, the worst case tolerance of the HyBal Network is expressed as a percentage of its magnitude, with the worst case transhybrid loss predicted by the optimization software TP3077SW. *Figure 5* is the polar representation of E(f) and H(f), with the tolerance of the HyBal Network expressed as R percent of $|H(f)|$.

Referring to *Figure 5*, if R is the tolerance of the HyBal Network in percent, then the worst case transhybrid loss is given by:

$$THLworst = 20 \times \text{Log}\,(|H(w) - E(w)| + R\%\ \text{of}\ |H(w)|) + TxG - RxG\ dB$$

Programming the HyBal Network

Three registers must be programmed to configure the HyBal Network of COMBO II devices:

Register 1 Functions:

- Enable/Disable HyBal Network
- Invert/Non-Invert the Cancellation Signal
- Program Attenuator Setting

Register 2:

- Set HyBal1 Configuration

Register 3:

- Set HyBal2 Configuration

Control data is written into or read back from the COMBO II device through a serial control port, which consists of control clock CCLK, serial data input/output CI/O (or separate input CI, and output CO for TP3070/72), and Chip Select $\overline{CS}$. Table I shows the two-byte programming instructions for Hybrid Balance Registers 1, 2 and 3. Further information on the serial control port can be found in the TP3070/71 and TP3072 data sheets.

On initial power-up, the HyBal Network is disabled, and Hybrid Balance Registers 1, 2 and 3 are cleared to ''0''.

Once the design for the SLIC is finalized, the echo signal can be defined either by measurement or by simulation of the SLIC model being used. Based on this echo frequency response, the optimzation routine in the TP3077SW software provides the necessary programming information for Hybrid Balance Registers 1, 2 and 3.

For applications that do not require use of the HyBal Network of COMBO II TP3070/71/72, Hybrid Balance Registers 1, 2 and 3 should be set to logic ''0''. Another option is to use the TP3075/76 which does not have the hybrid balance function. Further information can be found in the TP3075/76 data sheet.

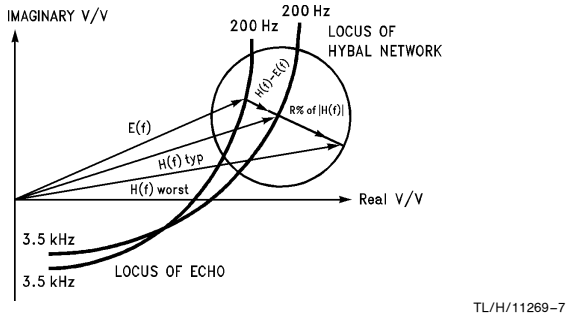

FIGURE 5. Tolerance of HyBal Network at Frequency f Expressed as Percent of $|H(f)|$

TABLE I. Two-Byte Instructions for Hybrid Balance Registers

Function	Byte 1								Byte 2
	7	6	5	4	3	2	1	0	
Write Hybrid Balance Register 1	P	0	1	1	0	0	1	X	Derive from Optimization Routine in TP3077SW Program
Read Hybrid Balance Register 1	P	0	1	1	0	1	1	X	
Write Hybrid Balance Register 2	P	0	1	1	1	0	1	X	
Read Hybrid Balance Register 2	P	0	1	1	1	1	1	X	
Write Hybrid Balance Register 3	P	1	0	0	0	0	1	X	
Read Hybrid Balance Register 3	P	1	0	0	0	1	1	X	
P = 0 for Power Up P = 1 for Power Down X = Don't Care									

TP3077SW HYBAL SOFTWARE

TP3077SW is an application program designed to run on an IBM PC or compatible. It contains a data base that describes the typical characteristics of the HyBal Network at 14 reference frequencies over the voice band.

This data base, obtained through accurate simulation of the HyBal Network, has been verified by product characterizaton to reflect the device's typical behavior.

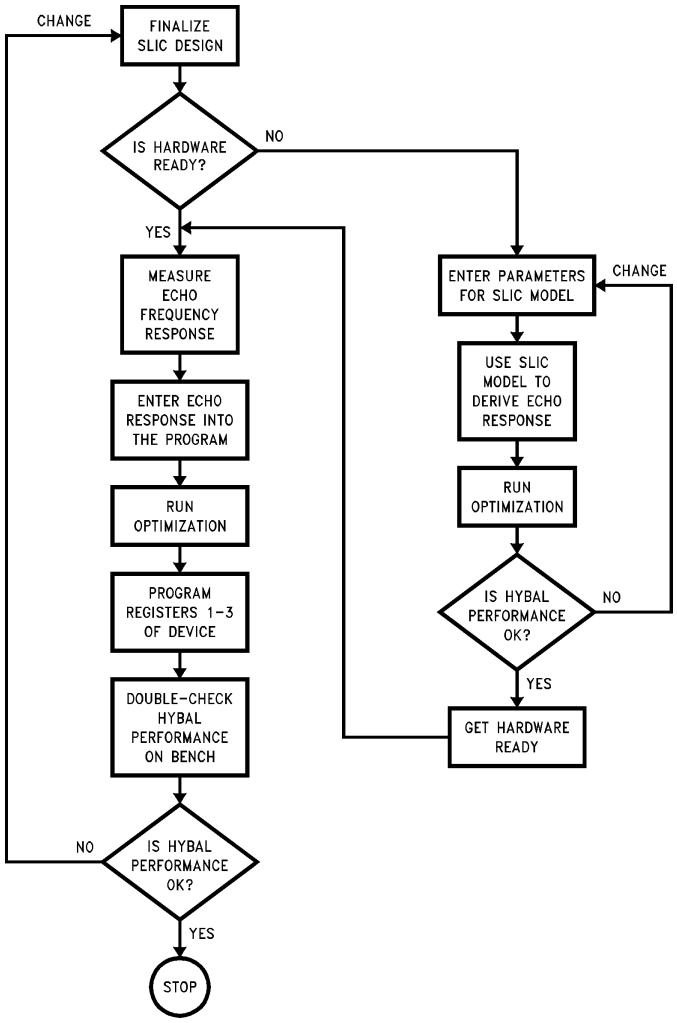

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FIGURE 6. Flow-Chart Illustrating Use of the TP3077SW HyBal Software

The primary function of the TP3077SW is to find a suitable combination of the HyBal Network that matches the frequency response of the echo signal generated by the user's SLIC interface. The program generates the codes needed to program the three Hybrid Balance Registers and predicts the echo cancellation performance. Based on the tolerance of the HyBal Network, it also predicts the worst case transhybrid loss from digital input Dr0 to digital output Dx0.

The user must provide the frequency response of echo signal to the program. It can be measured with a network analyzer. Alternately, the program provides calculation routines to derive the echo frequency response and other ac transmission characteristics for a transformer-based SLIC or an electronic SLIC, such as the PBL3736 or PBL3762 from Ericsson Components.

Please bear in mind that the echo frequency response derived from the model depends on the accuracy of the parameters entered into the program. It is intended to be used as a first order approximation to the echo response and should be replaced by measured data when the SLIC is available for measurement.

Figure 6 is a flow chart illustrating use of the TP3077SW HyBal Software.

TOLERANCE OF THE ECHO SIGNAL

The echo signal is also subject to a certain degree of variation, either caused by tolerances of components used in the SLIC, or by a change in loop current through the SLIC. This variation in echo signal has a similar impact on echo cancellation performance, and cannot be ignored.

It is recommended to use the average frequency response of the echo signal as a basis for selecting the optimum HyBal Network combination. Once selected, the user can use the worst case echo signal to determine the worst case transhybrid loss by using the ''HyBal Performance'' routine of the TP3077SW software. *Figure 7* is a flowchart illustrating the optimization process.

MEASUREMENT OF THE ECHO SIGNAL

The accuracy of the echo signal used in the TP3077SW program will obviously influence the choice of the correct HyBal Network, and consequently the echo cancellation performance predicted from the program. *Figure 8* is a suggested test method for measuring the frequency response of the echo signal.

An HP3577A network analyzer, or any instrument that can measure frequency response in magnitude and phase can be used. In many cases, the instrument's internal offset can introduce measurement errors when making absolute measurements. To improve accuracy, it is suggested that a ratioed measurement be used as follows:

- Connect output and input ports of the equipment together. Measure frequency response C(w) for calibration.
- Measure frequency response V(w) from Vrx to Vtx.
- Echo signal E′(w) = V(w)/C(w)

The output impedance, Ro, of the loop holding current device must be sufficiently high to prevent loading effects on the hybrid balance test impedance ZR.

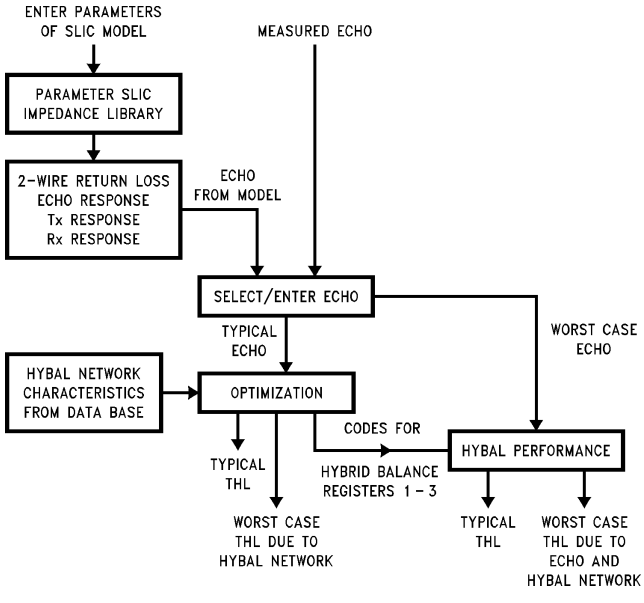
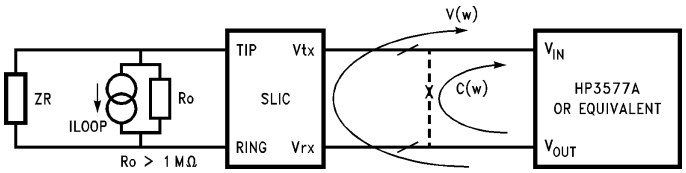


FIGURE 7. Flow-Chart Illustrating the Optimization Process



$C(w) =$ Calibration with V_{IN} Shorted to V_{OUT}

$$\text{Echo } E'(w) = \frac{V(w)}{C(w)}$$

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FIGURE 8. Measuring Frequency Response of the Echo Signal Path

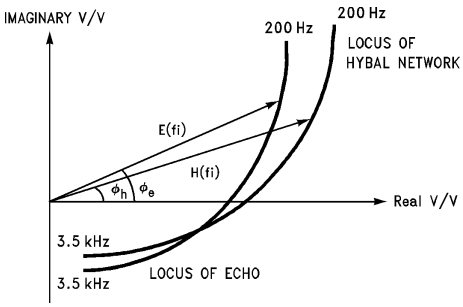
OPTIMIZATION PROCESS

The TP3077SW contains a data base that describes the typical characteristics of all possible combinations of the HyBal Network at 14 reference frequencies. Based on the frequency response of the echo signal, the program searches through the data base to find the one that is the closest match to the echo in magnitude and phase, $H(w) \approx E(w)$. This combination of the HyBal Network is the optimum one (out of the 64k combinations) that will give the best echo cancellation performance.

The optimization process used in the TP3077SW is a constraint optimization based on the sum of weighted squares method. Each reference frequency is assigned a number, ∂, that represents the relative importance of that frequency. The error (distance) between the frequency response of the echo and a possible combination of the HyBal Network is calculated, taking into account its relative weighting and sum over the 14 reference frequencies. The search continues until the program finds the minimum distance over the 14 reference frequencies. *Figure 9* illustrates the optimization process. Further information on the optimization algorithm can be found in the Appendix.

Frequency Weighting

There are usually several possible combinations of the HyBal Network that can be used. Some of them may match the echo signal very well at low band, while others may match better at mid band or high band. If the weighting of each frequency is set to 1, equal consideration is given to each frequency during the optimization process. For frequencies that may not meet the echo cancellation specification, or for which you want to improve the cancellation, the weighting of these frequencies can be set higher and the optimization rerun. *Figure 10* shows a case in which the performance at mid band is compromised to improve performance at low and high band frequencies.



$$HHQ = \sum_{i=1}^{i=14} \partial i \times |E(fi)|^2$$

$$GSQ = \sum_{i=1}^{i=14} \partial i \times |H(fi)|^2$$

$$GHQ = \sum_{i=1}^{i=14} \partial i \times E(fi) \times H(fi) \times \cos(\theta_e - \theta_h)$$

$$\text{Distance, } d = HHQ - \frac{GHQ^2}{GSQ}$$

∂i = Weighting at Frequency fi

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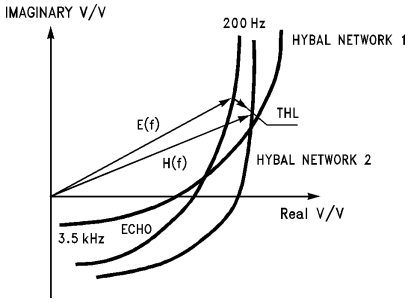
FIGURE 9. Optimization Method Used in TP3077SW



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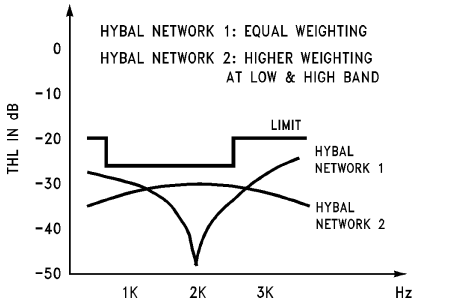

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FIGURE 10. Optimization Results with Different Frequency Weightings

OUT-OF-RANGE ECHO

Absolute Magnitude:

The programmable attenuator is used to correct the absolute magnitude of the cancellation signal in order to match with that of the echo signal. It has a correction range of −2.5 dB to −8.5 dB for echo signals at VFxI relative to VFrO. Many electronic SLIC's have echo magnitude of about 0 dB, which is outside the range that the attenuator can deal with. In such a case, it is necessary to decrease the echo signal magnitude by using a resistive divider in the echo path so that the echo signal falls within the range of the programmable attenuator. The loss in transmit signal level due to the divider can be compensated by the Transmit Programmable Gain stage of the TP3070/71/72. *Figure 11* shows the gain arrangement.

Before running optimization, the TP3077SW program will first check whether the echo signal is within the range of the attenuator. If not, it will issue a warning.

Phase and Relative Magnitude:

In some cases, such as special services applications, there is heavy equalization in either or both of the transmit and receive signal paths. The amplitude and phase changes introduced by the equalizers may be excessive in that the echo may fall beyond the range that HyBal1 and HyBal2 filter sections can handle. *Figure 12* shows a typical arrangement of a special services application.

In these cases, it is recommended to measure the echo signal, and then run an optimization using TP3077SW. The program will find the ''closest'' matching combination of the HyBal Network. It also plots the deviation in magnitude and phase between the echo signal and the selected combination of the HyBal Network. The user can visualize from the plot whether an out-of-range problem may exist.

HYBRID BALANCE FOR REAL LINES

Hybrid balance is usually measured against a fixed test impedance ZR terminating the subscriber line. This test impedance is specified by each national Telecom adminstration to provide adequate control of echo over a majority of their network connections. In applications which call for hybrid balance to be measured against a real cable with a one-time selection of the HyBal Network at the time of installation, it is recommended to determine the frequency response of the echo signal, and use TP3077SW to find the proper HyBal Network at the time of installation. A ''Batch Optimization'' routine is included in the program to facilitate optimization with respect to several echo files at a time.

There are 2 ways for users to find the frequency response of the echo:

1. By measurement
2. By using in-house or commercially available simulation tools to derive the frequency response of the echo signal, then store it in a floppy diskette, which the TP3077SW can read and use for running the optimization. The following format must be used when storing echo files:

   NF
   F(1), EchoA(1), EchoP(1), ∂(1),*
   •
   •
   F(i), EchoA(i), EchoP(i), ∂(1),*
   •
   •
   F(14), EchoA(14), EchoP(14), ∂(14),*

where:

NF is the number of data points, NF = 14

F(i) is one of the 14 reference frequencies, i = 1 to 14

EchoA(i) is the magnitude of the Echo signal in V/V at F(i)

EchoP(i) is the phase of the Echo signal in degrees at F(i)

∂(i) is the weighting of F(i), ∂(i) = 1 to 9

''*'' designates that F(i) will be used when running the optimization.

xyz.EFR is the name of the echo file.

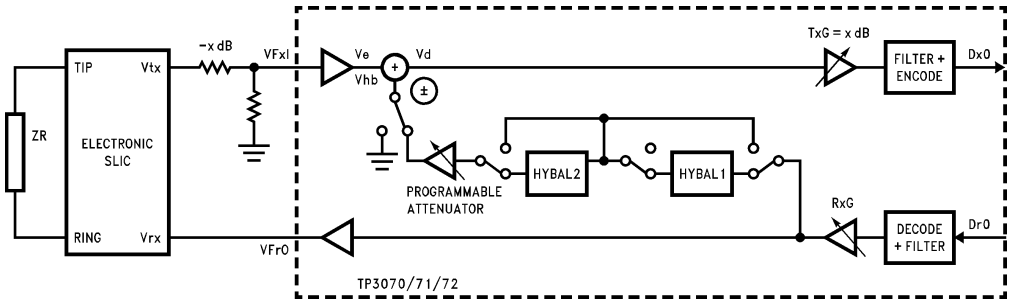

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FIGURE 11. Gain Adjustment for Electronic SLIC with 0 dB Echo Path Loss

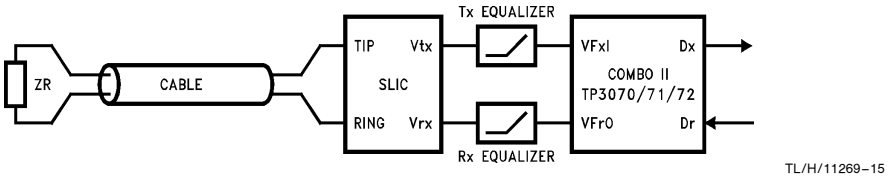

FIGURE 12. Special Services Application

SYSTEM REQUIREMENTS FOR TP3077SW

The TP3077SW requires the following:

- An IBM Personal Computer or ''compatible'' running MS-DOS or PC-DOS Version 2.0 or later
- At least one floppy disk drive
- 640k RAM available memory
- An IBM dot matrix printer or equivalent
- A math co-processor (optional for speed improvement)

DISKETTE CONTENTS

There are two versions of the program. TP3077 is the version of HyBal Software for systems that are not equipped with a math co-processor. If you have a co-processor installed in your system, use TP3077CP for significant speed improvement when running optimization.

However, if you use TP3077CP in systems that do not have a co-processor, the program will perform software emulation of the co-processor function. The time for running the optimization will then be increased rather than reducd.

In the text, TP3077SW refers to both TP3077 and TP3077CP. Depending on the program version, the program diskette contains files listed in Table II.

The first thing you should do is make a working copy of the TP3077SW program diskette using the DOS DISKCOPY command. The new diskette should first be formatted using the DOS FORMAT command. From then on, use the working diskette.

During program execution, data files will be created on the working diskette. The types of files are differentiated by the 3-letter extension of the filenames listed in Table III:

TABLE II. Contents of Program Diskette

TP3077	TP3077CP	Description
For systems without math co-processor	For systems with math co-processor	
TP3077.EXE	TP3077CP.EXE	Main Program
BRUN30.EXE	BRUN3087.EXE	Run-Time Module
HYBAL-2B.DAT	HYBAL-2B.DAT	Data File for HyBal Network
EXAMPLE.PRX	EXAMPLE.PRX	Example Parameter File for Transformer SLIC
EXAMPLE.IMP	EXAMPLE.IMP	Example Impedance Library

TABLE III. Data Files Generated during Program Execution

Filename	Description
xyz.PRX	Parameters of Transformer SLIC Model
xyz.PRM	Parameters of Magnetic Compensation Transformer SLIC Model
xyz.PRS	Parameters for Ericsson Components Electronic SLIC Model
xyz.IMP	Impedance Library Corresponds to the SLIC Model Selected
xyz.EFR	Frequency Response of Echo in Magnitude and Phase
xyz.REG	Byte 2 of Hybrid Balance Registers 1–3
first.REG	Byte 2 of Hybrid Balance Registers 1–3 for First, Second and Third Choices from Previous Optimization (if saved)
second.REG	
third.REG	
config.dat	Previous Program Settings

GETTING STARTED

To start the TP3077SW HyBal Software, insert the program diskette into the default disk drive and type **TP3077** (or **TP3077CP** depending on the program version) followed by <**Enter**>.

The program will start to run. All subsequent data files will be written to or read from the default drive.

GRAPHIC INTERFACE

The TP3077SW HyBal Software has the ability to show the results of some calculation routines in x–y plots on your monitor provided that you have the proper hardware graphic display interface card (such as CGA or EGA) installed in your system. In case you are using a display interface (such as Monochrome Display Adaptor, MDA) that does not have graphics capability, no plots will be shown on your monitor display.

To generate a hardcopy of a plot on a printer, the program relys on the user to install the proper screen dump program (such as **GRAPHICS** from DOS) before running the TP3077SW HyBal Software. The <**PrtSc**> key will send the plots on the screen to the printer.

SELECTION MENU

There are 12 routines in the TP3077SW program. Highlight your choice with the cursor direction keys (**Left, Right, Up, Down** keys), then press <**Enter**> to select. A short description of the routine will also appear on the screen that corresponds to the highlighted choice. Select the ''Quit'' routine or press the <**Esc**> key to quit the program and return to DOS.

PARAMETER-SLIC ROUTINE

The Parameters-SLIC routine is used to select and enter parameter values for a transformer SLIC, a Magnetic Compensation (MC-) transformer SLIC, or an Ericsson Components PBL3736 or PBL3762 electronic SLIC model for calculation of ac transmission characteristics.

To change or edit any component values, select ''**Edit**'' from the command line. The cursor starts to blink at the first component entry field. Enter the values within the field. You can also enter the component value with its decimal multiplier (i.e., p, μ, n, m, k, or M). Pressing the <**Enter**> or <**Tab**> keys will bring the cursor to the next field. At the last entry field, pressing the <**Enter**> or **Cursor Down** keys will bring you back to the command line.

TRANSFORMER SLIC

The program defines a ''general purpose'' equivalent circuit model for a resistive feed transformer SLIC. *Figure 14* shows the circuit arrangement and the equivalent circuit of the transformer SLIC referred to the primary windings (line side).

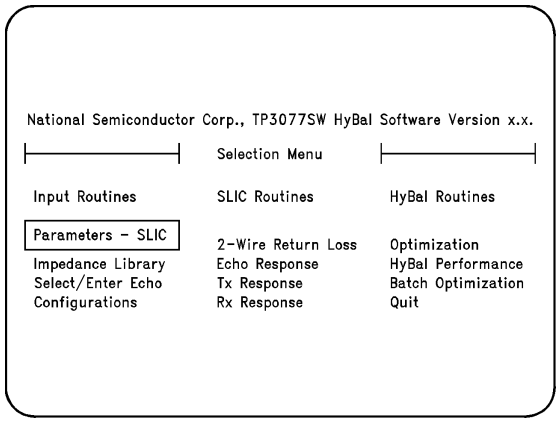

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FIGURE 13. Selection Menu

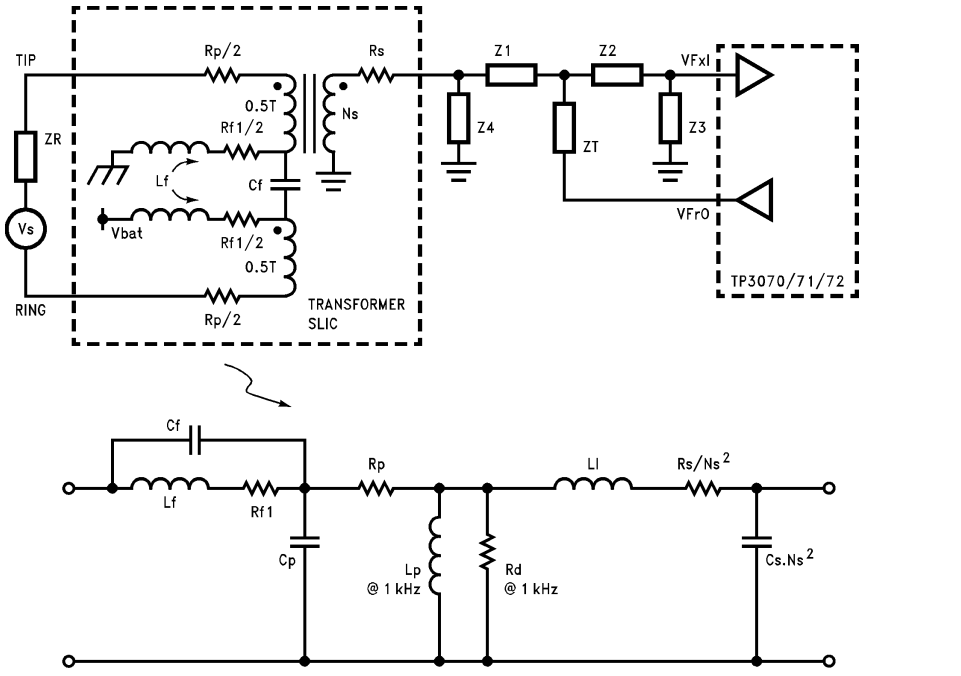

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FIGURE 14. Transformer SLIC Model

where,

Rf1 Total feed resistance in Ohms

Lf Feed inductance (if any) in Henries

Cf Feed capacitance in Farads

Cp Stray capacitance of the bifilar primary windings in Farads

Rp Total resistance of both primary windings in Ohms

Lp Total inductance at 1000 Hz of both primary windings (series-aiding). Units in Henries

Lp′ Total inductance at 200 Hz of both primary windings (series-aiding). Units in Henries

Rd Effective dissipation resistance at 1000 Hz. Units in Ohms

Rd′ Effective dissipation resistance at 200 Hz. Units in Ohms

Ll Effective leakage inductance of transformer in Henries

Rs Secondary winding resistance in Ohms

Cs Stray capacitance of secondary winding. Units in Farads

Ns Electrical turns ratio, secondary to both primary windings

Many parameters of the transformer model are non-linear. Both the primary inductance Lp and dissipation resistance Rd vary with frequency and are dependent on the core material as well as the structure of the transformer. The program requires the user to define the inductance and dissipation resistance at 200 Hz and 1000 Hz. Their relationship with frequency is approximated by the following two empirical equations kindly provided by Midcom, Inc:

$$Lp(f) = Lp \times (f/1000)^{\frac{-Ln\,(Lp'/Lp)}{Ln(5)}}$$

$$Rd(f) = Rd \times (f/1000)^{\frac{Ln\,(Rd/Rd')}{Ln(5)}}$$

Note that the equivalent circuit calls for the reflected impedance due to the secondary winding resistance Rs and stray capacitance Cs. The program, however, will prompt the user to enter the values for Rs and Cs, and the conversion to their reflected impedance is done by the program.

Dry Transformer SLIC

The equivalent circuit has been generalized to accommodate an inductive feed arrangement using a ‘‘dry’’ transformer, as shown in *Figure 15*.

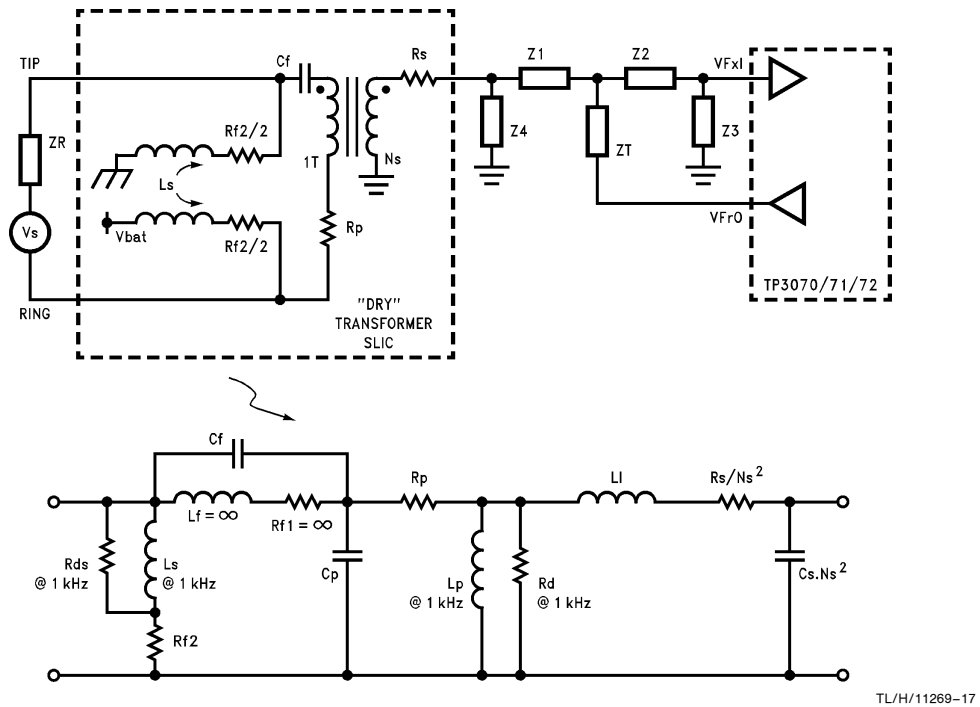

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FIGURE 15. "Dry" Transformer SLIC

where,

Ls	Shunt feed inductance at 1000 Hz. Units in Henries
Ls′	Shunt feed inductance at 200 Hz. Units in Henries
Rds	Effective dissipation resistance for Ls at 1000 Hz. Units in Ohms
Rds′	Effective dissipation resistance for Ls at 200 Hz. Units in Ohms
Rf2	Shunt feed resistance in Ohms

The values of those components that are not needed should be programmed in such a way that their effect is negligible.

For ''dry'' transformer applications, set:

Lf = 1000 H

Rf1 = 10 MΩ

For ''wet'' resistive feed applications, set:

Ls = 1000H

Rds = 10 MΩ

Rf2 = 10 MΩ

Ls′ = 1000H

Rds′ = 10 MΩ

MC-TRANSFORMER SLIC

The program defines an equivalent circuit model for a resistive feed transformer SLIC using a magnetic compensation (flux cancellation) technique. In such an application, the magnetic flux created by the loop current is cancelled by the flux due to a compensation current that flows through a compensation winding, thus allowing the use of a smaller transformer with no air gap.

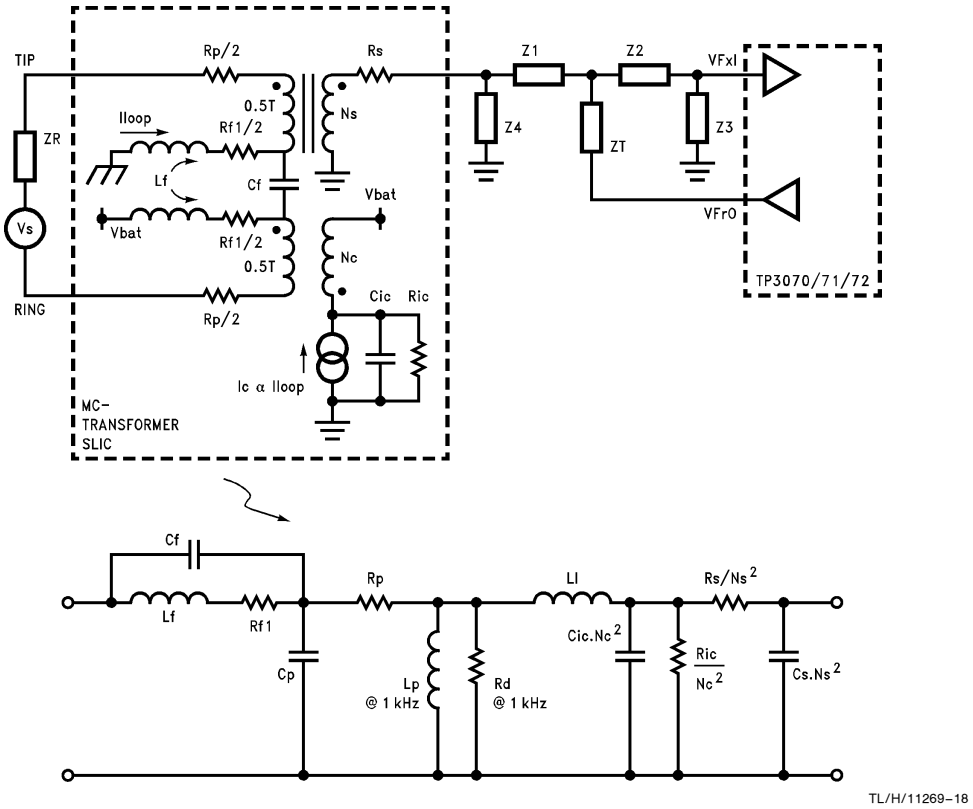

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FIGURE 16. MC-Transformer SLIC Model

Further details can be found from the National TP3200/04 MC-SLIC data sheet. *Figure 16* shows the circuit arrangement and the equivalent circuit of the MC-transformer SLIC referred to the primary windings (line side).

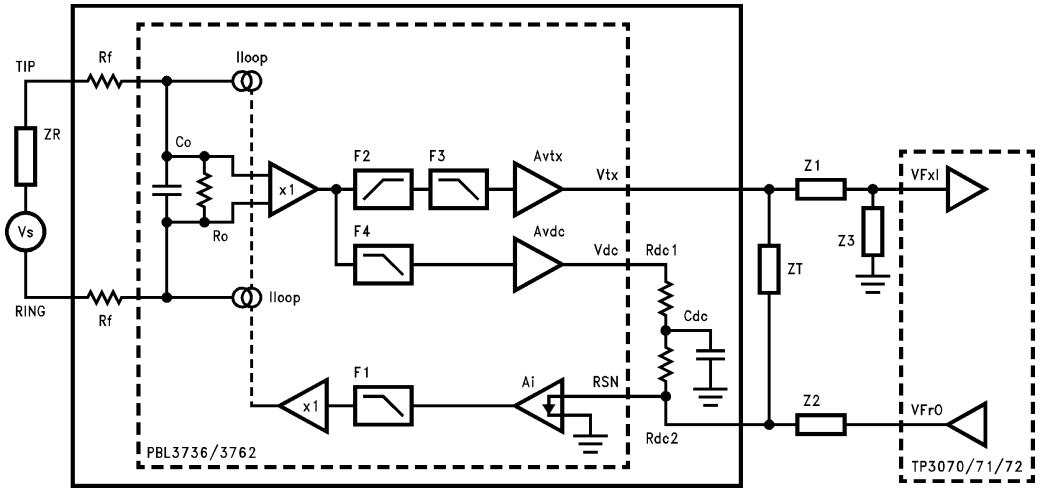
Note that the equivalent circuit calls for the reflected impedances due to Rs, and Cs from the secondary winding, as well as Ric and Cic from the compensation winding. The program will prompt the user to enter the values for Rs, Cs, Ric and Cic, and the conversion to their reflected impedance values is done by the program.

Ric is the terminating resistance of the magnetic compensation winding. Units in Ohms.

Cic is the stray capacitance across the compensation winding. Units in Farads. Nc is the turns ratio, compensation winding to total primary windings.

PBL3736/3762 ELECTRONIC SLIC

Figure 17 shows the conceptual equivalent circuit for modeling a PBL3736 or PBL3762 electronic SLIC from Ericsson Components. The phase shifts introduced in the transmit and receive paths are modeled as ideal first-order low pass or high pass filters. Further information can be found in Ericsson Components PBL3736/3762 data sheets.



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where,
Rf is the external protection fuse resistance in Ohms.
Avtx is the differential voltage gain from Tip-Ring to the Vtx node. Units in V/V.
Ai is the ratio of loop current to feedback current at the RSN node. Units in A/A.
Avdc is the voltage gain of the dc feedback path. Units in V/V.
Rdc1, Rdc2 are the external scaled dc feed resistances in Ohms.
Cdc is the external filter capacitance for the dc feedback path. Units in Farads.
Ro, Co approximate the input impedance of the device with ZT open.
F1, F2, F3, F4 are the −3 dB cut-off frequencies of the internal 1st-order low pass or high pass filters used to approximate the internal phase shifts. Units in Hertz.

FIGURE 17. PBL3736/3762 Electronic SLIC Model

Table IV shows the typical values for these parameters. The values for Ro and Co are empirical.

TABLE IV. Parameters for PBL3736 or PBL3762

Parameter	PBL3736	PBL3762	Unit
Avtx	1.0	1.0	V/V
Avdc	0.05	0.05	V/V
Ai	1000	1000	A/A
F1	34k	34k	Hz
F2	1.8	40	Hz
F3	200k	200k	Hz
F4	1.8	0	Hz
R_O	100k	100k	Ω
C_O	8 n	3 n	F
Rf	Depends on Application		Ω
Rdc1			Ω
Rdc2			Ω
Cdc			F

IMPEDANCE LIBRARY

This is an input routine for the user to select and define the reference test impedance ZR terminating the line, as well as the network arrangement (ZT, Z1–4) connected between the SLIC model and the TP3070/71/72. (See *Figure 14–17* for details.)

The Impedance Library contains 19 sets of impedance networks. They can be any one of the four combinations of RC circuits shown in Table V. The reference test impedance ZR can be selected individually for the ''2-Wire Return Loss'' routine, ''Echo Response'', and ''Receive Response'' routines. ZT and Z1–4, however, remain the same for all these calculation routines.

To select an impedance from the library, select ''**Edit**'' from the command line. The program will go to the editing mode. Enter your selection (1 to 19) in the highlighted field followed by <**Enter**>. You can also use <**PgUp**> or <**PgDn**> keys to step through the library. An <**Esc**> key will terminate the editing mode and bring you back to the command line.

TABLE V. Network Configurations of Impedance Library

IMPEDANCE#	TYPE
1 – 5	R0
6 – 11	R0, C0
12 – 17	R0, R2, R1, C1
18 – 19	R0, R2, R1, C1, R3, R4, C3, C4

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To change the parameter values, press <**Ctrl-Up**> while you are in the highlighted field for the impedance selected. The cursor will start to blink at the first component entry field. Enter your component values in the same way as in the ''Parameters-SLIC'' routine. An <**Esc**> key will terminate editing of the parameter values.

SLIC CALCULATION ROUTINES

When the parameter values of the selected SLIC model are fully defined (by Parameter SLIC and Impedance Library routines), SLIC calculation routines are used to derive the ac transmission characteristics of the SLIC model.

2-WIRE RETURN LOSS

This routine calculates the effective 2-wire impedance, Z2W, across Tip-Ring using the parameters of the selected SLIC model. With reference to the terminating impedance ZR defined for the 2-Wire Return Loss routine, the 2-Wire Return Loss is calculated using the formula:

$$RL2W = 20 \times \text{Log} \left| \frac{Z2W + ZR}{Z2W - ZR} \right| \text{dB}$$

TRANSMIT RESPONSE

This routine derives the transmit (or 2-wire to 4-wire) frequency response of the selected SLIC model. The transmit response is defined as:

$$Tx(w) = VFxI/VTR$$

RECEIVE RESPONSE

This routine derives the receive (or 4-wire to 2-wire) frequency response of the selected SLIC model. With the line terminated by a reference testing impedance ZR (defined by the Impedance Library routine for Receive Response), the Receive frequency response is defined as:

$$Rx(w) = VTR/VFrO$$

ECHO RESPONSE

This routine calculates the echo frequency response of the selected SLIC model. With the line terminated by a reference test impedance ZR for hybrid balance (defined by the Impedance Library routine for Echo Response), the echo frequency response is defined as:

$$E'(w) = V_{FXI}/VFrO$$

The echo frequency response may be needed for subsequent calculations using the HyBal routines. It is recommended to use a starting frequency of 200 Hz, step frequency of 100 Hz, and ending frequency of 3500 Hz in order to ensure that the calculated echo frequency response contains data points that match with the 14 reference frequencies used by the HyBal routines.

The calculated result can be stored on a floppy diskette by selecting ''**Save**'' from the command line. The echo filename has a default extension of ''.EFR'', and the echo data is stored in magnitude (V/V) and phase (degrees).

CONFIGURATION

This is an input routine to select display options:

- Display echo magnitude in V/V or in dB.
- Display Hybrid Balance Register contents in decimal, binary or hexidecimal numbers.
- If you have a color graphic interface, select the foreground and background colors.

HYBAL ROUTINES

The HyBal Routines consist of Select/Enter Echo, Optimization, HyBal Performance, and Batch Optimization routines. They are used to optimize the performance of the HyBal Network of the COMBO II TP3070/71/72 Programmable PCM CODEC/Filter.

SELECT/ENTER ECHO

This is an input routine for the user to select or edit the echo frequency response file for use in Optimization, HyBal Performance, and Batch Optimization routines. The echo characteristics are displayed in polar form, with magnitude in V/V or dB and phase in degrees specified for the 14 reference frequencies used by the HyBal routines.

When running an optimization, the weighting is a numerical value (1 to 9) that defines the relative importance of that frequency in selecting a HyBal Network. Each frequency is also assigned a symbol, ''*'' designating that it will be used when running the optimization, while a blank will mean otherwise.

Echo files may come from several sources:

1. From the SLIC Model

   Selecting ''**Model**'' from the command line will display the echo frequency response derived previously for the SLIC model.

2. From previously stored echo files

   Selecting ''**Read**'' from the command line will allow selection of one of the echo files that you may have in your floppy diskette.

3. By measurement of the echo signal

   Selecting ''**Edit**'' from the command line will bring you into the editing mode. You can enter the measured value of the echo frequency response for each of the 14 reference frequencies. <**Enter**> brings you to the next entry field, and <**Esc**> will terminate editing and bring you back to the command line.

```
        Echo File = From Model
        No. of Data Points with * = 14

Opt   Frequency, Hz      |A|, dB     Phase, deg   Weighting
 *         200          -5.5568      179.9057        1
 *         300          -5.5670      179.5812        1
 *         400          -5.5712      179.3286        1
 *         500          -5.5733      179.0996        1
 *         600          -5.5745      178.8811        1
 *         800          -5.5757      178.4587        1
 *        1000          -5.5764      178.0453        1
 *        1200          -5.5768      177.6362        1
 *        1500          -5.5772      177.0266        1
 *        2000          -5.5777      176.0158        1
 *        2500          -5.5783      175.0076        1
 *        3000          -5.5790      174.0001        1
 *        3200          -5.5793      173.5971        1
 *        3500          -5.5797      172.9925        1

 [Edit]  Save   Read   Model   Lprint   Quit
```

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FIGURE 18. Select/Enter Echo Routine

OPTIMIZATION ROUTINE

This routine generates the necessary programming codes for Hybrid Balance Registers 1, 2 and 3. Based on the user-defined echo frequency response, it searches through the data base of the HyBal Network and finds the combination that is the closest match to the echo signal. This combination corresponds to the case which provides the optimum cancellation effect out of the 64k available filter combinations.

The user can choose to perform a relatively ''Quick'' or a ''Complete'' search. A Complete search means that the program will search through all possible combinations of the HyBal1 and HyBal2 filter characteristics, while a relatively Quick search is a short-cut which searches through HyBal1 and HyBal2 in a successive manner. The Complete search takes a much longer time, however, it always provides the optimum combination of the possible filter characteristics. With an IBM AT equipped with a math co-processor, a Complete search takes about 30 minutes, while a Quick search takes about 4 minutes.

There are three parts in the optimization process:

1. First Pass

   The program will first check the echo data against two criteria:

   - That the magnitude is within the correction range of the programmable attenuator.
   - That there are consecutive data points to ensure a reasonably meaningful optimization with evenly distributed data points over the voice band.

   If the echo file fails either of the criteria, the program will generate a warning, and optimization cannot proceed.

2. Second Pass

   It searches through the HyBal Network combinations by using the Quick or Complete searches. The necessary programming codes for Hybrid Balance Registers 1, 2 and 3 are generated. Three possible sets of filter combinations are given by the optimization process. They are labeled as ''1st'', ''2nd'' and ''3rd'' choices as shown in *Figure 19*.

```
   Search Method = Quick
        Echo File = From Model
     Date/Time = 08-01-1988 18:41:22
   Elapsed Time = 0 Hr 1 Min 57 Sec

                    Register 1    Register 2    Register 3
Byte 1 in Binary:   P0110W1X      P0111W1X      P1000W1X
                    (P = 0/1 for Power Up/Down)
                    (W = 0/1 for Write/Read, X = Don't Care)
Byte 2 in Binary:
1st Choice:         10101100      00000000      01001000
2nd Choice:         10101100      00010001      01001000
3rd Choice:         10101100      00010001      11001100

 [Save]  Lprint   Cont   Quit
```

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FIGURE 19. Optimization Routine Results

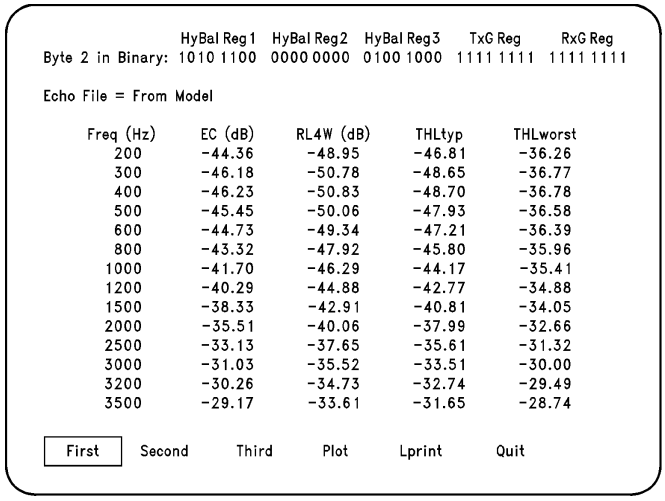

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FIGURE 20. Predicted Performance Optimization Routine

3. Predicted Performance

When "**Cont**" (continue) is selected from the command line, the program will calculate the hybrid balance performance based on the echo data, and the filter characteristics corresponding to the "first" choice. As shown in *Figure 20*, you can also use the "**First**", "**Second**", or "**Third**" command to derive the performance corresponding to the first, second, or third choices. Referring to *Figure 1*, the hybrid balance performance is given by the following ratios:

Echo Cancellation:

$$EC = 20 \times \text{Log} \left| \frac{Vd}{VFxI} \right| + TxG \text{ dB}$$

4-Wire Return Loss:

$$RL4W = 20 \times \text{Log} \left| \frac{Ve - Vhb}{Ve + Vhb} \right| \text{ dB}$$

Transhybrid Loss:

$$THLtypical = 20 \times \text{Log} |H(w) - E(w)| + TxG - RxG \text{ dB}$$

$$THLworst = 20 \times \text{Log} (|H(w) - E(w)| + R\% \text{ of } |H(w)|) + TxG - RxG \text{ dB}$$

where,

Ve = Echo signal at the summing junction

Vhb = HyBal signal at the summing junction

Vd = Output of the summing amplifier

TxG = Transmit programmed gain in dB

RxG = Receive programmed attenuation in dB

The value of TxG and RxG can be changed by using the HyBal Performance routine.

The data base also defines the tolerance of the HyBal Network. Based on the worst case of the HyBal Network for the optimum combination, the worst case transhybrid loss due to the HyBal Network is calculated, and is designated as THLworst in the program.

HYBAL PERFORMANCE

This is a routine that allows users to enter the programming codes (Byte 2) for Hybrid Balance Registers 1, 2 and 3 as well as the Transmit and Receive Programmable Gain Registers that affect the transhybrid loss calculations. The program will decode these registers and derive the hybrid balance performance against the current echo file.

This routine is useful for finding the hybrid balance performance of a particular HyBal Network against a given variation in the echo frequency response.

BATCH OPTIMIZATIONS

This routine allows users to select up to 5 echo files on the floppy diskette, and run optimization continuously to find the necessary programming codes corresponding to each of these echo files. The programming codes and the predicted hybal performance are sent to the printer automatically.

A list of available echo files with ".EFR" extension is shown at the top of the screen. Highlight your choice by using the cursor direction keys, and select by pressing <**Enter**>.

Pressing the <**Esc**> key will terminate the selection. Selecting "**Go**" from the command line starts the batch optimization.

AN EXAMPLE RUN OF THE OPTIMIZATION

We shall use a transformer SLIC interface to illustrate the various steps in using the TP3077SW. Assuming that we do not have the SLIC ready for measurement, we shall use the transformer SLIC model in the program to derive the echo frequency response needed for running optimization.

Step 1:

Select the "Transformer SLIC" model from the "Parameters-SLIC" routine. Select "**Read**" from the command line to read the parameters stored in the file "**example.PRX**" provided in the program diskette.

Step 2:

Use the "Impedance Library" routine to select and enter impedance networks for ZR, ZT, Z1, Z2, Z3 and Z4. Select "**Read**" from the command line to read back the impedance networks stored in the file "**example.IMP**".

ZT is chosen such that it fulfills the 2-wire return loss requirement of your system. In the example, ZT is chosen to meet 20 dB 2-wire return loss against a reference impedance of 900Ω + 2.16 μF, and ZT = 560Ω + 3.3 μF. We

shall also use the non-loaded line for the United States as the hybrid balance test network, where ZR = 800Ω//(100Ω + 50 nF) for echo response.

Step 3:

Use ''Echo Response'' to derive the echo frequency response. You can select ''**Save**'' from the command line to store your echo data onto your floppy disk. The program will then prompt you to specify a filename.

Step 4:

Use the ''Select/Enter Echo'' routine to examine the echo data at the 14 reference frequencies. Selecting ''**Model**'' from the command line will select and display the echo data that you have previously derived from the ''Echo Response'' routine.

Figure 21 shows the echo data for this case.

Step 5:

Use the ''Optimization'' routine to find the programming codes for the Hybrid Balance Registers. *Figure 22* shows the optimization results and *Figure 23* shows the predicted performance.

Step 6:

When the hardware for the SLIC interface and COMBO II TP3070/71/72 is ready, program Hybrid Balance Registers 1–3 and check the predicted hybrid balance performance by measurement.

Step 7:

Measure the echo frequency response, enter the data into the TP3077SW program and re-run the optimization for improved accuracy.

Echo File = From Model
No. of Data Points with * = 14

Opt	Frequency, Hz	|A|, dB	Phase, deg	Weighting
*	200	-4.8100	12.7463	1
*	300	-5.0392	6.6756	1
*	400	-5.1491	3.6717	1
*	500	-5.2123	1.7411	1
*	600	-5.2553	0.3023	1
*	800	-5.3183	-1.8832	1
*	1000	-5.3731	-3.6235	1
*	1200	-5.4293	-5.1398	1
*	1500	-5.5231	-7.1728	1
*	2000	-5.7102	-10.1655	1
*	2500	-5.9357	-12.8041	1
*	3000	-6.1948	-15.1392	1
*	3200	-6.3065	-15.9924	1
*	3500	-6.4814	-17.1873	1

Edit Save Read Model Lprint Quit

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FIGURE 21. Echo Data for a Transformer SLIC, ZR = 800Ω//(100Ω + 50 nF). Select/Enter Echo Routine.

Search Method = Quick
Echo File = From Model
Date/Time = 08-04-1988 19:47:25
Elapsed Time = 0 Hr 3 Min 28 Sec

	Register 1	Register 2	Register 3
Byte 1 in Binary:	P0110W1X	P0111W1X	P1000W1X
	(P = 0/1 for Power Up/Down)		
	(W = 0/1 for Write/Read, X = Don't Care)		
Byte 2 in Binary:			
1st Choice:	11101011	10010101	00101000
2nd Choice:	11101011	10000100	00101000
3rd Choice:	11101010	10000011	00101000

Save Lprint Cont Quit

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FIGURE 22. Optimization Results for a Transformer SLIC with ZR = 800Ω//(100Ω + 50 nF). Optimization Routine.

```
                HyBal Reg1  HyBal Reg2  HyBal Reg3   TxG Reg     RxG Reg
Byte 2 in Binary: 1110 1011  1001 0101  0010 1000  1111 1111  1111 1111

Echo File = From Model

     Freq (Hz)     EC (dB)     RL4W (dB)     THLtyp      THLworst
        200        -37.44       -42.06       -39.15       -30.05
        300        -60.00       -60.00       -67.40       -33.90
        400        -46.67       -51.25       -48.72       -32.73
        500        -43.75       -48.32       -45.86       -32.27
        600        -42.40       -46.97       -44.56       -32.20
        800        -41.10       -45.66       -43.31       -31.77
       1000        -40.29       -44.85       -42.56       -31.60
       1200        -39.54       -44.11       -41.87       -31.44
       1500        -38.64       -43.20       -41.06       -31.25
       2000        -37.25       -41.82       -39.86       -30.96
       2500        -35.91       -40.49       -38.75       -30.67
       3000        -34.60       -39.19       -37.69       -30.37
       3200        -34.05       -38.65       -37.26       -30.24
       3500        -33.33       -37.93       -36.71       -30.07

 [First]  Second   Third   Plot   Lprint   Quit
```

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FIGURE 23. Predicted Performance for a Transformer SLIC with ZR = 800Ω//(100Ω + 50 nF). Optimization Routine.

COMBO II TP3070 + Ericsson Components SLIC PBL3762 APPLICATION

Figure 24 shows a line circuit implementation using COMBO II TP3070 and an Ericsson Components electronic SLIC PBL3762. The interface latches IL0–IL4 are configured as outputs with IL0–IL2 used to control the operating modes of the SLIC, and IL3–IL4 used to activate two test relays driven by external relay drivers. For a low power relay such as a DS2E-S-DC5V relay from Aromat, a transistor driver can be used if the base current required is less than 1 mA. The interface latch IL3 is programmed as an input for passing hook switch status information ($\overline{DET}$) to the system through the serial control port of the TP3070. E0 is tied to logic "0" to enable the hook switch detect output $\overline{DET}$.

C1	C2	Operating Mode
0	0	Power Denial
0	1	Normal
1	0	Ringing
1	1	Standby

E1	$\overline{DET}$ Output
0	Ground Key Detect
1	Loop Current Detect

Rdc1, Rdc2 and Rsg determine the dc feed characteristics of the SLIC. Rd is used to set the loop current threshold for the hook switch detect circuit. The values for these components vary with the application. Detail information can be found in the Ericsson Components PBL3762 data sheet.

ZT is used to set the 2-wire line impedance across Tip and Ring. *Figure 24* shows a 600Ω system with the 2-wire impedance approximated by the following equation:

$$Z2W \approx (ZT/1000) + 2Rf$$
$$= (560\ K\Omega/1000) + 2x20$$
$$= 600\Omega$$

The Transmit response is approximated by the following equation:

$$Tx = \frac{VTX}{VTR} \approx \frac{ZT/1000}{(ZT/1000) + 2Rf}$$
$$= \frac{560\ K\Omega/1000}{(560\ K\Omega/1000) + 2x20} = 0.93$$

If the TLP on the line is set as 0 dBm into 600Ω, the 0 dBm0 test level at VFxI is 0.93 x 0.774597 Vrms. Byte 2 of the Transmit Gain Instruction is 1011 1001.

The Receive response is approximated by the following equation:

$$Rx = \frac{VTR}{VFrO} \approx -\frac{ZT}{Z2} \times \frac{ZR}{(ZT/1000) + 2Rf + ZR}$$
$$= \frac{-560K}{560K} \times \frac{600}{(560K/1000) + 2x20 + 600}$$
$$= -0.5$$

The output voltage at VFrO is 2 x 0.774597 Vrms. Byte 2 of the Receive Gain Instruction is set to be 1110 1010.

The echo response is approximated by the following equation:

$$Echo = \frac{VFxI}{VFrO} \approx -\frac{ZT}{Z2} \times \frac{ZR + 2Rf}{(ZT/1000) + 2RF + ZR}$$
$$= \frac{-560K}{560K} \times \frac{600 + 2x20}{(560K/1000) + 2x20 + 600}$$
$$= -0.53$$

With ZR = 600Ω, the echo amplitude is −5.46 dB, which is well within the range of the programmable attenuator of the TP3070.

The phase shifts introduced by the internal low pass filters in the receive path and the dc feedback path will affect the echo frequency response. *Figure 25* shows a plot of the echo frequency response, from which a HyBal Network combination is chosen by the optimization routine of the TP3077SW program. *Figure 26* is a plot of the transhybrid loss achieved by the optimum HyBal Network versus frequency.

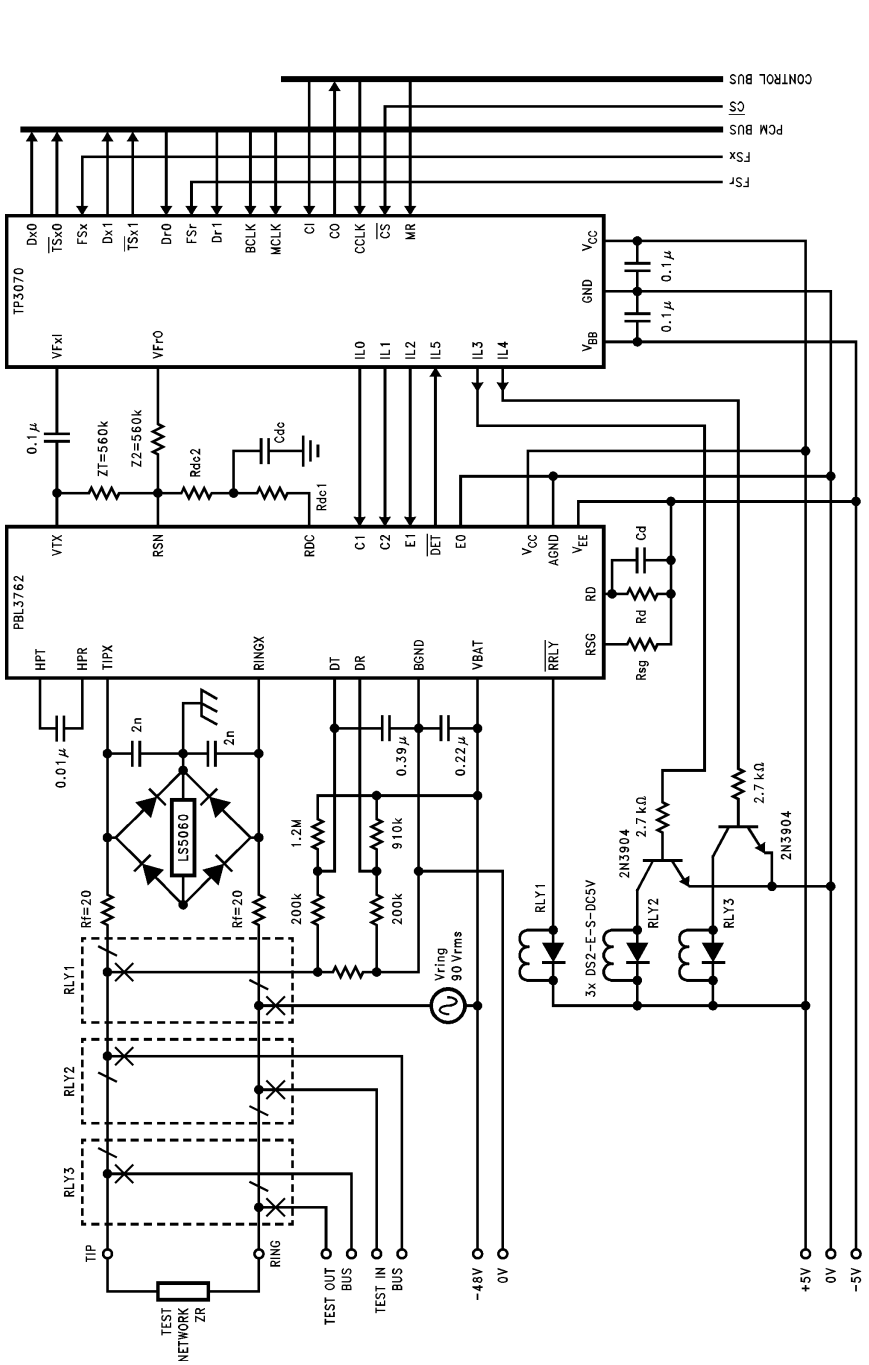

FIGURE 24. A Line Circuit Implemented by COMBO II TP3070 and Ericsson Components SLIC PBL3762

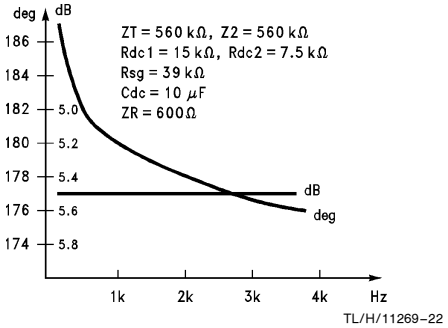

FIGURE 25. Echo Frequency Response: TP3070 + PBL3762, ZR = 600Ω

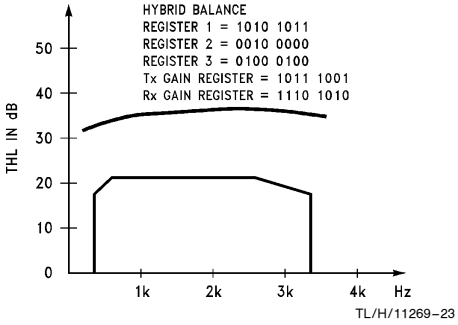

FIGURE 26. Transhybrid Loss: TP3070 + PBL3762, ZR = 600Ω

Application Hints

Problem	Possible Causes	Actions
Cannot achieve good cancellation performance	1. Echo magnitude may be outside the range of the HyBal Attenuator 2. Echo frequency response may be outside the range of the HyBal1 and HyBal2 filters	Scale down magnitude of echo and re-run optimization (See *Figure 11*) Select ''Plot'' command after running optimization. Select ''Dev Vs F'' to view the delta magnitude and phase between HyBal Network and Echo signal versus frequency.
Positive transhybrid loss from Dr to Dx	The sign bit of the selectable 180 degree inverting stage of the HyBal Network is wrong	Invert bit 6 of Hybrid Balance Register 1
Measured THL is worse than the THLworst predicted by the program	1. If you are using the echo derived from the model to run the optimization, errors from the calculated echo response may be the cause of the problem 2. If you are using measured echo to run the optimization, you may have a bad part 3. Optimization routine used incorrect echo data file 4. Using old version of HyBal software	Measure echo and re-run optimization. Try another part Go to the ''Select/Enter Echo'' routine. Select ''Edit'', ''Read'', or ''Model'' from the command line as appropriate, then go to the ''Optimization'' routine. Check the upper right corner of the ''Selection Menu''. The software should be Version 2.3.
Optimization routine refuses to run	1. Echo magnitude may be out of range 2. You may not have evenly spaced consecutive data points for the echo file	Use ''Select/Enter Echo'' routine to view and change echo
Program refuses to run the SLIC routines	You may have selected a SLIC model that does not match the current Impedance Library in the program	Use ''Parameter SLIC'' and ''Impedance Library'' routines to examine your model
Your SLIC is not modeled in the program		Generate echo data file by other means (by measurements or by other simulation tools). Use ''Select/Enter Echo'' routine to enter echo data into the program
Need Assistance?		Contact National Sales Representatives

Appendix: Optimization Algorithm

The optimization algorithm used in the Optimization routine of the TP3077SW program is a *constraint optimization.* Since the HyBal Network of the COMBO II TP3070/71/72 is comprised of a finite set of filter characteristics, the optimization result may not necessarily be ''optimal'', but represents the best of the possible filter characteristics of the HyBal Network.

The Optimization algorithm is based on the sum of weighted squares method. It is a search strategy in which all possible filter combinations of the HyBal Network are exhausted and the combination providing the best fit to the echo signal is chosen.

If E(wi) is the frequency response of the echo signal at frequency wi,

$\overline{E(wi)}$ is the conjugate of E(wi)

H(wi) is the frequency response of a combination of the HyBal Network

$\overline{H(wi)}$ is the conjugate of H(wi)

wi is one of the 14 reference frequencies in the voice band

∂i is the weighting assigned to frequency wi

A is a variable correction factor to H(wi)

The sum of squared errors (distance) D for fitting E(wi) and H(wi) is given by:

$$D = \sum_{i=1}^{i=14} \partial i\{E(wi) - A.\,H(wi)\}.\{\overline{E(wi)} - A.\overline{H(wi)}\} \quad \ldots\ldots(1)$$

$$= \sum_{i=1}^{i=14} \partial i.\,\|E(wi)\|^2 - 2A \sum_{i=1}^{i=14} \partial i.\,Re\{E(wi).\,\overline{H(wi)}\} + A^2 \sum_{i=1}^{i=14} \partial i.\|H(wi)\|^2 \quad \ldots\ldots(2)$$

To obtain the minimum D, differentiate D with respect to A and equate to zero.

The optimum A, Aopt, is:

$$Aopt = \frac{\sum_{i=1}^{i=14} \partial i.\,Re\{E(wi).\,\overline{H(wi)}\}}{\left\{\sum_{i=1}^{i=14} \partial i.\,\|H(wi)\right\}^2} \quad \ldots\ldots(3)$$

Substituting Equation 3 into Equation 1, the minimum D, Dmin, is given by:

$$Dmin = \sum_{i=1}^{i=14} \partial i.\,\|E(wi)\|^2 - \frac{\left[\sum_{i=1}^{i=14} \partial i.\,Re\{E(wi).\,\overline{H(wi)}\}\right]^2}{\sum_{i=1}^{i=14} \partial i.\,\|H(wi)\|^2} \quad \ldots\ldots(4)$$

The Optimization routine of the TP3077SW will search through all possible filter characteristics of the HyBal Network that are defined in the data base at the 14 reference frequencies. The search continues until it finds the combination with the minimum error (distance). This is the combination that provides the best fit to the frequency response of the echo signal, and hence the best echo cancellation performance.

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