A 10-kHz Highpass Filter for CE102 Testing

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INTRODUCTION

The recently revised MIL-STD-462D[1] specifies the equipment, test setup, procedures and data presentation for performing Method CE102, the procedure for measuring conducted emissions on the equipment under test (EUT) power leads from 10 kHz to 10 MHz. In the CE102 test setup, a line impedance stabilization network (LISN) uses a 50-µH inductor to provide isolation between the EUT and the power source impedance, while a 0.25-µF coupling capacitor in the LISN provides access to the EUT power line so the levels of any spurious EUT-generated emissions above 10 kHz can be measured with a 50-ohm receiver. However, in addition to providing a path between the EUT power line and the receiver for emissions above 10 kHz, the 0.25-µF capacitor also passes to the receiver a significant voltage level of the ac power line fundamental frequency. For example, for a 115-V, 60-Hz power source, a 60-Hz voltage level of 0.52 V root mean square (rms) appears across a 50-ohm termination at the LISN signal output port. For a 115-V, 400-Hz power source, the voltage level at the terminated signal output port is 3.4 V. If a 50-ohm receiver is connected directly to the LISN signal output port, the performance of the receiver could be degraded due to saturation of the receiver input stage caused by excessive voltage levels of the power line fundamental frequency and its harmonics.

A 50-ohm 10-kHz highpass filter can be constructed for CE102 testing.

The likelihood of receiver overload due to the fundamental line frequency was anticipated by the authors of CE102, and a 20-dB attenuator is specified to be inserted between the LISN signal output port and the receiver "...to protect the measurement receiver and to prevent overload."[1] The standard further states: "When an overload condition is predicted or encountered, a rejection filter can be used to attenuate the power frequency."[2]

In accordance with the MIL-STD-462D suggestion of using a filter, this article will explain how a 50-ohm, 10-kHz highpass filter suitable for CE102 testing can be designed, constructed and tested using readily available and inexpensive parts and equipment. The proposed 50-ohm highpass filter consists of three capacitors and three inductors and provides more than 70 dB of attenuation to all signals below 2 kHz. Because the filter has less than 0.6 dB of loss above 10 kHz, no correction factors are needed.

SELECTION OF FILTER CHARACTERISTICS

The magnitude of the impedance seen looking into the LISN output port can vary from near zero to more than 500 ohms depending on the frequency and the impedance seen looking into the EUT power port. But by inserting a 50-ohm, 20-dB attenuator, also called a pad, between the LISN signal output port and the measurement receiver (as specified in the CE102 measurement test setup), the former impedance variation of more than 500 ohms is reduced to a variation of less than 2 ohms centered on 50 ohms. Consequently, if the proposed 10-kHz highpass filter is placed between the 20-dB pad and the receiver, the filter will be properly terminated on both sides by relatively stable 50-ohm terminations, thus assuring that the expected filter performance will be achieved. Actually, a combination of a 10-dB pad and a highpass filter will also be quite adequate for this application. For example, if the specified 20-dB pad is replaced with a 10-dB pad and if the maximum voltage standing wave ratio (VSWR) seen looking into the LISN signal output port is as high as 40:1, the VSWR seen looking into the 10-dB pad output will be low enough to be quite acceptable for the proposed highpass filter. The advantage of using a 10-dB pad instead of a 20-dB pad is that an additional 10 dB of detection system sensitivity is gained.

The advantage of using padding to reduce the excessive VSWR of a signal source was explained in a previous *ITEM* article which showed the effect of pads between 2 and 16 dB in reducing unpadded VSWR as high as 4:1.[3] But for the proposed CE102 test application, it is necessary to know the effect of padding on a VSWR level as high as 40:1 (Figure 1). For example, if a signal source has a VSWR of 40:1, a 10-dB pad placed in front of the signal source will cause a load connected to the output of the pad to see a VSWR of only 1.21:1.

If increased receiver sensitivity is needed, the use of a 10-dB attenuator and a highpass filter should be tried in place of the 20-dB pad prescribed by MIL-STD-462D. For best results, the proposed 10-kHz highpass filter should be designed to have a low reflection coefficient so it will be relatively insensitive to impedance variations. Of course, if receiver sensitivity is no problem, the 20-dB pad by itself will be sufficient to reduce any spurious signals to acceptable levels.

Even though the 10- or 20-dB pad following the LISN signal port substantially stabilizes the impedance seen by the filter, the filter should be designed to have a low reflection coefficient (5% or less) so the filter will be relatively unaffected by variations in its termination impedance. Commercial filters, however, are usually designed to have a reflection coefficient of 20% (equivalent to a VSWR of 1.5:1), thereby making them more sensitive to variations in termination impedance. Also, if a filter with a 20% reflection coefficient is perfectly terminated with a 50-ohm load, the receiver connected to the filter output will see a 1.5:1 VSWR variation. In comparison, a filter with a 5% reflection coefficient will introduce a VSWR variation of only 1.105:1. If there is any doubt concerning the VSWR rating of a filter, the VSWR can be determined by terminating the filter with a 50-ohm load while measuring the return loss at the input to the filter. A return loss of more than 20 dB indicates a VSWR of less than 1.222, while a return loss of 14 dB or less indicates a VSWR of more than 1.5.

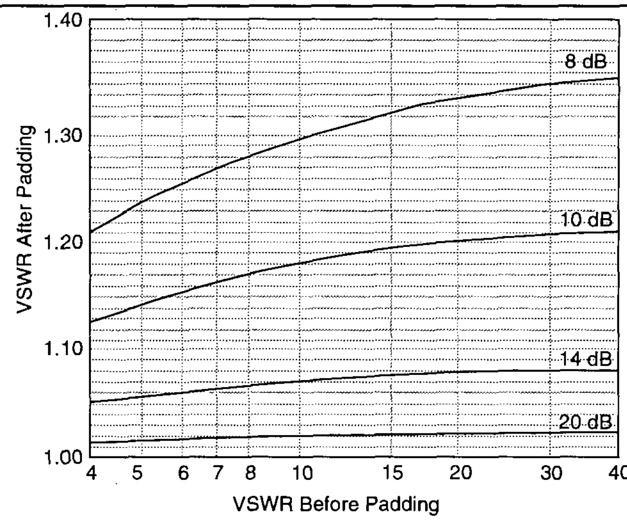

Figure 1. *The Relationship between Padded and Unpadded VSWR for Four Levels of Attenuation.*

Five- and 6-element Chebyshev highpass designs in a standard ladder configuration were considered to be reasonable compromises between selectivity and complexity. The abrupt rise in attenuation of the elliptic type is not needed in this application, so the Chebyshev type is preferable because of its simpler configuration; that is, there are no resonant branches that require tuning in the Chebyshev configuration as compared to the elliptic. The final configuration chosen was that of a 6-element Chebyshev design having a 5% reflection coefficient with the first element being a series capacitor and the sixth element a shunt inductor to ground. The filter port with the inductor-to-ground connection is intended for connection to the receiver. This dc-to-ground connection at the receiver input makes it less likely that the sensitive input stage of the receiver will be damaged by an electric charge buildup which is occasionally associated with highpass filters having a series-capacitor output.

For a 6-element Chebyshev filter having a 5% reflection coefficient and a ripple cutoff frequency of about 9 kHz, the minimum expected attenuation rise is 6 dB per element per octave, which should produce about 72 dB at 2.25 kHz (2.25 kHz is two octaves below 9 kHz). This level of attenuation will be more than adequate to eliminate excessive levels of any 60- or 400-Hz fundamental or harmonic signal associated with the ac power source.

The ripple cutoff frequency was selected to be 9.31 kHz so the input capacitor, C1, will be a standard value of 0.47 µF, and the filter insertion loss at 10 kHz and above will be less than 0.6 dB, thus making signal level corrections due to the filter loss unnecessary. Of course, signal level corrections are still needed between 10 kHz and 40 kHz due to the loss associated with the LISN coupling capacitor as explained in MIL-STD-462D.[1,2]

CALCULATION OF COMPONENT VALUES

After the type of filter response (Chebyshev), number of elements (6) and reflection coefficient (5%) have been chosen, the next thing to do is to select the filter impedance level and the ripple cutoff frequency. The impedance level is, in this case, 50 ohms and the cutoff frequency will be selected so that the filter input capacitor will be a standard value of 0.47µF. The only thing remaining before the component values are calculated is to find a filter reference text having normalized component values for a design having an even number of elements with equal resistive terminations and a reflection coefficient of 5%.

The more commonly available filter design references will not be suitable in this case because although they list the normalized component values for Chebyshev designs having both an odd and even number of elements, the only designs listed having equal terminations are those having an odd number of filter elements. Because a design having an even number of elements with equal terminations will be used, a reference must be found which has tables for this special type of design. A book by R. Saal includes the required tables, which are identified by a "c" suffix.[4] For example, the normalized table being used for the CE102 highpass filter design is identified in Saal's book as "C0605c" where the 06 indicates the number of elements, the 05 indicates the reflection coefficient percentage, and the c indicates a design having a special internal impedance transformation which allows the filter to be terminated with equal resistances.

The normalized lowpass designs for 6-element equally terminated Chebyshev designs having reflection coefficients between 1% and 8% were taken from the Saal reference. The standard lowpass-to-highpass transformation procedure was used where all inductors were replaced with capacitors and all capacitors were replaced with inductors. The original normalized component values were then replaced with their reciprocals. The results of these transformations are tabulated in Table A1 of Appendix A where the highpass normalized C and L values are listed for reflection coefficients from 1% to 8%. Their corresponding schematic diagram is also given.

In several preliminary trial calculations, the ripple cutoff frequencies of 50-ohm highpass designs for C1 equal to 0.47 µF were calculated for the six different reflection coefficients listed in Table A1, and the 5% design was found to give the most satisfactory ripple cutoff frequency. The normalized C and L highpass values for the 5% design were then put into a BASIC computer program to calculate the scaled component values associated with the C1 values from 0.46 to 0.48 µF. The results of the computer calculations are shown in Table A2 of Appendix A with the BASIC program listed under the table. This program uses the selected C1 value to calculate the corresponding ripple cutoff frequency, FAp, as shown in line 130 of the program where FA is the ripple cutoff frequency in kHz. The other C and L values in Table A2 are then obtained by multiplying the corresponding normalized C and L values by the C and L scaling factors calculated in lines 140 and 160, respectively, of the BASIC program. The resonant frequencies of F12, F34 and F56 are calculated using the equations in line 180.

If a C1 capacitor value of exactly 0.47 µF is not available, any of the other designs in Table A2 with C1 slightly above or below the 0.47 µF value can be used instead. If the C1 range from 0.46 to 0.48 µF is not wide enough, the BASIC program can be easily modified to accommodate a larger C1 range; however, designs with C1 less than 0.46 µF are not recommended because the cutoff frequency gets too close to 10 kHz.

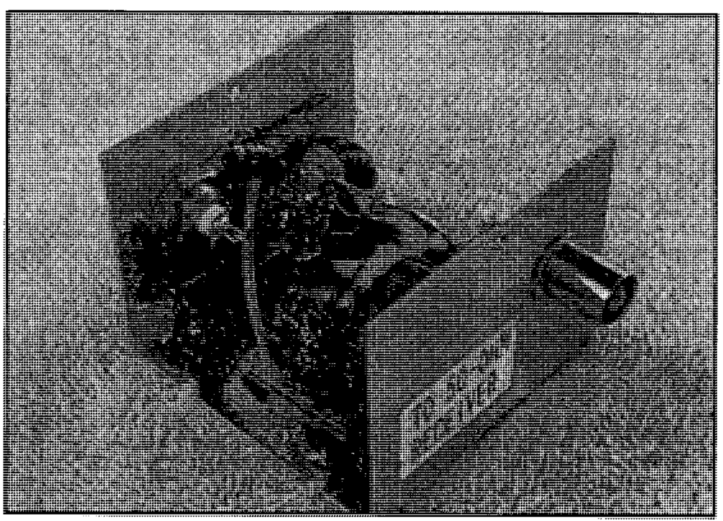

***Figure 2.** Filter Components Shown Assembled in a Small Aluminum Box. For the schematic diagram of the filter, see the Figure above Table A1 in the Appendix.*

REALIZATION OF CAPACITORS AND INDUCTORS FOR THE HIGHPASS FILTER

CAPACITORS

As previously explained, capacitor C1 is realized by selecting any 0.47-µF capacitor having a value between 0.46 and 0.48 µF. A metallized Mylar (polyester) capacitor with a voltage rating of at least 200 Vdc is recommended because of its small size. If it is anticipated that the filter may be connected directly to the ac power line, then capacitor C1 should have a working voltage rating of 630 Vdc (equivalent to an ac rating of 250 V). Capacitors C3 and C5 may consist of a 0.22-µF, 100 Vdc metallized Mylar capacitor selected to be within 1 or 2% of the design value, or a parallel combination of capacitors may be used to give the design value.

The Panasonic type ECQ-E(F) miniaturized metallized polyester capacitor is recommended for this application.[5]

The design values used in assembling the test filter shown in Figure 2 were taken from Design No. 6 in Table A2 where C1 = 0.470 µF. The corresponding FAp and F3 frequencies are 9.310 and 7.84 kHz. A group of 250-Vdc, 0.47-µF capacitors were measured with a digital capacitance meter, and a capacitor within 1% of the 0.470-µF value was selected for C1. C3 and C5 (0.213 and 0.248 µF) were obtained by paralleling capacitors to get a capacitance within 1% of the design value.

INDUCTORS

Unlike capacitors, it is not practical to order a small quantity of inductors from a distributor or manufacturer because the price is prohibitive. Instead, the inductors L2, L4 and L6 are hand-wound on molypermalloy powder (MPP) toroidal cores as explained in Reference 6. These cores are equivalent to Magnetics Part No. 55206 which has outer and inner diameters of 0.80 and 0.50 inches and a height of 0.25 inches. The core permeability is 125, and 100 turns gives an inductance of 680 µH with a tolerance of 8 %. The test setup and procedure used for adjusting the inductors for resonance at the F12, F34 and F56 frequencies listed in Table A2 is also explained in Reference 6.

The number of turns required for L2 (619 µH) for the highpass design in Table A2 where C1 = 0.470 µF is calculated using the equation N = 100[(L2/680)^.5] = 100[(619/680)^.5] = 96 turns. Similarly, L4 and L6 = 88 and 132 turns. If the cores are wound with bifilar magnet wire, the winding effort is cut in half as compared to winding the cores with the more common monofilar magnet wire. Using bifilar wire, the number of turns for L2, L4 and L6 is 48, 44 and 66. The recommended bifilar wire is #24 red and green, Part No. B-2242211, available from MWS Wire Industries.[7] About 14 feet of bifilar wire is needed for winding all three cores. Inductors L2, L4 and L6 require about 48, 44 and 66 inches, respectively, of bifilar wire.

After each core is wound with one more bifilar turn than the calculated value, the red start lead is connected to the green finish lead and the inductance of the winding is measured, either with an inductance meter such as the B&K Precision Model 878 Universal LCR meter[8] or by the resonance method described.[6] The resonant frequencies of F12, F34 and F56 listed in Table A2 are included to assist in adjusting the inductors to their design value when using the resonance method of inductor-turns adjustment. If the inductance is too high, turns are removed until the measured inductance is within 3% of the design value.

FILTER ASSEMBLY

The design selected for the 10-kHz highpass filter was assembled so its performance could be measured to confirm the validity of the design (Figure 2). If the reader wishes to duplicate this filter, the Digi-Key box, Part No. L111 with dimensions of 2.75 x 2.13 x 1.63, is recommended.

Female BNC connectors were used because the filter is expected to be used with standard 50-ohm coaxial cables having male BNC connectors on both ends of the cables. Both BNC connectors on the box are mounted off-center on the ends of the box to allow room for mounting inductors L2 and L6 against the ends of the box. Inductor L4 is mounted at the bottom center of the box.

Each inductor was first secured with silicone sealer to a small piece of cardboard cut from a cardboard box, and the assembly was then fastened in the aluminum box with more sealer. The cardboard serves as an insulating pad to separate the inductor windings from the metal case. The capacitors were installed and connected between the BNC connector center-pin terminals and the ungrounded inductor leads as shown in the schematic diagram in Table A1 and depicted in Figure 2. The short inductor and capacitor leads provide adequate support and rigidity so that additional support is unnecessary for the capacitors.

After the wiring of the components was completed, the BNC connectors soldered to C1 and to C5/L6 were marked on the outside of the box with labels of "TO 10-dB PAD & LISN PORT" and "TO 50-OHM RECEIVER," respectively, to eliminate any question as to how the filter is to be connected.*

FILTER RESPONSE TESTING

RELATIVE ATTENUATION

Figure 3 shows the test setup used to measure the stopband relative attenuation of the 50-ohm, 10-kHz highpass filter. Figure 4 shows the instrumentation used in the measurement procedure. The Hewlett-Packard Model 33120A function generator with an 8-figure digital frequency display was used as a 50-ohm test signal source because of its very low total harmonic distortion (0.04% from dc to 20 kHz). This low harmonic distortion allowed the highpass filter stopband attenuation to be accurately measured to a level of more than 60 dB. Other less expensive generators having a much higher level of harmonic distortion (typically specified as

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*Those wishing to build this filter may obtain a parts kit from the author. For details, send a self-addressed stamped envelope to the author at 1426 Catlyn Place, Annapolis MD 21401-4208.

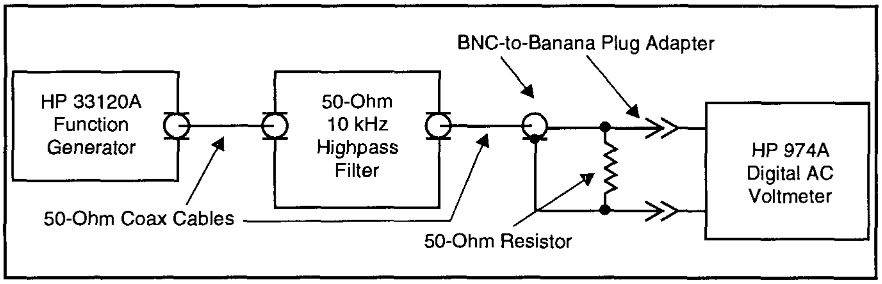

Figure 3. *Test Setup Used to Measure the Relative Attenuation of the Highpass Filter. The 50-ohm resistor connected across the BNC-to-banana plug adapter at the input of the HP 974A digital ac voltmeter serves to terminate the filter output in 50 ohms.*

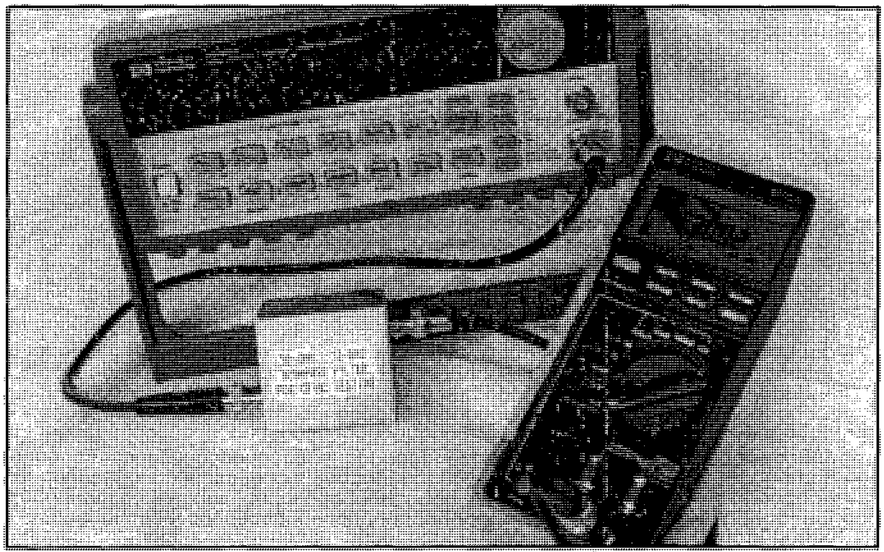

Figure 4. *Instrumentation Used to Measure Relative Attenuation of the Filter. Two 100-ohm resistors are connected in parallel across the banana plug to provide the 50-ohm termination for the filter.*

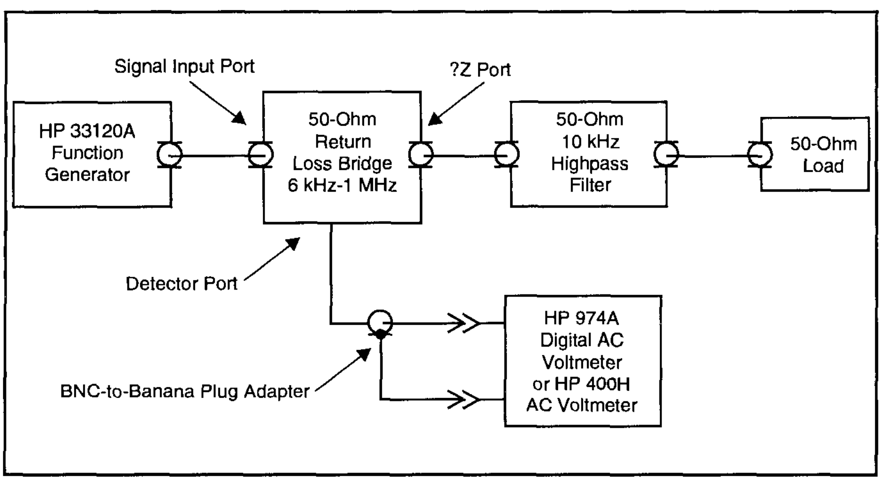

Figure 5. *Test Setup Used to Measure the Return Loss of the Highpass Filter. Except for the addition of the return loss bridge and the 50-ohm load on the filter output, the instrumentation is the same as shown in Figures 3 and 4. The 50-ohm resistor across the banana plug was removed because the detector port of the RLB is internally terminated with a 50-ohm resistor.*

less than 1%) allow highpass filter attenuation to be measured only up to about 50 dB, unless a tuned detector, such as a wave analyzer or a spectrum analyzer, is used. The ac voltage function of the HP 974A multimeter was used with the relative dB option activated to obtain relative attenuation directly in dB.

The output level of the generator was set for maximum at 10 kHz to give 3.29 volts rms across the 50-ohm load at the filter output (Figure 3). This voltage level was taken as the 0 dB reference level for all the relative attenuation measurements. The HP 974A meter was adjusted to read directly in relative dB by using the SELECT and REL switch options to obtain a zero dB indication at 10 kHz. The frequency of the generator was then gradually lowered while the HP 974A meter indicated the corresponding relative attenuation levels of the filter directly in dB. For example, at 7.726 and 5.009 kHz, the meter indicated relative attenuation levels of 3 and 30 dB, respectively.

The filter insertion loss at 10 kHz was measured by noting that the signal level across the 50-ohm load increased by 0.55 dB after the filter was removed and the 50-ohm load and the HP 974A meter were connected directly to the generator output connector through a 20-inch length of coaxial cable.

RETURN LOSS

Figure 5 shows a block diagram of the test setup used to measure the passband return loss of the 50-ohm, 10-kHz highpass filter. The HP 33120A function generator and the HP 974A ac voltmeter were again used as the 50-ohm signal source and detector, respectively. The 50-ohm return loss bridge (RLB) described in Reference 6 was used to obtain return loss levels over the 6-kHz to 1-MHz range.

The return loss measurement procedure consisted of setting the function generator for a maximum output level at 6 kHz with the "?Z" port of the RLB open-circuited. The HP 974A SELECT and REL switch options were used to obtain a 0 dB return loss reference level. The filter (terminated in 50 ohms as shown in Figure 5) was then connected to the RLB ?Z port and the return loss level in dB was recorded versus the frequency indicated on the digital display of the function generator. The frequency of the function generator was gradually increased while the corresponding return loss levels were recorded and plotted.

When the frequency limit of the HP 974A digital ac voltmeter was reached at 100 kHz, it was removed from the test setup and replaced with the HP 400H analog ac vacuum tube voltmeter. The 100-kHz output level of the function generator was adjusted until the return loss indication on the HP 400H dB scale was the same as indicated by the HP 974A voltmeter, after which the frequency was increased and the measurements were continued.

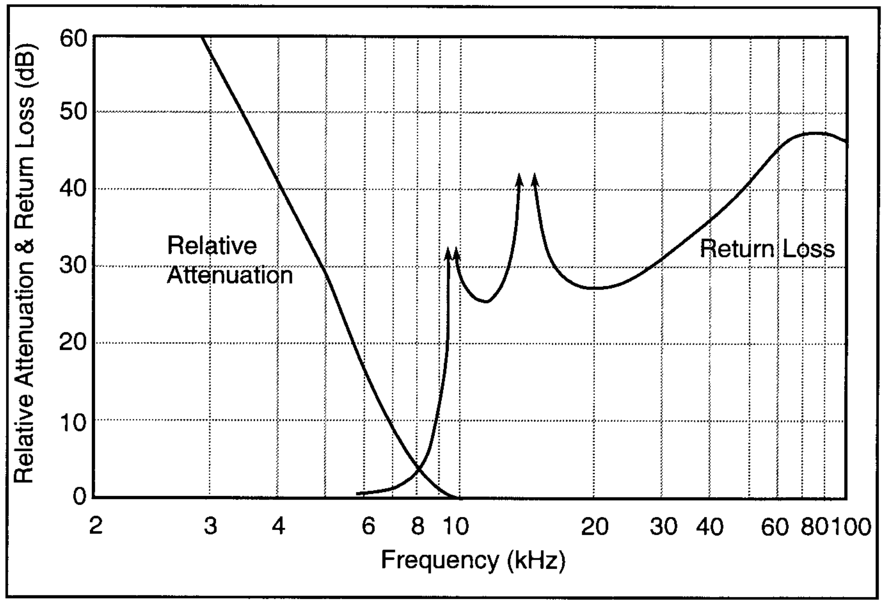

Figure 6. *Relative Attenuation and Return Loss Reponses of the 50-ohm 10-kHz Highpass Filter when Tested in a 50-ohm System. The reference level is 0 dB at 10 kHz.*

TEST RESULTS

Figure 6 shows the measured responses of relative attenuation and return loss over the 2-kHz to 100-kHz frequency range. The measured 3-dB and 40-dB frequencies of 7.73 and 4.23 kHz agree very closely with the corresponding calculated frequencies of 7.84 and 4.28 kHz listed for Design No. 6 in Table A2. The measured relative attenuation gives every indication that the assembled filter is performing correctly within the stopband frequency range.

The return loss response is a much more reliable indication of passband filter performance than an attenuation response. This is because passband attenuation variations of less than 0.1 dB are very difficult to measure, whereas the corresponding variations of return loss are easily measured. For a design with a reflection coefficient of 5%, the corresponding return loss is 26 dB. Thus, at the ripple cutoff frequency, a return loss of about 26 dB should be measured. According to Design No. 6 in Table A2, the ripple cutoff frequency (FAp) is 9.31 kHz, and at this frequency the corresponding measured return loss should be 26 dB. Referring to Figure 6, it is seen that the return loss at 9.31 kHz is about 28 dB, which is in close agreement with the expected value. Also, for frequencies above the ripple cutoff frequency, the return loss minimums should be 26 dB. Referring again to Figure 6, the return loss minimum at 10.7 kHz is 24.5 dB, and at 20.5 kHz it is 26.5 dB. These slight disagreements between the calculated and measured minimum return loss levels are quite reasonable and indicate that the passband performance is acceptable. The minor disagreement between the expected and measured minimum return loss values are most likely due to slight errors in the inductor values. In order to obtain the exact design inductance, it would be necessary to adjust the number of inductor turns to a fraction of a turn, but this is not possible with the inductors used.

The two pronounced return loss peaks at 9.5 kHz and 13.7 kHz are typical of this filter order and are to be expected; however, the broad return loss peak at 80 kHz is a surprise as this theoretically should not happen. Instead, the theoretical return loss should very gradually rise to a very high value as the test frequency increases. The presence of the return loss peak at 80 kHz may be due to the inductor interwinding capacity causing the inductors to self-resonate at a frequency several octaves above the filter cutoff frequency.

The return loss gradually dropped from about 46.5 dB at 80 kHz to about 39 dB at 1 MHz. Instrumentation was not available to evaluate the filter up to 10 MHz. In any case, the return loss up to 1 MHz is quite satisfactory, and the filter may be used with the assurance that there will be no significant loss of signal power due to mismatch loss at the filter. If the filter is to be used above 1 MHz, its insertion loss and return loss performance should be confirmed up to 10 MHz.

SUMMARY

The advantage was discussed of using a 10-kHz highpass filter and a 10-dB pad for increased

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sensitivity instead of the 20-dB pad suggested in the MIL-STD-462D CE102 test procedure. A 10-dB pad was shown to provide adequate smoothing between the varying impedances at the LISN signal output port and a 10-kHz highpass filter so that the filter could operate properly to provide more than 70 dB of attenuation to spurious power line harmonics below 2 kHz, thus protecting sensitive detection systems from the danger of signal overload.

After the preferred filter characteristics were decided, the normalized component values for a 6-element (three capacitor and three inductor) highpass design were entered into a BASIC computer program which calculated the capacitor and inductor values for eleven designs. The design selected for construction had an input capacitance of 0.47µF so that a single standard value capacitor could be used for the first capacitor to simplify construction. The remaining two capacitance values were realized by paralleling capacitors to get the design values within 1%. The three inductors were realized by hand-winding molypermalloy toroidal cores using bifilar wire to halve the winding effort.

Using the calculated component values, a highpass filter was assembled and tested for insertion loss, relative attenuation and return loss to confirm that the finished filter was correctly designed and assembled. The highpass filter performance was confirmed as being satisfactory for use in the MIL-STD-462D CE102 test procedure up to 1 MHz. Lack of suitable test instrumentation prevented the filter from being tested between 1 and 10 MHz.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance of Rex Cox, Heyward Preacher and St. John Martin in reviewing this article.

REFERENCES

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2. Ibid., pg. A-46.
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7. WMS Wire Industries, 31200 Cedar Valley Dr., Westlake Village, CA 91362. 800-423-5097.
8. B&K Precision, 6470 W. Cortland St., Chicago IL 60635. 312-889-1448; FAX 312-794-9740. The B&K dual display LCR meter is also available from MCM ELECTRONICS (800-543-4330) for $247.50. NOTE: A less expensive but apparently identical dual display LCR meter (made by TENMA™) is also available from MCM ELECTRONICS for $179.

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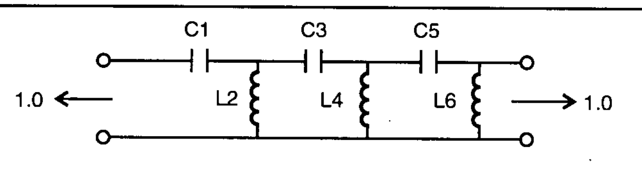
APPENDIX



R.C. (%)	R.L. (dB)	VSWR	C1 (F)	L2 (H)	C3 (F)	L4 (H)	C5 (F)	L6 (H)
1.00	40.0	1.020	2.0572	.90416	.74571	.74571	.90416	2.0572
2.00	34.0	1.041	1.74825	.81633	.68681	.68681	.81633	1.74825
3.00	30.5	1.062	1.5785	.77280	.65660	.65660	.77280	1.5785
4.00	28.0	1.083	1.4624	.74460	.63654	.63654	.74460	1.4624
5.00	26.0	1.105	1.3746	.72464	.62228	.62228	.72464	1.3746
8.00	21.9	1.174	1.1953	.69013	.59382	.59382	.69013	1.1953

NOTES:
1. All highpass values in the table were derived from the normalized lowpass values listed on pages 146 through 167 of Reference 4.
2. R.C. = Reflection Coefficient; R.L. = Return Loss.

Table A1. *Chebyshev 6-element Highpass Filter Values Normalized for a Ripple Cutoff Frequency of 1 Rad/sec and Equal Terminations of 1 Ohm.*

Design No.	FAp (kHz)	F3 (kHz)	F40 (kHz)	C1 (μF)	L2 (μH)	F12 (kHz)	C3 (μF)	L4 (μH)	F34 (kHz)	C5 (μF)	L6 (μH)	F56 (kHz)
1	9.512	8.01	4.37	.460	606	9.53	.208	521	15.29	.243	1150	9.53
2	9.471	7.98	4.35	.462	609	9.49	.209	523	15.22	.244	1155	9.49
3	9.430	7.95	4.33	.464	612	9.45	.210	525	15.15	.245	1160	9.45
4	9.389	7.91	4.32	.466	614	9.41	.211	527	15.09	.246	1165	9.41
5	9.349	7.88	4.30	.468	617	9.37	.212	530	15.02	.247	1170	9.37
6	9.310	7.84	4.28	.470	619	9.33	.213	532	14.96	.248	1175	9.33
7	9.270	7.81	4.26	.472	622	9.29	.214	534	14.90	.249	1180	9.29
8	9.231	7.78	4.24	.474	625	9.25	.215	536	14.83	.250	1185	9.25
9	9.192	7.75	4.23	.476	627	9.21	.216	539	14.77	.251	1190	9.21
10	9.154	7.71	4.21	.478	630	9.17	.216	541	14.71	.252	1195	9.17
11	9.116	7.68	4.19	.480	633	9.13	.217	543	14.65	.253	1200	9.13

NOTES:
1. FAp, F3 and F40 are the calculated ripple cutoff frequency and the 3-dB and 40-dB frequencies. F12, F34 and F56 are the resonant frequencies associated with the components having the same numbers.
2. The calculated 3-dB and 40-dB frequencies were based on inductor Q's of 50 at 10 kHz.
3. See the schematic in Table A1 for the capacitor and inductor connections.

Table A2. *C and L Values and Frequencies Associated with the 50-ohm Highpass Filter Designed for CE102 Testing. Reflection Coefficient = 5%; N = 6.*

BASIC PROGRAM USED FOR CALCULATING THE DATA IN TABLE A2.

```
10 REM  Program Name: C0605C.ASC  By: Ed Wetherhold, Annapolis, MD.
20 REM  BASIC program calculates component values and frequencies of
30 REM  50-ohm 10-kHz highpass filters based on C1 values .460 TO .480 uF.
40 REM  All designs are for reflection coefficient of five percent and N = 6.
50 PI = 3.14159  : R=50 : PP= 159.155 : A=1.3746 : B=.72464 : C=.62228
60 G1= A : G6=A : G2=B : G5=B   : G3=C  : G4=C  : PRINT
70 PRINT "Table A2.  C & L values and frequencies associated with the 50-ohm"
80 PRINT "highpass filter designed for CE102 testing.  Refl. Coef.= 5%, N = 6." : PRINT
90 PRINT " FAp  F 3  F40  C1  L2  F12  C3  L4  F34  C5  L6 F56"
100 PRINT "(kHz)  (kHz) (kHz) (uF) (uH)  (kHz) (uF) (uH)   (kHz)   (uF) (uH) (kHz)"
110 FOR CC = .460 TO .490 STEP .002 : REM CC values in uF for CC = C1.
120 IF CC> .481 GOTO 250  : REM  FA is the ripple cutoff frequency in kHz.
130 FA = G1*1000!/(CC*R*2*PI) : F3 = FA*.8426 : F40 = FA*.4597
140 SC = 1000!/(R*2*PI*FA)  : REM SC is the capacitance scaling factor in uF.
150 C1 = G1*SC : C3 = G3*SC  : C5 = G5*SC : REM Cap values associated with given CC.
160 SL = 1000!*R/(2*PI*FA)  : REM SL is the inductance scaling factor in uH.
170 L2 = G2*SL : L4 = G4*SL  : L6 = G6*SL : REM L values associated with given CC.
180 F12= PP/(SQR(C1*L2))  : F34= PP/(SQR(C3*L4))  : F56 =PP/(SQR(C5*L6))
190 PRINT USING"#.### " ;FA; : PRINT USING"  #.##";F3; : PRINT USING"  #.##" ;F40;
200 PRINT USING"  .### " ;C1; : PRINT USING" ####"  ;L2; : PRINT USING"  ##.##" ;F12;
210 PRINT USING"  .### " ;C3; : PRINT USING" ####" ;L4; : PRINT USING"  ##.## ";F34;
220 PRINT USING"  .### " ;C5; : PRINT USING" ####" ;L6; : PRINT USING"  #.## " ;F56
230 REM End of calculations for given CC value.
240 NEXT CC : REM Reads next given CC values.  Program ends if CC> .481.
250 PRINT: PRINT: PRINT "END OF RUN" : BEEP : BEEP : BEEP : END
```