TEMPEST

TEMPEST is an unclassified name referring to investigations and studies of compromising emanations. It is sometimes used synonymously for the term "compromising emanations", e.g., TEMPEST tests or TEMPEST inspections. TEMPEST approved equipment or systems are those which have been certified under past or existing TEMPEST specifications or standards.

Historically NAG-1A/TSEC was the earliest TEMPEST standard. NAG-1A was superseded in 1965 by Federal Standard 222, "Radiation Standard for Communication and Other Information Processing Equipment." In 1970 a new series of documents entitled, "National COMSEC/EMSEC Information Memoranda (NACSEM)" replaced Federal Standard 222. These new documents are applicable to equipments in the development stage, during and subsequent to production, and after any modification.

The Defense Communications Agency (DCA) has also issued a series of TEMPEST documents concerned with RED/BLACK engineering. The DCA series of documents will be replaced in the near future by a new Military Handbook (MIL-HDBK-232), Military Standardization Handbook RED/BLACK Engineering—Installation Guidelines, prepared by the Naval Electronic Systems Command.

Since the above TEMPEST documents carry security classifications, they are available only to qualified contractors with security cleared facilities and an established need-to-know. The need-to-know must be established with the contracting Government Organization who will authorize the release of the TEMPEST documents to the contractor. The need-to-know can be established when there is a contract for equipment which must meet TEMPEST requirements. If there is no contract of this type, the contractor must be able to show that the release of TEMPEST documents to him would be of direct benefit to the Government in the future.

Commercial firms with TEMPEST related Government contracts should address inquiries pertaining to TEMPEST to their contracting Government Department or Agency. Commercial firms with no TEMPEST related contracts should address inquiries pertaining to TEMPEST to a Government Department or Agency with whom they have (or have recently had) a classified contract, or (if no such contract exists or has recently existed) to the Director, National Security Agency, ATTN: S22, Fort George G. Meade, MD 20755.

The Air Force is conducting a school on NACSEM at their Cryptologic Depot in San Antonio, Texas. This is open to employees of private organizations under contract with the Air Force. An Air Force contractor desiring training for his employees must forward a written request to the major air command or designated subcommand supervising the contract for which the training is necessary, at least 30 days before the date training should begin (refer to paragraph 112, AFT 205-1). If the contractor does not have a current contract but can show that the training would be of direct benefit to the Government in the future, he may forward his request to Headquarters, U.S. Air Force Security Service, ATTN: SRE, San Antonio, Texas 78243. They will evaluate each request on a case by case basis. It should be pointed out that generally the Government will not pay for such training.

The RED Analog Signal Line Conduction Limits and Digital Signal Line Conduction Limits of NACSEM 5100 are unclassified. These limits for the various categories A through G are shown in Figure 1 and 2. Note that the analog signal limits are given in dB above one microvolt r.m.s. while the digital signal limits are given in dB above one microampere per meter per MHz equivalent r.m.s. sinewave.

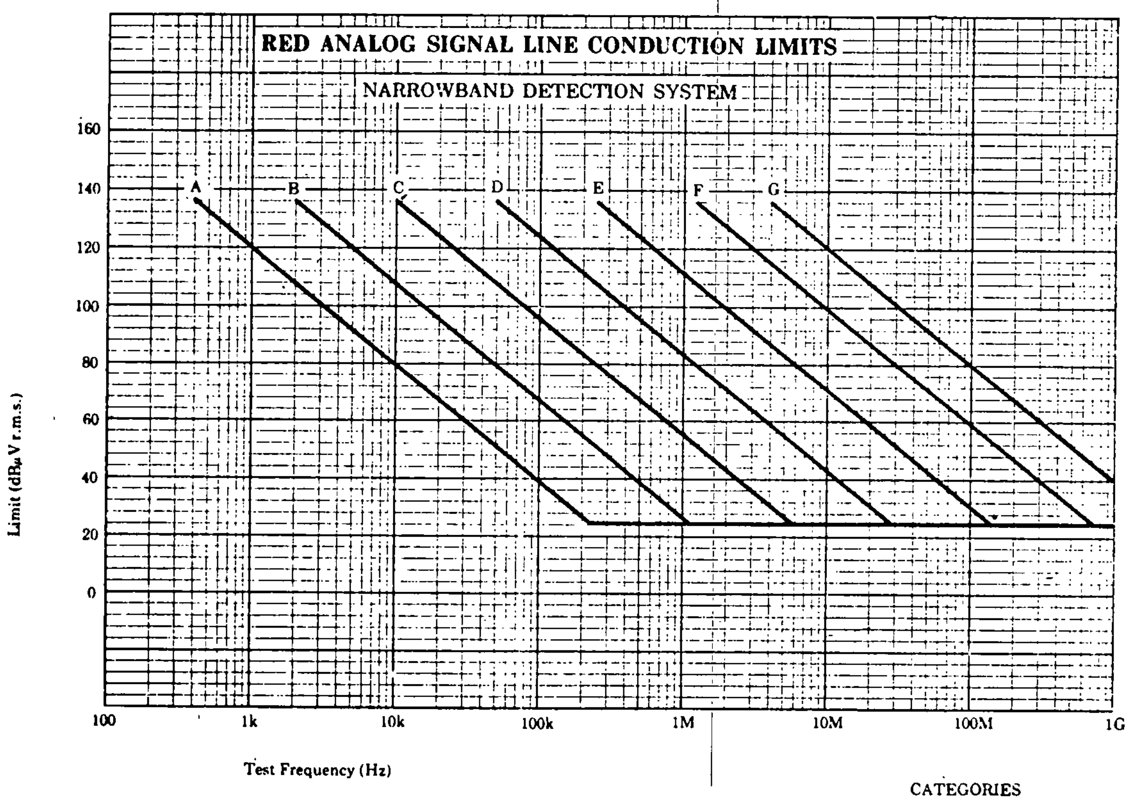


FIGURE 1

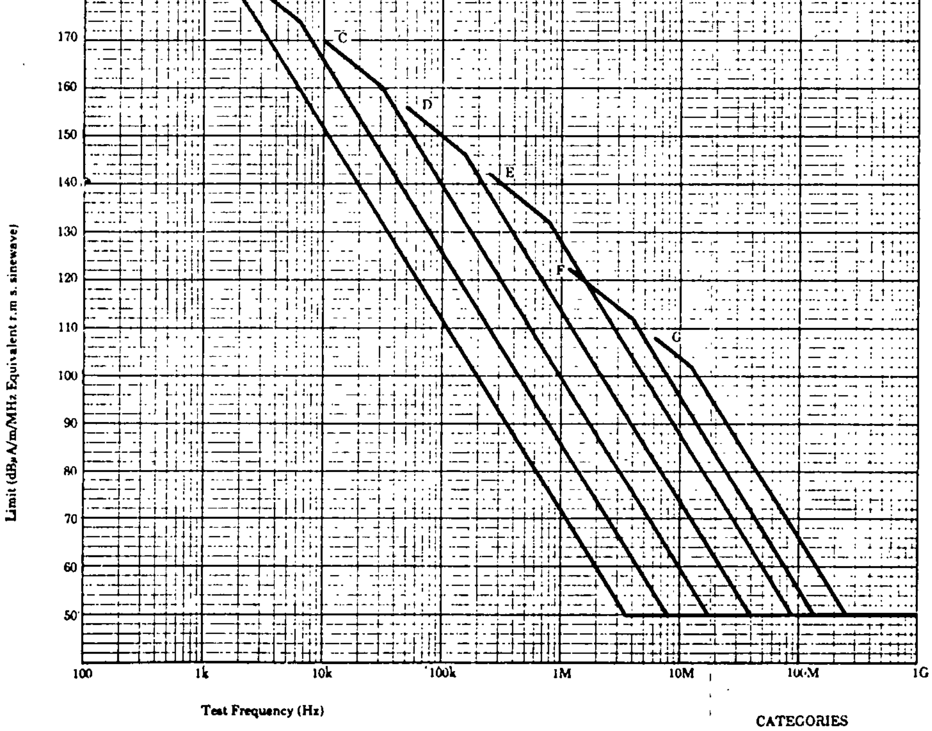


FIGURE 2

TEMPEST TERMS AND DEFINITIONS

Access . . . The ability and opportunity to obtain knowledge or classified information or to be in a place where one could be expected to gain such knowledge.

Alternating Current (AC) Protective Ground System . . . A ground system which provides a low resistance electrical connection to Earth Ground for the protection of personnel and equipment from AC power potentials, lightning hazards, and electrical circuit failures. The integrity of the system is normally insured by the connection of an insulated green colored conductor between the cases and frames of equipments afforded AC power service. The AC protective ground system is therefore often referred to as the Green Wire Protective Ground.

Black Designation . . . A designation applied to wirelines, components, equipment, and systems which handle only unclassified signals, and to areas in which no classified signals occur.

BLACK Equipment Area(s) (BEA) . . . The space within a Limited Exclusion Area (LEA) which is designated for installation of BLACK information-processing equipment, power, signal, control, ground feeder and distribution facilities

Classified Intermediate Distribution Frame (CIDF) . . . An Intermediate Distribution Frame used for RED wiring.

Combined Distribution Frame (CDF) . . . A distribution frame which serves as both a Main Distribution Frame and Intermediate Distribution Frame.

Communications Security . . . The protection resulting from all measures designed to deny unauthorized persons information of value which might be derived from the possession and study of telecommunications, or to mislead unauthorized persons in their interpretations of the results of such possession and study.

Compromise . . . Any occurrence which results in unauthorized persons gaining access to classified or other information requiring protection.

Compromising Emanation . . . Unintentional data-related or intelligence-bearing signals which, if intercepted and analyzed, disclose the classified information transmitted, received, handled or otherwise processed by any information-processing equipment.

Conducted Signals . . . Electromagnetic or acoustic signals propagated along wirelines or other conductors.

Controlled Access Area (CAA) . . . The complete building or facility area under direct physical control which can include one or more Limited Exclusion Areas, Controlled BLACK Equipment Areas, or any combination thereof. Spaces within a facility which are not under direct physical control but to which access is controlled (administration offices, halls, restrooms) are not a part of the actual Controlled Access Area but are considered as a part of the overall Physical Control Zone.

Controlled Black Equipment Area(s) (CBEA) . . . A BLACK Equipment Area which is not located in a Limited Exclusion Area but is afforded the same physical entry control which would be required if it were within a Limited Exclusion Area.

Equipment TEMPEST Radiation Zone (ETRZ) . . . A zone established as a result of determined or known TEMPEST equipment radiation characteristics. The zone includes all space within which a successful hostile intercept of Compromising Emanations is considered possible.

Fortuitous Conductor . . . Any conductor which may provide an unintended path for intelligible signals; for example, water pipe, wire or cable, metal structural members, and so forth.

Green Wire Protective Ground . . . See Alternating Current (AC) Protective Ground System.

Hardened Cable Path (HCP) . . . See Intrusion-Resistant Communications Cable (IRCC).

Intrusion-Resistant Communications Cable (IRCC) . . . A cable designed to provide substantial physical protection and electrical isolation for the wirelines making up the information-carrying core. When the protective measures used are devices which detect slight changes in the physical or electrical state of the cable and which provide visible or audible indications at a central control point of attempted intrusion, the cable is known as an Alarmed Cable. When the protective measures used are physical protection to provide a penetration delay factor, the cable is known as a Hardened Cable Path.

Isolation Device . . . A device designated to provide isolation and maximum attenuation of undesired signals with minimum insertion loss and distortion of the desired signal.

Limited Exclusion Area (LEA) . . . A room or enclosed area to which security controls have been applied to provide protection to a RED information-processing systems equipment and wirelines equivalent to that required for the information transmitted through the system. An LEA must contain a RED Equipment Area.

Normal Input Keying . . . Low level keying in which battery to the teletypewriter keying contacts is provided by the crypto-equipment.

Off-Line Crypto-Operation . . . Encryption or decryption performed as a self-contained operation distinct from the transmission of the encrypted text, as by hand or by machines not electrically connected to a signal line. See On-Line Cypto-Operation.

On-Line Crypto-Operation . . . The use of crypto-equipment that is directly connected to a signal line, making encryption and transmission, or reception and decryption, or both together, a single continuous process. See Off-Line Crypto-Operation.

Physical Compromise . . . The compromise of information through loss, theft, capture, recovery by salvage, defection of individuals, unauthorized viewing or photography, or by any other physical means.

Physical Control Zone (PCZ) . . . The space surrounding equipment processing classified information, which is under sufficient physical and technical control to preclude a successful hostile intercept of any classified information from within this space.

Protected Wireline Distribution System . . . A communications system to which electromagnetic and physical safeguards have been applied to permit secure electrical transmission of unencrypted classified information, and which has been approved by the cognizant department or agency. The associated facilities include all equipment and wirelines so safeguarded. Major components are wirelines, subscriber sets and terminal equipment. Also known as Approved Circuit.

RED/BLACK Concept . . . The concept that electrical and electronic circuits, components, equipments, systems, and so forth, which handle classified plain language information in electric signal form (RED) be separated from those which handle encrypted or unclassified information (BLACK). Under this concept, RED and BLACK terminology is used to clarify specific criteria relating to, and to differentiate between such circuits, components, equipments, systems, and so forth and the areas in which they are contained.

RED Equipment Area (REA) . . . The space within a Limited Exclusion Area (LEA) which is designated for installation of RED information processing equipment, power, signal, control, ground feeder and distribution facilities.

Signal Ground Point . . . A single designated point in a station to which all RED/BLACK grounds are either directly or indirectly connected. This point serves as the common zero potential reference for the station.

Signal Ground Reference Plane . . . An intermediate focal point between an equipment and the Signal Ground Plane for terminating an equipment's or Terminal System's RED or BLACK ground circuits. The Signal Ground Reference Plane is isolated from the equipment's AC Protective Ground and is connected to the Signal Ground Plane by a Signal Ground Bus.

Signal Ground Reference Point . . . Same as a Signal Ground Reference Plane but serving one of several Limited Exclusion Areas device or equipment or Terminal System.

Signal, Quasi-Analog . . . A quasi-analog signal is a digital signal, after conversion to a form suitable for transmission over a specified analog channel. The specification of an analog channel would include frequency range, frequency bandwidth, signal-to-noise ratio and envelope delay distortion. When this form of signaling is used to convey message traffic over dialed-up telephone systems, it is often referred to as voice data.

Single Point Ground . . . The basic technique used in RED/BLACK installations in which separate ground conductors are used for the various grounding functions (signal, power, hazard, and so forth) with each conductor connected directly or indirectly to a single point (Signal Ground Point).

Spurious Signals . . . Undesired signals appearing external to an equipment or circuit. They may be harmonics of existing desired signals, high frequency components of complex wave shapes, or signals produced by incidental oscillatory circuits.

TEMPEST . . . An unclassified short name referring to investigations and studies of compromising emanations. It is sometimes used synonymously for the term "comprising emanations"; for example, TEMPEST tests, TEMPEST inspection.

TEMPEST Approved Equipment or Systems . . . Equipment or systems which have been certified under existing (NACSEM 5100, KAG-30A, or DCAC 370-D195.2) or past (FED-STD-222) TEMPEST specifications as determined by the command or agency concerned.

TEMPEST Inspection . . . A general term which encompasses various means for conductng facility evaluations to determine the adequacy of TEMPEST control measures; for example, installation-engineering surveys.

TEMPEST Test . . . A laboratory or on-site (field) test to determine the nature and amplitude of conducted or radiated signals containing compromising information. A test normally includes detection and measurement of these signals, and analysis to determine correlation between received signals and potentially compromising transmitted signals.

Terminal Control Unit (TCU) . . . The device in an integrated complex of units constituting a complete Terminal System (TSY) which serves as the single interface point between the TSY and wireline distribution facilities of the Limited Exclusion Area. For example, the control device of a data terminal complex which has card or tape or card and tape devices and which control device is the single interface to the station wireline distribution facilities is considered, for engineering-installation purposes, as the Terminal Control Unit.

Timing Line . . . Line intended for the transmission of timing information, clock pulses, and crypto step.

Uncontrolled Access Area (UAA) . . . The area external or internal to a facility over which no personnel access controls can be or are exercised.

Vocoder . . . A vocoder (voice-operated coder) is a device used to compress the frequency bandwidth requirement of voice communications. It consists of an electronic speech analyzer which converts the speech waveform to several simultaneous analog signals and an electronic speech synthesizer which produces artificial sounds in accordance with analog control voltages.

RFI/TEMPEST ISOLATION

The need for an isolation device arises from the requirement to remove from a communications signal all other signals, both transverse (across pair) and longitudinal (between the pair and ground) (common-mode), which should not pass between the signal source and its load or pass beyond a specified point in the signal route. This general requirement would be typical of radio frequency interference (RFI) and TEMPEST problems.

Since the unwanted signals and noise may fall within the band-pass of the desired signal, it is not desirable to employ passive filters. The patented technique employed by Versitron, Inc. consists of interposing an isolation device in the signal line to propagate the signal by optical means, thus breaking the electrical conductor path. Almost complete isolation against longitudinal (common-mode) unwanted signal coupling is obtained.

Each isolation unit is housed in two separate modules marked "Input" and "Output". A non-metallic light guide is then placed between the two modules, thus propagating signals without a metallic path. Circuit techniques are employed for digital units in order to suppress transverse noise levels. In addition, time regeneration is available on digital units, while the bandwidth can be restricted as required in analog units. Therefore, with proper installation and choice of model, the isolation device becomes a unidirectional signal repeater covering practically all communications frequencies and isolation requirements.

Common-Mode Isolation:

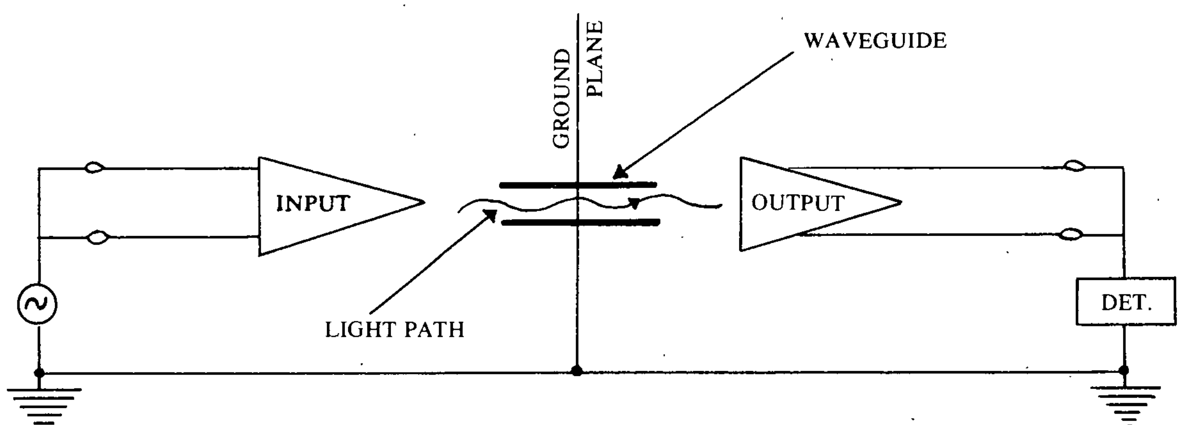
Common-mode signal isolation, for the purposes of the isolation devices discussed here, is defined as the signal attenuation between the shorted input and the shorted output of an isolation device when the generating source is between the shorted input and a ground reference, and the detecting instrument is between the shorted output and the same ground reference. (See figure 1).

Isolation devices accomplish this common-mode isolation by the use of seperate input and output module chassis. The input module converts the input electrical signal to a modulated light beam and the output module converts the light signal to an output electrical signal. Therefore, no electrical conductor exists by which to conduct the undesired common-mode signal. To complete the isolator installation, a grounded shield most be interposed between the input and output modules in order to eliminate space radiated coupling. This ground plane is normally a chassis wall or shielded room wall. The light beam is passed through the ground plane by means of a waveguide penetration. The dimensions of the waveguide are chosen so that its cut-off frequency is above the highest frequency of interest. This waveguide penetration must be chosen with two factors in mind. First, the wavelength of the highest frequency of interest must be large compared to the diameter of the waveguide. Second, the ratio of the length of the waveguide to the diameter determines the amount of attenuation below the cut-off frequency. In view of the above and the fact that the light guide is a non-conductor, it is obvious that the common-mode isolation is independent of the electronic circuitry of the isolator. This, assumes, of course, that the power sources for the isolator modules are properly isolated or filtered. Photon couplers that do not use the above technique do not provide the highest degree of EMI or TEMPEST protection. They provide only DC and low-frequency isolation.

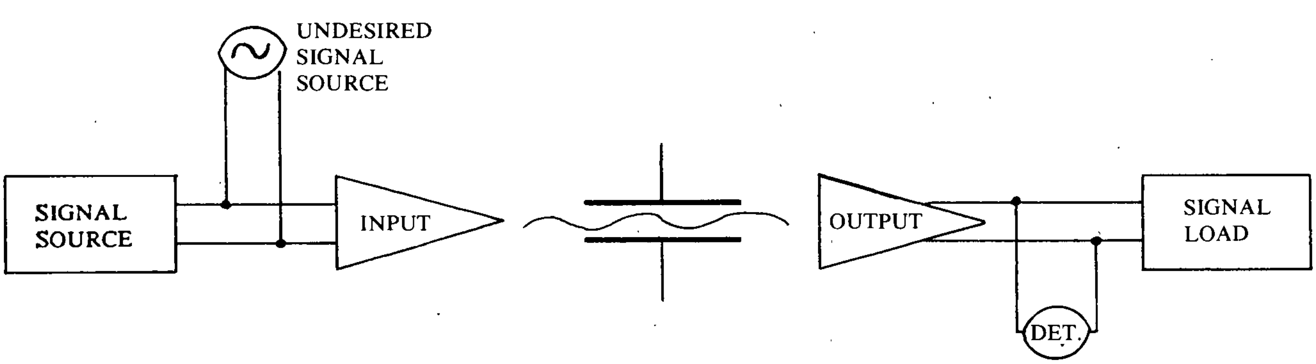
Transverse-Mode Isolation:

Since the common-mode rejection (balance) of practical circuits and wiring are never perfect and since cross-talk is a danger in multicircuit situations, it is often necessary to provide suppression of unwanted signals and noise in the transverse-mode. This mode is defined as the signal across the input or output terminals of the isolator, minus the desired signal. In the case of digital isolators, the input module light source circuitry is electrically saturated in the ON or OFF state and therefore, does not respond to superimposed undesired signals as long as the total instantaneous value does not exceed the threshold point for the opposite transition. (See figure 2).

Where the undesired signal takes the form of phase or frequency modulation, time regeneration of the desired signal is used.



COMMON MODE Figure 1



TRANSVERSE MODE Figure 2

A Narrowband Non-tunable Detection System for TEMPEST Testing

This article is directed primarily to the TEMPEST test engineer responsible for performing narrowband, non-tunable tests in accordance with the specifications of NACSEM 5100.[1] In addition, the EMI/RFI test engineer can also profit from the discussion on the design and fabrication of the bandpass filter included in this article as an example of a practical design.

Because of limited time and funds, the test engineer usually finds that the most expedient and/or economical way to obtain the many different filters required is to design and fabricate them himself. This is feasible because the required performance is usually uncritical and can be achieved with a relatively simple circuit having few components. Thus, the more sophisticated (and expensive) capabilities of the filter specialist and manufacturer are not needed, especially when only a few different filter designs will be required.

Although the filter design procedures to be discussed are well known to the filter specialist, this information is not conveniently available to the majority of TEMPEST or EMI/RFI test engineers. Consequently, the test engineer is unable to fully utilize the many different filter design techniques in an optimum manner to meet a particular test requirement. It is hoped that the information contained in this article will partially correct this situation.

DETECTION SYSTEM CHARACTERISTICS

The important performance characteristics the test engineer must consider in the design of a narrowband non-tunable detection system are bandwidth, skirt selectivity (rate of response rolloff), input resistance, dynamic range, and sensitivity. The detection system bandwidth is determined from the data rate of the equipment under test (EUT). The required skirt selectivity and detection system input resistance is given in the test specification. The required dynamic range and sensitivity of the detection system are dependent on both the ambient signal characteristics of the line under test and the limit given in the test specification. The ability to conveniently and inexpensively achieve these detection system performance characteristics depends on the ingenuity and experience of the test engineer.

Bandwidth and Skirt Selectivity

The detection system bandwidth consists of the range between the lower and upper frequencies where the response is 6 dB down from the center of the passband. These 6 dB cutoff frequencies (in Hertz) are found by multiplying the EUT data rate (in bits per second) by the two factors listed in Table 4 of NACSEM 5100. This bandwidth requirement for the detection system is most conveniently achieved by placing a bandpass filter in front of the most sensitive active portion of the detection system. For this application, the Butterworth filter type will be used. Although more selective types are available, the Butterworth is chosen because of its following advantages — it requires no tuning and is less critical of component tolerance, it provides maximum flatness in its passband and, most important, the frequencies of its 3 and 6 dB attenuation points are easily calculated for any number of filter elements. After the upper and lower 6 dB cutoff frequencies are calculated based on the known EUT data rate, the corresponding 3 dB cutoff frequencies must be found before the filter design can be started. This is necessary because the Butterworth design tables are based on a 3 dB cutoff frequency and therefore this frequency (and not the 6 dB frequency) must be used in calculating the filter component values. The relationship between the 6 dB and 3 dB cutoff frequencies for a lowpass Butterworth filter of one to ten elements is shown in Table 1. When the 3 dB frequency is normalized to 1.0, the 6 dB frequency will be 1.056 to 1.726 times greater depending on the number of filter elements up to ten. For a highpass filter, the 6 dB frequency will be 1/1.056 to 1/1.726 times lower than the 3 dB frequency. For example, if the 6 dB frequency of a 5-element lowpass filter is 26 KHz, the 3 dB frequency is 26/1.115 or 23.3 kHz. Table 1 will be used in the design of the bandpass filter example to be described later. To increase the usefulness of this table, the 1dB/3dB cutoff frequency ratios are also included.

Table 1. 1 & 6 Frequencies of a Lowpass Butterworth Filter for 3dB $F_{co} = 1$

Ratio of Cutoff Frequencies	Number of Filter Elements									
	1	2	3	4	5	6	7	8	9	10
$\frac{f_{co(6dB)}}{f_{co(3dB)}} =$	1.726	1.314	1.200	1.146	1.115	1.095	1.081	1.071	1.063	1.056
$\frac{f_{co(1dB)}}{f_{co(3dB)}} =$	.509	.713	.798	.845	.874	.894	.908	.919	.928	.935

The values listed in Table 1 were derived from the following equation:

Attenuation (dB) = $10 \log_{10}(1 + w^{2n})$, where $w = f/f_{3dB}$ and n = the number of elements in the lowpass Butterworth filter.

The upper skirt selectivity or response roll-off of the detection system is specified in paragraph 6.2.1.10 (c) of NACSEM 5100 to be a minimum of 40 dB/decade, which is equivalent to 12 dB/octave. Although this upper roll-off can be achieved with a 2-element Butterworth lowpass filter, more elements are desirable to obtain better selectivity and improved rejection to out-of-band signals. The response roll-off on the lower skirt is not applicable (according to NACSEM 5100) when the lower cutoff frequency of non-tunable instrumentation is specified as "equal to or less than a certain frequency." In this case, the highpass portion of the bandpass filter may be omitted. However, whether or not a low frequency roll-off is necessary depends on the judgement of the test engineer after he observes the effect on the detection system performance caused by the out-of-band low frequency ambient signals present on the line under test.

For example, when testing a power line for undesired signals, the low frequency skirt selectivity of the input filter should be such that sufficient attenuation is provided to frequencies of 60, 180, and 300 Hz to prevent the detection system from being overloaded by the power line fundamental frequency and its strongest harmonics. For a low cutoff frequency of 2400 Hz, for example, a 4-element highpass Butterworth filter will provide 24 dB/octave or more than 72 dB of attenuation at 300 Hz. Since the bandpass filter is placed in front of the active portion of the detection system, the synamic range of the entire detection system will be correspondingly improved. In a similar manner, the upper skirt selectivity may be chosen to attenuate any undesired signals in the upper frequency range outside the desired passband of the detection system. If the roll-off for the upper and lower filter skirts is identical, then the most convenient method of achieving the desired bandpass selectivity is to select a lowpass filter prototype with its 3 dB cutoff frequency equal to the 3 dB bandwidth of the bandpass filter. The lowpass prototype is then transformed to the desired bandpass filter using the standard lowpass-to-bandpass transformation procedure. However, if the upper and lower roll-offs must be different, then separate highpass and lowpass filters must be used. If separate filters are selected to provide the upper and lower roll-off responses, the filters may be connected in cascade if the cutoff frequencies are separated by more than one octave and if the termination resistances of the filters are identical. If the termination resistances are different a resistive matching pad of 6 to 10 dB may be necessary to obtain a flat passband response. For the majority of testing, the upper and lower skirt selectivities can be identical. Since equal roll-off rates are the most common requirement for the bandpass filter, the design example to be discussed later will use the lowpass-to-bandpass transformation design procedure.

Input Resistance

Paragraph 6.2.1 [Detection Systems (U)] of NACSEM 5100 specifies that all line conduction detection systems shall have a 50-ohm input impedance. This specification should not be incorrectly interpreted to mean that the active portion of the detection system (the input preamplifier) must have a 50-ohm input impedance. The preamplifier input impedance can be any value as long as the line under test (LUT) "sees" 50 ohms when looking into the input of the NB N-T detection system. Because the preamplifier is being used only in the audio frequency range, the need for 50-ohm impedance levels, normally required for r.f. detection systems, no longer applies here. There is no danger of high VSWR and signal reflections in the audio range; consequently, the preamplifier

1. *The full title of this document is "Compromising Emanations Laboratory Test Standard, Electromagnetics" (U), dated March 1974.*

input impedance can be any value that is required to achieve optimum performance and convenience of construction for the entire detection system. Thus, a high input impedance preamp (Z_{in} = 47k ohms, for example) might be used in combination with a bandpass filter having resistive terminations such that the line under test sees 50 ohms. In this case, a filter having 100-ohm resistors across the filter input and output terminals would suffice. Since the LUT would see the parallel combination of two 100-ohm resistors, the NACSEM 5100 50-ohm requirement would be satisfied. Unfortunately, the termination of the filter input by the LUT source impedance is not satisfactory. To obtain its expected response performance, the filter input should be terminated in a specific and stable resistive load but the LUT source impedance may be any value. From the view-point of the filter, this situation is not desirable and should be corrected so the filter is properly terminated at its input regardless of the LUT source impedance and, simultaneously, the LUT is loaded by 50 ohms provided by the detection system input circuit.

Another problem confronting the test engineer is that of designing a satisfactory and conveniently fabricated filter having a 50 to 100-ohm impedance level for use in the audio frequency range. For data rates of 10 kb/s, the upper and lower 3dB cutoff frequencies will be between 1 kHz and 20 kHz. A quick estimate of the inductor values required for a 50-ohm 1 kHz highpass and a 20 kHz lowpass filter shows that approximately 3 mH or less of inductance will be needed. Inductors less than 5 mH with good Q (50 or more) over the 1 kHz-to-20 kHz range are not conveniently available. For example, the Q versus frequency curves in the Torotel toroidal inductor catalog do not list inductance values below 5 mH for those cores recommended for frequency ranges up to 20 kHz. An optimum solution is to use a higher filter impedance level for the frequency range involved so that the inductance values required will be in the order of 20 to 200 mH. How this particular aspect of the filter design requirement will be reconciled with that of the NACSEM 5100 LUT 50-ohm termination requirement will be explained later in the design of a narrowband non-tunable detection system.

Preamplifier Dynamic Range, Sensitivity, and Frequency Response

The preamplifier portion of the detection system must, among other things, be selected for satisfactory dynamic range, sensitivity, and frequency response.

To prevent preamp overload and blocking by intermittent high level signals on the LUT, a dynamic range in excess of 60 dB is desirable.

The preamp sensitivity must be good enough to allow the detection of signals having levels at the limit specified in Figure D-7 of NACSEM 5100. This figure gives the conduction level limit in dBuV rms versus the 6 dB non-tunable bandwidth. The ability of the preamp to detect signals at the limit will depend greatly on its noise figure.

Since a non-tunable detection system is under consideration, the flat portion of the passband should not vary by more than 1 or 2 dB, otherwise the measured level of the signals within the detection system passband may be in error. Consequently, the input filter and the preamplifier should both have a relatively flat passband response.

For maximum convenience and for best low noise performance, the preamp should be battery powered. This feature removes any external connections to the a.c. power line and eliminates the possibility of ground loops being developed within the detection system.

A suitable and inexpensive preamplifier having all the desired characteristics will be discussed in more detail later.

DESIGN OF A NARROWBAND NON-TUNABLE DETECTION SYSTEM

The desired performance characteristics of a NB N-T detection system, suitable for performing TEMPEST tests in accordance with NACSEM 5100, have been discussed. An inexpensive and easily fabricated NB N-T detection system will not be designed to meet the test requirements.

Input Bandpass Filter

A bandpass filter, having a 6 dB bandwidth determined by the EUT bit rate, will be used in front of the preamp to protect the preamp from high-level out-of-band signals. To comply with the NACSEM 5100 skirt selectivity requirements, and also to substantially attenuate low frequency hum and noise, the lower and upper roll-off will be designed for 24 dB/octave. If the test engineer prefers a faster (or slower) roll-off with more (or less) filter components, the design procedure may be easily modified.

The problem of simultaneously (1) loading the LUT with 50 ohms, (2) properly terminating the bandpass filter, and (3) using an impedance level high enough to allow reasonable inductance values to be used, is solved by selecting a singly-loaded Butterworth filter having an output termination of more than 1000 ohms and an input termination of 50 ohms or less. For this particular type of design, the filter input termination appears to be, for all practical purposes, a short-circuit as long as the output termination is twenty times or more greater than the actual input termination.

To satisfy the LUT loading requirements, a 51-ohm, 1/2-watt, 5% resistor is connected from the filter input terminal to ground. Note that the LUT source impedance can vary from zero to infinity and the filter termination will also vary, but it will never exceed 50 ohms. The precise value of output load for the filter (some value greater than 1000 ohms) is chosen to give the most conveniently realizable values of inductance and capacitance. For the filter design example to follow, a value of 1300 ohms was selected. This particular resistance termination has the advantage of giving inductance and capacitance values that are particularly convenient to obtain.

Bandpass Filter Design Procedure & Calculations

A 4-element singly-loaded Butterworth lowpass filter will be designed and then transformed to a bandpass filter having the desired response and termination characteristics.

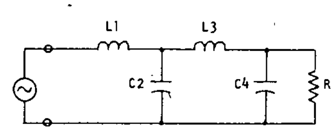
(1) The EUT data rate is assumed to be such that the 6 dB cutoff frequencies are: Upper 6 dB f_{co} = 19.2 kHz, Lower 6 dB f_{co} = 1.92 kHz, and 6 dB BW = 17.28 kHz.

(2) With the help of the factors in Table 1, n=4, the 3dB cutoff frequencies corresponding to the 6 dB cutoff frequencies are calculated:
Upper 3 dB f_{co} = 19.2 kHz/1.146 = 16.75 kHz
Lower 3 dB f_{co} = 1.92 kHz(1.146) = 2.20 kHz
3 dB Bandwidth = 14.55 kHz, $f_{mean} = [(16.75)(2.20)]^{.5}$ = 6.07 kHz

(3) A filter output termination resistance of 1307 ohms is selected after several trial calculations. This value of termination resistance was found to give the most convenient component values. The desired 3 dB bandwidth of the bandpass filter is 14.55 kHz. A lowpass prototype filter having a 3 dB f_{co} equal to the 3 dB bandwidth of the bandpass filter will be designed. The prototype filter will then be transformed into the desired bandpass filter. For the lowpass prototype filter, f_{co}' = 14.55 kHz and w_{co} = 91.42k rad/sec.

(4) The inductance and capacitance scaling factors are:
L Scaling Factor = R/w_{co} = 1307/91.42k = 14.3 mH
C Scaling Factor = $1/Rw_{co}$ = 1/(1307)(91.42k) = .008369 uF

(5) The normalized values (for w_{co} = 1, R_L = 1) of a 4-element lowpass Butterworth filter are taken from Table A3-12, page 132, of Geffe's well-known book[2]. The designs in this table are intended for the lossy-L case. At low frequencies, practical capacitors have extremely high Q, whereas the inductors are relatively poor. However, because the Q of the inductors to be used in constructing this filter are greater than 50 between 2kHz and 20 kHz, the tabulated values of the row for "d=O" will be used. Since the source resistance is to be zero and the load resistance some finite value, the filter configuration at the bottom of the page is used along with the lower tabular headings. (Additional design data is available in this excellent book for similar Butterworth filters having two to ten elements.) The schematic diagram and normalized component values of the filter are shown in Figure 1.



L1 = 1.531
C2 = 1.577
L3 = 1.082
C4 = 0.3827
w_{co} = 1 rad/sec
R = 1 ohm

Figure 1. 4-Element Singly-Loaded Butterworth Lowpass Filter.

(6) The tabulated component values are scaled from $w_{co}=1$, R = 1 to the desired lowpass prototype cutoff frequency of 14.55 kHz (w_{co}=91.42k) and the desired load resistance of 1307 ohms by using the L and C scaling factors calculated in (4).

L'1 = L1 (R/w) = 1.531 (14.3) mH = 21.9 mH
L'3 = (R/w) = 1.082 (14.3) mH = 15.5 mH
C'2 = C2 (1/Rw) = 1.577 (.008369) uF = .0132 uF
C'4 = C4 (1/Rw) = 0.3827 (8369) pF = 3203 pF

The scales lowpass prototype filter is shown in Figure 2.

(7) The lowpass filter in Figure 2 is transformed into the desired bandpass filter by resonating L1 and L3 with series capacitors and C2 and C4 with shunt inductors. These four circuits are tuned to the previously calculated mean frequency of 6.07 kHz. This completes the design of the bandpass filter. The schematic of the completed bandpass filter is shown in Figure 3.

Filter Construction

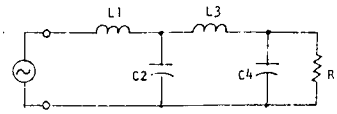
High quality unpotted toroidal inductors (surplus telephone line loading coils), now available on the surplus market for about 50 cents each[3], were used in the construction of the bandpass filter. These inductors are equivalent in performance and size to commercial units selling for ten times as much. The unmodified 44 and 88 mH surplus inductors can provide values of 11 or 44 mH and 22 or 88 mH depending on whether the two coils on each inductor core are connected in series or parallel aiding. Turns are easily removed to obtain any intermediate value. Several standard 10% .033 uF and .047 uF mylar capacitors were measured and one each, approximately 5% below the standard value, were selected for C1 and C3. C2 and C4 were obtained from paralleled 5% polystyrene capacitors. One unmodified 22 mH inductor was used for L1 and two 88 mH and one 44 mH inductors were connected in series for L4. The L2 and L3 values were obtained from 22/88 mH coils by removing the proper number of turns to get the design value within a few percent. The windings were connected in series to get the 52.1 mH value and in parallel to get the 15.5 mH value. The reason for the selection of 1307 ohms for the termination resistance should now be obvious from the very convenient component values that are required. Also, 1300 ohms is a standard 5% resistance value which can be used for the terminating resistance of the filter.

The filter components were assembled in a 2-1/4 x 2-1/4 x 5-inch Bud Mini-box with BNC connectors on each end for input and output connections. A photograph of the completed filter is shown in Figure 4 and the measured filter attenuation response is shown in Figure 5. The very slight difference between the measured and calculated upper cutoff frequencies is attributed to small errors in the values of the selected components. Since the permissable tolerance given in NACSEM 5100 allows the actual 6 dB upper cutoff frequency to be within ±25% of the calculated value (see Table 4, NACSEM 5100), the small error in the measured bandpass filter response can be ignored.

Low Noise Preamplifier

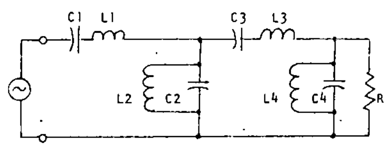
All of the desirable preamp characteristics of dynamic range, low noise, adequate sensitivity, high input impedance, and flat passband response are available in an inexpensive, compact, battery-powered device called a "phono preamp." To one accustomed to using more sophisticated equipment, the phono preamp appears to be unworthy of serious consideration. Nevertheless, the common ordinary transistorized phono preamp is entirely suitable for this NB N-T detection system. This detection system, comprised of a phono preamp, an amplifier having 60 to 80 dB gain, and a CRO as the output indicator, will meet the Figure D-7 limit of NACSEM 5100 for the 6 dB bandwidth of 17kHz.

The preamp evaluated for the NB N-T detection system consisted of seven transistors and miscellaneous other parts in an operational amplifier circuit. The circuit diagram is shown in Figure 6. The complete circuit with p.c. board is available in kit form[4] for less than $10.



L1 = 21.9 mH
C2 = .0132 uF
L3 = 15.5 mH
C = 3203 pF
F_{co} = 14.55 kHz
w_{co} = 91.42 k rad/sec
R = 1307 ohms

Figure 2. Singly-Loaded Lowpass Filter Scaled to Desired F_{co} and R_L



C1 = .0314 uF
L1 = 21.9 mH
C2 = .0132 uF
L2 = 52.1 mH
C3 = .0444 uF
L3 = 15.5 mH
C4 = 3203 pF
L4 = 215 mH
R = 1307 ohms

Figure 3. Singly-loaded Bandpass Filter for NB N-T Detection System

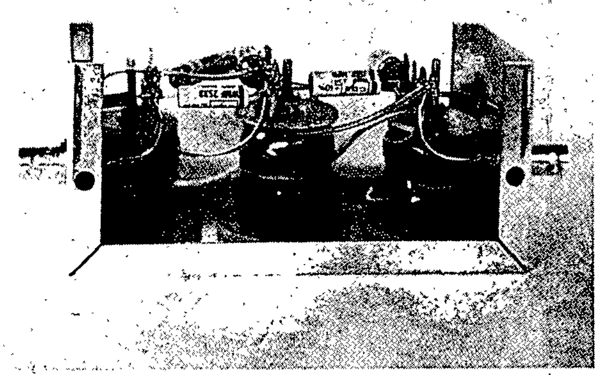


Figure 4. Photograph of Assembled Bandpass Filter.

Another interesting possiblity for a low noise phono preamp source is the National Semiconductor LM 381. This is a linear integrated circuit, low noise dual preamplifier designed for low level signal amplification requiring optimum noise performance. There are two completely independent amplifiers in each IC with individual internal power supply decoupler-regulators. The two preamps could be connected in cascade to provide low noise preamplification plus some of the needed additional signal amplification before the CRO input. An even more sophisticated low noise op amp is available from Analog Devices (AD504J or K for $11.20 and $20 each) and this may give even better performance.

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[2] *Philip R. Geffe, "SIMPLIFIED MODERN FILTER DESIGN," John Rider Publisher, 1963.*

[3] *44 and 88 mH, 5/$2.75 ppd, M. L. Buchanan, POB 74, Soquel, CA 94073*
88 mH, 5/$2.75 ppd, M. Weinshenker, Box 353, Irwin, Penna. 15642.

[4] *#195 Preamp kit, SOUTHWEST TECHNICAL PRODUCTS CORP., 219 W. Rhapsody, San Antonio, Texas 78216*

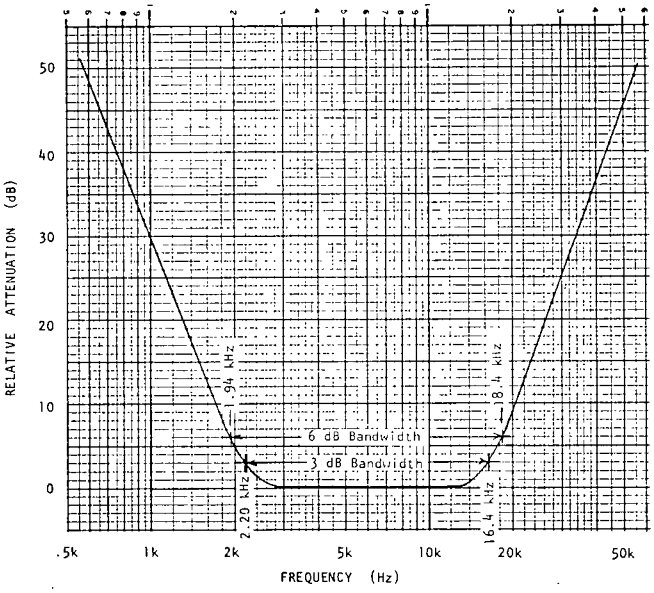

Figure 5. Measured Attenuation Response of Singly-Loaded Bandpass Filter

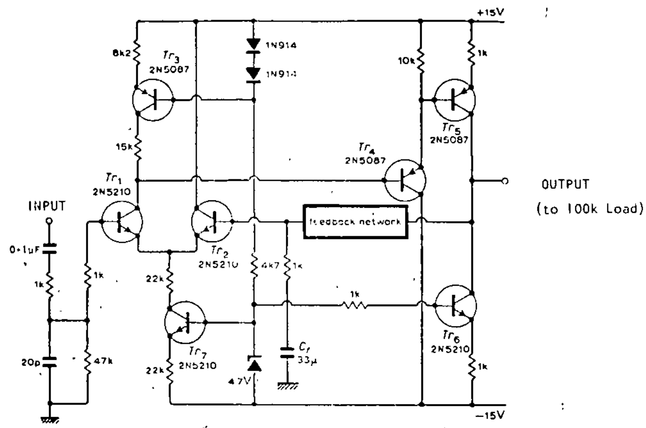

Figure 6. Low Noise Phono Preamp Used in the NB N-T Detection System

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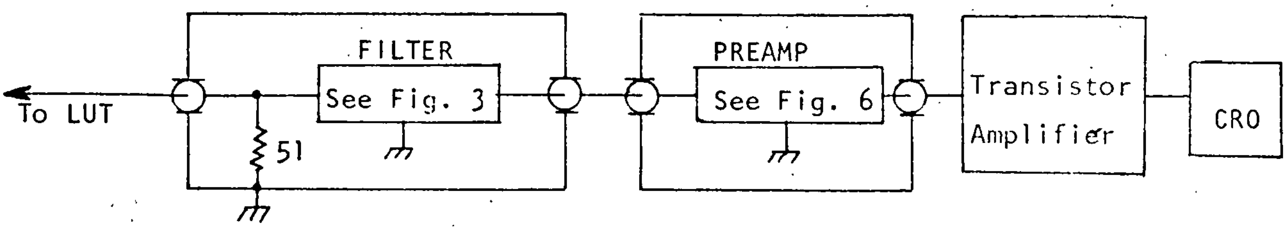

Figure 7. Block Diagram of Complete NB N-T Detection System

Complete Narrowband Non-Tunable Detection System

A block diagram of the complete detection system, comprised of the bandpass filter, preamp, amplifier, and CRO, is shown in Figure 7. The filter and preamp have been previously discussed. The amplifier, preferably transistorized and battery powered, should have an input impudance of 100k ohms or more and a gain of 60 to 80 dB. The amplifier response must be flat from 1kHz to 20kHz. The CRO is standard laboratory equipment.

CONCLUSION

The design and construction techniques discussed in this article appear to be exceptionally well suited to satisfying the requirements for NB N-T detection systems frequently needed by the TEMPEST engineer. It is hoped this information will be useful to those involved in this type of work. Any comments, suggestions or criticisms will be appreciated, and should be directed to the author, E. E. Wetherhold, HONEYWELL INC., POB 391, Annapolis, Maryland 21404.

ACKNOWLEDGEMENTS

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4. *E. E. Wetherhold, "L-C Filters for TEMPEST Testing," ITEM, pp. 82-85, 1974.*
5. *Daniel Meyer, "A Super Op Amp Preamp," pp 16-21, Vol. III, No. 1, October 1972, THE AUDIO AMATEUR.*
6. *Walter G. Jung, "Letters", p. 30, Vol. III, No. 2, January 1973, THE AUDIO AMATEUR.*
7. *D. Meyer and L. Greisel, "Letters", p. 32, Vol. III, No. 3, March 1973, THE AUDIO AMATEUR.*