ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

School of Electrical Engineering & computing

Department of Electronics & Communication Engineering

STUDY ON RADIO FREQUENCY INTERFERENCE IN SOUND SYSTEM

A Thesis

By

ALEMU HAILE RIKITU

Submitted to School of Electrical Engineering & computing in partial fulfillment of the requirements for the degree of Master of Science, in Communication Engineering

Advisor: Dr. M. Venkata Raghavendra

ADAMA, ETHIOPIA

DATE 28 FEBRUARY 2017

STUDY ON RADIO FREQUENCY INTERFERENCE IN SOUND SYSTEM

Submitted by:

Alemu Haile Rikitu Student	______________ Signature	______________ Date

Approved by:

Dr. M.Venkata Raghavendra Advisor	______________ Signature	______________ Date
Prof.Dr.Eng. Achim Ibenthal Internal Examiner	______________ Signature	______________ Date
Dr.Eristu Yigzaw External Examiner	______________ Signature	______________ Date
Eng. Hinsermu Alemayehu Chairman, Department Graduate Committee	______________ Signature	______________ Date
______________________ Dean, So EEC	______________ Signature	______________ Date

Declaration

I hereby declare that the work which is being presented in the thesis entitled, Study on Radio frequency interference in sound system, submitted to Adama Science and Technology University (ASTU) in partial fulfillment of the requirements for the degree Master of Science in Communication Engineering, is the result of my own research carried out under the supervision of Dr. M.Venkata Raghavendra and all material used and reproduced has been properly referenced.

Signature: __________

Name of candidate: Alemu Haile

Date: 28 Feb. 2017

This is to declare that the above statement made by the candidate is correct and true to the best of my knowledge.

Signature: ___________

Date: _______________

Acknowledgement

This project caps a long academic journey and it is difficult, at this point in time, to avoid feeling somewhat sentimental or nostalgic while looking back and reflecting on my academic life. I have a deep feeling of gratitude towards all those sharing parts of this journey with me whether mentioned here or not.

I would like to thank my advisor Dr. Raghavendra for giving me the chance to work under his guidance. I learned a lot from his approach to problems, his patience and his overall generous attitude towards life.

I would also like to thank my current colleagues and leaders at ORTO, who have contributed a great deal to my professional development. Last but not least, my journey started in school, so I would like to recognize my extended family, my teachers and all my friends growing up in that corner of the world.

I thank all!

Abstract

The growth in the number of wireless devices and applications underscores the need for characterizing and mitigating interference induced problems such as distortion and blocking. A typical interference scenario involves the detection of a small amplitude signal of interest (SOI) in the presence of a large amplitude interfering signal; it is desirable to attenuate the interfering signal while preserving the integrity of SOI and an appropriate dynamic range.

Internal or external sources of electromagnetic interference can degrade the performance of sensitive analog/digital circuits inside the audio equipment. Sources of RFI can be classified in numerous ways. Based on the method in which RFI is introduced in the systems, sources are classified as either Radiated or Conductive. Conductive RFI is caused by the physical contact of conductors as opposed to radiated RFI that is picked up by the radio. Radiated RFI is the dominant source that limits the performance of typical commercial wireless communication systems.

This thesis investigates the sources and strength of interference inside Television studio; mainly the radiated interferences and its effect on the audio quality of television production studio. Specifically, the means of RFI from the nearby AM transmitter entering television sound system, types and length of audio cables which can be used to reduce this interference will be studied. Different microphone from various manufacturer used to identify and test interfering signal strength. Since those RFI from AM transmitters picked from ground, test will be made by operating these microphones at different height from the ground. The variation in strength of interfering signal at different distance from the source will be made and compared will the audio level standard.

Online prediction and analysis software are used to perform the task of AM propagation prediction in 24 hour of broadcast which will identify types of propagation during day and night time. This RF propagation also depend on soil resistance in addition to time of broadcast. Different ways of mitigating or reducing interference from AM transmitters will be tested. The best solutions will be identified from the designing point view, while studio and transmitter location selection and construction.

Contents

List of figures

List of Tables

List of Acronyms

AES/EBU	Audio Engineering Society/European Broadcasting Union
AM	Amplitude modulation
AC	Alternating current
BW	Bandwidth, in Hz
DAW	Digital audio workstation
dB	Decibel
dBm	Decibels referenced to 1 milliwatt
dBu/dBv	Decibels referenced to 0.775 volt.
dBV	Decibels referenced to 1 volt
dBW	Decibel-Watt
DC	Direct current
DUT	Device under test
EMI	Electromagnetic interference
EMC	Electromagnetic Compatibility
FCC	Federal Communications Commission
FM	Frequency modulation
GHz	Giga hertz
HF	High frequency
IC	Integrated circuit
IEEE	Institute of Electrical and Electronics Engineers
ISM	Industrial, Scientific and Medical
LF	Low frequency
K	Boltzmann's constant
kHz	Kilo hertz
MF	Medium frequency
MHz	Mega hertz
PCB	Printed circuit board
R	Resistance in Ω
RCA	Radio Corporation of America
RMS	Root mean square
RSS	Root of the sum of the squares
RF	Radio frequency
RFI	Radio frequency interference
RTS/CTS	Request-to-send/clear-to-send
SCIN	Shield-current-induced noise
T	Temperature in degrees Kelvin
TV	Television
UHF	Ultra-high frequency
UTC	Universal Time Coordinated
VHF	Very high frequency
WiFi	Wireless Fidelity
XLR	X = Ground L = Live R = Return

Chapter 1

1 Introduction

1.1 Background

As a matter of convention, the ITU divides the radio spectrum into 12 bands, each beginning at a wavelength which is a power of ten (10^n) meters, with corresponding frequency of $3\times10^{8-n}$ hertz, and each covering a decade of frequency or wavelength. Each of these bands has a traditional name. This is just a naming convention and is not related to allocation; the ITU further divides each band into sub-bands allocated to different uses.

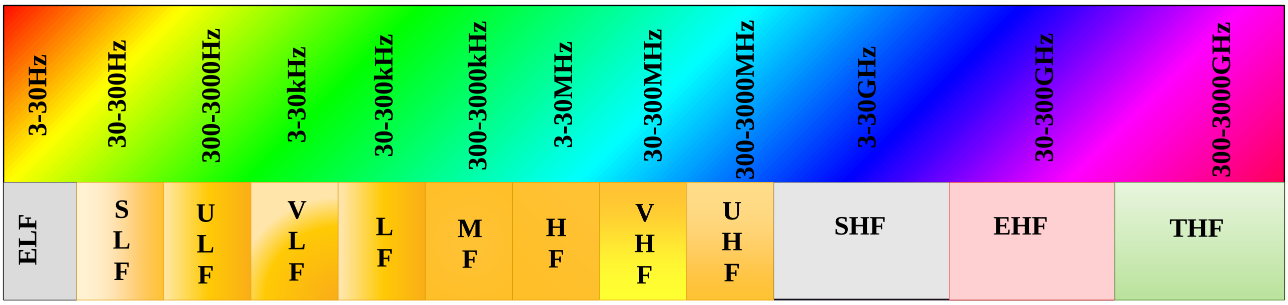


Figure 1.1 Electromagnetic spectrum

An audio signal is a representation of sound, typically as an electrical voltage. Audio signals have frequencies in the audio frequency range of roughly 20 Hz to 20 kHz (the limits of human hearing). Audio signals may be synthesized directly, or may originate at a transducer such as a microphone, musical instrument pickup, phonograph cartridge, or tape head. Loudspeakers or headphones convert an electrical audio signal into sound.

Digital representations of audio signals exist in a variety of formats. An audio channel or audio track is an audio signal communications channel in a storage device, used in operations such as multi-track recording and sound reinforcement. Signal flow is the path an audio signal will take from source (microphone) to the speaker or recording device. It is most frequently in a recording studio setting, where the signal flow is often very long and convoluted as the electric signal may pass through many sections of a large analog console, external audio equipment, and even different rooms.

Audio signals may be characterized by parameters such as their bandwidth, power level in decibels (dB), and voltage level. The relation between power and voltage is determined by the impedance of the signal path, which may be single-ended or balanced. As much of the older analog audio equipment has been emulated in digital form, usually through the development of audio plug-ins for digital audio workstation (DAW) software, the path of digital information through the DAW (i.e. from an audio track through a plug-in and out a hardware output) is also called an audio signal or signal flow. A digital audio signal being sent through wire can use several formats including optical (ADAT, TDIF), coaxial (S/PDIF), XLR (AES/EBU), and Ethernet.

Performance of wired or wireless communication systems is limited by the noise present in the system. The term noise has varied meaning, connotation, and impact based on the physical phenomenon it is used to describe from proving the existence of atoms to denoting undesired effects in electrical conductors. In wireless communication systems, noise is commonly used to denote the unwanted additive distortions caused by the system in conjunction to linear and other non-linear distortions to the transmitted signal. Additive noise degrades the ability of the receiver to successfully detect the information in the transmitted signal.

An unavoidable source of noise is due to the electronic circuitry at the receiver, and is termed as circuit noise. Impact of circuit noise on communication systems was first studied by Schottky in 1918, where he considered the impact due to two forms of circuit noise: thermal and shot noise. These are the dominant sources of circuit noise and are unavoidable in any electronic circuit. Thermal noise is due to random motion of electrons inside an electrical conductor and occurs regardless of the voltage applied. Shot noise, on the other hand, is due to statistical variations in the electrical current in a conductor as the moving charges are randomly emitted (hence the name shot noise). Schottky studied the impact of thermal and shot noise as they pass through the receiver and perturb the desired signal. This helped in recognizing that the fluctuations caused due to thermal noise and shot noise (under weak assumption that the rate of shots is greater than receiver bandwidth) are spectrally at and the amplitude statistics follow a Gaussian distribution. In this thesis, circuit noise is loosely referred to as thermal noise and is assumed to be spectrally at and Gaussian distributed.

Interference is not hard to find; it is actually difficult to avoid, especially in urban areas where the wireless revolution is well underway. By definition, interference originates from a source external to a signal path and produces undesired artifacts in the signal. A radio frequency is loosely defined as being in that portion of the electromagnetic spectrum above audio (about 20 kHz) but below infrared (about 30 THz). Electromagnetic interference (EMI), is a broader term having the same basic meaning but without frequency limitations. Electromagnetic compatibility (EMC), is a term coming into more widespread use regarding issues of equipment electromagnetic emissions and susceptibility.

Electromagnetic fields, such as radio and TV signals, travel through space (air) at the speed of light, about 300,000,000 m/sec. Because wavelength is the physical distance such a signal travels during a single cycle, as frequency increases wavelength decreases. For example, a 1 MHz AM radio signal has a wavelength of about 305 m, but for a 100 MHz FM radio signal, it is about 3 m, and for a 12 GHz DSS TV signal, only about 25.4 mm. Any wire can accidentally become a good antenna if its length happens to be, say, the wavelength of a strong local FM station.

Sources of RF interference fall into two broad categories-intentional and unintentional. Intentional sources include AM, shortwave, FM, and TV broadcast transmitters as well as ham and CB transmitters, remote controls, wireless phones, cellular phones, commercial taxi/police/aircraft radios, microwave ovens, motion sensors, radar systems, and a myriad of medical and industrial RF devices. Unintentional RF sources are most commonly devices that produce an electrical spark. Sparks are potent RF generators-before vacuum tubes, they were the heart of radio transmitters-that splatter energy over a wide frequency spectrum. Any wiring connected to the spark source not only conducts the RF but also acts as a transmitting antenna to radiate it. Common sparking sources include electric welders, brush-type motors, relays and switches of all kinds. Less obvious sources include arcing or corona discharge in power line insulators (common in seashore areas or under humid conditions), malfunctioning fluorescent or neon lighting and automobile spark plugs. Lightning is the ultimate spark and a well-known producer of momentary interference to virtually anything electronic.

Other unintentional RF generators are devices that abruptly interrupt current flow using some form of electronic switching. The most common examples are light dimmers, fluorescent lights, TV or computer CRT displays and any piece of equipment using a switching power supply or "clock" oscillator (computers and other digital devices). The RFI source may be in the same room as your system or, worse yet, it may be a part of your system. Sources of RFI can also be classified based on the method in which RFI is introduced in the systems as either Radiated or Conductive sources of RFI.

Conductive RFI is caused by the physical contact of conductors as opposed to radiated RFI that is picked up by the radio. Radiated RFI is the dominant source that limits the performance of typical commercial wireless communication systems. Focusing on radiated RFI, this thesis adopts a broad classification introduced by Middleton.

The task of transferring an analog audio signal from one system component to another while avoiding audible contamination is anything but trivial. The dynamic range of a system is the ratio, generally measured in dB, of its maximum undistorted output signal to its residual output noise or noise floor. Fielder has shown that up to 120 dB of dynamic range may be required in high-performance sound systems in typical homes. The trend in professional audio systems is toward increasing dynamic range, fueled largely by increasing resolution in available digital converters. Analog signals accumulate noise as they flow through system equipment and cables. Once noise is added to a signal, it's essentially impossible to remove it without altering or degrading the original signal. Therefore, noise and interference must be prevented along the entire signal path. Of course, a predictable amount of random or “white” noise, sometimes called “the eternal hiss,” is inherent in all electronic devices and must be expected. Excess random noise is generally a gain structure problem.

Ground noise, usually heard as hum, buzz, clicks or pops in audio signals, is generally the most noticeable and irritating, even if its level is significantly lower than background hiss, it can still be heard by listeners. Ground noise is caused by ground voltage differences between the system components. Most systems consist of at least two devices which operate on utility ac power. Although hum, buzz, clicks, and pops are often blamed on “improper grounding,” in most cases there is actually nothing improper about the system grounding. To assure safety, all user accessible connections and the equipment enclosure must be connected to the safety ground conductor of the ac power system. A properly installed, fully code-compliant ac power distribution system will develop small, entirely safe voltage differences between the safety grounds of all outlets.

1.2 Problem Statement

Now a day there more source of radio frequency signal in our world. From those sources media organization is the known one. Most media organization broadcasts both radio and television simultaneously, and build radio and TV studio in the same compound with transmitting system. Radio transmission will be done in different broadcasting technology. From those technology, MW/SW transmitters were the old technology and operate on lower range of frequency band. Most of the time coverage area is the main target to be fulfilled in broadcast industry. So, to cover more area they use high power transmitter with taller antenna tower. Due to very close installation of transmitters to other sound system, RF from those transmitters interfere with other sound system in different ways. Even transmitters designed with good quality filters, transmit out off band and harmonics signal. Since TV studio should be constructed wider area for production, using longer audio cable to interconnect systems is common. Those cables will be installed on the ground which will make them more susceptible to RFI from AM transmitters. The cables from manufactures has different property to surrounding RFI due to the electrical and magnetic property material they are made from.

Most mics handles the sound as analog signal which is more vulnerable for interference. In analog signal, it is more difficult to filter noise than in case of digital. The goal of this thesis is to study the how RFI from AM transmitter will be introduced or picked television’s sound system. The long audio cable picks more RF, because of this it is difficult to use long audio cable to interconnect the system and also the noise on sound increase when cables laid on ground. Sometimes the audio from television and radio (interfering AM transmitters) heard equally on the television broadcast receiver side. The other big problem is this interfering signals are unable to completely eliminate using inbuilt high and low frequency filter of audio mixer after once picked.

1.3 Objectives

1.3.1 General objectives

The general objective of the thesis is to study the way an unwanted RF signal entering the sound system, its level referenced to the signal of interest and the variation of its signal strength relative to distance from interfering source. The proper solution of eliminating or reducing this unwanted signal will also be experimented.

1.3.2 Specific Objectives

- The strength and ways signals from high power transmitter was interfering with TV sound system will be studied.
- The strength RFI entering the system with different type's audio cables will be measured.
- RFI strength relative to distance from transmitters experimented.
- Length of cables used to interconnect system and whys of installing it identified.
- Means of mitigating interfering signal addressed

1.4 Methodology

1.4.1 Theoretical study

Audio cables can act like transmission lines, but only when they are exceptionally long. To understand the concept of a transmission line, think of a length of electrical cable as a lot of tiny pieces of cable, all connected together, each having some series inductance and resistance, some parallel capacitance and some leakage resistance through its insulation. Three basic mechanisms often combine to cause RF interference to audio systems. They are:

- An audio cable will be excited as an antenna by radio signals that surround it, causing current to flow along its length. Most of the current will flow on the shield, but the current can also induce a common mode voltage on the signal conductor(s).
- Imperfect inductive coupling between conductors of a shielded twisted-pair cable converts shield current to a differential voltage on the signal pair (SCIN).
- Inadequate low-pass filtering of signal input and outputs lets RF present on the signal conductors into equipment. Equipment can be sensitive to both differential mode voltage (between the signal conductors) and common mode voltage (an equal voltage on both signal conductors).

Analysis of these mechanisms shows that RF common-mode current is a major contributor to all of them, so eliminating or reducing common-mode current should be the key to eliminate the interference. Virtually all cases of AM broadcast interference is through both mic and input equipment, many of them quite severe, were either eliminated or greatly reduced when a cable connecting the mic to the input equipment was wound around a toroidal ferrite to form a multi-turn RF choke. In this thesis, we will focus on the performance of a variety of ferrite parts over the range of 300 kHz to 1 GHz in reference of distance from interfering signal source.

1.4.2 Data Collection

There are several methods used to determine effect of radiated RFI in a system. Below is a tabulated summary of the possible measurement and investigation scenarios proposed for this thesis. On the right side of each measurement or investigation scenario is the reason why it should be performed.

Table 1.1 Different Measurement and Investigation Scenarios

No.	*Measurements and Investigations*	*Reasons*
1.	Screening for RFI	To locate possible sources of RF radiation and regions of high RFI. A method used to determine which system contribute to RFI in different modes.
2.	Examining means of picking	To determine possible loops, how it interfere, impact of different type audio equipment.
3.	Spectral analysis of interferences in different modes	To find out radiated frequencies and its strength; possible means reduction.

Here is some basic equipment that we will need for our study.

Table 1.2 Equipment used to troubleshoot RFI

No.	*Equipment*	*Quantity*
1.	Mic and Mixer	2
2.	Different types of Audio cable	Variable length
3.	Multimeter	1
4.	Spectrum Analyzer	1
5.	Signal (frequency) generator	1

AM broadcast interference is known to occur in sound systems when mic cables run exposed through the upper floor or around the floor. The amount of that current flow on the shields of balanced audio cables at frequencies that could cause interference if converted to a differential mode signal from 10 KW main and 1KW standby Radio Oromia transmitter at multiple location and different time operation will be collected. The specification of this AM transmitter and audio equipment will be taken from Oromia Radio and Television Organization.

1.4.3 Analysis

Audio frequency current flowing on the shield of twisted-pair audio cables will be converted to differential mode voltage on the signal pair. The test was done using a sine wave and square wave generator coupled to an audio power amplifier and output transformer to establish 100 mA of current on the shield of 40 m lengths of an assortment of commonly used audio cables. The measurements used 60 Hz, 600 Hz, and 6 kHz sine and square waves, and indicated that the differential mode conversion was analyzed.

The immunity of audio systems to radio frequency interference in the 200 kHz to 2 MHz region depending on different shielding type will be identified. The primary agent, converting common mode current set up by a microphone cable acting as a receiving antenna into differential mode voltage on the balanced audio pair will be analyzed. Some common causes of shield current in audio cables are:

- Potential differences between points where shields of opposing ends of an audio cable are connected. The potential differences typically result from IR losses (that is, voltage drops) due to leakage currents of motors, lighting equipment, and electronics equipment.
- Wiring faults in equipment unrelated to the audio system.
- Magnetic induction.
- Ground currents from building equipment such as variable-frequency-drive motors.
- Radio signals, most commonly broadcast signals, but also noise from lighting circuits and other incidental or unintentional radiators.

It has been noted that much higher currents have been observed between television studio complexes. These currents have mains power frequencies and lower order harmonics of mains power as their major components, but it is not at all unusual for components at high audio frequencies to also be significant. Impulse noise currents with components throughout the audio spectrum can also be present, most commonly the result of power faults, switching transients, and equipment faults. Impulse noise can, of course, include components well into the MHz range.

Some lengths, heights, orientations, and paths for receiving antennas could easily result in significantly greater currents, perhaps as much as 10 dB. In neither of the test setups could the audio cable shield have been considered a "good" receiving antenna. Different types interference reduction techniques will be applied to identify the best interfering signal attenuator with less impact on signal of interest.

1.5 Scope of the thesis

The scope of this thesis is to study and propose solution for the interfering RF signal with the TV sound system due to nearby high power AM transmitter and different RF source like mobile unit (cell phone) and etc. The source of this interfering RF will be identified and also how they will inter the system should be studied. This RFI will be picked by cables used to interconnect the system which will act as antenna for the RF to enter to the system or to be picked. Due to this the quality of audio in TV transmission is reduced. This interfering signal will not able to be filtered by audio mixer after demodulated by mixer. This interfering RF also make the means of communication in the studio more difficult because the sound of interfering signal overcome the original sound.

1.6 Contribution

Contribution of the thesis work is listed as bellow:

- This thesis identifies the designing problem in transmitting antenna location, studio construction and site selection and recommend minimum separation distance to be taken.
- Best alternative for RF interference reduction out of all possible method will be identified.
- Audio cable shielding types depending on immunity to interference as per distance from source will be identified used for selection as per the scenario.

1.7 Organization of the thesis

In this thesis, we first introduce a brief literature part concerning audio and its property in general, the different types detecting methods and the structure of audio interface. Harmful RFI sources and their possible impact on the sound systems will be discussed.

In the third chapter, detail discussion on source of RF interference and their categorization which help to find solution will be addressed. Chapter four RFI screening, to locate possible sources of RF radiation and regions of high RFI. A method used to determine which system contribute to RFI in different modes will be studied. Chapter five presents multiple mitigation methods to deal with these harmful interferences from the system. Technologies or circuit and mathematical calculation of values of different component used in the circuit will be discussed. In the result and discussion part, which is chapter six, the result of this study will be analyzed and the best will be selected. Finally, conclusion and recommendation will be mentioned in the last chapter.

Chapter 2

2 Literature Review

2.1 Introduction

This chapter conducts a literature review of RF interference with audio system these concepts are incorporated in the design and testing of the components that comprise the proposed interference improvement technique.

By studying how all of this works mathematically, electrical engineers learned long ago that if the signal frequency is low enough (or the line is short enough) and the length of the line is less than one-tenth of an electrical wavelength, don't worry the cable does not act enough like a transmission line. These short cables (short in terms of a wavelength) act like nothing more complicated than the sum of these parallel capacitances, series inductances and series resistances. When load impedances are high, the series inductance, like the series resistance, is too small to have significant effect.

Transmission line behavior is much more complicated. When lines get longer or frequencies get higher, the electrical signal can travel from one end of the cable to the other and be reflected back to the sending end, just like a sound wave bouncing off of a reflecting surface. This kind of reflection happens if the transmission line is not terminated (loaded) with a resistance equal to its characteristic impedance, and is the reason video, RF, and high speed digital lines need to be terminated. A line with no termination (or a different value of termination) is called a mismatched line, and can smear the signal or even weaken it significantly when a reflected signal exactly cancels the forward one. A line with the proper termination passes the signal with no problems more severe than the lines simple resistive loss (which gets larger at radio frequencies, mostly because of skin effect).

For high frequency signals, the cable will behave as an infinite number of tiny inductors, capacitors, and resistances that comprise a transmission line. Fig 1b and 1c show a circuit model that can help us understand how the signal travels along the line.

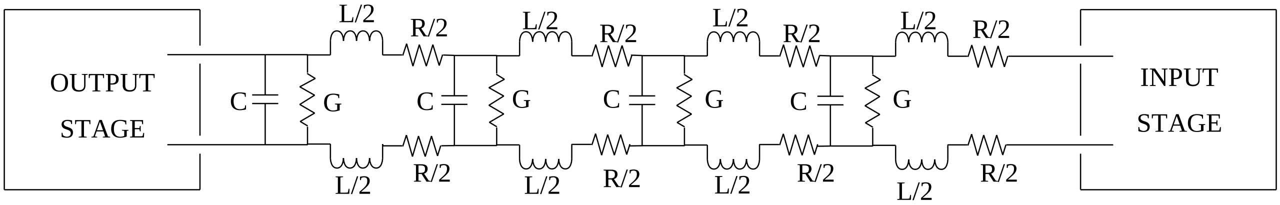


Figure 2.1 Fundamental transmission line model

When transmission line effects are minutely small, as they are in the vast majority of cables carrying audio signals, the pulses travel at the speed of light. A relatively short length of cable shows no measurable transmission line effects for low frequency signals. But if the cable is long enough (or the frequency components of the signal are high enough), transmission line effects will begin to appear with increasing frequency or length. [1]

The characteristic impedance of a cable depends on its wire size, the insulating material and the spacing between its conductors. For modern audio cables, this is on the order of 60Ω. (A recent major cable manufacturer's catalog specifies nominal characteristic impedances of its audio snake cables as 50Ω for one type and 70Ω for another). Significant harmonic energy is present in all live audio. Response problems up to 60kHz can cause measurable and audible distortion of the waveform when this ultrasonic energy is clipped or excites intermodulation, generating distortion products (including oscillation) inside the conventional (up to 20 kHz) audio spectrum. Minor transmission line effects will begin to appear at 60 kHz with about 330m of cable.

Audio cable is available in three ranges of capacitance. Standard cable, including most flexible and snake cable, has about 98.4-111.52 pf per meter. Low-capacitance cable has about 65.6 pf per meter and is more expensive. Special cable constructions optimized to reduce noise pickup (star-quad and some double-shielded cables) have 150.9-183.7 pf per meter. When you drive any of these cables unbalanced, the capacitance is approximately doubled. The classic equation for characteristic impedance in transmission lines is given by.

$$Z_0 = \left[{}^{L}/_{C}\right]^{1/2} \qquad (2.1)$$

In every engineering cases, we make equations simpler by assuming certain conditions will be true for what we think will be the conditions when we use them. That's fine as long as we don't forget those assumptions. The full equation for characteristic impedance is

$$Z_0 = \left[{}^{(R + j2\pi fL)}/_{(G + j2\pi fC)}\right]^{1/2} \qquad (2.2)$$

At high frequencies (that is, f is large), (2πfL) is much larger than R, and (2πfC) is much larger than G. So, at high frequencies, the equation becomes simply

$$Z_0 = \left[{}^{(j2\pi fL)}/_{(j2\pi fC)}\right]^{1/2} \; and\ further\ simplifies\ to\ Z_0 = \left[{}^{L}/_{C}\right]^{1/2} \qquad (2.3)$$

which is the familiar equation. But what if f is not large? Figure below shows the impedance of a typical coaxial cable at audio frequencies using the full equation.

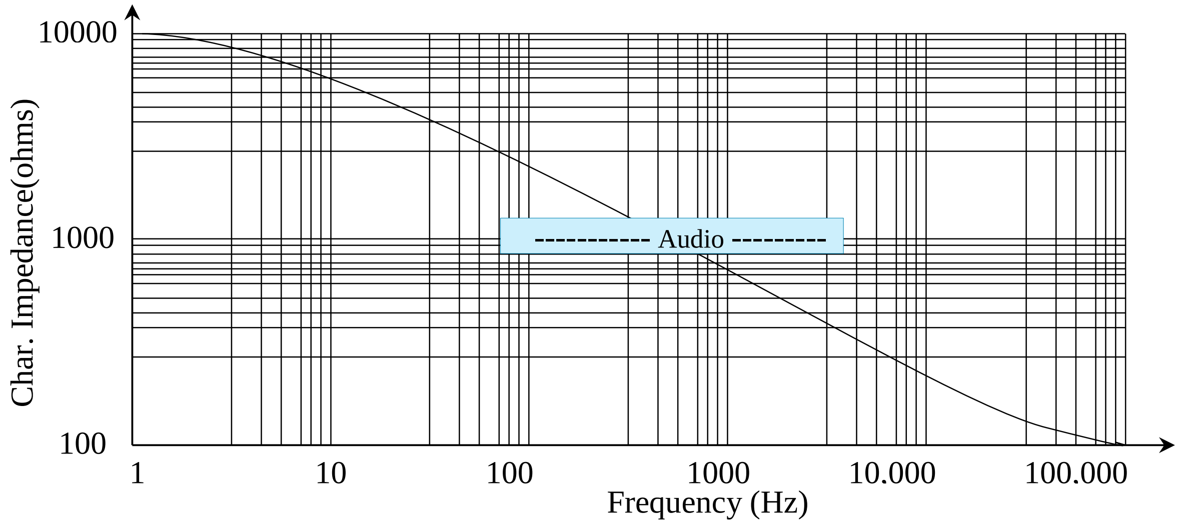


Figure 2.2 Characteristic impedance of typical cable at audio frequencies

The wide variation occurs, because at low frequencies, R is much greater than 2πfL, and 2πfC is much greater than G. Thus, at low audio frequencies, the equation simplifies to

$$Z_0 = \left[{}^{R}/_{j2\pi fC}\right]^{1/2} \quad (2.4)$$

Within the audio spectrum, R in this equation is simply the DC resistance of the cable (per the same unit length as the L and C parameters). This causes the impedance to be quite high and predominantly capacitive near zero frequency. As frequency increases, L becomes significant, and Z_0 transitions to the familiar 50-100 ohm impedances at high frequencies. The transition occurs right in the middle of the audio spectrum. Through the transition region, the "j" term causes Z_0 to be a combination of resistance and capacitance. Coaxial cables, all commonly used cables, including twisted pairs, exhibit these characteristics. Above the audio spectrum, R begins to increase with skin effect as the square root of frequency, causing attenuation to increase. The skin depth of a material is defined as the thickness through which a field must travel to be attenuated by 1/e (where e is 2.718, the base of natural logs). 1/e is 0.37, or a loss of 8.7 dB. [2]

A cable is a source of potential trouble connecting two other sources. Any signal accumulates noise as it flows through the equipment and cables in a system. Once noise contaminates a signal, it's essentially impossible to remove it without altering or degrading the original signal. For this reason, no system can be quieter than its noisiest link. Noise and interference must be prevented along the entire signal path. Delivering a signal from one box to another may seem simple, but when it comes to noise, the signal interface is usually the danger zone, not the equipment's internal signal processing.

How much noise and interference is tolerable depends on what the system is and how it's used. A monitor system in a recording studio obviously needs much more immunity to ground noise and interference than a construction site paging system. The dynamic range of a system is the ratio, generally measured in dB, of its maximum undistorted output signal to its residual output noise or noise floor up to 120 dB of dynamic range may be required in high-performance sound systems in typical homes. In video systems, a 50-dB signal-to-noise ratio is a generally accepted threshold beyond which no further improvement in images is perceivable, even by expert viewers.

As electronics developed, the common return paths of various circuits were also referred to as "ground," regardless of whether or not they were eventually connected to earth. In addition, a single ground circuit most often serves, either intentionally or accidentally, more than one purpose. Thus, the very meaning of the term ground has become vague, ambiguous, and often quite fanciful. Some engineers have a strong urge to reduce these unwanted voltage differences by "shorting them out" with massive conductors the results are most often disappointing. Other engineers think that system noise can be improved experimentally by simply finding a "better" or "quieter" ground. Many indulge in wishful thinking that noise currents can somehow be skillfully directed to an earth ground, where they will disappear forever! Here are some common myths about grounding:

Fundamental cable parameters can be computed from manufacturers' data. Z_0 at radio frequencies is published for most cables. Z_0 are resistance and capacitance per unit length. The inductance per unit length is simply CZ_0. For coax, C ranges between 65.6 and 104.96 pF/meter, L between 0.2 μ H/meter and 0.39 μ H/meter. R_{DC} ranges between 6.56 and 164 m Ω /meter. For balanced audio cables**,** C ranges between 39.36 and 131.2 pF/meter (as high as 360.8 pF/meter for star quad cables); Z_0 at radio frequencies is on the order of 60-90 ohms (110 ohms for digital cables), L is about 0.49 μ H/meter, and R is typically 65.6-164 m Ω/meter. Finding the value of R at radio frequencies in m Ω /meter is significantly more difficult. Wires have zero impedance and, therefore, can extend a zero-voltage reference to many locations in a system, eliminating voltage differences. In fact, wires are quite limited:

- The DC resistance of a wire applies only at very low frequencies and is directly proportional to its length. For example, the resistance of 3.048 meter of #12-gauge wire is about 0.015 **Ω**.
- The inductance of a wire is nearly independent of its diameter but is directly proportional to its length and increases at bends or loops. A 3 m of #12-gauge wire has an impedance of 30 **Ω** at 1 MHz (AM broadcast band). Substituting a 1.27cm diameter solid copper rod lowers the impedance only slightly to about 25 **Ω**.

- A wire resonates (becomes an antenna) when its physical length is a quarter wavelength. Fora 3 m wire, this means it will essentially become an open circuit at about 25 MHz. [3]

2.2 Interfaces and impedances

An interface is a signal transport sub-system consisting of a line driver (one device's output), the line or cable itself, and a line receiver (another device's input). An interface may be unbalanced or balanced, depending only on the impedances (to ground) of the line's two conductors. As shown above, in an unbalanced interface, one conductor is grounded (zero-impedance) and the other has some higher impedance.

The test setup is shown in figure below were done to measure the cables immunity to RF interference. A sine wave generator establishes current on the shield of a twisted-pair cable. A small resistor in series allows a radio frequency voltmeter to measure shield current. The twisted pair is shorted to itself (but not to the shield) at the sending end, and is terminated in 200 Ω at the receiving end. A scope meter, connected to the twisted pair at the receiving end measures the differential mode voltage. To allow the use of unbalanced instrumentation, circuit common (and the connection point for the shields of instrumentation) is at the receiving end, where the cable shield and the "low" signal conductor were connected together. A hand-wound balun isolated the Scope meter channel A input from common mode voltages. The channel B input read the voltage across the small series resistor, which was connected between the generator shield and the cable shield at the receiving end of the cable.

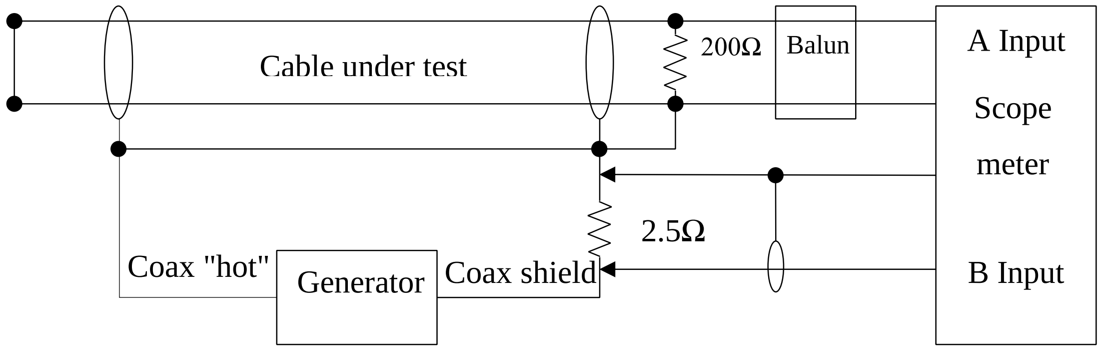


Figure 2.3 SCIN measurement setup

The range of the measurement is limited by the 5 mv/division sensitivity of the Scope meter combined with the current drive capability of the generator. The synthesized radio frequency generator is rated for 0.7 volt into 50 ohms between 100 kHz and 1 MHz and 1 volt above 1 MHz. The cable shield is a very low resistive load at audio frequencies, gradually becoming an increasingly inductive load as frequency increases. The longer (40 m) cable samples exhibited resonances beginning around 1 MHz.

The cable shield was thus a difficult load for the generator to drive below about 60 kHz due to its low impedance, and the current drive capability of the synthesized radio frequency generator degrades below 100 KHz. At the lowest frequencies, the frequency generator was substituted for the RF generator. The sine wave generator was able to produce about 38mA at 10 kHz into all of the cable samples. The voltage readout function of the scope meter was used for all differential mode voltages greater than its lower limit of -60 dBV. Below that level voltages were measured by counting divisions on the screen.

The cables were uncoiled, one at a time and run freely on floors so that their shields present the minimum inductance to the generator, thus maximizing the test current. Measurements were made at discrete frequencies in increments of one octave between 10 kHz and 4 MHz. Because the data was subsequently normalized to a constant shield current, this has no effect on the SCIN properties of the cable, but it does maximize the sensitivity of the test and allows the data to be collected with relatively simple test equipment. A variety of cables were tested, including multiple types having foil/drain shields, counter wound spiral shields, shields consisting of both braid and drain wires, one type having a braid shield, and one type having both a foil and braid shield but no drain wire. All cables were measured with XLR connectors soldered on, and with all copper shields soldered to pin 1 (and only to pin 1).

The cables used in an audio system and how they're put together can have a major impact on the sound of the system. Every cable in an audio system has the potential to add noise and to compromise the sound quality of the components it connects, so it's important to use the right cable for the right job. There are two main issues to consider here: the level of the signal and the signal type.

2.2.1 Balanced audio interfaces

A balanced cable has three conductors in the connector and three wires in the cable: two signals wires plus a separate ground wire. The ground wire surrounds the signal wires and is used as a shield against interference. But what makes a balanced cable special is the way the gear utilizes that extra signal wire. Balanced signals are what is called differential. The two signal wires both carry a copy of the signal, but the two copies are sent with their polarity reversed. If you sum two signals that are identical but are reversed in polarity, the signals cancel out, leaving you with silence. For example, each conductor is always equal in voltage but opposite in polarity to the other. The circuit that receives this signal in the mixer is called a differential amplifier and this opposing polarity of the conductors is essential for its operation.

The purpose of balancing is to make the noise pickup equal in both conductors, in which case it will be a common-mode signal which can be made to cancel out in the load. The impedances, with respect to ground, of the two lines is what defines an interface as balanced or unbalanced.

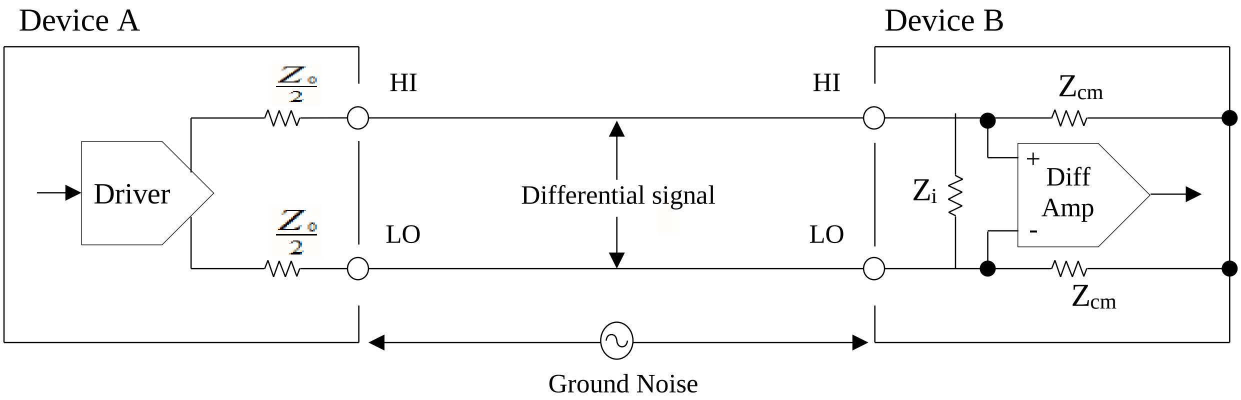


Figure 2.4 Balanced interface between two devices

The basic theory of the balanced interface is straightforward. (For purposes of this discussion, assume that the ground reference of Device A has a noise voltage, which we will call "ground noise," with respect to the Device B ground reference.) If we look at the HI and LO inputs of Device B with respect to its ground reference, we see audio signals (if present) plus the ground noise. If the voltage dividers consisting of $Z_o/2$ and Z_{cm} on each of the lines have identical ratios, we'll see identical noise voltages at the two inputs of Device B.

Since there is no difference in the two noise voltages, the differential amplifier has no output and the noise is said to be rejected. Since the audio signal from Device A generates a voltage difference between the Device B inputs, it appears at the output of the differential amplifier. Therefore, we can completely reject the ground noise if the voltage divider ratios are perfectly matched. In the real world, we can't perfectly match the voltage dividers to get infinite rejection. But if we want 120 dB of rejection, for example, we must match them to within 0.0001% or 1 part per million.

The ground noise received from Device A, since it exists on or is common to both wires, is called the common-mode voltage and the differential amplifier provides common-mode rejection. The ratio of differential or normal-mode (signal) gain to the common-mode (ground noise) gain of the interface is called the common-mode rejection ratio or CMRR and is usually expressed in dB. [4] [14]

2.2.2 Unbalanced audio interfaces

An unbalanced cable consists of two connectors with two conductors each, connected by two wires inside the cable a signal wire and a ground wire. Standard RCA cables used for many AV components are also unbalanced cables. Inside the cable, the signal wire is typically in the center of the cable with the ground wire surrounding it. The ground wire serves two functions it carries part of the audio signal and serves to shield the main signal wire to some degree from outside interference from noise such as the hum from lights and transformers, as well as RF (radio frequency) interference that comes from TV and radio transmissions.

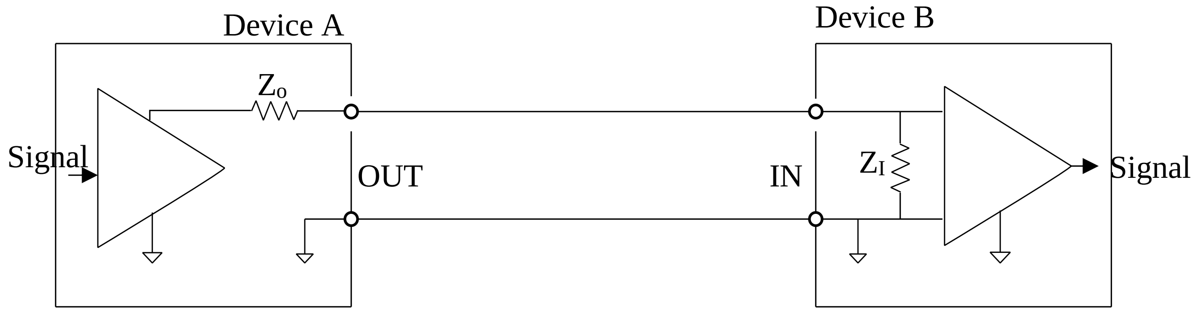


Figure 2.5 Unbalanced interface between two devices

Every driver has an internal impedance called its output impedance, shown as Z_o. For practical reasons, real equipment outputs do not have zero output impedance. Likewise, every receiver has an internal impedance called its input impedance, shown as Z_I. For practical reasons, real equipment inputs do not have infinite input impedance.

When an output is connected to an input, the output impedance of the driver and the input impedance of the receiver form a series circuit. Since current is the same in all parts of a series circuit but voltage drops are proportional to impedance, it is sometimes called a voltage divider. Thus, to transfer maximum signal voltage, Z_I should be much larger than Z_o. In typical equipment, Z_o ranges from 100 Ω to 1 kΩ and Z_I ranges from 10 kΩ to 100 kΩ. This transfers 90% to 99.9% of the available signal voltage. Low output impedance is important. Output impedance is often confused with load impedance and is frequently missing from vendor spec sheets. Sometimes "20 kΩ minimum load impedance" is the only spec for an output - and not very useful. [5]

2.3 Matching and Termination

A common misconception is that audio outputs and inputs must be impedance matched. Circuit theory tells us that when source and load impedances are the same, maximum power is transferred. Although useful in some passive signal processing systems, this concept does NOT apply to modern audio signal interfaces. Their goal is to transfer voltage, not power. If Z_I is made to match Z_o, half the signal voltage is lost and the output drives an unnecessarily heavy load.

However, impedance matching or termination is required for video and RF cables because the signals have much shorter wavelengths. As a general rule, cables begin to exhibit “transmission line” effects when their physical length is 10% or more of a wavelength at the highest signal frequency. This occurs with video cables over a few meters long and with CATV cables over a few inches long. To avoid reflections of energy from one end of the cable to the other, the driving source and receiving load impedances at each physical end of the cable must match the cable's characteristic impedance. Such reflections will cause visible "ghosts" or "rings" in video images. For audio cables, termination is not necessary unless cables are over about 1200-meter long.

With ungrounded devices, power-line leakage current flows in the grounded signal conductor. Since this conductor has resistance, a small noise voltage is generated over its length. Because the interface is a series circuit, this noise voltage is directly added to the signal arriving at the receiver.

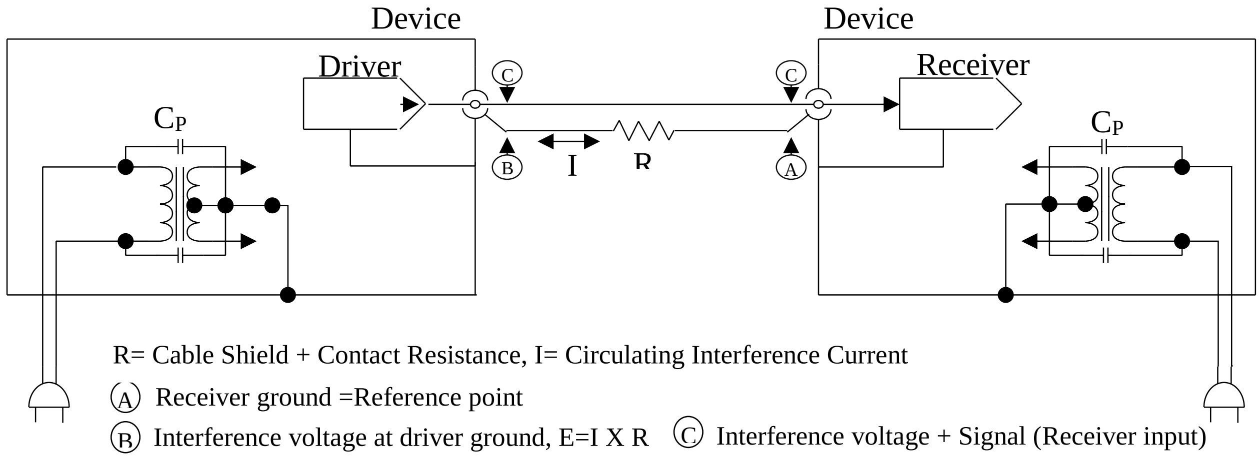


Figure 2.6 How noise enter in between two interfacing devices

Consider 8-meter interconnect cable with foil shield and a #26 AWG drain wire. From standard wire tables (or actual measurement) its shield resistance is found to be 1.0 Ω. The resistance of the inner conductor is insignificant. If the leakage current is 316 µA, the noise voltage will be 316 µV. Since the -10-dB reference level for consumer audio is 316 mV, the noise will be only 20 x log (316 µV ÷ 316 mV) = -60 dB relative to the signal. For most systems, this is a very poor signal-to-noise ratio. Replacing the cable with Belden #8241F, for example, would reduce shield resistance to 0.065 Ω and reduce noise by about 24 dB. To solve interference problems, we must understand them.

Detection at Semiconductor Junctions

Every semiconductor junction, whether part of a diode, transistor, or integrated circuit, is quite nonlinear, especially in the voltage region where it is beginning to conduct. In analog circuits, we prevent this non-linearity from causing distortion by properly biasing the circuitry, by using lots of negative feedback, and by preventing the signal from being large enough to cross into the cutoff region. Because of this non-linearity, every semiconductor junction will function as a square law detector, so it will detect any RF signal that it sees. A good designer prevents detection by shielding the equipment and its wiring, by filtering input and output wiring, and even by bypassing the junction. Because virtually all detection that causes RFI follows square law, the strength of the signal detected by audio equipment, telephones, and other consumer equipment will increase (or decrease) as the square of any increase (or decrease) in RF level at the detector. In other words, the strength of the detected RF changes by twice the number of dB as the RF signal changes. This means that if we manage to reduce the interfering RF signal by 6 dB, the detected audio will drop by 12 dB.

The most fundamental cause of radio interference to other systems is the fact that the wiring for those systems, both inside and outside the box, are antennas. When we transmit, some of the RF from our transmitter is picked up by those unintentional antennas, and RF current flows on them. What happens to that current determines whether there will be interference, and how severe it will be. And one of the things we know about antennas is that they work in both directions that is, they follow the principle of reciprocity so if RF trash from inside the box flows on those antennas, it will be radiated as noise and we'll hear it on the ham bands.

Figure 2.7 Microphone and it cable form dipole antenna

We connected a random wire to our receiver, and the antenna current flowed through the receiver to a "ground" that might have been a driven rod, but was more likely the safety ground of the AC power line (the third pin on the AC socket). Even if the radio was double insulated so that it didn't require the green wire connection, RF current still flowed through the stray capacitance of the power transformer to the power line and made the radio work.

RF picked up on the antennas we call loudspeaker wiring, video cables, the coax from the cable TV system or a rooftop TV antenna, and flows through equipment to get to the AC power system safety ground. Hams understand that some antennas are more effective than others. An antenna that is close to resonance will work better than one that is not. Long antennas tend to pick up more RF than short ones. Think about these fundamental principles when trying to diagnose which cables are bringing your RF into a given system.

Common Mode and Differential Mode Signal

A differential mode signal is one that exists between the conductors of a cable. At any given point along the cable, current flowing on one conductor is precisely balanced by current flowing in the other direction on the other conductor. The intentional signals carried by cables are differential mode signals the audio or video signal in a home audio system, Ethernet signals on CAT5/6 cable, and the RF signal carried by the feedline connecting our antennas to our transceivers. A common mode signal is one that places equal voltage on all conductors that is, the voltage between the two ends of the cable are different, but there is no voltage between the conductors. Antenna action produces a common mode voltage and current along a cable. The antenna current induced on audio and video wiring is a common mode signal. That is, with "ideal" cable, there is no differential voltage between the signal conductors as a result of this antenna action. If the cable is shielded, nearly all of this current flows on the shield (and skin effect causes it to flow on the outside of the shield). If the shield is ideal (that is, if the current is distributed with perfect uniformity around it), the field inside the shield will be zero, and thus none of this antenna current will flow inside the cable. Conversely, when a cable shield is carrying differential mode current, as in the case of coax, skin effect will cause that differential mode current to flow on the inside of the shield. Several cable defects certainly can and do convert this "common mode" antenna current to a differential signal (that is, a voltage between the signal conductors), but that is rarely the most powerful coupling mechanism. One common defect that affects both balanced and unbalanced cables is imperfect construction of cable shields. In balanced paired cables that use "foil/drain" shields, there is even more imbalance in the inductive coupling between each conductor and the shield. Noise (or RFI) coupled by this mechanism is called "shield-current-induced noise," or SCIN. All three of these mechanisms convert shield current to a differential signal that will show up on system input and output terminals. If the cable is an unshielded pair (loudspeaker cable, for example), RF will be induced approximately equally on both conductors (but, depending what the input circuit of the equipment looks like at RF, current flow into the equipment may not be equal on both conductors). This can also produce a differential voltage at the input (or output) terminals.

One of the most fundamental laws of electrical circuits is that the current that is magnetically induced into a circuit is proportional to the loop area of the circuit. Making the loop area small also minimizes the extent to which the wiring can act as an antenna. When we use a closely coupled pair of conductors to form a transmission line, we are reducing the loop area, which reduces the total current induced in the loop by an interfering signal, and the total magnetic field produced by current in that loop. The transmission line, of course, has other useful properties. The equipment designer can also use multilayer printed circuit techniques to place a "ground" (reference) plane next to all signal wiring, turning each circuit trace into an unbalanced transmission line, where the return current is carried on the reference plane under wiring. A single reference plane makes a very large reduction in the ability of that circuit trace to receive interference; sandwiching it between two such planes virtually eliminates it. These techniques, called micro strip (one plane), or strip line (the sandwich), are widely used by better designers. They reject noise coupling both inside and outside the equipment by drastically reducing the loop area of the current path.

As hams, we know that equipment needs good input and output filtering to prevent RF from coming in on input and output wiring. Audio equipment needs good low pass filtering to reject our signals. Many myopic designers of "high futility" audio gear (and even some professional gear) don't include low pass filters because they don't want to degrade the phase response of the audio path. While good phase response is certainly important, so is RF rejection. Ever since those early days, hams have always assumed that a good low pass filter will kill RFI in audio systems, and a good high pass filter will kill interference to FM and TV. Unfortunately, while good filtering is important, other mechanisms are far more important in most real-world situations. [6]

Chapter 3

3 Sources of RF Interference

Sources of RFI can be classified in numerous ways. Based on the method in which RFI is introduced in the systems, sources are classified as either *Radiated* or *Conductive.* Conductive RFI is caused by the physical contact of conductors as opposed to radiated RFI that is picked up by the radio. Radiated RFI is the dominant source that limits the performance of typical commercial wireless communication systems. Radio Interference Sources:

- AM Broadcast Transmitters
- FM Broadcast Transmitters
- Television Broadcast Transmitters
- Ham Transmitters
- Digital Wireless Mics
- Radiated Noise from Lighting, etc.
- Variable Speed Motors
- Cell Phones, Wireless PDA's

Focusing on radiated RFI, this thesis adopts a broad classification as *intelligent* or *non-intelligent* based on the presence or absence of information content in source emissions, respectively.

3.1 Intelligent sources of RFI

Intelligent or information bearing sources of RFI primarily include other wireless communication systems. The dominant form of such interference is due to sources that transmit in the same frequency band as the signal of interest, occupying partial or the complete band, are is commonly referred to as co-channel interference. Comparatively weaker, but still significant, form of intelligent interference is due to transmissions that ideally lie adjacent to the frequency band of desired transmission. Even though such sources are designed to occupy adjacent, but non-overlapping frequencies, some of the energy leaks into neighboring frequency band due to non-linearity in the transmitter circuitry. This form of interference is commonly referred to as adjacent channel interference.

3.1.1 Co-channel interference

Communication performance of many of the current wireless networks, such as cellular networks and wireless ad hoc networks, is limited due to co-channel interference. Driven by the increasing demand in user data rates, current wireless networks employ a dense spatial reuse of the available radio spectrum. This results in increased co-channel interference from other active users in the network that occupy the same radio spectrum.

In addition to interfering users associated with the same network, wire-less transceivers are prone to co-channel interference from users in co-existing wireless networks that occupy the same radio spectrum. This is particularly true for wireless technologies, such as Wi-Fi, Bluetooth, and ZigBee (built on IEEE 802:15:4 standard), that work in the globally unlicensed 2:4 GHz Industrial, Scientific and Medical (ISM) radio frequency band. One of the methods to reduce RFI in 802:11g networks involves the use of the request-to-send/clear-to-send (RTS/CTS) protocol. A user that wishes to transmit sends a RTS packet to the access point indicating the duration of the upcoming transmission. The access point responds by sending a CTS packet, thereby reserving the wireless medium for the duration indicated in the RTS packet. Other users in network refrain from using the wireless medium if they receive either the RTS or CTS packet. Thus, under idealistic assumptions, users within some distance of either the access point or the active user will not interfere. However, the users beyond that guarded distance may interfere if they also wish to transmit. The aggregate RFI due to all active users outside the guard distance can be significant.

3.1.2 Adjacent channel interference

Adjacent channel interference has been a growing concern for co-located wireless transceivers working in adjacent channels, e.g., Wi-Fi and WiMAX transceivers deployed on a laptop computer. Even with strict limitations, the spurious power leaking into the adjacent channel can cause significant degradation in communication performance due to close proximity as is the case in co-located transceivers. There is an increasing demand to integrate multiple wireless transceivers on the same platform, e.g., to have Wi-Fi and cellular connectivity on a mobile phone. In addition, simultaneous use of these transceivers is desired, e.g., downloading data via Wi-Fi during an ongoing voice call over the cellular link. The impact of adjacent channel interference among co-located wireless transceivers co-located on a platform, such as a laptop, is increasing as the demand for simultaneous use of multiple data transmission technologies increases and form factor of the platforms decreases.

3.2 Non-intelligent sources of RFI

Non-intelligent sources affect the communication performance of wire-less communication systems due to unintentional electromagnetic emissions. In contrast to intelligent sources of RFI, emissions from non-intelligent sources do not bear any information. Non-intelligent sources interfering with a particular wireless transceiver embedded on a computational platform can be further classified as in-platform or out-of-platform, based on their physical location being either inside or outside of the platform, respectively.

3.2.1 Out-of-platform

Commercial electronic devices, such as microwave ovens, emit electromagnetic radiations due to the electronic circuitry present in them. Commercial electronic devices are required to abide by regulations that limit the electromagnetic interference that they can produce. FCC regulations for devices causing unintended interference, for example, species the limit on radiations when measured at a minimum distance of 3m. The limit is generally intended to provide some protection and may still cause significant degradation in communication performance. For example, microwave ovens radiate power as high as -50 dBm at 15m in the 2:4 GHz ISM band, which is comparable to the transmit power of an access point of a Wi-Fi network. Thus, RFI from microwave interference is a common concern for 802:11b/g networks working in the 2:4 GHz ISM band.

3.2.2 In-platform

In-platform sources include clocks and busses in the platform on which the wireless transceiver in embedded. Because of the close proximity, RFI from in-platform sources may severely impair the wireless transceivers on the same platform. Moreover, there are no regulations by organization such as the FCC that limit the RFI inside the platform itself. For example, while a laptop computer has to abide by the RFI regulations as specified at a distance of 3m away, there is no limit on how much RFI power the LCD clock circuitry inside the laptop can generate at a distance of 3 cm where a Wi-Fi antenna is located. In-platform RFI is an increasing concern in computational platforms, such as laptops and smartphones, as the number of electronic components integrated on the platform increase and form factors decrease. [7]

3.3 Interference Mechanisms

Interference may happen in one of the mechanism listed below

- On-Channel interference
- In-band interference
- Impulse Noise
- Harmonics
- Passive Intermodulation
- Near Far problem
- Intentional

On-Channel interference can happen to broadcasters due to channel assignments that are close in frequency while also being geographically close. It can also happen due to variations in the ionosphere, which will cause signals to travel further. The classic example of this is how distant AM radio stations can be received easily at night, but not during the day. As we noted before, interference does not need to be on the receive channel. If the interfering signal is within the pass band of the receivers receive filter, that is often sufficient to cause receiver de-sense. These signals can come from: Carriers from other services, Intermodulation products and Harmonics of other signals.

Impulse noise is created whenever a flow of electricity is abruptly started or stopped. A surprising variety of items can create impulse noise. Arc suppressors work by allowing excess voltage to arc to a ground. Over time, as they age, the breakdown voltage tends to lower, to the point where the higher power legitimate RF transmissions can cause arcing, which can create receive interference. Many types of electric motors have brushes, which can create quite a bit of arcing and sparking.

Light dimmers operate by suddenly turning the AC power off part way through the power cycle of the sine wave. This creates impulse noise. Micro-arcing, or fritting, is created when RF connectors do not make firm contact. Fritting first shows up at peak RF power levels as wideband, intermittent, jumps in the noise floor. This can be a 5 dB to 20 dB jump. Most of these impulse noise sources affect the lower frequencies. It’s hard to give a specific number, but it’s unlikely to see impulse noise above 500 MHz Micro-arcing or fritting is the exception, since it is generated by the RF signal itself and can affect reception at any frequency. It is typically very broad-band, over a GHz wide. Micro-arcing or fritting can be caused by this sequence of cable mishandling:

- Over torqueing a 7/16 DIN connector and this causes the center pins to move back into the cable a bit
- Re-opening the connection, perhaps as part of a test
- Re-connecting the cables at the right torque, but now with pair of center pins that do not make firm contact

In a sound system, there are many sources of interference which can be in the form of radiated or conducted electromagnetic interferences and could affect the quality of signal perceived at the transceiver. These interferences cause signal integrity issues and improper functionality of sensitive analog/digital circuits inside the system.

The most common way that hum, buzz, and RF interference enters equipment is via a design defect. It is called "the pin 1 problem," because it is a miswiring of the shield of audio cables; pin 1 in the

XLR connector commonly used for pro audio, but it is just as much a problem in unbalanced interfaces of all types, as shown in fig below

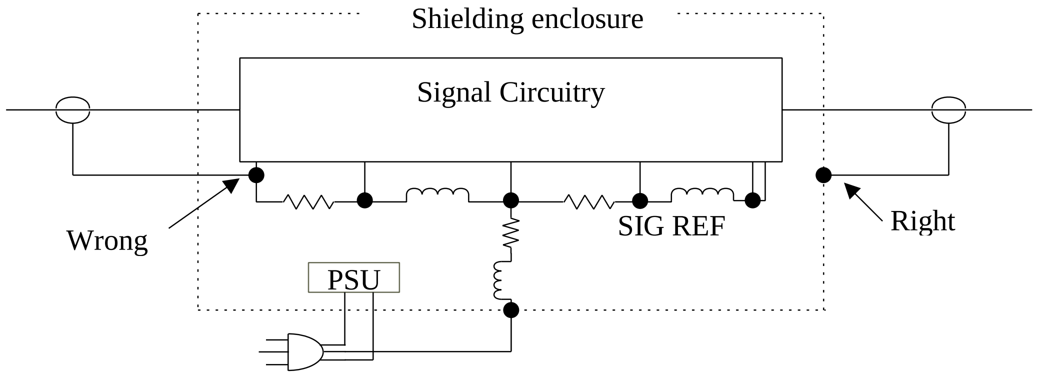


Figure 3.1The pin 1 problem

The proper connection for a cable shield to equipment is the shielding enclosure (chassis), but products with a "pin 1 problem" connect the shield to the circuit board instead. The above figure illustrates both right and wrong connection of the shield. The trouble-free connection on the right goes straight to the shielding enclosure, so shield current flows harmlessly out the safety ground on the power cord. The connection on the left, however, is a pin 1 problem. The wires and circuit traces that make up that invisible schematic have resistance and inductance by virtue of their length, and the IZ voltage drops across those R's and L's are coupled into each "gain stage" that connects to the ground bus. Once that happens, every semiconductor junction that "sees" the RF will detect it, and succeeding gain stages will amplify the detected RF. What if there is no "shielding enclosure" figure 3.2 a) and 3.2 b) shows how to avoid pin1 problems with unshielded or partially shield equipment. [3]

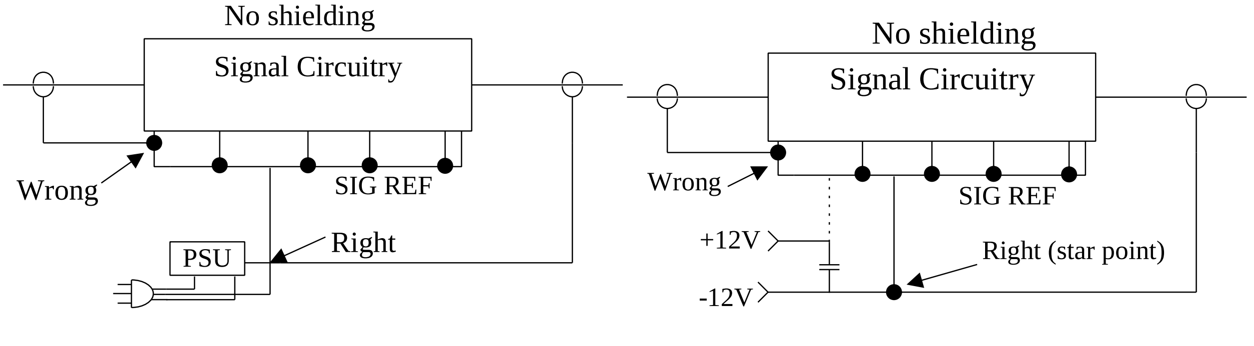


Figure 3.2 a) 120VAC power no shield enclosure and b) 12VDC power no shielded enclosure

3.3. Thermal Noise

Generally, noise is considered to be an electromagnetic interference. Unwanted voltages and currents induced by external magnetic fields, electric fields and ground currents fall into the category of noise and often cause serious errors in low power circuits. Usually conducting media generates internal noise without current flow. One common noise category is resistor thermal noise, which is the noise developed in a resistor in the absence of current flow. This noise is generated in a resistor independent of any current flow and has

$$V_{rms} = 4KTR\times BW \qquad (3.1)$$

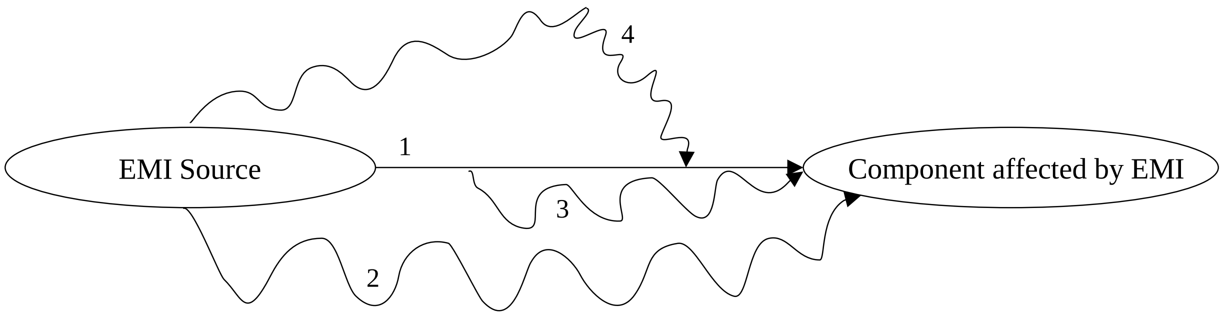
In this expression V_{rms} mean-square voltage k is Boltzmann's constant, T is temperature in degrees Kelvin, R is resistance in Ω, and BW is bandwidth, in Hz. In practice, there is always some parasitic capacitance across the leads of a resistor due to the printed circuit board or lead wire connections. For this situation, when the thermal noise in a resistor is shunted by a non-zero capacitance, the mean-square voltage value is given by

$$V_{rms} = \frac{KT}{C} \qquad (3.2)$$

Temperature and resistor values cannot always be minimized; however, using signal conditioning modules with small bandwidth multi-pole low-pass filters will ensure that external thermal resistor is essentially eliminated. [7]

3.4. Electromagnetic Interference

RFI is an electromagnetic radiation or interference which is emitted by electrical circuits carrying rapidly changing signals as a by-product of their normal operation. It causes unwanted signals in the form of interference or noise which in turn is to be induced in other circuits. This interrupts, obstructs degrades or limits the effective performance of those other circuits inside the system. EMI can be induced intentionally, or unintentionally, as a result of spurious emissions and responses, inter-modulation products, and the like.



(1) Conduction mode (2) Radiation mode (3) Conduction mode – Radiation mode (4) Radiation mode – Conduction

Figure 3.3 EMI Propagation Model

The efficiency of the radiation is dependent on the height above the ground or power plane; at RF one is as good as the other, and the length of the conductor in relationship to the wavelength of the signal components either the fundamental, harmonic or transient (overshoot, undershoot or ringing).

At lower frequencies, such as 133 MHz, radiation is almost exclusively via I/O cables; RF noise gets onto the power planes and is coupled to the line drivers via the VCC and ground pins. The RFI coupling paths are actually very few in terms of basic number. Three very general paths are by:

- Interference due to conduction (common-impedance)
- Interference due to capacitive or inductive coupling (near-field interference)
- Electromagnetic radiation (far-field interference)

Some of the general ways noise can enter a circuit from external sources.

- Impedance mismatches and discontinuities
- Common-mode impedance mismatches →Differential Signals
- Capacitively Coupled (Electric Field Interference): *dV/dt* →Mutual Capacitance →Noise Current (Example: 1V/ns produces 1mA/pF)
- Inductively Coupled (Magnetic Field): *di/dt* →Mutual Inductance →Noise Voltage (Example: 1mA/ns produces 1mV/nH) [13]

3.5. Power Supply Interference

Switching power supplies can be a source of RFI, but have become less of a problem as design techniques have improved. Noise which is conducted or radiated should be prevented from returning to the input source, where it can potentially cause havoc on other devices operating from the same input power. Here EMI filters are utilized to block this noise and provide a low-impedance path back to the noise source. The larger the noise interference; the greater is the size, expense, and difficulty of the filter to be designed. Power supplies that operate at a fixed frequency have their largest EMI emission at this fundamental, fixed frequency. Emissions also occur at multiples of the switching frequency but at diminished amplitudes. [7]

3.6. Interference due to PCB and Component Placement

The PCB connects electronic passive/active components such as transistors, diodes, capacitors resistors, oscillators and ICs. The routing of the traces on the PCB largely affects the electromagnetic compatibility performance of the PCB with respect to both electromagnetic radiations and susceptibility to electromagnetic fields. In order to get a PCB on which the circuits function properly, the trace routing, the placement of components/connectors and the decoupling used with certain ICs will have to be optimized.

Electromagnetic interference can be transferred by electromagnetic waves, conduction, and inductive/capacitive coupling. This interference must reach the conductors in order to disturb the components. This means that the loops, long length and large surface of the conductors are vulnerable to EMI, making the PCB the principle subject of EMC improvements. The following equation shows the relationship of current, its loop area, and the frequency to electric field which is in (V/m):

$$E = kIAf^2 \left(\frac{1}{r}\right) \sin\theta \tag{3.3}$$

Where k is the constant of proportionality, I is the current in amperes, A is the loop area in m^2, f is frequency in MHz, r is the distance and θ is the angle. And since the distance to the ground plane is usually fixed due to board stack up requirements, minimizing trace length on the board layout is crucial to decreasing emissions. [11]

Chapter 4

4. RF screening

To locate possible sources of RF radiation and regions of high RFI. A method used to determine which system contribute to RFI in what types of modes.

At first glance, it may not be obvious how a stray RF signal could cause problems in a audio circuit. The RF is not heard or recorded directly, being far above the audio spectrum. Even if the RF signal is mixed directly with the audio there might be no interference, as the output spectrum is simply the sum of the audio components and the RF components, each occupying its own frequency spectrum. Indeed, below a certain threshold amplitude for each of the circuits examined, no audio frequency interference is noted. When any two signals are mixed and pass through a non-linear device such as a semiconductor junction or a vacuum tube, each signal modulates the other, and sum and difference products are generated for all of the discrete frequencies present in the mixed signals.

Transmissions from an AM broadcast transmitter consist of a radio carrier frequency and a pair of sidebands for every frequency contained in the modulating signal. For example, an AM station transmitting an audio sine wave of 1 kHz on its assigned frequency of 1 MHz will transmit signals at 999 kHz, 1,000 kHz, and 1,001 kHz. That 1 kHz signal will be detected when it passes through a circuit that responds non-linearly to it, because the non-linearity will produce sum and difference components of the signals it sees, as well as sum and difference signals of whole number multiples (harmonics) of the signals. In this example, the first order differences are two signals at 1 kHz and signals around 2 MHz. Higher order differences (harmonics) will be present at higher radio frequencies and also within the audio passband. The 1 kHz signal is audio, and will be heard as an interfering signal if it appears in a audio circuit.

Detection is not a linear phenomenon. The RF signal amplitude must reach a threshold within some circuit element such that the element exhibits non-linear behavior to the signal. The threshold is a function of circuit parameters. The most easily detected signals are those that are amplitude modulated. The video component of television signals and AM radio broadcasting in the 500kHz to 2 MHz band are common forms of amplitude modulation. The primary mechanisms for amplitude modulation are:

1) square law detection, which can occur in virtually any semiconductor junction;
2) detection due to slew rate limiting; and
3) fundamental overload (clipping, rectification).

The audio circuitry in virtually any capacitor microphone will function as a detector if sufficient RF energy reaches it. An interfering signal may be too low in level to be detected in the first electronic stage through which it passes, but might be detected by a subsequent stage after being amplified by the first stage. This is a critical reason for limiting the bandwidth of audio circuits to the absolute minimum needed for accurate magnitude and phase response.

Frequency modulated radio signals (FM) can also be detected by audio circuits. Frequency modulated signals also consist of a carrier and sidebands, but the relationship is more complex than the simple sum and difference. FM signals are most commonly detected when they are converted to AM by some frequency response variation in either the transmission path or This mechanism is called slope detection. Again, non-linearity of an audio circuit that also contains the radio signal is required for detection to take place. Even un-modulated RF signals can cause interference. One mechanism is rectification due to nonlinearity detection of the RF signal upsetting the bias of an active stage. RF susceptibility is often either caused by or accompanied by circuit instability (oscillation), and oscillating circuits can detect FM signals. [10]

AM broadcast interference is known to occur in sound systems when mic cables run exposed through the attic or around the floor. An important question is, "how much current might be flowing on the shields of balanced audio cables at frequencies that could cause interference if converted to a differential mode signal."

Some important mechanisms that can combine to cause radio frequency (RF) interference to sound systems are:

1. An audio cable will be excited as an antenna by radio signals that are nearby, and current will flow along its length. Most of this current will flow on the shield. Antenna action will also cause a voltage to be impressed along the length of the cable, which can appear as a common-mode component on the signal conductor(s).
2. Improper termination of cable shields within equipment (the Pin 1 problem) injects RF shield current directly into the equipment, where it is detected.
3. Inadequate balancing of shielded cable converts RF shield current to a differential voltage on the signal pair; “shield-current-induced noise” (SCIN).
4. Inadequate low-pass filtering of signal input and outputs lets RF present on the signal conductors into equipment. Equipment can be susceptible to both differential mode voltage (between the signal conductors) and common mode voltage (an equal voltage on both signal conductors).

AM broadcast stations operating between 0.5 MHz and 2 MHz are a common source of such interference. The behavior of the random long wire antenna formed by the shield of an audio cable cannot easily be analyzed or predicted because of such complex factors as its radiation resistance, impedance, orientation, proximity to surrounding conductive objects, and exposure to the field. On the other hand, AM broadcast field strength outdoors can be reasonably well predicted on the basis of extensive empirical data, especially within about the first 60 km from the transmitting antenna. Measurements were made at selected locations, data of the amount radio frequency currents flowing on the shields of 40 m lengths of several type test cables were collected. At each measuring location, the shield of 40 m long audio cable was connected as a long wire antenna to the center conductor of the 50-ohm input of analog oscilloscope.

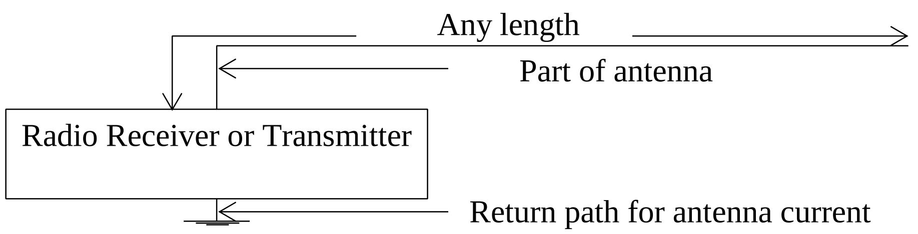


Figure 4.1 A simple random wire antenna

Measurements were made for the carrier strengths of 10KW/1KW AM transmitter during daytime, for which the RF propagate as ground wave. Different testing locations were selected as per normal operation during broadcasting. At location #1, the analyzer was within 500m radius of omnidirectional AM broadcast transmitter, which was operated at 10 kW/1 kW. At this location, SD studio TV ground floor, the cable was laid on the floor. For each cable having a drain wire, the relative distribution of current between the drain and the shield was

Table 4.1 AM broadcast measurements- location #1

Transmission freq. kHz	*Distance from ant. km*	*dBV in 50 Ω*	*Shield Voltage (mv)*	*Shield Current (mA)*	*Transmitter power kW*
1035	0.5	-10	316	3.89	1
1035	0.5	-3	708	5.78	10

Location #2 was set up in an open area outside 1 km from the transmitter and the 40-m audio cable was run on the ground to interconnect the system (mic to the audio mixer). For each cable having a drain wire, the relative distribution of current between the drain and the shield was

Table 4.2 AM broadcast measurements-location #2

Transmission freq. kHz	*Distance from ant. km*	*dBV in 50 Ω*	*Shield Voltage (mv)*	*Shield Current (mA)*	*Transmitter power kW*
1035	1	-22	79	1.59	1
1035	1	-13.5	224	3.88	10

Location #3 was set up in an open area outside 1.5 km from the transmitter and the 40-m audio cable was run on the ground to interconnect the system (mic to the audio mixer). For each cable having a drain wire, the relative distribution of current between the drain and the shield was

Table 4.3 AM broadcast measurements-location #3

Transmission freq. kHz	*Distance from ant. km*	*dBV in 50 Ω*	*Shield Voltage (mv)*	*Shield Current (mA)*	*Transmitter power kW*
1035	1.5	-25	56.23	1.13	1
1035	1.5	-16	158.5	3.18	10

Location #4 was set up in an open area outside 2.5 km from the transmitter and the 40-m audio cable was run on the ground to interconnect the system (mic to the audio mixer). For each cable having a drain wire, the relative distribution of current between the drain and the shield was

Table 4.4 AM broadcast measurements-location #4

Transmission freq. kHz	*Distance from ant. km*	*dBV in 50 Ω*	*Shield Voltage (mv)*	*Shield Current (mA)*	*Transmitter power kW*
1035	2.5	-32	25.12	0.51	1
1035	2.5	-20.5	100	2.341	10

The current induced in a receiving antenna (that is, the mic cable) will be directly proportional to the field strength. The primary means of propagation within 100 km of AM broadcast stations is ground wave. The ground wave field strength in volts/meter produced by an AM broadcast transmitter varies with the inverse of the distance and an additional loss due to resistivity of the earth. The additional loss increases with frequency and varies with soil conditions.

At each location, the RSS (root of the sum of the squares prediction of rms of the combined signals) value of the current and voltage were computed from the data for signals. The peak value of the voltage in a circuit establishes how much detection will occur, and can be estimated as 1.4X the RSS value, assuming that no other signals contribute significantly interference. From end to end, a cable shield has both resistance and inductance. Any AC voltage developed across this inductance will magnetically induce a similar voltage in each conductor (as well as any other conductors near the shield), thus effectively forming a three-winding transformer that has a turn's ratio of approximately 1:1:1.

In the interest of simplicity, I discuss only current drive of the shield that is constant with frequency. This results in a voltage across the transformer primary (shield inductance) and an induced common mode voltage in the signal pair that rises linearly with frequency. Magnetic induction is very strongly affected by physical proximity, especially when very near the field source, which in this case is the shield conductor. Ideal cable construction would locate the signal conductors at exactly the same distances to the shield conductor, even when the shield conductor surrounds the signal pair. Thus, exactly equal voltages would be induced and a differential (signal) component would not exist. Even with identical induced voltages, impedance imbalances in the driver, cable, and receiver can convert a portion of the induced common mode voltage into differential mode voltage. Twisting is a first order approach intended to "average" the proximity of the two signal conductors to a noise source.

An ideal cable would have a 1:1 turns ratio between the signal conductors (measured end to end). It would also have equal values of series resistance for the two windings representing the signal conductors, equal values for the inter-winding capacitances, and equal values for mutual inductance between the shield and each signal conductor. For each cable having a drain wire, the relative distribution of current between the drain and the shield was computed from a combination of computed and measured data. For some of the cables, engineering data for the dc resistance of the components of the shield were provided by the manufacturer. For others, the values were computed from measured data. When a drain wire was of the same gauge as a signal conductor, resistance measurements on the signal conductor were assumed to also represent the resistance of the drain. Where the drain was a different gauge, the measured resistance was multiplied by the ratio of the resistance per unit length of the drain wire to that of the signal conductor.

It should be noted that distribution of current throughout a foil or braid shield and between the shield and a drain wire will vary with frequency as a function of their respective geometries. It should also be noted that for most cables having a drain wire the drain is in contact with the more homogenous shield (that is, the braid or drain) along its entire length.

One common cause of both magnetically induced noise and ground fault current is a wiring fault commonly known as a bonded neutral, whereby the connection of a power system neutral to ground at more than one point sets up a path for neutral currents to flow through parts of the ground system.

The neutral of every power circuit is required to be bonded to ground at one, but only one point, either where the power service enters the building, or within the building where that circuit is created by the secondary of a transformer. Any additional connections violate building codes, but they are an all too common mistake in buildings.

Magnetically coupled noise and ground currents often result from a power distribution system known as 3-phase 3-wire "high leg" delta. In this system, the power company's service to a building grounds the center tap of one winding of a 3-phase 240-volt delta service. The 3 phases are brought into the building but there is no dedicated neutral. Instead, a single conductor serves as both neutral and ground. In such a system, any neutral/ground currents from surrounding buildings divide between the path to ground at the utility pole transformer and the path through the neutral/ ground conductor and its local path(s) to ground.

Magnetic induction is also produced by properly installed power wiring. For example, phase and neutral conductors are often neither twisted nor symmetrical, thus may not couple equally to nearby conductors, including the shields of audio cables. Even stronger fields can be produced by large triple neutral currents in 3-phase system feeders.

AM broadcast transmitters use vertical antennas having lengths ranging from 0.2 to 0.625 wavelength. Half-wave and 5/8 wave antennas have the advantage of the greatest field strength in the horizontal plane, providing gain in the vertical plane of 1.9 dB and 3.25 dB, respectively, over a quarter-wave antenna. In Oromia radio case, the antenna is omnidirectional. The field strengths from directional antenna systems deviated by about ±6 dB from those for omnidirectional antennas. Thus, making allowances for transmitting antenna directivity, the range of currents in a typical 40 m mic cable unshielded by conduit or building steel might be expected to range as specified in table below.

Table 4.5 Predicted AM Broadcast shield current range

No.	*Transmitter power kW*	*Current range*
1	1 kW	0.5 – 5 mA
2	10 kW	1.0 – 10 mA

Some lengths, heights, orientations, and paths for receiving antennas could easily result in significantly greater currents, perhaps as much as 10 dB. In neither of the test setups could the audio cable shield have been considered a "good" receiving antenna.

Chapter 5

5. RFI mitigation methods in sound system

The increased amount of radio frequency interference has lead to the development of several mitigation and excision methods in sound system. This chapter introduces promising pro- and reactive mitigation methods used in audio production system, to coexist with the ambient interfering radio environment.

Interference is annoying and often frustrating, especially when the problems are intermittent or when it seems that a problem has been solved, only to have it return later. Efforts to correct interference problems are also often complicated by the fact that there are several kinds of interference and each requires a different approach and a different solution. Sometimes a "quick fix" will work, more often it does not. Unless the problem is very simple, the only really productive approach is an orderly and systematic one that first finds the cause of the specific problem, then applies appropriate corrective action.

This chapter describes guidelines on how to tackle the problem of RF interference in the system. EMC describes the ability of electronic and electrical systems or components to function correctly when they are close together. In practice this means that the electromagnetic interference from each device must be limited and also that each device must have an adequate level of immunity to the interference in its environment the same holds in micro-level where components inside the device itself interfere with each other.

It is essential that the problem be localized to one part of the sound system. Start with simple tests and proceed to more rigorous ones. Problems range from simple to complex, but more fall into the simple category. Drop the level of the main fader on the mixer. If the RFI drops in level, then it is localized to the front end of the mixer (at least ahead of the main potentiometer). If it does not go away, unplug the output of the mixer from the rest of the system. If unplugging the mixer output stopped the RFI, the problem lies in the mixer and/or devices connected to it. Listen to the mixer output through a headphone and continue on. Drop the channel faders on the console one-by-one. If the problem goes away when a specific channel is dropped, then the problem is isolated. If the RFI drops in level a little with each channel, then many problems has been found. It is important to determine whether the RFI is getting into the mic lines (very common) or somewhere else. Listen to each mic line individually through the headphone amplifier. Below the flowchart to troubleshoot RFI in the system will be presented.

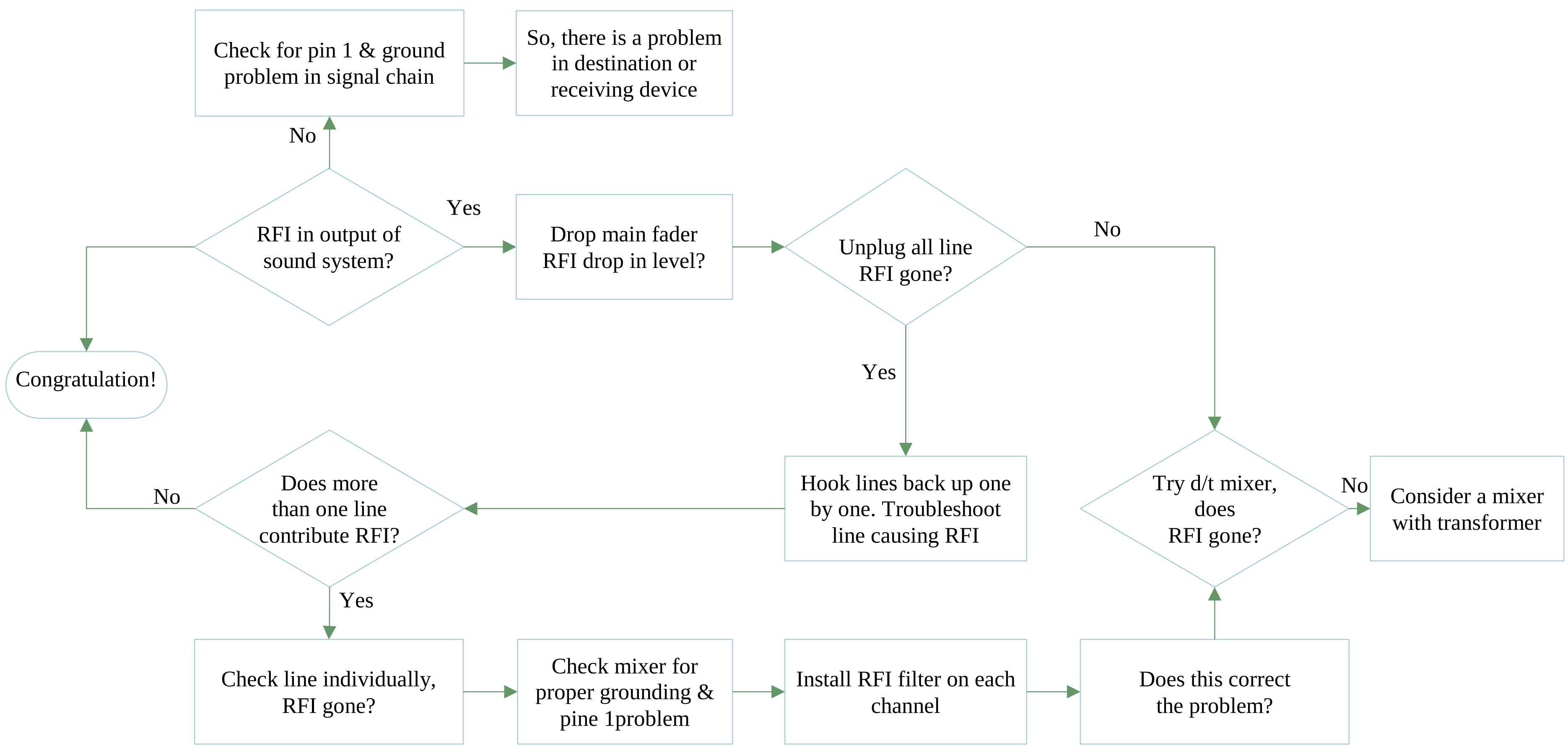


Figure 5.1 RFI Troubleshooting Flowchart

5.1. Filtering methods

There are many methods that can be used to reduce distortion in a signal. Basic reactive mitigation methods is: series resistive termination and RC filtering solutions that reduce the ringing effect and distortion of a clock signal improving its signal integrity. [See Appendix A] When a decoupling capacitor is connected from a noisy signal line or power line to ground; the circuit impedance decreases as the frequency increases. Since noise is a high frequency phenomenon, it flows to ground if a capacitor has been connected to ground, thereby making it possible to eliminate noise, see figure below. EMI suppression filters employing a capacitor in this way are used to eliminate this type of noise. [4]

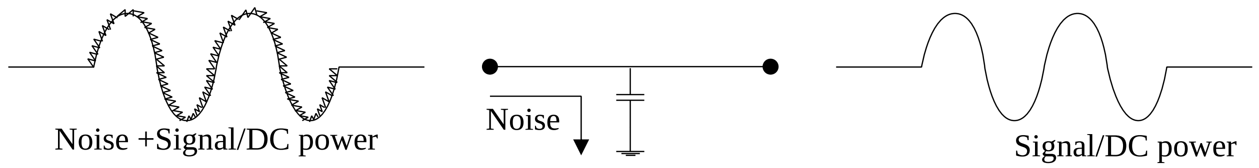


Figure 5.2 Capacitive noise suppression

$$|Z| = \frac{1}{2\pi f C} \qquad (5.1)$$

where f is the frequency and C is the value of the capacitance.

When an inductor is inserted in series in a noise producing circuit, see figure below, its impedance increases with frequency. In this configuration, it is possible to attenuate and eliminate noise components which are the high frequency components found in the signal.

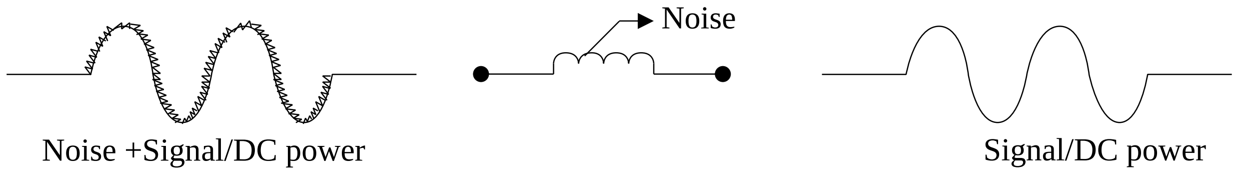


Figure 5.3 Inductive noise suppression

$$|Z| = 2\pi f L \qquad (5.2)$$

where f is the frequency and L is the value of the inductance.

Each inductive or capacitive component in the filter will reduce the RF interference by 20 dB per decade of frequency. Commonly available configurations are single inductor, single capacitor (C-filter), combination of one inductor and one capacitor (L-filter), one inductor and two capacitors (pi-filter), and two inductors and one capacitor (T-filter). Pi and C- filters are used when the source and load impedances are high, while a T-filter is used when the source and load impedances are low. Filter performance is defined by insertion loss (IL), voltage rating, and current rating. IL represents the signal attenuation by the filter.

A low pass filter can be made to filter out the AM radio interference. AM radio operates at a frequency higher than what we can hear, so we can roll off those supersonic frequencies using filters. These filters come in several forms. The most readily available (and simplest) are ceramic disc capacitors. These are soldered from pins 2 and 3 to pin 1 (see figure below). The capacitor becomes a low-pass filter that provides a low impedance path for frequencies above its corner frequency to ground. A common one is 0.01 µF. Since the filtering characteristics are dependent upon the circuit impedance, the best thing to do is to start with a small value and increase it until the high frequency roll-off becomes audible. A capacitor substitution box works well for this purpose and the same value used on each pin.

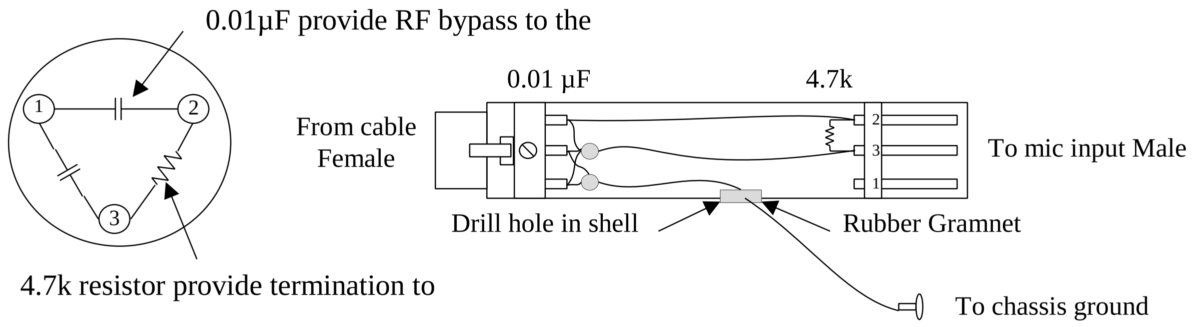


Figure 5.4 Filter between mic and mixer

Sometimes it is necessary to achieve a steeper roll-off than a single capacitor can provide. You can accomplish this by using a series inductor (or “choke”) along with the capacitor. Ferrite beads are also useful as input filters. These can be slipped over a small length of bus wire and placed in series with the signal.

The other simple low pass filter can be made with a 0.01 µF. Place one capacitor between pin 2 and pin 1. Place a second capacitor between pin 3 and pin 1. You might have to place this at the microphone end or you might have to place this at the mixer end. Try both ends and see which one reduces the RFI more. A better low pass filter can be made by introducing inductors as well as the capacitors. The circuit diagram below, shows you how.

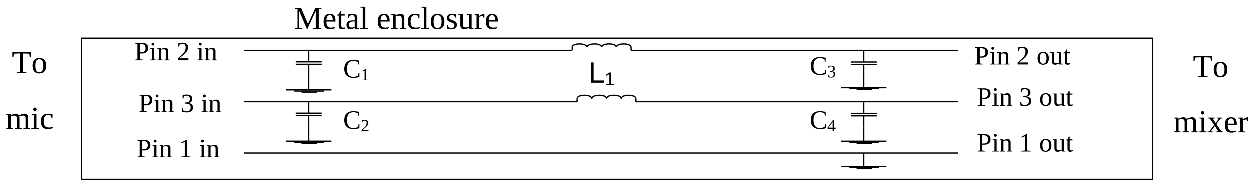


Figure 5.5 XLR audio connector with filter between its pin

The value of inductor, L1 = 820μH and that of common mode choke, C1-C4 = 68pF ceramic capacitor.

The order of the filter determines the sharpness of the rising edge of the processed signal, the higher the filter order, the slower is the rising edge, thus higher order filters might cause input/output driver not meet specifications and have signal integrity problems. Also in higher order filter simulations, the best rising time in a certain order of filter is different for different models of the same filter type (e.g. for 3rd order filters: the rising time was the best for the Butterworth Pi-model filter, while for the T-model filter the Chebyshev I filter was the best.). [See Appendix A]

5.2. Shielding methods

Applying the concepts of shielding effectively requires an understanding of the source of the interference, the environment surrounding the source, and the distance between the source and point of observation. If the circuit is operating close to the source (in the near, or induction-field), then the field characteristics are determined by the source. If the circuit is remotely located (in the far, or radiation-field), then the field characteristics are determined by the transmission medium.

A circuit operates in a near-field if its distance from the source of the interference is less than the $\lambda/2\pi$. If the distance between the circuit and the source of the interference is larger than this quantity, then the circuit operates in the far field. In Oromia radio case:

$$Wavelenght = \frac{3\times10^8}{1035\times10^3} = 289.5m \quad and \quad \frac{\lambda}{2\pi} = \frac{289.5}{2\pi} = 47.3m$$

Regardless of the type of interference, there is a characteristic impedance associated with it. The characteristic, or wave impedance of a field is determined by the ratio of its electric (E) field to its magnetic (H) field. In the far field, the ratio of the electric field to the magnetic field is the characteristic (wave impedance) of free space, given by Zo = 377 Ω. In the near field, the wave-impedance is determined by the nature of the interference and its distance from the source. If the interference source is high-current and low-voltage (for example, a loop antenna or a power-line transformer), the field is predominately magnetic and exhibits a wave impedance which is less than 377 Ω. If the source is low-current and high-voltage (for example, a rod antenna or a high-speed digital switching circuit), then the field is predominately electric and exhibits a wave impedance which is greater than 377 Ω.

Conductive enclosures can be used to shield sensitive circuits from the effects of these external fields. These materials present an impedance mismatch to the incident interference, because the impedance of the shield is lower than the wave impedance of the incident field. The effectiveness of the conductive shield depends on two things:

First is the loss due to the reflection of the incident wave off the shielding material. Second is the loss due to the absorption of the transmitted wave within the shielding material. The amount of reflection loss depends upon the type of interference and its wave impedance. The amount of absorption loss, however, is independent of the type of interference. It is the same for near- and far-field radiation, as well as for electric or magnetic fields.

Reflection loss at the interface between two media depends on the difference in the characteristic impedances of the two media. For electric fields, reflection loss depends on the frequency of the interference and the shielding material. This loss can be expressed in dB, and is given by:

$$R_e(dB) = 322 + 10\log_{10}\left[\frac{\sigma_r}{\mu_r f^3 r^2}\right] \qquad (5.3)$$

where σ_r = relative conductivity of the shielding material, in Siemens per meter; μ_r = relative permeability of the shielding material, in Henries per meter; f = frequency of the interference, and r = distance from source of the interference, in meters. In our case, it will be

$$R_e = 322 + 10\log_{10}\left[\frac{62}{(1.00002)(1035\times10^9)(500)^2}\right] dB = 165.8dB$$

For magnetic fields, the loss depends also on the shielding material and the frequency of the interference. Reflection loss for magnetic fields is given by:

$$R_m(dB) = 14.6 + 10\log_{10}\left[\frac{fr^2\sigma_r}{\mu_r}\right] \qquad (5.4)$$

and, for plane waves (r > λ/2π), the reflection loss is given by:

$$R_{pw}(dB) = 168 + 10\log_{10}\left[\frac{\sigma_r}{\mu_r f}\right] \qquad (5.5)$$

In Oromia radio case; since r is greater than λ/2π:

$$R_{pw} = 168 + 10\log_{10}\left[\frac{62}{(1.00002)(1035\times10^3)}\right] dB = 125.8dB$$

Absorption is the second loss mechanism in shielding materials. Wave attenuation due to absorption is given by:

$$A(dB) = 0.13t\sqrt{\sigma_r\mu_r f} \qquad (5.6)$$

For our case:

$$A = 0.13(0.3)\sqrt{62(1.00002)(1035\times10^3)}dB = 312.4dB$$

where t = thickness of the shield material, in millimeter. This expression is valid for plane waves, electric and magnetic fields. Since the intensity of a transmitted field decreases exponentially relative to the thickness of the shielding material, the absorption loss in a shield one skin-depth (δ) thick is 9 dB. Since absorption loss is proportional to thickness and inversely proportional to skin depth, increasing the thickness of the shielding material improves shielding effectiveness at high frequencies.

Reflection loss for plane waves in the far field decreases with increasing frequency because the shield impedance, Zs, increases with frequency. Absorption loss, on the other hand, increases with frequency because skin depth decreases. For electric fields and plane waves, the primary shielding mechanism is reflection loss, and at high frequencies, the mechanism is absorption loss.

Thus, for high-frequency interference signals, lightweight, easily worked high conductivity materials such as copper or aluminum can provide adequate shielding. At low frequencies, however, both reflection and absorption loss to magnetic fields is low. It is thus very difficult to shield circuits from low-frequency magnetic fields. In these applications, high-permeability materials that exhibit low-reluctance provide the best protection. These low-reluctance materials provide a magnetic shunt path that diverts the magnetic field away from the protected circuit (steel and mu-metal).

A properly shielded enclosure is very effective at preventing external interference from disrupting its contents as well as confining any internally-generated interference. However, in the real world, openings in the shield are often required to accommodate adjustment knobs, switches, connectors, or to provide ventilation. Unfortunately, these openings may compromise shielding effectiveness by providing paths for high-frequency interference to enter the instrument.

The longest dimension (not the total area) of an opening is used to evaluate the ability of external fields to enter the enclosure, because the openings behave as slot antennas. Equation below can be used to calculate the shielding effectiveness, or the susceptibility to RFI leakage or penetration, of an opening in an enclosure:

$$Shielding\ effectiveness(dB) = 20\log_{10}\left(\frac{\lambda}{2L}\right) \qquad (5.7)$$

where λ = wavelength of the interference and L = maximum dimension of the opening

Depending on the type of interference (pickup/radiated, low/high frequency), proper cable shielding is implemented differently and is very dependent on the length of the cable. The first step is to determine whether the length of the cable is electrically short or electrically long at the frequency of concern. A cable is considered electrically short if the length of the cable is less than 1/20 wavelength of the highest frequency of the interference. Otherwise it is considered to be electrically long. In our case, the wavelength of Oromia radio is 289.5m and 289.5/20 gives 1.5m and any cable which is longer than this is electrically long cable. [2]

For 1.035 MHz (Oromia radio transmission frequency) interference, the preferred method is grounding the shield at both ends, using 360° circumferential bonds between the shield and the connector, and maintaining metal-to-metal continuity between the connectors and the enclosure. When this is done, it creates a low frequency ground loop.

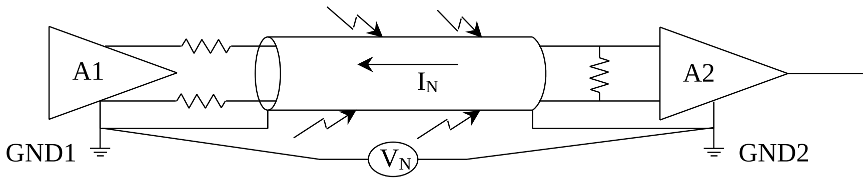


Figure 5.6 Ground loops in shielded twisted pair cable can cause errors

Differential error voltage is produced at input of mixer unless: mic output, mixer input, cable is perfectly balanced. Whenever two systems, mic and mixer are remote from each other, there is usually a difference in the ground potentials at each system, i.e., VN. The frequency of this potential difference is generally the line frequency (50 or 60 Hz) and multiples thereof. But, if the shield is directly grounded at both ends as shown, noise current I_N flows in the shield. In a perfectly balanced system, the common-mode rejection of the system is infinite, and this current flow produces no differential error at the receiver (mixer). However, perfect balance is never achieved in the driver, its impedance, the cable, or the receiver, so a certain portion of the shield current will appear as a differential noise signal, at the input of mixer.

It is necessary to check if there is any problem in shielding. Using an ohmmeter, check for shorts between shields of pairs of multi-conductor cables. Each pair of a snake cable should be individually shielded, and each shield should be isolated from the other shields. When the outer jacket is removed from a snake cable for wiring purposes, it is important to heat shrink the individual pairs to maintain their isolation. This is a time-consuming process, and many installers overlook it. If there are shorts between shields that can't be located at either end, you may need to pull new wire.

There are few practical RFI fixes for poorly shielded system. The most obvious is to shield it, but this is usually either expensive or impractical if it wasn't built with good shielding. We could, for example, wrap it in aluminum foil, but to make that shielding effective,

- We must bond the shields of all wiring that enters and leaves the equipment to that foil shield; and
- any openings in the shield must be small as a fraction of the wavelength of Oromia radio broadcast;

- Modify its defect by adding filters (ferrite beads, bypass capacitors) to the junctions that are detecting the RF

In many applications, to assure low susceptibility to external radiating RF sources, it is essential to use coaxial cables with a high shielding effectiveness (SE) in excess of 100 dB. An ideal shield would be highly conductive with 100% coverage, and have no holes or gaps; but such a shield would be rigid, heavy, and expensive. A typical braided shield only offers about -50 dB shielding effectiveness, and a double braid offers about -75 dB shielding effectiveness. [7]

Twisted-Pair cable is important to reduce RF pickup as an interconnecting cable. In many circuits, twisting is far more important in rejecting noise and RF than a cable shield. A cable shield prevents electric field (capacitive) coupling, but it provides very little shielding against magnetic fields (that is, inductive coupling). This is true at low frequencies because cable shields are not made of magnetic material. It is true at high frequencies because of imperfections in the shield that decrease the uniformity of current flow on the shield. A transmission line does reject magnetic fields, but it does this by virtue of the mutual coupling between the conductors that causes the current and voltage induced in them by an external field to be equal and opposite, so they cancel at the input circuit to which the cable is connected. The degree of this equality depends on the coupling coefficient k, which is typically on the order of 0.7 for a closely spaced pair.

Another important fact explains why coaxial cables don't reject magnetically coupled low frequency hum and buzz. Cables don't exhibit mutual coupling at frequencies where the resistance of the conductor is greater than its inductive reactance. The low frequency at which this transition occurs is called the shield cutoff frequency. For most cables, this is between about 1 kHz and 20 kHz. Twisting works to reject noise from the magnetic field because it causes the voltage induced in the two conductors to be more nearly equal. It also reduces electric field coupling in balanced circuits. In general, the "tighter" the twist, the more equal the induced voltage will be to the highest frequency. That's because any interfering field will vary with position based on the wavelength of the field. If the conductors are twisted, one conductor will be closer at one point along the cable, but one half twist further along the cable, the other conductor will be closer. The difference in spacing between the conductors may not sound like it should cause much difference in level, but if we need 100 dB of cancellation, the two voltages must be equal within .0001%, a very small margin of error. Sensitive microphone circuits connected with unshielded CAT6 cables are actually less susceptible to noise pickup than shielded balanced pairs, both at audio frequencies.

5.3. Ferrites reduction methods

Ferrites can be a very effective tool for eliminating RF interference between systems. To use them effectively, we must understand them.

Figure 5.7 Ferrites in different forms

Ferrites are partially conductive ceramics consisting of various oxides of iron, cobalt, nickel, zinc, magnesium, and other metals. Manganese-Zinc (MnZn) mixes are used mostly below a few megahertz, while Nickel-Zinc (NiZn) parts are most widely used at VHF and UHF. Depending on the material used, the bulk resistivity of ferrites varies from very high to rather low.

When a ferrite surrounds a conductor, the high permeability of the material provides a much easier path for magnetic flux set up by current flow in the conductor than if the wire were surrounded only by air. The short length of wire passing through the ferrite will thus see its self-inductance "magnified" by the relative permeability of the ferrite. The ferrites used for suppression are soft ferrites that is, they are not permanent magnets.

Permeability is the characteristic of a material that quantifies the ease with which it supports a magnetic field. Relative permeability is the ratio of the permeability of the material to the permeability of free space. The relative permeability of non-magnetic materials like air, copper, and aluminum is 1, while magnetic materials have a permeability much greater than 1. Typical values (measured at power frequencies) for stainless steel, steel and mumetal are on the order of 500, 1,000 and 20,000 respectively. Various ferrites have values from the low tens to several thousand.

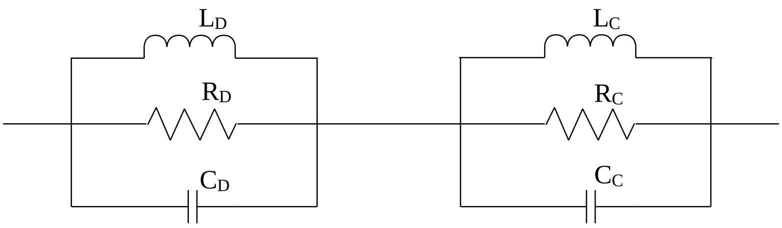


Figure 5.8 A multi-turn choke equivalent circuit

If the medium is relatively lossy, as most ferrites are in the portion of the spectrum where they will be used for suppression, both μ and ε will be complex, and that in such a medium, there will be a quadrature standing wave that gives rise to a peak in the observed magnetic loss and dielectric loss at resonance. There will be no standing waves, and thus no dimensional resonance, if the product of the magnetic loss tangent and the capacitive loss tangent is much greater than 1 (that is, if the total loss is high enough to damp the standing wave). This dimensional resonance is accounted for by the first parallel resonant circuit consisting of L_D, C_D and R_D (loss component) that is mostly due to eddy currents in the core. L_C, and R_C, and C_C are the inductance, resistance, (including the effect of the μ of the ferrite), and stray capacitance associated with the wire (coil of wire) that passes through (wound around) the ferrite. This resonance moves down in frequency with more turns because both L and C increase with more turns. C_C has two common components. First, there will be stray (parasitic) capacitance between the turns of a coil wound around a ferrite core. Second, the ferrite core will act as a dielectric between the two ends of the conductor passed through it. The latter effect will also be present for a multi-turn choke wound around the core.

As with all inductors, the inductance of a coil will be proportional to the square of the number of turns passing through the core. But as the number of turns increases, so does the stray capacitance of the winding. The parallel combination of C_C and C_D can cause either or both resonances to move down in frequency.

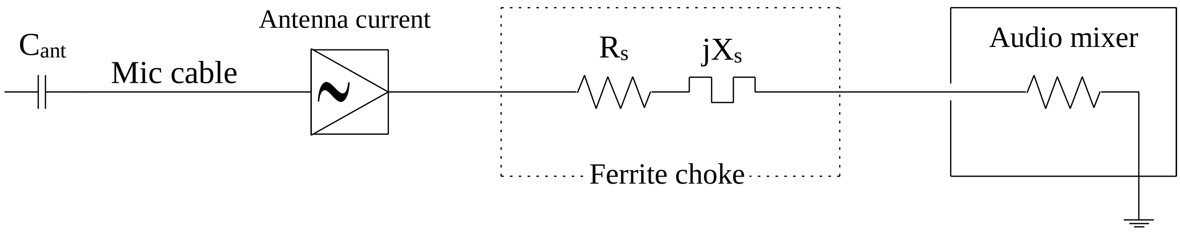


Figure 5.9 The choke interacts with the cable

Figure above shows how a choke used to reduce common mode current flow on a cable. Because that cable is also an antenna, it will have some impedance of its own, depending on its length and the frequency of the interfering signal. If the antenna is shorter than a quarter-wave (12.11m in Oromia radio case) it will look like a capacitance, and can resonate with the inductance of the ferrite choke. When this happens, the current is limited only by the resistance of the circuit; in this case, the loss component of the choke plus R_R and R_{IN} (the radiation resistance and the input resistance). The choke can also be capacitive, and the antenna can be inductive, as it would be if it were longer than a quarter wavelength. Antenna theory tells us that these impedance relationships will repeat in increments of ½ wavelength.

But virtually all product data for ferrite chokes is presented as series equivalent R_S and X_S because of first, it's easy to measure and understand, second, to forget there is stray capacitance, and third because ferrite chokes are most often used as series elements of a voltage divider. Figure 5.12 and 5.13 are both useful representations of the voltage divider formed by a ferrite choke and a small bypass capacitor across the device input.

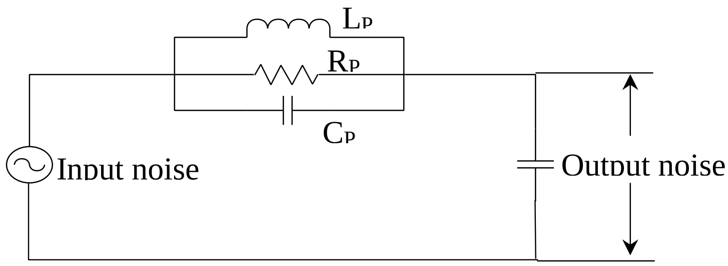


Figure 5.10 Series element of divider is a parallel resonance circuit

When designing ferrite chokes into equipment however, several other degrees of freedom are available. Figure 5.12 shows a ferrite choke, represented as its parallel equivalent components, forming a low pass filter with a capacitance that is placed across the signal line. In such a configuration, the combination of a much smaller choke and relatively small capacitance can form a very effective filter. In a series circuit, the larger value of R_S and X_S has the greatest influence, while in a parallel circuit, the smaller value R_P and X_P is dominant. In other words, for R_P to dominate, R_P it must be small.

In general, ferrite cores tend to have very little leakage flux, that is, because of their high permeability, they tend to contain all of the flux produced by current on the wire passing through them. On the other hand, small values of capacitance can be obtained by placing a ferrite core parallel to and very close to a ground plane. The wire passing through the core will have parasitic capacitance to the ground plane, with the ferrite acting as the dielectric.

Ferrites can exhibit amplitude non-linearity at high signal levels due to saturation (that is, μ decreases as the material saturates). In audio applications, saturation would likely occur only if an individual ferrite were applied to one conductor of a high-power loudspeaker circuit. If the ferrite were applied common mode (that is, if both conductors pass through it), their fields will cancel and no saturation will occur unless the common mode current is sufficient to saturate it. Ferrites also exhibit a reduction in their permeability with increasing temperature. Again, the threshold of this effect is unlikely to be reached in typical audio applications. The above leads to these general guidelines:

1. The length of cable between a choke and the equipment it is protecting should be a small fraction of a wavelength at the frequency of the interference. In our case, it will be a meter away.

2. When multiple chokes are placed on a cable to suppress multiple frequency ranges, the choke covering the highest frequency range should be nearest to the equipment.
3. When equipment at both ends of a cable is susceptible, chokes should be placed at both ends of the cable to suppress interference at frequencies for which the cable is longer than about 10% of a wavelength. Therefore, a single choke would likely protect 40 m cable against Oromia radio broadcast interference.

Analysis shows that RF shield current is a major contributor to all of them, so eliminating or reducing shield current should be the key to eliminating the interference. Experimental work near 10 kW/1 KW AM Oromia radio transmitter confirmed this hypothesis. Virtually all cases of interference in both microphones and input equipment, many of them quite severe, were either eliminated or greatly reduced when a cable connecting the mic to the input gear was wound around a toroidal ferrite to form an RF choke that reduces that current.

The choke used for the tests probably had Z on the order of 750 ohms at 1035 kHz (Oromia radio's transmission frequency).

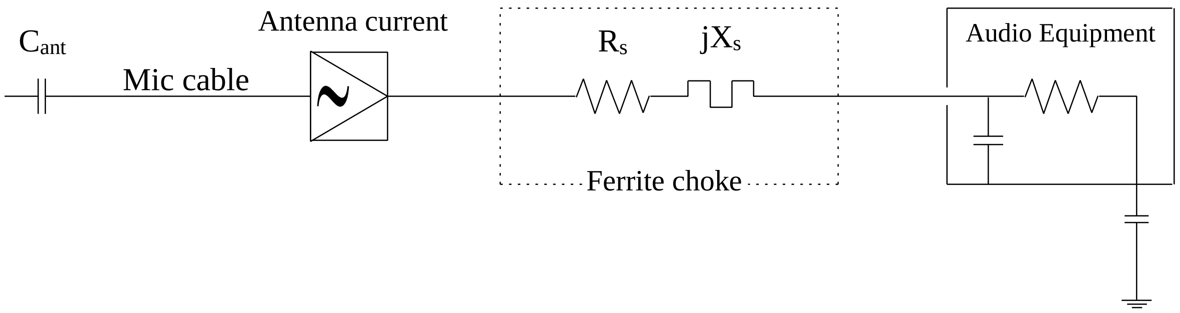


Figure 5.11 A ferrite choke on wiring connected to un-grounded equipment

The figure above explains some interesting things I observed, the setup consisted of a condenser mic on a stand, connected by two lengths of 40 m of cable to a mixer that had both a pin 1 problem and poor filtering of its input circuit. One of the cables had a foil/drain shield, so it produced a lot of SCIN, while the other, with a braid shield, produced a lot less. Various mics were plugged in to test their susceptibility and the mixer out were listened. Some of the mics were clean until hold by hand that make the change, the began detecting RF. The capacitance between human body and earth completed the circuit so that enough current could flow to excite either a pin 1 problem or SCIN in the mic.

The power system neutral grounded by copper rode into the earth. When this grounding disconnected, almost no RF was detected by the mixer. Again, without the earth connection, the impedance of the path to earth (for antenna current) provided by the capacitance between the power supply system and the earth was too high to allow much current to flow on the mic cable shield.

A choke of 6-8 turns would work to suppress Oromia radio broadcast RFI picked up by one or two mic cables. Not only that, but using ten such clamp-ons would provide only about 120 ohms' series resistance at 1.035 MHz. Large clamp-ons can also be a problem solver when a multi-turn choke is needed on smaller diameter cables and it is inconvenient to remove large connectors. The solid #31; series resistance of two very large solid cylinders are a bit more useful for suppression of this broadcast; ten of them would provide 350 Ω at 1.035 MHz, 20 of them about 700 Ω. Even protected by really good heat-shrink, that would a pretty awkward package on a portable mic snake, and since the ferrites are quite brittle, probably wouldn't be safe. If we are able reduce the RF current by 6 dB, the detected interference will drop by 12 dB (because all detection is square law). That would make the interference roughly half as loud. To do that, a choke must add enough resistance to double the total impedance. In other words, we need to end up with 600 Ω.

The length of wire between the choke and the equipment can act as an antenna if it is long enough. Ferrite chokes should be placed to provide maximum rejection at:

- A choke should be within 2.422m of the equipment at 1.035 MHz.
- Chokes may be needed at both ends of cables longer than about 6m.

5.4. Isolation distance methods

AM broadcast stations operating between 0.5 MHz and 2 MHz are a common source of such interference. The behavior of the random long wire antenna formed by the shield of an audio cable cannot easily be analyzed or predicted because of such complex factors as its radiation resistance, impedance, orientation, proximity to surrounding conductive objects, and exposure to the field. On the other hand, AM broadcast field strength outdoors can be reasonably well predicted on the basis of extensive empirical data, especially within about the first 50 km from the transmitting antenna. The current induced in a receiving antenna (that is, the mic cable) will be directly proportional to the field strength. The primary means of propagation within 100 km of AM broadcast stations is ground wave. The ground wave field strength in volts/meter produced by an AM broadcast transmitter varies with the inverse of the distance and an additional loss due to resistivity of the earth.

Below the AM broadcast prediction with respect to 24-hour time propagation location with noise level of noisy (139) area. The receiving antenna was 40-meter-long audio cable which was assumed as dipole antenna with length of 40 meter.

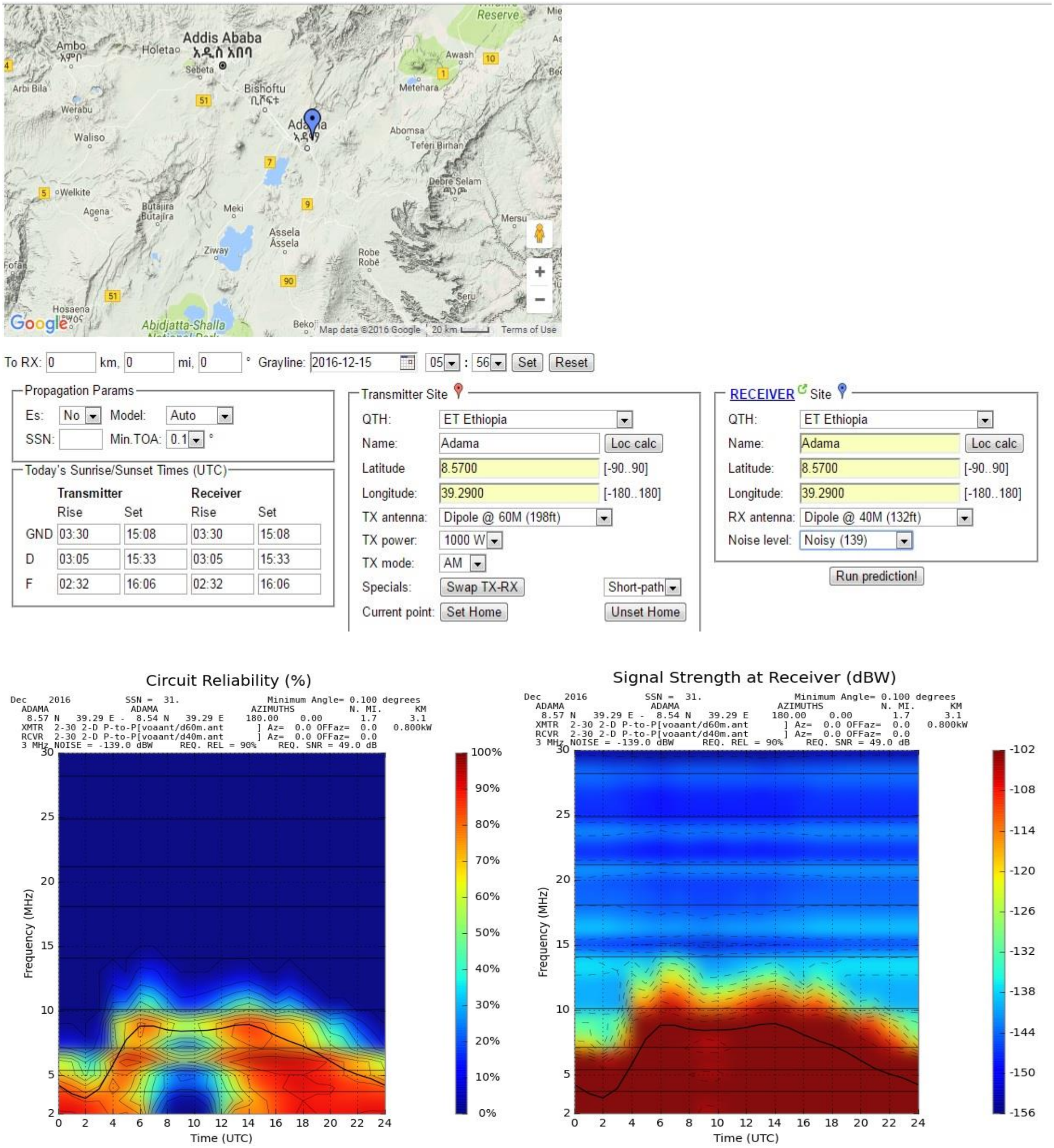


Figure 5.12 A 1000W TX and RX location and propagation prediction in noisy area

The AM broadcast prediction with respect to 24-hour time propagation with location noise level of quite (153). The receiving antenna was 40-meter-long audio cable which was assumed as dipole antenna with length of 40 meter.

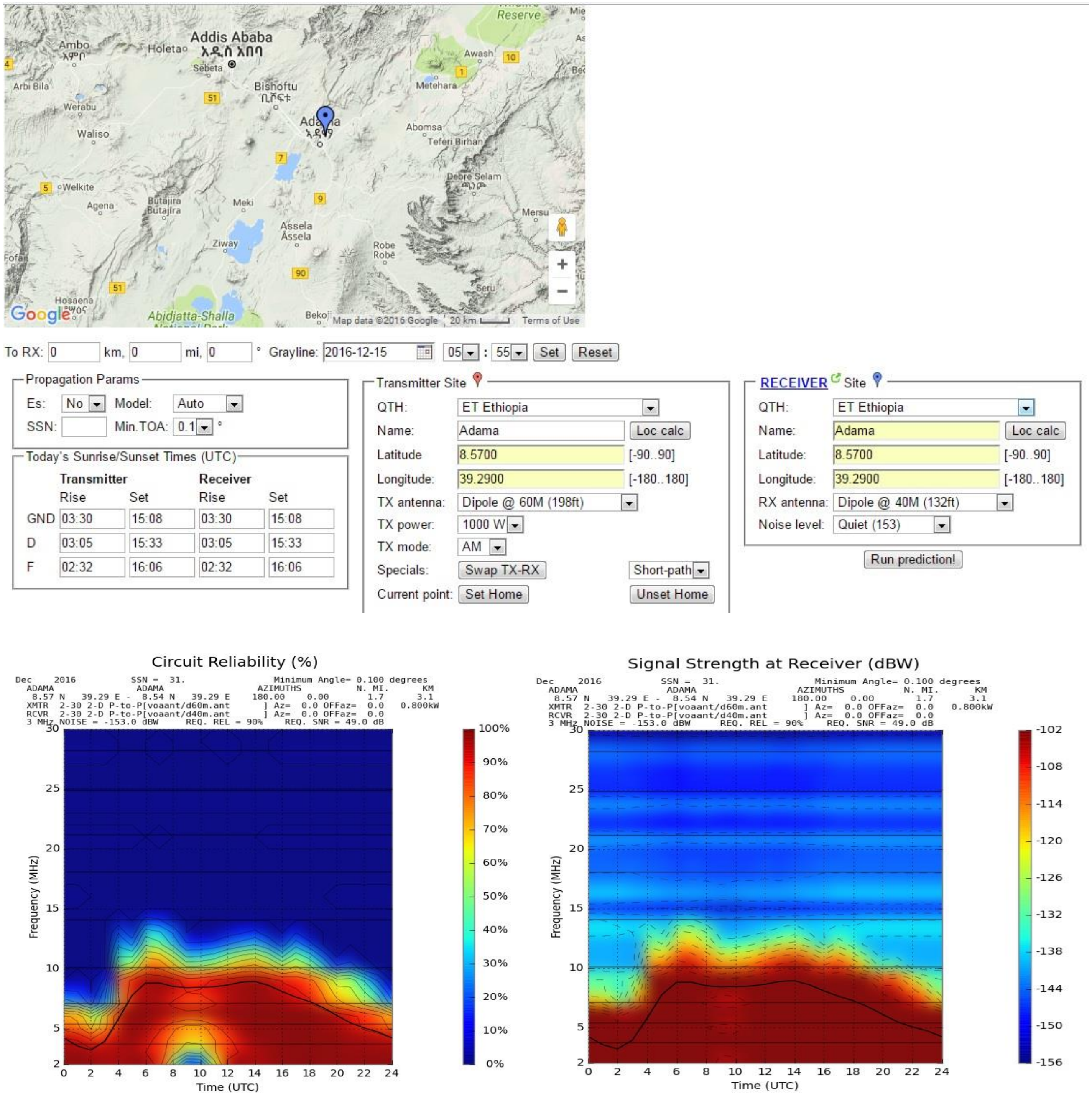


Figure 5.13 A 1000W TX and RX location and propagation prediction in quite area

The change in received signal strength is because of the way in which the relatively long wavelengths of AM radio signals interact with the ionized layers of the ionosphere miles above the earth's surface, the propagation of AM radio waves changes drastically from daytime to nighttime. This change in AM radio propagation occurs at sunset due to radical shifts in the ionospheric layers, which persist throughout the night. During daytime hours when ionospheric reflection does not occur to any great degree, AM signals travel principally by conduction over the surface of the earth. This is known as "groundwave" propagation.

Chapter 6

6. Result and Discussion

Current flow on the shield of a twisted-pair cable produces a corresponding differential mode voltage on the twisted pair that is proportional both to frequency of the current and the length (therefore its inductance) of the cable for cables that are shorter than 1/20 the wavelength of the interfering signal. This differential voltage is called shield-current-induced noise or SCIN. Between 1/20 and 1/10 wavelength, SCIN will continue to increase approximately in proportion to frequency and cable length. When a cable is longer than 1/10 wavelength at the frequency of the interfering current, complex, frequency-dependent terms will dominate and no easy prediction of SCIN can be made. SCIN appears to include an additive term whose magnitude is approximately proportional to the fraction of the shield current that flows through a drain wire to the total shield current.

The data suggest that the maximum degradation caused by a drain wire is on the order of 25-30 dB. SCIN appears to include algebraically additive reactive terms that result from imbalances in the lengths of the signal conductors, imbalances in the inductance of the signal conductors, and imbalances in the capacitances between the signal conductors and the shield. Because these reactive components have both positive and negative sign, because magnitude and phase of voltages and currents vary along the length of a cable longer than 1/20 wavelength, and because the mechanism of production of the current is so variable from one installation to another, prediction of these terms is a complex under taking and unlikely to be worthy of the effort.

For cables, less than 1/10 wavelength at the frequency of the shield current, reactive factors are insignificant for foil/drain-shielded cables, and relatively low in influence with braid/drain shielded cables. For foil/drain-shielded cables, SCIN attributable to the drain wire is on the order of 20-30dB greater than SCIN attributable to other factors. For most braid-shielded cables having a drain wire, SCIN attributable to the drain wire is on the order of 10 dB greater than SCIN attributable to other factors. Any asymmetry in the termination of a cable can degrade SCIN performance. This is most significant with cables having relatively good SCIN characteristics. Manufacturing tolerances should be expected to cause variations the SCIN performance from one sample to another of braid-shielded cables. Improved SCIN performance of foil-shielded cables is possible and should be a goal.

A 3-dB reduction in the interfering signal, whether by filtering, shielding, orientation of a microphone cable, or some combination thereof, can result in a reduction of 6-12 dB in the audibility of the interference when more than 3 dB above the threshold of detection, and an even greater reduction when closer to the threshold.

Mild RF interference can be made inaudible simply by wrapping the microphone cable a few turns around a metallic microphone stand and minimizing the exposed loop of cable between that point and the microphone. Such an expedient must be used with care, however, since it can also degrade mechanical isolation of a microphone in a vibration-isolating mount.

Against this RFIs, several pro- and re-active mitigation methods introduced in chapter 5 can be used. One of the most promising mitigation methods in AM radio interference is making enough distance of separation between interfering antenna and studio constructions.

The figure below shows us how the signal level in milli-Volt picked by cable running on floor looks like versus frequency and time plot. The case for both audio input to mic or person speaking and the case where the mic kept idle.

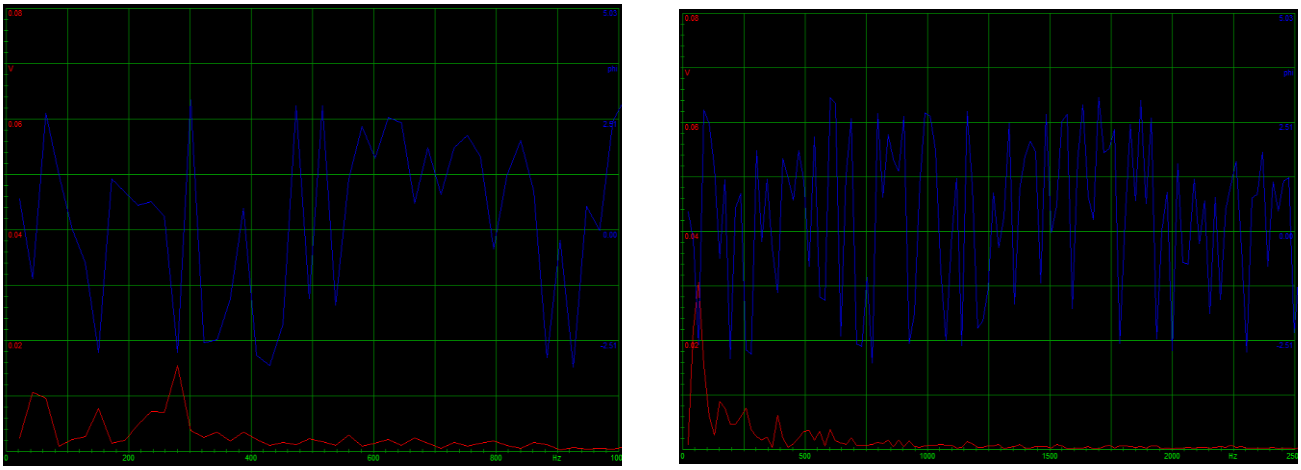


Figure 6.1 Signal picked by cable without audio input for mic

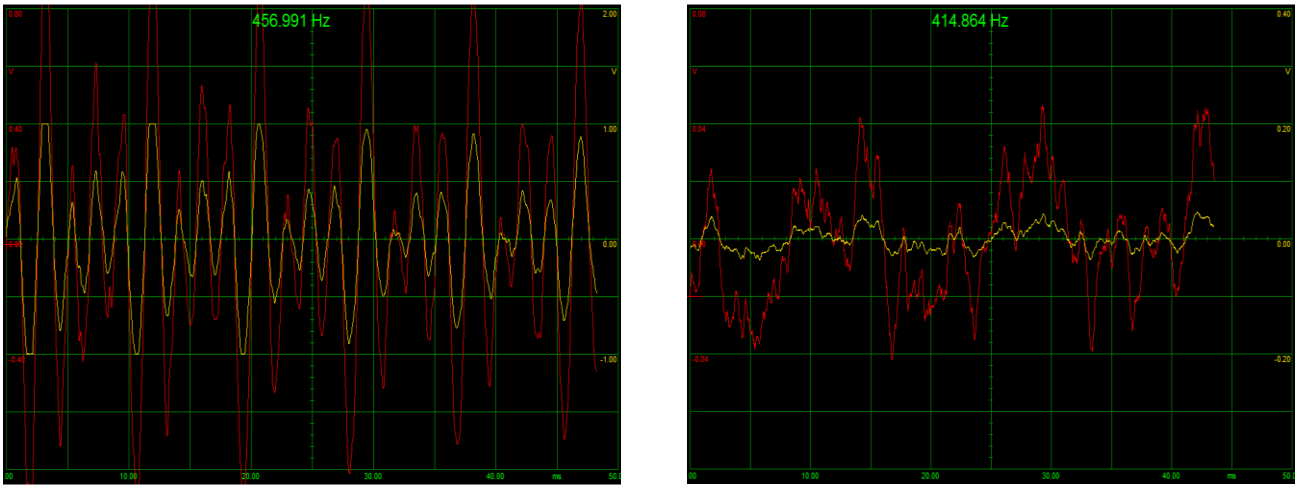


Figure 6.2 Signal picked by mic cable while there is audio input to mic

The current induced in a receiving antenna (that is, the mic cable) will be directly proportional to the field strength. The primary means of propagation within 100 km of AM broadcast stations is ground wave. The ground wave field strength in volts/meter produced by an AM broadcast transmitter varies with the inverse of the distance and an additional loss due to resistivity of the earth. The figure below shows the strength of interfering signal in near distance from the transmitting antenna. This cause, audible noise that can create so many challenges for broadcast station.

Table 5.1 For 1kW measured dBV noise

No.	Frequency	TX power	Distance	Measured dBV
1	1035 KHz	1kW	0.5km	-10
2	1035 KHz	1kW	1.0km	-22
3	1035 KHz	1kW	1.5km	-25
4	1035 KHz	1kW	2.0km	-32

Table 5.2 For 10kW measured dBV noise

No.	Frequency	TX power	Distance	Measured dBV
1	1035 KHz	10kW	0.5km	-3
2	1035 KHz	10kW	1.0km	-13.5
3	1035 KHz	10kW	1.5km	-16
4	1035 KHz	10kW	2.0km	-20.5

The values at point interest is below studio gear audio level but it creates audible noise. It decreases as the distance from the transmitting antenna increases.

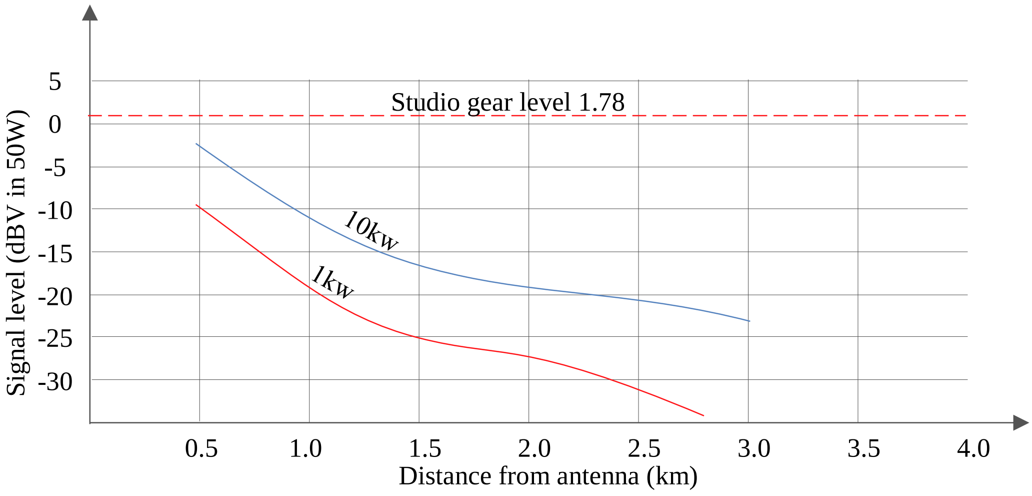


Figure 6.3 A Measured dBV versus distance for 1/10kW Tx

Chapter 7

7. Conclusion and Recommendations

7.1 Conclusion

Radio frequency interference is an ever-increasing problem in sound system installations. All kind of radio broadcasts and new radio applications are deteriorating the audio signal if they are allowed to do so.

This thesis discuss, the impact of the radio interference in sound system, different source interference and the potential mitigation methods to minimize the effects of the audio broadcast quality. The radio interference picked up by the wire is brought into the mixer as radio frequency signal. This radio signal is de-modulated by the mixer, resulting in audio from the radio transmitter added to TV sound. Interference from nearby AM transmitter is worst in hundreds of meters. Even some filtering mechanism can't totally remove it. While reducing the RF interference it also affects the signal of interest (SOI). The first thing to be done is while designing the construction of studio and transmitter location, there should be enough distance separation, 5km, and above between them as observed from measured data. If we compare this result with the general theory radio signal propagation, it is true that the strength all signal decreases as they propagate more distance.

Avoid the use of shielded cables with a drain wire if the system will be exposed to strong RF below 10 MHz (AM broadcast, ham transmitters, light dimmers). Any cable with a drain wire will have significantly greater SCIN below about 10 MHz than a cable that uses a good braid shield. The best cable is one that has both a foil and braid shield.

Interference caused by pin 1 problems can generally be eliminated by preventing current flow on the shield at the frequency or frequencies of the interference. This can often be accomplished by the use of an RF choke improvised by winding multiple turns of the cable around a suitable ferrite rod or toroidal ferrite core. Pin 1 problem is an improper connection of the shield terminal, pin 1in XL connectors.

Ferrite chokes can be an effective tool for reduction of RF interference to audio systems and their loss is of greater value than their inductance but also impact on signal of interest.

7.2 Recommendations

- The work of this thesis can be extended by considering a scenario in which VHF/UHF are present very nearer the sound system.
- We know that pin 1 problems are a common cause of RFI, so fixing them is always worth the trouble. The best fix is one that disconnects the cable shield from the connector pin that goes to the circuit board, and connects the cable shield instead to the equipment's shielding enclosure. This is particularly important with VHF and UHF interference sources. Don't forget that pin 1 problems can occur with unbalanced inputs and outputs too if the equipment has RCA and/or 0.64cm connectors mounted to a circuit board.
- The work of the thesis may further be improved by using transmitters of different model from various manufacturer.

Appendix A

Types of audio cable

The first letter or letters indicates the shield type. B indicates a braid shield, F indicates a foil shield, S indicates a double spiral shield, and D indicates a drain wire. A indicates a cable intended for analog audio, a second letter D indicates a 110 ohm cable, and M indicates a miniature cable.

BA - A 0.262" diameter rubber covered portable microphone cable with a braid shield.

BDA - A 0.194" diameter 76 ohm twisted-pair braid/drain-shielded portable microphone cable.

BDAM - A 0.138" diameter 60 ohm twisted-pair braid/drain-shielded portable cable.

BD95 - A 0.272" diameter 95 ohm twisted-pair braid/drain-shielded portable cable.

BDD1 - A 0.211" diameter 110 ohm twisted-pair braid/drain-shielded portable cable.

BDD2 - A 0.235" diameter low-loss 110 ohm twisted-pair braid/drain-shielded portable cable.

BDQ - A 0.24" diameter quad-star braid/drain shielded portable microphone cable.

BF - A 0.14" diameter twisted-pair braid/foil shielded cable for fixed installation.

FDA1 - A 0.135" diameter twisted-pair foil/drain shielded cable.

FDA2 - A 0.14" diameter 60 ohm twisted-pair foil/drain-shielded cable.

FDA3 - A 0.138" diameter 45 ohm twisted-pair foil/drain-shielded cable.

FDA4 - A 0.132" diameter twisted-pair foil/drain shielded cable.

FDD1 - A 0.143" diameter 110 ohm twisted-pair foil/drain-shielded cable.

FDD2 - A 0.19" diameter low-loss 110-ohm twisted pair foil/drain-shielded cable.

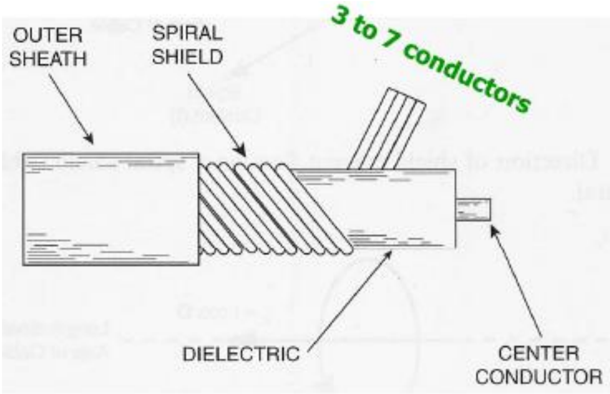
SD - A 0.204" diameter 110 ohm twisted-pair cable with two spiral shields wrapped in opposition.

Appendix B

Types of shield

Spiral shield

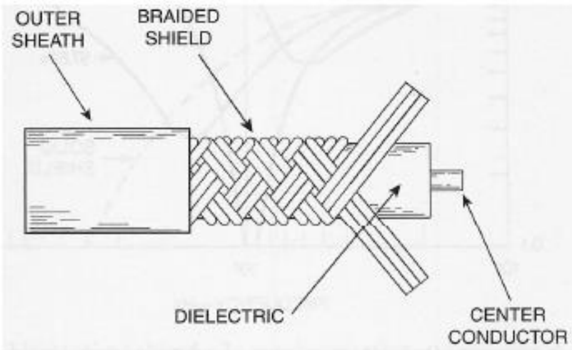
A spiral shield is used for reduced manufacturing cost, ease of termination and increased flexibility.



Spiral shields are used at audio frequencies.

Braided Shields

The advantage of braid is flexibility, durability, strength, and long flex life.



Appendix C

Types of filter and their outputs

The table below describes different filtering solutions on a transmission line having a specific length and driver technology driving the input/output of the transmission line:

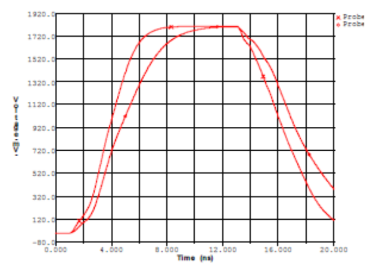
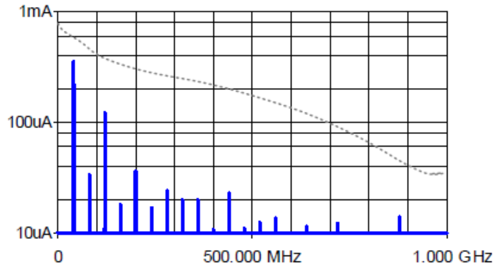
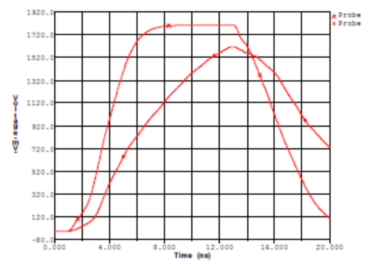
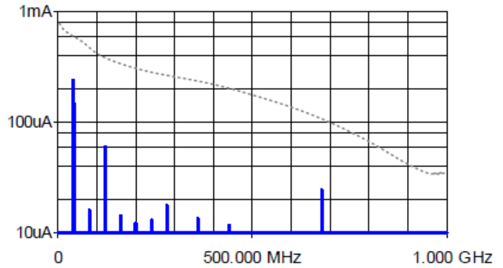
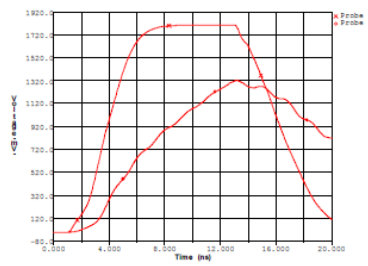
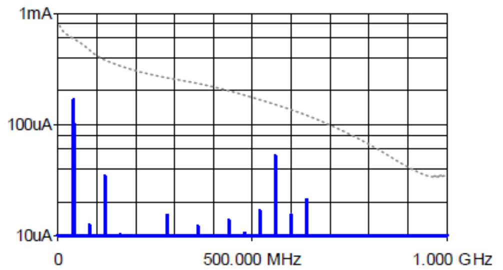
Type of Filter	Signal Waveform	EMI Suppression Effect
Signal Rising/Falling Edge & Noise Spectrum before/after filter Mounting 1st Order Chebyshev I PB Ripple = 1dB		
Signal Rising/Falling Edge & Noise Spectrum before/after filter Mounting 3rd Order Chebyshev I PB Ripple = 1dB		
Signal Rising/Falling Edge & Noise Spectrum before/after filter Mounting 5th Order Chebyshev I PB Ripple = 1dB		

Table 4: Different Chebyshev Filtering Solutions

The table below describes basic methods for distortion suppression: series resistive termination and RC filtering solutions that reduce the ringing effect and distortion of a clock signal improving its signal integrity.

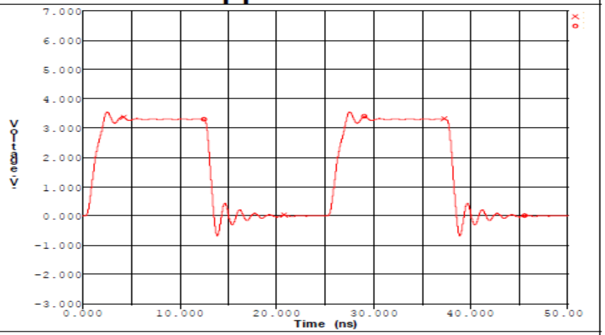
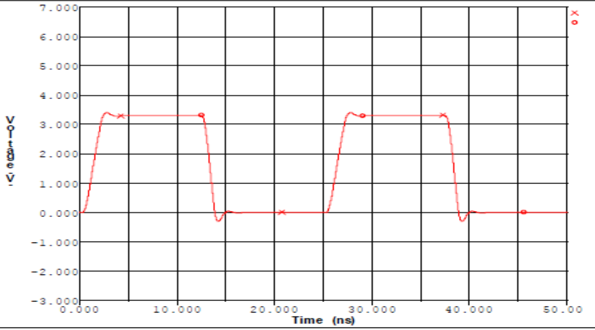
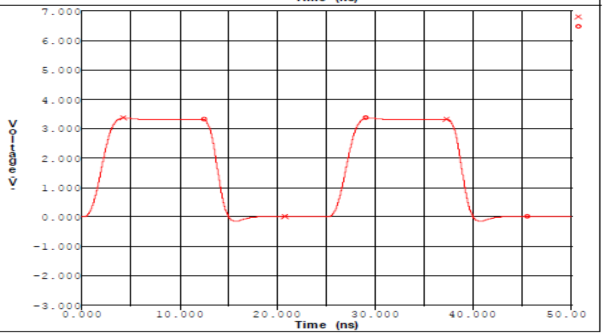
Type of Signal	EMI Suppression Effect
Initial waveform	
Series resistor termination applied / waveform ringing effect reduced.	
RC filtering solution applied / waveform distortion is suppressed	

Table 5: Different Distortion Suppressing Solutions

Appendix D

Standard audio level

The origin of the index of dBu comes from "u = unloaded" and dBV comes from "V = 1 volt".

A logarithmic voltage ratio with a reference voltage of V_0 = 0.7746 volt ≡ 0 dBu

A logarithmic voltage ratio with a reference voltage of V_0 = 1.0000 volt ≡ 0 dBV

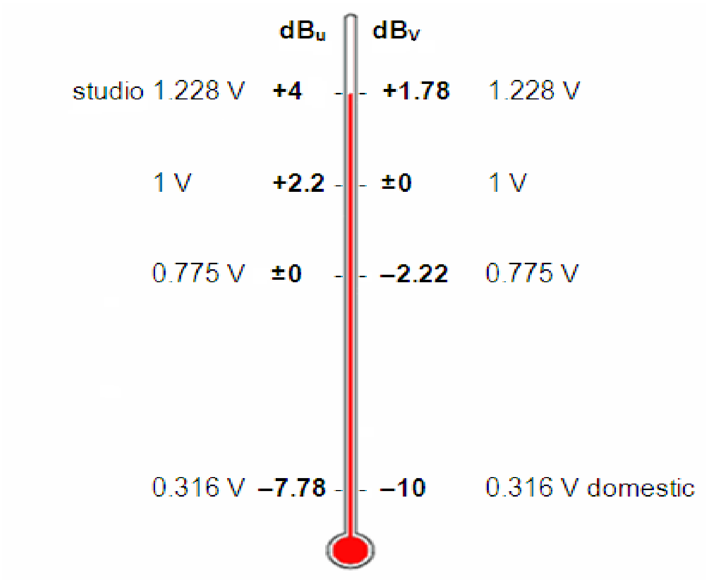
The home recording level (consumer audio) of −10 dBV MEANS 0.3162 volts, that is −7.78 dBu.

The studio recording level (pro audio) of +4 dBu means a voltage of 1.228 volts.

The maximum undistorted level of audio amplifiers is +18 dBu.

Domestic gear with a −10 dBV level is USUALLY unbalanced.

Studio gear with a +4 dBu level is always balanced. 0 VU = +4 dBu.



The level difference between +4 dBu studio level and −10 dBV consumer level is Δ L = 11.78 dB (12 dB).

The level difference between dBu level and dBV level is Δ L = 2.2 dB.0 dBV equals 2.2 dBu or 0 dBu equals −2.2 dBV.

Bibliography / References

[1] Cables, Transmission Lines, and Shielding for Audio and Video Systems (http://audiosystemsgroup.com)

[2] Belden Engineering Department, "Characteristic Impedance of Cables at High and Low Frequencies,"

[3] A Ham's Guide to RFI, Ferrites, Baluns, and Audio Interfacing Revision 2 (http://audiosystemsgroup.com)

[4] Keltz, A., Unbalanced vs. Balanced Lines and Cables, Technical Articles, Whirlwind USA

[5] Whitlock, B., Interconnection of Balanced and Unbalanced Equipment, Application Note AN003, Jensen Transformers, Inc., 1995.

[6] Brown, J. and Whitlock, B., Common-Mode to Differential-Mode Conversion in Shielded Twisted-Pair Cables (Shield-Current-Induced Noise), Audio Engineering Society 114th Convention, 2003.

[7] Morrison, R., Noise and Other Interfering Signals, John Wiley & Sons, 1992.

[8] http://k9yc.com/publish.htm

[9] http://www.intersil.com/content/dam/Intersil/documents/an12/an1299.pdf

[10] Gruber, M., Editor, The ARRL RFI Book – Practical Cures for Radio Frequency Interference, 2nd Ed., American Radio Relay League, 2007.

[11] http://www.audioholics.com/audio-video-cables/bulletproofing-your-system-from- interference

[12] Nelson, W., Interference Handbook, Radio Amateur Callbook (Watson-Guptil Publications),

[13] Kodali, V., Engineering Electromagnetic Compatibility – Principles, Measurements and Technologies, IEEE Press, 1996.

[14] Design of High-Performance Balanced Audio Interfaces, Bill Whitlock, Jensen Transformers, Inc.

[15] Henry Ott, Noise Reduction Techniques in Electronic Systems, Wiley Inter science, 1988

[16] http://siriuscyber.net/rfi.htm

[17] http://www.audio-technica.com/cms/site/d0c406516fd8b42b/