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AN RF BANDWIDTH SWITCH FOR MULTIMEDIA TRANSMISSION

by

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SAMEVATTING

`n RF Bandwydte skakelaar vir multimedia transmissie
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Graad: Magister Scientiae

Die doel van hierdie navorsingsprojek was om `n RF bandwydte skakelaar te ontwikkel wat multimedia skakeling en transmissie in `n tegnologie gebaseerde onderrigstelsel moontlik maak, sonder om staat te maak op persoonlike rekenaartegnologie.

Die dissiplines binne tegnologie gebaseerde onderrigstelsels wat kortliks ondersoek word, is die opvoedkundige vereistes soos vasgestel deur didaktiese kundiges, asook kommunikasiestelsels wat moderne multimedia ondersteun.

Kenmerke van moderne tegnologie gebaseerde onderrigstelsels word onder die loep geneem binne die Suid-Afrikaanse konteks, sowel as nie-tegniese aspekte, soos toegevoegde waarde verkry van audio, video en geïntegreerde rekenaartoepassings.

Informele eksperimente word beskryf waartydens `n RF bandwydte skakelaar toegepas word om die funksionele kenmerke van `n tegnologie gebaseerde onderrigstelsel te verkry, sonder om staat te maak op persoonlike rekenaartegnologie. Die lewering van `n informele lesing tydens die eksperiment word bespreek, asook waarnemings gemaak tydens die eksperiment.

Die eksperimente mag dien as `n metode om die potensiële toepassing van bandwydte skakelaars vir tegnologie gebaseerde onderrigstelsels te evalueer. Aanbevelings vir toekomstige projekte van hierdie aard kan vervolgens gemaak word.

Sleutelterme:
RF bandwydte skakelaar, multimedia transmissie, Ruthroff se impedansie transformator, transmissielyn transformator, hibride sommeerder, invoegverlies, transmissiekenmerke, analoog video transmissie, faseverwisselende lyn, tegnologie baseerde opleiding (T.B.O.).

ABSTRACT

An RF bandwidth switch for multimedia transmission
by Pierre van Rhyn.
Advisor: Prof. J. J. D. van Schalkwyk.
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Degree: Magister Scientiae.

The purpose of this research project was to develop an RF bandwidth switch to make multimedia switching and transmission possible within a technology based training system, without reliance on personal computer technology.

The disciplines briefly examined within technology based training systems are educational requirements set by didactic expertise, as well as communications structures supporting modern multimedia.

Features of modern technology based training systems are considered within the South African context, as well as non-technical aspects of technology based training systems such as the value added by audio, video, and integrated computer applications.

Informal experiments are described wherein an RF bandwidth switch is applied to obtain the functional characteristics of a technology based training system, without reliance on personal computer technology. The delivery of an informal lecture during the experiment is discussed, as well as observations made during the experiment.

The experiments may serve as a method to evaluate the potential application of RF bandwidth switches for technology based training. Recommendations for future projects of this nature may then be made.

Key terms:
RF bandwidth switch, multimedia transmision, Ruthroff's impedance transformer, transmission line transformer, hybrid combiner, insertion loss, transmission characteristics, analogue video transmission, phase alternating line (P.A.L.), technology based training (T.B.T.).

This study is dedicated to
my wife Elsa
for her support
and personal sacrifices.

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Chapter 1

INTRODUCTION, PROBLEM STATEMENT AND METHODOLOGY

1.1 INTRODUCTION

This dissertation discusses various aspects of technology based training (T.B.T.) systems and describes the development of an RF bandwidth switch, that performs the functional characteristics of T.B.T. systems, without reliance upon personal computer technology.

Advances in computer technology such as faster processors and better data compression schemes have made it possible to integrate audio and video data into the computing environment. An alternative type of lecture material, namely desktop multi-media, has become possible. Unlike conventional media centres, which requires specially equipped rooms with expensive media, desktop multi-media may be obtained by adding software and hardware to standard desktop computers.

One benefit of desktop multi-media is the convenience of not having to physically move to a special location. Another benefit is the ability to incorporate data from other desktop computer applications into the lecture delivery. Desktop multi-media systems should cost only a few thousand rand to set up, which is significantly less expensive than room media centres which typically cost a minimum of R100000 to set up [1].

The information technology explosion renders an enormous amount of multi-media, available on several media formats such as CD-ROM and magnetic tape. The bandwidth required for transmission remains, however, in direct proportions to media capabilities achieved.

Computer aided instruction and PC driven T.B.T. systems appear to offer instantaneous solutions to our educational problems. However, computers cannot be effectively used for lecture delivery in South Africa, because of embedded social and cultural disadvantages.

The problem of delivering media to students is firstly complicated by the fact that the majority of students in South Africa are not computer literate, and may remain so for the near future. The second complication is one of language. Educational software in English cannot be effectively applied in a culture of ethnic diversity with eleven spoken languages.

It is believed that the many people in South Africa that are not regarded as computer literate, may indeed be at ease with other forms of media technology, such as the radio frequency (RF) format of television and video equipment. This belief suggests that an alternative approach may be, to attempt to obtain the functional characteristics of T.B.T. systems, utilising such existing technology that people are familiar with.

For the interim, the PC should merely be regarded as a multimedia input device. This will allow the system to be used by people that are not computer literate, although the system will allow computer literacy training. The system should furthermore be dynamically designed, so that it may be adapted to computer control with minimum effort, if so required at a later stage when computer literacy prevails.

1.2 PROBLEM STATEMENT

1.2.1 The application requirement

A requirement for a technology based training system was identified at the South African Weather Bureau's Irene Weather Station. The experiential training class was proposed as a suitable group to use for learning system experiments based upon T.B.T. principles. Students in this class work in teams to conceive, design, develop, implement and maintain laboratory grade meteorological instruments and systems.

An important part of this class is the periodical seminars given by speakers on combined meteorological issues. Normally these seminars are held in an auditorium, but problems are experienced when practical demonstrations are required which involve scientific instruments.

Such demonstrations require that the number of students attending be limited and to attend as smaller teams rather than as a group, due to limitations imposed by geographical distribution of facilities, as seen in Figure 1.1.

A second aspect to keep into account when considering a T.B.T. solution at Irene, is the occurrence of localised radio frequency interference caused mainly by the HF transmitting station (1). The station operates four 10-kW single sideband transmitters, with the main building situated within a few wavelengths from the transmitting antennae.

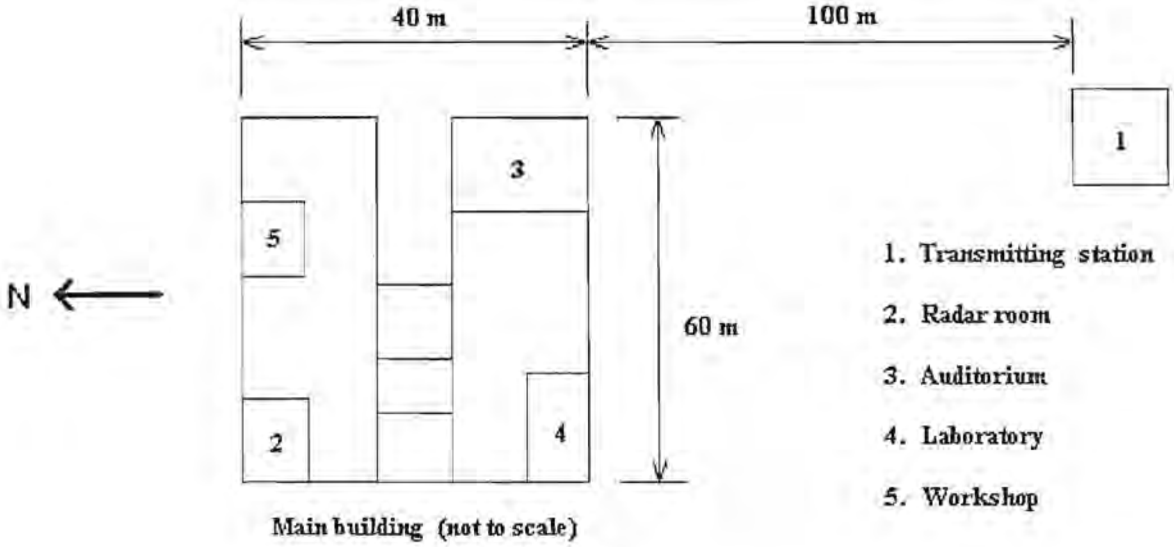


Figure 1.1. Geographical distribution of facilities at Irene weather station.

Additional sources of radio frequency interference are the various microwave systems at Irene such as the upper air balloon tracking equipment, as well as an Enterprize DWR93 meteorological radar (2). Interference is acutely observed on the southern side of the main building, including within the vicinity of the auditorium (3) and the development laboratory (4). Any electronic system required to operate within these vicinities require additional attention during construction to minimise the effects of external interference.

Also, with electronic systems proposed to be utilised at the Weather Bureau's premises, the interference radiation should be kept to a minimum and should not cause any interference with systems currently in use. All new RF products are tested rigorously to ensure conformance and compatibility.

Preliminary tests were conducted with several different brands of audiovisual equipment such as television receivers, video cassette recorders and compact disc players. Only a small percentage of the equipment that was tested did not noticeably display effects of interference, notably the higher priced examples.

The effects of interference observed with some of the other brands are audio distortion and foreign signals introduced to the audio stages, as well as video interference manifesting itself as visible lines and spots on display screens.

Corrective measures such as earthing, or screening of components yielded limited success, although in a few cases the effects of interference were totally eliminated.

1.2.2 The aim

The aim of the study is to develop an RF bandwidth switch, for multi-media transmission within a technology based training system, without reliance upon personal computer technology.

1.2.3 The objectives

The first objective is to define the functional characteristics of technology based training systems that must be obtained by the RF bandwidth switch, as well as the distribution network structure within which the RF bandwidth switch may be deployed.

The second objective is to specify a format for primary transmission, as well as a suitable frequency plan.

The third objective is to specify and develop the electronics to devise a suitable bandwidth switch capable of obtaining the functional characteristics of technology based training systems, primarily enabling the user to select any one of a minimum number of four RF bandwidth inputs, to be presented at the output port for transmission. Typical full-bandwidth inputs are personal camera, workbench camera, video cassette recorder and personal computer.

1.2.4 The hypotheses

The first hypothesis is that the functional characteristics of technology based training systems, as well as the network structure required, may be specified after a literature study of PC driven technology based training systems.

The second hypothesis is that a suitable frequency plan and format for primary transmission may be specified after a literature study of ITU (International Telecommunications Union) specifications.

The third hypothesis is that the electronics may be cost-effectively specified and developed to render a suitable bandwidth selector, once the primary transmission format as well as the functional characteristics for technology based training systems are known.

1.3 REVIEW OF THE RELATED LITERATURE

1.3.1 Video transmission theory

Books, publications and papers published in scientific journals such as the IEEE proceedings provided information on video transmission theory. The literature on video transmission theory provided useful information on transmission formats and techniques of transmission. Specific attention is drawn to an article *Some broadband transformers* by C. L. Ruthroff, published in the Proceedings of the I.R.E., in August 1959, and referred to in Annexure A.

1.3.2 Educational requirements and social issues

Papers presented at the following conferences contained data related to educational parameters like human-computer interaction and lecturer/student interaction:

1.3.2.1 National Forum on Communication Technology for Effective Learning and Information Exchange, which was hosted by the FRD at the CSIR on 27 March 1996.

1.3.2.2 The Technology Based Training Conference, which was hosted by the INSTITUTE FOR INTERNATIONAL RESEARCH, at the BIFSA Conference Centre, Midrand, on 23, 24 and 25 February 1998.

1.3.3 Video transmission standards

The purpose of creating a standard algorithm is to ensure world-wide compatibility of dissimilar systems. The international body that defines the standards for video transmission was the International Telegraph and Telephone Consultative Committee (CCITT). This committee ratified standards in four year periods, beginning in 1984:

1.3.3.1 1984 Recommendations in CCITT "Red Book".
1.3.3.2 1988 Recommendations in CCITT "Blue Book".
1.3.3.3 1992 Recommendations in CCITT "White Book".

Recommendations were also adopted between plenaries through accelerated procedures every two years. The CCITT was replaced by the International Telecommunications Union (ITU), incorporating the Telecommunications Standards Sector (TSS), in March, 1993.

1.3.4 Electronic product descriptions and application notes

Technical literature on components was supplied by their respected manufacturers. This service is extensive for the larger manufacturers like Alcatel, Philips and Sanyo. Product descriptions, technical specifications and detailed application notes were obtained with ease utilising the internet.

1.4 METHODOLOGY TO SOLVE THE PROBLEM

1.4.1 The data

The data used was historical in nature at the time used, and was obtained from the literature reviewed as well as a number of standards doctrines and other publications. The data reflected the following:

1.4.1.1 Video transmission theory applicable to modern information technologies.
1.4.1.2 Educational concepts and applications of technology based training systems.
1.4.1.3 International transmission standards, recommendations and specifications.

1.4.2 The sample

Data was drawn from the literature reviewed in chapter 1.3, as well as from papers presented by discipline related experts at conferences, referred to in chapter 1.3.2.

1.4.3 Administration

The following steps were taken in the execution of the development:

1.4.3.1 A literature study of video transmission theory and communications technologies was conducted, to consider all options before specification of the primary transmission format.

1.4.3.2 The educational requirements for technology based training systems were specified based upon data obtained from publications and conferences reviewed in paragraph 1.3.2.

1.4.3.3 The primary transmission format was specified, based upon data obtained from the literature study and publications referred to in paragraph 1.3.1, as well as transmission standards referred to in paragraph 1.3.3.

1.4.3.4 The functional characteristics of technology based training systems were specified, and the communications medium to serve as network interconnections was selected, based upon data obtained from the literature and publications referred to in paragraph 1.3.

1.4.3.5 The electronics was developed to render a suitable RF bandwidth switch to be deployed in an experimental set-up.

1.4.3.6 Identical RF bandwidth switches were connected into a network configuration to test the main hypothesis. This configuration forms the basis for the academic evaluation and future research.

1.4.4 The delimitations

The study covered the working prototype development of the electronics for the switching and transmission apparatus, including the signal conditioning of inputs or outputs to and from the primary transmission format.

The study only considered the following factors:

1.4.4.1 Measurable specifications set after completion of the literature study.
1.4.4.2 Performance specifications obtained from analysis of prototype apparatus.
1.4.4.3 Informal testing of the switch within a local distribution network.

The study will not consider the following factors:

1.4.4.4 Contents of programmes switched.

1.4.4.5 Encryption of programmes switched.

1.4.5 Assumptions

The first assumption is that components for development are available for the format and frequency bandwidth selected for primary transmission, and the second assumption is that all multi-media formats are convertible to the format and frequency plan selected for primary transmission and vice versa.

1.4.6 Definition of terms

1.4.6.1 RF bandwidth switch. An electronic device that is capable of selecting any one of a number of different RF bandwidth signals presented to its input, and configuring it to its output port for distribution.

1.4.6.2 Primary transmission format. The format at which information bandwidth is manipulated to perform the function of switching.

1.4.6.3 Electronics. All products, equipment and systems manufactured for the purpose of processing, storing or transferring information, data or images by means of electro-magnetic phenomena, but excluding the raw materials from which such items are manufactured.

1.4.6.4 Encryption. Any method to encode or decode transmitted or distributed signals to prevent unauthorised monitoring.

1.5 PROJECT DOCUMENTATION

The research project will be thoroughly documented in accordance with the University's "Guidelines for study leaders, promotors and students", as well as the department's proposed format of theses and dissertations.

1.5.1 Overview of the chapters

Chapter 1 sets out the nature of the problem investigated.

Chapter 2 considers human factors and issues involved with multimedia lecture delivery.

Chapter 3 describes all factors considered for the selection of the primary transmission format, as well as the medium that may be used for network interconnection. This chapter also contains the frequency plan for the primary transmission format.

Chapter 4 describes all the factors considered for prototype development, and defines minimum specifications. The prototype RF bandwidth switch is described, as well as assembly and test procedures.

Chapter 5 defines the experimental network structure within which RF bandwidth switches are demonstrated to perform the functional requirements of technology based training systems, as well as the evaluation thereof.

Chapter 6 draws conclusions and provides recommendations for future work.

Chapter 2

EDUCATIONAL REQUIREMENTS, HUMAN/MACHINE INTERACTION AND SOCIAL ISSUES

When evaluating the use of technology based training (T.B.T.) systems, there are important non-technical aspects to consider. Specifically, systems must support the way people work or they will not be successful [2].

2.1 EDUCATIONAL REQUIREMENTS

2.1.1 Components of an interactive T.B.T. system for educational purposes

To deliver interactive multimedia services, the video server (i.e. lecturer) must communicate with other key components of the system. See Figure 2.1 below.

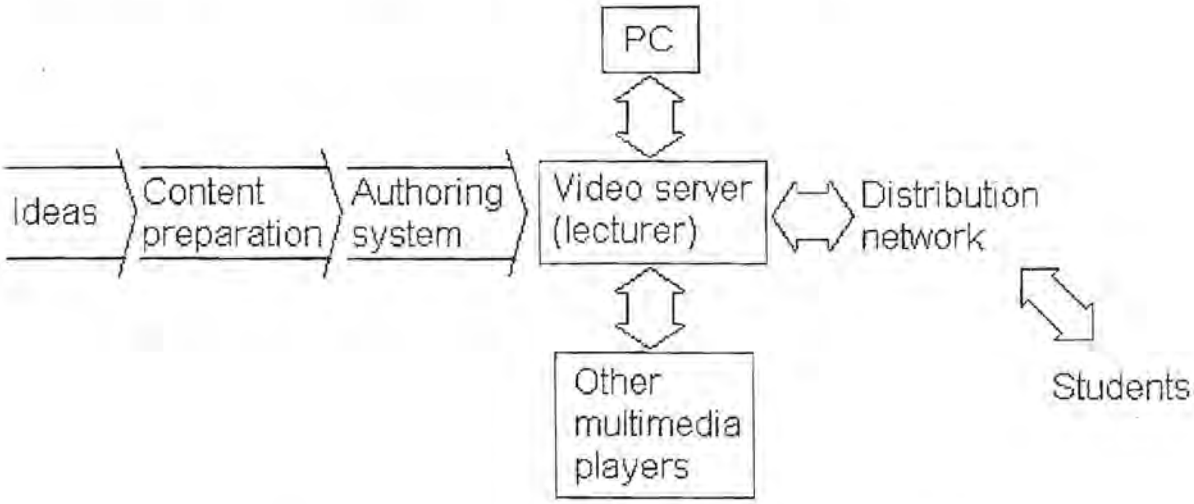


Figure 2.1 Components of an interactive T.B.T. system

Delivering interactive multimedia requires a system that integrates media preparation and authoring tools, a video (or media) server, a distribution and access network, and receiving equipment at the student workstation.

The integration of media preparation and the authoring system may to a large extent be initiated by educational entities themselves. This conclusion was drawn from case studies and papers presented at the "National forum on communication technology for effective learning and information interchange", hosted by the F.R.D. on 27 March 1996 (See para. 1.3.2.)

2.1.2 Functional requirements of T.B.T. systems for educational purposes

In his paper "How to make interactive television interactive"[3], Professor J Cronje of the Department of Didactics, University of Pretoria, argues that the strength of interactive television for distance learning lies therein that the student can talk back to the lecturer via the multimedia display unit, and that systems for education should be designed specifically for this purpose.

He stated that only three T.B.T. (technology based training) systems existed in South Africa at that point in time [3], namely:

i. The S.A.B.C. learning channel, through non-interactive television with broadened lessons, with occasional telephone feedback.

ii. The Africa Growth Network that follows a similar non-interactive system, although courseware and even CBT (community based transmission) may also be deployed.

iii. The University of Pretoria has a system with direct video broadcast in lecture mode, but with only telephone feedback.

While some degree of interactivity is obtained by these three systems, none of them achieve the real-time interactivity required by institutions of tertiary education.

2.2 HUMAN/MACHINE INTERACTION

There are two distinct paradigms to consider with the educational requirements for technology based training systems: *lecture mode* and *collaboration mode*. These modes differ by the type and amount of interaction that takes place among the participants. It is important to understand the difference between these modes because each require the technology based training system to support different types of interactions.

2.2.1 Lecture mode

Lecture mode is typically a one-to-many interaction. There are distinct and unequal roles of the participants. There is typically one lecturer and multiple students. The lecturer is in control of the conference. The lecturer may ask for interaction from the students in the form of questions or discussion. Students may indicate their desire for interaction by raising their hand. Lecture mode utilises asymmetric communication among the participants.

2.2.2 Collaboration mode

Collaboration mode is typically a many-to-many interaction. Each participant is a peer who participates in the conference equally, although in some cases there may be a facilitator who manages the conference and keeps the agenda flowing smoothly. Collaboration mode utilises symmetric communication among the participants.

Users will be frustrated if the system does not support their required mode of interaction. For instance, in lecture mode it may be difficult for students to indicate that they have a question if the lecturer can not see the student or if the interface does not provide a way to "raise a hand".

Another problem is that of language or social culture. Collaboration mode suffer difficulty when education across these barriers are considered.

2.2.3 The value of audio

The importance of good quality audio in a conference can not be overstated. Since not many of us can read lips, effective communication can not occur without intelligible audio. Audio delay can make interaction difficult. Audio that is not synchronized with video can be distracting. However, some studies suggest that users prefer having audio with minimal delay over having audio in sync with video if a noticeable delay is imposed [4].

2.2.4 The value of video

Intuitively, it seems that video adds value to a conference. Video enhances communication by creating a sense of presence. Video allows for communication through gesturing. Objects can be shown to other participants by holding them up in front of the camera. Video from auxiliary sources (such as a VCR) can be included in a conference. Video allows for interpretation of what is going on in the environment of other participants. For example, long pauses may not be perceived to be unusual if video information gives some indication to the meaning of the pause (for instance, the other person is looking for a particular slide in a stack of papers) [4].

One of the author's personal observations is that it seems easier to concentrate on what the lecturer is saying (i.e. stay awake) if visual information is present. Perhaps this is a side-effect of a generation that grew up with television.

2.2.5 The value of integrated computer applications

Anyone that has tried to explain something to someone over the phone (for example, give directions) has probably experienced the desire for some sort of shared drawing surface to supplement communication with sketches and annotations. Most desktop videoconferencing applications have a shared whiteboard capability.

In the lecture environment, it is very helpful to have a good view of the speaker's written materials. It is also very helpful to be able to save a copy of the visual material and/or print it out. In conference mode, feedback on visual materials such as annotations is very useful.

Application sharing is another useful feature of desktop videoconferencing. A common example used to illustrate this capability is participants collaboratively editing a spreadsheet or word processor document.

2.3 SOCIAL ISSUES

Our world of human diversity motivates that existing systems used to train humans be examined, and placed within social and sometimes cultural aspect. It is therefore necessary to also examine the videoconferencing model of technology based training systems within the South African scenario, also due to the limited success that this model appear to achieve.

2.3.1 Benefits of the videoconferencing model of T.B.T. systems

Room videoconferencing systems typically offer two way real-time audio and video. In addition, they usually have the capability to send high quality still images to remote sites. However, surveys of room videoconferencing system users have identified additional desired features such as a shared drawing area, ability to connect multiple sites, and ways to incorporate computer applications into the conference [4].

These types of features can be provided with desktop videoconferencing systems. Perhaps the most important aspect of desktop videoconferencing is not that it is on the desktop but that it is integrated into the computing environment that the user may already be familiar with. This opens up the possibility for data conferencing as well as videoconferencing.

2.3.2 Disadvantages of the videoconferencing model

Room videoconferencing systems have scheduling and booking problems. Time slots sometimes have to be booked well in advance. With desktop systems, more impromptu and informal interaction can take place. Users will be more likely to use a system if they have easy access to it. However, this can be a disadvantage since on the desktop there are likely to be more distractions than in a conference room setting (for example, incoming email, phone calls, etc.), and also due to the fact that participants' attention is divided between the desktop hardware and the actual conference proceedings.

2.3.3 Social issues within the South African scenario

The problem of delivering media to students is firstly complicated by the fact that the majority of students in South Africa are computer illiterate and this is expected to remain unchanged for the foreseeable future.

This observation was made by Peter T. Knight, Chief: Electronic Media Centre of The World Bank Group at a recent conference held at the CSIR.[5]

The second complication is one of language. Most educational software is written for high level English, and cannot be effectively applied in a culture of ethnic diversity with 11 spoken languages.

The situation suggests that T.B.T. systems for the South African market should support computer literacy training, without being dependent upon computer technology to function. Thus computer technology should for the interim merely be regarded as a multimedia input source.

2.3.4 The Forum prototype

Some research has been done by Sun Microsystems toward developing an application that is suited to delivering interactive presentations to distributed audiences. This research prototype is called Forum [6]. Forum attempts to address many of the problems that are encountered during the lecture delivery via a technology based training system.

Forum is specifically designed to facilitate lecture mode interactions. Roles of lecturer and student are clearly defined, and the two types of participants have different user interfaces and different capabilities.

Students receive audio, video and slides from the lecturer. They are able to interact with the lecturer through a poll, a spoken question, or written comments. Lecturers receive audio and a still snapshot of a student asking a question. Both the lecturer and students can see a list of who is in attendance and the results of polls.

Some valuable features found on this prototype model are:

1) the ability for students to queue up to indicate they wish to ask a question,

2) the ability for students to "raise their hands" by the poll function,

3) the ability for students to send in written comments without disrupting the lecturer, and

4) the ability for students to send messages to other students. These features are valuable because they increase the amount and ease of interaction between the lecturer and students as well as interaction among students.

2.3.5 Problems to overcome

With T.B.T. systems that rely upon PC technology, it takes time to compress video and audio and transmit it. This lag can contribute to a loss of interactivity as experienced with videoconferencing systems [7].

There is a learning curve involved with effectively utilising new tools. Some people are not yet computer literate and may be wary of using educational media that relies on personal computer technology.

Unforeseen circumstances are bound to happen, especially when computers are involved. The new replacements for excuses such as "my dog ate my homework" may be; "the network was down" or "my computer crashed in the middle of the lecture".

2.4 NETWORK TOPOLOGY FOR SYSTEM DEVELOPMENT

This subsection discusses the network topology for system development. Both methods of deployment are addressed, namely simplex (lecture mode) and duplex (collaboration mode) operation.

2.4.1 System overview for simplex delivery.

Figure 2.2 describes a single bandwidth switch network that may be deployed for simplex operation (lecture mode), or one-way delivery of multimedia. Inputs allowed for are personal computer (PC), video cassette recorder (VCR), personal camera (PCAM) and workbench camera (WCAM).

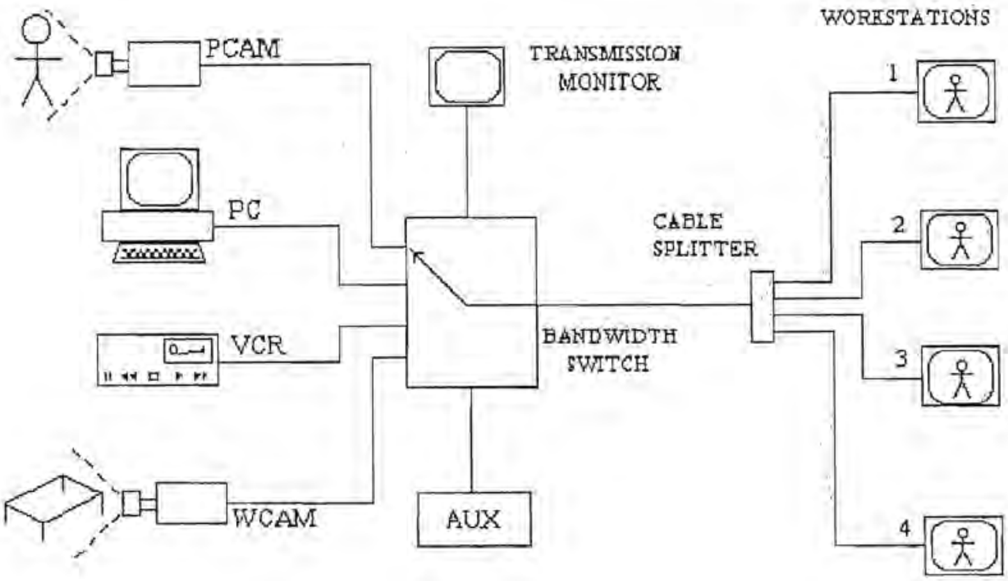


Figure 2.2 Simplex (lecture mode) network topology

The minimum system described in Figure 2.2 allows for multimedia delivery to 36 - 60 individuals, when considering conventional television monitors at the student workstations. Alternatively, large-screen projection units may be used in larger auditoriums. Picture sizes of up to a few metres may be obtained by these units, which require a standard PAL or NTSC composite video input [8].

2.4.2 System overview for duplex delivery

Fig. 2.3 describes a full-duplex system, utilising two separate bandwidth switches BS1 and BS2. With this configuration, full interactivity is obtained by the added feature that any workstation may be selected by BS2 and connected to the auxiliary input of BS1. The lecturer may switch BS2 to receive any workstation's camera to answer questions any individual may have, and configure the said workstation's input to be broadcast over the network, if so desired. With this configuration the student has no control over the flow of information, other than contributing localised audiovisual information when so configured by the lecturer.

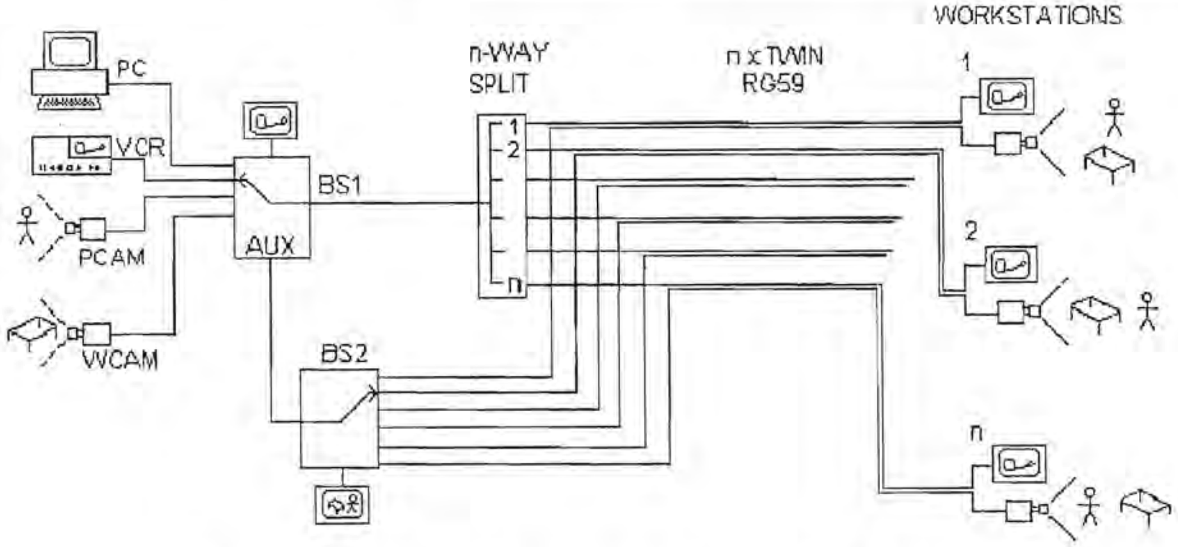


Figure 2.3 Duplex (collaboration mode) network configuration

2.4.3 The functional requirements of the transmission apparatus

The RF bandwidth switch for development must be able to obtain the following functional requirements of technology based training systems, without reliance on computer technology:

2.4.3.1 *Combination and Selection function :* The operator must be able to select one of a minimum number of four RF bandwidth inputs, to be presented for transmission, by depressing a single button.

2.4.3.2 *Activation function:* The operator must be able to activate transmission of the switched input by depressing a single button, from a warm standby condition. In the deactivated transmission mode, a station ID, or colour bars must be displayed.

2.4.3.3 *Multiple forward connections:* Multiple forward connections are required to distribute the switched input to several display units simultaneously.

2.4.3.4 *Two feedback connections:* Two feedback connections are required for interactive operation, one from the display stations to the operator, and a second connection from the operator to the display stations. The second connection may share the forward transmission links.

Chapter 3

THE PRIMARY TRANSMISSION FORMAT

This chapter describes all factors considered for the selection of the primary transmission format, as well as the medium that may be used for network interconnection.

The chapter is concluded with a broad specification of the primary transmission format, also in terms of its frequency plan and channel separation.

To perform the functions of a technology based training system, it is necessary that information be exchanged within the system. The term *primary transmission format* shall specifically refer to the information format chosen to be manipulated by the RF bandwidth switch.

3.1 FACTORS CONSIDERED FOR THE SELECTION OF THE PRIMARY TRANSMISSION FORMAT

Several factors were taken into consideration before choosing the primary transmission format as PAL system I composite baseband for analogue video and audio, with its corresponding CCITT frequency specification for 6 MHZ sound IF (intermediate frequency):

3.1.1 The standardized free network

The idea of a 'standardized free network' was first propagated by Dr. Hiroshi Harashima, Professor of the University of Tokyo [9]. He considers that a fundamental solution to standardisation may only be obtained when network systems are developed to a form that requires little or no standardisation.

A practical solution would be to choose a standard compatible with a large percentage of existing technologies, yet adaptable with ease to emerging standards. It is the author's belief that such a system standard should also be understood by the user, as referred to in the second paragraph on page 2 in the introduction to this dissertation.

3.1.2 Media players

If images or visuals are stored on CD's or magnetic tape, then the players for these media are recognised to be multimedia players or input devices [9]. The T.B.T. system, and consequently the RF bandwidth switch, should therefore be fully compatible with all the input devices of multimedia, including unintelligent players of 4 track magnetic tape (audio), VHS magnetic tape (audiovisual), CD (audio), CDROM (audiovisual), laser diskette (audiovisual).

3.1.3 Communication networks

For broadband analogue video, also referred to as the composite baseband for video and audio, 6MHz of RF bandwidth is required for each channel when considering PAL system I.

Transmission channels should be placed two frequency channels apart, to minimise adjacent channel interference. Relatively large RF bandwidth is thus required when planning several channels operating simultaneously.

Coaxial cable and optical fibre are most suited for local area transmission networks supporting multimedia, when considering their wide bandwidth capabilities. Coaxial cable carries a relatively large RF bandwidth, from DC to upwards of 750 MHz [10]. The added advantage of conventional coaxial cables is tremendous industrial support, whilst remaining fully compatible with optic fibre cable and microwave radio via suitable translator interfacing, as well as cost-effective.

3.1.4 The Radio Act (Act 3 of 1952)

The Radio Act, Act 3 of 1952, regards "wired or cabled systems for the reception and distribution of sound and television transmissions in the frequency bands 87,5-108 MHz 174-254 MHz, and 470-854 MHz *not to be* radio apparatus for the purposes of the said Act", and therefore require no licensing in terms of the Act.

3.1.5 Availability of components for development

Components supporting PAL system I are freely available with favourable costing implications. This situation is expected to remain stable as long as PAL is retained as a world wide television standard.

3.1.6 Compatibility with associated technology

The advantages gained by desktop computer systems in terms of video compression and storage techniques is augmented when supported by realtime media players. PAL system I facilitates realtime video and corresponding FM quality audio information exchange with desktop systems.

3.1.7 Practical considerations

The primary transmission format accommodates composite RF transmission of video and audio per the specified frequency plan, as well as composite video an audio on separate cables. For transmission, the RF frequency plan is preferred, mainly because the video and audio information is integrated on a single medium, and thus eliminates echo's and delays as experienced with PC driven desktop T.B.T. systems.

3.2 SPECIFICATION OF THE PRIMARY TRANSMISSION FORMAT

The following specifications are adopted for system model development. Please note that these specifications will be used within the sphere of the development of the RF bandwidth switch, but may also be used for specification of the entire distribution network.

The selected primary transmission format, namely PAL system I [11], may be broadly specified in terms of its CCITT frequency planning per geographical destination and channel allocation, with the aid of two suitable tables:

3.2.1 PAL system I frequency plan/destination

DESTINATION	CTV system	CHANNEL		RF MODULATOR
		Band IV	Band III	
EUROPE	PAL I, BG	21 - 68	2 - 4, 5 - 12	30 - 39 (36)
EUROPE cable TV	PAL BG	21 - 69	2-4, X, Y, Z S1, S2, S3-S19, 5-12	30 - 39 (36)
UK	PAL I	21 - 69	-	30 - 39 (36)
HONG KONG	PAL I	21 - 69	-	30 - 39 (36)
AUSTRALIA	PAL BG	21 - 69	3 - 4	3 - 4
SOUTH AFRICA	PAL I	21 - 69	4 - 13	30 - 39 (36)
MALAYSIA	PAL BG	21 - 69	2 - 4, 5 - 12	30 - 39 (36), 3 - 4
IRELAND	PAL I	21 - 69	A - C, D - J	30 - 39 (36)
NEW ZEALAND	PAL BG	21 - 69	2 - 3	2 - 3
INDONESIA	PAL BG	21 - 69	1 - 3, 4 - 9	2-3 IND, 3-4EUR

Table 3.1. PAL system I frequency/destination

Table 3.1 sets out the PAL system I frequency planning for destinations as indicated. It is interesting to note similarities between Europe, Hong Kong and South Africa, which implicate favourable availability of similar components at these destinations.

Table 3.2 sets out channel spacing with corresponding frequencies allocated. Vision carrier frequencies are expressed in MHz, and in each case the sound IF is 6-MHz higher than the indicated vision carrier.

3.2.2 PAL channel spacing and frequency planning

CHANNEL	VISION CARRIER	CHANNEL	VISION CARRIER	CHANNEL	VISION CARRIER
A	53,75	21	471,25	49	695,25
B	62,25	22	479,25	50	703,25
C	82,25	23	487,25	51	711,25
D	175,25	24	495,25	52	719,25
E	183,75	25	503,25	53	727,25
F	192,25	26	511,25	54	735,25
G	201,25	27	519,25	55	743,25
H	210,25	28	527,25	56	751,25
H1	217,25	29	535,25	57	759,25
H2	224,25	30	543,25	58	767,25
1	41,25	31	551,25	59	775,25
1A	42,25	32	559,25	60	783,25
2	48,25	33	567,25	61	791,25
2A	49,75	34	575,25	62	799,25
3	55,25	35	583,25	63	807,25
4A	62,25	36	591,25	64	815,25
4	175,25	37	599,25	65	823,25
5	183,25	38	607,25	66	831,25
6	191,25	39	615,25	67	839,25
7A	192,25	40	623,25	68	847,25
7	199,25	41	631,25	69	855,25
8A	201,25	42	639,25		
8	207,25	43	647,25		
9	215,25	44	655,25		
10	223,25	45	663,25		
11	231,25	46	671,25		
12	239,25	47	679,25		
13	247,43	48	687,25		

Table 3.2. PAL channel/frequency planning

Chapter 4

PROTOTYPE DEVELOPMENT OF RF BANDWIDTH SWITCH

This chapter sets out the specifications of an RF bandwidth switch to be used in a T.B.T. system model, as well as the development of the electronics.

The prototype circuitry will first be specified in terms of its expected electrical inputs and outputs, where after each section will be specified and dealt with separately during the development of the electronics, namely the *combiner*, *the selector* and *the modulator* respectively.

The chapter is concluded with setup and test procedures.

4.1 SPECIFICATION OF RF BANDWIDTH SWITCH

4.1.1 Block diagram of RF bandwidth switch

Figure 4.1 shows the block diagram of the bandwidth switch. All electrical inputs and outputs are indicated. A separate ganged switching feature for composite video and audio is included.

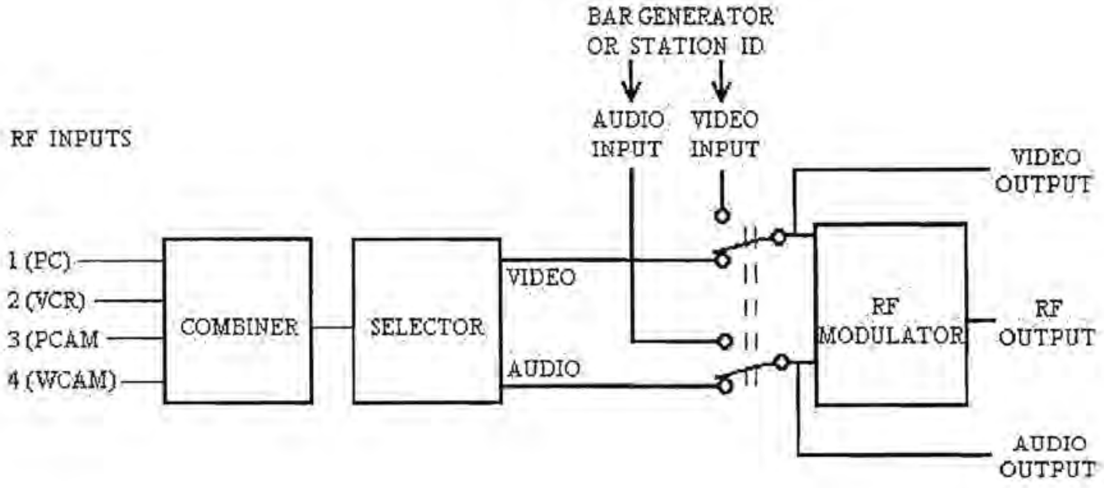


Figure 4.1. Block diagram of RF bandwidth switch.

The ganged switching arrangement provides for an additional video/audio input such as colour bar generator, or station ID (identification) screen, that may be generated by a PC, electronic generator or VCR. This feature is required to incorporate a method of transmission activation or deactivation, while maintaining warm standby condition at all times. For the purpose of the thesis it shall be known as the activation function switch.

4.1.2 **Electrical inputs and outputs**

Inputs and outputs for the prototype are specified in corresponding sections for video, audio and RF.

4.1.2.1 Video

Input voltage:	0,5 - 2,0 Vp-p
Input impedance:	75 ohm
Output voltage:	1 Vp-p, typically
Output impedance:	75 ohm

4.1.2.2 Audio

Input level:	-10 dBm
Output level:	-5 dBm
Output impedance:	High, typically 600 ohm
Frequency response:	50Hz - 10kHz

4.1.2.3 RF (Radio Frequency)

Input RF bandwidth:	174-254 MHz and 470-854 MHz
Input channel bandwidth:	6MHz
Input RF level:	60 dB/μV to 90 dB/μV
Input impedance:	75 ohm
Number of inputs:	Minimum 4
Output RF bandwidth:	Ch 30 - Ch 39. Typ Ch 36
Output RF level:	Typically 75 dB/μV
Output impedance:	75 ohm
Overall S/N:	better than 40 dB
Noise figure:	better than 3 dB

4.1.3 Combiner

The function of the combiner is to accept a minimum of four inputs of RF bandwidth at separate channel frequencies, and combine them to a common broadband output.

The four input channels are allocated for most common sources of media; a video cassette recorder (VCR), a personal computer (PC) and two camera inputs (CAM1/2). An auxillary channel for electronic whiteboard input is nice to have, as well as a commercial television input. Specifications are as follows:

Type:	broadband transformer type
Frequency range:	174 MHz to 854 MHz
Characteristic impedance:	75 ohms
Insertion loss:	less than 14dB across the band.

4.1.4 Selector

The function of the selector is to pre-select any one of a minimum number of four RF inputs, and to extract the modulated video and audio information. To achieve high selectivity and sufficient adjacent channel rejection, combined with relative broadband operational capabilities, the selector requires two integrated RF superheterodyne receiver sections in a single tuner section for signal selection. A common intermediate frequency (IF) section will extract the vision intermediate frequency (VIF) and the sound intermediate frequency (SIF), and consequently the composite video and audio components of the signal. The selector will require AFC (automatic frequency control) and AGC (automatic gain control) circuitry, as well as a sophisticated IF filter to keep the IF stable and at a constant level. This is a crucial requirement to ensure satisfactory operation.

4.1.5 RF modulator

A wide range of modulators designed for use in AV and cable TV applications is available in the industry. It is believed that a suitable unit may be easily obtained which requires little or no modification to be utilised in the prototype.

4.1.6 Power supply requirements

The RF bandwidth switch is specified to operate from a single 12VDC power source. The reason for this is twofold: the latest manufacturers' trend is to design electronic equipment to run from external DC supplies, and supporting this trend, renders manufactured equipment to be world standardised even though AC mains voltages differ between countries.

4.2 DEVELOPMENT OF THE ELECTRONICS

The combiner is regarded as the nerve centre of the RF bandwidth switch. In the development of the electronics for the RF bandwidth switch, this study will therefore be focused upon the combiner, selector and modulator in the descending order of their importance.

For the purpose of explanation, it was decided to extract most relevant information from a literature study conducted by the student, to be presented in Annexure A to this dissertation.

4.2.1 Hybrid combiner for RF bandwidth switch

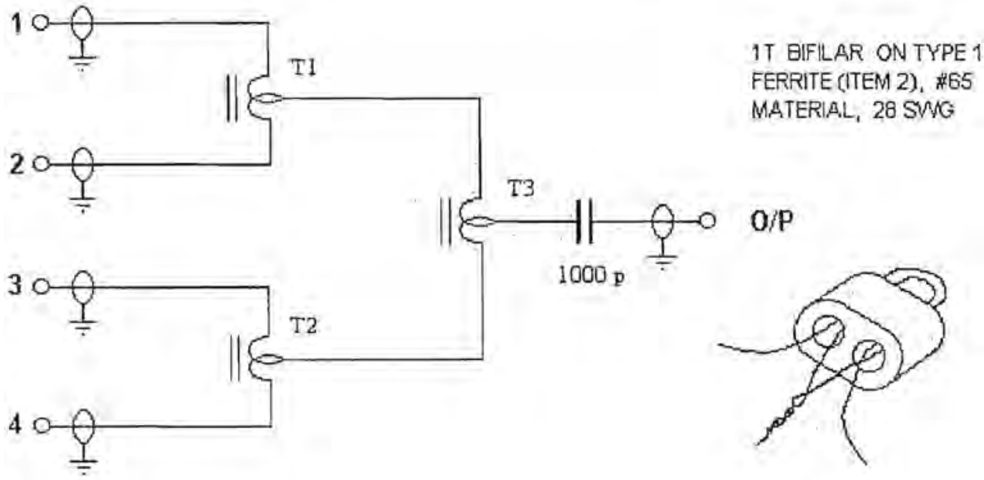


Figure 4.2 Cascaded hybrid for RF bandwidth switch.

The circuit initially considered, as depicted in Figure 4.2, provides for three broadband transmission line transformers, accepting four PAL I RF inputs in the frequency range as specified. Inputs are evenly spaced across the RF bandwidth, spaced at two channel intervals.

The output is via a 1000pF capacitor to eliminate unwanted DC components that may be present on the input signal. The minimum recommended RF signal level for PAL system I is 60-dB/μV. Most commercial modulators have their RF output levels set to around 80-dB/μV.

Four commercial modulators were obtained for test purposes, and their outputs were measured at 80, 76, 74 and 81 -dB/μV respectively, which yields an average of around 78-dB/μV. The maximum acceptable insertion loss across the combiner circuitry would therefore be around 18-dB.

The inductance of the single broadband transformer had to be determined at the low end of the operating frequency band, as well as at the high end of the same. To determine the inductance at the low end of the band, the inductance was measured with a Hewlett-Packard 4260A universal LCR bridge. The measurement indicated an inductance of 0,2-uH, expected accuracy within 20%. The inductive reactance X_ℓ may now be calculated for the low end of the operating band (170 MHz), where $X_\ell = 2.\pi.f.\ell$, which yields 213,6-ohm.

At high frequency, and since the effects of the ferrite vanish electrically at high frequency, the inductance was first calculated using the formula [12]:

$$L(\mu H) = \frac{d^2 n^2}{18d + 40\ell} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

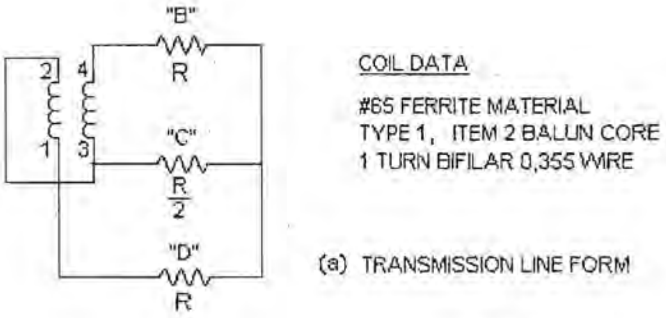
where L = inductance in microhenrys, ℓ = coil length in inches, n = number of turns, and d = coil diameter in inches. Substituting with $d = 0{,}16"$, $\ell = 0{,}05"$, and $n = 2$, then $L = 0{,}021$-μH.

The calculation was confirmed by connecting a known value silver mica capacitor (0,47-pF 5%) across the inductor, and measuring the resonant frequency (519-MHZ) of the tuned circuit with a grid dip meter. Since $f_r = \frac{1}{2\pi\sqrt{LC}}$, the value of L = 0,02-μH. Accuracy of this measurement is subject to the tolerance of the known value capacitor, rated at 5%. This value for L equates to an inductive reactance of 88-ohms at the high end of the band.

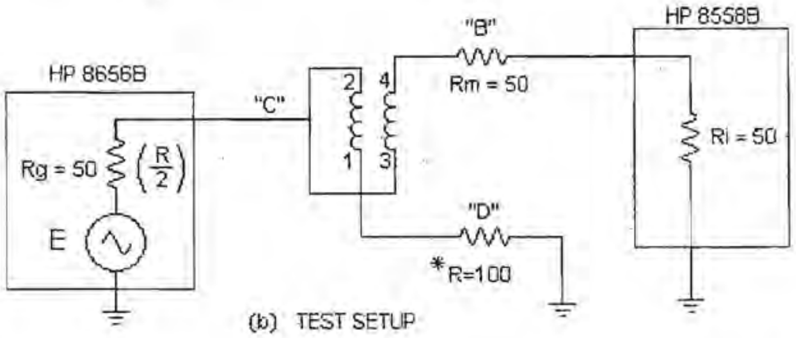
To determine the effects of insertion loss across the combiner, two measurements were conducted. The insertion loss characteristics vs. frequency for a single transformer was firstly determined, where after the insertion loss vs frequency across the cascaded transformers, i.e. complete combiner was measured.

4.2.1.1 Insertion loss across a single broadband hybrid.

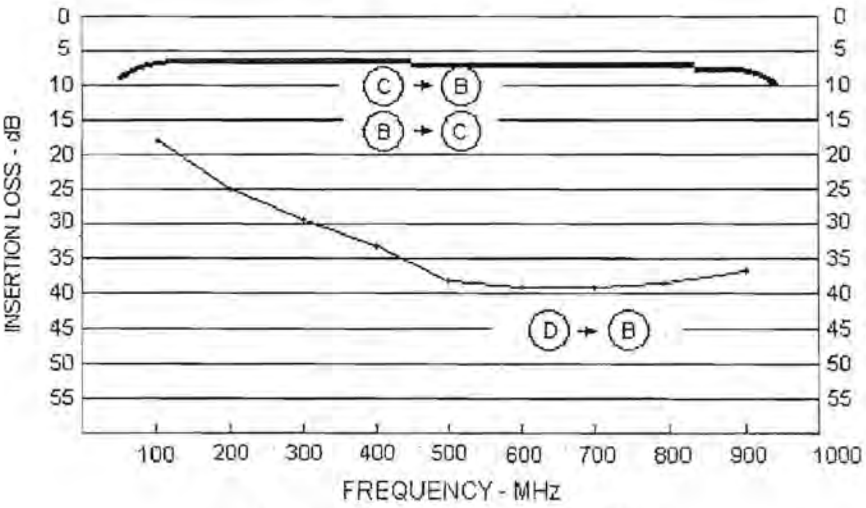
The transmission characteristics for a single hybrid is depicted in Fig. 4.3.



(a) TRANSMISSION LINE FORM



(b) TEST SETUP



(c) TRANSMISSION CHARACTERISTICS

Figure 4.3. Single hybrid combiner : Insertion loss vs. frequency.

The response of the hybrid in Fig. 4.3.a is depicted in Fig. 4.3.c. For this measurement R = 100-ohms. In order to measure the hybrid in a 50-ohm circuit, arms B and D were measured with a 50-ohm resistor in series with the 50-ohm measuring gear. This accounts for 3 dB additional loss observed. The return loss between arms C and B is tabulated below:

Transmission characteristics C to B for single hybrid with arm D terminated in 100-ohms.									
Insertion loss (dB)	-7	-6	-6	-6	-6,2	-6,2	-6,5	-7	-8
Frequency (MHz)	100	170	340	430	510	600	680	840	920

Table 4.1

The test set-up was calibrated by setting the HP8656B generator output to 0dBm at 100-MHz, and the reading observed as 0dBm on the HP8558B measuring gear. This reading was confirmed by measuring the true RMS voltage of the generator output with a RACAL-DANA 9302 RF-millivolt meter, which yielded 223 mV-RMS.

Set at 170-MHz, the 50-ohm series resistor R_m was installed at the input port of the HP8558B, and the reading observed as -3dBm. Next, the generator output was fed to port C and the response observed as -6bBm at port B, with port D terminated in 100-ohms.

Measurements made at 170-MHz, 340-MHz and 430-MHz all yielded -6dBm. At 510-MHz the reading is tabulated as -6,2dBm, also at 600-MHz. The response falls to -6,5dBm at 680-MHz, -7dBm at 840-MHz, and to -8dBm at 920-MHz. The measurements were repeated with arm D open circuit:

Transmission characteristics C to B for single hybrid with arm D open circuit.									
Insertion loss (dB)	-6	-6,5	-7,5	-7	-6,5	-6	-6,5	-7	-7,5
Frequency (MHz)	100	170	340	430	510	600	680	840	920

Table 4.2

Isolation between arms B and D were measured with arm C terminated in 50-ohms. For this measurement a 50-ohm resistor was connected in series with the 50-ohm generator as well, as shown in Fig 4.3.d, similar to the series resistor used with the HP8558B in Fig. 4.3.

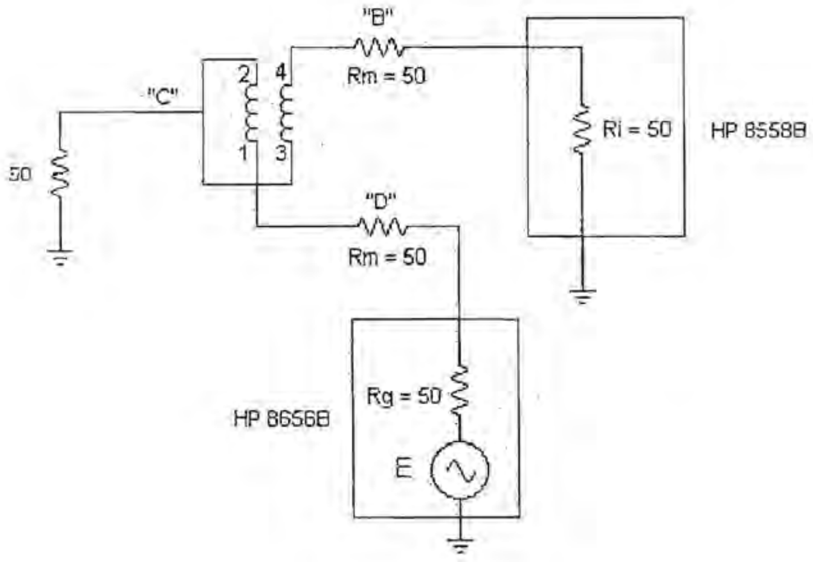


Fig. 4.3.d. Test setup for isolation measurement

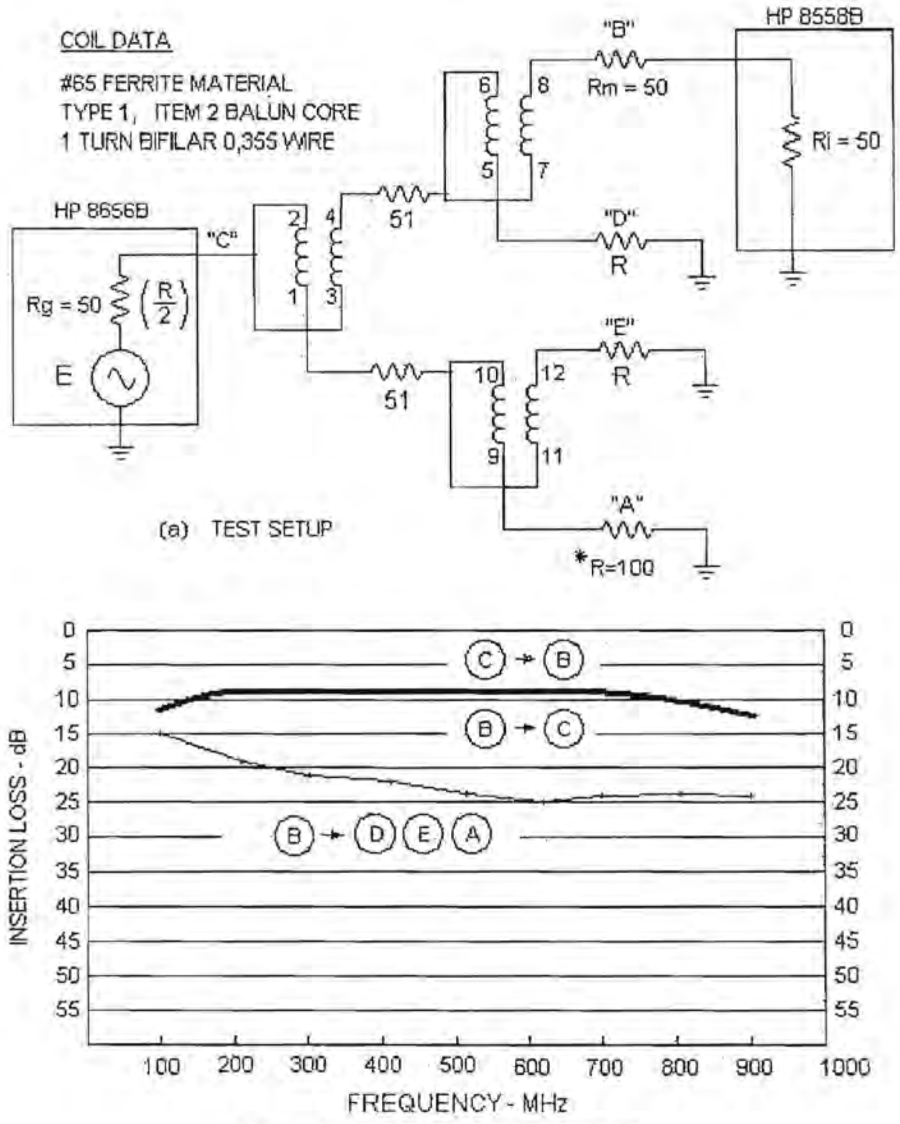
The results are tabulated below:

Isolation characteristics between B and D for single hybrid with arm D = 50-ohms.									
Isolation (dB)	18	25	29	34	38	39	39	38	37
Frequency (MHz)	100	200	300	400	500	600	700	800	900

Table 4.3

It was noted that the 50-ohm termination resistor's value at port C is critical to obtain optimum isolation between ports B and D. Adjusting this value by 50% reduces the isolation by approximately 15 dB in the high frequency operating range between 400 and 600-MHz.

4.2.1.2 **Insertion loss across cascaded broadband hybrid.**



(c) TRANSMISSION CHARACTERISTICS

Figure 4.4 Cascaded hybrid combiner

As shown in Figure 4.4, the measurements were conducted with the D, E and A arms terminated in 100-ohms, and repeated with the inputs open circuit. Series resistors (51-ohm chip resistors) were inserted between cascaded sections to prevent mismatched operation. The resistors were selected for their low noise characteristics, but were unfortunately not available in 50-ohm.

Transmission characteristics C to B for cascaded hybrid with arm D, E and A = 100-ohms.									
Insertion loss (dB)	11	9	9	9	9	9	9	10	12
Frequency (MHz)	100	200	300	400	500	600	700	800	900

Table 4.4

The measurements were repeated with arms D, E and A open circuit:

Transmission characteristics C to B for cascaded hybrid with arms D, E and A open circuit.									
Insertion loss (dB)	9	8	7,5	8	8,5	8	8	10,5	12,5
Frequency (MHz)	100	200	300	400	500	600	700	800	900

Table 4.5

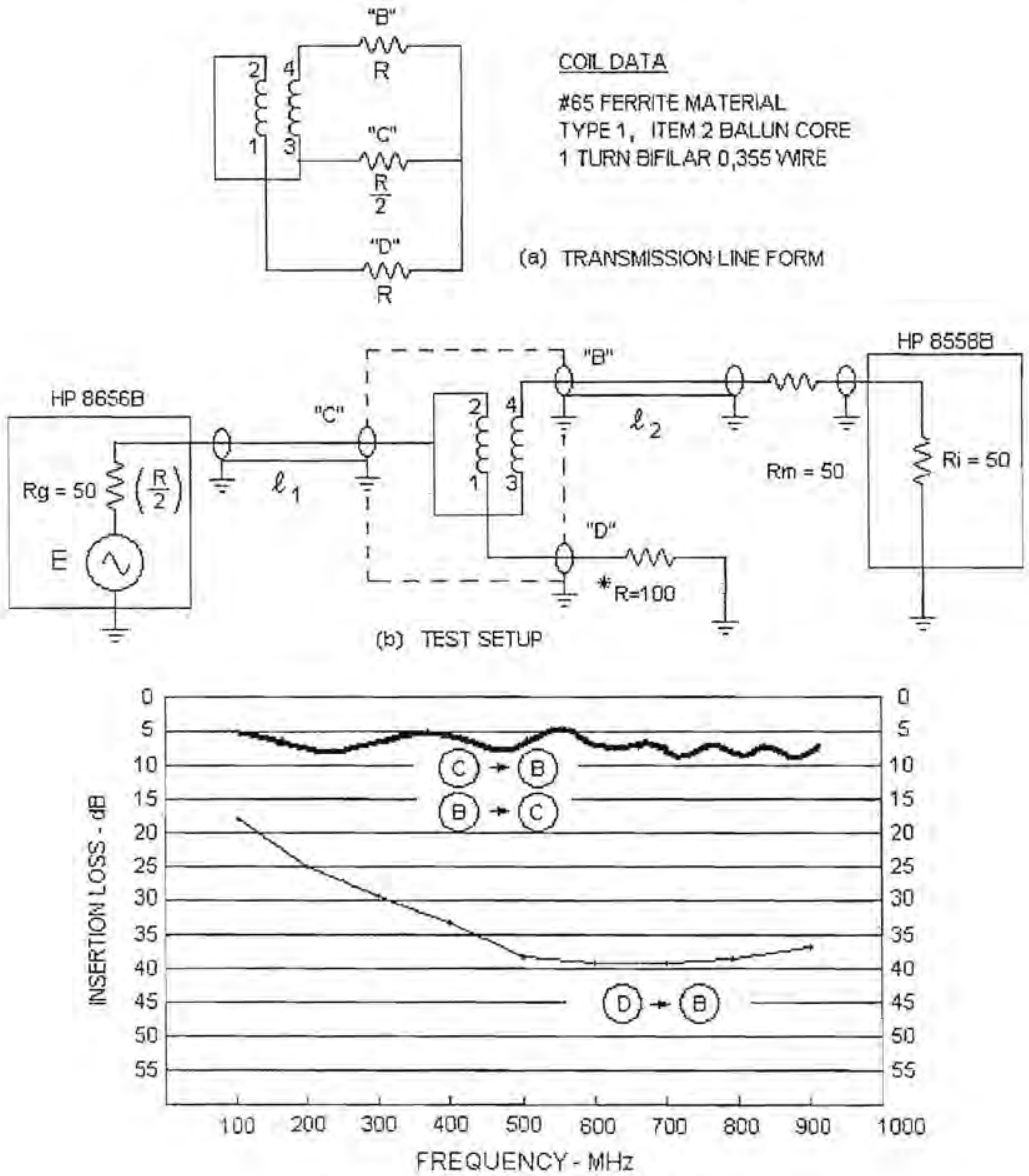
Isolation between arms B and DEA were measured with arm C terminated in 50-ohms. As with the isolation measurement for a single hybrid, a 50-ohm resistor was connected in series with the generator as well. The results are tabulated below:

Isolation characteristics between B and D for cascaded hybrid with arm C = 50-ohms.									
Isolation (dB)	15	19	21	22	24	25	24	23	24
Frequency (MHz)	100	200	300	400	500	600	700	800	900

Table 4.6

4.2.1.3 **Recurring pattern mismatch**

The results depicted in Fig. 4.3 appears to conform to the theory described in Annexure A to the thesis, until the transmission characteristics are measured at 10-MHz intervals. The results may be described as a near sinusoidal recurring pattern that appears to be superimposed upon the transmission characteristic curve of insertion loss vs. frequency.



(a) TRANSMISSION LINE FORM

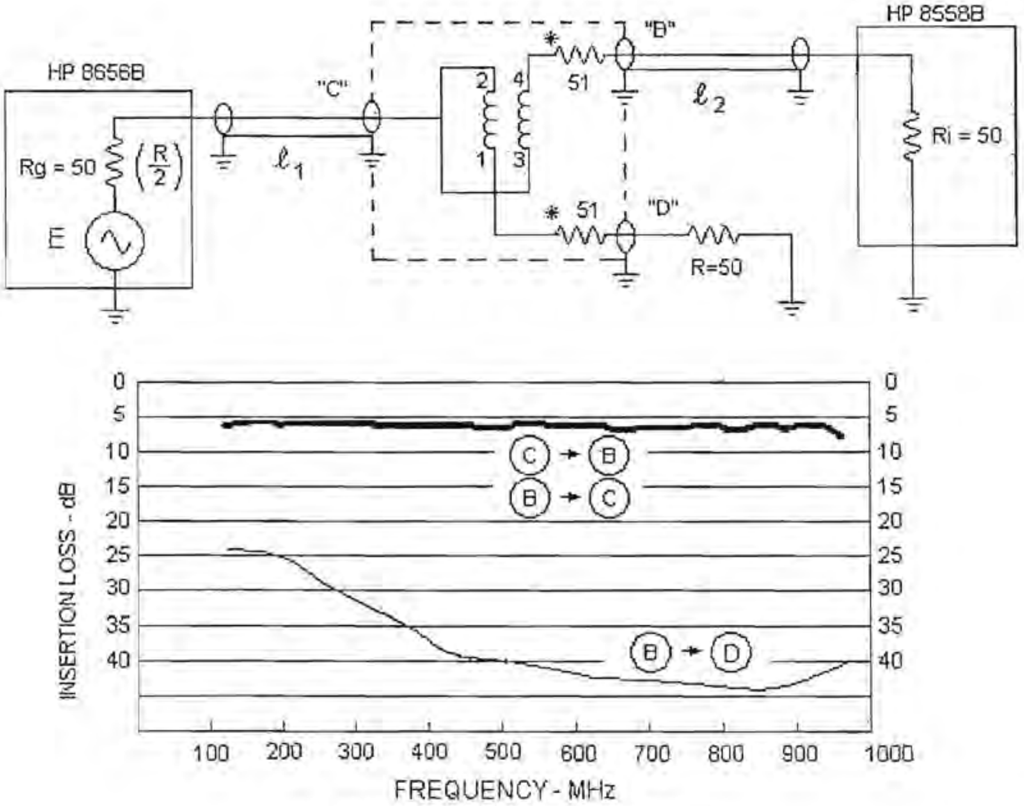
(b) TEST SETUP

(c) TRANSMISSION CHARACTERISTICS

Fig.4.5 Recurring pattern mismatch

As seen in Fig. 4.5, the series resistor R_m was placed in line with the HP8558B, approximately 25-cm (the length of ℓ_2) away from the hybrid. The resistor was realised by placing a 51-ohm resistor inside a 20-mm length of brass tubing, with a male and female BNC connectors at the ends. The apparent frequency of variation of the pattern lowered by shortening ℓ_2 to 15-cm, as did the apparent deviation of the recurring pattern.

The series resistor was then moved back towards the hybrid, and finally mounted inside the hybrid enclosure, with optimum results. The resistor finally used for this purpose was a 51-ohm chip resistor, and was duplicated in the D arm of the hybrid. The device could now be measured with standard 50-ohm measuring gear, without additional matching of load to generator, as shown in Fig. 4.6 below:



(b) TRANSMISSION CHARACTERISTICS

Fig. 4.6 Matched 50-ohm hybrid

Results are tabulated under column 1 in Table 4.7. The key to the table follows at the end.

Table 4.7. Transmission characteristics

f (MHz)	1	2	3	4	5	6	7
130	-5,5	-5	-24	-12	-10	-27	-5,5
140	-6	-5	-25	-12	-10,5	-27	-6
150	-6	-5,5	-25,5	-12	-10,5	-28	-6
160	-6	-6	-26	-12	-11	-28	-6,5
170	-6	-6	-27	-12,5	-11	-28	-7
180	-6	-6	-27,5	-12,5	-11	-28	-7
190	-5,5	-6	-28	-12	-11	-28	-7
200	-6	-5,5	-28	-12	-10,5	-27,5	-6,5
210	-5,5	-6	-28,5	-11,5	-10,5	-27	-6,5
220	-5,5	-6	-29	-11,5	-10,5	-27,5	-6
230	-5,5	-6	-29,5	-12	-10,5	-27,5	-6
240	-5,5	-6	-30	-12	-10,5	-28	-6
250	-5	-5,5	-30	-12	-11	-27,5	-6
260	-5	-5,5	-30	-12	-10,5	-27	-6,5
270	-5	-5,5	-30,5	-11,5	-11	-27	-6,5
280	-5	-6	-31	-11,5	-11	-26,5	-7
290	-5	-6	-32	-11,5	-11,5	-27	-7
300	-5	-6	-32,5	-12	-11	-27	-7
310	-5,5	-6	-33	-12	-11	-27,5	-7
320	-5,5	-6	-33,5	-12	-10,5	-28	-7
330	-5,5	-6	-34	-12	-10,5	-28	-7
340	-6	-6	-34,5	-12,5	-11	-28	-7,5
350	-6	-6	-34,5	-12,5	-11	-28	-7,5
360	-6	-6	-35	-12,5	-12	-27,5	-8
370	-6	-6,5	-36	-12,5	-12,5	-27,5	-8,5
380	-6	-7	-37	-12,5	-12,5	-28	-8

f (MHz)	1	2	3	4	5	6	7
390	-6	-7	-37,5	-12,5	-12,5	-28	-8
400	-6	-6,5	-38	-12	-12	-28	-8
410	-6	-6,5	-38,5	-12,5	-12	-28	-8
420	-6	-6	-38,5	-12	-11,5	-27,5	-7,5
430	-6	-6	-39	-12	-11,5	-27,5	-7,5
440	-5,5	-6	-39,5	-12	-12	-27	-8
450	-6	-6	-40	-12	-12	-27	-8
460	-6	-6	-40,5	-12	-11,5	-28	-8
470	-6	-6	-40,5	-12,5	-11	-28	-7,5
480	-6	-6,5	-40,5	-12,5	-11	-28	-8
490	-6	-6	-40,5	-13	-11,5	-28	-8
500	-6,5	-6	-40,5	-13	-12	-27,5	-8,5
510	-6	-6	-40,5	-12,5	-12,5	-27	-8,5
520	-6	-6	-41	-12	-12	-26	-8,5
530	-5,5	-5,5	-42	-12	-12	-26	-8
540	-5,5	-5,5	-42,5	-11,5	-11,5	-26,5	-8
550	-5,5	-5,5	-42	-12	-11	-27	-7,5
560	-6	-5	-42	-12	-11	-27	-7,5
570	-6	-5	-41	-12,5	-12	-27	-8
580	-6	-5	-40,5	-12,5	-13	-27	-9
590	-6	-5	-40,5	-13	-13,5	-26,5	-10
600	-6	-5,5	-41	-13	-14	-26	-10
610	-6	-5,5	-41	-12,5	-14	-26	-10
620	-6	-5,5	-42	-12,5	-14	-26	-9,5
630	-6	-5	-42	-12,5	-13,5	-26,5	-9,5
640	-6	-5	-42	-13	-14	-27	-10

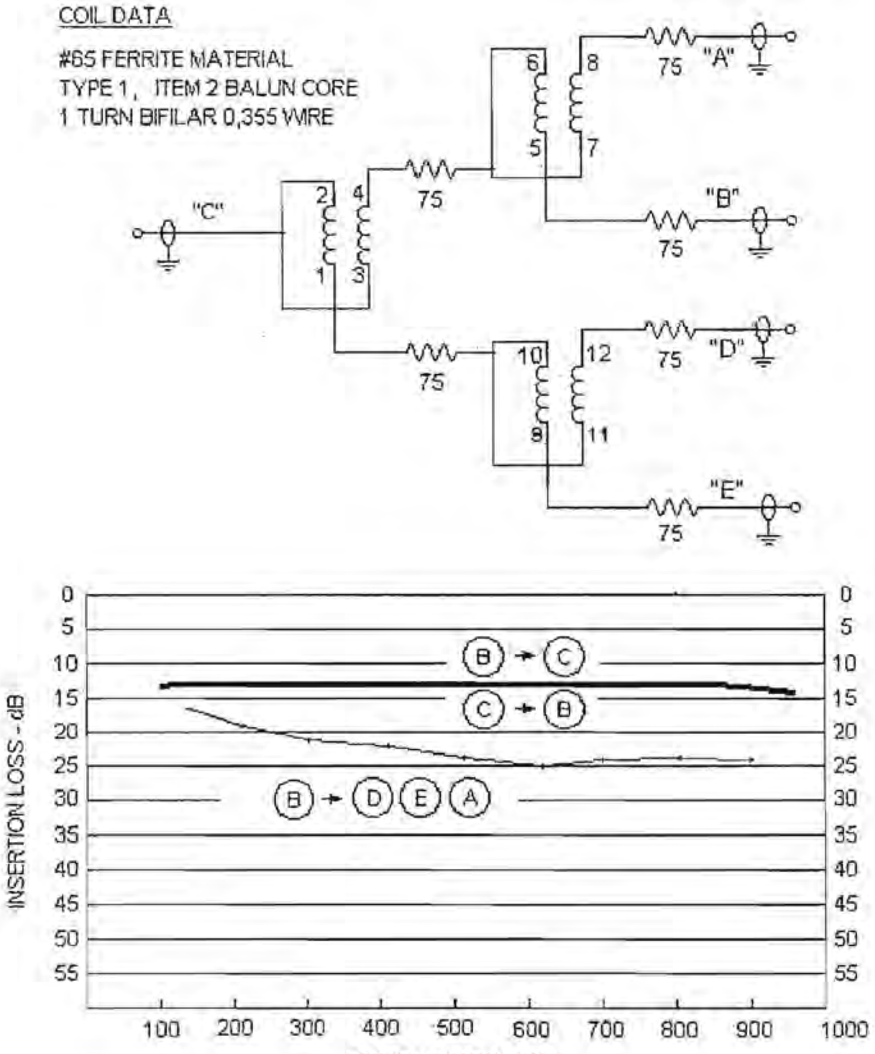
f (MHz)	1	2	3	4	5	6	7
650	-6,5	-5,5	-42	-13,5	-14,5	-27	-10,5
660	-6,5	-6	-41,5	-13,5	-15	-26	-11
670	-6,5	-6	-42	-13	-15,5	-26,5	-12
680	-6	-6	-42	-13	-16	-25	-12
690	-6	-6	-43	-13	-15,5	-25,5	-11,5
700	-6	-6	-43,5	-13	-15	-26	-11
710	-6	-6	-44	-13	-15	-26	-11
720	-6,5	-6,5	-44	-13,5	-15,5	-26,5	-12
730	-6,5	-6,5	-44,5	-13,5	-16	-26,5	-12
740	-7	-7	-45	-14	-16	-26	-12,5
750	-6,5	-7	-46	-13,5	-16	-25,5	-12,5
760	-6	-7	-47	-13	-15	-25,5	-12
770	-6	-6,5	-48	-12,5	-14	-26	-10
780	-6	-6,5	-48	-12,5	-13,5	-26,5	-9,5
790	-6	-6	-48	-12,5	-13,5	-27	-9,5
800	-6	-6	-47,5	-13	-14	-27,5	-10,5
810	-6,5	-6	-47	-13	-15	-27,5	-11
820	-6,5	-6	-46,5	-13,5	-15,5	-27	-12
830	-6,5	-6	-47	-13	-15,5	-26,5	-12
840	-6	-6	-48	-13	-15	-26,5	-11
850	-6	-6	-48	-12,5	-14,5	-27	-10,5
860	-6	-6	-47,5	-12,5	-14,5	-27,5	-10,5
870	-6	-5,5	-47	-13	-15	-28	-11
880	-6,5	-5	-46	-13	-16	-28	-12
890	-6,5	-5	-45	-13	-16	-27	-12,5
900	-6	-5	-44	-13	-16,5	-26,5	-12,5

f (MHz)	1	2	3	4	5	6	7
910	-6	-5	-44	-13	-16	-26,5	-12
920	-5,5	-5,5	-43,5	-12,5	-15,5	-26	-12
930	-6	-5,5	-43	-13	-15,5	-27	-11,5
940	-6,5	-6	-43	-13,5	-16	-28	-12
950	-7	-6	-43,5	-14	-17	-29	-13
960	-7,5	-6,5	-43	-14,5	-18	-29	-14
970	-7,5	-6,5	-42	-14,5	-18,5	-28	-14,5
980	-7	-6	-40	-14	-18	-27,5	-14
990	-7	-6	-38	-14	-17,5	-27	-13,5

Table key :

1. Single matched hybrid insertion loss (C-B), port D = 100-ohm
2. Single hybrid insertion loss (C-D), port D = open circuit.
3. Single hybrid isolation (B-D), C = 50-ohm.
4. Cascaded matched hybrid insertion loss (C-D), D E and A = 200-ohm.
5. Cascaded hybrid insertion loss (C-B), D E and A = open circuit.
6. Cascaded hybrid isolation (B-D), E = 200-ohm, F = 200-ohm, C = 50-ohm.
7. Cascaded hybrid insertion loss, unmatched with no termination or series resistor.

4.2.1.4 **Matched 75-ohm cascaded hybrids for signal combining and splitting.**



(c) TRANSMISSION CHARACTERISTICS

Figure 4.7 Matched 75-ohm cascaded hybrid

The circuit depicted in Figure 4.7 is matched to 75-ohm characteristic input and output impedances. The disadvantage of inserting 75-ohm matching resistors is an increase in return loss across the circuit, to around 13-dB across the operating frequency band. Isolation characteristics and flatness are however improved when compared with an unmatched hybrid, especially at the high end of the operating band. The circuit may serve as a signal combiner at the front end of the bandwidth switch, as well as a signal divider at the output of the same, in order to obtain multiple forward connections.

4.2.2 Development of the selector electronics

The selector consists of separate RF and IF sections, which will be described in the following subsections:

4.2.2.1 RF section

Figure 4.8 indicates the block diagram of a combined RF section (SANYO part number 4-115V-17400), for operation in band III (175 - 248 MHz) as well as band V (470 - 860 MHz).

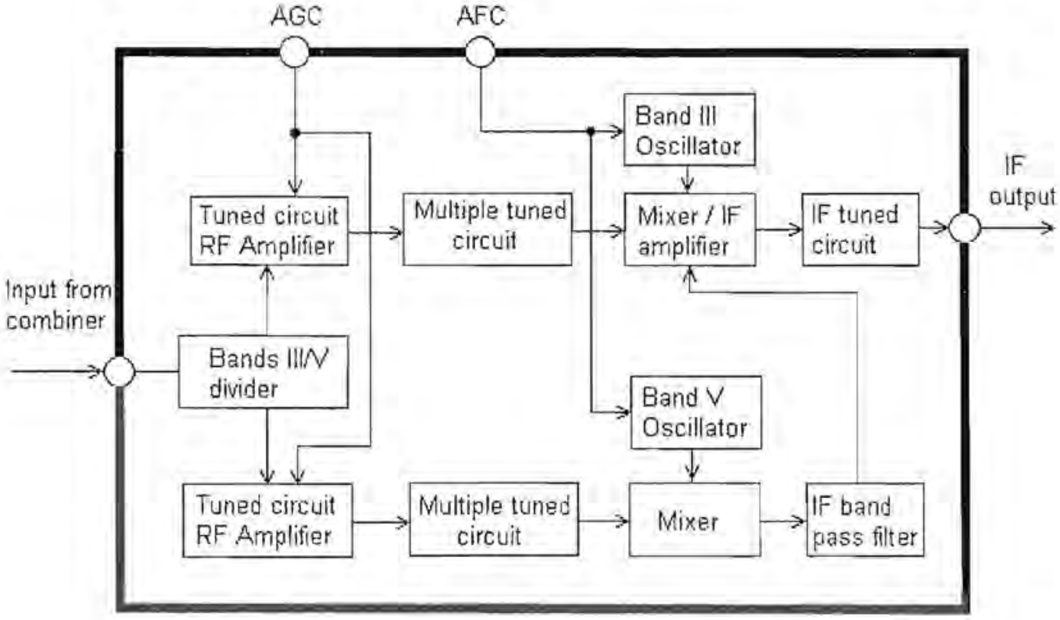


Figure 4.8 Block diagram of RF section

The frequency band divider employs a low pass filter and a high pass filter to divide the frequency bands III and V respectively.

The band III tuner and RF amplifier suppress all signals other than the desired channel signal. The AGC circuit is engaged by the signal strength and the output voltage is uniformly maintained.

The multiple tuned circuit has high selectivity characteristics and suppress all signals other than the desired signal.

The oscillator circuit generates the correct frequency required to convert the desired signal into an intermediate frequency (IF) signal.

The mixer/IF amplifier circuit functions as the band III mixer and band V IF amplifier. When band III signals are received, the output signal of the band III oscillator and the channel being received are mixed and converted into the IF signal. When band V signals are received, the circuit functions as an amplifier of the signal which is converted into the IF signal. The IF tuned circuit ensures that only the IF signal is present at the designated output.

The band V circuitry is a duplication of the tuned circuit/RF amplifier, the multiple tuned circuit, oscillator and the mixer that is also utilised by the band III section:

However, an additional IF bandpass filter with high selectivity characteristics is employed in the band V section to ensure that no unwanted signals are propogated to the mixer/IF amplifier.

4.2.2.2 VIF and SIF circuit

The VIF (vision intermediate frequency) and SIF (sound intermediate frequency) circuit were designed around the TA7607AP and LA1365, both large scale linear integrated circuits indicated as IC1 and IC2 respectively in Figure 4.9.

These circuits serve to obtain the required selectivity response and to amplify and detect the VIF signal and SIF (sound intermediate frequency).

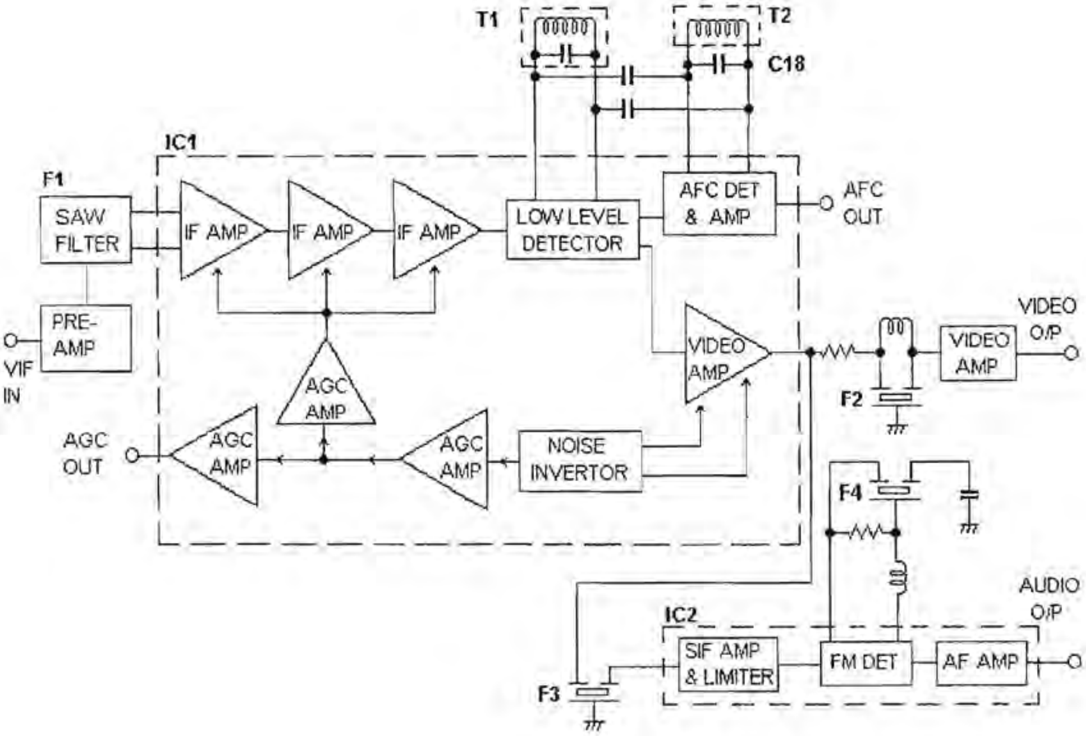


Figure 4.9 Block diagram of VIF and SIF circuits

The selectivity characteristics required are produced by the surface acoustic wave (SAW) filter F1. The SAW filter unfortunately also introduces a loss effect, therefore an amplifier is required to compensate for this loss.

In order to obtain a high signal-to-noise ratio, an emitter-earthed single stage amplifier Q1 is employed before the SAW filter as indicated in Figure 4.10.

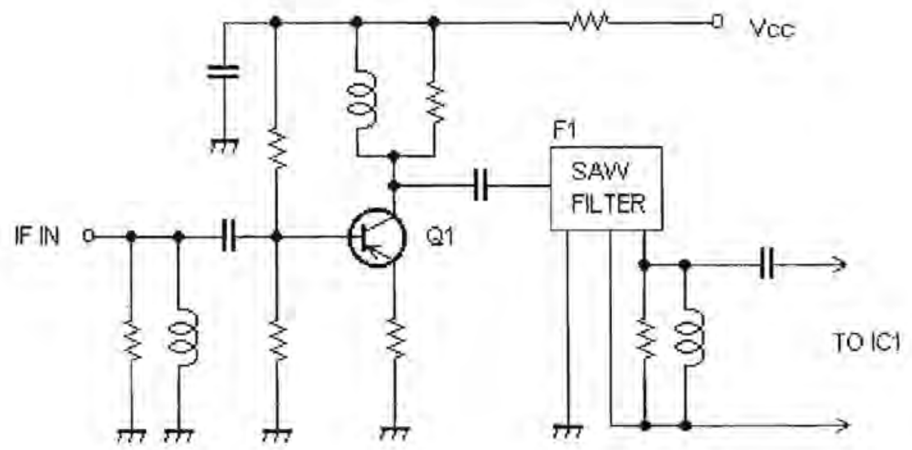


Figure 4.10 Pre-amplifier

The VIF signal enters IC1 from the SAW filter. IC1 contains the VIF amplifier, the video detector, the AFC circuit, as well as the AGC circuit.

The signal is amplified by a 3-stage variable gain IF amplifier. The amplified VIF signal is applied to a tuned circuit contained in T1, and sync detection is performed.

The detected video signal is amplified while its signal-to-noise ratio is simultaneously improved by the noise invertor circuit.

The AFC circuit comprises of T2 and C18, as indicated in Figure 4.11, and includes a phase shifter. The carrier output of the sync detector is applied to the phase shifter and as the phase is detected, a DC voltage proportional in magnitude to the VIF carrier is obtained.

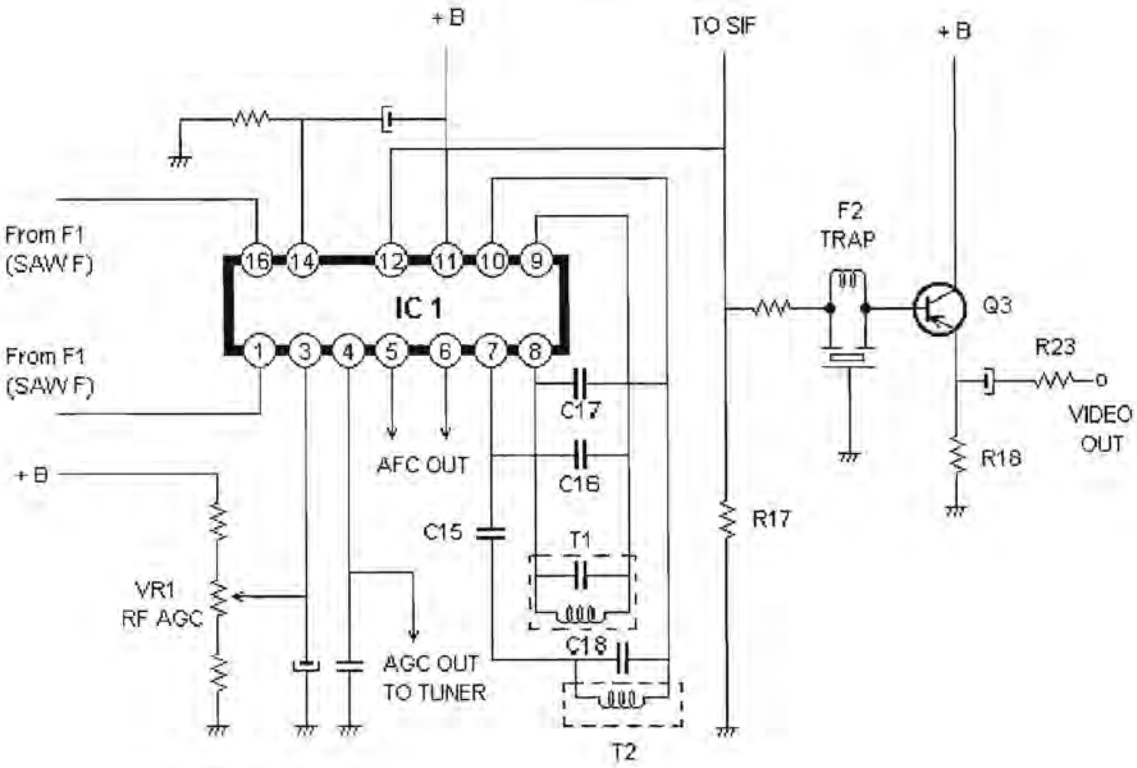


Figure 4.11 AFC and AGC circuits

The AGC circuit is required to maintain the video output at a constant level with respect to fluctuations in the RF input voltage. The control circuit takes the form of a peak AGC system.

The synchronising signal level of the video signal is detected, and the gain of the VIF amplifier circuit is varied accordingly, so that the output level is maintained at a fixed value.

The AGC voltage is supplied to the RF amplifiers contained within the preceding RF stage. When the RF input voltage is low, the RF AGC action ceases and the RF amplifiers function at maximum gain. Once the RF input voltage exceeds approximately 65 dB/uV, VR1 is set so that operation commences.

The level of the video signal detected by IC1 is set by R23 so that a 1V p-p output is obtained at the video output connector (75 ohm termination). The SIF signal contained within the video signal is eliminated by the ceramic trap F2.

Due to the fact that the level of the video signal detected is comparable to the level of the chromananace signal, the latter (4,43 MHz) is attenuated.

Finally, the high ouput impedance is reduced by the emitter follower stage and R18 is applied to set the output impedance to 75 ohms.

The SIF (sound intermediate frequency) signal which is contained within the video signal detected by IC1 is extracted by the ceramic filter F3 and supplied to IC2.

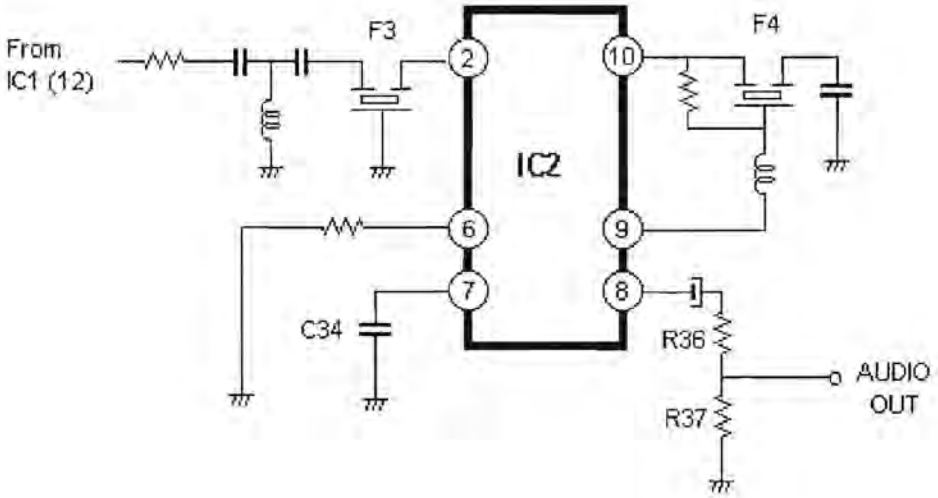


Figure 4.12 SIF circuit

IC2 contains an amplitude limiter circuit and an FM detector circuit. The SIF signal has its AM component removed by the amplitude limiter circuit. The signal is then fed to the differential peak detector circuit, and the sound signal is produced.

The sound signal has undergone pre-emphasis at the transmission end, and is now de-emphasised by C34 combined with the internal impedance of the IC, and the frequency response is smoothed. The audio output level is determined by R36 and R37.

A muting circuit is included for noiseless switching, that may be exploited when considering PC driven manipulation. For this purpose, a voltage forcibly applied to IC1 pin (14) will increase the AGC voltage for the IF amplifier, which will mute the video signal output as well as the SIF signal output.

The RF section utilised for the selection function uses varactor diodes to adjust various tuned circuits required for functional operation. These semiconductor devices are in essence variable tuning capacitors, their values dependend on the tuning voltage applied at any given time.

Tuning is realised by a variable resistor network connected across a 30-VDC power supply rail. (See para 4.2.3). With a desired bandwidth and channel, the wiper of the selector variable resistor is rotated until the channel centre frequency is observed.

Several circuits may be preset to different centre frequencies along the frequency plan. Each circuit is selected by means of a physical switch for manual operation, or reed-relays for manipulation by PC.

An AFC defeat circuit is included to prevent AFC misoperation. When operating AFC mode this circuit momentarily shuts off the AFC during channel-change operation to prevent AFC mis-operation.

The detailed VIF and SIF circuits are indicated in Figures 4.13.a and 4.13.b respectively. Figure 4.13.c depicts the channel pre-set and select circuitry. Labelled terminal blocks represent electrical connections between circuits. The RF section is shown connected to the VIF circuit for operation with AFC and AGC.

The SIF circuit is indicated separately, but forms an integral part of the VIF printed circuit. Plugs are indicated separately but are one and the same for all circuits.

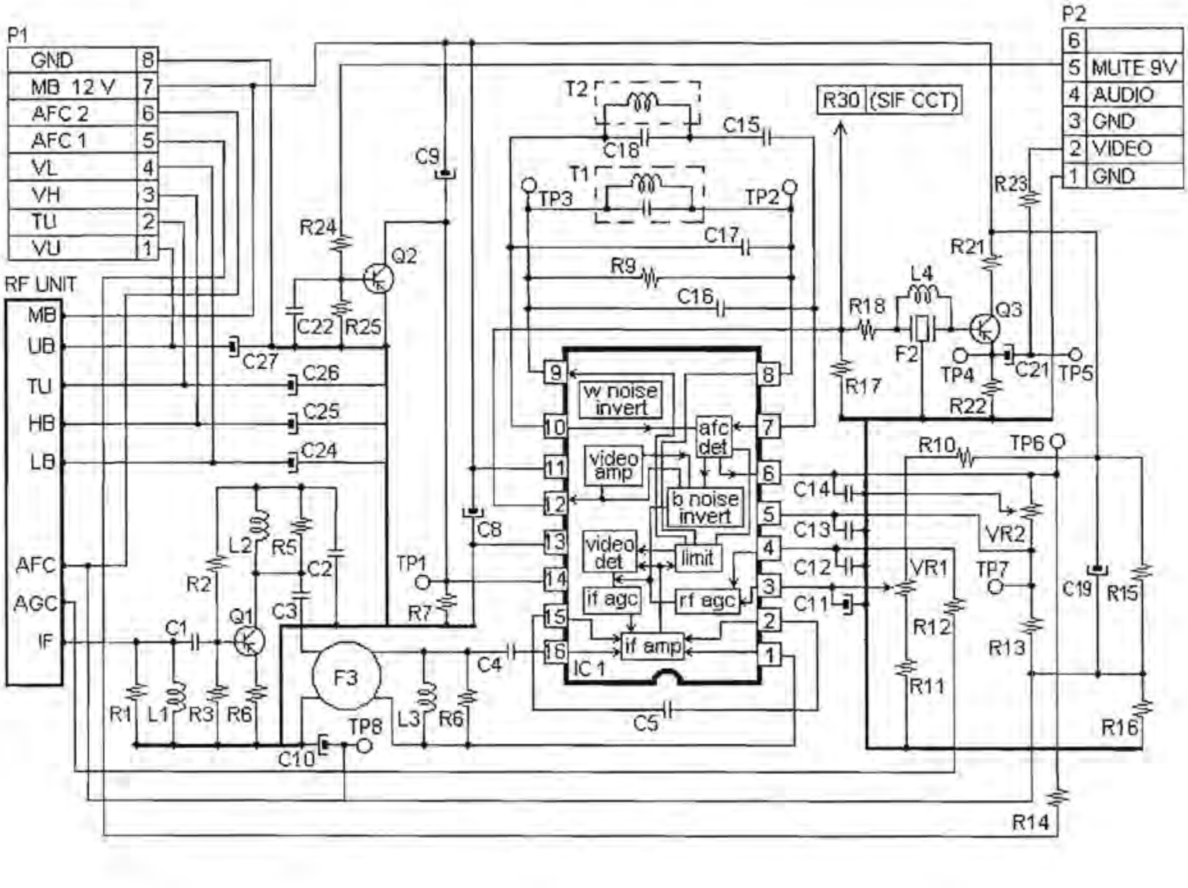


Figure 4.13.a Detailed VIF circuit

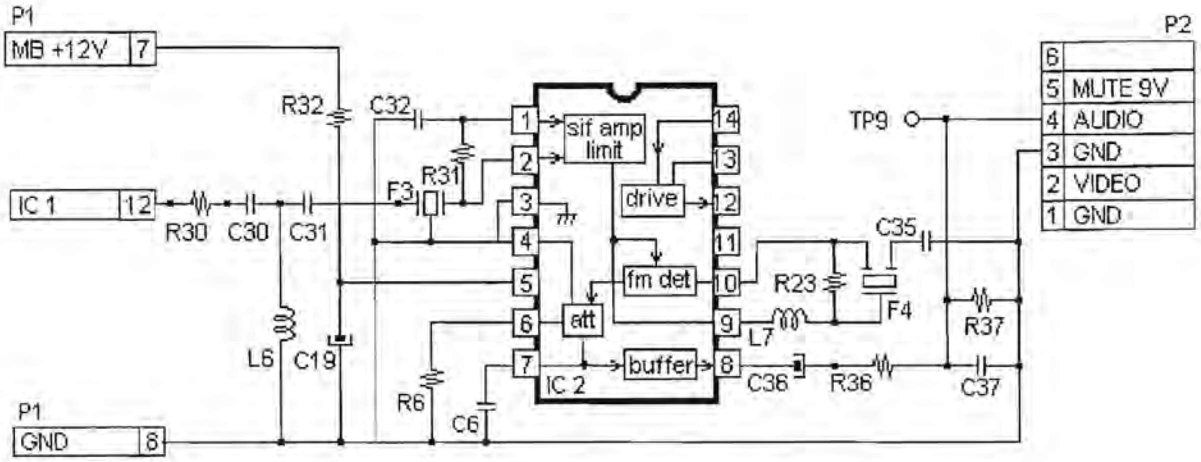


Figure 4.13.b Detailed SIF circuit

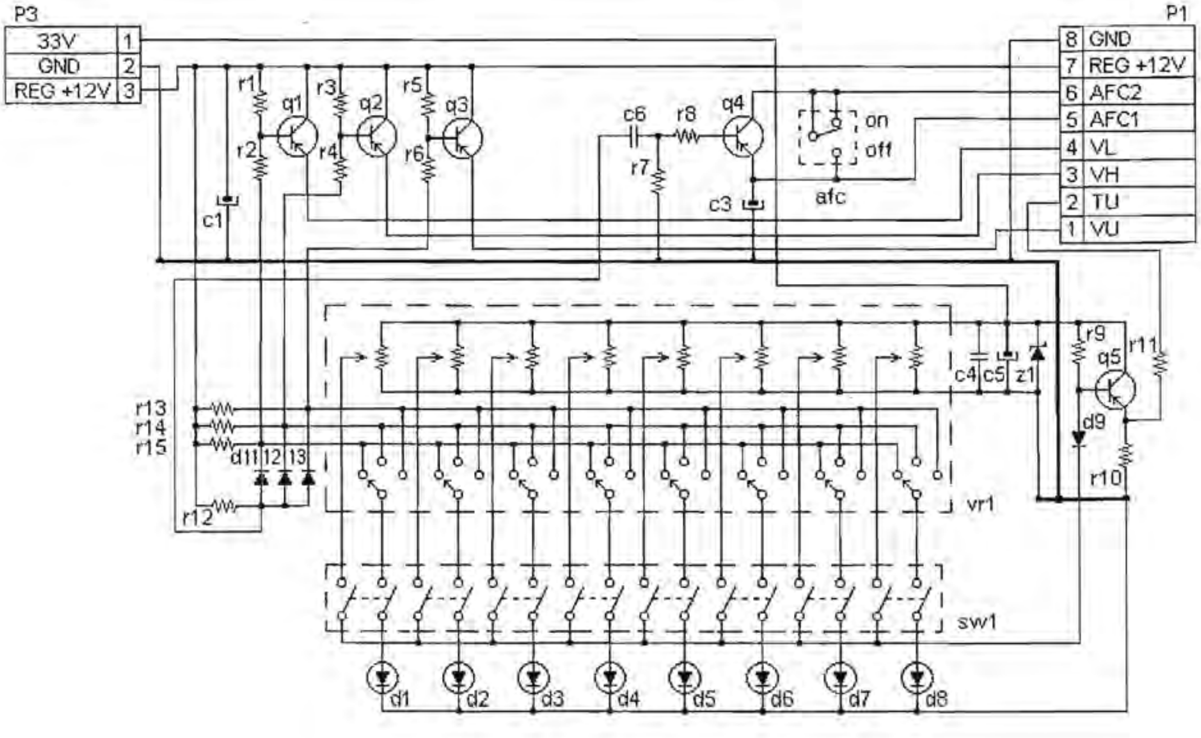


Figure 4.13.c Detailed pre-set/select circuit

4.2.3 Development of the power supply.

The RF bandwidth switch was specified to operate from a single external DC power supply voltage of 12-VDC.

Tuning of the RF section of video and television equipment is effected by the varicap method, whereby the voltage is adjusted across a varicap diode to change its capacitance. A mains transformer is normally used to obtain a 33-VAC line for this purpose.

An alternative method had to be devised to generate the regulated 30-VDC tuning rail from the specified operating voltage of 12-VDC. A switch mode power supply module is used to provide the external unregulated 12-VDC to the prototype, and a dual rail internal DC power supply provides unregulated 33-VDC and regulated 12-VDC. The power supply for the prototype bandwidth switch is shown in Figure 4.13.d.

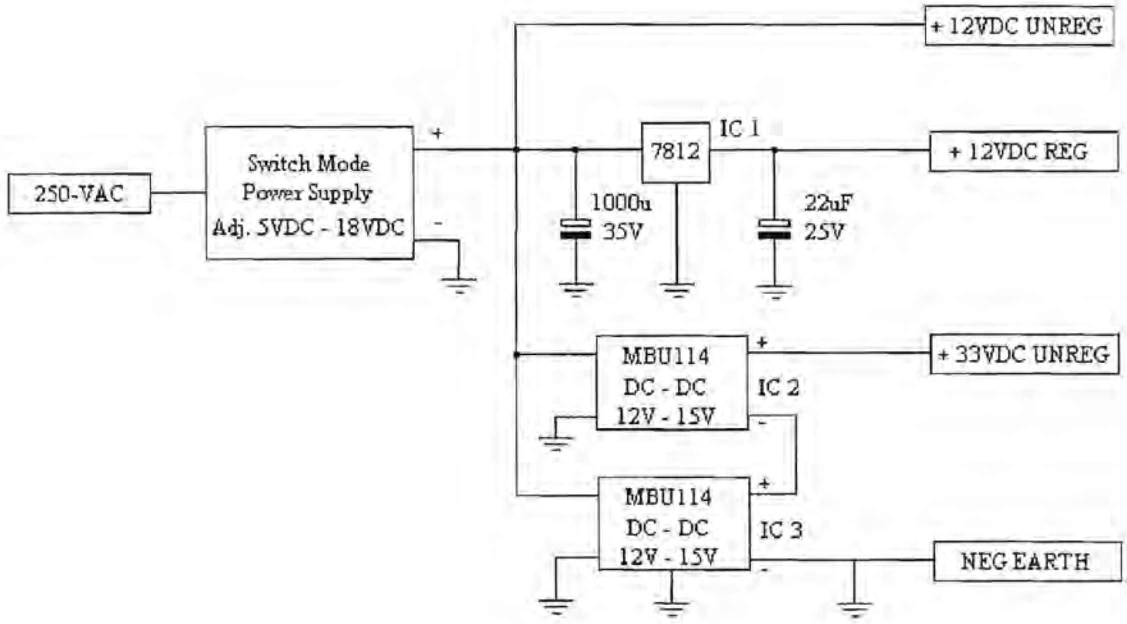


Figure 4.13.d. Dual rail DC power supply for Bandwidth Switch.

The unregulated 33-VDC is applied to a reference diode regulator network as in Figure 4.13.c, consisting of C4 (0,01uF), C5 (22uF/50V) and Z1 (uPC574J). The virtual tuning voltage on the wiper on the selected variable resistor in the voltage dividing network VR1 is applied via D9 to the base of Q5 (2SC536KE). The actual tuning voltage (2-VDC - 28-VDC) TU, is applied via R11 (1K) to pin 2 of P1.

The mounting of the switch mode supply module within the same (metal) enclosure as the bandwidth switch circuitry introduced severe ripple noise in the regulated 12-VDC line. Worst affected was the RF modulator that resulted in a visible noise pattern on the bandwidth switch transmission output.

The regulated 12-VDC line to the RF modulator was screened with copper braiding that was electrically connected to earth within the metal enclosure. This action, together with another wired connection between earth (and earth!) solved all problems experienced with electrical noise introduced from internal, and external sources.

The switch mode power supply module output voltage is adjusted to 13,8-VDC, measured across the input to IC1, the 7812 voltage regulator.

The following table indicates measured values of the power supply output voltages during normal operation of the bandwidth switch:

Parameter	Test point	Adjustment	Value (VDC)
12VDC UNREG	Pin 1 of IC1	External supply	13,8
12VDC REG	Pin 3 of P3	-	11,53
30VDC	Pin 1 of P3	-	29,58

Table 4.8 Dual rail power supply output voltages

4.3 Set-up procedures

The RF and VIF circuitry may be set up for adjustment with either the use of a tracking generator cum spectrum analyser, or by using a sweep- marker generator along with an oscilloscope.

The latter is described, as the financial implications are certainly reduced when considering spectrum analysis equipment.

4.3.1 Pre-test setup

Connect a sweep-marker generator and an oscilloscope as shown in Fig 4.14. The output signal from the sweep-marker generator is applied to the RF unit through an input probe, and the parameter measured is applied to the oscilloscope through an output probe.

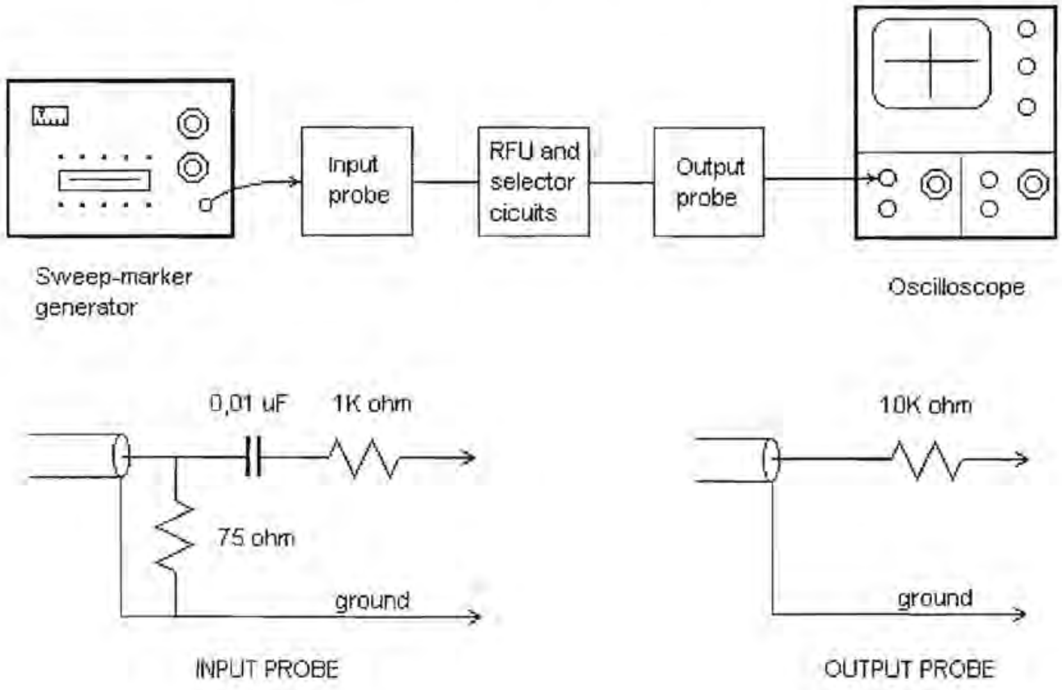


Figure 4.14 Pre-test setup

4.3.2 VIF adjustment

Adjustment location	Measuring point	Measuring equipment	Adjustment condition
Convertor transformer	TP 4 (E of Q3)	Sweep-marker generator. Oscilloscope. DC power supply. Special adj. tool	STOP mode

a. Connect a 22 ohm resistor between test points 3 and 4 (pin 8 and pin 9 of IC 1, as shown in Fig. 4.13.a) and disconnect the P2 connector.

b. Supply DC +0,8V to TP1 (pin 14 of IC 1) as an AGC voltage.

c. Set the output level of the sweep-marker generator to VIF, -25dB (28 mV RMS) and connect the output to the TP terminal of the RF unit through an input probe.

d. Connect the output signal at TP4 (E of Q3) to the oscilloscope through an output probe, and observe the waveform.

e. Adjust the AGC voltage so that the waveform level is 0,8Vp-p.

f. Adjust the RF unit's convertor transformer so that P (the 39,5 MHz marker) becomes 38±2%. See Figure 4.15.a

g. Remove the 22 ohm resistor and reconnect the P2 connector.

4.3.3 Detection transformer adjustment

Adjustment location	Measuring point	Measuring equipment	Adjustment condition
T1	TP4 (E of Q3)	Sweep-marker gen. Oscilloscope DC power supply Special adj. tool	STOP mode

a. Supply DC +2V to TP1 (pin 14 of IC 1, as shown in Fig. 4.13.a) as an AGC voltage, and remove the P2 connector.
b. Set the output level of the sweep-marker generator to VIF, -25dB (28mV RMS) and connect the output to the TP terminal of the RF unit through an input probe.
c. Connect the output signal at TP4 (E of Q3) to the oscilloscope through an output probe, and observe the waveform.
d. Adjust the AGC voltage so that the waveform level is equal to 2,5Vp-p.
e. Adjust the T1 core so that P (the 39,5 MHz marker) becomes 70%. See Figure 4.15.b.
f. Disconnect the P2 connector.

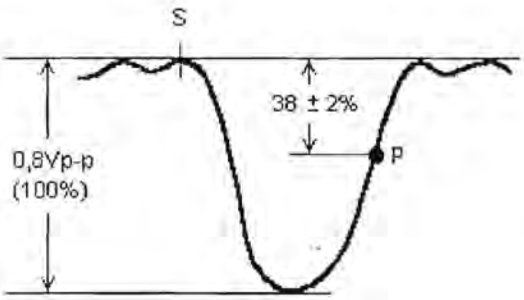


Figure 4.15.a. Wave-form example

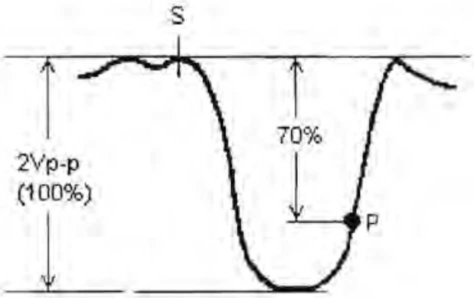


Figure 4.15.b. Wave-form example

4.3.4 AFC circuit (1)

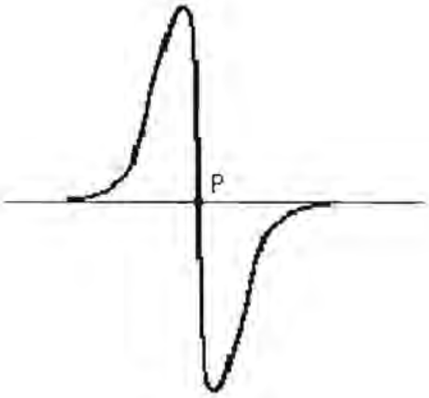
Adjustment location	Measuring point	Measuring equipment	Adjustment condition
T2	Pin 6 of P1	Sweep-marker gen. Oscilloscope DC power supply Special adj. Tool	STOP mode AFC switch "ON"

a. Supply DC +3,5V to TP1 (pin14 of IC 1) as an AGC voltage.

b. Set the output level of the sweep-marker generator to VIF, -13dB (112mV RMS), and connect the output to the TP terminal of the RF unit through an input probe.

c. Connect the output signal at pin 6 of P1 on the circuit board to the oscilloscope through an output probe, and observe thewaveform.

d. Adjust T2 so that P (the 39,5 MHz marker) is positioned on the base line, as in the sketch below.



4.3.5 AFC circuit (2)

<table>
<tr><th>Adjustment location</th><th>Measuring point</th><th>Measuring equipment</th><th>Adjustment condition</th></tr>
<tr><td>VR2</td><td>TP6 (pin 6 of IC 1)
TP7 (pin 5 of IC 1)</td><td>DC power supply
DC voltmeter</td><td>STOP mode
AFC switch "ON"</td></tr>
<tr><td colspan="4">a. Eliminate all input signals.
b. Apply DC +5V~ +8V to TP1 (pin 14 of IC 1).
c. Adjust VR2 so that the voltage between TP6 and TP7 is 0 ~ 0,5V.</td></tr>
</table>

4.3.6 RF AGC circuit

<table>
<tr><th>Adjustment location</th><th>Measuring point</th><th>Measuring equipment</th><th>Adjustment condition</th></tr>
<tr><td>VR1</td><td>RF unit AGC terminal</td><td>Colour bar generator with RF section. Digital volt-meter. Video monitor (composite video).</td><td>STOP mode</td></tr>
<tr><td colspan="4">a. Connect the colour bar generator to the input of the RF unit. (VHF input, channel 5 or UHF input, channel 31, 69dB/uV, modulation degree 87,5%).
b. Connect the video output (pin 2 of P2) to the video monitor composite video input.
c. Press channel 1 on the channel selector, and adjust to channel 5 or channel 31, setting for the best possible picture quality observed on video monitor.
d. Set the AFC switch to the "ON" position.
e. Measure the voltage at the AGC terminal of the RF unit, and adjust VR1 so that the voltage observed is 5,7± 0,1VDC for VHF, or 5,0± 0,1VDC for UHF.</td></tr>
</table>

4.3.7 Audio output

Adjustment location	Measuring point	Measuring equipment	Adjustment condition
-	TP9 (pin 4 of P2)	Television signal gen. Oscilloscope.	STOP mode
a. Connect the TV signal generator to the input connector of the RF unit. (VHF input, channel 5, 60dB/uV (1mV RMS) or higher, 60% modulation with sine wave audio signal at 400 Hz). b. Press a channel, select VHF and adjust for best possible picture quality observed. c. With AFC "ON", observe thewaveform of thesinewave audio at TP9 on the oscilloscope, and confirm the signal level at 0,69± 0,34V p-p.			

4.4 **Test procedures : Internal noise measurement**

Before proceeding with the noise measurements on the RF bandwidth switch, we shall have to discuss noise created by any of the passive devices found in receivers. Such noise is generally random, and is thus impossible to treat on an individual voltage basis, but easy to describe statistically since it is truly random.

Since the noise is randomly distributed over the entire radio spectrum there is on average, as much of it at any frequency as at any other, and it may therefore be assumed that random noise power is proportional to the bandwidth over which it is measured.

4.4.1 Thermal agitation noise

This noise is generated in a resistance or the resistive component of any impedance, is random, and is referred to as *thermal, agitation, white,* or *Johnson* noise (after its discoverer) [22]. It is due to the rapid and random motion of the molecules, atoms and electrons of which, according to simplified atomic theory, any such resistor is constructed.

In thermodynamics, kinetic energy shows that the temperature of a particle is a way of expressing its internal kinetic energy, so that the 'temperature' of a body is the statistical RMS value of the velocity of motion of the particles in the body. The theory states that the kinetic energy of these particles becomes approximately zero, at $0\ K$ (Kelvin or absolute), which very nearly equals -273°C. It is thus apparent that the noise power generated by a resistor is proportional to its absolute temperature, in addition to being proportional to the bandwidth over which the noise is to be measured. Thus:

$$P_n \propto T\ \delta f = kT\ \delta f \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

where k = Boltzmann's constant = 1,38 x 10^{-23} J/K (joule/kelvin)

T = absolute temperature, K (kelvin) = 273 + °C

δf = bandwidth of interest

P_n = maximum noise power output of a resistor

If an ordinary resistor at the standard temperature of 17°C (290 K) is not connected to any voltage source, it might at first be thought that there is obviously no voltage to be measured across it. That is correct if the measuring instrument is a DC voltmeter, but it is decidedly incorrect if a very sensitive electronic voltmeter is considered; there may even be quite a large voltage across the resistor, but since it is random and therefore has a definite RMS value but no DC component, only an AC instrument will register a reading.

This noise voltage is caused by the random movement of electrons within the resistor, which constitutes a current; although as many electrons arrive at one end of the resistor as at the other over any long period of time, at any instant of time there are bound to be more electrons arriving at one particular end than at the other because their movement is random.

Equally, over a period of time, this imbalance will be redressed, but as the rate of arrival of electrons at either end of the resistor varies randomly, so does the potential difference between the two ends, thus a random voltage across the resistor definitely exists and may both be measured and calculated.

It must be realised that all formulae referring to random noise are applicable only to the RMS value of such noise, and not to its instantaneous value, which is quite unpredictable. So far as peak noise voltages are concerned, there is reason to believe that they are unlikely to have values in excess of 10 times the RMS value.

From Equation (1), the equivalent circuit of a resistor as a noise generator may be drawn as in Figure 4.16, and from this the resistor's equivalent noise voltage E_n may be calculated.

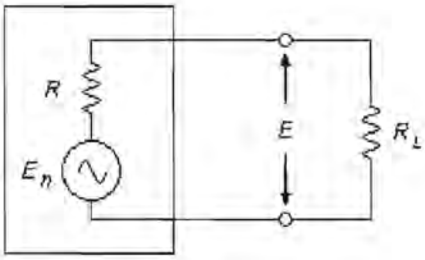


Figure 4.16. Resistance noise generator

Consider that R_L is noiseless and is receiving the maximum noise power generated by R; under these conditions of maximum power transfer, R_L must be equal to R. Then:

$$P_n = \frac{E^2}{R_L} = \frac{E^2}{R} = \frac{(E_n/2)^2}{R} = \frac{E_n^{\,2}}{4R} \quad \ldots\ldots\ldots\ldots (3)$$

thus $$E_n^{\,2} = 4RP_n = 4RkT\ \delta f \quad \ldots\ldots\ldots\ldots (4)$$

and $$E_n = \sqrt{4kT\,\delta f\,R} \quad \ldots\ldots\ldots\ldots (5)$$

It is seen from Eq. (5) that the square of the noise voltage E_n associated with a resistor is proportional to the absolute temperature of the resistor, the value of the resistance, and the bandwidth over which the noise is measured. Note especially that generated noise voltage is quite independent of the frequency at which it is measured; this stems from the fact that it is random and evenly distributed over the frequency range considered.

4.4.2. Noise figure

Measurement of the signal-to-noise ratio (*S/N*) of an amplifier, a receiver or a device is often used for either of two purposes, or sometimes for both; the comparison of two circuits for evaluation of their performance or the comparison of noise and signal at the same point to ensure that the former is not excessive.

Signal-to-noise ratio *S/N* is defined as the ratio of signal *power* to noise *power* , at the same point.

Thus, $$\frac{S}{N} = \frac{P_s}{P_n} = \frac{E_s^{\,2}/R}{E_n^{\,2}/R} = \left(\frac{E_s}{E_n}\right)^2 \quad \ldots\ldots\ldots\ldots (6)$$

Equation (3) above is a simplification which applies whenever the resistance across which the noise is developed is the same as the resistance across which the signal is developed, and this is almost invariably the case. An effort is naturally made to keep the signal-to-noise ratio as high as possible under a given set of conditions.

For comparison of receivers or amplifiers working at different impedance levels the use of *noise figure*, or sometimes known as *noise factor*, is defined and used. The noise figure F is defined as the ratio of the signal-to-noise power supplied to the input terminals of a receiver or amplifier to the signal-to-noise power supplied to the output or load resistor.

Thus, $$F = \frac{Input\ S\,/\,N}{Output\ S\,/\,N} \qquad (7)$$

It can be seen immediately that the noise figure is 1 for an ideal receiver or amplifier or device which introduces no noise of its own, so that the signal-to-noise ratio does not deteriorate as a result thereof.

Also known is the alternative definition of noise figure, which states that F is equal to the S/N of an ideal system divided by the S/N of the receiver or amplifier under test, both working at the same temperature over the same bandwidth and fed from the same source. In addition, both systems must be linear.

The noise figure may be expressed as an actual ratio, or in decibels. The noise figure of practical receivers can be kept to below a few decibels up to frequencies in the order of 1-GHz by a suitable choice of the first MMIC or transistor or tube, combined with proper circuit design and the use of low-noise resistors.

4.4.3 Calculation of noise figure

Noise figure may be calculated for an amplifier or receiver or device on the same basis by treating either as a unit; that is, each may be treated as a four-terminal network having an input resistance R_t, an output resistance R_L, and an overall gain A. It is fed from a source (antenna or generator) of internal resistance R_a, which may or may not be equal to R_t as the circumstances vary. A block diagram of such a four terminal network is shown in Figure 4.17.

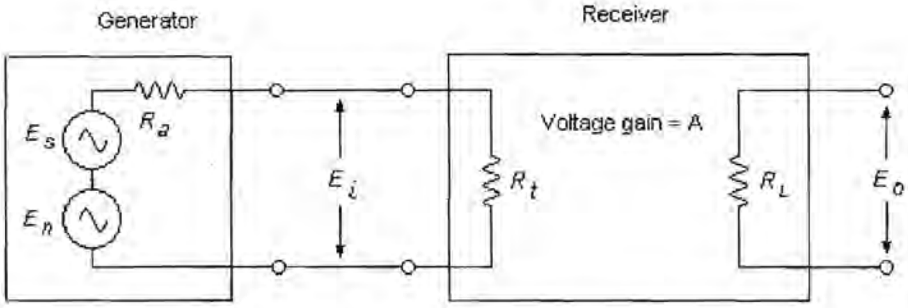


Figure 4.17. Block diagram for noise figure calculation

The calculation procedure may be broken down into the following steps, each followed by the number of relevant equation(s):

1. Determine the signal input power (8, 9).
2. Determine the noise input power (10, 11).
3. Calculate the input signal-to-noise S/N_i, from the ratio of P_{si} and P_{ni} (12).
4. Determine the signal output power P_{so} (13).
5. Write P_{no} for the noise output power to be determined later (14).
6. Calculate the output signal-to-noise ratio S/N_o from the ratio of P_{so} and P_{no} (15).
7. Calculate the generalised form of noise figure from steps 3 and 6 (17)
8. Calculate P_{no} from R_{eq} if possible, and substitute into the general equation for F to obtain the actual formula, or determine P_{no} from measurement and substitute in Eq. (17) to obtain the formula for F.

It is seen from Fig. 4.16 that the signal input voltage will be:

$$E_{si} = \frac{E_s R_t}{R_a + R_t} \quad \text{. . . . . } (8)$$

$$P_{si} = \frac{E_{si}^{\ 2}}{R_t} = \left(\frac{E_s R_t}{R_a + R_t}\right)^2 \frac{1}{R_t} = \frac{E_s^{\ 2} R_t}{\left(R_a + R_t\right)^2} \quad \text{. . . . . } (9)$$

Similarly, the noise input voltage will be:

$$E_{ni}^{\ 2} = 4kT\delta f \frac{R_a R_t}{R_a + R_t} \quad \text{. . . . . } (10)$$

$$P_{ni} = \frac{E_{ni}^{\ 2}}{R_t} = 4kT\delta f \frac{R_a R_t}{R_a + R_t} \frac{1}{R_t} = \frac{4kT\,\delta f\, R_a}{R_a + R_t} \quad \text{. . . . . } (11)$$

The input signal-to-noise ratio will be:

$$\frac{S}{N_i} = \frac{P_{si}}{P_{ni}} = \frac{E_s^{\ 2} R_t}{\left(R_a + R_t\right)^2} \div \frac{4kT\ \delta f\ R_a}{R_a + R_t} = \frac{E_s^{\ 2} R_t}{4kT\ \delta f\ R_a\left(R_a + R_t\right)} \quad \text{. . . . . . } (12)$$

The output signal power will be

$$P_{so} = \frac{E_{so}^{\ 2}}{R_L} = \frac{\left(AE_{si}\right)^2}{R_L} = \left(\frac{AE_s R_t}{R_a + R_t}\right)^2 \frac{1}{R_L} = \frac{A^2 E_s^{\ 2} R_t^{\ 2}}{\left(R_a + R_t\right)^2 R_L} \quad \text{. . . . . . } (13)$$

The noise output power may be difficult to calculate; for the time being, it may simply be written as:

$$P_{no} = \text{noise output power} \quad \dots\dots \quad (14)$$

Thus the output signal-to-noise ratio will be

$$\frac{S}{N_o} = \frac{P_{so}}{P_{no}} = \frac{A^2 E_s{}^2 R_t{}^2}{\left(R_a + R_t\right)^2 R_L P_{no}} \quad \dots\dots \quad (15)$$

Finally, the general expression for noise figure is

$$F = \frac{S/N_i}{S/N_o} = \frac{E_s{}^2 R_t}{4kT\ \delta f\ R_a\left(R_a + R_t\right)} \div \frac{A^2 E_s{}^2 R_t{}^2}{\left(R_a + R_t\right)^2 R_L P_{no}} \quad \dots\dots \quad (16)$$

$$= \frac{R_L P_{no}\left(R_a + R_t\right)}{4kT\ \delta f\ A^2 R_a R_t} \quad \dots\dots \quad (17)$$

Note that Eq. (17) is an intermediate result from which an actual formula for F may be obtained by substitution for the output noise power, from a knowledge of the equivalent noise resistance or from actual measurement.

4.4.4 Measurement of noise figure

The above sections 4.4.1 to 4.4.3 were included to demonstrate that accurate noise measurement remains not an easy task to perform. In an attempt to determine the noise figure of the bandwidth switch, it was decided to obtain sophisticated measuring gear, and to follow the route of measuring the input signal power and noise power, as well as the output signal power and noise power, as opposed to using the equivalent noise resistance. This option may serve to measure not only noise that is generated from within the receiver, but also the noise due to external influences.

A VCR may be regarded as a typical input to the bandwidth switch, and the same was thus used to perform the measurement. The input signal power from the VCR modulator to the RF bandwidth switch measured -26,8-dBm, and the noise power was estimated at -69,2-dBm for a 6-MHz span width, resulting in an input *S/N* of 42,4-dB.

The output signal power of the modulator used in the bandwidth switch measured -24,9-dBm, and the output noise power was estimated at -64,6-dBm, resulting in an output *S/N* of 39,7-dB. It can be seen that although the output modulator has a signal output power 1,9-dB higher than the input, the RF bandwidth switch has added noise to the signal, with a resulting noise figure *F* of 2,7-dB. The bulk of the noise is most probably generated within the mixer stages of the RF tuner unit, and perhaps a lesser part within the RF modulator.

Signal power was measured at a relatively narrow resolution bandwidth of 30-kHz, otherwise noise generated from external sources may affect the measurement. To estimate the noise power for a 6-MHz span width, the noise power was measured for a resolution bandwidth of 100-kHz, after employing the video averaging feature of the HP8593E spectrum analyser. The result was multiplied by 60 to estimate the noise power for the 6-MHz span of interest.

The expected output *S/N* of 40-dB was not obtained, although the actual figure of 39,7-dB is regarded as acceptable for the purpose of this dissertation. All the other expected electrical inputs and outputs as set in paragraph 4.1.2 were measured to fall within the expected specifications.

4.4.5 Accuracy of the noise measurements

The measurement gear used to perform the noise measurements was the Hewlett Packard HP 8593E Spectrum Analyser with HP 85714A Scalar Measurement Personality option. When resolving signals of equal or different amplitudes in terms of their power levels, one must consider the characteristics of the measuring gear before comments may be made about the accuracy of the measurement. Annexure B considers factors which may affect the accuracy of the noise measurements.

4.4.6 Informal transmission testing

The VCR used for the test was firstly connected directly to a television receiver, and a standard video cassette was viewed by several students at Irene weather station. Transmission was terminated and the VCR output was presented to the input of the prototype RF bandwidth switch, and the output reconnected to the same television receiver and again viewed by the same students. Picture and sound quality was reported to be non-compromised. Following the single input test, four generators were connected to the input of the RF bandwidth switch, and the signals resolved at the output of the combiner. The four generator frequencies were evenly spaced at two channel intervals, situated at channel 30, 32, 34 and 36 respectively. See Figure 4.18 below:

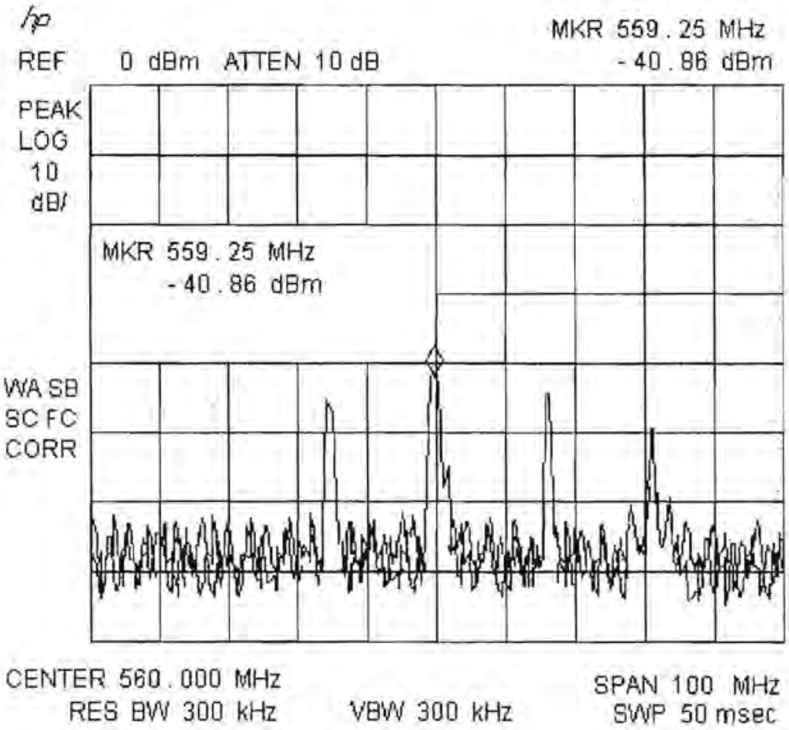


Figure 4.18. Input channel spacing

Next, the preset output of the bandwidth switch modulator was observed, also at channel 36. Attempts to set the output to channel 38 were fruitless, so it was reset to channel 28, to minimise interference with the fourth RF input. The inputs were switched to the output sequentially, and the output observed on a television receiver. Picture and sound quality were reported as acceptable, with no indication of interference between input signals.

Chapter 5

INFORMAL EXPERIMENTS AND DEMONSTRATIONS

The purpose of the experimentation was to test the hypotheses, and to demonstrate the RF bandwidth switch within a model for T.B.T. (technology based training) systems.

The experimentation tested the hypotheses positively, and demonstrated that the RF bandwidth switch may be used to obtain the functional requirements of technology based training transmission without reliance on personal computer technology.

The following sections describe the hardware and network infrastructures utilised in the experiments. Each experiment will be dealt with separately, stating objectives on an Outcomes Based principle, with specific reference to the functional requirements of the transmission apparatus discussed in paragraph 2.4.3.

5.1 **Experiment 1**

Selection and broadcast function

5.1.1 Objective

Considering the typical network used for dynamic system modelling, each individual bandwidth switch should have the ability to *select* any one of a number of four inputs at various formats, and *broadcast* the same via a single output, at the press of a single button.

For experimentation a standardised free format [9] namely PAL system I was employed as the primary transmission format.

5.1.2 Hardware

i. Inputs: one introduction level PC (personal computer), one VCR (video casette recorder, one lecturer's PCAM (personal camera), one WCAM (workbench camera) and one RF bandwidth switch.

ii Outputs: one audiovisual display unit to display the switched output, as well as one smaller audiovisual display to serve as transmission monitor.

iii. Format adaption (D) : one SVGA (super video/graphics adapter), to composite video/audio, to ch 33-39 PAL system I

5.1.3 Infrastructure setup

The equipment was set up as indicated in Figure 5.1:

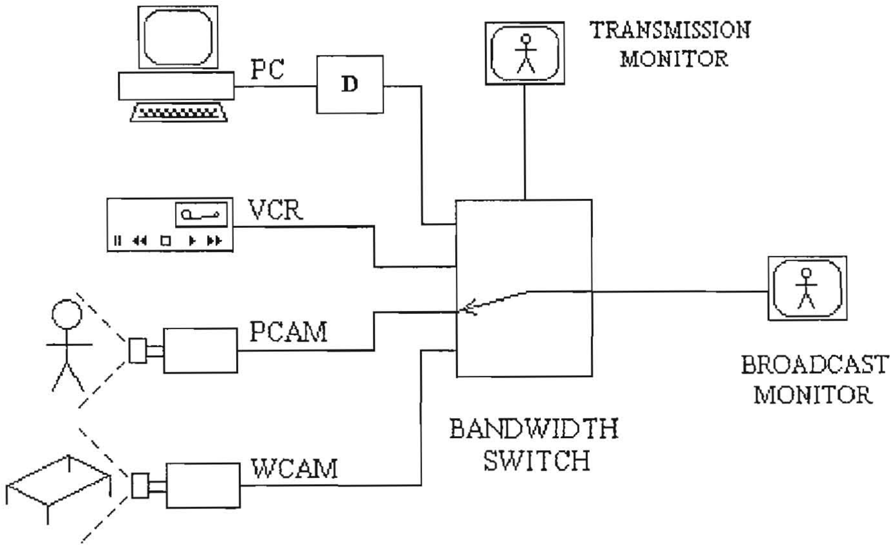


Figure 5.1

5.1.4 Observations

The bandwidth switch enabled the operator to select any one of four inputs at the press of a single button, to be displayed on the broadcast monitor. All inputs were full bandwidth, colour video with corresponding soundtrack. No change in video or audio was observed when the output was respectively compared with the selected input. No audio delay is imposed as is the case with many computer driven systems.

5.2 Experiment 2

Activation function and multiple forward connections

Considering the typical network used for dynamic system modelling, the activation function as well as 4 forward connections had to be obtained.

5.2.1 Objective

The objective of this experiment was the switched simultaneous distribution of the primary transmission format from a single input to four forward connections, by pressing one button. Activation function switching may be defined as the activation of broadcasting by the operator/lecturer for the 'on' mode, opposed to the termination of broadcasting for the 'off' mode.

In the off mode, a blank raster may be displayed, or a station identification screen from any auxiliary source, eg VCR. The auxiliary input must be in composite video + audio format, which is also a standardised free format but distinguishable from the primary inputs.

5.2.2 Hardware

i. Inputs: The output of the bandwidth switch as described in Experiment 1, as well as any other input device, eg. a PAL colour bar/pattern generator with modulated sound and separate composite video and audio outputs.

ii. one four-way distributer.

iii. Outputs: four audiovisual display units, to display the switched forward connections simultaneously.

5.2.3 Infrastructure setup

The equipment was set up as indicated in Figure 5.2.

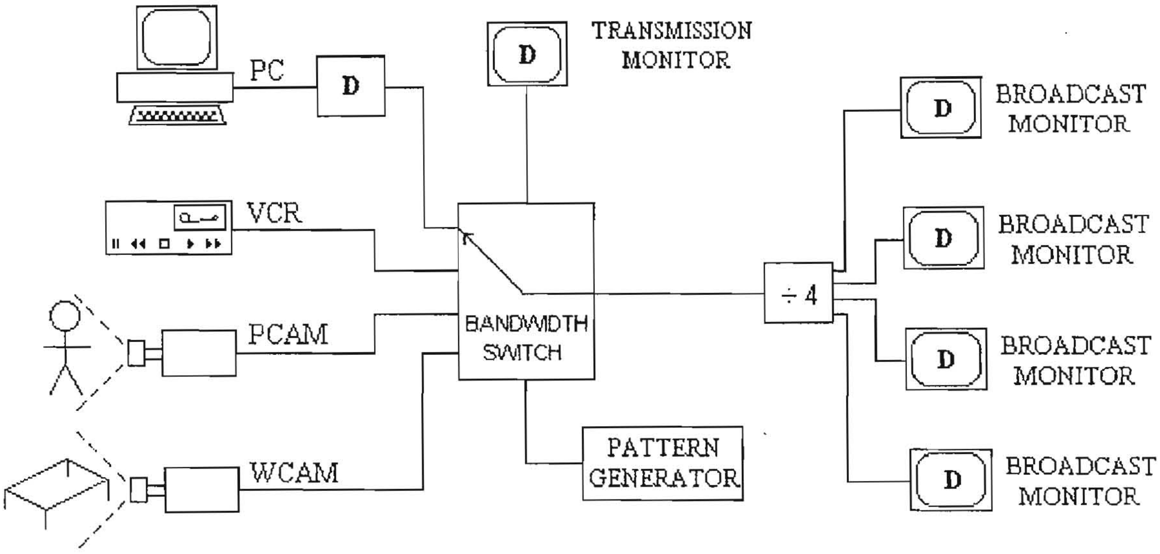


Figure 5.2

5.2.4 Observations

The activation function with multiple (four) forward connections enabled the operator/lecturer to commence or terminate broadcasting of the selected input at the press of a single button. Upon activation the switched output appeared on all four of the broadcast monitors, with no visible difference in video or audio quality. A noticeable difference exists, however, between the SVGA monitor of the PC, and the picture displayed by the audiovisual monitor at the output. Upon investigation it was found that picture quality was already compromised at the input of the bandwidth switch. The input of the format adapter was compared with its output. The difference between formats are noticeable but not unacceptable.

5.3 Experiment 3

Two feedback connections

Considering the typical network used for dynamic system modelling, two feedback connections had to be obtained, in order to fully simulate the T.B.T. dynamic model. The feedback connections are required to effect interactivity between the lecturer and student workstations.

5.3.1 Objective

The objective of this experiment was to devise two feedback connections, or a single connection with combined functions. The operator/lecturer should be able to select any distant workstation, to monitor it constantly, yet be able to configure the distant workstation into broadcast mode, so to enable all other workstations to monitor the selected workstation as well.

Selection of the distant workstation should be effected by pressing a single button, and the re-configuration into broadcast mode by depressing another single button. All bandwidth switches should be situated in the same geographical position, namely with the operator/lecturer.

5.3.2 Hardware

i. First layer inputs: The output of the bandwidth switch as described in Experiment 1, as well as another input device, eg. a PAL colour bar pattern generator with modulated sound and separate composite outputs.

ii. One four-way distributer.

iii. Outputs: four audiovisual display units, to display the switched outputs simultaneously.

iv. Four colour camera/microphone combinations, each situated at an audiovisual display unit, to capture interactive video and audio input material.

v. Output layer bandwidth switch's inputs : four camera/microphone inputs situated at audiovisual workstations.

vi. Output layer bandwidth switch's output reconnected to the WCAM input of the first layer bandwidth switch.

5.3.3 Infrastructure setup

The equipment was set up as indicated in Figure 5.3.

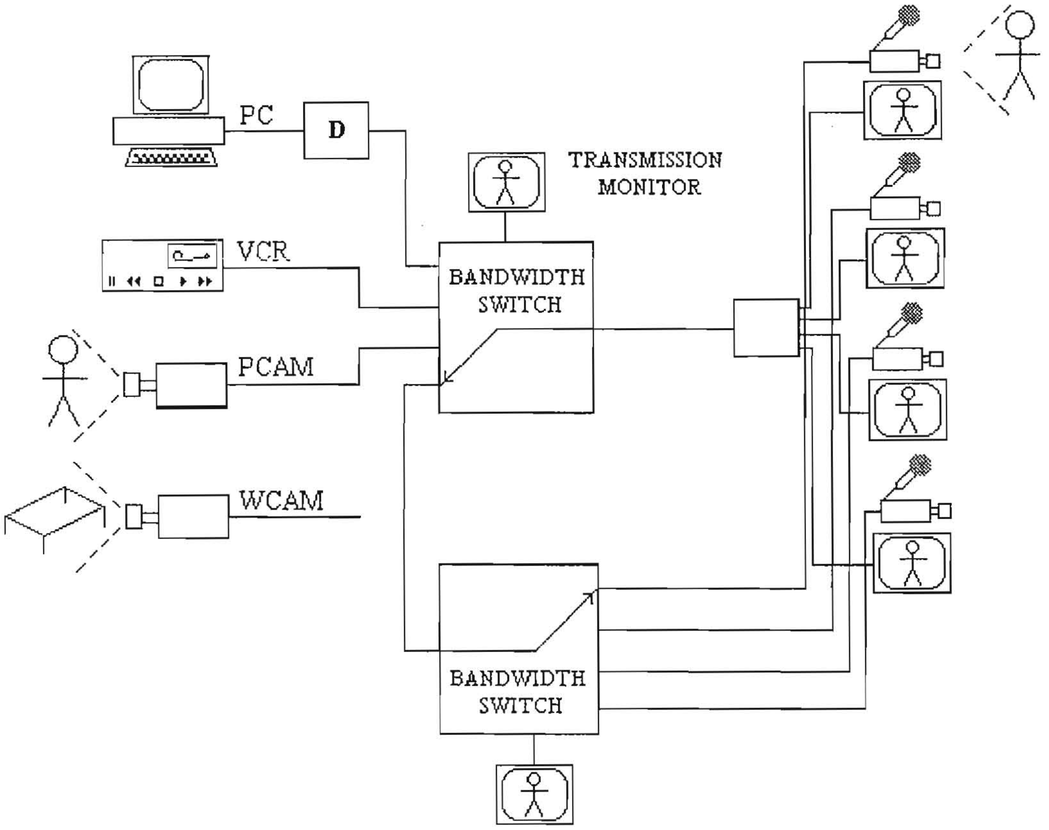


Figure 5.3

5.3.4 Observations

The second bandwidth switch enabled the operator to select any distant workstation and monitor it constantly. By presenting the output of the second bandwidth switch to one of the primary switch's inputs it was possible to configure the distant workstation into broadcast mode, so to enable all other workstations to monitor the selected workstation as well.

Selection of the distant workstation was effected by pressing a single button on the second RF bandwidth switch, and the re-configuration into broadcast mode by depressing another single button on the primary switch. Both bandwidth switches were situated in the same geographical position, namely with the operator/lecturer.

The activation function with multiple (four) forward links still enabled the operator to commence or terminate broadcasting of the primary bandwidth switch input at the press of a single button.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

The dissertation described an RF bandwidth switch applied in an informal experimental model for technology based training systems.

The experiments tested the hypotheses positively. The study has revealed a method to obtain the functional characteristics of technology based training systems, without reliance upon personal computer technology, resulting in a start-up model for future research. This method may be used to enable T.B.T. for a broader spectrum of students within the South African context.

The dissertation briefly discussed important non-technical aspects of technology based training systems. The successful use of these systems requires understanding of the benefits of having value added by audio, video and integrated computer applications. The perception amongst participants was that the proposed model concentrates on the spoken word of teaching, supported by applicable multimedia. One of the problems solved, compared with compressed data PC driven systems, was facilitation of effective audio communication, free from echo's or delayed reception.

During the development of the electronics, recently developed ferrite technology was merged with previously developed circuit techniques, that made it possible to extend the bandwidth capabilities of hybrid power combiners.

During the development of the hybrid combiner, an interesting phenomenon was observed, and termed *recurring pattern mismatch* for the purposes of the dissertation. Searches conducted on the internet did not reveal a detailed description of the phenomenon, only a reference reporting its effects [13]. In experiments conducted on MediaTwist^{TM} cable, by Belden Cable Inc., the UHF band was observed for picture quality when transmitted across substantial lengths of cable. It was observed that alternative channels may differ substantially in output signal strength and obvious picture quality, even when just two channel spacings apart within the same frequency band. The problem was solved for continued testing by broadband amplification of the entire frequency band, in order to improve marginal signals. No explanations were discussed. The observed phenomenon (*recurring pattern mismatch*) may be used within an alternative method to match broadband circuits for optimised signal power transfer.

The positive testing of the hypotheses should serve as an inspiration for continued experimentation with this technology. Future experiments should involve a larger number of participants that may be more remotely situated. Alternative frequency plans up to 2,4-GHz may be considered to extend available bandwidth.

The bandwidth switch performed satisfactory across several metres of interconnecting cable, considering that the expected overall *S/N* ratio of 40-dB was not obtained. Continued experimentation may investigate matched hybrid combiners or dividers with 0-dB transformation loss by low noise broadband amplification, in order to improve cable transmission capabilities.

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Annexure A

For the purpose of explanation, with specific reference to Chapter 4, it was decided to extract relevant information from a literature study conducted by the student, to be presented in this Annexure to the thesis.

Broadband transformers

Broadband transformers are employed in circuits which must have a uniform response over a substantial spread of frequency. To be able to consider all factors involved, three specific papers were consulted [14, 15, 16] and some of the information included in the following sections, before the detailed description in chapter 4.2 of the hybrid combiners that were developed for the purpose of this thesis. Other references [17 - 20] are referred to for the sake of completeness.

A.1 Broadband transformer requirements

The broadband transformer is a device that will step up or down a voltage or current, or step up or down the impedance, or provide DC isolation, or any combination of these. In the process of providing the above, the transformer reduces the transmitted signal slightly. This is called attenuation or insertion loss. A typical plot of the insertion loss versus frequency is shown in Fig. A.1.

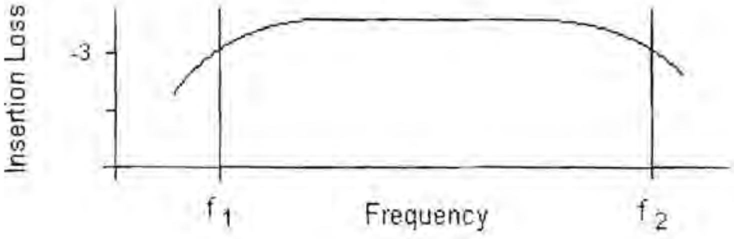


Figure A.1. Typical curve of Insertion loss vs. Frequency for broadband transformers

From this graph it can be seen that the insertion loss increases at frequencies below f_1 and above f_2, which are called the cut-off frequencies of the device. The useful range of the transformer is the frequency range between f_1 and f_2, and the problem of designing a broadband transformer is to extend the bandwidth of the unit while keeping the insertion loss at a minimum.

A.2 The equivalent circuit

The equivalent circuit of the device must be reviewed to understand the design of the broadband transformer. In Figure A.2 is shown the ideal transformer (one that does not have any losses), with resistors, capacitors and inductors that represent those factors that generate losses within the unit. These elements determine the cut-off frequencies of the device, where R_c = coil resistance, L_l = leakage reactance, L_p = parallel inductance of core, and C_d = winding capacitance.

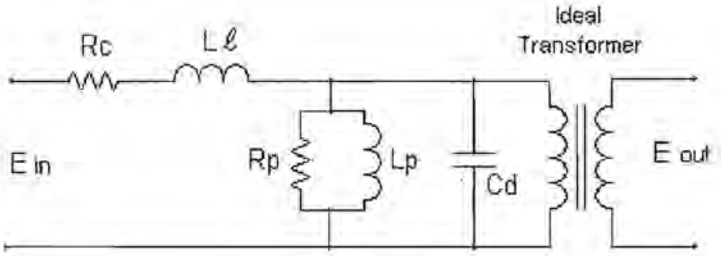


Figure A.2. Lumped element equivalent circuit of a transformer

In this diagram elements marked L_p and R_p represent the inductance and losses in the magnetic core of the transformer. These items are shown in parallel with the ideal transformer and it indicates therefore, that if the values for inductive reactance (X_p) and resistance (R_p) of the core are reduced, the output of the ideal transformer is also reduced. Since the values of L_p and R_p are usually lowest at low frequencies, they are the main elements responsible for the low frequency cut-off, f_1.

The elements marked L_l and C_d in the diagram represent the leakage inductance and winding capacitance respectively of the transformer. As frequency is increased the inductive reactance of L_l increases and the capacitive reactance of C_d decreases which also reduces the output of the transformer. Therefore these elements are responsible for the high frequency cut-off , f_2.

Since these elements largely determine both the high and low cut-off frequencies of the transformer, their values for particular cores must be known for design purposes, if they are to be changed or modified to meet bandwidth requirements.

A.3 The ferrite material data

The magnetic properties of ferrites are usually presented as the variation of permeability and loss factor of the ferrite materials at various frequencies.

The initial permeability and loss factor of a ferrite material is a result of measurements on a core, expressed as though it were an inductor and a resistor in series. Such measurements are generally useless to the designer because he needs his information in a different form.

As described in para A.2 and Figure A.2, the designer needs material and core information in terms of the parallel components of the inductance and resistance values. This data is the result of measurements of cores expressed as an inductor and a resistor in parallel.

The manufacturer often refers to the material cut-off frequency in describing ferrite materials, which is the point where the series permeability has dropped a significant amount from its low frequency value. For broadband transformers the important parameter is the parallel inductive reactance (X_p), which is very nearly equal to the series permeability multiplied by the frequency. Thus, although the permeability has become less with increasing frequency, the X_p is either increasing or remaining constant and the material remains quite useful as a broadband transformer.

Therefore, when selecting a material for a broadband transformer application, it is necessary to compare the parallel components of the magnetic parameters such as the parallel inductive reactance (X_p) and the parallel resistance (R_p), as a function of frequency, rather than as the initial permeability and loss factors of various materials. It is for this reason that the Fair-Rite Products Corporation supply curves of the parallel parameters versus frequency for all their materials commonly used for broadband transformers [14].

Three materials that best cover the high frequency range, were selected by measuring the parallel parameters of all materials versus frequency. In Fig. A.3, a graph is shown of the total impedance for a particular balun core, per turn, versus frequency, for each of the three materials, namely #73 material, #65 material and #43 material.

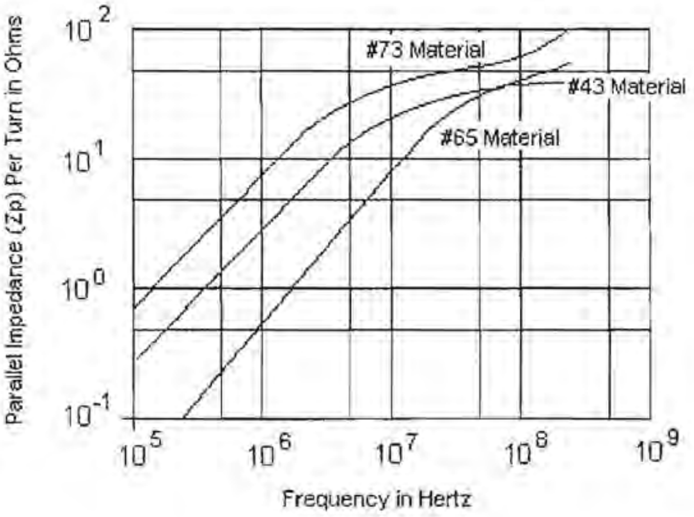


Figure A.3. Parallel impedance per turn for balun type core in 3 materials [14].

Fig. A.3 indicates the typical differences in impedance that can be expected between these three materials in cores of the same size and shape. The graph shows that #73 material has a higher impedance at all frequencies than either of the other two materials and should therefore be considered as the best material for broadband transformers.

For a broadband transformer, it is necessary that the lowest impedance within the frequency span of the transformer be used in determining its attenuation, which in most cases occurs at the lowest end of the transformer bandwidth. Since the curves in Fig. A.3 all have a positive slope, the critical impedance for them is regarded as the one at the low end of the desired frequency range.

However, the resistivity of this material is low (typically 100-ohm per cm), which means that if the windings of the core become shorted to the ferrite, the input impedance of the wound transformer is decreased. To prevent this, the core is usually wound with an insulating tape or a protective coating is added, which increases the cost of the complete device.

As an alternative, the #65 material may be considered for frequencies above 80 MHz, since its impedance is higher than #43 material at this frequency. Below 80 MHz, #43 material is preferred, as it has the higher impedance at this instance.

A.4 **The core shapes**

After following the process of selecting a material for a particular application, it is necessary to select the core and the number of turns needed for the finished transformer. In order to assist in this selection, the manufacturer included in their application notes a series of graphs depicting the impedance, reactance and resistance per turn versus frequency for each of the standard broadband transformer cores in each of the three transformer materials [14]. This information for #65 material is shown in Fig. A.4, Fig. A.5 and Fig. A.6, with each of the parameters for three core shapes shown on one graph. All the other cores' characteristics fall within the limits of item 5 and item 8.

These graphs were all made using a single turn through both holes of the core. Therefore the magnetic parameter will equal the number taken from the graph, multiplied by the number of turns squared.

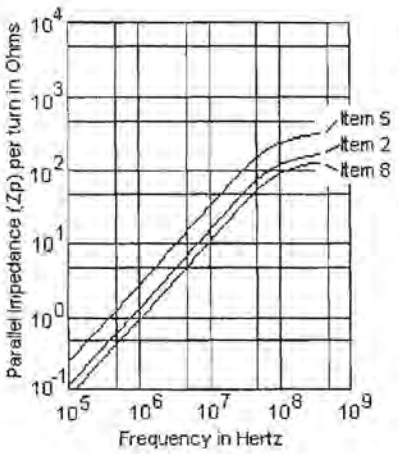


Fig. A.4.

Parallel Impedance per turn vs. Frequency (Fair-Rite #65 material)

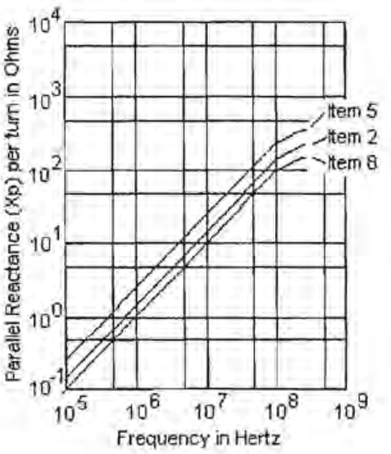


Fig. A.5.

Parallel Reactance per turn vs. Frequency (Fair-Rite #65 material)

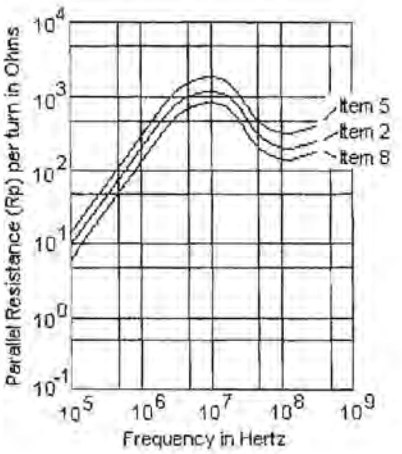


Fig. A.6.

Parallel Resistance per turn vs. Frequency (Fair-Rite #65 material)

The cores most often used for winding broadband transformers at high frequencies are the two hole balun types as shown in Fig. A.7. These cores may be wound either with the winding through one hole and around the outside or through both holes.

The latter method produces the higher inductance per turn and is the method used in generating the impedance curves shown in Fig's. A.4, A.5 and A.6 [14].

Many designers use the single hole ferrite bead for winding broadband transformers with good results [12]. The main advantage of using a shield bead with a single hole for a transformer core is that it is less costly than the balun type. However, it will not produce a transformer with as wide a bandwidth as the two hole type [14].

A.5 The form factor

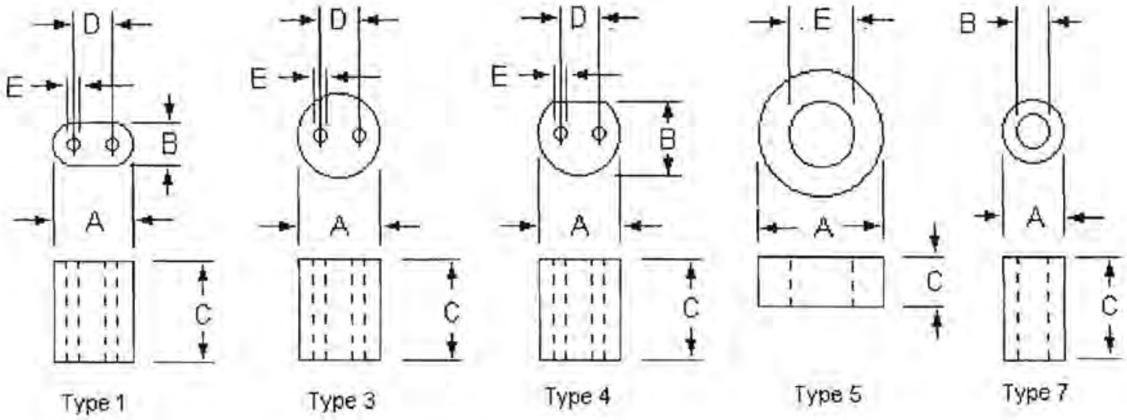
In previous sections it has been mentioned that the core inductance, leakage reactance and winding capacitance all have an effect on the cut-off frequencies of the transformer. Since these parameters vary between core sizes and shapes, it would be useful to have a numerical factor for each core that denotes its relative value as a broadband transformer. It can be shown that such a number may be generated so that the lower the number determined for a particular core, the wider the frequency range of the finished transformer. This number, known as the form factor, is defined as follows: Form factor = $\ell_w C_\ell$, where $C_\ell = \frac{\ell_e}{A_e}$, ℓ_w = length of one complete turn of wire, ℓ_e = effective magnetic path length and A_e = effective magnetic area. This form factor has been calculated by Fair-Rite Products for each core listed in Fig. A.7 [14].

The lowest form factors (and highest frequency response) are for items 4 through 7, which are types 3 and 4 balun cores. The next lowest form factor is for the type 1 balun core while the toroid has the highest.

The toroid is sometimes used with several cores in parallel [12]. The form factor for such an assembly would be markedly lower than the factor for a single toroid, due to several increased parameters, but mainly the effective magnetic area A_e. Figure A.7 also shows that the form factor for shield beads (type 7) is somewhat higher than for balun cores, but they are in the same general vicinity and therefore, make acceptable transformers.

Interesting to note is that items 1, 2 and 3 in Fig. A.7 are the two hole balun cores with similar form factors. The main difference between them is their overall size and hole size. In general the smallest is the least expensive in first cost and mounting space, but it also has a small hole for the winding. If the hole size cannot accommodate the number of turns and wire size required, the next size core has to be considered.

It is obvious, therefore, that many factors other than the form factor alone should be considered in choosing a core, but it is an important tool which can make the designer's job easier.



Type 1 Type 3 Type 4 Type 5 Type 7

Figure A.7. List of ferrite core shapes for broadband transformer design [14].

Item	Part Number	Core Shape	Nominal Dimensions (inches)					Form Factor
			A	B	C	D	E	
1	28_ _000302	Type 1	.525	.295	.407	.225	.150	13.0
2	28_ _002402	Type 1	.277	.160	.244	.114	.071	14.3
3	28_ _002302	Type 1	.136	.079	.093	.057	.034	14.0
4	28_ _001802	Type 3	.250	-	.242	.100	.050	9.5
5	28_ _001702	Type 3	.250	-	.471	.100	.052	8.6
6	28_ _000902	Type 4	.284	-	.218	.104	.035	8.8
7	28_ _002802	Type 3	.220	-	.250	.090	.197	7.8
8	26_ _002402	Type 5	.350	-	.190	-	-	29.0
9	26_ _000101	Type 7	.138	.051	.118	-	-	17.3
10	26_ _000201	Type 7	.076	.043	.150	-	-	24.3
11	26_ _000301	Type 7	.138	.051	.236	-	-	14.9
12	26_ _000401	Type 7	.138	.051	.500	-	-	13.7
13	26_ _000801	Type 7	.295	.094	.297	-	-	11.8
14	26_ _002401	Type 7	.200	.082	.250	-	-	15.2
15	26_ _021801	Type 7	.200	.082	.437	-	-	12.3

A.6 The circuit configurations

Broadband transformers have been described in detail by C. L. Ruthroff [15] as well as G. Guanella [16], resulting in two models, aptly named the 'Ruthroff balun' and the 'Guanella balun'. Certain variations of these unique configurations have also been discussed elsewhere, and are included here for the sake of completeness [17, 18, 19, 20]. The transformer models are shown in Figs. A.8 to Fig. A.16. When drawn in the transmission line form, the transforming properties are sometimes difficult to see. For this reason, a more conventional form is shown with the transmission line form, with some winding arrangements [15].

In conventional transformers the interwinding capacitance resonates with the leakage inductance producing a loss peak. This mechanism limits the high frequency response. In transmission line transformers, the coils are so arranged that the interwinding capacitance is a component of the characteristic impedance of the line, and as such forms no resonance to seriously limit the bandwidth. Also, for this reason, the windings can be spaced closely together maintaining good coupling.

The net result is that transformers can be built this way which have good high frequency response. In all of the transformers for which experimental data are presented, the transmission lines take the form of twisted pairs. In some configurations the high frequency response is determined by the length of the windings and while any type of transmission line can be used in principle, it is quite convenient to make very small windings with twisted pairs. The sketches showing the conventional form of transformer indicates clearly that the low frequency response is determined in the usual way, by the primary inductance. The larger the core permeability, the fewer the turns required for a given low frequency response and the larger the overall bandwidth. Thus a good core material is desirable.

The transformer configurations are shown using ferrite toroids, for explanatory purposes. Ferrite toroids have been found very satisfactory [14]. The permeability of some ferrites is very high at low frequencies and falls off at higher frequencies. Thus, at low frequencies, large reactance can be obtained with few turns.

When the permeability falls off, the reactance is maintained by the increase in frequency and good response is obtained over a large frequency range. It is important that the coupling is high at all frequencies or the transformer action fails. Fortunately, the bifilar winding tends to give good coupling.

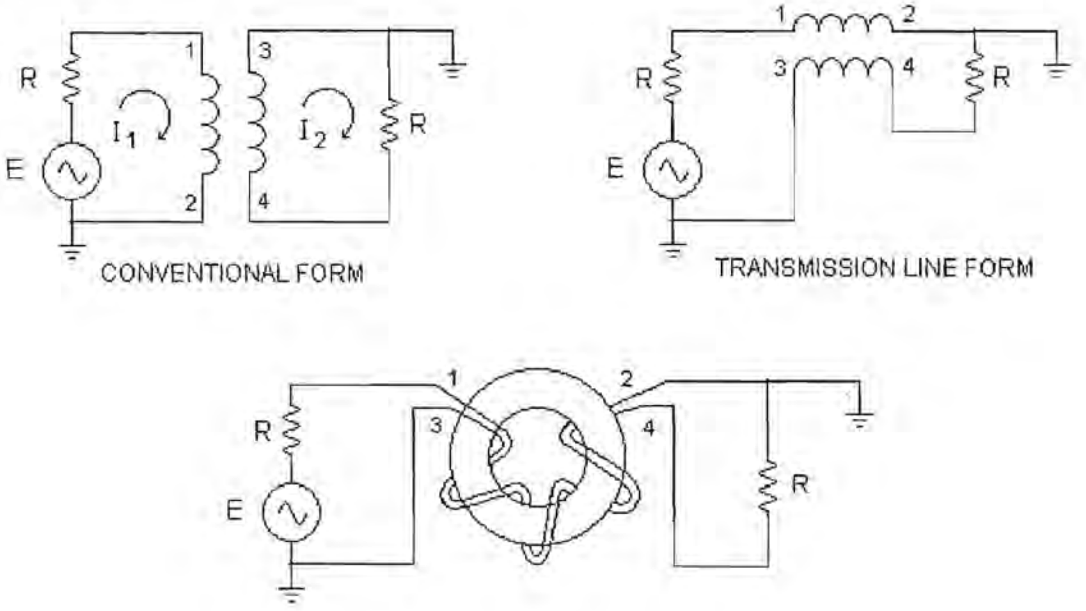


Fig. A.8. Reversing transformer

A.6.1 Ruthroff's polarity reversing transformer - Fig A.8 [15]

This transformer consists of a single bilfilar winding and is the basic building block for most of the transformer configurations presented here.

The fact that a reversal is obtained can be seen from the conventional form, which indicates the current polarities. Both ends of the load resistor are isolated from ground by coil reactance. Either end of the load resistor can then be grounded, depending upon the output polarity desired. If the centre of the resistor is grounded, the output is balanced. A suitable winding consists of a twisted pair of insulated wire. In such a winding, the primary and secondary are very close together, insuring good coupling. The interwinding capacitance is absorbed by the characteristic impedance of the line.

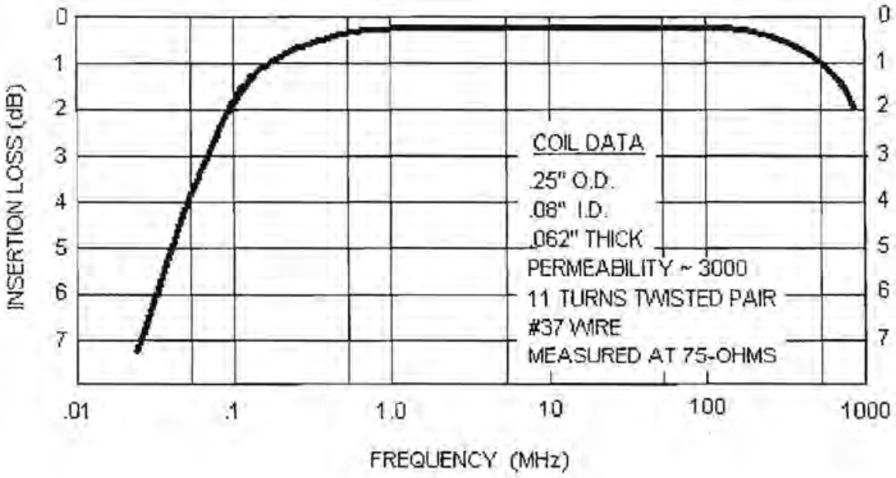


Fig. A.8 (a) Ruthroff's reversing transformer. Insertion loss vs. frequency [15].

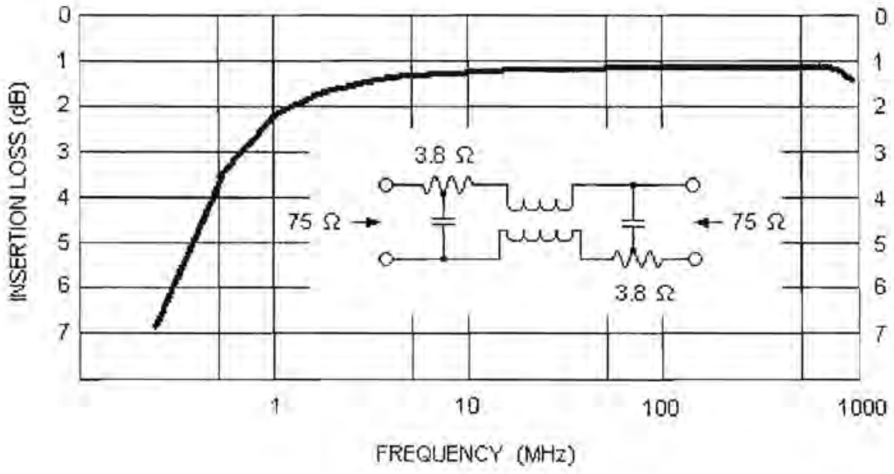


Fig. A.8 (b) Ruthroff's matched reversing transformer [15].

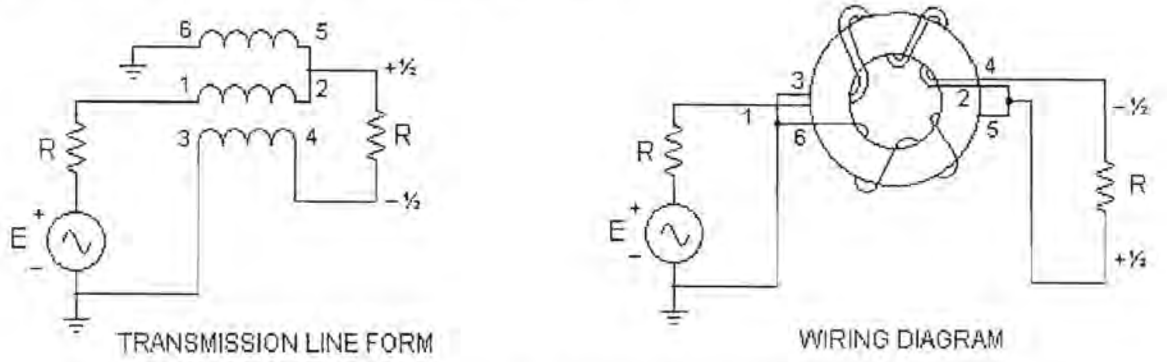
At high frequencies this transformer may be regarded as an ideal reversing transformer plus a length of transmission line. If the characteristic impedance of the line is equal to the terminating impedances, the transmission line is inherently broadband. If not, there will be a dip in the response at the frequency at which the transmission line is a quarter wavelength long. The depth of the dip is a function of the ratio of terminating impedance to line impedance and is easily calculated.

Experimental data on a reversing transformer are shown in Fig. A.8 (a) and Fig. A.8 (b) [15]. Fig. A.8 (a) is the response of a transformer with no extra impedance matching. The return loss of this transformer to a 3 nanosecond pulse is 20-dB.

The transformer of Fig A.8 (b) has been adjusted to provide more than 40-dB return loss to a 3 nanosecond pulse by C. L. Ruthroff [15]. The transformer loss (about 0,5-dB before matching) is matched to 75-ohms with the two 3,8-ohm resistors. The inductance is tuned out with the capacitance of the resistors to the ground plane. The match was adjusted while observing the reflection of a 3 nanosecond pulse.

A.6.2 **Unbalanced-to-Balanced 1:1 Impedance transformer - Fig. A.9 [15]**

This is similar to Fig. A.8 except that an extra length of winding is added. This is necessary to complete the path for the magnetising current.



TRANSMISSION LINE FORM

WIRING DIAGRAM

Fig. A.9. Unbalanced to balanced transformer [15].

A.6.3 **Unbalanced-Unsymmetrical 4:1 Impedance transformer - Fig. A.10.**

This transformer is interesting because with it a 4:1 impedance transformation is obtained with a single bifilar winding such as used in the reversing transformer. The transforming properties are evident from Fig. A.10. Not so easily seen is the high frequency cut-off characteristic.

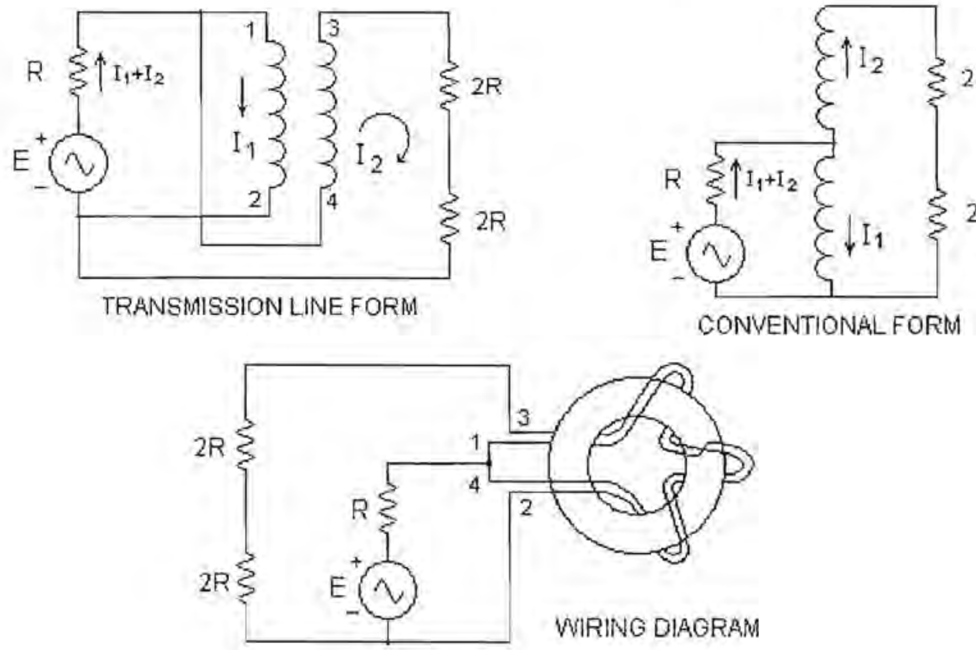


Fig. A.10. Unbalanced-Unsymmetrical 4:1 impedance transformer [15].

The response of this device at high frequencies is derived from the transmission line equivalent. With the characteristic impedance of the winding denoted as Z_o, the reactance of winding *W* may be denoted as $X >> R_L$, R_g. The loop equations are as follows:

$$e = (I_1 + I_2)R_g + W_1$$

$$e = (I_1 + I_2)R_g - W_2 + I_2 R_L$$

$$V_1 = V_2 \cos\beta.\ell + jI_2 Zo \sin\beta.\ell \quad \text{.......................... (1)}$$

$$I_1 = I_2 \cos\beta.\ell + j\frac{V_2}{Zo}\sin\beta.\ell \quad \text{.......................... (2)}$$

This set of equations is solved for the output power P_O, where $P_O = |I_2|^2 R_L$, from which follows:

$$P_O = |I_2|^2 R_L = \frac{e^2(1+\cos\beta.\ell)^2 R_L}{\left[2R_g(1+\cos\beta.\ell) + R_L\cos\beta.\ell\right]^2 + \left[\dfrac{R_g R_L + Z_o^2}{Z_o}\right]^2 \sin^2\beta.\ell} \quad \ldots\ldots (3)$$

From this expression, the conditions for maximum power transmission are obtained by setting $\ell = 0$ and setting $\left|\dfrac{dP_o}{dR_L}\right|_{\ell=0} = 0$. The transformer is matched when $R_L = 4R_g$. The optimum value for Zo is obtained by minimising the coefficient of $\sin^2\beta.\ell$ in (3). In this manner the proper value for Zo is found to be $Z_o = 2R_g$.

Now, setting $R_L = 4R_g$ and $Z_o = 2R_g$, (3) reduces to:

$$P_o = \frac{e^2(1+\cos\beta.\ell)^2}{R_g\left[(1+3\cos\beta.\ell)^2 + 4\sin^2\beta.\ell\right]} \quad \ldots\ldots (4)$$

Also,

$$P_{available} = \frac{e^2}{4R_g} \quad \ldots\ldots (5)$$

and dividing (4) by (3):

$$\frac{Power\ available}{Power\ Output} = \frac{(1+3\cos\beta.\ell)^2}{R_g\left[(1+3\cos\beta.\ell)^2 + 4\sin^2\beta.\ell\right]} \quad \ldots\ldots (6)$$

where β is the phase constant of the line, and *l* is the length of the line. Thus, the response is down 1 dB when the line length is λ/4 wavelengths and the response is zero at λ/2.

This function is plotted in Figure A.11.

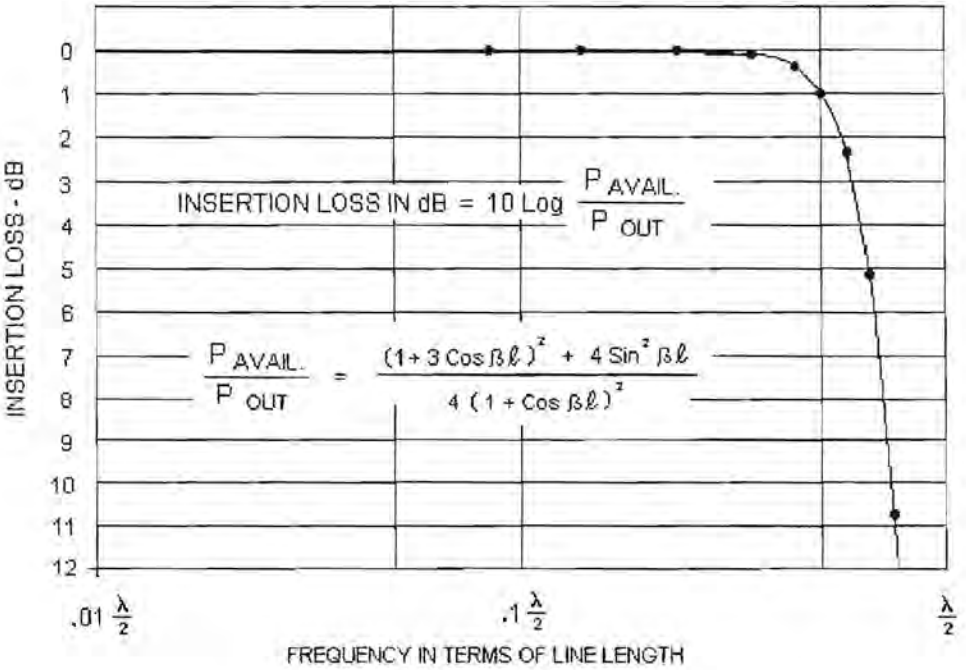


Figure A.11. Theoretical insertion loss vs frequency [15]

The impedances seen at either end of the transformer, with the other end terminated in Z_L have been derived [15]. They are:

$$Z_{in} \text{ (low impedance end)} = Z_o\left(\frac{Z_L\cos\beta\ \ell + jZ_o\sin\beta\ \ell}{2Z_o\left(1+\cos\beta\ \ell\right)+jZ_L\sin\beta\ \ell}\right) \ldots\ldots\ldots (7)$$

and

$$Z_{in} \text{ (high impedance end)} = Z_o\left(\frac{2Z_L\left(1+\cos\beta\ \ell\right)+jZ_o\sin\beta\ \ell}{Z_o\cos\beta\ \ell + jZ_L\sin\beta\ \ell}\right) \ldots\ldots\ldots (8)$$

A.6.4 Balanced-to-Unbalanced 4:1 impedance transformers - Fig. A.12.

The circuitry in Fig. A.12 is rather simple. The single bifilar winding is used as a reversing transformer as in Fig. A.8. The high frequency cut-off is the same as that for the transformer of Fig. A.10.

In some applications it is desirable to omit the physical ground on the balanced end. In such cases, Fig. A.12.(b) can be used. The high frequency cut-off is the same as for the transformer of Fig. A.10.

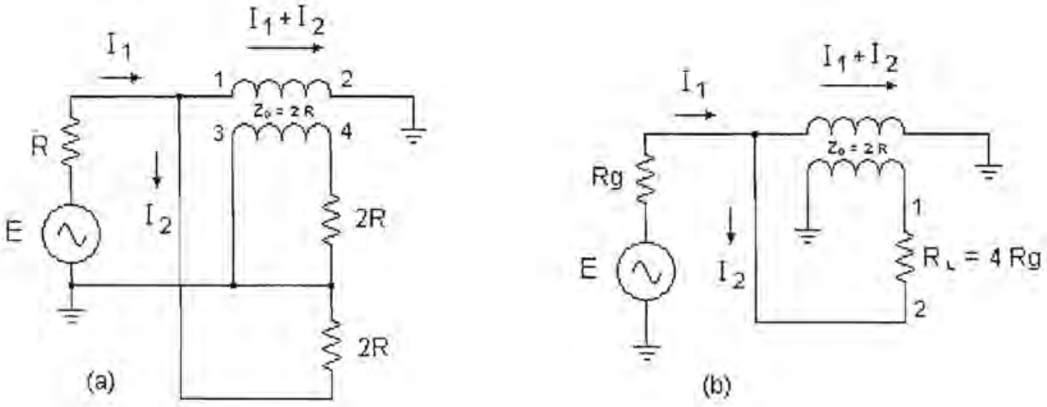


Fig. A.12. Balanced-Unbalanced 4:1 impedance transformer [15]

In the low frequency analysis of the transformer in Fig. A.12.(b), the series impedance of each half of the bifilar winding is denoted by Z.

The loop equations are:

$$E = \left(R_g + Z\right)I_1 - (Z + kZ)I_2$$

$$E = \left(R_g - kZ\right)I_1 + \left(R_L + Z + kZ\right)I_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

from which

$$\frac{I_1}{I_2} = \frac{R_L + 2Z(1+k)}{Z(1+k)} \approx 2 \ \ if \ \ Z >> R_L \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

The voltages from points 1 and 2 to ground may now be calculated as $V_{2G} = I_1 R_g$,

and when the transformer is matched, $E = 2I_1 R_g$, and $V_{2G} = I_1 R_g$ .... (11)

Similarly, $V_{1G} = I_2 Z - kZ(I_1 - I_2)$. With the aid of (10), this may be rearranged to:

$$V_{1G} = ZI_1 \left[\frac{Z(1+k)^2 - kR_L - 2kZ(1+k)}{R_L + 2Z(1+k)} \right] \qquad (12)$$

Now let the coupling coefficient $k = 1$, then

$$V_{1G} = I_1 Z \left[\frac{-kR_L}{R_L + 2Z(1+k)} \right] \approx -\frac{I_1 R_L}{4} \quad \text{for } Z >> R_L.$$

When the transformer is matched, $R_L = 4R_g$, so that $V_{1G} = I_1 R_g = -V_{2G}$, ... (13)
the load is balanced with respect to ground.

From (13) it is clear that the centre point of R_L is at ground potential, and can therefore be grounded physically, resulting in Fig. A.12.(a).

A.6.5 **Hybrid circuits - Fig. A.13 to Fig. A.16 [15]**

Various hybrid circuits are developed from the basic form using the transformer configurations discussed previously. The drawings are very nearly self-explanatory. In all hybrids in which all four arms are single ended, it has been found necessary to use two cores when ferrite toroids are used, in order to get proper magnetising currents [15].

Figure A.13.(a) indicates the Ruthroff basic hybrid and Figure A.13.(b) the unsymmetrical version of the same, with equal conjugate impedances.

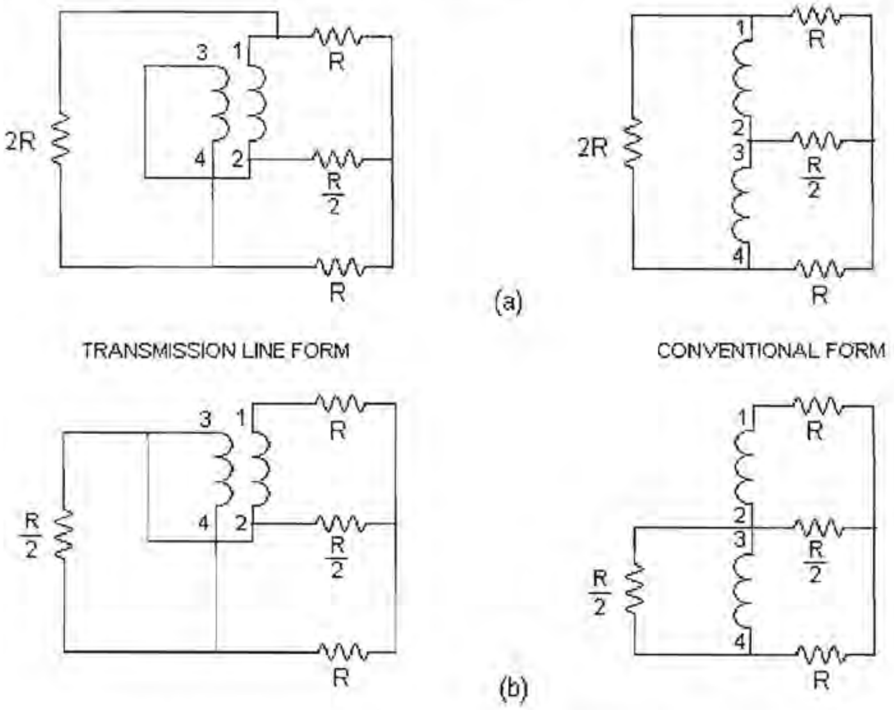


Fig. A.13. (a) Basic hybrid. (b) Unsymmetrical hybrid

Fig. A.14 indicates the Guanella symmetrical hybrid with conjugate impedances [16]. This hybrid is used very effectively as an antenna balun, specially in HF applications [20].

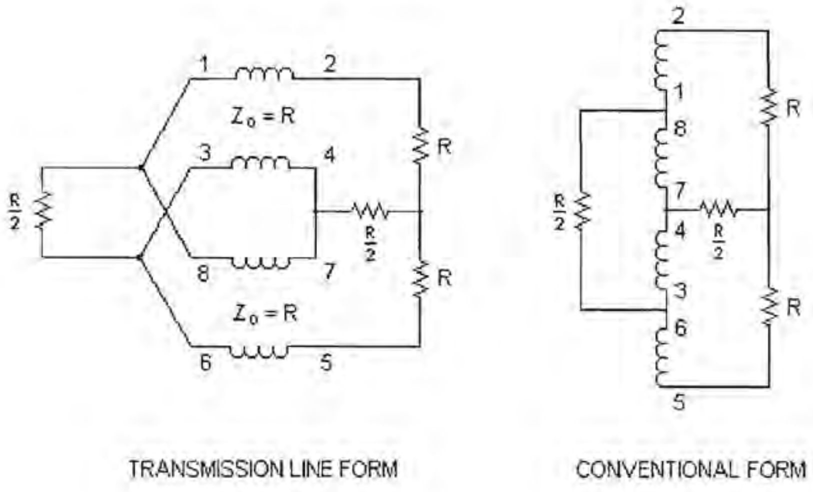


Fig. A.14. The Guanella hybrid

Two hybrids have been measured and data included here [15]. The response of a hybrid of the type shown in Fig. A.15 is given with the figure of the same. For this measurement R = 150-ohms. In order to measure the hybrid in a 75-ohm circuit, arms B and D were measured with 75-ohm resistors in series with the 75-ohm measuring gear. This accounts for 3-dB additional loss measured. Apart from these conditions arms B and D have a 3-dB insertion loss with respect to arm C.

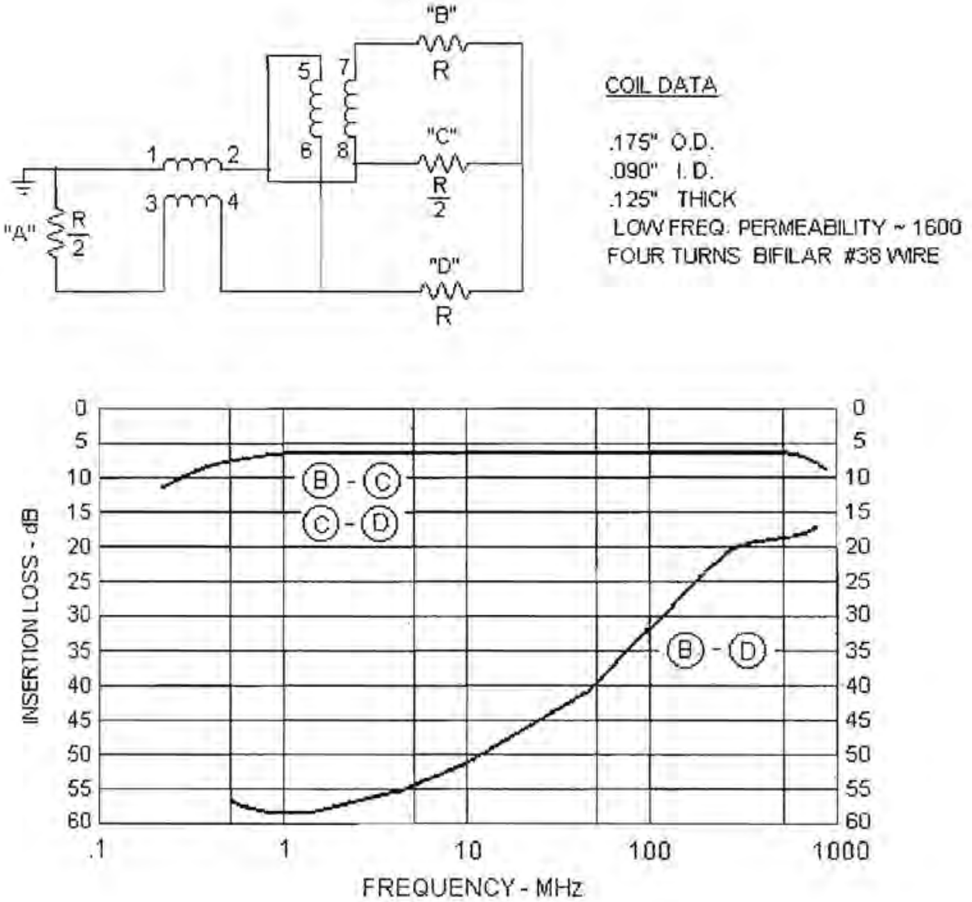


Fig. A.15.(a) Hybrid with equal conjugate impedances. (b) Insertion loss vs frequency [15]

As a power combiner, two signals fed into ports C and D yield their vector sum a port B.
As a power divider, a signal fed into port B divides into two equal amplitude, equal phase, isolated output signals at ports C and D. A signal fed into port A divides into equal amplitude, 180° out of phase, isolated signals at ports C and D.

The transmission characteristics of Fig. A.16 is shown with the same. The hybrid takes the form of a resistance bridge, with all arms single ended. This hybrid, with equal impedance loads, has been matched using the technique described previously in para. A.6.1 for the reversing transformer in Fig. A.8.(b). The results of this matching are included in the figure. [15]. The hybrid has a 3dB loss, dissipating in the resistive elements of the circuit, in addition to transformer loss.

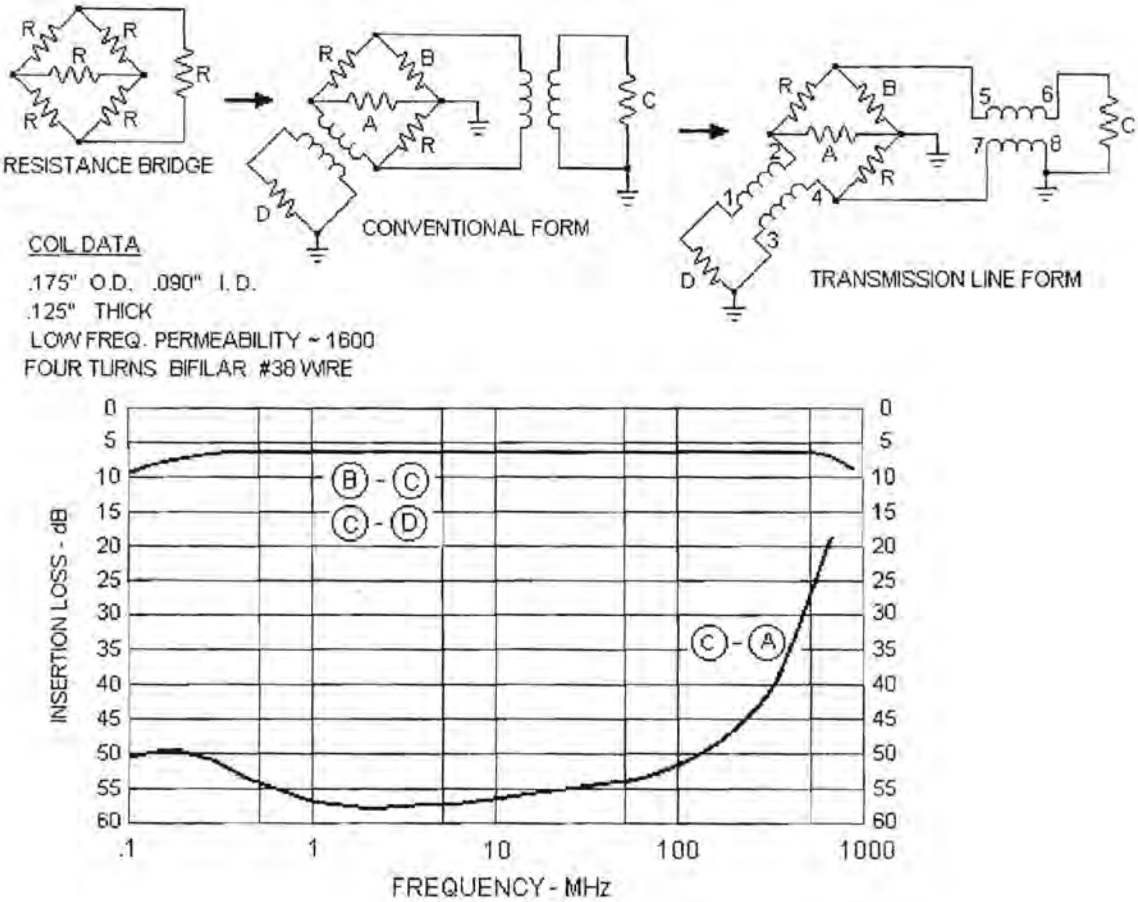


Figure A.16. (a) Matched resistance hybrid. (b) Insertion loss vs frequency [15].

When considering hybrids for use as power dividers or combiners, it is interesting to note that resistors used within the matched circuit in Fig. A.16 have the same insertion loss as the circuit depicted in Figure A.15, but with improved return loss at higher frequencies.

Annexure B

ACCURACY OF THE NOISE MEASUREMENTS

The measurement gear used to perform the noise measurements was the Hewlett Packard HP 8593E Spectrum Analyser with HP 85714A Scalar Measurement Personality option [21].

When resolving signals of equal or different amplitudes in terms of their power levels, one must consider the characteristics of the measuring gear before comments may be made about the accuracy of the measurement.

B.1 Resolving signals of equal amplitude using the resolution bandwidth function

In responding to a continuous wave signal, a swept-tuned spectrum analyser like the HP 8593E traces out the shape of the spectrum analyser's intermediate frequency (IF) filters. As we change the filter bandwidth, we change the width of the displayed response. If a wider filter is used and two equal-amplitude input signals are close enough in frequency, then the two signals appear as one. Thus the signal resolution is determined by the IF filters inside the spectrum analyser.

The resolution bandwidth (RES BW) function selects an IF filter setting for a measurement. Resolution bandwidth is defined as the 3-dB bandwidth of the filter. The 3-dB bandwidth tells us how close together equal amplitude signals can be and still be distinguished from one another.

Generally, to resolve two signals of equal amplitude, the resolution bandwidth must be less than or equal to the frequency separation of the two signals. If the bandwidth is equal to the separation a dip of approximately 3-dB is seen between the peaks of the two equal signals, and it becomes clear that more than one signal is present. See Figure B.2.

In order to keep the spectrum analyser calibrated, sweep time is automatically set to a value that is inversely proportional to the square of the resolution bandwidth. So, if the resolution factor is decreased by a factor of 10, the sweep time is increased by a factor of 100 when sweep time and bandwidth settings are coupled. (Sweep time is proportional to $1/BW^2$).

For fastest measurement times, use the widest resolution bandwidth that still permits discrimination of all desired signals. The HP8593E allows you to select from 30-Hz to 3-MHz resolution bandwidth in a 1, 3, 10 sequence, plus 5-MHz for maximum flexibility.

Example: Resolve two signals of equal amplitude with a frequency separation of 100-kHz.

B.1.1. To obtain two signals with a 100-kHz separation, connect the calibration signal and a signal generator through a suitable coupler (see Figure 4.6, p.39) to the spectrum analyser input as shown in Figure B.1. (If available, two signal generators may be used.)

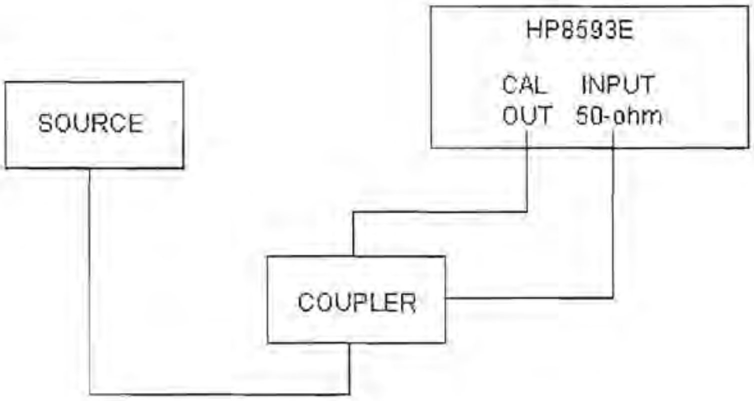


Figure B.1. Set-up for obtaining two signals

B.1.2 If using the 300-MHz calibration signal, set the frequency of the generator 100-kHz greater than the calibration signal, (i.e. 300,1-MHz). The amplitude of both signals should be approximately -20-dBm.

B.1.3 On the spectrum analyser, press [PRESET]. Set the centre frequency to 300-MHz, the span to 2-MHz, and the resolution bandwidth to 300-kHz by pressing [FREQUENCY] 300 [MHz], [SPAN] 2 [MHz], then [BW] 300 [kHz]. A single peak is visible.

B.1.4 Since the resolution bandwidth must be less than or equal to the frequency separation of the two signals, a resolution bandwidth of 100-kHz must be used. Change the resolution bandwidth to 100-kHz by pressing [BW] 100 [kHz]. Two signals are now visible as in Figure B.2. The rotating knob or step keys may now be used to further reduce the resolution bandwidth to better resolve the signals.

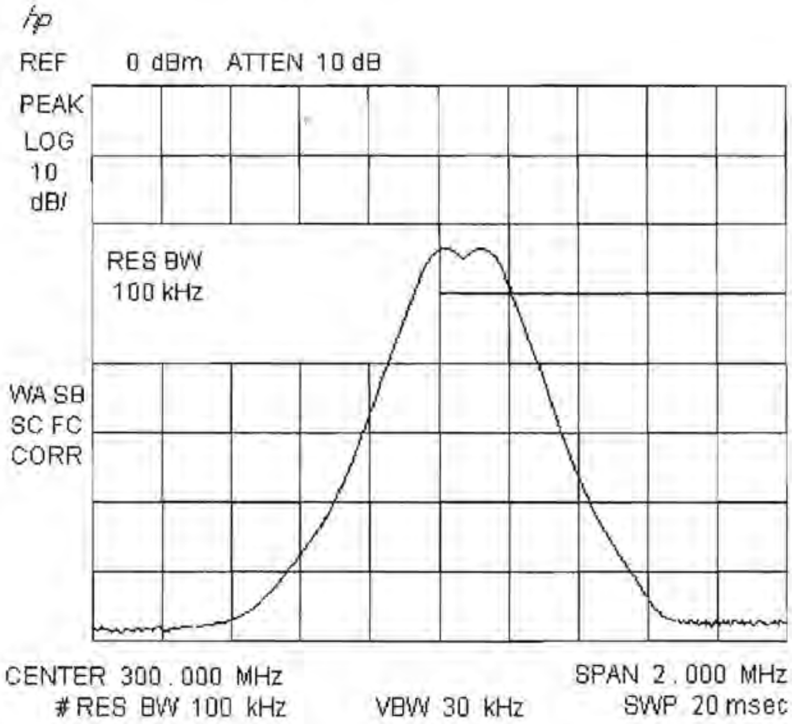


Figure B.2. Resolving signals of equal amplitude

As the resolution bandwidth is decreased, resolution of the individual signals is improved and the sweep time is increased. For the fastest measurement times, use the widest possible resolution bandwidth. Under preset conditions, the resolution bandwidth is coupled (or linked) to span.

If the resolution bandwidth has been changed from the coupled value, a "#" mark appears next to RES BW in the lower-left corner of the screen, indicating that the resolution bandwidth is uncoupled.

B.2 Resolving small signals hidden by large signals

When dealing with the resolution of signals that are not equal in amplitude, one must consider the shape of the IF filter as well as its 3-dB bandwidth. The shape of the filter is defined by the shape factor, which is the ratio of the 60-dB bandwidth to the 3-dB bandwidth. (Generally, the IF filters in the HP4593E spectrum analyser have shape factors of 15:1 or less)

If a small signal is too close to a larger signal, the smaller signal can be hidden by the skirt of the larger signal. To view the smaller signal, or to resolve the large signal in terms of its amplitude, one must select a resolution bandwidth noticeably smaller than the frequency separation, such that k is less than a. See Figure B.3. The separation between the two signals must be greater than half the filter width of the larger signal, at the amplitude level of the smaller signal.

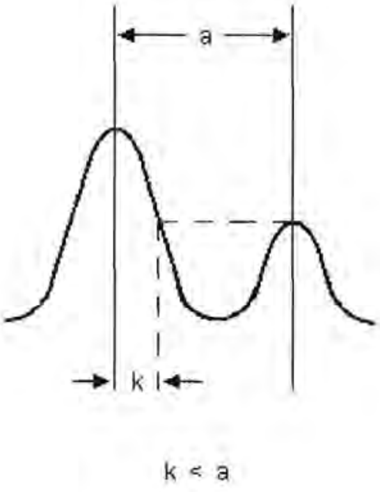


Figure B.3. Resolution bandwidth requirements for resolving small signals.

Example Resolve two input signals with a frequency separation of 200-kHz and an amplitude separation of 60-dB.

B.2.1. To obtain two signals with a 200-kHz separation, connect the equipment as shown in Figure B.1.

B.2.2. Set the centre frequency to 300-MHz and the span to 2-MHz; press [FREQUENCY] 300 [MHz], then [SPAN] 2 [MHz].

B.2.3. Set the source to 300,2-MHz, so that the signal is 200-kHz higher than the calibration signal. Set the amplitude of the signal to -80-dBm (60-dBm below the calibration signal)

B.2.4. Set the 300-MHz signal to the reference level by pressing [PEAK SEARCH], and [MKR - >], then /MARKER ->REF LVL/.

If a 10-kHz filter with a typical shape factor of 15:1 is used, the filter will have a bandwidth of 150-kHz at the 60-dB point. The half-bandwidth (75-kHz) is narrower than the frequency separation, so the input signals will be resolved.

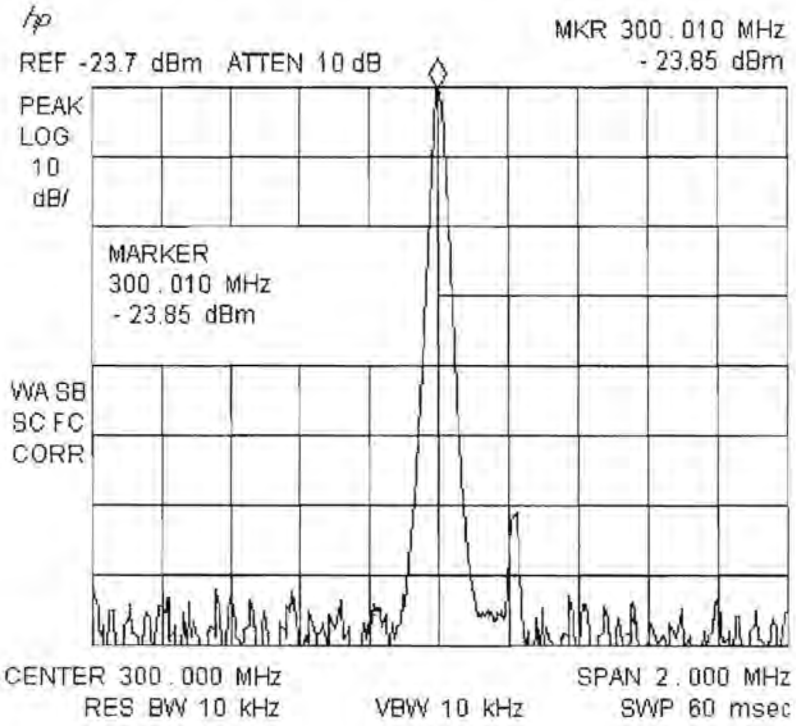


Figure B.4. Signal resolution with a 10-kHz resolution bandwidth

If a 30-kHz filter is used, the 60-dB bandwidth will be 450-kHz. Since the half-bandwidth (225-kHz) is wider than the frequency separation, the signals most likely will not be resolved. See Figure B.5. (To determine resolution capability for intermediate values of amplitude level differences, consider the filter skirts between the 3-dB and 60-dB points to be approximately straight. In this case, we simply used the 60-dB value.)

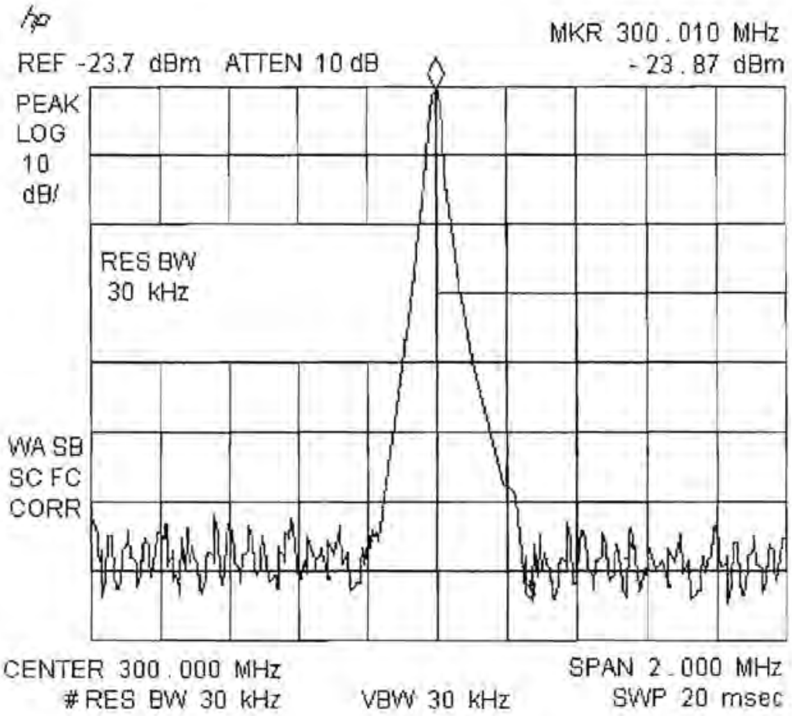


Figure B.5. Signal resolution with a 30-kHz resolution bandwidth

B.3 Measuring low-level signals using Attenuation, Video Bandwidth and Video Averaging

Spectrum analyser sensitivity is the ability to measure low-level signals. It is limited by the noise generated inside the spectrum analyser. The spectrum analyser input attenuator and bandwidth settings affect the sensitivity by changing the signal-to-noise ratio.

The attenuator affects the level of a signal passing through the instrument, whereas the bandwidth settings affects the level of internal noise without affecting the signal. If a signal is very close to the noise floor, reducing input attenuation brings the signal out of the noise. Reducing the attenuation to 0-dB maximises signal power in the spectrum analyser.

When, after adjusting the attenuation and resolution bandwidth, a signal is still near the noise, visibility may be improved by using video-bandwidth and video-averaging functions. Video-bandwidth function allows for the video-filter control, which is useful for noise measurements and observation of low-level signals near the noise floor. The video filter is a post-detection low-pass filter that evens the displayed trace.

When signal responses near the noise level of the spectrum analyser are visibly masked by the noise, the video-filter may be narrowed to smooth this noise and improve visibility of low-level signals. (reducing video bandwidth requires slower sweep times to keep the instrument calibrated.)

Video averaging is a digital process in which each trace point is averaged with the previous trace-point average. Selecting video averaging changes the detection mode from peak mode to sample mode. The result observed is a sudden decrease in the displayed noise level. The sample mode displays the instantaneous value of the signal at the end of the time or frequency interval represented by each display point, rather than the value of the peak during the interval. Sample mode is not used to measure signal amplitudes accurately because it may be incapable to find the true peak of the signal.

Video averaging clarifies low-level signals in wide bandwidths by averaging the signal and/or the noise. During averaging, the current sample appears at the left side of the graticule. Changes in active function settings, such as the centre frequency or reference level, will restart the sampling. The sampling will also restart if video averaging is turned off and on again. Once the set number of sweeps has been completed, the spectrum analyser continues to provide a running average based on this set number of sweeps.