NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

Public Switching Telephone Network

Graduation Project
EE- 400

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[redacted]

kCKNOViLE'lJGEMEN'I'S

First of all 1 would like to- thank my supervis.o-r Prof Dr. Paklıreddin. Maınedov upon hiır attitude towards my project·. He- gt:idcl me A!i reııeh as he ean-and with all his efforts I was able to complete my Graduation Project . He provides ·me a -great knevAedge ebcet this project ·and also abeut the ,comm.ı..micat-ion field. His words of oocouragement kept me going, and under: his; s.up;ervis:ion I made thi5" graduation: project and it is a writirıg good experience for me. I took 2 fübjecti about -ooıntn:ıımcationand get good .grads because when I was in the lecture 1 felt my self- tl'l:fluend.ng under !:-he world -of -knO'wledge. His way of teaching is so kind that I could tmd:grstand whole }ectıne at the momem I chose this project beeause he has good **knmvledge on communication.**

I am. very great fu:U to my friend Malik Osama Nazar, who helped me i:n. this project. He is nice and gentleman and always he helped me in. my any difficulties. Also 1 am h1ınr'ıkfül to M-aılik M.Sajio and, Naveed- Akhtın because· they s.pent· time for me and helped me to search some Information from Internet These both mends have a greaHmp-o-rtancdn-my heart I-wishaed peay-fer-them for-bright futereand happy life,

At the end I anı paying rega:rds to my parents, who help me on every stage of my life where ever I need, and they pick me up about studies and in all matters of life, and' it is only because of their prayers that I am completing my degree.

ABSTRACT

In d;;tily füe. RS:IN has, a: gRear. i1nportance.:.:aoo, used. in w:ezy mp€lt1autdiekkti-ke:, hı: officfal & public work. P.STN is also used ırı, Army communıkatio-ns, tt also play an . ·impo-rtınıt role in flledof science, ·With PS'fN; it-became 'possible 'to eenneet 'the a.H 'over world .through Internet, which keeps t-0 in touch with cm:rent-affair~ of the Wotl:d. *A* telecomm:unii::atıort system, can take many dffferent forms: PSTN· has a very' iiiI.eortanc role in our fife:

The PSTN is one of the most important aspects of information theory, upon which many of technological advancements in Communication. .

Public Switching Telephone Network is now part of our environment. Everyday we receive and transmit information by this network, often without knowing it.

Because of these and more, I prepare to choose my project's subject as "Public Switching Telephone Network ".

PSTN is very wide field, and itcanrıot be covered even by one book, So we can find lot of books taHdng abouHms,sulıjeotand- each. book has,his own point of view;

One of the mean object-ive of this project is to give the .reader enough of understand mg to :aHow him or he? toask the right question.

As- I am doing: füis project to- cover the: impurtruıt snlıjec.t -such· a: yrtal field. Whatever; the· assnrrrttti'otı~ o-ne can be- assured- *that* PSTN Wm· continue *to*- occepy arr important place as a mean of communication.

INTRODUCTION

Telecommunications is a term for a broad field that can include transmission through satellite; miemw.rve, telephone, and computer networks. Public Switching' Telephone Network has a great importance and used in every important field like in official & public work.

PSTN is also used in Anny communications. It also play an important role in filed of science. With· PS-TN, it became possible to conrrect the all over world through Internet, which keeps to in touch with current affairs of the World. A teiecomm.'lmication -system 'Can take many different furms ,PSTN has -a very i.-ınportant role in our life.

In Chapter 1 we briefly describe the major elements .and types of communication device, switching systems in telephones and telephone network. pervious and Modern history of Telecommunications. and. nnportanceef PS.TN ın.coıaemıiication and in Life span.

In Chapter 2 there is a discussion about Telephone Set that how telephone works and how the systems layout k

In Chapter 3 we briefly described which type of interference..would . involve in telephone- system. How the long and short distance· calls can- b-e· transferred and· which main factor is involved.

In -Chapter 4 we brrefly de-scribed· the failure of ·PSTN and which factors •ııottld he iıwolved·tC' fa-it the Ptı:b-Hc Switehing·Telephone Network (PSTN).

To aid in the volume of traffic between of toll centers and primary centers, sectional eeaters ffl'ld -r-egronai -eenters are used. T-he best reet is -shertest route er the route utfüzing smallest rrnrrrberof switching centers.

1. ·Introduction to 'feiec-omtnunications & PST:N

l~~utmr:rıınicatior.BiS- a term for a: broad: field that. can indttıie: ttan.."IDlf£•ritrn thruugh sarellite, microwave, tetephene, and computer networks. In order to traıısmit infomı:ation from one computer . to .ancıiher, one must have access to a teiecornmunicatien system that maintains a large computer server with connection facilities:. Uni:vernities,;. commercial teleco.mııta:m~ı:ion~ system pmvid:ers~~ an:d. community frees, neı usuaUy have connecfaın: facilities. There: are· three primary methods used ftH'·es:tab:li•shing.coımectirın:

l)Dial-up connections with modem and a regular telephone line (Terminal Emulation). Fm· this: kind. of connection you need a; tefocomnıunicatiı.:nr s:o:ftware:·µackage'{.Pmoom~ Zmcdem, Versa term, etc...) installed mı your haul disk.

2) .PPP (Point to Point Protocol) conneeılon with high speed modem and a regular telephone line. This kind of connection provides access to all multimedia features of ınternet. To establish this ki1ld of connecti@ı:ı, you need. to: itıs1aU special PPP software,. and TCP/IP (Transmission Control Protocol *f* Internet Protocol) software on your hani disk.

3) Direct connection through local area network.

Lt-History of Telecommunications

1.1.1 Brnadc-.ı~üıigthe. Human: Voice; ..

Since telephone: wires could carfy the hnmmr voice, could·tlıe·~ireless broadcast: speech seımds as well? In 1906, R Caeadtan scientist named Reginald Fessenden converted sound waves into a pattern, or signal, in the radio waves, This pattern altered tire amplirude; or height~ oıf radio waves,. This ınethO'dc of changing: nrdicı wa~es. was, called amplitude·mb'dulation~Wl: eaU·irAM forshort:

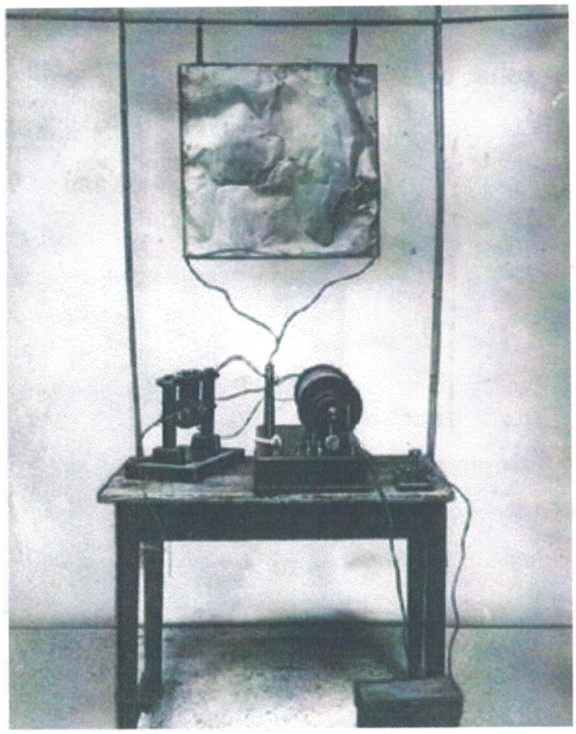


Figure 1.1

By the early 1920ıs, regular broadcasts 'Nere being made i
n many "Countries. Radio was a great success. People everywhere could keep in touch with the latest news and listen to children's programs, concerts, er plays. In 193-9, the American engineer Edwin Armstrong discovered a way to improve the signal further. It is known as frequency modulation, or H.1.

1.1.2 Television

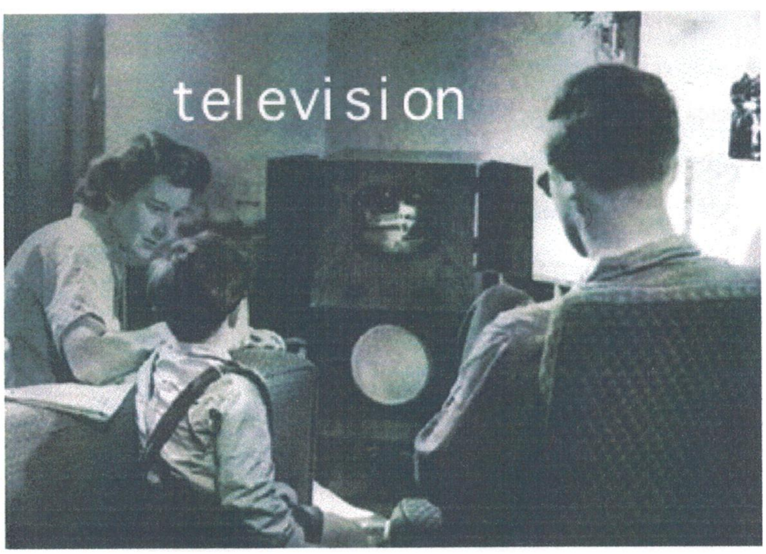
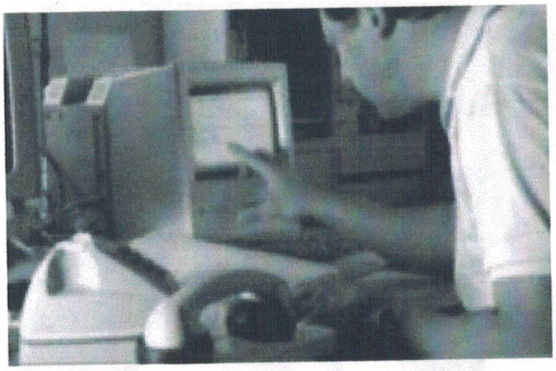


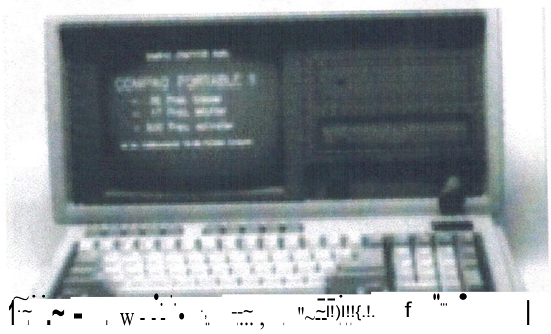
Figure 1.2

In December 1883, a young German named Paul Nipkow had thought of a way to send a moving pieture by wire, He knew that a substance called selenium lets more electricity pass through it in bright light than when it is in the dark. He thought he could use this fact to tum a picture into an electrical signal,

l.1.3 Computer and New Media

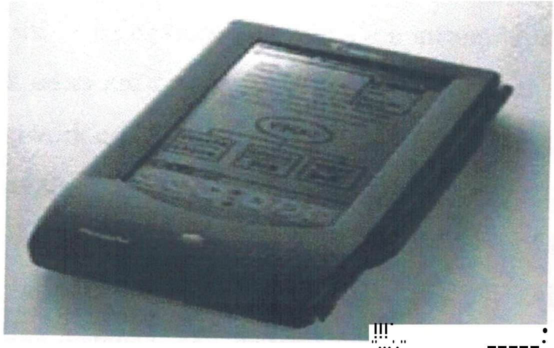


Modems and acoustic-docking-stations. More and more people are using modems and acoustic-docking-stations. Speed: 300-



First real Laptop. Compaq launches the first portable AT (with batteries)

PCMCA-cards. The PCMCA-standard is going to be the most common standard for mobile communication and online hardware.



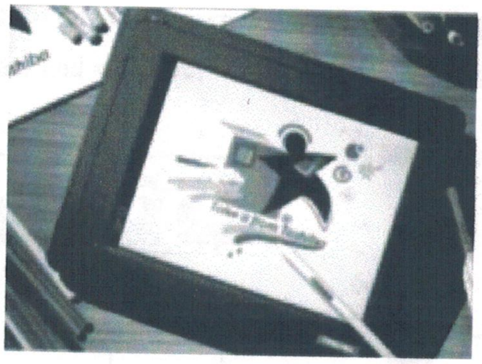
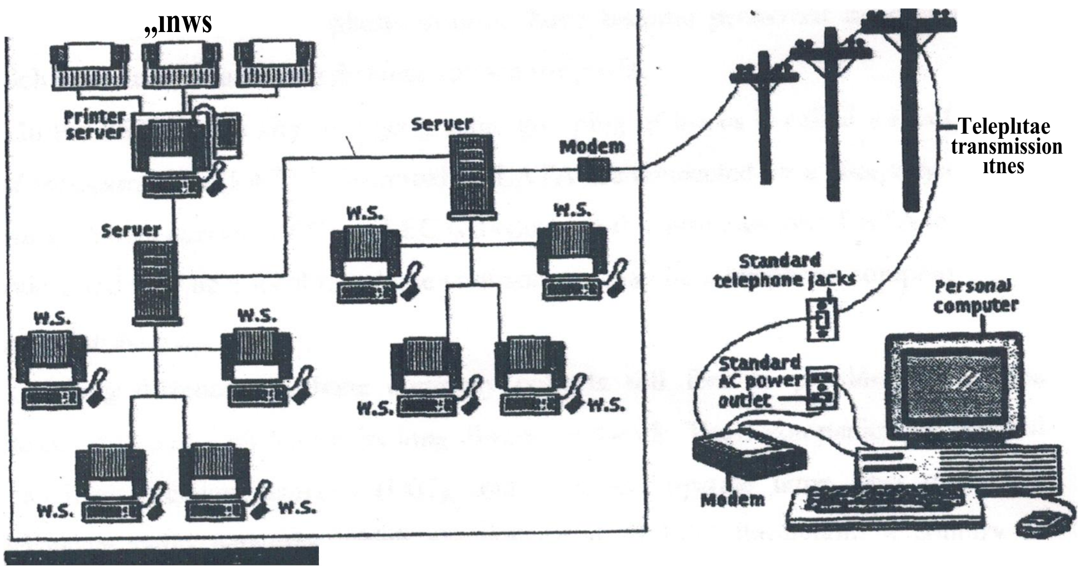


Figure 1.3

1.2 Networks

Despite being very complex, global telecommunications service is comprised of a few basic network components, which are: (1) user equipment telephones, computers, and all the other devices ttu~t provide a means of accessing the network; (2) the access network users are connected to the main network by wire line or radio links; (3) the ın.rirr network copper wire, microwave radio, and optical fiber cables connecting all the nodes of the global network; (4) transmission equipment the means by which huge vohımes of L."lfomıation{there are many minions oftelephone and data calls made every second) are carried over the network; and (5) switching equipment the hierarchy of local, long-distance, and İnternational switches that allow any user of the network to connect to any other user. Each of these components has to consist of a combination of hardware and software.



Figurel.4

ttardware

This usually covers items such as telephones, transmitters, cables, interface devices, switches, and computers, In the past, telecommunfoations have relied heavily on hardware, such as dedicated switching elements, and on the logic providing. its control functions. *A* situation is new developing İn which mere of the system relies on elements operating under computer {software) control. Because this software can be upgraded, this makes it easy to add new, enhanced functionality lat-er.

Software:

This is- cede that instructs a computer or network device. Until the 1980s, mest of the operational instructions used hy a teleeommuaications network were lıard.-wired or

·pPe$et. The advent of digital systems 'and data networks has led to .a murh wider m.nge of network services, Sniıware solutions are weli suited to the eonrpiexity and flexibility inherent ın these serviees,

1..3 Public SwitchıngTelephoııe' Network (PS1N)

The PSTN is a. ·:highiy integrated oommumcations network dınt connects over 70% of the world's inhabirants, In early 1994., the international Telecommımications Unfön estimated. that. tl'lere:. were:~ 650 .m:illiaır. rnıbl:te: lıntıiHrıe, teiepoooo roım:h'e~, as. cı,mpared tn 10' rriiHfo-n c:eHular relepho.rıe :mmı:hers: f1TU91J,.. while buıdline tdephones are being added at a 3% rate, wireless s.ub.sm:ptions are .growing .at .gre.ater th.an;a.509./o rate . .Every teftıJlmn:e .in the world Is given calling access over file PSTN.

Each. country is respcms:föfo for the regw:ati-orııof the: PSTN within: tis:· homers~ Over time, some gnvernn.tent refopl'n:nıe- :i'Jstmi~ haw- heoome pri~aı!.czed by cntı:ıc1c-.ttforı& which provide local and kıng distance.serviee for profit

In the PSTN, :each city or a gengrapiıic .grouping of ıtnms is ral:Jed a *fot:al access: and trrm:fJ!O"f:tarea.* (LAT A)~ S:ur:round.ıng: LATA -are:·connect.edby a oom:pımy call-ed:a *focal exeh:ange·earmr* (hEC); A.-LE.C is a- cmn:pany- that pruvitk.:1 inter LAT A rek'pb:on:e service, .and n:my be .a ·foca11:eJeplıo-ne ,eom.pany, or may be.a .telephone ro:mpany that is regiomd in scope,

A lal'Jg drstance relep:ha~ crnn-pcımy collects toll fees *ta* provide- co.nnect:itıns between· different:' I.Alf A. over its toog· distance; aetwu-rk. These- c.ootp.~ art: referred io as mter exe:hange carriers (D(C), and own and operate hırge fi.her optic .m:ı.d microwave radio networks which are connected to LEC throughout .a country or oomıw.em~

Figure (3) is a:- simplınat ttbıstrati:ou of a local telepb:oae ne:tw-ork; t.-aUed a lo'e.at excfuınge. Each focal ·exchange c:01:ısists ofa -central office (CO) w:hie.h provides

figur-e (L5)is a simplified iH:ustration of a focal tdephoııe network, cai1ed .a focal ~haage~ Each local exchange oo:rıstst'l of a central: o-ffi.ee {Cü) which: prövides PS1N cmme.ctınn ı:a the· custorıer· µre:uti.,es equip.nrem fCPE} whidı. umy be.· au rudivcduat phone at a residence or a ·private bra.neh exehange {PBX) .at a ,pfa.ce of business. The CO :rmıy handle as many as a million 'teiephnne cormectiorrs; The CO *is* connected "to a taınl.6m switch wb:idf in rum. eeeeecıs the kıcaI ~ci'fange:ı:.-0 ı:he- VSTN. nW, tandem s:witcbp.h:ysieaıUy com1ecis rtre local telephone network ttt the pomt of presenee (POP): of tnmked km·g d'is.tanee Jines ·p:tO'Vid'ed by eme or mere IXC Il1Pec9-2j. StJnıeti:rtJes JXC connect directly to the CO switch to avoid local transport charges levied by the LEC.

figure (LS) also shows hew a 'PBX may be used to provide telephone eonaections throughout a building or campus. A PBX allows an organization or entity to provide i'ntermd ealling and other rrr-bınlding services (which do not involve the LEC}, as well as private networking between other organizational sites (through leased lines from LEC and 1XC providers), in addition to conventional local and long distance senders which pass through the CO. Telephone connections within a PBX are maintained by the private owner, whereas connection of the PBX to the CO is provided and maintained by the LEC

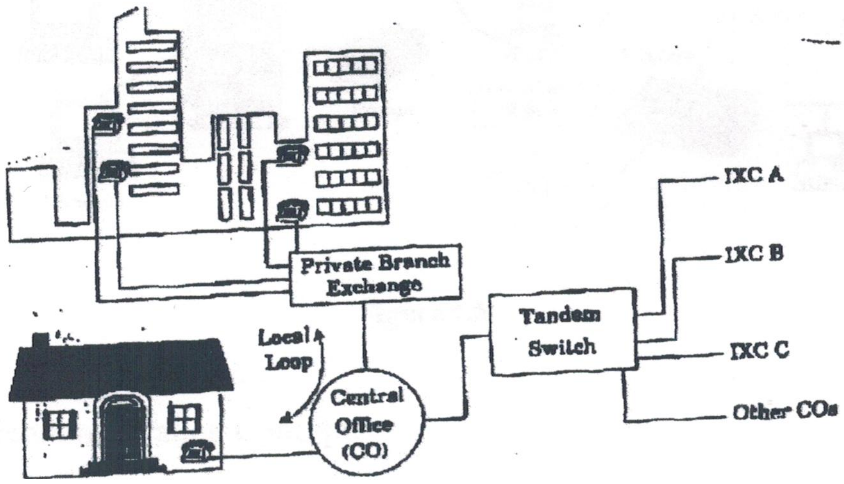


Figure 1.5

Since the invention of the telephone the public switch telephone network (PSTN) has grown proportionately with the increase demand to communicate. Switching services beyond metropolitan areas were soon developed increasing the size and complexity of the central office. New methods of switching were required to interconnect central offices through the use of interoffice trunks and tandem trunks as shown in figure. When the call is made outside the local area, they are routed through Toll Trunk and Toll Center.

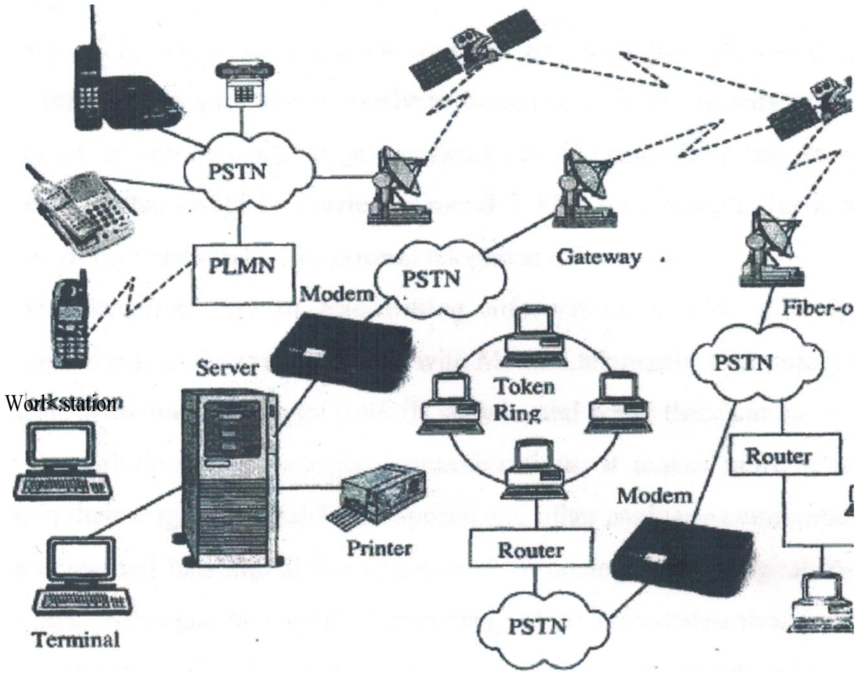


Figure 1.6

·1A Teiecommnnicatien Concept:

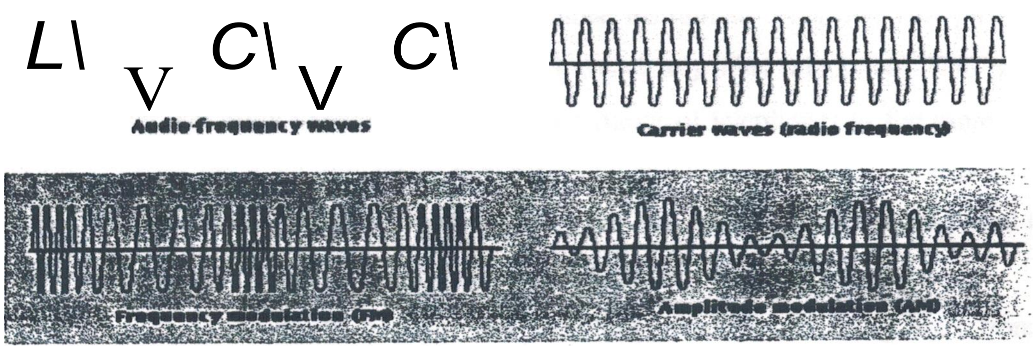


Figure 1.7

There mı: several w.ays of carrying information between senders and users. Th.e options: c:hosen should reflectthe.type ofcommumc:ationreq.uired. For lnstance, humans compensate. for noise. and transmission errors wben they talk to each other. Unexpected delays or echoes cause problems in understanding, however. Computers have the reverse characteristics being tolerant ef-shert delays and less so of transmission errors. The-fölto·wing canceptsmıderpıın relecommtutlcationsnetworh.

1~4..1 Analogue and Digital Networks:

Many ,o{der telecottımfflltca:tioos ,systems are analogue; t.J:ıe electrical signals conveying iıformaıioıt vary eo.nti:ntıoüsly in harmony with. the sounds· they represent The quality of spee.dı: across. ana.logue. ne:n.vark:s is determined by the. anınunt: of the speech· spectrum that coııld be carried. Around 3 kHz was accepted as .a reasonable C(H:ttprom~~ of eost and quality for norn.tal telephone ,culls.

The alternative way of transmitting information is with a strargiıtförward electrical signal. that is either: mı or off,.. *as* with:, Morse's. telegrap:h.- Cı:ımputets also, Communicate with discrete, digital (on/oft) .signals, and while these can be converted to tones .for *tra:nsmjssi:on* over analogue romınl:h'lİ~a.tions;it makes *more* .sense to .send them back in their o.riginal digfüıf form. Speech and other analogue cnn1n1wıieatians cal'l' readiıy be can:verte.ı:t into digital fürnı;. and hack tff analffgue·*(see:* Digitıitc.to-..../£..narl~gue' Converter and. Analogae-to-Digitat Converter). Most telecommtl.ITİcationsnetworks today are "integrated" digital systems, .ideally suited kl camputer ,networking and other multimedia app,füıatiom, such as speech (voice), data, text, faxasd video..

1.5 Switching.

13~1Service Ev.olution

As ·or:igına1 1y jnve:ntecl *by* Bell, {dephone comeıenication went from *a* particular tefephone, instnıment to only one. other telephoee i-ı:tStnımen.t. This was:trıı!:)l'" private;-line servi.ce (Figuu: l.-&{a)}, and there was no wa-y to reach any other telephones. This private-line service was soon extended to connect a number of telephones to the same line, a f't>.rm ,3f p;,ırty--}lrıe. Ev-eryone -C<fül<l hear everyone else hence there was no privacy, and once call would prevent anyone else tram· using füe line. Clearly, there was the need fora telephone to be switched to any other desired telephone.

One way to perform this switching would be to bring lines from all telephones to all other telephones. A switch at each telephone would then make the eormection with: the appropriate ate line-to the desire.cl' telephone (Figure t-8(c)). ffth'e:. universe· eftelepboae stations, to be reached is smaH~ suck a ıi)'Stem v,<ould he ,vodrahk~ However, ·.ifthe universe is large, then the large number of.lines that must terminate at each telephone makes such a system of station switching impractical.

The nltimste sohrtlon was discovered arrtf rmvlemerı:ted: mıl:y a *few* years aüer tr-..e invention of the telephone by Belt The s.olutio-n was a centralized: s)vitdüng -Mra_n,gemen:t {Fi-gtl\"t: *l* c..:8{JJJ· .,*.H tic Hnes f:r0m aH 'tr,e te:k:ph.3fi'C s,lddaas ~re ,oı•tni:ght to a common place where the electrical connections were made to connect one station to another. The actual connections were made by people. The central place where the lines all came together was called the "central office" or the "exchange."

As exchanges grew to cover greater geographic areas, it became uneconomical to bring lines from the more outlying areas to one central office. More central offices were created, each serving a nearby surrounding area. Connections between central offices were made on lines called trunks (Figure 1-8(e)). As growth continued, special switching offices were developed to handle the trunks between a numbers of central offices. This centralized switching of trunks was performed at a switching office called a tandem office. New switching needs developed to serve long-distance or toll circuits between cities. Switching offices were thus devised to perform the switching of toll trunks only. These offices were called toll offices (Figure 1.8(g)). For businesses, a fair amount of telephone traffic was between telephones that were all located on the customers' premises. These telephones, therefore, could be served most efficiently with a private switch located on the premises. This switch was called a private branch exchange, or a PBX-a term that is still in use today. Present PBXs are automatic (PABX), using electromechanical or electronic technology (EPABX).

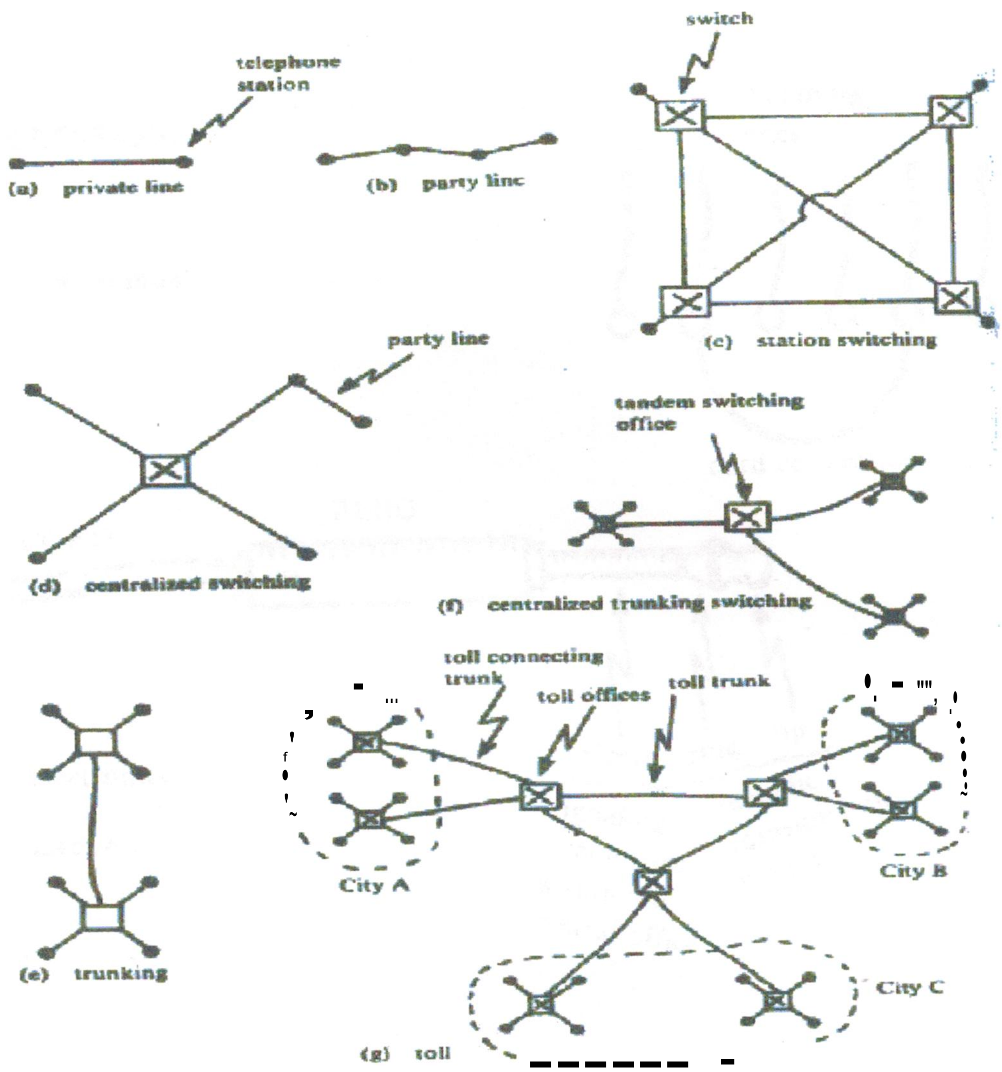


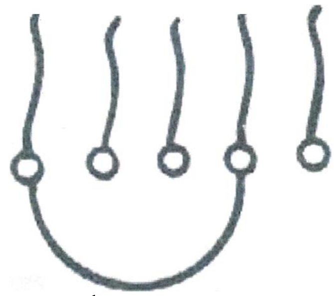
Figure 1.8

1.5.2 Technology Evolution

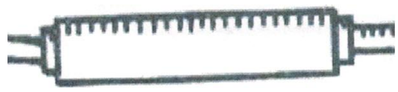
During the first few decades of telephone communication, switching was a manual operation performed by human beings who made the actual connections of circuits. (Referto Figure 1-9.) The connections were made at a switchboard utilizing cords with plugs at the ends. The plug had a tip and a ring, which made the actual connection between the lines. The sleeve: was used for signaling, and supervisory purposes, in common-battery ex-changes. The terms "tip" and "ring" continue to be used to this day for the two wires between the central office and the actual telephone instrument. The circuits desiring 'Serviceand the availability of trunks were indicated by small lamps.

PROGRESSION:

- **Manual --**



CORD



- Electromechanical
- Electronic
  - analog
  - digital

signaling
circufr usca
within the
Central o[fice

Figure 1.9

The first major innovation in switching came in 1892 with the first installation of an automatic switch. controlled by the telephone instrument itself. This switch was conceived *by* Almon B. Strowger. A later modification I of this system included the invention of the dial and the use of dial pulses to control the operation of the switching system. The Strowger switch was an electromechanical device. Strowger's invention was adopted for use by the Bell System in 1919. Bell System engineers later developed improved automatic switching systems using electromechanical technology: The elec-tromechanical technology was somewhat slow, not very flexible in terms of offering new services, and frequently generated electrical noise in the connection.

The current generation of teehnology for telephone switching.is elec-tronic using either ımırtog ~witches·*ar* digitzrfswitching teclıniques. The eleetromc tedmology is extremely fast and flexible. There are two major parts of any telecommunication switching system: the switches themselves and a control .section, .as shown hy Figure 1-10. The switches form the switching network. The controi section operates the -switches at the proper time in order to make a communication connection.

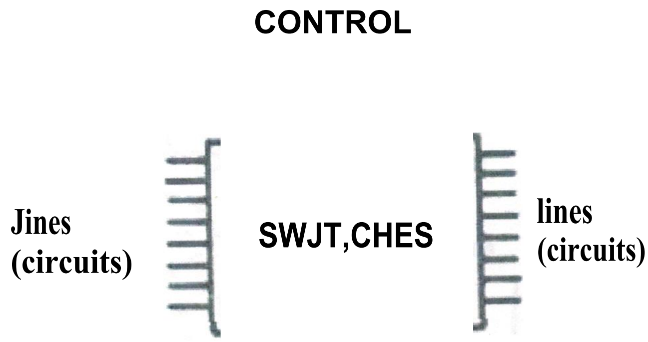


Figure 1.10

1.5.3 Net Work Switching

The switching. network is composed of a number of centralized loca-tions celled switching offices, where the switching or connecting of circuits is actually performed. These offices are organized into a hierarchy dependent upon whether a call is -lecal {exchange} or long-distance {t-0H}. The three major types uf switdıi-ng offices are local, tandem, and toll. The local office is. the one closest to the telephone station and connects directly to the local loop. A tandem office serves a cluster of local offices. Toll offices, or toll-centers as they are sometimes called, are concerned with long-distance toll connections.

There are five classes of offices in the Bell System switc:hi:ng hierarchy. At: the lowest leve] ſS the loeal office er end office. This is the switchirtg office where the call first originates and finally terminates, The end office is classified as a class-S office. A class-S office will attempt to make the connection directly to the terminating class-S office over a direct interoffice trunk. If necessary, the switching capabilities of a tandem office may be used. If the call is a. toll call, then the toll switching offices become involved.

The. *class-5* offlces connect to class-d offices, or toll centers, Toll centers co1lnect to d:ass-3 effices, er primary centers. Primary centers cennect to elass-2 offices, or sectional centers. Sectional:centers connect to class-I effiees, or regional centers. The whole lüenm:hy is organized in a tree' fashion with regional centers at the- *iup*- of the tree, as tuu~trated in flgure .1.I i

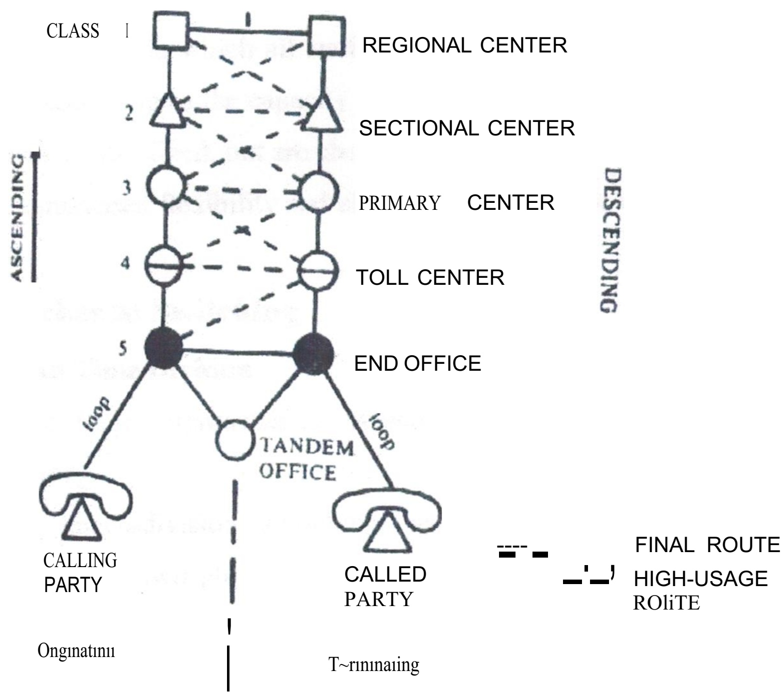


Figure 1.U

The number of offices increases as the tree. is descended. There are only about 20 regional centers serving the United States and Canada, while there are well over 20,000 end offices.

Normally, a call will be connected using as few switching offices as possible.. The intent is. to keep the actual, final route low in the switching network. The preferred route is to cormect across from an originating office to a lower terminating office using routes called high-usage routes. if this route is busy, then the next preferred route is to connect across to a center at the same ievei, or, if this route 'is busy, then across to the next higher center, If all the routes. across are busy, then the route of last resort *i*s to ascend higher in the originating office to the next higher office and attempt

.ıo eross over again. The mutes .connecdng .cenıers in the originating offwes and in-the "terınimıtmg 'Offices are t:al.ted inter toll trunks.

The call sseends the- m:erarehy in the- eall:iı:ıg,-affice: sequence- and then: descends: the hierarchy in: the: callat-Office;. sequence~ Actual traffic· conmt:intıs~ at tlıe' ti::me: ·öf a:: cail detennine the final route.

'The- routing used in the. AT&T Ioog,;d:i:stance -network İs- moving, toward a. dynamic rronhleratclıical: system in; whidı ait switching centers arc equal and the mute for each can is chosen according.to 'tile capacity-that i-s available. Thus, with this newer system, tire fiml routes are not fixed, but..a:re'chosen ,dynamically at the moment of the call. This s:ystem: offers increased- flexibility and efficiency in the use of the network..

1.6 App.roaches to Switching

1.:6.1 ·Space-and Time Divisimı

There are two basic approaches to switching: space-division switching- and time-divisioıı swit~lıing

In space-division switching; as Figure· 1-12 shows, each telephone 'OO-n-versati-on has ks own physical -pai:h ibt-ough the switch. Each path is ,dedicated to that conversation oaly, and: the physical. connection is maintained through-out the duration of the conversation.

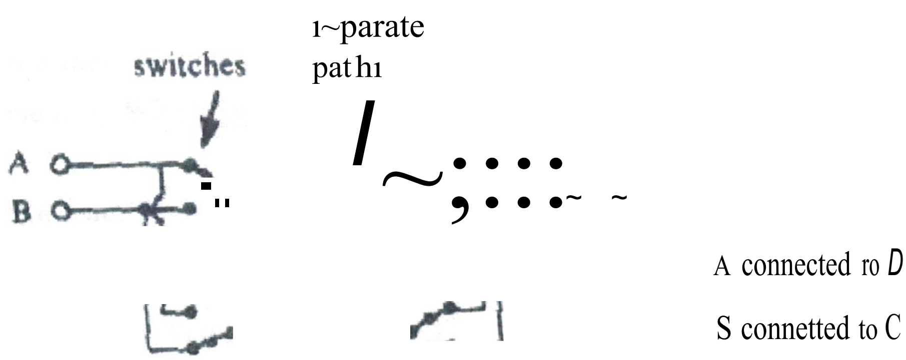


Figure 1.12

LU Time Division

i,11 tim'e-divis1tm ıswitc-hing, ·.ı'S shown by figure i.13, paths for separate conversations are separated in tiine, and connections between various paths are made for very short time intervals. In effect, each conversation is broken into samples, and these sample values are. muted to their appropriate destinations along the, shared..path. This ~ of switching is most appropriate for signals that have been sampled and digitized.

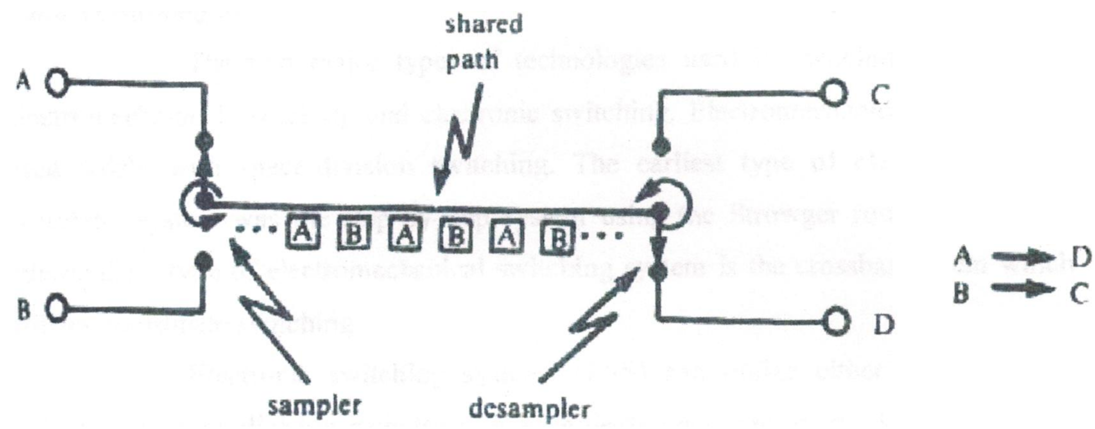


Figure 1~13

With space-divison switchlng, signal paths are switched in J}hysicai space. With time-division switching, sample values of a number of signals sharing a common medium are reorganized, or switched, *m* their time sequence. The earliest automatic switches transferred physical paths and were space-division .switches. The newest switches are called digital switches because they switch digitized signals by using a combination of space-division and time-divisron switching.

There is a thlrd possible approach to switching, namely, freqrrency-division switching {see figure Ll4). Wit-ldrequency-division'Switching.

1.6.3 Frequency Division:

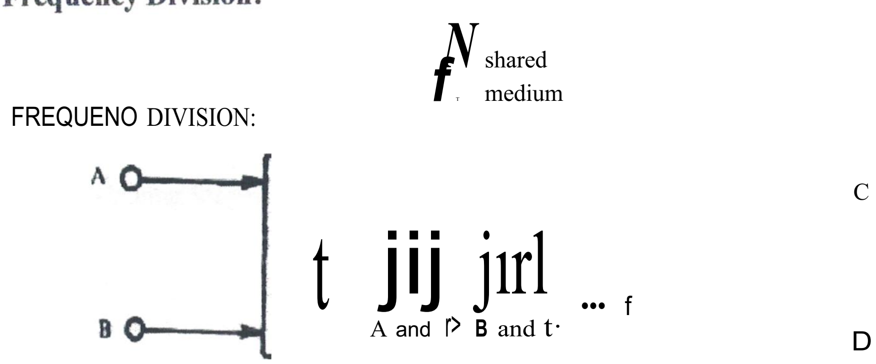


Figure 1.14

Bands would be assigned to different connections. This type of switching could be particufarly applicable to the single broadband medium that might be shared by a number of users, such as the coaxial cable in a CATV system, Each pair of users would need to agree on a specific· band of frequencies to be used for their pa-rtieular conversatios.

L6.4 Technologies

The two major types of technologies used in switching systems are electrmnechankar switching and electrorrk switching. füectromecharıkal switching is used solely with space-division switching. The earliest type of electromechanical switching system was the stef}"by--stepsystem using the Strow~er rotary switch, Ah intermediate type of electromechanical switching system is the crossbar system which utilizes coor<lirmte switchittg.

Electronic switching systems (ESS) can utilize either space-division switching or time-division switching. A coordinate switching network of small reed ['iWitehes was used in the first electronic switching system, along wHh starell program control'. The newest electronic' :-.witching systems are digital switches using combinations of .space-division and time-division switching. All ·~-witching is accomplished *bj'* using wtid-stıne de'Vices. These 'Sj~'temsMe described in more detail in: the following sections.

1.6.5 Space-Division Switdıing

NonnaUy, not everyone wiH·want to coneerse wittı everyone -else at the same.time. Henee; it rs not necessary to design a. switching system so that all lines. can be- eonneeted snntdratlt'Xfft:.dy with- aH ether lines. The lıcom-ing lines can therefore be concentrated and distributed through a smaller number of switching paths before being expanded at the last sta:ges of the switehmg process, as iHustrated by i.he flow chart of Figure l-15. In this fashion, the switching is accomplished in stages consisting of eoncenıratiorr, distribution, and expansion.

E1ementıırySwitclüng Stages:

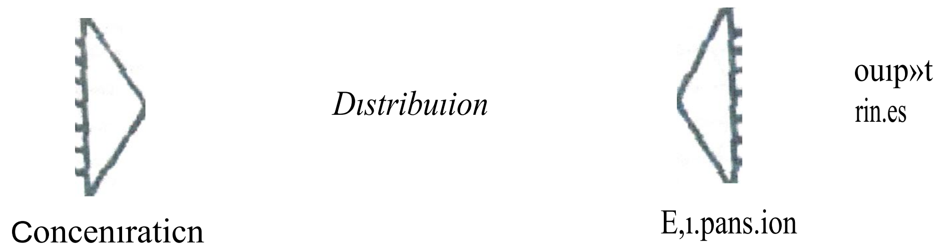
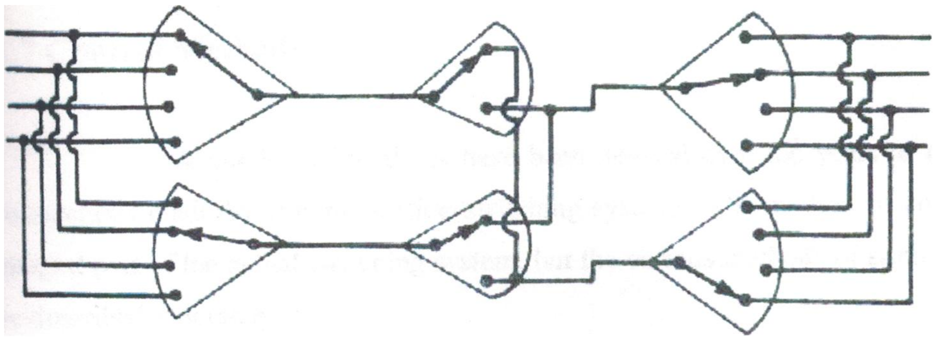


Figure 1.15

Clearly, it is possible that some paths in the switching system might become completely congested. Irr tlris case, some calls desiring service will be blacked. The blocking can occur at any stage, and the switching system must be designed to minimize blocking for the traffic that it handles. The actual design depends on the type of customer served by the switching office, insofar as dlfferenı customers have different traffic patterns, The two approaches to space-divisron switching depend on the type of basic switch that is used at each switching stage. The earliest switching systems used the Strowger switch in which a set, or bank, of contacts was swept by one wiper contact.

The electromechanical switch mverııed.by Strowger was a.stepped.rotary switch that could move hı two dimensions (see Figure l-16). The actual electrical connections were made by contacts that wiped across each other and were, therefore, subject to considerable wear and tear. The large amount of mechanical motion meant that a fair amount of time was needed to make the actual, final connection. The Strowger type of switch made a connection between one contacts to one of many contacts.

Rotary S'vvitching Network;



Concentration [lines in / lines out > 1]

Distribution [lines in/lines out ≤ 1]

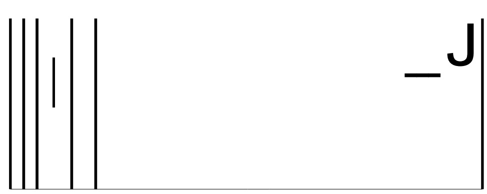
Expansion [lines in/ lines out < 1]

Figure 1.16

An improved approach to switching compared. to rotary switching is coordinate, or matrix, switching (see Pigere 1-17}. fa coordinate switching, connections are made· at single contact .poinıs in a matrix consisting of .all input lines and all output lines. The electrical connection at the contact point can be made by using a variety of technologies, such as conventional switch contacts, small reed switch contacts sealed in glass, and diodes and transistors biased to conduct or not to conduct

Coordinate Switching Network:

Many telephone calls are to other telephone lines served by the same switching office. In these cases, the output lines from the switching system are connected to the incoming lines to make the actual connection. Su-ch lines used for interoffice calls are called interoffice trunks.



tnınkı
to
oıh(r
omca

Coll(tntralıon

Diıribuıon

Elı,.nsion

Figure 1.17

1.7 Control Methods

A number of methods have been devised over the years to control the connections made· by cornnrrmicatiorr switching systems. The method of control is an integral part ofthe actual switching system, but the various methods of control can also be described separately.

1.7.1 Direct Progressive Control

The oldest method of control is direct progressive control. With this method, sketched in Figure 1-18, each stage of switching responds directly to the digits dialed by the calling telephone. As one stage completes its connection, the next stage responds progressively to the dialed digits. The final connection through the switching system is made gradually as each stage receives its digits and progressively sets up the final path through the system.

The dialed digits contain the information necessary to operate each switch. The digit information is transmitted over the same lines that will carry the speech signal after the last connection has been made. The control path thus is the same as the speech path. Each switch has its own control associated with it.

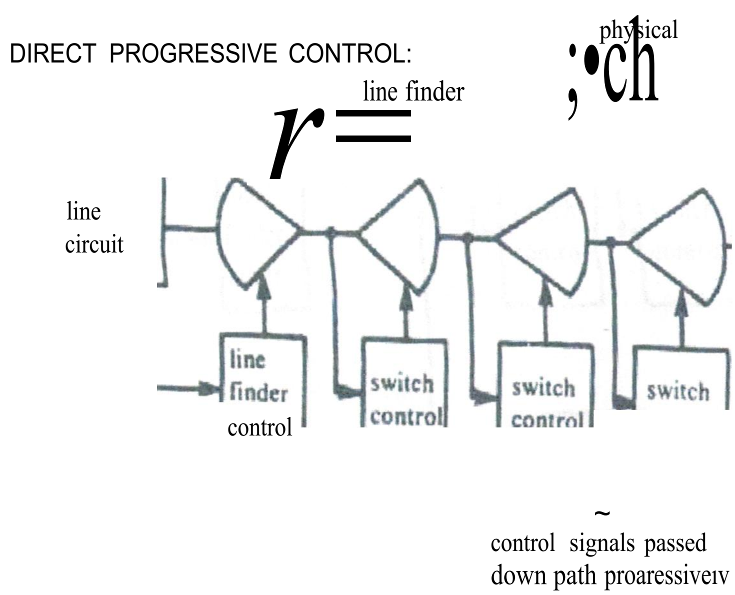
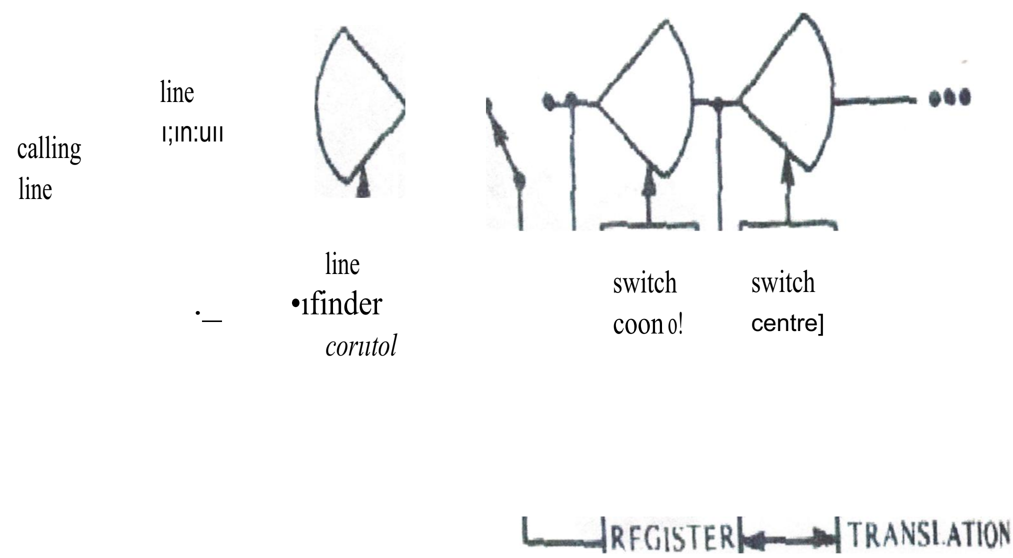


Figure 1.18

Direct progressive control is simple and economical. However, because the paths through the system are created progressively, it is not possible to look ahead to determine whether future paths will be blocked, This means that additioחa! spare capacity is needed. to minimize the effects of blocking, Because the dialed digits control the switches directly, there must be a strict correspondence between the dialed; digits, which represent the telephone number of the called party, and the physical contact to which the called line is connected.

1.7.2 Register Progressive Control

The solution of some of the disadvantages of direct progressive control is achieved by the use of a register to receive and temporarily store the dialed digits. {Refer te :Figure 1.1'9.) After the cailed number has been completely dialed into the register, the register then redials, the number down the line and iaıo the. switches. If blocking occurs, the number is still available in the register so that redialing can be tried. A translator can he used with the register to translate the telephone number into the digits required to control the switches in order to Teach the appropriate contact, This means that the actual connection to the s.witcliing system does not need to be changed if the· telephone number is changed for some reason, and vice versa. The use cf a register with progressive control is called register progressive control.



Fıgurel.19

Direct progressive control and register progressive control are used in step-by-step ~switching-systems. '.fhe- ·hasic cSwite.h in <Step-by~.ste-p swit-ching systems ·is dıe Str-0-wgtır switch.

1.8 Step –By-Step Switching System

Invention

The step-by-step s:witchirrg s;systeı:m..was-ınvente.d: *by* A.hn.oa R... Strowger; an. ınıdertaker who was: nvs:et that aU the blısittess in:-· biS: town' went to his, co-n1:--petito-r~ who-se·wifüwas the operator ofthe local telephone.exchange. The basis ofhis invention was an autl.>maiic ,ı,witch Or.rt .stepped ıvertic.tHy and horirontaHy nnder t-he- wntrıtl of digits dialed aHhe-telephône irıstttr,..ment by the teleph(Hıe· user, Ilı:.e' first rr:ıstaUation of *W!'J* ifU:tom.atic s.wi:rch was- in 1&92:. A few ye-.ırır later, in 18:96, the teleplıtltre dfal waS' invented -by some -of Strowger's assseiates. The ·Strowger switch -system was manufactured by the Automatic .. Electric Company and sO!d *w* the nona:Bell, i.nde~pendent te.lepb.an:e companies. The: first instaUatiorr of a Strowgerswitchiog system: *in* the' Bet} systettf ilid oot a-t.°\tl'fl!' afifti,) f 91~:

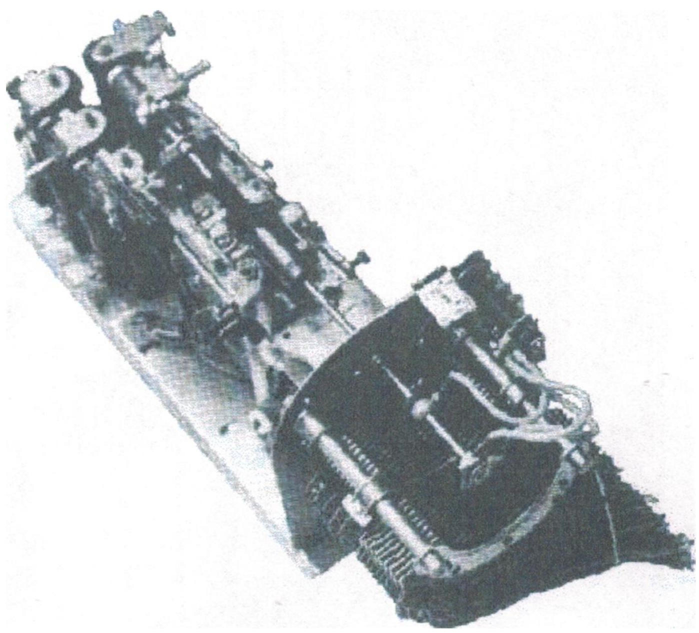


Figure 1.20

Photo of a Sırowger switch, Note: The contact hanks are shown alosg with thewiper *arms* amt the relays at the- top can!rol the movemerıt ofthe wiper'arıns.

The Strowger Switch The Strowger .switch, shown in the photograph of Figure 1-20~ is an 'ingenious, electrcrmecha.nfoal device coasisting of electromagnets and ratchets.

1.9 Panel Switching System.

The pıınel s.witchiıtg,sys:tem: was devised by the Bell System as: its· answer· to the Strow ger switching -system, The first installation of a panel switching system was made' in 192 l.

The basic switch in the' pand system. was. a hO'.fl'endotı:s affair. able. to aecess any of füe. 500 terrtrinais,. as cuntpaıted: witlı: access to: arry- ö:f HJO terı1 1irıaJs för the- .Strowger -switch. This was accomplished by zotaıing cork rollers that moved the tselect.-mg. enntacts h!Jri'irmtaHy and vetifoaUy. The basic swiıch was extremely rtpisy, and the system needed considerable maintenance. Hence, there, is virtually no panel: equipment in service. in the· United· States.

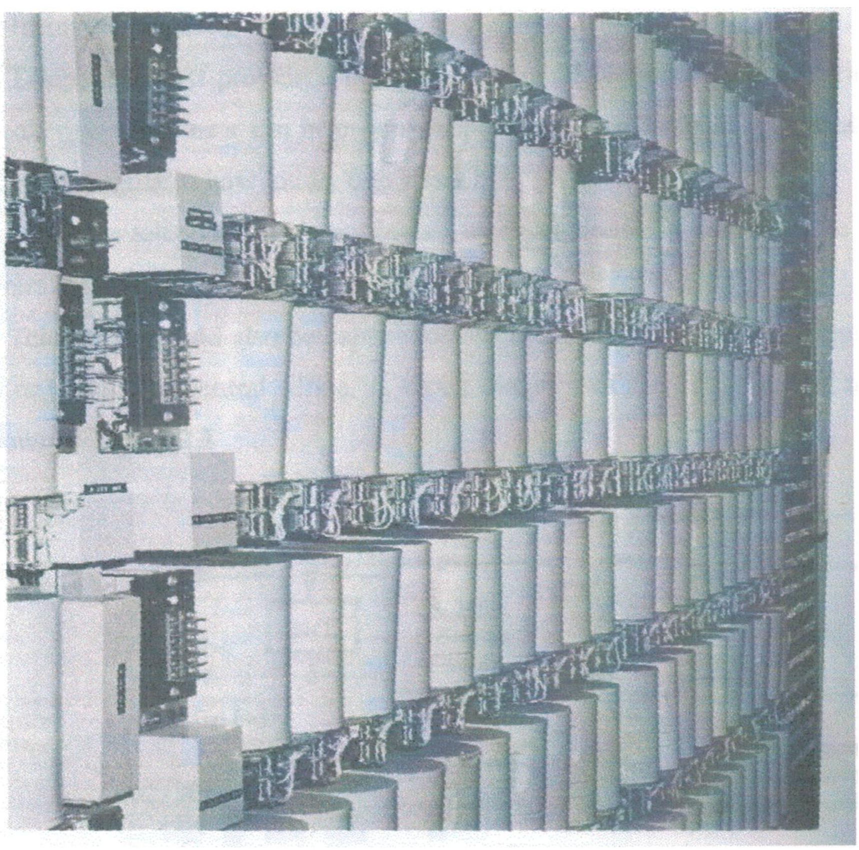


Figure 1.21

2. TELEPHONE & TELEPHONE NETWORK

2.1 Telephone Set

I~I.I Basic&ınctions Of Telephone Set

1. Telephone must notify the user of an incoming call through an audio tone such as .a ring_
2. Tdephmıe must convert ealler's sı1eeeh to- electrical· sigmıls>. Otherwise; electrieai signals must be converted to speech signals
3. Oealing'cs -method (subscriber numbers} may be pulse or tone.
4. Telephone must regulate the speech amplitude of the. calling. party by compensating fur the varying distances to the lo-cal-Telephone *Company* (Centralvffice):
5. Telephone must.gain the attention of the central office when a ıserreqnests service by lifting the handset.
6. Telephone must provide a nominal amount. of feedback from its microphone to .its speaker so th-at a. user·cart hear person. ~peaking: Tbts feedback is ealled side tone. The. side tone regulates how loudly one speaks.
7. When the telephone set is oot *in:* use, ~ {}pen--c-ircuJ.t de patl;ımust be provided to· the central office.
&. Telephone· sh.(nrld also be capa:Me of receiving ealt progress tones (busy, ringing, and so on) from the central office. A block diagram of the conventional telephone set is 'shown in Figure 2.1

Figure 2.1

When -pfacing :or answering a call, the telephone is lifted offof it,s cradle ,and the on-tlo~ 'Ot soif-itook ,e1.'f-cuit et\tli'ge'S t4ıı.e telet)lı.ene set 'to the ,releı,hene ◦s,stoo:1. Power of the telephone set is derived from a - 48V de at the central office (see Figure 2.2).. The power is. delivered to, fue. teleplıatıe set .via the snhscrib:er-kıop, Since most subscriber loops are two...wire pairs, a hybrid circuit is necessary te lransfurın the t\.'ro~wirce transnıission Iine into füur wires. To compensate fur the ,qarying. lengths of' wire between the- central o ffiee alla its.

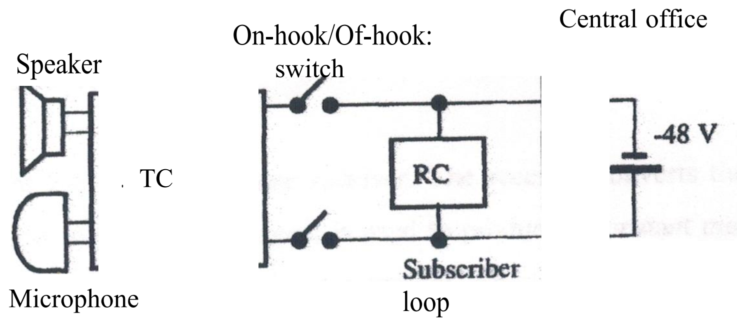


Figure 2.2

1.1 .Z The Basic Elements OfTbe· Tetephone Set Telephone

2.1.2'.a Transmitter

The part of the telephone into which a person talks is called the transmitter. ft oonv:erts speech signal fut{') an ,electric enrreaı trntt can he 'tranSmitted 1:hrough the transmission system to the receiver; The most common- telephone transmitter hl use: tt1day r.s rn prirndple Hke the: crne-- invented abour 1OO' years- ago· by Tham as- *A*. Edison.s .n1ierophone.Figut<e 2.3 iUıxsttate. a ·etlı~s sceetiona1 view 11f1be tta-nımilitet.

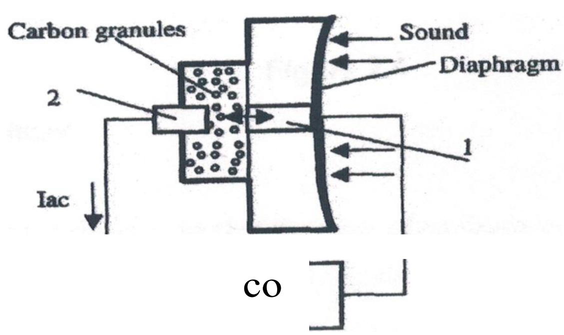


Figure 2.3

DC current provided by the Central Office (CO) is passed through two -electrodes separated by thousands of.carbon granules. One electrode (J) is atıached to a diaphragm that vibrates, in response to. the acoustical pressure of sound, The opposite second electrode {2J is· fixed. Vib:ra:tion of the diaphragm. cc.tu-ses the. contact resJstan:e:e· between the two electrodes io vary im>ersely with pressure. *As* the resistance varies, the current (lac) varies inversely, thereby translating the aco.ustical message into the electrical sigı:ıal-that is tmnso:ı:itted. ta-the cetıtral~effiee-..

2.1.2.b Telephone Receiver

Figure 2.4 shows telephone receiver. The receiver converts the ac current ,lac back *to:* snund. A perımıneut· nıagııet is used *ta* produce a con1itattt rt:t_:a:g:ttetic: ftetd <Ile. Insulated wire is wound around the armature, which passes the ac signal *lac.* The varying electrical ceur.rem representing speech prudu:ce.ı.
Varying electromagnetic_ fields <l>c. It alternately aids and opposes the permanent nmgn'l.'!t ftebl; tlms italb::nıatefy trı:creases arrd de(,"teas-es the total ma:gn.e.tk t'iield acting. on the diaphragm through armature. This causes 1he diaphragm to vibrate in step with ·the v.a:rying,cmrent-and "moves the ai:t10°re-pr0ducet-he ori-girıal speech .signal.

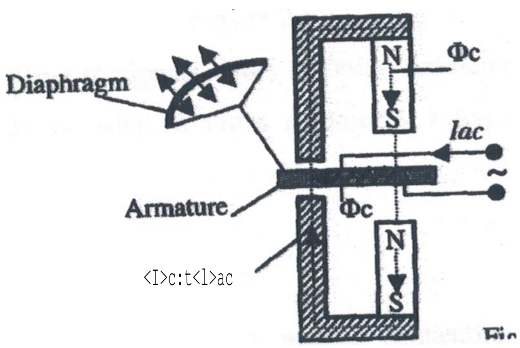


Figure.2.4

2.1.2.c Telephone Ringer

The function of the: ringer is to alert the party of an incoming call. The audio tone gener.ıted. lıy the- ringer must be loud erttwgh for the piırty to hear from a d:tstcm-c:e·. Several variations of ringer are used in today's telephone sets. The most popular types ate the cot1vent10nal eloctromechankal and more recently, -semioonduct:or sound generators. In the United States, telephone companies will ring the called party with an ·a.c Ti:n-gmg signal, typi:cally -90 V rms, at 2.-0 Hz. The .ring signal is superimposed upon the existing -48 ,V· de signals.

2.1.2.d Telephone Hybrid

'the telephone hybrid is used to interface the transmitter and receiver. The hybrid fa ıth.owri. ia Figure 2.5 {a). A multi:ple·whtding transformer is wound-ma masner to ..efoctricaUy .separate the

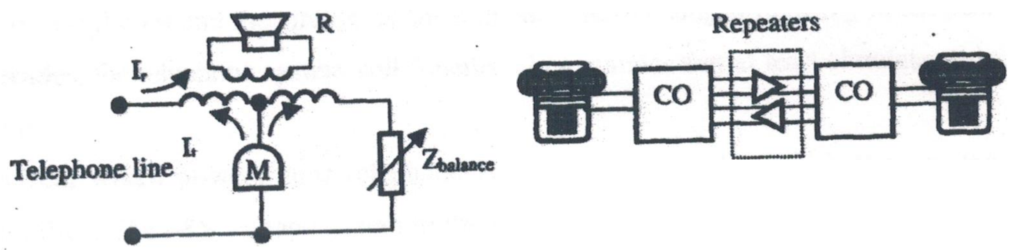


Figure2.S

mınsmitted it and received Ir signals.. This .permits simutatleous t-ra~ion aod reception: of the speech, or what is more commonly referred. to as a full-duplex op er arian.

2.2 Telephone Network

First of aU, I must ·offi:eiaHy advise against coJın.ecting anything ,other ro the telephone line. than equipment approved for the purpose by the telephone contparty or some: other regulatory body. Telephone company· tend· to· be very strict about unauthorized gear hanging on their lines, and if something does go wrong with your -gadget {like puttmg-dıngerous voltage-s to telephone line) .you-will be -in deep trouble.

2.2.1 How Telephone Works

A telephone uses an electric current to convey sound information from your me to that of a friend. When the two of you are talking on the telephone, the .Jephone com-pan-y i:s semling -a steady etectric current through your te-1:e-phones. The ,·o telephones, yours and that of your friend, are sharing this. steady current. But as you ıalk into your telephone's microphone, the current that your te1evhorre draws from the :elephonecompany fluctuates up and down. These fluctuations are directly related to the air pressure flu-ctu'.1tions that are the sound of your voice at themicn..""Phone.

Because the telephones are sharing the total current, any change. in the current through your telephone causes a change in the current through your friend's telephone. Thus as you talk, the current through your :friend's telephone fluctuates, A speaker in that telephone responds to these current fluctuations by compressing and rarefying the air. The resulting air pressure :fluctuationsreproduces the sound of your voice. Although the rurture af telephones and the circuits conrı:ectirı:g them rr.:rve· changed ra:dfoaHy in the past few decades, the telephone system -still function.s in a manner that at least simulates this behavior.

The current which powers your telephone is generated from the 48V battery in the central office. The 48V voltage is sent to the telephone line through some resistors and indictors (typically there is 2-000 to 4000 ohms in series with the 48V power source).

The otd

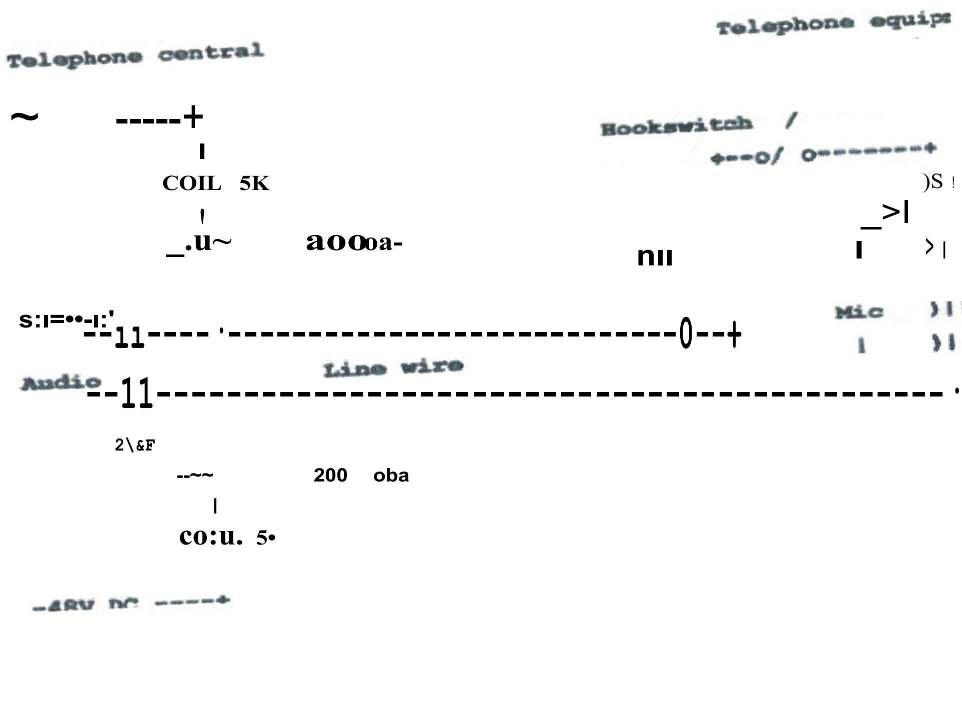


Figure 2.6

u go off hook, and current is dra ,

8v. This means that there is about

voltage between the wires going to telephone in normal operation condition. The resistance of typical telephone equipment is in 200-300 ohm range and current flov through the telephone is in 20-50 mA range.

2.2.2 Why 48V voltage is used in telephone systems?

The -48V voltage was selected because it was enough to get through kilo me s of thin telephone wire and still low enough to be safe (electrical safety regulation: many

Countries consider DC voltages lower than 50V to be safe low voltage circuits). voltage is also easy to generate from normal lead acid batteries (4 x 12V car batterie series). Batteries are needed in telephone central to make sure that it operates also w mains voltage is cut and they also give very stable output voltage which is needed reliable operation of all the circuit in the central office. Typically the CO actually off of the battery chargers with the batteries in parallel getting a floating charge.

The line feeding voltage was selected to be negative to make the electrochem reactions on the wet telephone wiring to be less harmful. When the wires are at nega potential compared to the ground the metal ions go form the ground to the wire inst of the situation where positive voltage would cause metal from the wire to leave wl causes quick corrosion-Some countries use other voltages in typically 36V to 6 range. PBXes may use as low as 24 Volts and can possibly use positive feeding volt instead of the negative one used in normal telephone network- Positive voltage is m commonly used in many electronics circuits, so it is easier to generate and electrol in telecommunications wiring is not a problem in typical environment inside of buildings. Some older offices employ battery reversal (swap DC feed to tip and ring signal off-hook at the remote end.

2.2.3 What is sealing Current?

The current sent to telephone line as an another advantage besides that it supplies the operating power for your telephone. Telephone practice uses (or did use) twisted splices. These splices did not always make good connections. Placing a small DC bias on a long transmission pair is often done by telecommuncation carriers to reduce poor connections, and noisy lines. The DC bias is often refered to as a "sealing current". So putting DC current through the cable sealed the connection and so improved the transmission.

2.2.4 Why Full Duplex Operation in Single Wire Pair?

Full-Duplex is a term used to describe a communications channel which is capable of both receiving and sending information simultaneously. Telephone sets (ordinary analog ones) have only 2 wires, which carry both speaker and microphone signals. The signal path between two telephones, involving a call other than a local one, requires amplification using a 4-wire circuit. The cost and cabling required ruled out the idea of running a 4-wire circuit out to the subscribers' premises from the local exchange and an alternative solution had to be found. Hence, the 4-wire trunk circuits were converted to 2-:wİre local cabling, using a device called a "hybrid".

1'his- fünction can s.em:l- and receive amti:o signals at the saere time- is accomplished by designing the system *so* that there is a well balanced circuit İn both ends of the wire which are capable or separating incoming audio from outgoing signal This function is done by telephone hybrid circuit contained in the network interface of the telephone.

2.2.5 What is the bandwidth of the telephone line?

A POTS line (in the US and Europe) has a bandwidth of 3kHz. A normal POTS line cart transfer the frequencies between 400 Hz and 3A Khz. The frequency response is limited by the telephone transmission system (the actual wire from central office t-0 your wall can usually do much more). Nowadays POTS is sharply band limited due to the fact that the line almost always is digitally sampled at 8 kHz at some point in the circuit. The absolute, theoretical limit (with perfect filters) is therefore 4 kHz - but this isnt reality, 3.4 kHz maximum frequency.

'fl\e -bass frequency response is timted because of the limitatians ·in telephone ystem components: trensfromers and capacitors, can be smaller if they doı:ı!t have to deal with lowest frequencies. Other reason to drop out the lowest frequencies is to keep the possibly strong mains frequency (50 or 60 Hz and it's harmonics) hummign away from the -audiosignal you w-iH ~ar.

2.3 Network Interface Details

The telephone has a circuit called network .interface (also called voice network ur relephone :hybrid') which .connects the microphone and speaker to the telephone line. Network interface circuitry is designed so that it. sends only the. current. changes- the o;ther telepfame causes to the speaker. The. current changes which the telephone's 'OW11, microphone generates..are not send to the speaker, All this is accomplished using quite ingeıııous transform.er ckcııitcy. In theory the Jrybrid ,circuit -ean separaıs .au incnıning oudion frnm the audio sent aut at the same time if all the impedances in the circuitry {h.yhdds on. both. ends and the wire impedance; in hetweerr): are well matched. Unfortunately., the hybrid is .by its very nature .a "leaky" device, As voice signals pass ftom cthe-4-~-wire .:to 11:re ,2-;;.,wire pnrtion ,of the·.netwo:rk, the high.er energy level in the 4~ wire section İs also reflected back on İtself~. creating the. eehoed speech. The beeaese cif:cu.it does not work per{ectıy and you can still hear sorue of your own voice in the speakw

Tire ·actual :ameunt·of·signat,which--is ,refrected back depends on hçfw wen the balance circuit of tlıe.hylıdd ..matdtes-the:.2,,,wire line. In the vast majority of cases, the match ·ts quite poor; resulting in a considerable level of-signals being reflected back;

The signal which is reflected back is not always bad and in normal telephone -some if it ·is realty itıtentional by the design- The separation. uf the received :and transmitted audio could- be done much better with modem electronics than with old ph.mıes~ but but people who use the telephone prefer to bear some of their own voice" back. Radio Shack's "Understanding Telephone Electronics" (copyrighted around 1985 I think) ,cans this e.ffeet ·side u:nıe and -gives the impr-0ssi-0n that this was indeed imeıltioool in order for the;speaker to determine how loud"they were s.ıreaking with reference to the caUed party.

2.4 Signaling

2.4.1 Manual-Exchange Signaling

.In the .early days of telephony, exchange service was accomplished with manual -swi-tch1ng by a ·human operator. The teiep:ho-ne subsCfiher desiring service first had to alert the operator.,This was done by turning the crank on the telephone, which caused a lamp to flash on the panel at th~ exchange office. The' operator would see the flashing lamp and then plug in on that line. The calling party would verbally request the operator t.o mske the w:rmection to t-he-caU.ed party.

The operator would then visually check the cords and jacks to deter-taine whether a corinecfam could· be made to the e-aHed party. ff not, the operater would infctw the calling party that the called party's line was in use. If the .called party's line were av.aUahle, the operator would make a connection and rfrrg the .called party. The lamp,s for both the called party's line anıl the calling party's line would remain lit as long as the telephones were iwuse. As seerr as one tel-epnone were·h1u1ı:r up, the corresptmı:fü1g lalll'p' wouldge out, and the operator, noticing this, would unplug the connection.

If the call were from t·he local exchange to another exchange, the operator at the caning party's exchange-would use special interex:change lines called *trunks* to reach the operato-r at the called· patty's exchange-. 'Fhe number to be called would be passed verbally from operator to operator, and .the operator at the called party's local exchange wouid make the final con."'1ection.

The making of a telephone connection involved a large amount o-f humarı labor dm-in-g the early days: o.f tdephm1:y_ Te.chnolo.g.y has, over the years, reduced and finally :eliminated all human labor required in making % telephone connection. This was arooniplishert -through ootomnterl :switchiııg m-acbirıe:s and varinus electricai signals tg request senı:ice, forward telephone numbers, and set up the actual connection of the lines.

The general topic that deals with the various signals used to request service and to controlthe p:mgress ofthe teleptıo:ne ·call is -kntrw·rı as si.gıwJhıg.

This latte function is supervisory in nature, Thus, de signaling on the subscriber loop; is used for alerting and supervision functions. Address information can be transmitted in two ways:on the suhs:crihe loop. The flow of direct current can be interrupted by the telephone dial tü generate dial pulses. These pulses are at a rate *(if* about H) pulses per second, The second way that address information can be transmitted is in the form of unique two-tone combinations caHed touch-tone dialing.

Information is transmitted onthe subscriber loop as either audible tones or recorded announcements. Four major tones are- dial tone, ring-back tone; line busy tone, and trunk-busy tone, Four generic frequencies (3.50, 44fi, 480, and 620 Hz) are used, either

Dial tone is a continuous tone formed by combining a 350 Hz sine wave with a 440 Hz sine wave by addition of the two waves. Ring-back or audible ringing is formed by the addition of a 440 Hz sine wave to a 48-0 Hz sine wave. The combination is onfüt

There is one last alerting signal that is transmitted over the subscriber loop. This is the rhıging signal which causes the called telephone to ring. It is a sine wave of 75 volts rms at a frequency of 20 Hz.

The oldest and most basic type of signaling between central offices is. direct current, or de; signalirrg; The presence or absence of a de signal on a trunk would indicate whether the trunk *was* idle or in use. Normal or reverse direct current is

cannot be transmitted over circuits derived from a carrier system, and hence. de signating cınmot be ased. The sohrtlorı was to use a single-frequency tone, either lrr tire voice band (200-3400 Hz}. or outside -ıhe voice band (3700-3825 Hz). One popular

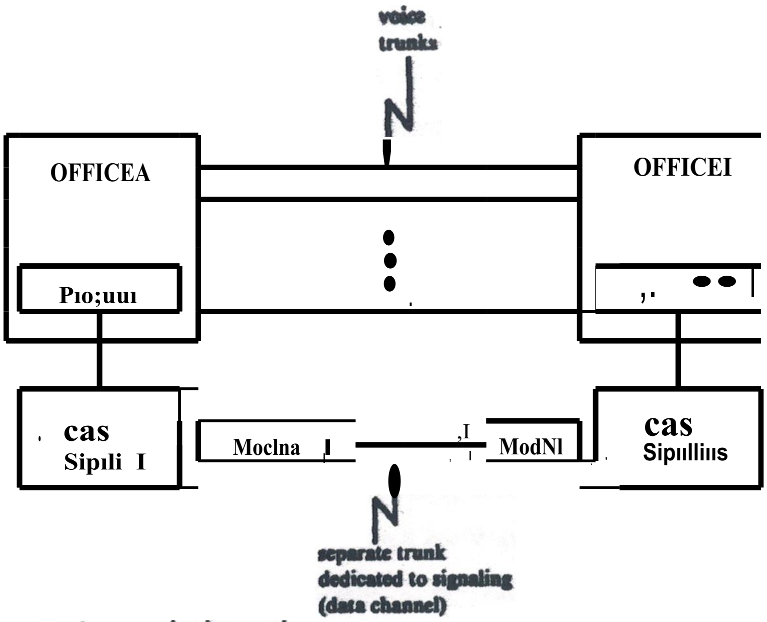
Unfortunately, there were problems with this in-band, single-frequency, signaling scheme. For one, some people discovered they could generate their own tones for the fraudulent purpose of avoiding toll charges. For another, some speech signals could cause accidental disconnections. The use of an out-of-band frequency was not without its problems, too. One problem was the loss of usable bandwidth for the speech signal.

The address information was transmitted over the seized trunk by using two-frequency tones sent at a rate of 10 tones per second. The tones consisted of two-frequency combinations of 700, 900, 1100, 1300, 1500, and 1700 Hz. With the various combinations of these frequencies, it was possible to
Represent all ten digits and up to six control functions. This type of a signaling was called multiple frequency key pulsing (MFKP).

2.4.5 Common Channel Interoffice Signaling

In 1976, a new interoffice signaling scheme was first installed in the Bell System, and it is currently in use on practically all interoffice circuits. This new system is called common channel interoffice signaling, o CCIS for short.

With CCIS, as shown by Figure 2.7, a separate channel between the offices is dedicated as a data link for transmitting only signaling information No signaling information is sent over the voice circuits. The switching machines used in most central offices are actually computers or procession that control the switching of voice circuits or paths. As such, the use of data link to enable these computers to communicate with each other about the availability of the voice circuits between offices is quite consistent with the capabilities and requirements of the newer switching technology.



speed	circuits served
2.4k bps	1100
4.8k bps	3600

Figure 2.7

A single analog circuit is, used to convey the digital signaling, information. Conventional full-duplex modems operating at either 2.4 k bps or 4.8 k bps are used. Each signaling circuit can control .about 1800 or 3600 voic6 circuits, respectively, Because the signaling information is transmitted over a separate circuit, there is a need to determine whether the transmission quality of the specific voice circuit is acceptable before it is connected for use. This is accomplished by performing a transmission quality check on each voice circuit before it is connected for service. The voice circuit is looped back onto itself, and a tone is transmitted down the circuit. The return level of the tone is checked to be certain that it is within specifications.

With conventional signaling, a busy tone is sent from the office closest to the called party, all the way back down the network to the calling party, thus tying up a full voice circuit. With CCIS, a busy tone is generated at the office closest to the calling party, hence freeing voice circuits for use with actual conversations. ,

CCIS at present does not transmit the calling party's identification to the terminating office. However, CCIS could be given the capability of doing so, which would make possible call screening at the local terminating central office. Also, it is possible to envision that the calling party's identification might be transmitted all the way down the local loop so that the called party would know the identity of the calling party before answering the telephone. CCIS, therefore, might make possible many new services In the future.

2.4.:6 Telepbmıe Numbering ,Plan

During the early days. of telephony, a total of 10,.000 lines was the maximum number served *by* a, telephone exchange. Thus, a four-digit number specified the party to be reached in an exchange. The exchange was specified by two alphabetic characters followed by a decimal digit, for example, WA5 for Waverly-five. Area codes were then introduced to specify the area. in the c:rn.ırıtry to be reached. Area codes. are also called *numbering plan areas* (NP-A).

A special nomenclature is used to describe the telephone numbering plan. The. symbol *N* is used for any of the decimal digits 2 through 9; the symbol X for fi...'11' ofıh.e decimal digits 0 throogiı ~l; and 0/1 for the- digits 0 or 1 only.

The sfatıdard format far tdeçhmıe numbers in the United States has been NO/ *\X-NXX-XXXX. NQ/l* Xspecified the NPA; *NXX* gave the local exchange in the NPA; and ***}:1!10:*** denoted **the specific subscriber** line in **the local exchange.** Because the number **of** area-eodes possible with the *NOil X* format is being gradually exhausted, a.new format of *NXX* is being introduced for the NPA.

The format *N* I1 is used for special services. For example, 411 specify directory assistance; 61 i is the repair service; and 91 l is for emergencies.

2.4.7 Local-Loop Signaling Design

The resistance pf the local loop must not be too high; otherwise not enough current win flow in the line ta activate the ime relay at the central offiee, The resistance uf the local lo-op depends on the total length of the loop. and the gauge of the wire. Resistances for various gauges of wire are as follows:

2.6.1 Simplified Traditional Network Interface

microphone and one resistor.

26 gauge - 83 ohms per 1000 ft,

24 :gauge-'- 53 ohms per 1000 ft,

22 gauge - 12: ohms p.er 1000 ft,

19 gauge·- n ohm₀s1erlOOO·ft.

The maximum resistance of the local loop .can be calculated as follows. The telephone instru:tmmtreqn.iresabout23 .mA far ilie..rarbon .gramı.le transmitter to operate reJiubly. The eommcm battery at the central offiee has, an, electromotive forc:e.of·4'&· votts. Thus, the· total· resistance· of the circuit must not exceed- 48/0J)2J· = 2100· .ohınS'. The resistance of the telephone instrument is ~equivalentto 400 ohms. Similarly, the reshtance of the central .o-ffise .eiN:Uitry is·atso- 400· oorns. Henee, the resistaııc.eof Jhe kı-op must not exceed 2100 - 860 : 130fr ohms.

The maxim um loop resistance of 1'30&crhms, detemrines the wire· ga:uge·-fon.t giveff loo'},o/ length.

2.5 Telephtnıe Line ·Panımeten·

Telephone line resistanee, capacitance. and inductance do oot: depend, on· the voltage ot' current on the line.

2.5.1 Line Balance

For· telephone· local loops, crosstalk is related to how well bala!lee füe eiı•cflit is. Loop current does not affect that balance, even if excessively high'- If the balance i-s not :good enough! you can near crosstalk form .other .telephone lines or from .other noise sources. The balance of the telephone line is determined by the circuits connected to ,telephone fine· ends (typically line transformers) and the quality of the telephone cable (wet cable ca» eaase tmticeabk balance problems if wires are-in contact with the water).

2.5.2 Loop current effects

'Fhe detrimental effects, cf exeeseive. loop·current weuld· be tHstertion eansed.by saturation of tr-ansfornıers-("repeat coils" in the vernacular). Within the raage ı;ıt· acceptable loop current (up- to 120mA), no transformer used in telephone equipment should become saturated. If.an inferior .transformer is used, or ff loop ,carreın were significantly higher than i 20mA, then distortion could be expected. Neither situation is cornrrron,

],.&Network Interface in Telephone

The telephone has a circuit called network interface (also called voice network or telephone hybrid) wh...'Ch connects the 'micr-cptıone and speaker {{} the telephone fine. Network interface circuitry is designed so that it sends enly the current changes the mher-telephone causes-to the speaker. The current changes whiclr the telephone's own microphone generatesare not send to the speaker. AH this is accomplished using quite ingenious transformer circuitry. The circuit does not work perfectly and you can still hear some of yon:r own voice ın the speaker (it could· be done better nowadays but people who use the telephone prefer to hear *same af* their awn voice back),

2.6.1 Simplified Traditional Network Interface

ı,

Normal telephone eonsists of ringer, dialing circuit and voice circuit. A traditional telephone voice circuit consisted of hybrid trarrsfbrnter; speaker, carborr microphone and one resistor,

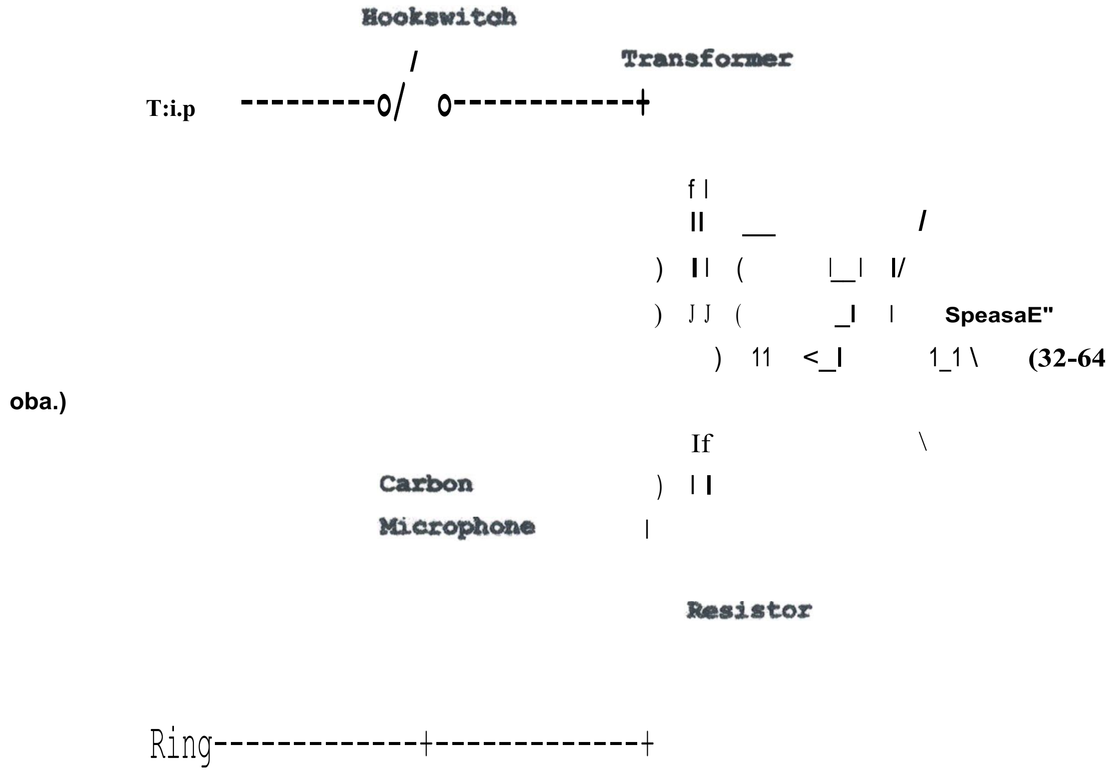


Figure 2.8

The circuit is: designed; s:o that the impedance. at audio frequencies looks like abcut 600- ohms, The audio İmpedance rs corrtrolled by the transformer charaeteristics; carbon microphone, speaker impedance and the resistor in series with the transformer.

The DC resistance consists of the transformer coil in series with the resistor and part of the coil in series with carbon microphone. The carbon microphone is put to the transformer so that the changes in the current flowing through it do not generate voltage to the secondary coil where the speaker is connected.

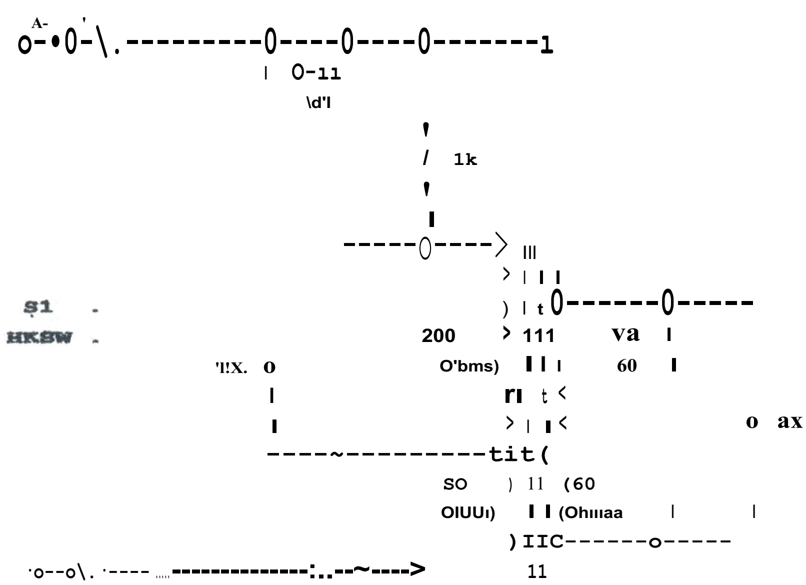
Modem telephone circuit is much more complicated because they typically include compensation for the attenuation caused by long subscriber lines. This compensation is done so that the audio levels are controlled according the current flowing through the telephone (longer line has more resistance so there is less current which you get form 48V source through it).

2.6.2 why carbon microphone in telephones ?

Carbon mikes were the first microphones and consisted of a small button of carbon powder connected' to- a· metal diaphragm; Wlıetrsuund· flexechhe-dfap-1ınrgm; the carbon grains changed their electrical resistance. When a voltage source is applied between the microphone wires a variable current is generated. This is how the first telephones were constructed, and many phones to this day still use the idea. Carbon mierepbenes have poor frequency response and bad signal..*ta*-noise ratios and they are only suitable for-telephones and such cemmımication applications.

2.6.3 Typical European Network

The following network circuit schematic was shown in BUILDING AI'ID USING PHONE PAT-Cfl..:ES by Julian Mecassey:



Figare 2.-9

Note: I ha,•e ed'ited· the schematic· by reptacingihe cumpo:nent rıumbers,.with' the' component values Iisted in component list

2.6.4 Simplified U.S. Standard "425B"

This circuit is put here to show an example of the electronics inside typical ıradiıiona! telephone which ases hybrid transformer circuit. Modem telephones usually beve special !Cs to do the -samethings with{mt the transformer. The circuit tries just to be a;r~ example whats: an mside typ.ie:a:1 old tclephaıre fo.r those wha want to know how telephone works. .Building this circuit is· 001 a goad idea because the circuit diagrams does not have all component values and the circuit is optimized only for telephones (it is oot good for anything else).

This circuit is taken from UNDERSTANDING TELEPHONES article by Julian Maeassey. Component values may vary between manufacturers. The circuit is designed to operate with standard telephone speaker (RX) and carbon microphone (TX}. Ccanections **for, Dials, Ringers etc. not shown to keep the piCture a little bit** clearer, **The** circuit is quite eomplicated because it is optimized for usein standard telephone: which ÏS used in various conditions. veristers VRl and VR:2 are used for loop compensation circuit which tries to keep the telephone volumes (incoming and outgoing) at suitable levels **even if the· local loop attenuation varies. This compensation** can **be done** because longer loca} }oop which bas more attenuation has. also more resistance, so less current passes through the telephone. **If** the loop **is- very** short **there· is more current** passing through the telephone and the varistors cause more signal attenuation inside the telephone hybrid.

The-hyhrid drcnits in telephone sets are deliberately mismatched. so tlıat you can hear yourself in th.e earpiece when you: speak. This is· ca-Herl "side tone".

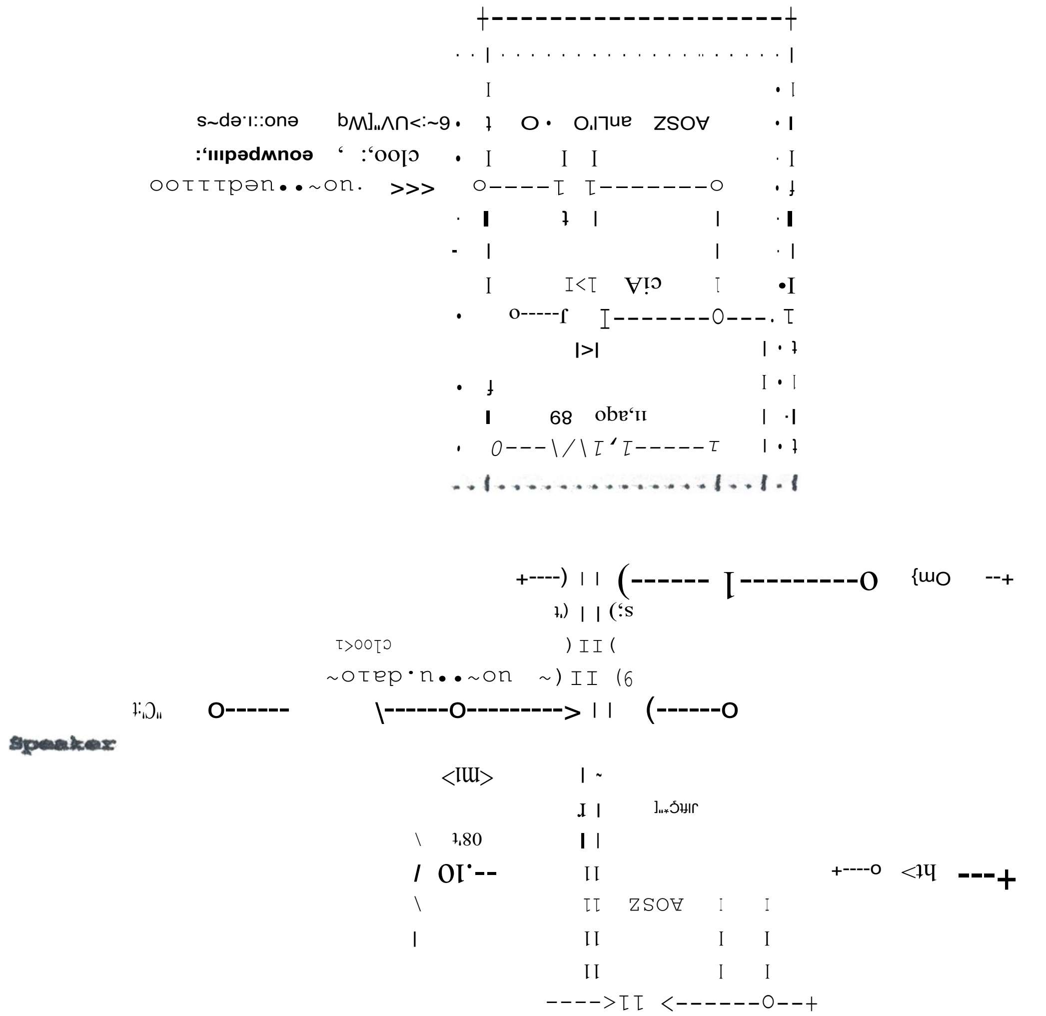


Figure 2.10

2.6.5 Details of wiring inside telephones used in USA

The following wiring info is from <u>wiring.inside.phones</u> document from <u>TELECOM Digest Archive</u>

[illegible]

dial/ringer/network block/ handset configuration. Everything basically talks to the network block. The network block contains the ringer capacitor, the induction coil that handles the handset, and very little else save some spare screw terminals. The network block can function as a standard line load [it looks electrically like a phone] when a line is connected across RR and C (These are the inputs to the coil). The ringing capacitor is

Across A and K contacts.

Handset connections: Green and White are earpiece leads which connect to R

.and ·GN :respectively. Black .and Red are mike leads BDd ·ihey connect to· B and :R ~ti.v:tly.

Ring.er: Conneenhe single winding, rn series with the; A-K. Capacironıfld· th'h,, whole thing across the line. Rotary dial: Blue and Gr,eengo to mterrupter (~t E atıd: RR) Touch-tone -dial; Green is + line in and counects to net F. Black is + line out and ~ffıı}ffl'S t-0 'fl'et. RR. Qtg,'Blk ':is - ·n\f,l'.e ai;m sacntl -oo~.ct~ t-o 1Jet £. ~eıMGırn'lB t}ntput common and.eennects to ncl R Bhıe is signal output and,C<,nme-cis-lo- Ret B.

Hook switch: Yoıı"ll find many variants of this ht different units; some configurations. switch both sides of the line; some only one; some switch out the ringer wh:ett off-hook. One ,'Switch ·switdıes 1he ·oonnect'ion 'between Li ·and C. Another switch s..vıtches the cennection between LI and RR. L.r-ne·*itr.'*Gr'een amt Red: cmıne«t. to LJ and L'.:L 1'ry ese *pefaıitty.:* ff the- touchtorre dial doesn't work then fl:ip' tlTenr.

2.7 Telecom Hybrid Circuits For Other Equipment

2.7.1 Traditional transformer hybrid circuit

The transförıner typ,e was the mo.st used :to make telephone .hybrids (around 19"-04 'Or :tro} ,was· fi')ın wintiıiug "tr.a1ıs,futroet. 'f:w0.,,0f'l.tlooe wet>e~1teeınm,for..oıın ,h;ynriasoircuit.

Rieh:-ard· Harrison ga:ve me the föUwông description how to- make such hybrid· -cw..mit: To make the .hybt"M, strttp· twe £'-0ils together in -each trausforme1(series-aidi11g in. each case). Call them primaries. One primacy will serve as the 4-wire transmit ,,cormoofron. Tehe ,ather ,primm<y -wm -sew:e -as ,the -4-,.wire arecei-ve ,comınction. .f'.aur ,ooils, two arr each transformer remain undedicated at this. point. Connect the start terııinalo.f a ~ondary coil on one transformer to the finish terminal of a. Hke. eoH on the other transformer. The other two terminals ofthi~ pair of secoedary coils wiH be dedicated to -a-baınm:;-iflg~net-werl<.

Two coils now have no coeeeetiens; yet Connect the start term:inalof the coil on one transformer to the start terminal of tne coil on the other transformer. The other two terminals of this pair of secondary coils will be dedicated to the 2-wire line.

„Suame•there-is :.Fp{}!arity ,re<Ver-sa!-in lhe -inte~nne&ti@n ·i:n,one.oHhetwu-paths between the two- transfümıers, no coupling will exist lıetween: tlıe transmit and: receive cnımections of the 4--wi-re paths (provided perfect balance in: the line-balance network

.agaim,1the.2-wire line). The.2-wire line will.however, be coupled with the transmit and T~-vtrpair::S c0.Hbe 4-w:ire.U,ne. ThaLis -wbat tlre hybrid is s.uppased to do.

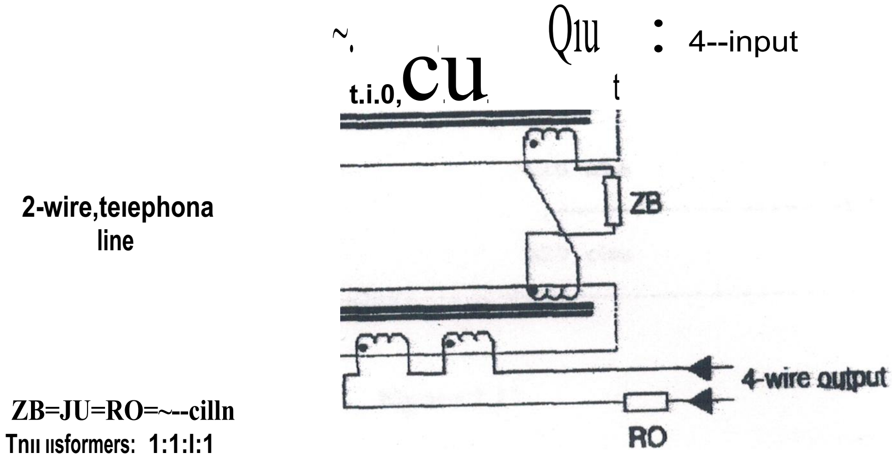


Figure 2.11

Tbe.advantageg, of the traditioıta:l circuit are.. High. isolation~ No de path exists hetween any tines. The circuit is completely passive and precislorı balance can preduee almost any desired transtıybrid loss. You should get very good results when you ~1np:lemerıtthis £jwuit ₀ns·ing nigh ;qua~1ty au.dfo transformers (for exami)l:e t'lrmıdoa..~ cp.ıafüy Westem Electric. Hl-€ "repeat coils". Lundahl Transiornıers Hybrid Transformers etc.).

2..8 Siemens and ITT Resistive Hybrids

This ,is a simplified 'Circuit tl.iagram you can made a s-iınple -600 ohm hybrid -as such. The circait.is indeed. a Wheatstone' bridge consisting of four 6-20 ohm impedances (one-of them is telephone {ine-ln series- witl:t2 u:F DC blocking capacitor);

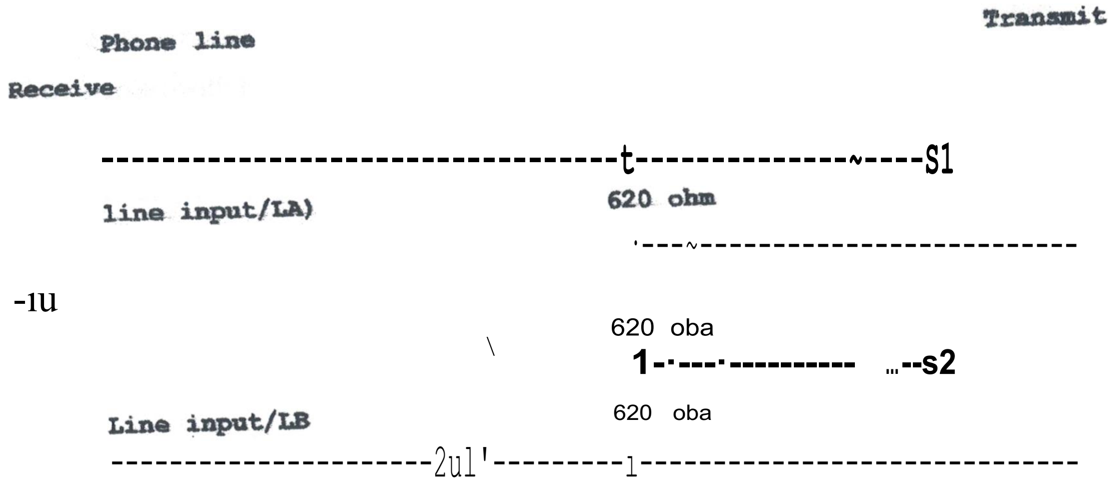


Figure 2.11

Receiver .cennected to.Rl/R2 'and transmitter is connected to S1/S2. Note that this -cireutt does not -shew any <le -paths whiclı would be needed for real telephone line hybrid. Loss. on all ports is 6aB nominal. This hybrid design can: be used for simple experimenting when measuring telephone equipments and such applications.

Better hybrids with two transformers have a typical loss of 3.5d.B and JOdB isolation from TX to RX (but typically little isolation from RX to TX but that does not typically matter).

2.8.1 One Tı:ımsfoı:mer Hybrid Circııit for 2 Wires to 4 Wires Omversion

'fhis is a -quite'fypicai '4 wire to 2 wire wn~i'On eircuit whiclı ts 'Shown. in telecom books.

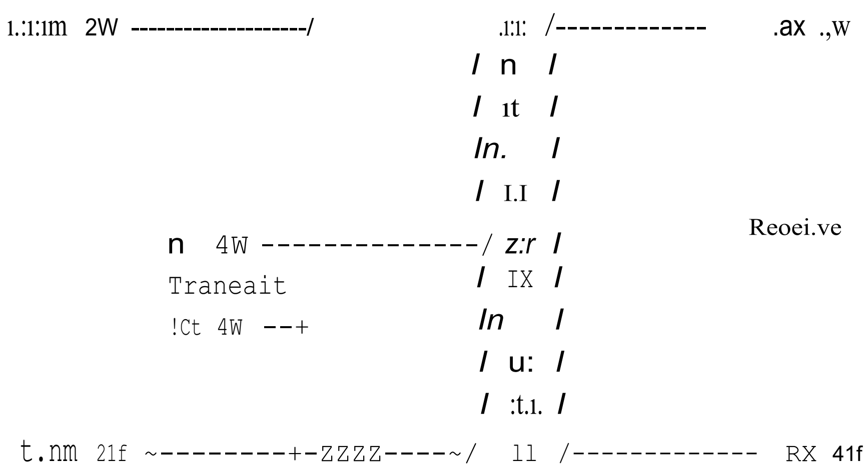


Figure 2.12

Here the wires marked with LINE .2W are the wires ofthe2 wire duplex line. Wires marked with: RX and TX belong to 4 wire line. RX is the pair where the received amlio form 2 wire line comes.. TX is the.pair where the. audio which is to be transmitted to 2 wire line are sent The corrrponent marker with ZZZZ nrodels the tefophone line· -ıın-p-edftnce {typically around'600 ·onm--s').

2.8.2 Connecting Hybrids and Telephone Equipments

Sometimes there is need to connect normal telephone equipments directly to the tcleplmne hybrid circurt without any -c-orınectioo to pu:blk telephone network. This kind of interfacing. ts. need:e.d for example for· telephone equipment measurements using hybrids or for Itnerfaclrrg' telephones to computers through a hybrid circuit. There are few different ways to do the interconnection of hybrid and telephone equipment.

2.8.3 Simple Interconnection with no Power Provided to the Line

Simplest interconnection is just wiring the telephone equipment to the hybrid. This kind of simple interc-onnection works for eases where the telephone equipment does not need any telephone line loop current to operate (normal telephone avera:ted orr loop· current and can not be used in. this way).

```
      Green  0--------------------C
TELEPHONE                          Hybrid
EQUIPMENT                          circui~
       Red   0--------------------0
```

Figure 2.13

2.8.4 Simplest Powered Circuit

Tills circuit is suitable for simple telephone equipments like normal telephones ·con..1lecied. to -transfonner based tdephcm.e nybricl-s "'Wffi:ch -can withstand 'flffl'ffl:'al telephone line OC current (use "wet" t';pe transfünner whic.hcan ;..\tithstand at least SO mA DC without saturation).

```
                    Battery
                    + 12V
   Green ü-------;' \'  '------------0
TELEPHONE                         Hybrid
EQUlPMEN?           '             circuit
    Red   o--------   .----------------o
```

Figure2.l4

The drouit works· so that the battery voltage 1m,•rersthe tdephoue equipment. The current taken. from..h: is limited. lıy teh resistance in. telephone itself and the DC resistance of the hybrid. If you fear of excessive current, you: can put a 220 ohm l W resistor in series with the power supply. This Wm limit the current below 50 mA in all

cases and
does not cause too much' impedance mismatch to the circuit:

2.8.5 General Hybridinterface

This is a general circuit suitable for interfacin.g "dry" hybrid circuits to practicaHy any telepheen equipments (works' atso förllwetll hybrids):

```
                 :;..ine  cur~cnt.
                  feed.  -
                              C1
                             2.2 ur
                              li
   Gre,en-----+----------     | |-------0
TELEPHONE                     !' ,     Hybrid
EQUIPMENT                              circuit
     Red  o----+-------------------c-

                 Line cur.1;ent
                  feed -
```

Figure2.1S

This circuit uses a capacitor Ct to isolate the line current fed to the equiprrtent from the hybrid circuit but still passes the audio signals. The C\ should, have a voltage rating so high that it can •.vithstand'tht~· voltage'S' which mrght be· present' in the line. The value of C\ is not very -critical, 'a\\ values from 1 uf te 50 uf •.ır,U work well. A "dry"

:capacitor type like polypropylene is preferred capacitor type-to be used.

The current feed is an -external circeit which is ·use-d to ,supply the current to the telephone equipment inuse. For normal telephone equipments and ideal current source with nom-ina:l current in 20-30 mA range and the open circuit voltage in range 12.-48V would be ideal. NOTE: The source must be current source type. Normal voltage sources like ·batteries or normal DC "Power 'Supp-lied does not work for this-bec-au~ eof-their low Internal imçedarıce which would just short-circuit the audio.

Ifyou do not have a suitable ideal current source, you can use other methods for making "close enough" substitute for telephone -apptic'fttions.The closest thign to a traditional power supplied by Telephone Company would be a 48V power source fed thro-ttgharound 1 k ohm resister and 2H inductor. If you use lower resistanee·values yo-tt can use lower voltages. The2H coil is needed to keep the impedance on audio frequencies ti-gh -se that·tne 'P'CVl'"Cr 'Sttppij -cfoes net "'Short cireuit" the 'aılü'İe 'Signa1 'OT cause serious impedance mist aches.

1f the actual impedance matcheg are not very important, them you can try methods like 12V power source-fad through the coil ofsman 12V relay or through '680 ohm 1W resistor. Both methods work in some cases, but can cause impedance miss match which can cause poor operation of the hybrid (the isolation between incoming and outgoing audio signals will not be very good).

2.8.6 Components for Telephone Line Interfacing

If you are looking for components relays. and tranSformers. for making telephorr~ interface; cheek the-foHowing eompanies:

- Clare
- ·Mitltom:
- Prem Magnetics
- BotrrrıS.

Using ready-made type approved interface can make designing small volume telecommunication product more easily, but unfortunately those ready made DAA are usually more expensive than the discrete components. The following companies make DAA products:

- X-ecommakes miniature telephone interface modules
- Cermetek has a selection of DA.A, p:ro.du¢tş
- "'·Siemens-makes-optically isolated DAA Mmhrle:D.AA:20.0&

The. frequency response of the line depends on the line length. When line gels long high-tones drop-off much more quickly than the low tones (with the obvious effect on speech). It's not aU-thaLdi:fficultto tell the distance an analog phone-is from a central offi~e- {~s.·mming an: an<a\og Hl'ie is the c:onne-ctor): rt there are'nt>" highs- i-t's far:

Take also note that the telephone equipment has a. huge effect err the speech quality. For example carbon and eleetrets handset rnlcrophorres have radically different frequency responses. The. frequency response and, overall sound. q.ualiey of carbon mi~opho:ı-ıesused in o\d·releplrones:are not very good. Many modenr telephones. with electret-micropboaes give 'better sound-quafüy.

2.9 Telephone Line Details in Different Countries

Normal telephone line is theoretically designed to be 600 ohm resistive impeelanoe. This 6:@0 ohm ,hı; kept as intemational -r-efot-ence for designing telephone line equipment (typically-the signal·powers. are. measmed to 600 ohm lead), In practice the telephone line does tot took tike pure 600 -ohm resistance. The cable and equipments used by the telephone companies have effect what the· real impedance is.

Telephone --eeruipment whi'ch is ,des-i,gned to 'l1perate with 600 ohm toacls win operate with. tnese re.al-life:rınes~ but it:s performance-is worse than in id.ea! sitnatfon. TypicaUy the modems are designed for600- ohm reference impedance because they ean handle· the side tone, hut fut best perfonnance the telephones are designed to the exaot -line -im·-ped.mre.

When crest performance is needed the circuit should be exacdy matched:to. the impedance of the real telephone lines, Matchhıg the. hybrid circuit to the real line: im-pedance(instead of.600 ohm) will improve the füedhack ;typically by 3--6dB. 20dB .side tt'>tı'C is easy to achieve, but 3-0dB .is also noı too 'difftcult pmvirled you can measure the line impedance and take steps to build a-correct balancing netwmk

Different countries have different charactertstics on the telephone: lirre ₒpa:tameten;. Here ,a-re seme impedance m-Oclels fü:r typical lines in <lff:fereflt «nuıt,ries.

2.9.1 USA

Normal telephone subscriber lines in USA (0.4-0,6mm subscriber PE insulated vaseline filled cable) are 770 ohm resistor (with 2uf series capacitor) and 47nF parallel capacity.

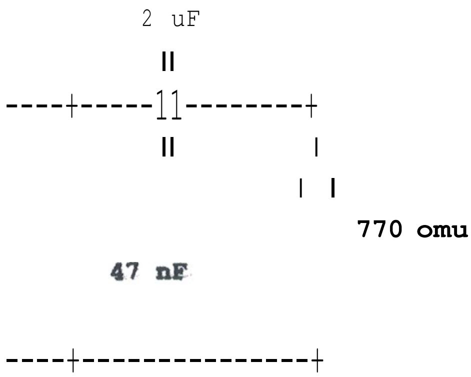


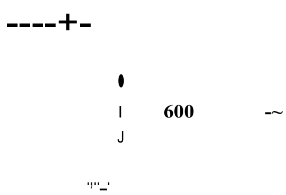
Figure 2.16

This diagram is referred to 800Hz, but impedance is rather complex, and varies from high value at low frequency and drops to ca. 150 ohm on 1OkHz and 120-125 ohm above lOOkHz.

Some telephone lines can have higher impedance (typically 1100 ohms *in* lines with io'atlingtons or telephone-air cabtes).

2.9.2 Finland

The equipments connected to public telephone network in Finland must meet NET4 (ETS 300 001} tecbnieal specs. AH pmv-er specs and 'return loss measurements are taken so that the reference impedance is 600 ohnr resistive.



The return loss of the terminal equipment must be greater than 10 dB when compared to 600-ohm reference. This measurement applies to telephones, modems and other terminal equipments. NET4 technical specs are European specs and they are used in many European countries (NET4 is actually a collection of different specs in use in different countries). Telecommunications Administration Centre in Finland also mentions in it's regulation THK 20 1/1997 M that the telephone line equipment can tie measured against the 600 ohm resistance mentioned in NET4 or complex impedance of Z= 270+ (750 //150 nF). Here is a picture of that complex reference impedance:

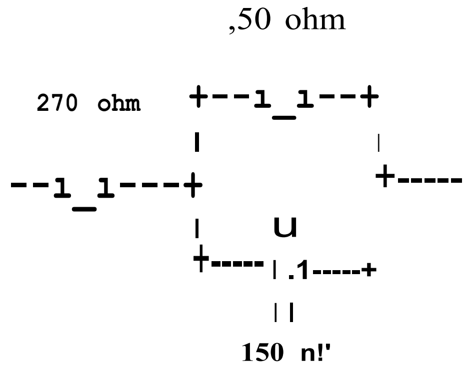


Figure 2.7

Typical cable used in forsnbscriberlines has fcllowiag characteristics: 0.5 mm diameter wire, loop resistance 182 ohm/km and pair capacitance 39 nfTkm.

2.10 Notes abot.~ Telephone Transformers

Telephone line interfacing transformers are usually called 600;600 ohm transformers (or 1:1 ratio 600 ohm transformers). The both markings teTT" that the transformer has (around} same number of turns:on both primary and secondary coils and they are optimized to operate at 600 ohm load. The 600 ohm load does not tell the primary or secondary coil resistances or impedance, it just tells in what kind of application the transformer is designed to be used. The DC resistance of typical telephme line transformer coils is around in 40--150 olun ranges and inductance- is **typically in range** of **fe\V** henries:

A 600:600 transformer is optimised for 600 ohms use. but of course wilt work ever a range e-f impedances raore 'Of less well {for -example you lose a whole octave at the low frequency end if the impedance is 1200 ohms).

3. Comparisons of Communication Modalities and Media

3.1 Voice and Video

It is enlightening to compare various communication modalities -in terms of tlıni-r analog and :digital requiremı:mts.

Voice.telephony req~ires a-base band analog bandwidtho:f4 kHz: The digtttzatimı of the. speech signal: results.:· hı the data; rate of 64 k: bps. This dıigitat s;ignal can be- oempressed in its data rate by capitalizing on the many redundancies that occur in the speech signal. The degree of.compression d.epe.nds on.how mach .degradation .of,quafü.y is.. acceptable. Th-e 6.4 k bps signal can he: redııced to 3:2 k bps with virtually no noticeable degradation of quality. The: digital signaLe.outd· he further r.educ:ed to a, data'.: rate as low-as L2 k bps, but-the degradation of quality would be quite noticeable, and it .sometimes might be difficult to reoogn~zewhat was said.

A television video signa1requires abase hand analog bandwidthof 4;5 MHz. The· digitization of the video s.igna:l resmes ia adata.rate of 50-M bps, There·is a consi:derabl'e' amount of redundancy in video images, both within an individual frame and also betw:eetlframes. The d.i:gfüzed video signal can be eo-mp.ressed t-0 1 .5 Mbps .with some <l.egra.dation o-f quality, particula!'ly for those. portions of the image that move appreciably from frame to frame. Compression r0- the' data rate' as low as- ahoı:ıt OJrM bps is even possible, but the degradation of quality would be more noticeable. The preceding can be summari-zed ln the following table; 3J

ANALOG	DIGITAi,.	
Bandwidth	*Baseband*	*Compressed*
4kffz	64 k bps	1.2 k bps
4.5 MHz	SOMbı>_s	0.8-1.S M bp_s

Table 3.1

An interesting observation is that the ratio of the requirements for video compared with speech is always about 1000 to 1 when like methods of .encoding are considered, J:ndeed, the old .adage that "a-picture .is worth' one-thous-and words" appearı,; m-he well grounded and applicable even to communication techaelagy!

3.2 Text an.ii Image

Electronic mail holds great promise for the fütur-e as a new coıımıunication -moo.ıtity. T~er-e -m<e tw--o- ways in ·whefcit the 1n:fo:rmation -0n a sheet -of paper can be eoocıded .md cnmmnmcate'd eloctrmricaily .. ln: one way, the: image: on the sheet of paper, he it text: er -pieımres, ls sea-mı-ede. ele:ctronicaılsy and elnTverted int& an anackıg: or ı:iigital signal. This signal can ·be transmitted to a distant location where the image of the page wi1l be reconstructed. This type of tmage -scanning and :reco:nstru-c-tion ls called facsimile trammıi-ssimı.. The s.econd way of efl.€0.dıng the inf-orınarion oa a.sheet of paper is i:n terms- of the· A-SCH syrrtb'ols: that comprise ı-.n-e text (ASCH is Hıe,-ae:l'ottyıw ftlYr the: · American Standard Code for Information Ieterehange.) Facsimile can cope with bc,th 1ert-a:rui pktmes, hut A.SCH can mı}y cope with text

1'he--digita-l-i,ı1f0fffl--ati&ff on apege-ef text a-r1d images- depends ttpü-ft seeh factors as: the resolution-of-the:: seanningp-ro-eess,. the mıınbe-cr of quantiza-trio.nc levels mre.d t-0'· eneede each point, and the sophisıieaıion of the compression technique used to rednee redundancy. A resolution of 2HO Hnes per inch i,s exceUeın for must dom:ıment-s.

1f a resolution of 200 lines- per inch is used in the vertical direction with a oorrespı;nıdmg res_&l:mi.an i-n, the. horizontal direction~ then- an 8-hy-H inch· page. has a little less than 4 mill-ion picture elements. ff-a single hit is used to encode each picture -ere-ment, ,t;\;\e,11-4 mH-Hen .\;Hs ar-e'need-ed to eneode the image digitally.

There is, a great deal oJ empty space (Hr mos-t pages. Hence, a lwge a:mEH:tnt o-f ooıtff.mtssfon rs fe-asrhle- for facsimile tr'JJtsrtt-ission. Compression, by 20- to 1 is possible, thereby reducing the number of hits per page to 200,000, or possibly even less, if fancier ,e:nm;preil.siıl-n ıecl'ıniqın$ Jıt,e.used.

A page of text is most efficiently encoded in-terms of the AS-CU characters,whieh go,mpıi&e- it. ff a- full p-<iğıı:t- o.f text eoesists of 60 tows of S0, ehıııraete-ı-:s each:, then the füU page would eonıain nearly 5000 characters. At eight bits per .eharacter, a full page of 1ext would -r~ırir--e 411;000 hits_ There is redu.nrlanq in text because ~:n eombimrtiuHS of characters occur more frequently than others; and- thus the number of hits needed ro ertende the cbaraeıers o.n a page. of text might be: reduced. hy at least a

factor öf two toabout 20,000 bits. Such reductions are rarely performed because ASCH :ıs -rure-arly *sa* effu::.ient compared with ,other com:mıınicatio-n mo.dal.itl¢S,

3.3 Text and Speech

A fairly good rate for reading aloud is about 120 words per minute. If an average word is *six* charscıers long; :then the-text equivalent of one minute *Hi* read afoud would be 720 characters or *5'16&* bits: using eight-bit, ASCH eneöllmg. The'text equivalent of a ftve~ro:i:nttte te:lep:h.€ıne co:ı:ı:versati@n- wottld tbeııefaııe he 5 X :ic16l), bı,ıt.<o-y eı'ıı' nea,.rty 3.0.,00Q; hits. At ,64 k bps, the five..:miHute telephone conver:Sation would -require 5 X -60 X 64i)OO hits, .G:r neatly 20-miUion bits. Clearly, te.xt is o:ıns1dembly more.effici~nŧt~~ speech in its use of bits by a factor ofroughly 700· *ta* I.

Voice mail is- a- funn- e,f. eleetrffflf£ mail l,ı;ı, wtıieın, actuaı speeeh messages ai:e: stoted digitally for later retrieval by the intended re~.}ipient. The digitization of speech at a -64 k bps rate wouid require uTireafürticaity farge amı:·nınts nf ·stmag.e for a:n :but the shortest messages_ Hence, compression is used. with most. voice- mail systems. A nominally acceptable quality m,ight b-e possible at a, hit r,a,te of_9,.li>: k. lJp~~

For the sake of comparison; it will be assumed that the speech message is encoded at a rate of 1 .'2 kbps; ·.althoughthe quality now av.ail-able .at such a low raıe would not be acceptable. A one-minute message would. thus require- a, total of 60 X L2 k bits, or 72,000-bits. The textual equivalent, of the speech,-message w-0tı\d,be 120,wer<l~, whiclT would require less -than -6000 bits using -eight-bit ASCII encoding. Thus, text is far more effi.cknt than speech, even·withmaximum compression ofthe-speech'S'igna\.

3.4 Total Traffic

The yearly total traffic in bit equivalents for various communication modalities and meaia--'.Can h:e,,estimate:d. 'fih:e traffic ,represents cthe-ıicigiw:l ,ca:p~~'Ɏ41~ -to trffAsmit o:t store· all the messages for each mediıxm ..

The·average daily mımbe:r of lncal and toll telep:hune conve-rsa:timıs for Bell and independent teleph-on.e companies is· &D0 mlllioa *(Slat Abs: 1984)*. Assuming that the kngth of an average tdephone -001we:ı-saüo-n -is :three mim:ıtes and that -the :Speech :is encoded at 64 kbps; we- have a total. yearly traffi:c. of J.4 X J;0:18 bits, o't" 3400 quadrillion bits.

For television programming, it is assumed that there are three major networks, two minor networks,_and seven cable broadcasters. for a total of 12 eaanncls. Each channel WIll be-assurredtd' bmaı:kas~20 noun of programming each and every day of the year. At 50 M bps digital encoding of the television signal, this amount of programming is equivalent to 1.6×10^{16} bits, or 16 quadrillion bits.

In 1982, 71.8 billion pieces of first-class and second-class mail were carried in the United States, Asrumrng that·eac'h piece of ma:rt contained the equivalent of one ftıll page of text (4800 characters), we have a total yearly traffic of 3×10^{15} bits, or 3 quadriHion hits.

It is estimated that about 3& billion clıecl<s will be negotiated in 1985 *IT}* the United States. Each check can be assumed to contain about 200 characters of text. Thus, the yearly digital equivalent.capacity of all checks,..assuming.eigb.t-,bitASCII encoding is used, 'is 6.1×10^{13} bits,er·OJ)6 quadrillion bits.

There-are· abotrt 9200-newspapers in the· United States, about 6800 of which are weeklies, The average lengtkof ır newspaper is about 100 pages. This means that about 123 million newspaper pages are published a year. It.will be assumed that each page contains about 7000 characters of text, which is equivalent to 56,000 bits using eight-bit ASCII encoding. In addition, it wiH be· assumed that each page contains about 200 square-inehes of pictures·and advertising. Using 200 lirresdper:..inch sampling and 2()-to'-' l image compression, this pictorial informaıion is equivalent to 400,000 bits per page. Thus, each newspaper page is equivalent to about 456,000 bits. Thus, yearly production of newspaper publishing is 123 million times 456,000, which equals 56 X 10" bits, or 0.06 quadrillion bits.

The preceding can be summarized in the following table: 3.2

MEDIUM	TOTAL UAaLY TIIAffIC (111 p I •• (11") lıllı)
Voice Telephony	3400
Television Prograıımini	16
Mail (fiıst.-dus. and secoıld<hm)	3
Checks	0.~
Newspapers	0.06

Table 3.2

Clearly, voice telephone traffic swamps all other communication modalities and media. This is not surprising because each telephone conversation is a unique message, requiring a considerable amount of bits.

3.5 Philips Recording Interface

The first circuit is Philips LFH0117/00 telephone recording adapter, which is not manufactured anymore I think. The circuit is quite typical telephone recording adapter design. I have used successfully for getting audio from telephone line to soundcard and my stereo system.
because the telephone provides them (this circuit is designed so that it disturbs the operation of telephone as little as possible so it has high impedance input).

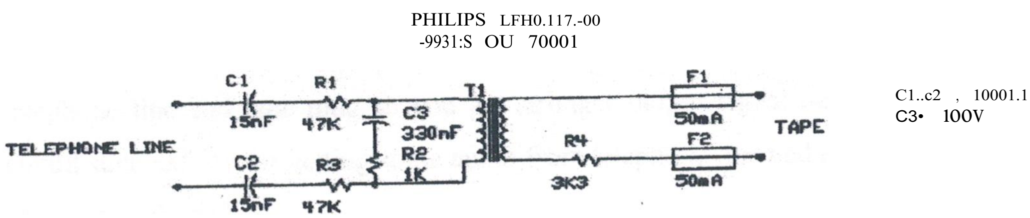


Figure 3.3

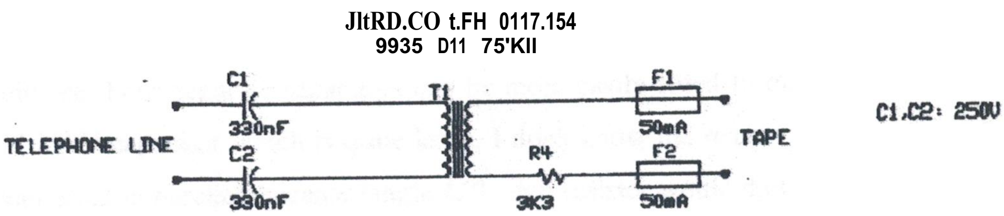
I found out the type of all other components than the transformer Tl. Tl is the audio isolation transformer, which seems to have properties quite similar to typical 600:600 ohm telecom isolation transformer. The components Fl and F2 are 50mA fuses. The signal output level is suitable for microphone input because the resistors attenuate the voice signals form telephone line around 40 dB (some telephone equipment regulations in Finland needed this).. On the picture below you can see a picture of the inside of the Philips LFH0117/00 telephone recording adapter: Show in figure 3.4

Figure 3.4

In the circuit the two 15nF capacitors *are* blocking the line DC level and the low fr-eqa,ıency for ringing. AH other eornprıents are safety requirements, for lowering Hre· noise and for matching. the telephone equipment regulations (signal isolation from line, impedances etc.). This schematic is basically a very safe one: fuses are not necessary for proper function(just for extra safety) and the transformer provides galvanic isolation from telephone line; The circuit is designed to be connected to the microphone input of a recorder. (the mıtput signal level is typically few millivolts: which is too low for any other type of input).

3.6 Noreico Recording Interface

The second circuit is made by Noreico and ıs also designed to be used in **t}a=rallel witl1 existing** telephone, This **circuit** has mueh **less attenuation between** telephone line and tape plug so you get stronger output signa! out I have used this circuit successfully for getting some audio from telephone line and sending some audio **back** to~ **telephone·** line:



Figu.re3.5

I found out the type of all other components than the transformer Tl. Tl is the audio isolation transformer, which .seems to .have properties quite siıüilar """to :typical ·600:600 ohm telecommunications isolation transformer. The components Fl and F2 are 50mA fuses.

3.7 Recording Interface From Tekniikan Maailma Magazine

The third circuit was shown in an article written by Martti Koskinen in Tekniikan Maailma magazine issue 8/1994 pages 94-95. The circuit is designed for recording telephone conversations using normal tape recorder. The circuit has an option to also play back sound tot the telephone line from reparate connector. The transformer Tl is typical 600:600 ohm telephone isolation transformer with centre tapped secondary. This circuit is also designed to be used in parallel wiht existing telephone.

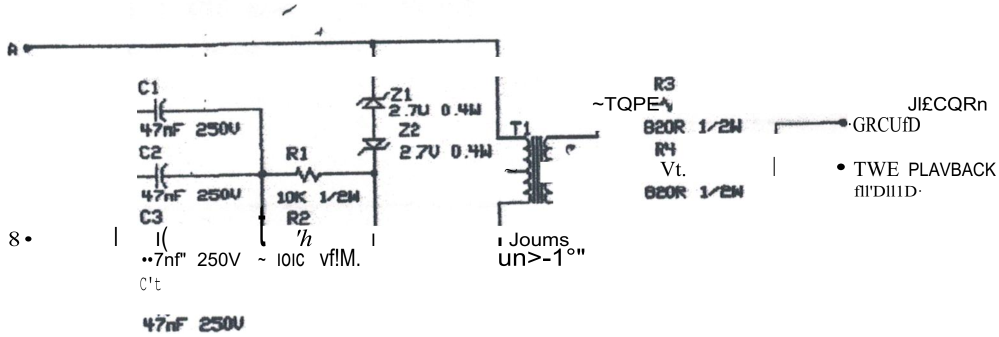


Figure 3.6

The capacitors Cl to C4 are connected in parallel to make about 200 nF capacitance. Four separate capacitors can be more easily fitted to one case than single 200nF 250V capacitor which is quite large. I don't know the reason of why Rl and R2 are connected in parallel, because single 4.7k ohm resistor would do their job as well.

3.8 Marantz PMD Recorder Series

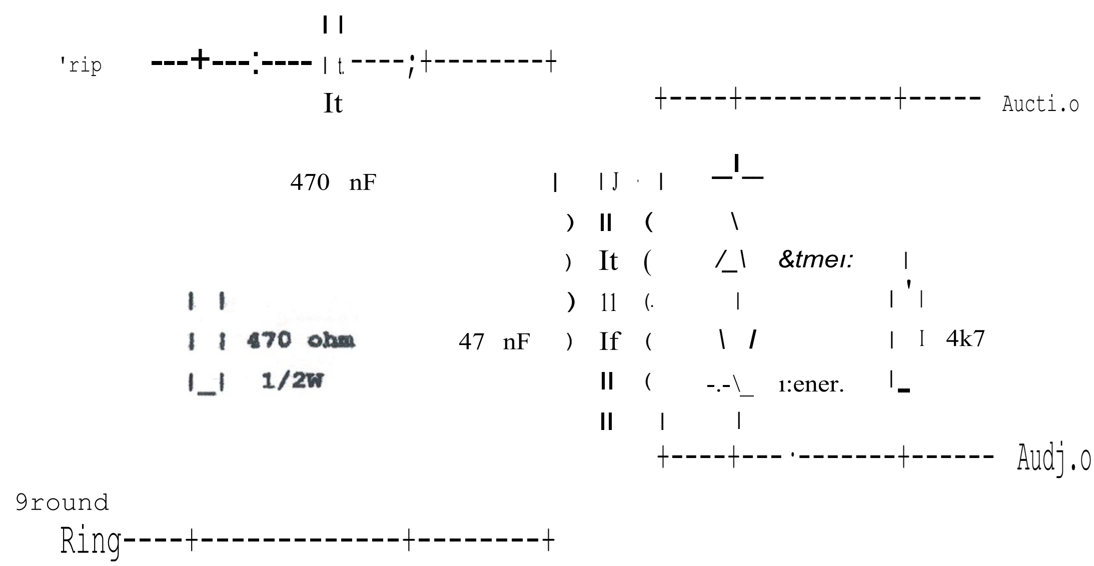


Figure 3.7

Tip and ring are first shunted with a 470 ohm 1/2 W resistor (to allow the interface to sieze the line). Next, before the transformer primary, there is a 470nF series cap (high pass, and DC transformer isolation) and a 47nF shunt cap (low pass to limit the upper end). The transformer is a 1:1 600 ohm, I believe, though the schematic doesn't specify.

On the secondary there is first a shunt pair of back to back Zeners to limit the max voltage seen by the recorder circuit, and then a shunt 4.7K ohm to ground.

3.9 Telephone to Studio Mixer Interface

The transformer and 44 nF capacitor keeps the impedance seen from line high enough that not bad mismatching happens when connected to studio mixer. If I would be connecting something like this to my audio gear I would add some type of surge protection to the circuit (two zener diodes in output would be nice) or add external surge protector. But let's the original text to describe the circuit in more detail.

We use telephone audio in our studio all the time. And yes, it's an off the shelf design. I designed and built such a device with scrap door components. I used an audio coupling transformer and a capacitor. The primary windings add in series to 500 ohms. Instead of connecting them directly together I added a cap between them. I it was something tike 0.047 micro farads with a 600 volt rating. And the secondary which is 500 ohms runs Into the control room mixer.

```
            ~ip.     >------------/ 11
                                  / II/------------<
      (primary winding 1)         / II  /
                                  / II  /
                     >-----x------/ u   /
                           I        II,/
          0.047  uF        =        II  / -----------C1r    (secondary
  Winding)
                           I        II  /
                    >------x------/ II  /                    Out:put Side
                                  / n   /                      to Mixer
      (pri.Jla.ry winding 2)      / II  /
                                  / TT  /-------------~
```

'Figure3.8

TtY füiş circuit it works great for us in the studio. The circuit is designed to he- used in parallel witfrexisting telephone. Just make sure, you use properly rated comp ,

3 .to Audio interfaces without Transformer Isolation

In some, special, case the. audio interface is built. without isolation transformers. *In* these eases the audio- :;i'gnaY is' pas-sed from telephone· lirre tt<ırotrgh the- capacitor which blocks the DC from telephone line. This type of isolation works quite well in applications where you don't want to use the transformer but you still want to get some audio from the, line. 'Eypical.applicatkın is. called- ID boxes'.

A typical capacitor isolation circuit:

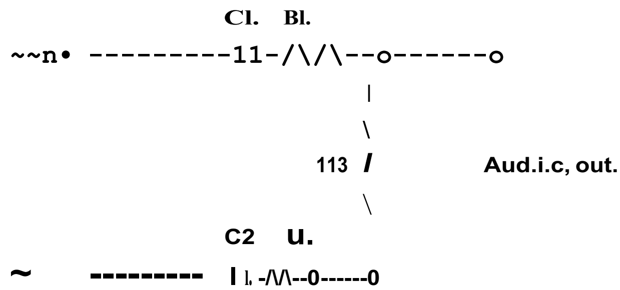


Figure 3.9

The cepaeitors Cl and C2 '#İH block the DC ·and pass the ·audiö sigaal to the output. The resistors RI· and R2 provide some protection against the spikes on the teleehene line and [illegible] the circuit [illegible] irmreda [illegible] does: not disturb the telephone line operation. Rl, R2 and R3 make together a voltage division network which will attenuate the audio signal coming from telephone line to the desired s.ignal output level.

The- eirettff s-hcrtı!d **be** eonnected ***to·*** **differential** audio input **If the circuit is** connected **to** single-ended input the circuit works worse and .gets easily all kinds of interference, Capacitors Cl and C2 should be rated to handle the 1.5 kV pulses. The capacitors Cl, C2, Rl and R2. should provide sn high:. impedance; to the. telephone line. that the. telephone Hne balaneing ıs not disturbed. You shotttd also note that this circuit does not provide as .good .snrge protection as transformer (surges can quite .easily pass trough Cl, C2, Rl and R2). This is not the preferred way to do the telephone line interface! Preferred way is to use transformer isolation instead.

3.11 Simple Teleeom Hybrid -Circuits

Telephone hybrid circuit is the circuit which is designed for converting 2~wire **interface to 4·-wir~ interface and- is one of the· basic building blocks of. the** telephone system. Telephone hybrid is the circuit which separates the transmitted and received audfo which üre sent both at the same wire pair in 2-wire normal telephone interface.

There are many different types of hybrid cireuit.in use, Traditienally telephones. **have used** combination **of special** transformer **and few** additional components **to- keep·** incoming and outgoing signal separated from each other. Nowadays this is done more or less electronically.

In telephone central end hybrid circuits are needed when must be done any amplification to the signal Traditionally the systems separate the incoming and outgoing signal, then they are ru:nplifted -seperately Tu."ld -sent to other telephone central using separate ··wires or otherwise separate commıınicaticm channels. The oldest models of those circuits have been built from one or two transformers and some other balarıdng components to .get best results. The problem have been how to. get go·od balance to the hybrid circuit, said in other way how to separate incoming and outgoing signals as well as possible.. Nowadays e:veryb-miy is a:Y.o.iding. bulky and exp·.ensive special transformers. and more and mere eleetror.ies ts used becanse it is cheaper. Modem hyorid circuits consists only of one audio lsoletion transformer, two operational amplifiers, resistors and some capacitors, and the most modem approaches *try* to avoid that transformer altogether by using active e.le..ctronics circuits. in telephone line side to do: the job. and opto-coup!ers to do the isolatioı where needed.

Many different system circuit have been used and I am showing here just one basie transformer based circuit which easy to tmderstand and is useful for many experL.111e11ts.

```
        Prim,uy 600 oha                   seconda.J:y 600oba+600 oba

            T~p   >------------/II/------------<  audio to telephone
 line
                               / :I1 /             (1ow impedaııce
 output)
                               / II /
                               / II /
                               / U. /
                               / IZ ı------600ohır--Ground
                               / xr /
                               / .n /
                               / II /
                               / XI /
                  >------------/II/------------->  audio to mixer
                                                   (lip   i ııpedence
 input}
```

Figure3.10

This first circuit is a traditional simpıe hybrid drcui-t which have be-err ear-lier successfully used in many telephone circuit (for example modems). The circuit works so that the 600 ohm resistor in the center pin of the secondary is seen as 600 ohm impedance load in primary circuit The end of the secondary which is connected to low impedance audio"ou1pttt·(for example amJ}ii-fier made-for-driving sımın speaker; must be always connected to amplifier or ground to make the circuit work as expected. The audio signal output from the circuit must be fed to high impedance (>10 k ohm) audio input to make sure that the operation of the circuit iS' not dlsnırbed. The circuit gives quite aeeeptable separation between Ineernirrg' arrd outgnirrg signals when aH impedances are set correctly. The 600 ohm impedance is kind of idealistic value and -dees not fully reflect the reality. In real life tire impedance ef the -telephorıe line or telephone is not exactly 600' ohm and the- transformer has it's losses. A 600 ohm resistor is anyway quite a good starting point.

If transmitted and received signals mix with each other, you will have to fiddle with the- balancing network. For experiments I can suggest fitting 1 k ohm variable resistor to the pace of 600 ohm resistor for experimenting which impedance value gives the best results. You may also want to try other type of line impedance simulation circuits if you know what what matches your system better. If the impedances presented by betll the· send and recei ve· sides are the same the-lıybri-d dr-cuit will work quite welt. You will find that the send and receive signals don't interfere with each other, but both come and go from and to the line.

If you are thinking of connecting this circuit to telephone line or otherwise sending OC current t,l->.rough the -prın:rary of the transformer remember tr) use a transformer which can· handle the DC without saturating (telephone transformers made for "wet" eircuits). Anıl' remember- that there' are- strict rotes what the· equipment you· .connecı to telephone line must 'meet .and you are ·not allowed to connect anyıhing not approved te public telephone system.

3.12 Modified Circuit

The following circuit is for telephone line interfacing when using a 600 ohm to 600 ohm transformer with center tapped output:

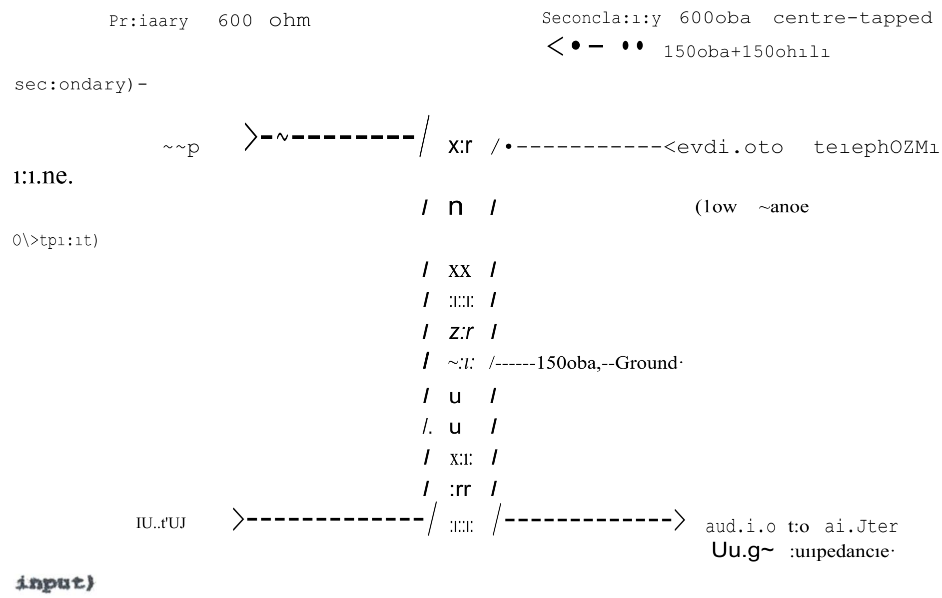
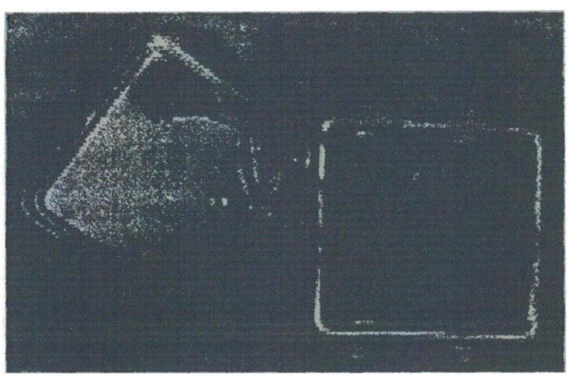


Figure J..11

This circuit works the same as that cir<.:uit above, but uses standard telephone line transformers easily available. One commoa transformer type has 600 ohm primary and '600 ohm centre-tapped secondary. In ceetre-tapped secondary each secondary side presents. 150 ohm impedance. By using 150 obnr resistor-eormected to secondary centre-pin. the primary sees 600 ohm impedance. Experimenters can try for example 470 ohm variable resistor instead of 150 ohm fixed resistor to test which value gives the best results. You can: see this type of circuit built to a ·smallplastic box at the picture below:



FigureJ.12

3.13 Soundcard To Telephone Line Interface

The following circuit a modified version of the circuit above, This circuit ·inÇ;fo.des: snitabl.e: audio: output which; ca;rt- he. fed to: a PC. snıı-ruiea-r.:d: and a- on'loff_huo-k switch:

```
        Pruıary  600  ohm                        Secondary  600ohm  cen~-tapped
                                               •.-(uae  -••  .150obııı+150obııı
secondary)
                   /
      TIP ----o/   o------------1  II/------------<  aoundoard  apeker.
output
            ON/OFF  HOOK        / I.I  /
             SWl'.TCH           / II  /
                                / II  /     -     +-<  speker  connector
ground
                                / II  /
                                / rl  ı---ısoobfıı-+
                                / ıı  /
                                / ıı  /
                                / ıı  /           +->  li.ne  .input  connector
ground
                                / ıı  /
     RING--------------------/   II/------------>   souııdcard  ı~ne level
input
```

Figure 3.13

Remember that in telephony applications.the- signalSı le:.vels must he adjusted.carefülly ~nd sma must lıtt nifüie:., tirat-the. ckcuit is, in good enough, balaaee that thete, Ix;c no annoying feedback in the whole system. Warning that this cirueit is a little bit simplified-interface d·iagram. Thi~:dfagram lades for ex-a.ınple overvoltage ·p:ro.te:cthm on the audio output and also limitıng circuits which: stop too large signal levels to entertfie tet'ep:frorıe network.

3.14 Operational Amplifier Based Hybrid Circuits

Modem modems use hybria c:itcmts: built from operational anıplifiers~resistors: and Gtıe.· li00:600 ohm is:olatiowttanmornı,er: With, ~kn~l amp\tfrer~c~ttit ~he- cir£Uit can be made .cheaperand,p.edor.min:g,hctıe-e.

```
            Prilıııaıy 600 oha          Secondary 600ohm

                                               .......;....
                                                      -'-_
   LI:NZ ---------------/  :U /--+--l_         l------+---< Aııd:io to t.lephon•
 line                                                                      ----
                         / II  /  t  600 ohm        .I
                         / I:I: /  I                 I  I
                         / n   /  I                 ,I  I 600 ohm
                         / \I  /  I                  I
                         / II  /  +--> diff <----+
                         / h   /  opamp e:i.rcui t
                         / //  /   .for  received    I  I
                         / IL  j       audio        /  I 6.00 ohm *
                         / II  /                     I
   LrNE --------------/II/-----------------+----  Ground
```

Figure 3.14

Tue· s-ffurce for audio signal which rs-. transmitted:- tff the telephone-ime- sne:uld be low impedance to easure that the impedance matching tct telep:lıo:ne Hıe is. e~rr-ec.L For Tete-iv:-ing audio a diffeı:.oo.tml mnplifier ·mnst he used to separate the inooıning signal -fol'.m -out-going signal~ but differeri.t4'J :am.:plifre:r is *vı;ty* ₒe&'!.J to imp,le-t:ınn1 ,U~R.g Qop,eııarion-a1 ampJifieFS·, The peFfo.mıınıce- of Ure-eircuit eaa- be made lret:te:r: by r~pla~iflg the 6.0.0: ohm- res.-istor wh.i'.ch is: mark-cd by with some better tnodel fot th:e telephoffe füıe .seen through -the-isolation.,amplifi:er. *A* better model provides better isolation·b:etween ioo.o:ming awi ~-gmng aı.ınm signals.

A quick rwte to mixing desk ssers: profüssiônal mixing des-k9 nowadayg have 4i~rımfia{ mputs. and low impedaucc: t)'Ufpl1ts. This ma.kes i.tvery easy to -(,~pccim:crtt' :with this type .of circuit :ifyo:u happen to own .a good audio mixer.

Here is the full operational amplifier based hybrid circuit diagram (theoretical circuit):

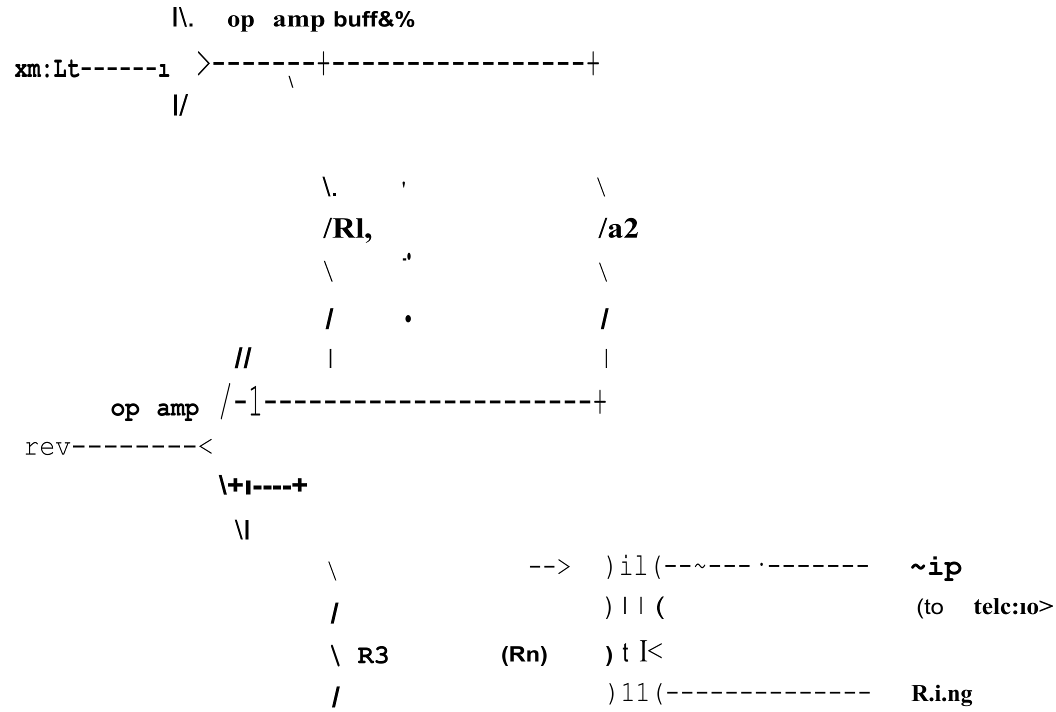


Figure 3.15

In the above diagram Rn = the telco network impedance as seen at the other side of the transformer.

This circuit is an example of an "active" hybrid. Essentially it is a balanced network. If the ratio of R1/R3 = R2/Rn, then you have infinite return loss - that is, you should have none of your transmit signal appearing on your receive line (when this happens, this signal is called side-tone). Yet the receive signal from the "far-end" will appear on the receive line. In other words, two signals can use the same two-wire interface, yet are separable. Not theat the resistors which define the amplification of the op-amps are not drawn here. so if you are planning to build this circuit you will have to add them.

Unfortunately, Telco line impedances can vary quite a bit, so the ratio of R2/Rn rarely equals R1/R3 except in situations where the designer has tight control over loop lengths and terminations. Any imbalance in the balanced network creates side tone - a small amount of the transmit signal will appear on the receive line. In typical situations the side tone can be attenuated around 20-30 dB with a weH designed hybrid circuit. Another typical way to implement a hybrid circuit is to build an opto amplifier Cir~ıtiı whlcrr take-s the signal over the trans.former coil and subtracts the transmitted signal from it. The· föHc,W'l:'rrg crı-reratinrra! amplifier e-İr-e·nit dues this:

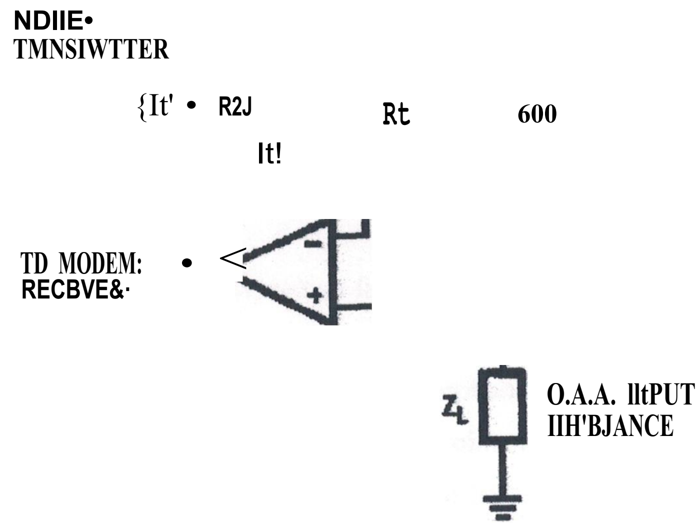


Figure 3.16

The eireıııı below is, partly redrawn optimized. hybrid circuit from National Semi comfoctor apptrca:tiurr nete "Optimum Hybrid· Design" from 1-98'5 (that applicatiorr note is no lenger -avaiiable),

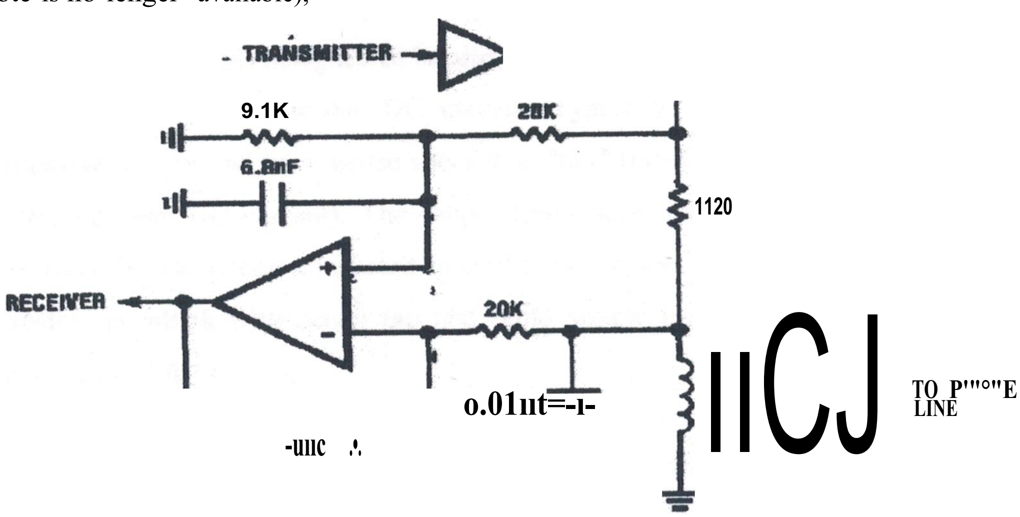


Figure 3.17

TJ:ıe transform.er in :this circuit *is* 600:600 ohm telephone line transformer~ For best results you have to adapt the component values sHghtly to match the line Jmpedanee and the transformer you are- us:rrrg:

That upper amplifier (the triangle.with one input arrd output wire) is just a buffer amplifier' wiıh.anrplification factor of .ene, Signal from transmitter is connected to the positive input of opamp. The negatiwt: inpııt of that op-amp is conected to the op-amp outpul

.3.15 More-aetails.ImpJenı:eııüng T-el:eplıone.Lmc lnt-eda-ce

T~lıpno-ne line interface has to _pı:u-v.rde two functions when it is off-hook:

- Provide DC path for eurrenı flowing in telephone Une. Normally. there, flows about 20-SOmA current in telephone line and telephone regulations typically sepcify that the DC resistance must be less than 400 öhms.
- Provide pmper termination for telephone- audio frequencies (300·-3400 Hz). This is typically specified to be GOO 0-l-ıms.

3~1S.I''\\~t'transformer

Traditionally those two fuın;tiom; are aooompii-s:l-ıoo in mooemcs and ttıeit te-lep-ltöfie htter:fae:eı.i are:accrnn plisrutd hy "wet" telephmıe· trruısfuruıer. Wet type ıaeans that the transformer is designed to hartdle the: DC mne:m (typicaUy 20--5-0mA) properly and does not saturate at tlıis DC ,eu,rreo:t. Typ-ically "wet" transformers are more expensive, bigger and. have worse specs than *"dry"* transformers (wtıi:ch do not h.ave to withstands tnııy DC current). Tire *proper* termmation rn: modenı-s *is* pmvid:ed h:y the' cleetro-nic hybrid oireuit eonneeied to of the tta:ns-fo-r-mer~ Anofüeı-· possibility is tcy use -transfur-mer -which· with center tap and build "Simple 1ransformer and resistor ;hybrid circuit around it

Here is. a. typiea:l eit:'cui-t for "wet transformer:

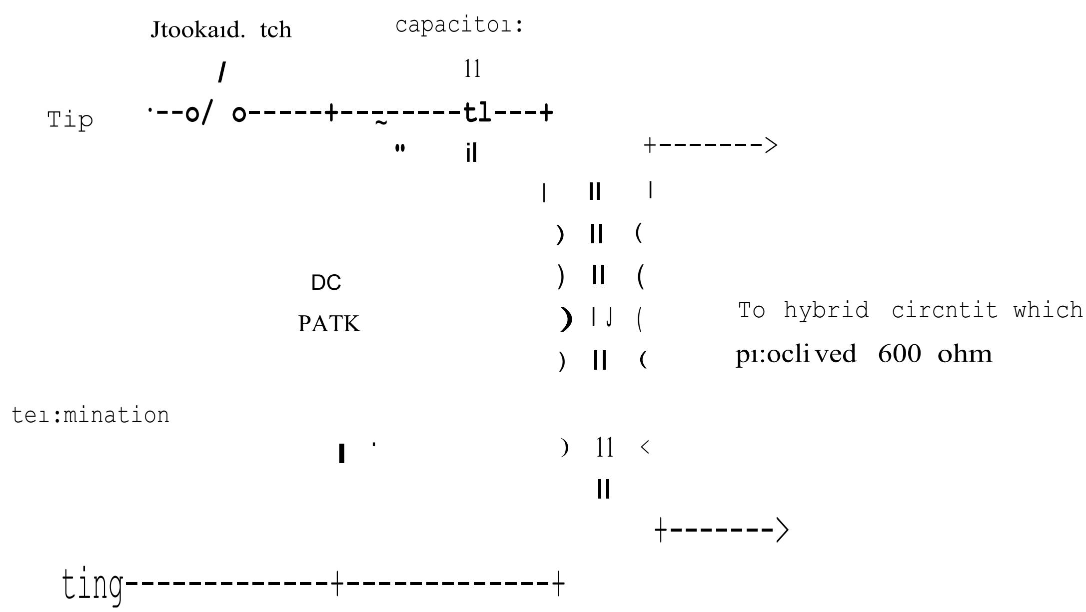
```
          Hookswitch
              /
  ~~P·   ---o/ o--------------;-#--+
                            1          +------->
                                    ||
                                    || (
                                    || (
                                    || c      To hybrid circuit which
                                  ) ||        prodiv.d  600 ohııı
termination
                                  ) || (
                                 I  11  I
                                       ·+------->
  Ring---------------------------+
```

Figure 3.18

The:circuit operation is quite straightforward, when the.hockswitch is closed the telephone- line DC current starts to flow trough the· transformer primary coil: The DC resistance of the circuit is determined by the resistance of the transformer primary coil {typicaHy in ·60-200 orun range in'-600~600ohm -tele:ceımmurjcationtransformers). The transformer is: l :1 traınsformer designed to operere.at .600 olınr impedances, so 600 ohm termination provided in the secondary reflects as 600 ohm to primary (this in not totally accurate because transformer has some losses so you need a little smaller than 600 ohm resistance in secondary so that it looks 600 ohms in primary).

3.15.2 "Dry" transformers

Dry transformers are transformers which are not designed to handle DC current flowing through them (if you put DC through them they saturate and do not work correctly as transformers). 600:600 ohm dry transformers are very useful for example in modems because they are available in small sizes (even so small that can be fitted inside PCMCIA modem card) and can have very good performance figures. Because the dry transformer can't stand DC then in telephone application where there is DC present the DC must be blocked by suitable capacitor (usually 2.10 uF) and alternate path for DC must be provided. Here is an example circuit:



Figttff 3.19

The DC path. must he designed so that. it will pass DC well but provides lıigh impedance to telephone audio frequencies (so that *it* does· not distmrr the impedance matching done elsewhere). A large inductance coil can be used in this but it is not 'practical because yenı-wanted to -get rid -ef %lat hulky "wet" transformer using small '"dry" transformer instead, so you don't want an expensive and bulky coil in your circuit.

Fortunately coils can be simulated electronically using gyrator circuit. With 5yratcor it is very easy to have a simulated coil which has low DC resistance and -the circuit looks like high inductance: cell (few He.mi.es. simulated: coil can be. made easily). Another possibility is to use constant current sinking circuitry. Constant current circuit provides path to DC current but has very high impedance (before using constant current circuitry take a look if your telephone regulations allow constant current operation or you can make the circuit to work inside the specs in varying line conditierıs).

When you add electronics to· transformer primary side remember that those must work at both line polarities. A bridge rectifier will help to make sure that the current going to DC path circuit is alwa;ıs at correct polariıy, Another thing to eonsider is overvcltage protection because your circuit in the transformer· primary side has to withstand the spikes vıhkh exist in telephone lines primary side. Make also the circuit so that it is not.zlamaged by .a little more eurrent :than :normally present intelephöne line {sometimesther,e~e tlV:el' ettrreut i,it'l:Urtions and you oodt want 1nur ckcuit r0 break dowtı,tQO easily).

3.16 Problems in Linking Telephone Hybrid to Audio System

Even stn:ınd' eııgmeer has: had·ttı dear wifü te'lep1rone:Jrn--es: at one tmıeor aoofüer: Urıki.ng the·poone.·c-0nversatförft-o audio system H:ke-takiug-caUs~toa:dio studio carrbe mere prob}{lına,tidh.ın you tiı;stthnught You ;can :get-:a g:ond view of~ scsnario at artiole ~Phone·Line Hasws .article from *JK* Au.dit1_ The füain ftablem ·.in ·making-the audfo co:tınestiorr: is: that· tı~ of ııe- flMUe" pıncb (transfumrer: aflalt!ig .hybrid, dfgitru. hylır-id; etc~}. to the.·caUer, and back ter the studio i'u·to the..tdephonei line. input' of the. phone patch. (Yoa can hear this leakage in the earpiece-ofyour telephone handset. Just , li~en4@!:ı@w<m.uclı'.@fy.oınc.GWıı ,v.oi.ce-~m.Gsha.ek to you!')

3.16.1 Level Matching on Local and Remote Voice

'fJpical eammer-cial telephone <hybrid ·allows the equalizing of telepbone line ıs fı;ill-duplex iıııterfcree .implemented usmg single twisted -pair. When 'an :announcer ·speaks, ·msflıer vofoe travels through -the phone line output fevers ·of focal: and remote voices. Typically a hybrid needs aqjustment for every new connection because of impedance changes. Today -automatic 4:iglt.al-hybri<ls-ar.e--liSOOfor equalizinglocal -and reınote-telephonecconversations.

3.16.2 Trans-hybrid loss and announcer voice distortion

Trans.;:hybrid loss is that portion of the announcer's voice that 'leaks :through .flıe1ıybrid to -its audio .output. The .higher this spedfiGll-0n, in db, the better isolation -in the device. This ieakırge i's distorted and:phase shifted after its long journey~ lnthe s.tudici, the-amıoencer andfo is: mixed at the.console with.the phone patch (caller),otttpllt to. create the on-air mix, When you use a·poor .phone patch,' its oınput ıncluıdes a distorted, phase shifl:.ed .version of the .anaouncer sigrıa1. When 'this leakage is combined with the u1ean a.c,nounc.eı: m.'oıııo,..a. uo'll'ow of "t"uıny sOUil:ıl·.l&pr ü,..,<,=as, Jo,,,,,.. affected by phase cancellation than others: The greater the trans-hybrid.. loss, .the Jess announcer audio that leaks into the hybrid output .and the less the announcer voice

,distortion. :Ide.atty~ ıhe output of:the !ıy.hrid shoııld .conslst of caller andin o.nlyA Digital lı:;4'r-M-s lıa\'e -stgnaled f}T-ooe-s-sıng eleotreaics -to 'get better kafiHlybr'-icl Iess -figur-es lhıtti which are available with simple analogue solutions;. you have to- decide what's best for your budget. There are different requirement depending the application (broadcast, teleconference or remote training).

It have been suggestions that ISDN be used as its full duplex is good one, but it might he only practi.cal if both sides of the Tek-o path have ISDN: When calling, between plain old telephones services (POTS} and, ISDN, the above problems remain.

3.1-6.3Echo Problem ·in Long Distanee-CaHs

Echô is caused because of the coupling between incoming and out going audio in The-telephorre-circuit anchhe-delay in the-"tclephorre line (especially in' long distance· calls); Echoed hack audio is usually caused by an impedance mismatch a! a 214-wire eonversion point (such as a codec-annex-hybrid, analog CO Iirıe interface) and by-acoustic feedback, Thus there is echo: ISON nı, other digital telephone set on an all-digital connection: would

Not cause· echo because af conversion mismatch; but if normat handset or hand, free 'telepheae is used the acoustic echo is still possible.

Echo doesn't become audible until the delay in the circuit exceeds a certain tbre:-shold value wrudı depends mı the losses in the, dreuit Even milliseconds of terrestrial echo· oarrbe mrı:o-ying, hut typically the ·edm rs not annoying if the delay stays below 25ms. Old Beli standards said tha:ı on. calls of more than 1800 miles, an echo suppressor was used. In general, you need echo cancellation when the delay exceeds some subjective value in the 30-50 ms range.

A5 it is practically impossible to prevent eeho (by perfectly matching the impedance İn line circuits and by acoustically insulating ail phones), it either has to be -sappressed or cancelled when -it -dces occur. For this reason, echo cancellers are deployed by Telephone Company on long,,.hauJ routes thaı; when used, l>rıng the total circuit delay to above the echo threshold value determlned by line loss. These echo cancellers are deployed on both sides of such long-haul routes and the echo canceller at ~the remote end of the call ls responsible· for ensuring that you don't hear any echo.

For more iftformaiioff on how eeho canceling works, please consult ITU-T reeonnnendation frf 65 or seme-geed telecommunication book. The morale is therefore that if you hear echo, you can't .do practically anything about.it, as both the cause of the vrohlem and .the solution ·to it. :lie :at. the remore .end of tlıe ceonnection {ty.pjcally at the ·telephoıne ~mp:arıy .ceqwipmcents). H the .cenneetioa you'rce talking about *is* across a priv-a:te networ:ky make sure· that the· echo: cancellers are: eorreetly dimensiemed- because wrcnıgt,y dt-mensiıı:nred eeho eanceUer win he tötalty ineffecti.ve

3..16.4 MetalUc-Sounding Caller Voice Problem

If yo.ur teleplıone. com:ıection·is though· a: d.igitırH PBX·rnr digital switch{typical nffwa.tfa:yss-} thert ytnt migftt- enoounter· a, problem füaıt the vo,i:0'e which. nügllt soufld OK on telephone hut sound "metallic" when you connect it to the mixing desk through your hi,gh'·quafüy h,yhr<i<l ·oir-cuit The metallic sound prehlem is afi ırHasing problem cause by the digital telephone: system. where there. rıt not. m:u.dr :filtering after the: BIA. c.ofl\i'etıer whi~h, oı&tpY!ts. the s0und. The ab-sence: of the °'utput fütevs causes-that there: are high frequency noise compcment~added to the output audio signal. The audio sounds fine on oo:rmal te-lephone because it can 4;}nly ,playbaok the normal tefoptıone autlkı ·mnıe. The p:roblem *is* audible with yem· hybrid cin:.-ıüt of t,har e-ircuit has. wider bafldwidrlı füan:-, normaHelephone. The solution to make this signal sound normal telephoneis to-remeve: everything -above 4 kHz by *:a* sharp- low 'Pass filter. You can try if your nrixing desk: ooa-ımel ·-0q:ı;ıa~,izer-s ,ar,e .·d,fltti¥e -eımugh ,to :r-01:ı1t<l¥e ,th.is ,pr~hlem. Whoo '}'HU st~ equa-liziıg tlıe· signal :&om telephone: hybrid the11 you ~an ~ı-so reınoNe tlıe bass freq,uendes aJso: (there ·ſS usable sound information below 2-00 Hz orr normal telephone line) so you can also get Tid -0f the possible low .frequency noise {maim, 5-0 Hz or 60 Hz) whfoh .is ~em.etim.es -pr-e-sent-0:n ,te!.ephon~line.

3.17 Helpful Tips for Telephone Hybrid Circuit Designers

3.17.1 Measuring Return Loss figures

Reıurırless !'3~ *tr* measure af mfftc'lı lıetweewthe- impeoonee-"tt:fthe"Hne--terminatioifff and the. füıe itself. ff the. impedance of the line rs Zo and the termination or load *is* *Zl* then the return loss is given by the formula:

$$RL = 20 * \log \{(ZI-Zo\} \; l\{:Z.O+Zl) \;)$$

The log function İn the .formula above. *is* togarithm of Hl.

The return loss must meet the _regulations in 'the whole specified frequency range. The measurements can be quite easily made using a variable frequency signal sine wave genı;;r-ator and the reference 'impedance Zo (can be beilr easily from. resistors and capacitors). The following circuit can be used to measure the return loss:

```
Vin   -----------+---------------+
                                 ' |
                 600 ohftl

                    +-----Vout-----,-+

                 600 ohm            Zl

GND   -----------+---------------+
```

Figüre **3.29**

If y.ou want to test the device with the signal Ievel of Vm then you put .the voltage 2.*Vin to the circuit from the signal generator (the input impedance of the eircuiı is **Around 600 ohms İf** *Zo* **and, Zt are near- 600·o~ıms)'. Connect· the reference impedance** *Z»* and the measured telephone interface circuit Zl to this measurement circuit. Connect millimeter to the circuit to place marked with Vout to measure the Vout voltage. In ideally balane.ed c.ireuit this voltage. is always. zero. Make sure that your millimeter can measure the AC voltages in the frequency range you are using accurately (some ·millimeters have very large measurement error when frequencies go much higher than few hundred Hz).

Using the circuit İs very simple. Just apply- the input signal and measure. the output voltage. Do es many measurements as necessary *ta* cover the whole specified frequency range. When you have made the measurements you can calculate the return loss using following formula:

Rl=20 * lo9,2~vouWm)

If you want **to-** measure **telephone equipment** which **need** some **DC** current flowing through the circuit you try to measure you have to use a little bit more **-c-cmplicat-ed -c·ir-c:ui-t** to **00 tt1at~** Yee can separate **t.Jıe DC si=gna! fr-om -the m-cas-u-remcnl** circuit using capacitor (to uf capacitor does not cause much error on telephone 300-

3400 Hz -frequency range, for -lower frequencies use higher value). The power to the measıısed telephone or ;otheı- eqııip:ı:nent must be fed from separate power supply And run through AC block circuit which preverıts the: power source for short circuiting.the AC signals-. This- AC hlocki:n.g circuit can be a large: eoi] {preferably more than 5 henri-es)~ gyrator circuit or constant current source.

```
 Vin------------+---------------+            +----<  power to the
:elephone

                600 ohm                Zo     AC Block
                                         C
                 +-----Vout-------+--1 I---+
                                         10U
                600 olun                     a1
                                              |
 ·GND ·-----------+·---------------------+
```

Figüte 3:.21

The measurements can be dene-with this circuit in the same way as the origınal ₀cirouit. The Kmly thh,g you mu-ı:;t coosicde:r ts the possible Titea,;;urem:ent errcrs caused by •e capat:.ltQf' and AC lı~kmg:--ci.rccitYo:a nıcrst.make swe that Z >ı 1/.fl*pi-*f*C). H} uF is a good, value· to sta1t because- it has maxi-mum resistance of about: 50 ohms· in 4elepi.mne-audm ·s-pectrnm-(100-3400-Hz}.

3.18 Simulating telephone line

3.18.1 Resistor and capacitor network simulation models

Tlıe most traditional way to simulate. telephone line İs to use resistor and cap.rcitor networks to sjmulate the attenuation caused by the tele-phone f.it:te- A typical model for this typ:e of telephone 'line simulator is a resistor and capacitor network which looks lik~ This:

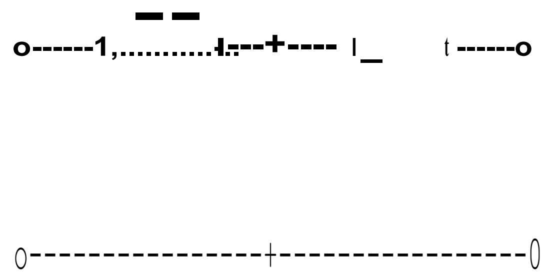


Figure 3.22

The resistor R and capacitor C values depend on the cable characteristics. Old Swedish telephone equipment regulations have listed the following values for simulating a typical

4ocın foop oob!e:

Length	Cable diameter		
O.S km	0'.4 mm	70ohm	10' nF
1.-0 km	0.4mm	140 ohm	40 nF
"0.-'S kın	{LS mm.	4-Sohm	20 nF
1.0 km	0.5mm	90ohm	40 nF

The circuit can be modified for simulating symmetrical cable better in some measurement by dividing the resistance to four wires. This arrangement leads to tbUowing circuit:

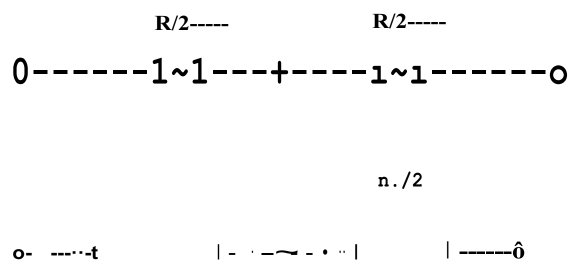


Figure 3.23

3.18.2 Build a Telephone Line Test system From Telephone Cable

Find an old spool of 25 pair cable, preferably pulp insulated, from the back of the warehouse. Punch down each end to opposite sides of a 66 block, only on one side start with pair *two*, and bring pair one down to the last two terminals, after pair 25

Stick in bridging clips across all but the bottom pair of the block. In this way you get quite easily very l-ong line to test ,quite easily. AUach one end of this to a cheap phone line simulator (all it needs· to provide is battery, dial tone, and ring voltage.) Buy a couple of test dips from your usual supplier, and new you have a fairly easy ta use test device for cheap,

ff j'eU need tu simulate aiw the interfererrce which carı. go to the cable, use an old. office, fan and an interference-source lıy putting.this right next to the spool of cab-le and tum it on during testing.

If you are doing worst case testing, you should use junky cable from the recycling bin and stick in loading coils at the appropriate intervals. To be really nasty, take a couple dozen feet of your telephone this: cable, create leaks ta the·cab-le- and put that cable into water (you can add same salt and dirt to the water· for mere· realistic situation). Add this into the middle of your test circuit someplace, Now you have something that is beginning to approach the real world cable plant worst case.

3.19- Testing StaRdards,

To be able to do any repeatable testing one must have control over th.,e equipment m ıı. eontroHetl environment Aim to cnrrefatınn you -resınts to mıy test tlone by other individuals, one must test to a given. set. of "standards". For USA standards **TSBJ7 A and TSB38 deal en** telephone **fines and modem** testing **(Loop** 1 **condition for** them is EAI 1, which is a 2k:ft of26ga). For longer loop there can he up to 5 loading coils in the line. Other countries have also standards on the testing conditions but I have not found references to them.

3.19.l Other Technical Regulations For Telephone F:iııe Terniinal. EiJfflpmffli's

The folkn.v-ingspecs are taken from the European NE:T4 (ETS JOO 001,. second edition- April 1994) regulations. ETS 300 001 is, basically, a big collection of the various European countries parameters I have pat some parts of the specs (Finnish part) to 'here:

On-clmok

- DC resistance must be at least 1 M ohm when measnred.et 100 V wlta.ge
- Isolation resistance must be at least 5 .M ohm from line to touchable- metal parts measured at 100 V voltage
- The impedance in voice frequency (200-3400 Hz) must be greater than 10 k ohm when measured' w#h &5V RMS audio signal

Off-hook

- Isolation resistance must be at least 5- M, ohm from. line:-. ta: tmrclmb'le: .metal: par.tSs measured at H}O V vafüıge
- DC-resistance must be less than 400 ohm in current values between 20 mA and 50 mA
- If the terminal equipment used: constant current prineiple then tı're: current must be in 20--50 *mA* regionhr aH eondltions
- The impedance uf the terminal equipmenr must be so matched that the return loss is -grea1e-r"than to dB eempared to 000 ohm reference
- When the terminal equipment transmit voice or music the mean signal level must not be greater than -10 dBm level in any 10s timeslot
- When other signals are sent to line the .signal must not be greater than -1 0 dBm in any 200 ms tİm:e-siot
- The :Ügual level between 1400 Hz and 12 kHz must be attemratoo 12 dB/act and the signal level in frequencies greater than 12 kllz must be less thm:r-5-5-dBm
- Common mode rejection must be greater than 40 dB in 40-300 Hz region, greater than S-0 dB in 300---600 Hz region and greater than 55 rlB in '600e3400 Hz region.

Note on sign-al levels: 0 dBm means 0.775 Vrms level, so -Hl dBm is around 0.2 Vrms.

3.19.2 E1111ipmen.t in Series '\'\-itb Teleplmn:e

- 'Fae series resistance must be less than 200 ohm:
- The- atterıuation of audio signal must be less tharr 1 dB- at 800- Hz

There are also many otbertechni.cal specs in NET4 do.cmnent, but those are the Most -criticalto hjbrid 'Circuitswhen buil:dingtetephone signals you should aisö Uııdersiırnd the telephone equipment: electrical safety regulation in EN 41 003 standard. This means generally that the equipment must withstand 2-1 kV surge and DC [illegible] between the telephone line. The .equipm..ent does not be .able to cause danger-onsvoltages to the telephone line or to touchable parts in any probable single component failure. And many other safety- regulations.

4. Sources of Failure in the PSTN

Whal maıkes-a distrilımed system .refoılıle'?' A Sffldy of furmres in the US Public Switched Telephone Network shows that human irıterventimt- is. one ke:y t-0 this. large system's reliability. To operate .suocessfiılly, .most large distributed systems depend on 'S04lw~ hardw:ar,e, c.ınld-~ sQ~'l$ -and 4U:ainta~-s-4i0 f:u~tıi@AA·,oo~tly~ F.aiaitlre ef any one af these element~ carr disruptor brirrg dawn an ent'rre. system. One· su.err distributed system, the US Public Switched Telephone Network {PSTN), is the US :portion of p<:fssibly the ·largest d~stribured system. in existence. {1] Like all telepkt:ııfi.e ,&witching .n~om, :the -PS:r:N -pıetfö:r-m-s :a-fairly ~mpıe task: .It connects -point A with point B. Pa:radoxkaUy, this seemıngly trivial task .requires some of the. must c,Hrrp:lex and sophisticated computing systems in existence. Software for a switch with even a relatively small-set of features may comprise several milfion lines of rode.

The PSTN contains thousands ef switdws. Switcnes mduôe redundant hardware and extensive sdf-dıeckirıg and reoovecy software: .Fer several decades,, AT&T has expected its s.witches. to- expecience no:t mo:r-e. than. two h0:ms-rJJ failare. irı, 4Q; Jears [2l a failure Tate of 5.7 'X 104>. Since 1992, telephone eorapanies have been required 'to noti:fy tile US Fwer.ı:l Comnnınicati'l'>ns Commi'ssil;')n (FCC} ·of :out.ages "afft:eting 1nore than 3-0;flOO eestomers .. I used these outage, records to, determiae the r,rindpal casses- of P&TN failures. To account for the possible effects of seasonal fluctuations in call processing· v-0.h:ııne, I-analyzed failures over two years, ·from April 1992 to March 1994, beginning with the ,eadiest F:CC,rep-orts. I made -qum:ıti~we m-easu~ l:tıf hr:rw -eooh ~Hut-e 'Soot~ affects system dep;endahility, in an effort ro shed some ıight on. the de:pe;ndalli'licy of different eon1ponerıts {inı:ırucl:ing suftware):

Major sources .of failure were human- ermr (on the p~rt of :both telepho~ ·oompan-y persowıd .and ,bthers}, acıs t'.l.f tınture, and ·0cv.er'.l0ads. {Jv-erJoaclcs -caused ·flea:r:Jy half of a:U downtmıe {44 per.cmt)-in tenn:sofoutage minutes, An unespected :fitıdfog, :given.the-compfe:x:ity of:the ,PST:N ıllld indıeavy reliance on software, was Hıat software-ermrs caused less system downtime {2 percent) than a'fly ott-rersoı,trce'offaih:ıre- e-xcept vandalism. Hardware ı:trtd süftw'Mecfailures were simila~iu te~ of aver.a:gea-numberof customers, affected' f96:00& and 1 lll,066} and duration; of eıtage (lôO and 119 minutes).

Errors on the part of telephone company personnel and acts of 11atıaT~caused sim-ilar amounts- of downtiin.ef lk and: 1:8; percent)t

4.1 F-ai!ure Classifications

Table 1 Hsls: the failure- classi:fto.aticm scheme I used, a, sehenre that is general: enough for c:omp'atisons- with-failures in other large- distributed systems. tn-theease of the human error. category, I separated -errors made by telephone compaay personnel from those made by mm employees beeause the companjes have direct control over employees only. Overload eonditions are aceoumed for separately beeaese. tne:y ı,~prgsent- failures aeeepted as aJY engirıee'ring· trade-offbetween- dependability amt cost. '

Tah1e-4.1 Failure categories

Category	Somme	Examples
Humarı error- -eompany	Errars made-by telephone company Persorme l	En-ors in· * cable maintenance * power supply maintenance * power monitoring *- Facility or hardware beard maintenance * Software version {mismatches) * foUowing software mıtintenance procedures {Such as errors ,in patch installations an Confrguration changes; does not include source eode. changes:} * Data estry
Hurrımı error-	.Errorsmade by people	Cable cuttings

-others	ulher than telephone ,~~ny ~aeA	Accidents (for example, cars striking tele.phone ,poles,t:u-,etı.uiprt~)
.A~-aof, Nattt~;.	Majorand:ımntWnatfflral events,	Cable-,, poweF S:U:Pf1ly; or faeilityı damaged'· from• butto:wirıg: mtrmıııls: o,r' lrghtıting
Natural disasters		Earthquakes, hurricanes, or floods
Hardware		Hardware component Failures of cable eom'J)'Ottetıts:;,, power.: supplies:;. t5r facility ·components, dock or >c'lock -~yncfuonization faihıres
S&ft:ware faU:ı.n:es,	l:rrter:naleıtıW'niı.J:tlre;· so,ftwaı•e:	S'<}ftware; ~·11s,,u,nder no-rm-alıEtpeF.atioo'•OF in~ recoveryHtl'ode:
Overloads.	Service demana· exceeds ·:the lieNigned sysrem Capacity	
Vandalisnı	Sabotage or other intentional :d:amag.e	

Table 4.1

4.2 Findings

Figure 4.2 suınmarizes the nurı:iber- arıcf duı:ation· of outages, customers affected',. and customer nıiı:mtes: by, eatJsesı Figure shg,ws, the. percentage of. outageaffiıitıfut~d: r~ eaeh, major ,category: Figure2, the peteenttıge of,e$totnet miruıtes. The Daıe--shnw that -the IDmihtır -and .magnitude :of,outages .,differs :sigmf~y .für most failure -eategories. For ·exa:ınple, although overloads caused. only 6 percent of tne total outages, they accounted· for nearly half the total customer· ırunutes.. Hıımın error caused nearl:.y half o.f ttıe: o:ut.a:ges,. bur <Jmy about· a, quaıttt of the downtime.

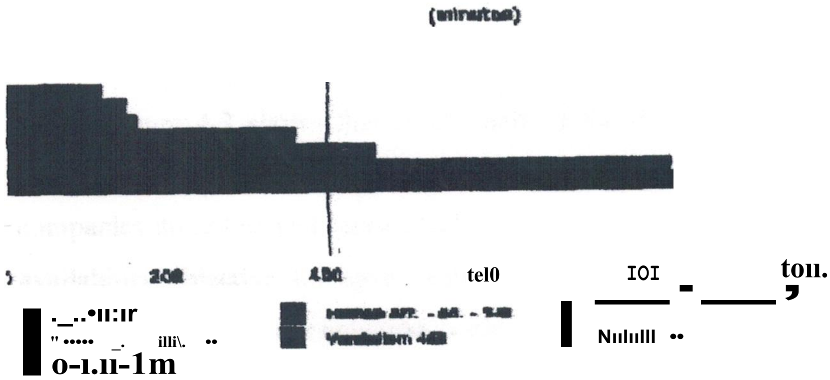


Figure4.2

Figure 4..2 illustrates. the outage durations for the- different failure: categories and reveals part of the reason number and magnitude measures differ. Software, hardware; and human error by company personnel caused the shortest duration outages. Figure 4 eompares **the** -duratien **and** customers **affected** for the **major** faihırecategeries. The ·x axis displays outage: duration, while: the y axis d;is;p}ays the. number of customers affected. Only overloads and acts of nature (in the upper right comer) are extended and widespread. Failures due to the errors of telephone company personnel (upper left) are brief but have widespread effects. Hardware and software failures were similar in terms of outage duration and customers affected. Vandalism and human errors caused by others were also similar **in their effects.** Table **4.2 Failure effects by** categories **and** sources, for outages from April 1992 to March 1994

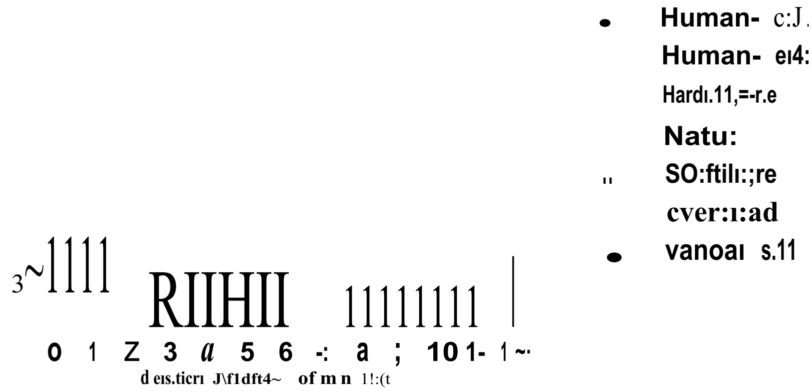
Categories and Sources outages	No.of outages	Average no, of customers Affected	Average outage duration	Customer minutes (in

Tab1e4.'2

4.3 Observations

Figure 4.3 shows that rre-.ıdy half ı'l'f füıe- d:o,wınime is caused by (Jverlo.ads, whfch are expected outages. Because- of eee-t'l&rrtic and techrrieal c0nstrain:ts, telephone companies do not expect service to be available all the time. For example, Bell cote's :avaifa:b:iHty <:Jbjective for iöca! ,e:ıc"ttıange .networ~s in üs client companies is 99:93 percent, Lwgercapatcity ne-twor.ks co1t:hf pırobaM,y dmr-inate trmst of thls: downtiınre bıııt i:ncf'ease cost. Through decades of experience~the- telephone industry has estab'\:isheda balance between°henefits and the cost-their consumers find acceptable.

Although the errors -attributed t-0 t-ek:phoue empksyees are ırotthe maj:or source of cn:ıtages,. they are: ehe ntaj@r's~mree:offail-ute-aı-n-0ng füese:operafror.ıal- aspeets umder· the cmnpanies' contn:ıt Human: errorby company personnel accounteu for only 25 percent of outages and 54 percent of.downtiıne. But .fai-ill'fe sonrees controllable by - the telephone 'C0ffl1'Klnies '{human error ph.ts hardware and so-ftw-are failures) accourıtetl for 5& percent af autag~s' and 21 percent of downtime. S-0 human errors by e:ourp:m-ıy· 15ers:onnel contributed nearly half of these outages (25 divided by 58) and nearly two-thirds of customer minutes of downtime (14 divided by 23). 'Effects of humarı error were about the same for hardware and software maintenance. Human error fur m&i11tennce oJ cable arıd, ha,dware- eampomınts a,f.ld for -p.ewer momtı:rring aceo:untedi for about t5 percent of outages and 7 percent of downtime StrftwaTe-rehrted human errors included mismatched versions, ieeorrect data entry, and procedural errors ,d:ı;ı.ring upgrades 1lıese errors accoo;nteJ for Hl per,rent -0f .outages ;ar~ 'J pereeent -0f downtime.



,Eigıre43

'5oftw~.e ,e:ı:r-0.rs caused .a significant number -0.f .moderate ~utages. A:U:tıough softw,are:error--s causeti appı<aximately 14· perce.nto-:K the.outages, they acı:eo'tmted.für, on1y 2 petcent-of the customet·nrinutes excluding. human error by others, acts' of nature; and overloads~ however, :software .;,accounted for 24 per.cent .of .outages .and 9· percent -0f :cuest:Dmer minutes {dt)wntime). 'fwtı fa~tors probably caıise ~oftware-eutageste be ~{: the hworpoFatio'fl- of human intervention eapahilities in the VSTN and the use; of extensive error detection. and recovery softwate.

4.A. Wlt.y So lleliable"!

Hes:plte-its: eeormees size .tml e©m'plex'ity, the··P-STN: a;ııeragexl an availalıility Tate better füau. 99.999 percent in die time. period studied. Wlty should perhaps me world's largest andmest complex computerized distributed system also be among the most reliable?

,t.4.1 **Reliable** Software-

Te begin with,.telephone -switchmanufacturer&are among th.e world's ,leaders :in rom:puting te~hno1ogy. They focus much:oftheir research on developing highly reHaMe S:JSterns.. Their software development processes typically ineotl}'ürıtte the· mast sophistieated practices, su.pplemented'.hy dahorate- quafüy a:ss:ı:trance.· functions, The'

:PS':fN software's fow 'fafüır-e rate tlemonstr-ates -that we can develop .highly reliable software using the best -practfoJs.

4.4.2 Dynamic Rerouting

But :other-faeeors .add to the PSTN dependability. In particular, -teiephoae network designers .appear to have exploited some aspects of the :network's nature- to: c.om,~e: foF eo:mFJilie~ffiies ıintromıcedi by-fuecd~errdalıiHty ıı:eqmrtınııoots.,

By·· itSc veı:y: namı:~~ the tdepbotıe nrtwo:rk, is. mgb}y disu:ibtıted;- stY kYcmized failures .are more likely, and switches can reroute traffic dynamically to avt)id a {ailed network node, Mme important, intemı{ttent failures are usually trot catastro-phic. O.th:er-sy,stenıs- fa:~ ınueb greater rislfs fi:0111- a· füiltwe, na matter how brief. For example, failttre:;. of a-- few seeoml&- in~ so.me tly-hy.,.-wire av.ionics- software may Tesutt in tlıe aircrafüs destmctioıı. A brief failure in one network rompmıent has r-elatively little imttaci: ® the ,ava:i'labjlit-y f;tgur..es .fur ·the >entire J>S'fN ,acro~s ille US. H:ewever for -the PSTN to- rermıte,. c~Us, it must ke~p- a goodc.dea1 of mfmmatioJf, glohatıy. Ma-i-ntainmg: consistent d:istr-Unıted databa<ses. e.m: veqtt~re- complex- inw~ıiOn-s a\\f'i:6»!1 system components.

'In his book Norm.a} Accidents, Charles Perrow identified two factors- int:eractio:ns mrd coupling"- mat are s.igmfi-ea'.nt m deter:mming a system 5 safety ptop:ettres, f6'J: Imeraetils)ffii refer' t-o- the· depen:de-rreies: between· compôıtertt-s~ w'hite· ,coupling ,refers to the flexibility in a syf.,tem. He.clıaractooz~-dmier.a~İefı5·,as linear ,or ,oomple:x,whi·le,c.erupling,i~ .loose.or tight .Syst-emt. with simple, lill~r mt~ctro11s have oomµcr-rıents- tlıat: aife®t oo!y Otlıer oomponents- tlınt: we -fun£tio.naU-y oo-ı-.VBStre:am. Cmnplex: system· etlınpem.ent1. itı:tera.e.t: w-ith m:ar.t,y other component~in different parts ef the system. Loosely coupled systems have more flexibility in time constraints, operation sequencing; and assumptl-ons about the environment than do tightly coupled: system,s wiıw cOınpJe,ı; iatenwti-ons an0, right: eeupM,ng are likely t-e- proıwıore a-eeMent&. Com~le-x intera~tions- al\Q,w- for more'. comp{icationi to develop· and. make the system hard· Ut underı.1aml .andpredict. Tight coupling.also means that .the system has less :flexibility *is* recovering when things go wrong.

John-RusJı,by applied Perrow's, *aooysis* of :faihıres m larg~. plıysieal S'ystems to-- computer systems [7}. fn, sueh systems, intetacti-QnS-• ean, for example, take the fümt of signaling1lıni coordinates processes or keeps distrihuted·da:tab:ases consistent Coupling ,refors.to.;-00nstrwinıs {'}Tl ·tirrting, ,operatfon seqeıencing, ,aaeptabte input•da1arzmges,·ood 0.ttw:r a.spe€t'S, of system :flecxfüifüy. Cofltro} systems. wfü1 fMJıfl-'He:got-iahie'- :real-time ·t.foııd:fü1eS' aretightty·cuupted, whRe' the· Inteı-rret~ with multiple paths tO' route' pa'.ckets, is" a 1oose-cooıpiing ex-aınpre. Systems that requtre frequent updating of a -distributed ·-Oatabas.e -are •likely to have "GOm't)l{}x ,inteva:ct1Gn8 ,t-0 -exchange -messages amxnıg -0orrıponerıts and maintain the database's glabal eensisteney.. A smıple· ur,dıate: and rerrorting.system, which updates ,r database. artd writes frtes for input to report programs, *is* an example of linear mteraction.

4.S Loose· **Coupling·**

Iıı ·m.ost ·systems,a tr-ade-.fltf,can be ınade -beı'Weefl simplicity of ınter.actio.mı and Iooseness of.c.oupförg. We can cons-itler the 'PSTN a loosely coupled system because it can dyna.mk~Hy rereate calls along many paths<-. However; *it* aclıieves· this loose--- roupling at the cost of some complex interactions between components. These irıc:lu:de ,the need far erul40--0rn:hıcknow!edg1nents, interactions among many .sy:s.tems, and the maintenance *of* some globally consistent databases. Major switching un1e.rs store infcrmetieuen alternative-paths and exchange data<'Yt1' tmffic patterns and switeh starus throughout the day. Such complex interactim1S- can contribute to failures. hy maldng; system behavior difficult to analyze.

The most speetaeutar example nf a failure due to .eomplex intera.cti:o.rıs i:n~the PS-TN is. ~ :k99fl natie:nwide: AT&T Retw:orw fa:ihı'fe'. This faikrre' reruLted w011v interaetions between systems attempting ta rrtairttain consistent information. about a 'failed switch . Dn fhe other hand, the PSTI..T distribored .ı:latabase .of reıııing infunnatkm promote-s loose ,coupfrng, whfah,ı,mntrfüutes to system dep.etıdabiHty.

Fer a courmtınicatfons. system, coupling is: pıobably the :t'ı:t@re: important of tlıe- two properties in determining its capacity to tolerate·failures. It is. dit:ectly related to the sys;t~m's :prhna:ry iwıction; maintaining .co:ıme.ctions between points. The PSTN is lOGsel;;r c~Jtıp,lecl, alfowi'l1g ·for {kıübility "" sfeco:v:el'-iTig .&om failıees. fu:r -the PS~J. Loose côup,Hng· p,robably more than makes- uv· ft'rr tre interaetiott eom:plexity. Designers sfiouM eonsider the- trade-off 'Between these facton,..-Hnear cintera:ctior:ıs *:.or* :!o(IS:e :ct:tuplh:rg4o :add cdepeı-1d1ıhHity to :any high-integrity ·syste'm. Two l~ve!s of recovery m-ootıanism:s-autom:ated and manmı:l"' •expl-<:ıit"ltıe PET~ -leY0se·-c01:tplhl'g,

Designers, devote· abaut half af the- software hı telepherıe s:w]tches to eITOr detee:tiffi'i· atıd oorreetim:t Such: a rn:gb percentage of self-checking is;- pro:balılJL atypical for oofiware :systems. Altoough some researchers note that adding fa:nlt-tolm-ance anıl faı:ılt~avo:idance mechanisms to software sometimes decreases dependability' because of the reemery m€\\lhani:sms' a<ldoo· co.mple:ıüty f&-}; these mechzınrsms work with great ~nıccess:.m switdıings:ystems~ Oilier computer-driven: syst~ms.might benefit from more: -extensive use -of huitt-in ıliagnostic :and recovery software.

4.6 Human-lnterve'rtfion

In .addition to bırilt-in self-test .and recovery mechanisms, operators monitor telephone switclles. 2.4 ,!mttrs. a ·day and -ııstlaHy have .'tlıe ıab.Hlty,to 41't@dify -switch soft,;v·a<f.e y,:l£ tke flıy~ Svme.11, m~wfa~{;fS:; ,mvide: 2:4-htomr Support, services; $W~}y with a remote -maint-enanec,ce:ap-abüity t-bat allows them. to eereecı software, in a switch thou-sands of miles .away .. Human intervention corrected many failures m less. -dınn one fa:mr. Simply "restarting -a -switoh 1:emporarily fixed a ·significant nt1mbeT of -software-eattsed- aut-ages.

Tnıffic. rootfrıg moo benefits -&om atttoınated ffl'fd hnınan ope-rnt-i-o-rts. Using infönn:ation on switch staaıs and traffic patterns exchanged by switches, software w·ithia -a ·switch wm ·automaticaUy-seleet an -alternativc reutc-if-thc-preferred mute beeemes twıtrloaded ar mrıarvai-lalıle~ l:ll t1re ScWitclr e:ıdımısts" all ~lt.ematwe renıtes) 1mnrarr 1nterventicn1ı~an Teconfigurc the network, sometimes solving the problem in a few minutes. S:tat:us data exchanged r,egufarly hetweı.m switcbes makes aınomated and -hu.m®·.cıper.ations,to ·-r.econüg.ur,e .r,0uti.ng ,possih~e.PS'.fW-designer,s made theceupting-int:er-aetions- trmie~aff in faver of hmuse: e:oopfuıgr LaO'Se tr('fttpfüı:g:, aUg;w..s,,, ıınn,;tnı operators to. intervene in the event of failure, rather than relying entirely on computer oontr-ol

Software is not the weak lin:k in the ~8TN system's ~:a:hllity:Ert-ensiv-e use ofbuil1:-in sel:t~test and• recover*'· mechm:ıis:tns iı:ı major system components (s.witefaes}eon:triütted to· -software dependability and are significant design features in the PSTN. The network's high dependability in<lirates that .tlıe tra4e-off -between .dependaoifüy' gains and complexity

introdıwed by built-,in self-test and recovery mechanisms caa be positive. Likewise, the tmdeoff 'between romplex irıter1ıttioos -rurd 'loÖ'Se -roupli:fig -öf -system roınpooent-s 1i:as been positive, permitting quick human intervention in most system failures and resulting İn an extremely ·relittbfe system.

CONCLUSION

Despite its enormous size and complexity, the PSTN averaged an availability rate better than 99.999 percent in the time period studied. Why should perhaps the world's largest and most complex computerized distributed system also be among the most reliable. To begin with, telephone switch manufacturers are among the world's leaders in computing technology [5]. They focus much of their research on developing highly reliable systems. Their software development processes typically incorporate the most sophisticated practices, supplemented by elaborate quality assurance functions. The PSTN software's low failure rate demonstrates that we can develop highly reliable software using the best practices.

A circuit switched network, such as the PSTN, provide end to end connection on demand, as long as the necessary network resources are available the connection's end to end delay is usually small and always constant, and other user's cannot interfere with the quality of communication.

prno:l wqı ın~ıs,(s i'JU!l{:)l!M.s :,newoıne cm podopxop J~itM..OJlS uomıv 688 I Ul
uoµ:eA!ıouı s,ıgftM.o.ı:ıs roıaıadc ınmmq e. Aq uo;ıu~.u~ırn.; ınoq,ı!A\HBO. ;;,uoqd;;,1::ıı R dn ~S.
S!lf £.q .ıom~du.ıoJsssarsnq e oı p;Jµ~AlP ~l'lµ)q SffB:l S!lt lll~A::ud oı f.ı:?M uonu~AU! srqı roJ
local operator. The impact of the invention was much wider as it provided the basis for the current telephone network.

In 1901 Guglieimo Marconi demonstrated that radio waves could be used to transmit information over long distances when he sent a radio message across the
AflBUll!:" ~?IdfO S! SIM ouo OJ I~ {(~A ıı.ısmſU!SS!OU w:~!B ıodı:!:l>'. ıund ts!{ſ{. bns!s OJ uınun A
'S;;)J!AJ::lS awtonı

In 1947 William Shockley, John Bardeen, and Walter Brattain invented the transistor. This enabled the electronics revolution to take place and provided the basis for a computerized, rather than mechanical, telecommunications network.

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J.O .su.ı:~w u .;}.pf.ı..\.OID Pl .p~op,~p .~ A{lU~nh:,)S4ns ~uıı .;:)~.1 ·s;:).ıqy .JnJµdo jll!sn
:iqı UUOJ S)JQY fl?s)!ldO -~ds lfil'N AJ';}A ltr ırOWJIDIOJU! JO SllmOUlW ~ıimJ ıiu!AJ.m:r
bı~(.JQG.)f~tıq ~ıJO ~{uQb&"{ {ıUSRUm{SS!.OU UnC:MOF(j"

The modem telephone network can be viewed as a globally distributed machine that operates as a single resource. Much of it uses interconnected computers. The network. that most people use to carry voice traffic.can. also be used. to transfer data in the·fmrn of pictures, text, and vldeoImages.

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