STUDY OF VULNERABILITY OF ELECTRONIC COMMUNICATION SYSTEMS TO ELECTRONIC INTERCEPTION. VOLUME II

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FOREWORD

This document is Volume II of a two-volume report. Volume I presents the analyses, a summary of findings and the conclusions of the study. This volume contains three appendices that present additional descriptive background information and the detailed derivations of some of the analyses discussed in Volume I. The descriptive material is given to indicate the variety and complexity of communication systems confronting an interceptor. It also demonstrates the level of sophistication required of potential interceptors.

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WIRE AND CABLE TRANSMISSION SYSTEMS

A.1 INTRODUCTION

A large portion of the communications in the U.S. are transported over metallic conductor transmission lines broadly referred to as "cables". The variety of cable communications systems extends from a simple pair of wires used to carry a single voice conversation to bundles of coaxial tubes capable of carrying hundreds of thousands of voice conversations.

Cable communications systems can be divided into two broad categories:

(1) Non-carrier wire and cable communications systems.

(2) Cable-carrier and coaxial-carrier transmission systems.

The simpliest form of non-carrier wire is the pair of wires carrying a single voice conversation. However, most modern cable communications systems are "multiplexed" systems comprising complex aggregates of electronic equipment enabling either a single pair of wires or a coaxial tube to carry a multiplicity of voice "channels". The physical construction techniques used to implement the first category are the most basic but are also relevant to the cable-carrier transmission systems because such systems must traverse similar wire/multi-pair cable facilities.

The vast majority of Bell System trunks are carried on multi-pair cables, either as voice pairs, or as channels of cable-carrier transmission systems. In fact, one third of the entire Bell System plant investment is in wire/multi-pair cable plant.

A.2 PHYSICAL CHARACTERISTICS OF WIRE AND CABLE SYSTEMS

The design of wire and cable communication systems is concerned with both the electrical parameters and physical characteristics. The following sections describe the physical characteristics relevant to this study. Physical characteristics of interest are size, weight, strength (of conductors or support messengers), and cable covering with respect to its ability to maintain the integrity of the cable in the face of mositure, chemicals, rodents and other physical damage.

The insulated conductors within multi-conductor wires and cables used for communications systems are usually segregated into pairs of conductors known as twisted wire-pairs. The conductors of each pair are uniquely identified throughout the entire cable length -- one is called the "tip", the other the "ring".

A.2.1 Types of Wire and Cable Systems

Wire and cable used in communication systems can be divided into five basic categories: wire, open-wire, multi-pair cable, video cable and coaxial cable. Each of these will be described below.

A.2.1.1 Wire

When "wire" is spoken of, "metallic conductor" is often the intended meaning. Communications parlance has other more specific meanings for the term "wire". The term "cable", other than steel suspension cable or the like, also has meanings peculiar to the communications jargon.

Wire refers to conductors used as transmission media, insulated or uninsulated, where one to four conductors may be utilized as a single compact unit. "Open wire" consists of single conductors (both insulated and uninsulated) which are strung individually on the crossarms of telephone poles. Although strung individually, there are at least two such conductors (a pair) required for each open wire telephone circuit.

"Drop wire" and buried "service wire" are used to connect a subscriber to his distribution cable. Drop wire or service wire consists of two to four insulated conductors within a common plastic covering. The conductors in drop wire and service wire are arranged in pairs and each pair of insulated conductors is twisted together to form a "twisted pair". Normally, if there are two pairs in drop or service wire, they are twisted together to form a "twisted quad" or simply a "quad". Distribution cable containing less than six pairs is often referred to as "distribution wire". In some quarters, the criterion for terming a bundle of less than six pairs "wire" rather than "cable" is that the bundle has no armored sheath.

The term "cable" usually refers to a bundle of six to 3000 pairs within a single sheath. The pairs of cable are almost always twisted pairs, but may or may not be quadded.* Aerial cable and wire are often attached to steel "messenger" cables or hung from "suspension strands" to give added strength for pole line applications. Sometimes the conductors of a cable are permanently associated with a suspension strand as in the case of "Figure 8" distribution cable (or wire).

Figure 8 distribution wire or cable is an aerial facility attachable to crossarms or to poles used to connect feeder cables to drop and service wires at subscriber premises. This type of cable is almost

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*"Quadding" is the formation of a two pair "quad" by longitudinally twisting two pairs, each one of which has been twisted.

never used in feeder plant. Figure 8 distribution cable is so named because its cross-section resembles the number "8". It will be described in greater detail later in the section.

A.2.1.2 Open-Wire

The first facility to be commonly used for the transmission of telephone conversations was "open-wire" plant. In one of the first standard arrangements, up to ten wires were attached to crossarms mounted on telephone poles. Some of the materials which have been used as open wire are iron, steel, copper, copper-clad steel, and more recently, aluminum. Steel was used by itself and in various combinations with copper to lend strength to the wire and permit longer spans between poles. Pure steel, of course, presented far too much attenuation to telephone signals when used by itself, and hence copper cladding was added to reduce losses. Copper-clad steel represents a very economic and satisfactory transmission medium. All of the materials mentioned above are found in the existing telephone plant, but copper-clad steel predominates. Insulated wire is occasionally strung on cross-arms but, classically, open-wire is bare.

Open-wire is simple to manufacture and install. The wires are available for bridged service anywhere along the route. This was advantageous when multiparty service was more pervasive. An "open-wire" route is obviously very susceptible to monitoring along its entire length.

Adjacent telephone circuits can induce voltages in each other resulting in "crosstalk". Crosstalk occurs when conversations occurring on one pair are intelligible on another. Open-wire, because of long runs of parallel pairs, suffers from crosstalk due to magnetic induction unless one pair is "transposed" with respect to the other. Transpositions consist of criss-crossing the conductors of one of two parallel pairs at regular intervals in order that mutually induced voltages will be cancelled.

A.2.1.3 Multi-Pair Cable

Frequently many pairs of wires are combined within a single protective sheath. These are known as "multi-pair" cables. In early cables, cable cores were built up by applying successive layers of paper-insulated pairs over a few pairs in the center. These layer-type cables were fabricated with all pairs having the same length of spiral twist and with adjacent layers spiraled around the core in opposite directions (reversed lay). Cross-talk between adjacent pairs was relatively high, but the cable was spliced randomly in order to even out the amount of cross-talk signal (and decrease the intelligibility) accrued by each pair in a cable length.

In layer-type cables, different twisted pair lengths (and to some extent different layers) are identified by intermittent bands of color on one conductor of each pair. Layer-type cables have been superseded by "multi-unit" type cables.

In multiple-unit cables, a "unit" is a bundle of pairs held together by a "binder". Such units consist of 25, 50 or 100 pairs. The pairs in each unit have nine different lengths of twist resulting in considerably less capacitance unbalance and hence considerably less cross-talk. Pairs and units in pulp-insulated cable are color coded. The tip side of each pair is uncolored while the ring side is colored solidly (green, red, blue) or is banded with 3/8 inch color band (15 per foot). The tip is intermittently banded to show the length of twist for each pair. Each unit appears in its own layer only. Each layer contains exactly one green-white unit regardless of the number of units in the layer. This green-white unit is adjacent to a red-white unit followed by a blue-white unit. Red-white and blue-white units alternate for the rest of the layer until the green-white "starter" is reached.

In polyethylene insulated conductors (PIC) ten colors of insulation are available. Five colors are dedicated to Ring conductors, and five other colors to Tip conductors. Cables containing between 6 and 25 pairs will consist of a single unit. In multi-unit cables the determinative subdivision of the cable is the 25 unique color combinations referred to collectively as the "binder-group". A 25-pair unit will have in it all 25 color combinations. There are 12 and 13 pair units that utilize only 12 or 13 color combinations from the binder-group, respectively. The color combinations of the 12 pair unit are different from those of the 13 pair unit. Table A-1 shows the 25 unique color codes of the binder group. Note that the Ring color of the binder group follows the standard cable color code (BL, O, G, BR, S) while the tip, sequenced W. R. BK, Y, V, acts as a most significant digit. Figure A-1 shows typical cable constructions. The upper portion shows individual wire pairs and the lower portion, typical binder group color codes. The pairs within the binder group have the color code discussed above.

A.2.1.4 Video Cable

Video pairs presently consist of two 16-gauge copper conductors insulated with foamed polyethylene. The conductors are supported with two glass-fiber reinforced polyethylene insulators. The pair is shielded longitudinally with two layers of copper. Video pairs are primarily used for the transmission of video signals within exchange areas and between studios and transmitters.

A.2.1.5 Coaxial Cables

Coaxial cables are used for high capacity carrier systems, television transmission and, occasionally, wide-band data. Coaxial cables

TABLE A-1

COLOR CODE FOR PIC CABLE

<table>
<tr><th colspan="3">25-PAIR COLOR CODE</th><th colspan="3">BINDER GROUPS</th></tr>
<tr><th colspan="3"></th><th colspan="2">STANDARD</th><th>SUPERSEDED[1]</th></tr>
<tr><th rowspan="2">PAIR NUMBER SEQUENCE</th><th colspan="2">COLOR CODE</th><th rowspan="2">12-13 PAIR UNITS</th><th rowspan="2">25 PAIR UNIT</th><th rowspan="2">8-8-9 PAIR UNITS</th></tr>
<tr><th>TIP</th><th>RING</th></tr>
<tr><td>1</td><td>W</td><td>BL</td><td rowspan="12">12</td><td rowspan="25">25</td><td rowspan="8">8</td></tr>
<tr><td>2</td><td>W</td><td>O</td></tr>
<tr><td>3</td><td>W</td><td>G</td></tr>
<tr><td>4</td><td>W</td><td>BR</td></tr>
<tr><td>5</td><td>W</td><td>S</td></tr>
<tr><td>6</td><td>R</td><td>BL</td></tr>
<tr><td>7</td><td>R</td><td>O</td></tr>
<tr><td>8</td><td>R</td><td>G</td></tr>
<tr><td>9</td><td>R</td><td>BR</td><td rowspan="8">8</td></tr>
<tr><td>10</td><td>R</td><td>S</td></tr>
<tr><td>11</td><td>BK</td><td>BL</td></tr>
<tr><td>12</td><td>BK</td><td>O</td></tr>
<tr><td>13</td><td>BK</td><td>G</td><td rowspan="13">13</td></tr>
<tr><td>14</td><td>BK</td><td>BR</td></tr>
<tr><td>15</td><td>BK</td><td>S</td></tr>
<tr><td>16</td><td>Y</td><td>BL</td></tr>
<tr><td>17</td><td>Y</td><td>O</td><td rowspan="9">9</td></tr>
<tr><td>18</td><td>Y</td><td>G</td></tr>
<tr><td>19</td><td>Y</td><td>BR</td></tr>
<tr><td>20</td><td>Y</td><td>S</td></tr>
<tr><td>21</td><td>V</td><td>BL</td></tr>
<tr><td>22</td><td>V</td><td>O</td></tr>
<tr><td>23</td><td>V</td><td>G</td></tr>
<tr><td>24</td><td>V</td><td>BR</td></tr>
<tr><td>25</td><td>V</td><td>S</td></tr>
</table>

ABBREVIATIONS

BL - Blue
O - Orange
G - Green
BR - Brown
S - Slate

W - White
R - Red
BK - Black
Y - Yellow
V - Violet

Note 1: The 8-8-9 pair units were manufactured prior to 1964.

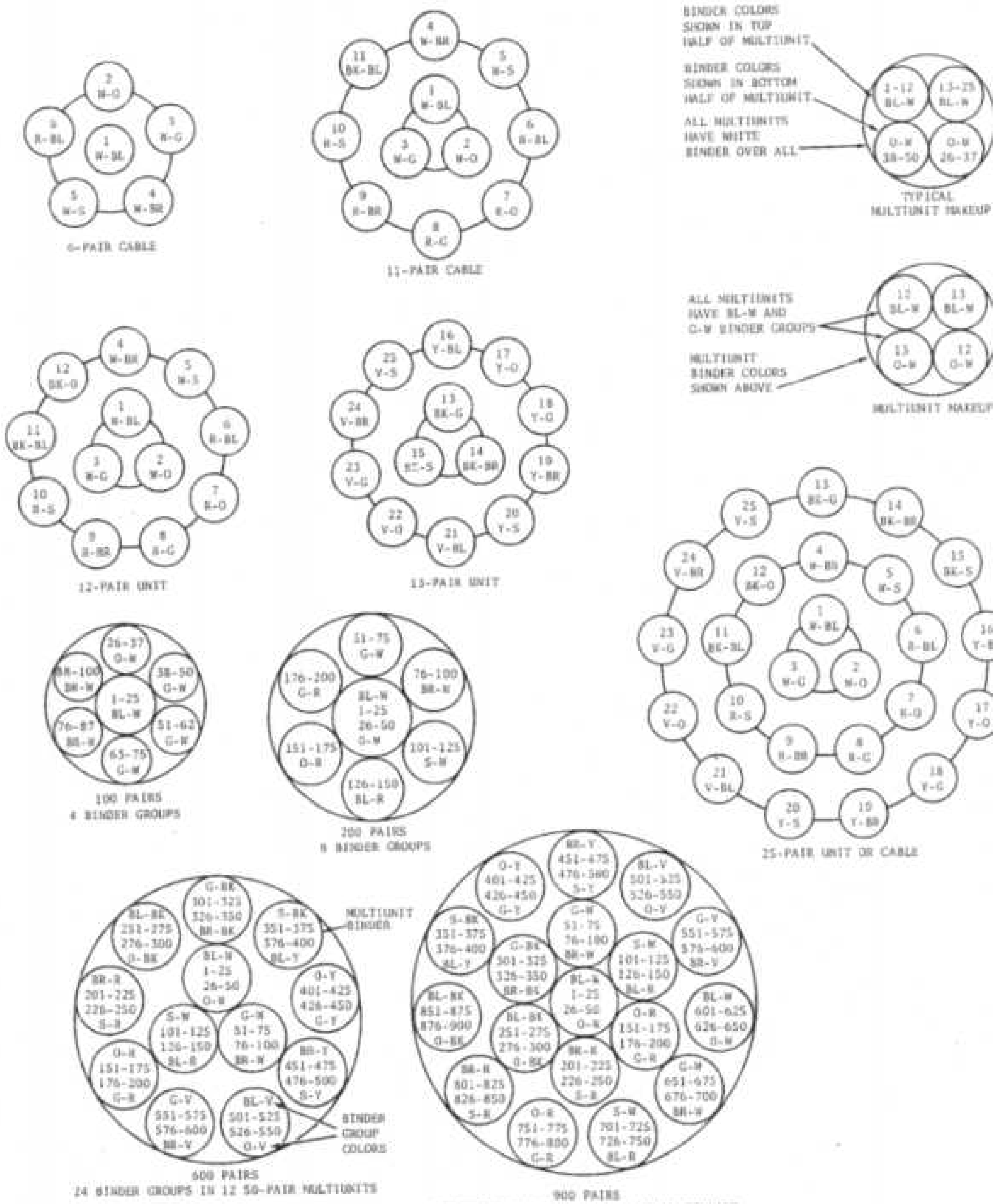

FIGURE A-1
PIC CABLE MAKEUP

in their function as "Wire Line Entrance Links" (WLEL), can carry any one of those traffic types as well as combinations of them. A WLEL is a connection between a microwave radio tower, usually located outside of an urban area, and the central office (in the urban area) which serves large capacity DDD switches and television stations.

The standard coaxial cable found on an L4 route consists of 20 coaxial tubes spiralled around 47 wire pairs (19 and 16 gauge) and 10 non-paired conductors (19 gauge). The 47 pairs and 10 conductors serve as the cable core. The 20 coaxial tubes and the wire core are enclosed in a lead-polyethylene-paper (lepeth) sheath. Each coaxial tube consists of a .1003 inch copper center conductor which acts as the hub for a string of polyethylene discs spaced one inch apart longitudinally along the cable. The discs are surrounded by a copper outer conductor which is a tube closed longitudinally along the cable. The copper outer conductor is covered with a double spiralled layer of steel tape.

The signal is transmitted as a high frequency voltage difference between the center conductor and the copper outside conductor. In general, repeaters on coaxial systems are spaced between 1 and 4 miles apart, depending on the system in use. The repeaters are powered by DC voltage on the center conductor of each coaxial tube. This voltage is hazardous and can be as high as several thousand volts.

In general, coaxial tubes may be disc insulated (as in the example above), expanded polyethylene insulated, solid polyethylene insulated, or insulated with a number of other dielectric materials.

The cables themselves may consist of single coaxial tubes, or up to 20 or more tubes and a number of service pairs. Many different coaxial cables contain metallic twisted pairs in addition to the coaxial tubes.

All coaxial cables used for high capacity carrier transmission systems are pressurized and equipped with fast-acting alarm systems which quickly inform maintenance forces of any significant cable ruptures.

A.2.1.6 Conductor Gauge

The signal-to-noise ratio at any point in a telephone circuit or connection varies inversely with the gauge of cable used in the cable plant. As the gauge decreases the resistance decreases, the attenuation decreases and the signal-to-noise ratio increases. The attenuation is also a function of the distributed interconductor capacitance in the cable. The higher the capacitance is, the higher the attenuation; and the lower the capacitance, the better the signal-to-noise ratio.

There are a number of different gauges of cable used in the telephone plant, but only two standard capacitance values: .062 (Low Capacitance) and .083 (High Capacitance) microfarads per mile.

The numerous sizes of open-wire conductors were mentioned in the description of open wire. In cable plant only four sizes of copper conductors are commonly used: 19, 22, 24, and 26 gauge. Recently, a 17 gauge aluminum, high-capacitance (.083 microfarad per mile), solid polyethylene-insulated cable was introduced that can be substituted for 19 gauge copper conductors.

A great deal more 26 gauge cable is used in Bell System plant now than has ever been before, following the introduction of the

"Unigauge Concept". This concept proposes the universal use of 26 gauge conductors on loops up to 30,000 feet in length with inductive loading added only to loops longer than 24,000 feet. In the central office, loops are divided into two categories: loops shorter than 15,000 feet, which are treated no differently than they have ever been and loops longer than 15,000 feet which are equipped with "Range Extenders". The range extender is capable of putting a higher voltage (72V) talk battery on the line, permitting higher talk levels and signaling currents at the subscriber. The range extender also includes an amplifier which provides about 5 dB midband gain to offset the increased insertion loss of the long 26 gauge loops.

A.2.2 Types of Conductor Insulation and Protection

As indicated previously, conductors are insulated to provide both electrical isolation and physical protection. Bundles of wires such as multi-pair cables are provided with additional outer protective sheaths.

A.2.2.1 Conductor Insulation

There are a variety of insulation types used in the communication industry. In older cables, the separate conductors were insulated with cotton string, jute, and other textile materials. The finished mass of insulated conductors, referred to as the cable "core", was then impregnated with a resin compound, oil or paraffin. Strip paper insulated conductors were the most common cables manufactured until the middle 1960's. Some "paper-insulated" cable is still being manufactured. Polyethylene insulated conductors (PIC) were introduced in the 1950's and this type of cable is now the most popular in the telephone industry.

Conductor insulation is usually color-treated to help installation and maintenance forces identify the individual conductors.

A.2.2.2 Cable Sheaths

The cable sheath protects the pairs in the cable core from moisture and physical damage. Lead is used for cable sheaths because of its malleability, ductility, high resistance to corrosion, and because it can be readily soldered. Lead sheathed cables were used almost universally in underground plant until the sixties. At present, lead is used only where the more economical polyethylene sheaths would be exposed to oil or other chemicals. Lead casing is also used on loading coil cases, apparatus cases and terminal stub sheaths.

There are presently a wide variety of plastic sheaths found in the telephone plant. There are numerous combinations of polyethylene and polyvinyl chloride (PVC) jackets, with aluminum and steel shields. These jackets and shields have been combined in various ways to furnish protection against moisture, lightning, AC induction, corrosion, rodents and rocks.

In a newer type of cable, aluminum-steel polyethylene (ASP) sheath is used over polypropylene-insulated cores. ASP cable is completely jelly-filled and cannot be pressurized. It is intended for buried use in high moisture areas since it is virtually impervious to water. ASP is also suitable for use in high lightning areas.

Almost any type of PIC cable is available in a filled "T-Screen" version manufactured by the Superior Cable Co., Hickory, KY. T-Screen cable is compartmented into halves by a longitudinal metallic screen. This permits both directions of transmission of 1.544 Mb/s PCM system to be used within a single sheath. This cannot be done with ordinary cable because of cross-talk problems.

The Bell System also has a special very low-capacitance "T-2" cable with 22 gauge polypropylene insulated conductors. This cable is designed for 6.312 Mb/s PCM transmission. It is available in 25 and 50 pair sizes.

A.2.2.3 Sheath Outer Protection

A number of different outer protections are available for use over the standard sheaths of buried, underground, and aerial cables. The outer protection serves to augment the resistance of standard sheaths to hazards such as corrosion, mechanical damage, low frequency cross-talk, gophers, rocks and immersion in water. These outer protections consist of various combinations of steel tape, paper tape, jute and polyethylene. Underwater cables for deep-water crossings such as rivers are covered with outer protections of jute and neoprene jacketed steel wires. Additional layers of outer protection are added as the probability of severe abrasion or high tensile strain is increased.

A.2.3 Methods for Wire and Cable Support

The telephone industry employs several forms of cable support systems. This section discusses the types and their uses.

A.2.3.1 Types of Wire and Cable Support

Legal, physical and economic circumstances dictate the manner in which a cable route is constructed. Much could be said about the constraints leading to each type of cable support structure, but such discussions are not within the scope of this study.

The following definitions of cable plant, classified according to support structure, are recognized by GEEIA, the Bell System, the REA and the independent telephone companies.

A.2.3.1.1 Aerial Cable

Cable attached directly to poles or to the cross-arms of poles or hung from messenger cables or suspension strands is referred to as "aerial cable". It is often spiraled around messenger cables or other aerial cables. Aerial cable is far more susceptible to physical damage and unauthorized penetration than any other kind. This type of cable is employed frequently because of its flexibility, accessibility and low initial cost. However, unsightliness, frangibility and legal disputes have led to less frequent use of aerial cable.

A.2.3.1.2 Buried Cable

Cable placed directly in the ground with no conduit or ducts is known as "buried cable". Buried cables are more susceptible to physical damage, electrical damage, and unauthorized penetrations (between access points) than under-ground cables. Buried cables are spliced in manholes, conduit boxes, or permanent splicing pits. They are sometimes spliced in the trench and covered with soil. This type of cable route usually contains branch feeders, trunk/toll cables, and to a much lesser extent, main feeders and suburban distribution cables. Buried cable is more flexible than underground cable with respect to splicing and branching, but less flexible than aerial cable. Cables of high service value (toll/trunk) are usually buried deeper than those containing loop elements.

A.2.3.1.3 Underground Cable

Cable placed in a fixed underground conduit structure is called "underground cable". This type of cable is relatively immune to damage or penetration. All cable appearances are accessed through manholes and conduit boxes (handholes). Manholes may contain splice cases and/or larger cable terminals. Conduit boxes are too small to contain anything but splice cases. Underground cable routes usually contain main feeder, urban distribution and, to a lesser extent, branch feeder cables. Underground cable access points are usually between 600 and 1000 feet apart. A maximally filled route can contain 9 ducts and 2700 pairs per duct for a total of 24,300 pairs.

A.2.3.2 Utilization of Support Structures

The structures that support cables and wires can be shared by customer loops and trunk/toll plant. Underground conduit systems often transport trunk, toll and customer loop cables at the same time. Pole lines may also carry all three circuit types as well as several different physical kinds of aerial conductors simultaneously, such as multi-pair cable, open-wire (on cross-arms) and distribution cable. Drop wires to customers may also be found to branch from the distribution cable on those poles.

A given subscriber loop may have several different kinds of support structure along its length. Large underground main feeder cables generally serve densely populated urban areas. As one leaves the city, service requirements diminish and the underground cables may be spliced to buried and/or aerial branch feeder cables. These buried or aerial cables then divide into buried or aerial distribution cables to serve the neighborhoods they traverse. At length, a point is reached where customers are connected with drop or service wire. It is easy to see that the pair density per route diminishes as the distance from the central office increases. In fact, telephone parlance speaks of the "diminishment" of a cable route as it proceeds away from the central office. Engineers plan the orderly diminishment of each cable route.

A.2.4 <u>Wire and Cable Terminals, Splices and Other Vulnerable Appearances</u>

Each type of outside plant has a multitude of "appearances" where the cable is brought out to a splice case, terminal housing, or other type of terminal enclosure. Such appearances may be in manholes, conduit boxes, suspended from messenger cables, mounted on poles, mounted on the surface of the ground, attached to the walls of buildings, or, in some cases, even buried.

Cable appearances occur at the following locations along a cable route:

(a) Subscriber distribution points;

(b) Cable/wire route junctions;

(c) Junctions between buried and aerial cable;

(d) Cable loading points;

(e) Bridge-tap isolator points;

(f) Cable reel splice points;

(g) Potential subscriber distribution or cable junction points;

(h) Pole/manhole mounted repeater points (where impedance compensators may also be found);

(i) Points necessary to add gas pressurization equipment, load section build-out capacitors, and fractional load coils (although such gear is almost always co-mounted with items (a) through (h)); and

(j) Any additional points necessary to ensure a maximum terminal separation of 5000 feet along the cable route.

It should be pointed out that some individual telephone organizations may not adhere consistently to the above practices, and most may deviate from them on some occasions (especially in rural areas), but the above has been represented in the literature as "good outside plant construction practice."

Over the years, a number of different cable types have been used such as paper-insulated, pulp-insulated, textile-insulated and plastic-insulated conductor cable. This cable evolution, plus technological advances in the materials used in splice cases, terminal housings, terminal enclosures, and ready-access closures* have resulted in a variety of such devices being inserted into the Outside Plant. Today, all vintages of cable appearance hardware may be found throughout the nation's telephone facilities. The types of route construction used, i.e., aerial, buried, or underground, also add to the variety of cable terminals encountered in Outside Plant.

A.2.4.1 Aerial Cable Terminals

Before the advent of plastic-insulated conductors, paper or pulp-insulated conductors were prevalent in the telephone industry. This necessitated the use of hermetically sealed terminal chambers in order to keep the conductor insulation dry. The entire cable terminal consists of a sealed chamber containing ceramic face-plates studded with binding posts. The binding posts are, in turn, connected to the conductors of a lead-sheathed cable "stub". A terminal such as this (where the conductors of the stub are spliced directly to pairs in the cable and the splice is enclosed in a sealed sleeve) is referred to as a "fixed-count terminal". Termination of originating wire or cable at the terminal is accomplished by connecting the originating conductors to the binding post.

The introduction of PIC cables eliminated the need for hermetically sealed terminals. Cable Terminals designed specifically for PIC cable applications are called "ready-access" terminals. The cable within the Ready-Access enclosure is protected by a rubber boot which can be readily peeled back, making all cable pairs readily accessible.

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*"Closures" is the term applied to the newer compact terminal enclosures used to terminate PIC cable.

When pulp- and paper-insulated cables were employed more extensively, the inflexibility of the fixed-count terminal coupled with a greater incidence of multi-party lines and difficulties in correctly predicting service requirements forced the proliferation of permanent multipling connections (Bridge-Tap). However, the advent of PIC with its ready-access terminals resulted in easier cable rearrangements thus reducing the quantity of bridge-tap in modern plant. Now all pairs within a distribution cable are available for use at every terminal location. This, of course, increases the vulnerability of local telephone plant to unauthorized penetration.

A.2.4.2 Buried Cable Terminals

Compared with aerial cables, buried cables are difficult to augment or modify. Accordingly, steps are taken during route design to plan for all possible contingencies. The size of both cables and terminals are predicated on two cable pairs for each domicile or business premise in the locale that a cable is serving. Terminals for buried cable on feeder routes are located in manholes or above ground terminal enclosures.

Terminals for buried distribution cable are usually the ready-access type mounted in a "pedestal" above the ground, mounted in a flush-with-the-ground conduit box or an encapsulated type, where service-wires (buried drop-wired) are spliced directly to the cable pair and the splice is hermetically sealed. Lightning protectors, load coils, branch splices, and cross-connect cable terminals can all be mounted in pedestal type enclosures.

A.2.4.3 Distribution Terminals

Distribution cables are terminated in cable terminals located at or near the point or points to be served. In the case of paper- or pulp-insulated cables, these terminals are hermetically sealed chambers equipped with cable stubs. Pulp- or paper-insulated terminals for use on poles or the outside walls of buildings have weather-proof covers, but are not hermetically sealed. Pulp- or paper-insulated terminals for mounting inside manholes are equipped with water-tight covers and water-tight connectors. Since, for a given number of pairs, PIC cable has a larger outside diameter than paper- or pulp-insulated cable, new terminal enclosures have been designed called Ready-Access Enclosures or closures. Furthermore, with PIC cable, whether jelly-filled or not, the polythylene is resistant to moisture, which eliminates the necessity of hermetic sealing in aerial cable terminals. Water-tightness, however, is a requirement in buried or underground PIC terminals. Ready access terminals for buried distribution systems are available for mounting above ground in pedestals (terminal posts), in manholes, or on building walls.

A.2.4.4 Outside Cable Terminals

There is a large number of terminal types used with the outside cable plant. Some of these are described below.

(1) Strand-Mounted (Distribution)

The strand-mounted pulp- or paper-insulated cable terminal is intended for attachment to a cable suspension strand. In cases where it is not possible to strand mount such a terminal, hardware is available to mount it on poles and walls. These terminals may be found on branch feeder or distribution cables. Various sizes are available to accommodate between 10 and 32 pairs.

(2) Pole-Mounted (Distribution)

The pole-mounted pulp- or paper-insulated cable terminal is intended for mounting on poles. In cases where it is not possible to pole mount such a terminal, hardware is available for mounting it on building walls. They are available with drop-covers or slip-covers. These terminals are used to terminate distribution cables. Various sizes are available to accommodate between 11 and 26 pairs.

(3) Pole-Mounted Cross-Connections

The terminals are intended for mounting on poles. Cross-connection terminals are generally found at junctions between pulp- or paper-insulated aerial feeder and distribution cables. They are much larger than pole-mounted distribution terminals accommodating between 100 and 600 pairs.

(4) Manhole-Mounted (Distribution)

These terminals are intended for mounting in manholes. They are used to interconnect pulp- or paper-insulated underground (conduit contained) cable and service wire. The terminal consists of a cast iron box and a water-tight cover. The binding posts are similar to those of the slip-cover, pole-mounted terminal. The terminals can accommodate between 6 and 16 pairs.

(5) Buried Service Wire (Distribution)

These terminals are used to terminate buried pulp- or paper-insulated distribution cable routes. They are used at junctions between buried cable and aerial cable: i.e., between aerial distribution cable and buried service wire or between buried distribution cable and aerial drop wire. The terminal consists of a cast iron base, a terminal plate, and a cover and can accommodate from 4 to 60 pairs.

(6) Cable Stubbing (Feeder Cable)

Cable stubs are short pieces of cable bridged to pulp- or paper-insulated cable at an inter-reel splice point to provide a means to add or modify branch cable connections without opening the main splices. Cable stubs at splice points are usually restricted to underground and buried cable plant. Stubs are provided at splice points along an underground feeder route where it is expected that branch feeder cables will be connected. Stubs usually are brought out in manholes. On multi-pair cable feeder routes the practice is to stub no more than one cable per manhole. Buried feeders are not stubbed as frequently as underground feeders since not all splice points appear in manholes. However, stubbing is done wherever manholes are provided for any purpose, at selected buried splices and other convenient cable appearances, where branch feeders may be added. Stubs vary in size from several hundred pairs down to tens of pairs depending on what size branch cables will be required.

(7) Ready-Access Terminals (Feeder and Distribution)

Ready-access terminals are used exclusively with PIC cable. The aerial type is designed to be attached to suspension strands. The enclosure (or closure) can contain terminal blocks, loading coils, or bridge-tap isolators (see Section A.3.1.3). The assembly is enclosed by a molded neoprene cover which is readily replaced or removed without tools. Openings are provided in the base for drop wire entrance. The ready-access terminal cover is water-tight but it is not hermetically sealed.

Ready-access terminals are available for use with buried cable and are mounted above ground on pedestals (also called terminal posts) or building walls. These ready-access enclosures can house terminal blocks, loading coils or bridge tap isolators. Newer encapsulated ready-access closures are used on buried cable routes.

(8) Cable Closures (Main Feeder and Branch Feeder)

Cable closures are used to enclose branch cable splices on aerial and buried PIC feeder routes. The aerial splice closures use the ready-access method of pair termination and are weather-proof but not gas or moisture proof.

(9) Terminal Housings (Buried Wire and Cable)

Best practice has it that all splices in buried wire and cable are made above ground and are protected by either pedestal (terminal post) or pole-mounted terminal housings. Protection, loading, junction and distribution points also occur above ground and are protected by terminal housings. The terminal housings are equipped with a mounting strip in the top of the housing for the installation of terminal blocks, load-coils and bridge-tap isolators. Terminal housings can be obtained in various sizes to accommodate between 6 and 60 pairs (or up to 40 loading coils) and are made of fiberglass, galvanized steel, and galvanized painted steel. Encapsulated splice enclosures or direct burial splice enclosures are used in place of terminal housing pedestals at connections between buried cable and buried service wire and at reel end splices.

Ready-Access Enclosures for PIC cable can accommodate, at most, 24 pairs. Only working PIC pairs are usually connected to terminal blocks in ready-access enclosures or terminal housings.

More recent practices dictate that, in buried terminal housings, every effort be made to seal the plant by avoiding the use of terminal blocks.

When terminal housings, terminal enclosures, ready-access enclosures, splice-cases, cable stubs, and the like are considered from the point of view of the penetrator, they are soft spots, because not one of these enclosures are locked or otherwise purposely protected from unauthorized entry. They all are fastened shut with simple fasteners that can be removed with the proper tools.

A.2.5. Gas Pressurization of Cable Systems

Many cable systems are pressurized to prevent moisture damage. There are two types of pressurized systems, alarmed and non-alarmed. Each is discussed below.

A.2.5.1 Alarmed Pressurization Systems

The hazards that water, or even moisture, present to pulp- or paper-insulated conductors were recognized long ago as a major maintenance problem. The paper-insulated cables are covered with a gas-tight lead sheath. Openings develop in the sheaths of both aerial and buried cable as time goes by. Moisture will, of coures, enter these openings and result in damage. In pulp- and paper-insulated cables, the absorption of water presents a major maintenance problem causing telephone transmission on the pairs to quickly deteriorate. Water can cause excessive losses, echo, and noise (resulting from pair imbalance) in telephone circuits. In paper insulated cables the absorption of water by the paper insulation makes it swell thus blocking the entry of more water. However, in PIC cables the insulation will not swell and the water travels much further down the cable causing transmission impairments when the water covers a sufficient number of pinhole insulation leaks.

The process by which water can penetrate the sheath of buried cable is fairly evident, but aerial cable is surprisingly quite vulnerable. In aerial cable, water falling or condensing on the upper surface of the sheath in appreciable quantities will simply be drawn through leaks by the force of gravity. However, another more significant phenomenon called "breathing" is present in aerial cable. Breathing occurs when the temperature of the cable is made to change quickly so that a large temperature differential suddenly develop between the cable and the air. For example, a heavy summer shower will quickly cool the cable sheath, and a hot summer sun will warm it just as quickly. Cable that is warm will develop a positive internal pressure, but cable that is cooled will develop a lower than atmospheric pressure, in which case moisture will be quickly inhaled through any leaks. A pressure differential as high as ± 2 PSIG (pounds per square inch gauge, i.e., pounds above atmospheric pressure as shown on a special gauge) can be made to develop between the inside and outside of the cable sheath.

In order to combat the invasion of moisture, buried cable is pressurized to 9 PSIG and aerial cable at 6 PSIG. However, custom has it that pressurization will still do its job of barring moisture if the <u>average</u> pressure falls as low as 2 PSIG in buried cable and 1 PSIG in aerial cable. Pressure sensors (contactors), which inform maintenance forces of excessive leaking, alarm when the gas pressure drops by 3 PSIG in both buried and aerial cables, although operating points vary from company to company.

The idea of making cable sheaths gas-tight and keeping them under continuous internal pressure was conceived early. Eventually contactors were added to detect a significant drop in gas pressure and initiate an electrical alarm at a central office. These pressurization systems were initially applied to lead sheathed cables, but lately some PIC cables and all high capacity coaxial tubes have been pressurized (to 9 1/2 PSIG). Obviously, the new PIC jelly-filled "Water-proof" cables would not be pressurized under any circumstances. Gas pressurization would seem to present some potential problems to would-be interceptors.

The gases used to pressurize cable systems are air and pure nitrogen. The gas is supplied from either nitrogen cylinders or a standard cable pressurization system. The standard cable pressurization system also dehydrates the air, dropping the humidity of the air entering the cable to just a few percent. The type of gas feed system selected for a specific application depends on the length and state of repair of the cable to be pressurized. All pressurized cables develop sheath leaks as time goes by. The flow of gas required to compensate for sheath leaks and keep a cable pressurized is referred to as the "venting" of the cable. Venting for a large system should not exceed 30 standard cubic feet of gas per day (SCFD). A nitrogen cylinder should be employed to pressurize a section only if the venting does not exceed 1 SCFD.

A quantity which is basic not only to the design of cable pressurization systems, but also bears upon the usefulness of pressurization as a potential deterrent to unauthorized monitoring in cable systems, is the "pneumatic resistance" of the cable. The pneumatic resistance of a length of cable is defined as:

$$\rho = \frac{\text{pressure (PSIG) applied to cable input}}{\text{rate of gas flow (SCF per hour) through cable}}$$

This definition assumes the cable length has no leaks. The pneumatic resistance is important because the time interval between the occurrence of a significant leak (zero resistance) and the detection of that leak at the CO is directly proportional to the pneumatic resistance of the cable section between the leak and the contactor. It is also important that the pneumatic resistance is directly proportional to the length of the cable section. The detection interval is lengthened as the distance between the leak and the contactor increases. Pneumatic resistances for various size cables are given in Table A-2.

TABLE A-2

CABLE PNEUMATIC RESISTANCE (PAPER CABLE) PSIG-HR/SCF (pnohms)

No. of Pairs	19 Guage	22 Gauge	24 Gauge
16	15	40	50
26	10	25	40
51	6	15	20
76	4	10	16
101	3	7.5	13
151	2	5	10
202	1.5	4	8
303	1.0	3	5
404	0.8	2	4

The pneumatic resistances of PIC cables are approximately one-fifth (1/5) of the values given in Table A-2.

Various criteria are set forth for placing the leak detection contactors along cable routes. One organization proposes a nominal spacing of 10,000 feet between contactors, and another prescribes that contactors should be separated by a section of cable having a pneumatic resistance of 30 pnohms. Some of the Bell companies adhere to maximum separation criteria of 15,000 feet. Because of low pneumatic resistance, PIC cables can be pressurized over much greater distances than paper-insulated cables and some organizations take maximal advantage of that fact. Obviously, the longest time interval required for a zero resistance leak to be detected at the contactor will occur when the leak is in the middle of the longest inter-contactor cable section. When the entire cross-section of telephone company practices is considered, contactor operating times are found to vary between one hour and ten hours. The one hour operate time is found on some PIC routes, and the 10 hours on paper-insulated cable routes. Nominal times of about 4 1/2 hours occur on both types of routes. The amount of venting can also influence contactor operation times.

In most contactor systems, the contactor alarm is transmitted over subscriber pairs in such a way that the transmission and signaling suffer no degradation. When the contactor operates, a 270,000 to 330,000 ohm resistor is shunted across the subscriber pair by the contactor. Central office personnel discover the alarm by periodically (two or three times a day) checking (scanning) the subscriber loops for alarms. This can introduce considerable inter-scan delay into the detection process. Some telephone companies use automatic devices to scan the pertinent subscriber loops and other dedicated alarm pairs coupled to automatic detection systems. Automatic detection systems usually "annunciate"* contactor operations when they occur.

* "annunciate" means to provide an audible and/or visual alarm.

In addition to delays in the detection of leaks resulting from cable time constants and the central office inter-scan time, there is a reaction time involved, i.e., the interval between the central office's learning of the leak and the time maintenance people arrive at the location of the leak. The sum of the detection times, the inter-scan delay and the reaction time will, for our purposes, be defined as the "Delay Time". Delay times can be very short in some fortuitous cases, however, delay times are almost never less than 7 or 8 hours and usually on the order of 24 hours. This, of course, assumes that service has not been affected. Noticeable service degradation will cause central office personnel to look for detectable causes and dispatch maintenance crews in the shortest possible time. In most cases, the judicious choice of a penetration point and a penetration time by a would-be eavesdropper will result in at least 70 hours of uninterrupted monitoring time, if service has not been affected. Careful selection of a monitoring point -- i.e., somewhere near the middle of the cable and in the middle of the longest inter-contact section -- will usually permit at least four hours of uninterrupted monitoring regardless of the time of day.

The general thrust of the maintenance philosophy is to put off costly cable repairs for as long as possible (if service is not interrupted) and accomplish such repairs on a routine or scheduled basis.

An important consideration is the insertion of "plugs" into pressurized cables in the midpoints of all inter-contactor section and at the ends of the pressurized section. These plugs permit the isolation of short cable sections for maintenance purposes. The plug completely blocks the passage of gas through a section of cable. Once installed, all plugs except those on the ends are bypassed by valve and tube arrangements. Plugs are also installed at the ends of submarine cable sections in order that the higher than normal pressure can be applied to that section if the cable is punctured. Most telephone companies insert bypass isolation plugs at intervals of 1000 to 3000 feet along the cable. There are valves strategically placed along most cable routes so that the ambient cable pressure may be checked at known points during trouble shooting and for routine maintenance. Once a trouble is isolated to a section bounded by plugs, the valves at the plugs are closed, and the section is pressurized from a cylinder (or cylinders at both ends) so as not to put a drain on the central office.

A would-bepenetrator has a number of viable alternatives in avoiding detection while penetrating a cable:

(a) Existing by-pass valves at plugs could be shut (or shut just the right amount to simulate venting) and the cable pressurized from a portable source during penetration;

(b) A permanent penetration could be installed by the penetrator by inserting plugs at either side of the penetration and bypassing it with a valve and tube arrangement (the installation of plugs in all types of cable is well documented, and can be done easily with the proper tools) and

(c) The penetrator could breach the cable, insert monitoring attachments, reseal and repressurize the cable before the central office detected a pressure drop.

A.2.5.2 Non-Alarmed Systems

Some cables are capable of pressurization but continuous pressure is not maintained. Instead of contactors to determine loss of pressure, "flash testing" is employed. The cable is pressurized only during periodic maintenance visits in the specific section to be tested. After pressurization soapy water is applied to the cable sheath to detect leaks. Other cables are continuously pressurized but no contactors are located along its length. Pressure checks are routinely made at valves strategically located along the cable route. Both of these systems present no threat to the prospective penetrator.

A.2.5.3 Toll Cable Systems

In the Bell System, pressure contactors (tranducers) on toll cable systems are continuously monitored. Each transducer's resistance varies with the pressure and this valve is read and recorded by equipment in the central office. Thus a record of all pressure readings at all transducers is printed out in the central office or forwarded to a central testing point. The gradients can then be studied to visualize potential troubles and locate serious leaks. Alarms are automatically activated when the pressure falls below preset thresholds. This arrangement decreases the delay time by inter-scan delays, however, the other considerations with respect to penetration opportunities still apply.

A.2.5.4 Auxiliary Air Sources

In the Bell System, aluminum-lined plastic pipe that originates from a pipe-alarm meter panel in the central office is used to convey dry, pressurized air from the central office source via major underground cable conduits to remote locations along pressurized routes where the pipe is manifolded to the cable at each auxiliary source location.

A.2.5.5 Pole-Mounted Air Dryers

Another Bell pressurization system employs small pole-mounted air dryers located along aerial cable routes.

A.3 NON-CARRIER WIRE AND CABLE COMMUNICATIONS SYSTEMS

The simplest and most basic cable communications systems are the non-carrier types where usually only a single two-way voice conversation is assigned to one or two wire or cable pairs. Since all original cable constructions were designed with non-carrier cable systems in mind, and most of the existing cable literature has been written in this context, this appendix will treat all basic system construction under the broad category of non-carrier cable systems.

Non-carrier wire and cable communications systems account for a large portion of the circuit mileage of public switched network and private line connections, making such systems especially important in any discussion of interception. That part of a cable system most exposed to penetration is to be found within the domain of "outside plant". Outside plant may be classified as either customer loop plant, by which a subscriber is connected to the central office (CO), or toll and trunk plant through which CO's are interconnected. Although distinctly different in purpose (and transmission design), customer loop plant and toll/trunk plant often share many specific elements of outside plant. For example, any given buried cable or underground conduit system or pole line may contain some cable pairs devoted to customer loops and others to trunk/toll circuits. Therefore, it appears that the most useful approach is to describe the outside plant in its entirety with special emphasis on those attributes which enhance its vulnerability.

A.3.1 Two-Wire and Four Wire Transmission

Most subscribers to the DDD are connected to their local dial CO's via "two wire" loops. Two-wire telephone circuits are simply circuits that carry two directions of conversation over a single pair of conductors. Most trunks interconnecting local dial CO's

(End Offices) are two-wire, as are those interconnecting toll centers and primary centers to toll centers.

Most "private line" subscribers are connected to their CO via "four-wire" loops. Four-wire telephone circuits utilize a separate pair of conductors for each direction of transmission. All trunks between regional centers and between sectional and regional centers employ four-wire transmission facilities. The majority of private line circuits are four-wire over their entire length. High-gain amplification can be easily achieved in four-wire circuits using standard voice amplifiers.

When two-wire to four-wire conversion is required at dial switches and carrier terminals, balanced impedance bridge arrangements known as "hybrids" or "four-wire term sets" are employed.

A.3.2 The Subscriber Loop Cable Hierarchy

The outside plant portion of a customer loop is bounded on one extremity by the station protector at the customer's home or business premises and, on the other, at the central office main distribution frame (MDF). As shown in Figure A-2, the customer loop consists of the following elements:

Loop Section	Cable Element Designation
(a) From the Station Protector to the Distribution Terminal	Drop Wire (Aerial) Service Wire (Buried)
(b) From the Distribution Terminal to the Branch Feeder Terminal	Distribution Cable Distribution Wire
(c) From the Branch Feeder Terminal to the Main Feeder Terminal	Branch Feeder Cable

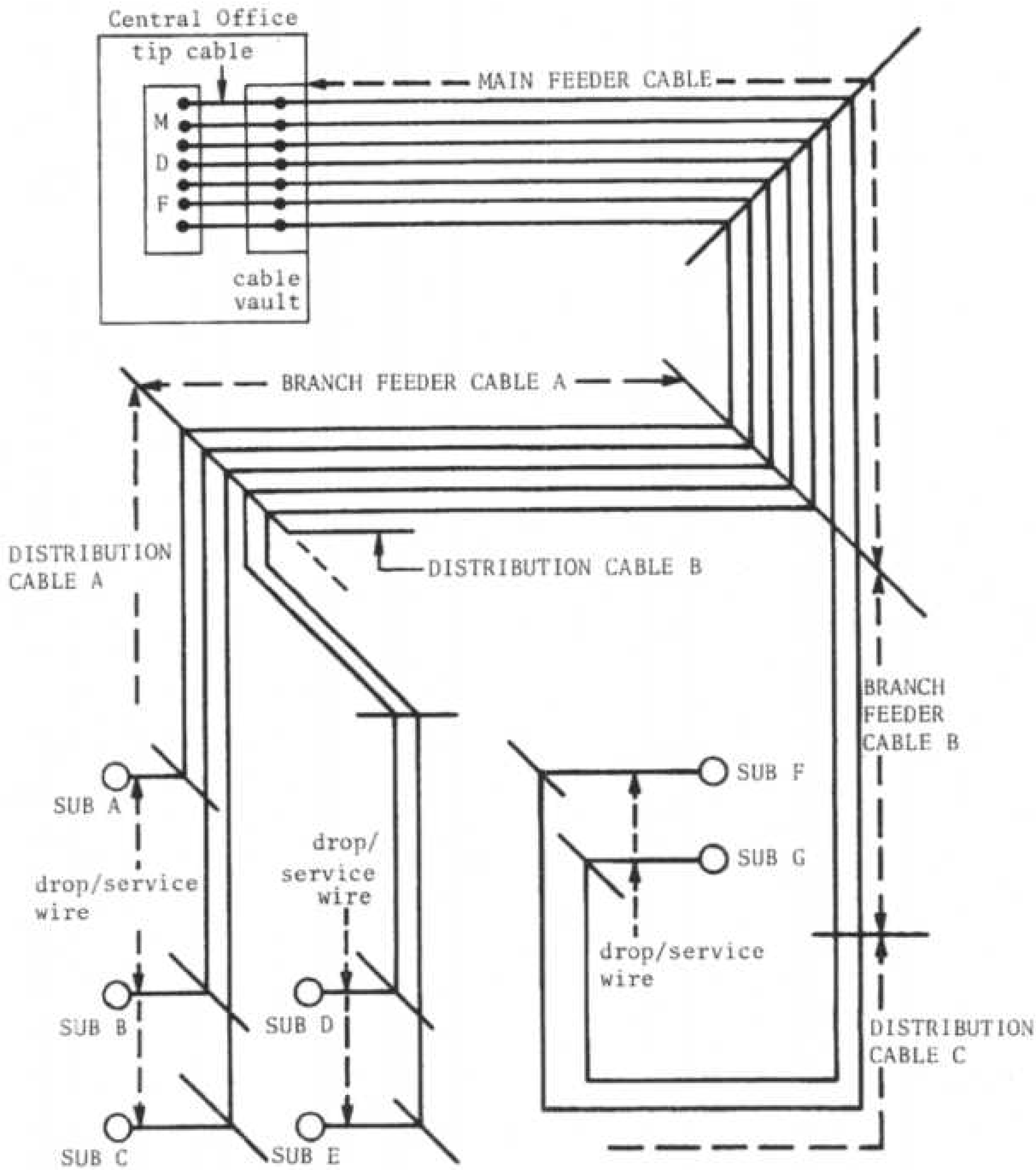

FIGURE A-2
SUBSCRIBER LOOP CABLE SYSTEM

(d)	From the Main Feeder Terminal to the Splice in CO Cable Vault	Main Feeder Cable
(e)	From the Splice in CO Cable Vault to the CO MDF	Tip Cable

The loop plant can be likened to a tree where the CO is the root system, a main feeder cable is the trunk, the branch feeder cables are the large branches, the distribution cables are the small branches, and the drop/service wires are the twigs. Figure A-2 depicts a sample subscriber loop cable system. At each branching point may usually be found one of several types of splice cases or cable terminals. The abundance and placement of such cable "appearances" will be discussed later in this section.

Distribution cable is the part of the outside plant to which the customer's drop or service wire is directly connected. Feeder cables interconnect distribution cable with the central office. Main feeder cables are high capacity backbones into major service areas. The branch feeders connect the distribution cables to the main feeders.

The main feeder cables enter the central office cable vault via underground conduit. The typical cable vault is a basement room that serves as a splicing chamber. A "tip" cable is usually spliced to the main feeder in the cable vault. The tip cable is then terminated on high voltage protection devices (lightning Arrestors) on the MDF. The interface between central office equipment and the outside plant is accomplished at the MDF.

A.3.3 Multipling and Bridged Tap

"Multipling" (or bridging) refers to the practice of making the same cable pairs (or count) available at a sufficient number of distribution points to provide for multipoint service, party line service, and/or potential subscriber development with minimal cable rearrangement. The "multipled" pairs may or may not be physically interconnected (bridged). If cable pairs are physically bridged, all "originating" cables bridged onto "through" pairs at cable terminals (or other splice points) are referred to collectively as "bridge-tap".

The modern tendency in urban and suburban areas is for subscribers to take one or two party service. This is making it feasible to provide a separate cable pair to each domicile or business premises in an area. Under these conditions bridging of the few remaining multi-party lines and any other loop/equipment rearrangements can be done entirely at the central office. This approach is referred to as "dedicated" pair assignment.

Permanent multipling, which necessarily leads to permanent bridge-tap, has been resorted to extensively in the past and is still done where cable terminals are not employed. Where flexible terminals appear at splices or cross-connect points, permanent bridging is unnecessary. However, even in the most modern cable plants, bridge-taps, once made, are often never removed until the transmission requirements demand it. This remnant bridge-tap occurs because of economics and inertia. A 1964 Bell System Customer Loop Survey reveals that at that time there was an average of 2,478 feet of bridge-tap per customer loop and an average of only 228 feet of this was actually being used in customer loops. That is, 82% of the sampled main stations had bridge-tap not in use. A GTE loop survey made in about 1970 reveals that there was an average of roughly 2,600 feet of bridge-tap attached to each GTE customer loop. It is probable that the above averages have decreased further in the time following those surveys inasmuch as increases in the use of "dedicated" plant and the number of data services tend to result in a steady reduction of excess bridge-tap in the plant. As telephone and data circuits are engineered, the amount of bridge-tap on the circuit becomes a critical parameter that must be closely watched.

Bridge-tap isolators (BTI's) are used at bridging points to electrically isolate sections of bridge cable from a through subscriber loop pair. There have been several different kinds of BTI employed over the years, including electro-mechanical devices, but the most acceptable modern device is a saturable reactor.

A.3.4 Phantom Circuit

The phantom circuit is a "bonus" circuit derived from two other physical cable circuits. Although the phantom circuit is virtually extinct, they are still found scattered around the country in the Bell System and independent telephone companies.

Phantom circuit operation is found in both the open wire and cable plants. A two-wire, one directional phantom circuit is created by superimposing a "simplexed" conductor over each of two cable pairs which are members of the same quad. Thus, the two-wire, one directional members of the quad, called the "side circuits", are used to derive a third two-wire, one-directional circuit called the phantom. Since the three circuits of most phantom/side-circuit combinations operate as two-wire, unidirectional paths, practical four-wire telephone circuits require two quads to achieve three four-wire, bi-directional telephone circuits.

A.3.5 Line Concentrators (Remote Concentrators)

Concentrators are devices which permit a number of geographically grouped subscribers to share a lesser number of cable pairs between their geographic region and the central office (CO).

The location of concentration stages near groups of subscribers results in significant savings in wire. Before the advent of the dial network, 20 cable pairs were made to serve a group of 100 subscribers by inserting a concentrator between the customers and an operator manned manual board. Modern concentrators are inserted between groups of remote subscribers and dial machines. They are used near new housing developments in suburban areas. In modern concentrators, the ratio of customers to cable pairs is usually somewhat less than 4 to 1.

A.4 TRUNK CIRCUITS

There are two general categories of trunk circuits, non-carrier trunks and carrier trunks. Carrier trunk systems make use of the "multiplexing" techniques discussed in Appendix C to send two or more voice or data messages simultaneously over the same transmission medium. The wire and cable construction techniques described above apply to trunk circuits as well.

A.4.1 Non-Carrier Trunk Circuits

The above discussion of the subscriber loop circuits is generally applicable to non-carrier trunk and toll cables. The only significant differences are:

(1) There are usually many more pairs in a trunk/toll cable than in subscriber branch feeder and distribution cables (although sometimes trunks are routed through main and branch feeder cables).

(2) There are fewer above ground appearances because most trunk/toll cable is the buried type outside of cities and the underground type within cities. By the same token, the vulnerability of long stretches of buried cable in isolated areas presents opportunities to interceptors. However, some of the fastest reacting most modern computerized gas pressure alarm systems are installed on trunk/toll cables.

(3) There are few bridge-tap access points on the trunk/toll plant.

(4) Long trunk/toll cable routes can often be traced cross-country by a well-manicured right-of-way, frequent signs warning the public of the cable's presence, and occasional repeater huts (because some of the pairs are usually dedicated to a multiplex system). Repeater huts are equipped with open-door alarms that inform the central office maintenance personnel when the hut has been entered. A few medium length toll routes are composed exclusively of thick aerial cables which also can be easily traced from pole to pole.

(5) The trunk circuits in such routes are not usually dedicated to any specific subscriber, but, rather to interconnect switching machines. This means, of course, that, except for random snooping, a signal-decoding capability must accompany the more prosaic monitoring amplifiers/headsets mentioned above. Accordingly, trunk selecting and monitoring arrangements would probably be several times more costly than the equipment required to intercept communications on subscriber loops.

A.4.2 <u>Carrier Wire and Multi-Pair Cable</u>

Cable-carrier trunk circuits fall into the following categories:

a. short-haul systems (within urban areas) using frequency division multipled (FDM) and time division multiplex (TDM),

b. long-haul systems (between urban areas) using frequency division multiplex (FDM).

The multi-pair cables used with the short-haul systems are usually specially treated wire-pairs of main feeder cables and branch feeder cables. Hence, most of the discussion regarding short-haul systems is similar to that covered under non-carrier wire and multi-pair cable systems. The peculiar problems pertaining to the "trunk" character of these circuits are similar to those addressed above concerning non-carrier trunk circuits. The only additional attributes to be considered are as follows:

(1) Demultiplexers must be added to the interception equipment discussed above in order to access a single voice channel.

(2) High-frequency wide-band line repeaters are occasionally inserted in the longer multiplexed routes. TDM systems such as T1-carrier need regenerative repeaters every 6000 feet. These repeaters are sometimes installed in central offices but more often, of late, have been mounted in manholes. These repeaters present additional appearances for potential communication interception.

The long-haul cable-carrier trunk communications ride on pairs which are subject to the same considerations posed for long-haul non-carrier trunk circuits except for the increased complexity resulting from the demultiplexing requirement, as stated in items (1) and (2), above. Circuits on long-haul systems are more likely to be carried by FDM systems equipped with line repeaters.

In summary, the interception of communications on short-haul and long-haul cable-carrier trunk circuits is somewhat more costly and complex than non-carrier trunk circuits because of the demultiplexing equipment required. However, long-haul cable carrier trunk interception is similar to the long-haul non-carrier trunk interception in that long stretches of buried cable in isolated areas present abundant opportunities for sophisticated, virtually non-detectable incursions where relatively permanent taps could be established.

One decisive drawback for the interceptor is that greater expertise must be exercised in the design and application of penetration devices because the wideband FDM/TDM signals are easily affected by bridged devices. An inexpert attempt at monitoring could affect the signal in such a way that either central office alarms would be activated or service would actually be degraded or interrupted.

A.4.3 Carrier Coaxial Cable

Approaches to intercepting communications on coaxial cable differ markedly from those previously addressed for wire/multi-pair cable communications. Even the tap methodology calls for a considerably different approach. The clamp-on inductor and the soldered/alligator-clipped connection which can easily be used for acquiring communications signals on wires are not suitable for the tapping of coaxial cable tubes.

The signal is transmitted as a high frequency voltage difference between the center conductor and the copper outside conductor. In general, repeaters on coaxial systems are spaced between 1 and 4 miles apart, depending on the system in use. The repeaters are powered by DC voltage on the center conductor of each coaxial tube. This voltage can be as high as several thousand volts.

The cable is pressurized and has a fast-acting gas pressurization alarm system which quickly reveals any significant cable punctures. Actuation of the alarm results in crews being immediately displatched to determine the cause.

When acquiring communications signals from a coaxial system it is impossible to elicit any meaningful signals (except at the repeaters) without first opening the lead sheath and separating the individual tubes. Studies have shown that the amount of loss the information bearing signal suffers when measured by induction coils on the outside of the steel tape is too large to yield a usable signal-to-noise ratio.

At present, too little is known about the noise level on the copper outer conductor (after the steel tape is peeled off) to determine whether useful signal-to-noise ratios can be achieved using physically manageable induction coils. Outer conductor noise is a complex signal resulting from the periodic common grounding of all outer copper conductors plus spurious earth currents. The loss that the information signal suffers, when measured by a reasonably sized induction coil on the outside copper conductor is quite large although it still may be usable. However, the total useful signal-to-noise ratio is determined by the complex conductor noise currents. Making the use of this technique for interception is highly questionable.

An alternative method would involve the development of a specialized precision tool which would puncture the steel tape and copper outer conductor, seal the resultant hole instantaneously so that gas pressure would be maintained, and insert a probe near or onto the center conductor to directly tap the signal without shorting the repeater power supply to ground. This would probably yield an extremely high signal-to-noise ratio. Great care would have to be exercised in the design and use of this device because of possible adverse effects on the gain-frequency response of the cable. Such effects would be noted at the central offices.

Another approach to interception involves entry into the repeater manhole or auxiliary hut and monitoring directly on the test jacks of the repeaters. This would present difficulties to the penetrator because some of the manholes and all the auxiliary repeater huts have burgular alarms which are extended by telemetry to responsible central offices whose forces react immediately after an incursion. In addition, the manholes and repeaters are securely locked against intrusion. The entire cable/repeater/apparatus case system is pressurized and the individual apparatus case must be isolated before the twin test jacks can be accessed. Accordingly, it appears that only a very sophisticated approach backed up with considerable expertise would permit monitoring at coaxial cable repeater points.

High capacity coaxial cable systems utilize wideband signals which can be very easily degraded by poorly designed or inexpertly used monitoring equipment. In this event, the degree of degradation can vary between triggering of pilot alarms to interruptions to service so that a high level of expertise must be exercised in the design and use of coaxial interception equipment.

APPENDIX B

INTERCEPTION OF TERRESTRIAL AND SATELLITE MICROWAVE COMMUNICATION SYSTEMS

B.1 MICROWAVE SYSTEMS

Microwave communication systems with line-of-sight paths have assumed, in the last three decades, a position of considerable importance in the communication field, and in many respects such systems are competitors to wire line and coaxial cable systems. The wide range of possible applications extends, for example, from regional terrestrial systems providing a small number of telephone circuits to international satellite systems providing several thousand telephone circuits or several television channels over intercontinental distances of several thousand miles with the high standards of performance and reliability essential for national and international trunk circuits.

Microwave communication systems are employed for the transmission of voice, television, digital data (including teletype and telex), facsimile and other services. Nearly all microwave systems (especially the common carriers) employ frequency modulated r-f carriers. The modulating signal is usually a multichannel frequency-division-multiplex waveform derived from frequency separable single-sideband channels; a notable exception is television where the modulating signal is the low-pass video signal itself.

B.1.1 Terrestrial Systems

Much of the development work on the feasibility of microwave radio for multichannel communication was carried out prior to World War II. Interest in using the band of frequencies above 300 MHz for commercial purposes began to grow in the early 1930s, and one of the first microwave links was set up on an experimental basis in 1931 across the English Channel between Dover and Calais. Operating at what was then regarded as an extremely high frequency of 1,700 MHz with a radiated power of about one watt, it was regarded as an enormous advance on the techniques of the day, and it demonstrated the potential of the then little-used band of frequencies above 300 MHz. The world's first commercial terrestrial microwave line-of-sight link was set up three years later in 1934, also across the English Channel.

Commercial terrestrial microwave communications were not introduced to the United States until after World War II when a single link was set up in 1946 between Los Angeles and Santa Catalina Island. The first terrestrial microwave system in the United States was ATT's TD-2 system which was opened in 1950 to provide commercial service between New York and Boston. Today, microwave radio relay systems supply about 70 per cent of the Bell System toll message circuit mileage in the United States. Individual circuit lengths range from less than 20 to over 4000 miles. Route cross-sectional capacities range from less than 60 to more than 30,000 telephone message circuits.

The technical parameters characterizing nearly all terrestrial microwave systems are, in a sense, limited by two fundamental constraints: (1) the desirability of line-of-sight transmission without extraordinarily expensive towers; and (2) the desirability of employing a modulation technique relatively immune to the effects of fading and non-linear distortion. The former constraint leads to intersite repeater spacings of about 40 kilometers; the latter, along with the recognition that most traffic is telephony, leads to the selection of frequency modulation (FM). Because of these constraints and their engineering implications, the technical parameters characterizing terrestrial microwave system do not differ significantly in spite of the large number of manufacturers. Consequently, to characterize terrestrial microwave systems, it seems sufficient to describe the systems available from a single manufacturer for several of the most-used microwave bands. Since the microwave systems of Western Electric are, by far, the most pervasive in the U.S., only the technical characteristics of those systems are provided here.

A summary of the most common Western Electric terrestrial microwave systemsis presented in Table B-1. Most of the technical parameters identified in that table will be employed later to assess, quantitatively, the vulnerability of terrestrial microwave systems to interception.

B.1.2 Satellite Systems

Use of satellites for communications began in 1960 with the launching by the U.S. of the passive repeater, Echo I. This satellite, which remained in orbit until 1968, successfully relayed voice and television signals across the Atlantic between Andover, Maine and Goonhilly in England and Pleumeur Bodou in France. The first active repeater, Courier 1B, was launched in non-stationary orbit also in 1960 by the U.S.; it operated for only 17 days. The world's first successful synchronous communications satellite, Syncom 2, was launched on July 26, 1963 by NASA following the unsuccessful Syncom I which six months earlier suffered a communications failure upon orbital injection.

Commercial satellite operations may be considered to begin with passage by Congress of the Communications Satellite Act of 1962. This was followed with the establishment of the Communications Satellite Corporation (COMSAT) in 1963, the formation of the International Telecommunications Satellite Consortium (INTELSAT) in 1964, and the launch in 1965 of the first satellite to provide commercial service, INTELSAT I (Early Bird). INTELSAT now operates 4 satellites to provide international communications between 80 countries.

Presently, only two satellite systems are available to provide communications service to U.S. subscribers: (1) the INTELSAT IV system, which provides international circuits between the U.S. and the rest-of-the world; and (2) the WESTAR domestic satellite system of Western Union, which provides domestic service within the U.S.

	TD-2(*)	TD-3(*)	TH-1	
Radio Frequency Band	3.7 - 4.2 GHz	3.7 - 4.2 GHz	5.925-6.425 GHz	5.925-
Number of RF Channels	12	12	8	8
(Traffic & Protection)	(10 + 2)	(10 + 2)	(6 + 2)	(7 +
RF Channel Separation	20 MHz	20 MHz	28	30
Telephone Channel per RF Channel	1200 (B),1500 (C)	1200 or 1500 (D)	1860	1860
Nominal Power Radiated per RF Channel	33 dBm (B), 37 dBm (C)	37 dBm or 38.5 dBm	40 dBm	40 dB
Antenna Type	Horn (KS-15676)	Horn (KS-15676)	Horn (KS-15676)	Horn
Polarization	V&H	V&H	V&H	V&H
Mid-Band On-Axis Gain	39.5 dBi	39.5 dBi	43.1 dBi	43.1
* Median Section Distance	40 km	40 km	40 km	40 km
* Median Section Loss	65.3 dB	65.3 dB	61.8 dB	61.8
Nominal Power Received per RF Channel	-32 dBm (B)	-28 dBm (1200 channels)	-21 dBm	-23
	-28 dBm (C)	-26.5 dBm (1500 channels)		
Receiving System Noise Figure	7.5 dB	7.5 dB	10.0 dB	7.5
(at waveguide pre-selector input)				
Effective Noise Bandwidth	35 MHz	30 MHz	43 MHz	40 MH
rms Test-Tone Deviation (0 dBm0)	(B): 165 KHz	( ) 165 KHz	135 KHz	135
	(C): 100 KHz	(D) 100 KHz		
Pre-emphasis Gain of Top Telephone Channel	(B): 9 dB	( ) 9 dB	7.5 dB	11 dB
	(C) 10 dB	(D) 10 dB		
Multiplex System	L600 or U600	L600 or U600	MMX-1R or MMX-2R	MMX-1
Baseband	L600: 60-5684 KHz	L600: 60-5684 KHz	MMX-1R: 312-8284 KHz	MMX-1
	U600: 312-3084 KHz	U600: 312-3084 KHz	MMX-2R: 312-8525 KHz	MMX-2
Percentage of Long-Lines Circuit -km	58.8 %	8.1%	9.7%	18.3

*Variants of basic system are denoted by letters (e.g., B, C).
.001% Peak Factor of 12.9 dB assumed, $-16 + 10 \log_{10} N$.

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TH-1	TH-3	TH-4	TJ	TL-2	TM-1
5.925-6.425 GHz	5.925-6.425 GHz	5.925-6.425 GHz	10.7 - 11.7 GHz	10.7 - 11.7 GHz	5.925 - 6.425
8	8	8	6	6	8
(6 + 2)	(7 + 1)	(7 + 1)	(3 + 3)	(3 + 3)	(4 + 4)
28	30	30	40 MHz	40 MHz	
1860	1860	1200	600	600	600
40 dBm	40 dBm	30 dBm	27 dBm	20 dBm	20 dBm
Horn (KS-15676)	Horn (KS-15676)	Horn (KS-15676)	Horn (KS-15676)	Horn (KS-15676)	Horn (KS-15676
V&H	V&H	V&H	V&H	V&H	V&H
43.1 dBi	43.1 dBi	43.1 dBi	47.7 dBi	47.7 dBi	43.1 dBi
40 km	40 km	40 km	40 km	40 km	40 km
61.8 dB	61.8 dB				
-21 dBm	-23 dBm	-33 dBm	-40 dBm	-42 dBm	-42 dBm
10.0 dB	7.5 dB	9.0 dB	10 dB	10 dB	10 dB
43 MHz	40 MHz	40 MHz	30 MHz	20 MHz	16 MHz
135 KHz	135 KHz	206 KHz	233 KHz	292 KHz	292 KHz
7.5 dB	11 dB	9 dB	9 dB	9 dB	9 dB
MMX-1R or MMX-2R	MMX-1R or MMX-2R		L600	L600	L600
MMX-1R: 312-8284 KHz	MMX-1R: 312-8284 KHz		50-2788 KHz	60-2788 KHz	60 - 2788 KHz
MMX-2R: 312-8525 KHz	MMX-2R: 312-8524 KHz				
9.7%	18.3%				

4	TJ	TL-2	TM-1	TM-2	TN-1A
.25 GHz	10.7 - 11.7 GHz	10.7 - 11.7 GHz	5.925 - 6.425	5.925 - 6.425	10.7 - 11.7 GHz
	6	6	8	8	12 or 24
	(3 + 3)	(3 + 3)	(4 + 4)	(4 + 4)	
	40 MHz	40 MHz			40 MHz or 20 MHz
	600	600	600	1200	1200 or 1800*
	27 dBm	20 dBm	20 dBm	30 dBm	37 dBm
15676)	Horn (KS-15676)	Horn (KS-15676)	Horn (KS-15676)	Horn (KS-15676)	Horn (KS-15676)
	V&H	V&H	V&H	V&H	V&H
	47.7 dBi	47.7 dBi	43.1 dBi	43.1 dBi	47.7 dBi
	40 km	40 km	40 km	40 km	40 km
	-40 dBm	-42 dBm	-42 dBm	-32 dBm	-29 dBm
	10 dB	10 dB	10 dB	8 dB	8 dB
	30 MHz	20 MHz	16 MHz	16 MHz	40 MHz
	233 KHz	292 KHz	292 KHz	206 KHz	206 KHz (1200 channels) 168 KHz (1800 channels)
	9 dB	9 dB	9 dB	9 dB	9 db (1200), 11 dB (1800)
	L600	L600	L600	L600	L600
	50-2788 KHz	60-2788 KHz	60 - 2788 KHz	60 - 5772 KHz	60 - 2788 KHz

TABLE B-1
SUMMARY OF WESTERN ELECTRIC MICROWAVE SYSTEMS

between dedicated telephone subscribers and/or switched and dedicated TTY subscribers. The technical characteristics defining these systems are shown in Table B-2 and B-3.

TABLE II-2
INTELSAT IV SYSTEM SUMMARY

Space Segment:	
1. Satellite	INTELSAT IV
2. Number of Transponders	12 + 0 spares (only active elements are configured for redundancy
3. Transponder Type	RF Translating; Hard-limited for single carrier Quasi-Linear for Multiple Carrier (Back-off dependent upon No. of carriers)
4. Bandwidth per Transponder	40 MHz nominal; 36 MHz usable)
5. G/T of Satellite	-17.6 dB/°K
6. EIRP of Satellite	e.i.r.p. (single carrier): 22.5 dBW (global beam) 34.2 dBW (spot beam)
7. Satellite Antennas	Global Receive (2): Flat Plate Reflector, Gain = 20.5 dB, 17° full 3dB beamwidth, (2 HP) Global Transmit (2): Flat Plate Reflector, Gain = 20.5 dB, 17° full 3dB beamwidth, (RHP) Spot Transmit (2): Parabolic Reflector, Gain = 31.7 dB, 4.5° full 3dB beamwidth (RHP)
8. De-spin Mechanism	Mechanical (Dual-spin method)
9. Expected Lifetime	7 years
10. Launch Dates	26 January 1971 (F-2) 23 August 1973 (F-7) 19 December 1971 (F-3) 21 November 1974 (F-8) 23 January 1972 (F-4) 13 June 1972 (F-5) 22 May 1975 (F-1)
11. Launch Vehicle	Atlas Centaur
12. Size: Height Diameter	5.3 m (overall), 2.8m (Solar Drum) 2.4 m
13. Weight	703 kg
14. Location	2°W (F-2) 20°W (F-7) 35°W (F-3) 174°E (F-8) 178°E (F-4) 63°E (F-1) 60°E (F-5)
Earth Segment	
1. Earth Terminals	(US only): Andover (Me), Etam (WVa), Brewster (Wa), Jamesburg (Ca), Paumalu (Ha), Cayey (PR), Guam
2. Antennas	(Except Andover): Parabolic, 85' or 95' diameter, Cassegrain feed, Gain ≥ 57dB (Andover only): Horn
3. G/T of Earth Station	≥ 40.7 dB/°K
4. EIRP of Earth Station	75 - 95 dBW (dependent upon traffic)
5. Tracking	Auto-tracking and manual
Frequency Plan	
1. Frequency Band	4/6 GHz
2. Frequency Plan	Downlink: 3787 - 4193 MHz Uplink: 5932 - 6418 MHz Beacon: 3947.5 and 3952.5 MHz Command: 6GHz band
3. Traffic per Transponder	Up to 1092 or 1872 voice channels for global and spot, respectively 1 or 2 color TV per transponder
4. Multiple Access	FDMA
Modulation	
1. R-F Carrier	
Type	FM
Test Tone Deviation (0 $dB_{m}0$) Carrier Deviation (Telephony Carrier Deviation, TV	Traffic Dependent
2. TV Audio (Transmitted Separately)	
Frequency	6303.25
R-F Carrier Deviation	
Sub-carrier Deviation	
Sound Channel	
3. FDM Baseband	
Number of Telephone Channels	24 - 1872
Pre-emphasis & Weighting	CCIR
4. Noise Objectives:	
Telephony	10,000 pWp (in any hour)
TV	54 dB (SNR)

TABLE B-3
WESTAR

Space Segment

1. Satellite	WESTAR (by Hughes), similar to Anik
2. Number of Transponders	12 + 2 spares
3. Transponder Type	RF Translating; Hard Limited for Single Carrier Linear for Dual Carrier (requires 7 dB backoff per carrier relative to single access.
4. Bandwidth per Transponder	40 MHz nominal, 36 MHz usable
5. G/T of Satellite	-7.4 dB/°K (CONUS)
6. EIRP of Satellite	33 dBW (design spec, CONUS) 35 dBW (nominal, CONUS) 27 dBW (nominal, Hawaii)
7. Satellite Antenna	Parabolic, 5' diameter, 4 feeds, Gain = Coverage: CONUS + Alaska + Puerto Rico (3 feeds), Hawaii (1 feed)
8. De-spin Mechanism	Mechanical + "SUDS" (Backup De-spin System)
9. Expected Lifetime	7 years
10. Launch Date	13 April 1974; 10 October 1974
11. Launch Vehicle	3 stage 2914 Delta
12. Size: Height Diameter	3.45 m 1.9 m
13. Weight	306 kg. (after apogee burn)
14. Location	99°W, 123.5°W

Earth Segment

1. Earth Terminals	Glenwood (N.J.) Atlanta, Chicago, Dallas, Los Angeles
2. Antennas	Parabolic, 51' diameter, Cassegrain feed, Gain = 57 dB
3. G/T of Earth Station	37.4 dB/°K
4. EIRP of Earth Station	83.0 dBW
5. Tracking	Auto-track (monitors received signal strength).

Frequency Plan

1. Frequency Band	4/6 GHz
2. Frequency Plan	Downlink: 3720-4160 MHz in 40 MHz increments (HP); Uplink: 5945-6385 MHz in 40 MHz increments (VP); Beacon: 4200 MHz; Command: 6420 MHz
3. Traffic per Transponder	1200 FDM/FM voice channels (single carrier), or 240-360 FDM/FM voice channels (dual carrier) or 1 Color TV
4. Multiple Access Technique	FDMA with two models: Single carrier per transponder & dual carrier (± 7MHz) per transponder

Modulation

1. R-F carrier	
Type	FM
Test Tone Deviation (0 dB_m0)	650 kHz (rms)
Carrier Deviation, Telephony	24.0 MHz (pk-pk)
Carrier Deviation, TV	17.3 MHz (pk-pk)
2. TV Audio Sub-carrier	
Frequency	6.2 MHz (typical)
r-f carrier deviation	879 kHz (pk)
sub-carrier deviation	75 kHz (pk)
sound channel	10 Hz - 15 kHz
3. FDM Baseband	
Number Telephone Channels	1200 (may include TTY, high speed data)
Pre-emphases & Weighting	CCIR (Telephony) EIA (TV)
4. Noise Objectives:	
Telephony	10,000 pWpO
TV	56 dB (pk-pk signal including sync tips-rms (weighted noise)

B.2 PERFORMANCE OBJECTIVES

An old maxim states, "you get what you pay for." To illustrate the veracity of this maxim as it applies to the relation between the cost of electronics equipment and the quality of the information extracted, one need only consider commercial broadcast reception: a customized, high-fidelity (hi-fi) radio receiver will cost considerably more than an off-the-shelf, low-fidelity radio receiver. This qualitative relation between cost and quality also extends to the reception of radio communication circuits. A quantitative assessment of radio communication circuit vulnerability to interception, however, as measured, for example, in terms of the interceptor's equipment cost and complexity, necessarily requires a quantitative measure for the quality of the information extracted.

The quantitative quality measures employed depend upon the character of the information. For digital information, the performance (quality) measure is typically one of accuracy: e.g., the bit- or character-error-rate (BER or CER) defined to be the fraction of received bits or characters in error. For analog information, the performance measure is typically some subjective measure of fidelity. Because of its subjective character, fidelity measures of analog information are usually quantified on the basis of statistics derived from polling subscribers.

Several organizations (e.g., the International Telecommunications Union, the Bell System, and the Electronic Industries Association) have published recommendations, regulations, rules, and standards relating to quantitative performance measures as a guide to system architects, engineers, and planners in ensuring subscriber satisfaction. However, in contradistinction to authorized subscribers who typically demand high quality performance, an interceptor is likely to be more tolerant of poor quality performance. In the following sections, quantitative performance objectives for several types of traffic will be proposed which for authorized subscribers would be only marginally acceptable but for the presumed more tolerant interceptor would be quite adequate.

B.2.1 Telephony

The quality or performance of a telephony channel depends upon the received level of (1) acoustic speech pressure, (2) additive noise, and (3) distortion. For an interceptor desirous of minimizing equipment costs and the possibility of detection, additive noise thermally generated within the radio equipment, will prove to be the dominant performance limiting factor by far. Several organizations have suggested maximum allowable levels necessary for ensuring subscriber satisfaction. For example, the International Telecommunications Union recommends* that, for a hypothetical terrestrial microwave system 2500 km in length, the mean psophometrically-weighted noise power at a zero TLP not exceed 10,000 pwpo (including an allowance of 2500 pwpo for multiplex equipment). The Bell System recommends** that, for a hypothetical terrestrial microwave system 4000 statute miles in length, the mean c-message weighted noise power at a zero TLP not exceed 40 dBrnc0. The U.S. military recommends*** that, with a mean received speech volume of -28 vu, the level of noise power for acceptable service be set at 44 dBrnc at the line terminals of

* CCIR Recommendations 393-1.

** Bell Telephone Laboratories, "Transmission Systems for Communications (1971), pg. 52.

*** Military Standard 188-100, paragraph 4.2.2.3

the subscriber telephone set. It is important to note that all of these recommendations relate to subscriber satisfaction; an unauthorized receiver is likely to be considerably more tolerant of less-than-toll-quality performance.

A noise performance objective more consistent with unauthorized reception can be obtained by considering the statistics derived from a subjective performance evaluation study of subscribers. The results of one study, conducted by the Bell system, are presented in Figure B-1. To compare these curves with the standards cited in the previous paragraph, it is first necessary to refer the noise level measured at the subscriber terminals to a 0 TLP. Since the TLP of the subscriber terminals is not specified, an approximate translation can be effected by noting that the mean speech volume at a 0 TLP is typically -18 vu. Since the mean speech volume at the subscriber set is -28 vu, it may be assumed that the subscriber set is a -10 TLP. Accordingly, the noise levels at the line terminals may be expressed in dBrnc0 by simply adding 10 dB to the values of the abcissa. The Bell System 4000-statute mile objective of 40 dBrnc0, the CCIR 2500-kilometer objective of 10,000 pwpo (40 dBrnc0), and the U.S. military standard of 44 dBrnc at the line terminals (54 dBrnc0) are also indicated in Figure B-1. The Bell System and CCIR standards would provide excellent customer satisfaction to about 50 percent of the subscribers and fair-or-worse customer satisfaction to less than 1 percent of the subscribers. The U.S. military standard would provide good-or-better customer satisfaction to about 23 per cent of the subscribers and unsatisfactory customer satisfaction to less than 1 percent of the subscribers. For an interceptor a reasonable performance objective appears to be 65 dBrnc0; fewer than 50 percent of the authorized subscribers would consider such performance unsatisfactory.

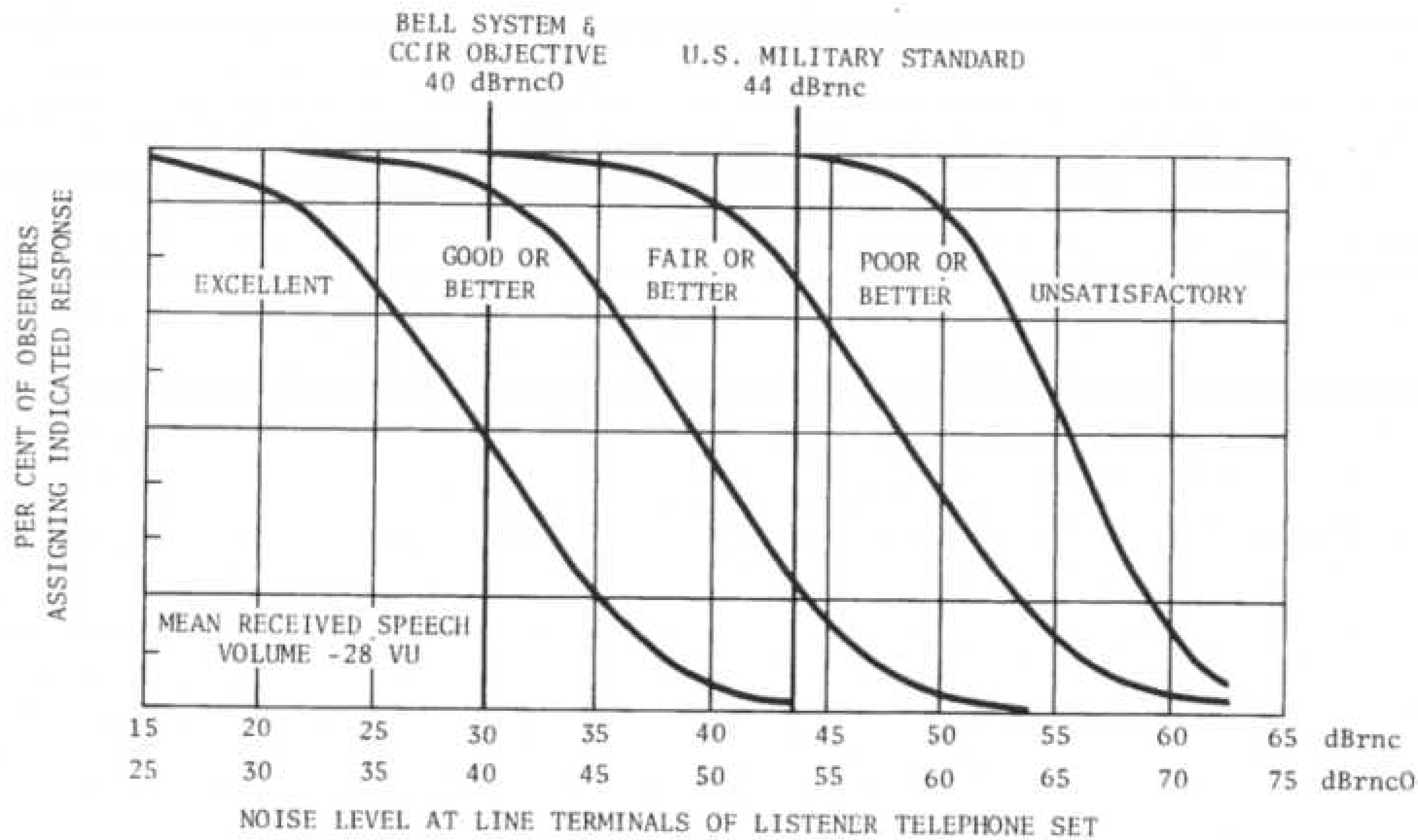

FIGURE B-1
SUBJECTIVE RATINGS OF RECEIVED NOISE POWER

In the design of radio communication systems, it is often found more convenient to express performance objectives in terms of the signal-to-noise ratio (SNR) rather than in terms of the noise level at a 0 TLP. The signal typically considered is a sinusoidal test-tone of level 0 dBm0, rather than the speech level itself. The noise level may also be expressed in dBm0 by employing the relation

$$N(dBm0) = N(dBrnc0) - 88$$

Accordingly,

$$SNR = 88 - N(dBrnc0)$$

and the interceptor performance objective of 65 dBrnco is equivalent to a test-tone signal-to-noise (unweighted) ratio of 23 dB.

B.2.2 Television (Video)

As with telephony, the performance quality measures for television are subjective in character. According to the Television Allocation Study Organization* (TASO), the subjective evaluations of picture quality may be related to the signal-to-noise ratios in the following manner:

- Excellent (no perceptible snow) .... 45 dB
- Fine (snow just perceptible) .... 35 dB
- Passable (snow definitely perceptible but not objectionable) .... 29 dB
- Marginal (snow somewhat objectionable) ..... 25 dB

It should be noted that for video transmission, the signal-to-noise ratio is typically measured (in the United States) as the voltage ratio of the peak-to-peak signal, excluding the sync tips, to the weighted rms noise.

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*Television Allocation Study Organization, "Report to the FCC", March 16, 1959

For an interceptor, a signal-to-noise ratio of 25 dB appears acceptable.

B.2.3 Voice Frequency Carrier Telegraph (VFCT)

The 4 kHz channels normally employed for telephony can also be used for the transmission of digital data. For narrow-band data with transmission rates not exceeding 1200 baud (e.g., teletype (TTY) and Telex), non-coherently detected Frequency-Shift-Keying (FSK) is the modulation technique most often employed. Suitable multiplexing systems exist to permit several VFCT channels to occupy a single 4-kHz telephone channel. A sixteen (16) channel Frequency Division Multiplex (FDM) system employing 170-Hz channel spacing and ± 42.5 Hz frequency shifts is detailed in Table B-4.

Most VFCT are asynchronous and employ a 7-unit Baudot code with start and stop bits identifying the beginning and end of a single character. A 100 wpm TTY system employing the 7-unit Baudot code transmits data at 75 baud; a 66-2/3 wpm Telex system at 50 baud.

A signal design objective for VFCT is a bit-error rate (BER) of 10^{-5}. The signal-to-noise ratio (SNR) required to achieve the BER is about 18 dB. Since for the FDM-FM system; most often employed for VFCT this SNR is nearly always achieved if the received carrier level exceeds the carrier-to-noise ratio (CNR) threshold of the FM discriminator, (typically 10 dB), the interceptor's performance objective for VFCT will be taken as a CNR no less than 10 dB.

TABLE B-4

16-CHANNEL SYSTEM CENTER, MARK, AND SPACE FREQUENCIES

CHANNEL DESIGNATION	MARK FREQUENCY (Hz)	CENTER FREQUENCY (Hz)	SPACE FREQUENCY (Hz)
1	382.5	425	467.5
2	552.5	595	637.5
3	722.5	765	807.5
4	892.5	935	977.5
5	1062.5	1105	1147.5
6	1232.5	1275	1317.5
7	1402.5	1445	1487.5
8	1572.5	1615	1657.5
9	1742.5	1785	1827.5
10	1912.5	1955	1997.5
11	2082.5	2125	2167.5
12	2252.5	2295	2337.5
13	2422.5	2465	2507.5
14	2592.5	2635	2677.5
15	2762.5	2805	2847.5
16	2932.5	2975	3017.5

B.3 ANALYSIS RATIONALE

In the previous section, B.2, it is shown that the performance objectives of several types of traffic frequently carried on microwave communication systems could be expressed in terms of the minimum allowable signal-to-noise ratio. For the FM modems which typify most terrestrial microwave and satellite systems, the signal-to-noise ratio (SNR) of the traffic can be related to the carrier-to-noise density ratio (C/No) of the r-f carrier with the help of the modulation parameters. The carrier-to-noise density ratio can, in turn, be related to the r-f parameters. Because the number of parameters characterizing the performance of a microwave radio system is so large, the analysis of radio system vulnerability can be considerably simplified if several of these parameters can be grouped together and employed as one.

In this section an analysis rationale is developed which seeks to simplify the quantitative assessment of radio system vulnerability to interception by introducing certain so-called figures-of-merit which can be used to simplify the characterization of the target system, the traffic, and the system employed for reception. The application of the figures-of-merit developed in this section to the vulnerability analysis is deferred until Sections B-4 and B-5.

B.3.1 Modulation Performance

B.3.1.1 EDM-FM Telephony

For an FDM-FM telephony system, the rms test-tone signal-to-noise ratio may be related to the radio system parameters by the expression

$$SNR = \left(\frac{C}{No}\right)_R \left(\frac{f_r}{f_m}\right)^2 \left(\frac{1}{b}\right)(pe)(w) \qquad \text{(B-1)}$$

where

f_r = rms frequency deviation of 0dBm0 test-tone

f_m = highest baseband frequency

b = voice-channel bandwidth (3.1 kHz)

pe = pre-emphasis gain at f_m

w = voice-channel noise weighting

The signal-to-noise ratio, SNR, may also be expressed in decibels:

$$SNR = C/No + 20 \log_{10}(f_r/f_m) - 10 \log_{10} b + pe + w \quad (B-2)$$

An alternate representation of Equation (B-1), particularly useful for radio communication systems operating near the FM discriminator threshold, is afforded by

$$SNR = (\frac{C}{N})_R (\frac{f_r}{f_m})^2 (\frac{B}{b})(pe)(w) \quad (B-3)$$

where C/N_R is the received carrier-to-noise ratio is measured in the pre-detection bandwidth, B. When expressed in decibels, Equation (B-2) acquires the form

$$SNR = (C/N)_R + 20 \log_{10}(f_r/f_m) + 10 \log_{10}(B/b) + pe + w \quad (B-4)$$

When the $(C/N)_R$ is below the discriminator threshold,* the SNR is found to decrease with $(C/N)_R$ much more rapidly than the linear relation predicted by Equations (B-3) and (B-4); as a consequence, below threshold Equations (B-3) and (B-4) cease to remain valid. In contradistinction to Equations (B-1) and (B-2), the application of Equations (B-3) and (B-4) requires the evaluation of the received carrier-to-noise ratio, $(C/N)_R$; a comparison of this value with the discriminator threshold provides an immediate check on the validity of the computation.

---

*For FM limiter-discriminators (e.g., the Foster-Seeley type), the threshold value of C/N_R is about 10 dB.

B.3.1.2 Television (Video Only)

For radio communication systems employing television, the performance requirements are most usually specified in terms of the peak-to-peak signal to rms (weighted) noise voltage ratio as measured at the video connection point across 75 ohms. At this connection point the composite video signal (including sync tips) is nominally 1 volt, peak-to-peak.

For the transmission of the video signal as the baseband of an FM system, the peak-to-peak signal to rms (weighted) noise voltage ratio may be related to the radio system parameters by the expression

$$\frac{V_{p-t-p}}{N_{rms}} = \frac{f_{pp}}{f_m^{3/2}} \sqrt{3 \left(\frac{C}{No}\right)_R}\; d \qquad \text{(B-5)}$$

where,

f_{pp} = peak-to-peak deviation of the r-f carrier

f_m = upper limit of the video baseband (4.2 MHz for NTSC)

d = factor accounting for pre-emphasis and weighting

If the voltage ratio of Equation (B-5) is expressed in decibels,

$$\left.\frac{V_{p-t-p}}{N_{rms}}\right|_{dB} = (C/No)_R + 4.77 + 20 \log_{10} f_{pp} - 30 \log_{10} f_m + D \qquad \text{(B-6)}$$

If the carrier-to-noise ratio of the discriminator input is introduced, Equation (B-6) becomes

$$\left.\frac{V_{p-t-p}}{N_{rms}}\right|_{dB} = (C/N)_R + 4.77 + 20 \log_{10} (f_{pp}/f_m) + 10 \log_{10}(B/f_m) + D \qquad \text{(B-7)}$$

where

B = pre-detection bandwidth

Contrary to North American (Bell) practices, the CCIR (and Intelsat) define the signal to exclude the synchronizing pulses so that

$$S_{p-t-p} = 0.7\ V_{p-t-p} \qquad \text{(B-8)}$$

and

$$\frac{S_{p-t-p}}{N_{rms}} = \frac{f_{pp}}{f_m^{3/2}} \sqrt{\frac{3}{2} \left(\frac{C}{No}\right)_R}\ d \qquad \text{(B-9)}$$

or, in decibels,

$$\frac{S_{p-t-p}}{N_{rms}}_{dB} = (C/No)_R + 1.76 + 20 \log_{10} f_{pp} - 30 \log_{10} f_m + D \qquad \text{(B-10)}$$

or,

$$\frac{S_{p-t-p}}{N_{rms}}_{dB} = (C/N)_R + 1.76 + 20 \log_{10} (f_{pp}/f_m) + 10 \log_{10} (B/f_m) + D \qquad \text{(B-11)}$$

B.3.2 r-f Performance

B.3.2.1 Terrestrial Microwave System

For a terrestrial microwave system, performance is typically limited by a single (worst) link -- for the interception problem addressed in this study, the worst link will be terminated by the interceptor's receiver. Thus, the received carrier-to-noise density ratio may be calculated directly from the transmission parameters of the intercepting link so that (in decibels)

$$C/No = C - No \qquad \text{(B-12)}$$

where,

$$C = P_t + G_t + G_r - (L_p + L_{wg,t} + L_{wg,r} + L_{f,t} + L_{f,r}) \qquad \text{(B-13)}$$

$$No = 10 \log_{10} (nkTo) \qquad \text{(B-14)}$$

and

P_t = radiated power of transmitter

G_t, G_r = antenna gains of transmitter and receiver, respectively

L_p = propagation loss

$L_{wg,t}, L_{wg,r}$ = feeder (waveguide or coaxial cable) loss of transmitter and receiver, respectively

$L_{f,t}, L_{f,t}$ = filter, duplexer and/or circulator loss of transmitter and receiver, respectively

n = receiver noise figure

k = Boltzmann's constant (1.38×10^{-23} joules/°K)

To = reference temperature (290°K)

B.3.2.2 Satellite Systems

The received carrier-to-noise density ratio, $(C/No)_R$, of a satellite communications system may be expressed as

$$\left(\frac{C}{No}\right)_R^{-1} = \left(\frac{C}{No}\right)_U^{-1} + \left(\frac{C}{No}\right)_I^{-1} + \left(\frac{C}{No}\right)_D^{-1} \qquad \text{(B-15)}$$

where

$(C/No)_U$ = carrier-to-noise density ratio of the up-link

$(C/No)_D$ = carrier-to-noise density ratio of the down-link

$(C/No)_I$ = equivalent carrier-to-noise density ratio associated with intermodulation noise created in the satellite transponder

If, as for a terrestrial system, performance is limited by the interceptor's link, then to a good approximation

$$(C/No)_R = (C/No)_D \tag{B-16}$$

The carrier-to-noise density of the down-link, $(C/No)_D$, can be expressed in several equivalent forms depending upon whether the transmitter (the satellite) is characterized by its radiated power (P_t), effective radiated power (e.i.r.p.), or its flux density (Φ). Accordingly,

$$(C/No)_D = \begin{cases} P_t + G_t - L_p + 228.6 + (G/T) \\ \text{e.i.r.p.} - L_p + 228.6 + (G/T) \\ \Phi - 20 \log_{10} f_{MHz} + 267.2 + (G/T) \end{cases} \tag{B-17}$$

where,

L_p = (free-space) propagation loss

G = antenna gain of the receiving earth station

T = receiving system noise temperature of the receiving earth station

It is apparent from Equation (B-17) that the fundamental parameter characterizing the interceptor's receiving earth station is the ratio G/T.

B.3.3 Figures-of-Merit

B.3.3.1 FDM-FM Telephony

According to Equation (B-1), the test-tone signal-to-noise ratio (SNR) in the top FDM telephone channel may be determined from the expression

$$SNR = \left(\frac{C}{No}\right) \left(\frac{f_r}{f_m}\right)^2 \left(\frac{1}{b}\right) (pe) \; (w) \tag{B-18}$$

For terrestrial microwave systems, the carrier-to-noise density ratio, C/No, is expressed by Equation (B-13) so that

$$C = P_t + G_t + G_r \quad (L_p + L_{wg,t} + L_{wg,r} + L_{f,t} + L_{f,r}) \tag{B-19}$$

$$No = 10 \log_{10} (nkTo) \tag{B-20}$$

For satellite systems, the carrier-to-noise density ratio may, according to Equation (B-17) be written in either of the alternative forms

$$C/No = \begin{cases} P_t + G_t - L_p + 228.6 + G/T \\ e.i.r.p. - L_p + 228.6 + G/T \end{cases} \tag{B-21}$$

All of the parameters employed here, except one (L_p), may be identified as being uniquely related to (1) the (terrestrial or satellite) microwave system targeted for interception [e.g., P_t, G_t, $L_{wg,t}$, $L_{f,t}$, e.i.r.p.], (2) the receiving system employed for interception [e.g., n, G_r, $L_{wg,r}$, $L_{f,t}$, G/T], or (3) the modulation system [e.g., f_r, f_m, b, pe, w]. Consequently, it will be found convenient to define the following figures-of-merit which condense all of the above parameters into three, easily managed factors. Hence, for terrestrial systems,

$$\eta_t \triangleq P_t + G_t - L_{wg,t} - L_{f,t} \tag{B-22}$$

$$\eta_r \triangleq G_r - L_{wg,r} - L_{f,r} - 10 \log_{10} (nkTB); \tag{B-23}$$

for satellite systems,

$$\eta_t \triangleq P_t + G_t = e.i.r.p. \tag{B-24}$$

$$\eta_r \triangleq (G/T) - 10 \log_{10} (kB) \tag{B-25}$$

and, for both systems,

$$\eta_{FDM} \triangleq 20 \log_{10} (f_r/f_m) + \log_{10} (B/b) + pe + w \qquad \text{(B-26)}$$

The pre-detection bandwidth, B, has been introduced and compensated to simplify the claculation of the received carrier-to-noise ratio, CNR.

In terms of these figures-of-merit, the received carrier-to-noise ratio of the interceptor as measured in the pre-detection bandwidth, B, may be expressed as

$$CNR = \eta_t + \eta_r - L_p \qquad \text{(B-27)}$$

The test-tone signal-to-rms noise ratio in the top FDM channel may be written as

$$SNR = \eta_t + \eta_r + \eta_{FDM} - L_p \qquad \text{(B-28)}$$

The utility of Equations (B-27) and (B-28) to the r-f intercept problem will be addressed in Sections B.4 and B.5.

B.3.3.2 Television (Video)

In a manner similar to that employed for FDM-FM telephony, figures-of-merit can also be defined for the transmission of television. According to Equation (B-5) the peak-to-peak signal-to-rms (weighted) noise voltage may be determined from the expression

$$\frac{V_{p-t-p}}{N_{rms}} = \frac{f_{pp}}{f_m^{3/2}} \sqrt{3 \left(\frac{C}{No}\right)} \, d \qquad \text{(B-29)}$$

Taking cognizance of Equation (B-20), Equation (B-29) may be re-written in the form

$$\left.\frac{V_{p-t-p}}{N_{rms}}\right|_{dB} = C - 10 \log_{10} (nkTo) + 20 \log_{10} f_{pp} - 30 \log_{10} f_m + 10 \log_{10} 3 + D \qquad \text{(B-30)}$$

Comparison of Equation (B-29) with Equation (B-18) reveals that in view of Equation (B-26) the figure-of-merit for television modulation may be written as

$$\eta_{tv} = 20 \log_{10} (f_{pp}/f_m) + 10 \log_{10} (B/f_m) + 10 \log_{10} 3 + D \qquad \text{(B-31)}$$

The transmitter and receiver figures-of-merit, given by Equations (B-27) and (B-28), respectively, remain unchanged.

B.4 TERRESTRIAL SYSTEMS

The susceptability of terrestrial microwave systems to r-f interception is engendered by the inadvertent (and, often, unavoidable) radiation of electromagnetic energy in directions other than toward the intended terrestrial receiver. Most of the unintentional emission arises as a result of the non-zero angular width of the main antenna lobe which is directed toward the intended receiver and inadvertent radiation from side- and back-lobes. The azimuthal dependence of the AT&T horn-reflector antenna KS-15676, the predominant antenna type employed by the Bell System, is described by the antenna gain patterns of Figure B-2.

In the following section, Section B.4.1, a methodology is developed to assess the vulnerability of terrestrial microwave systems to clandestine interception. In Section B.4.2, this methodology is exemplified by evaluating, quantitatively, the vulnerability of the Western Electric TD-2 microwave system. This choice of the TD-2 system as an illustrative example of the methodology is particularly well suited to this study since (1) the TD-2 system characteristics (refer to Section 3.1) typify nearly all well designed terrestrial microwave systems operating in the crowded 2-, 4-, and 6-GHz frequency bands, and (2) the TD-2 system is employed within the AT&T Long Lines to provide nearly 60 percent of all circuit-kilometers.

B.4.1 Methodology for Interception

The successful interception of any terrestrial microwave system requires satisfaction of the following two criteria: (1) the CNR of the intercepted carrier should exceed any discriminator threshold (nominally about 10 dB for typical FM discriminators); and (2) the SNR of the intercepted traffic should exceed the minimum required for the extraction of intelligibility (refer to Section B.2). For any specific performance objectives of the interceptor, say, $SNR|_{min}$ and

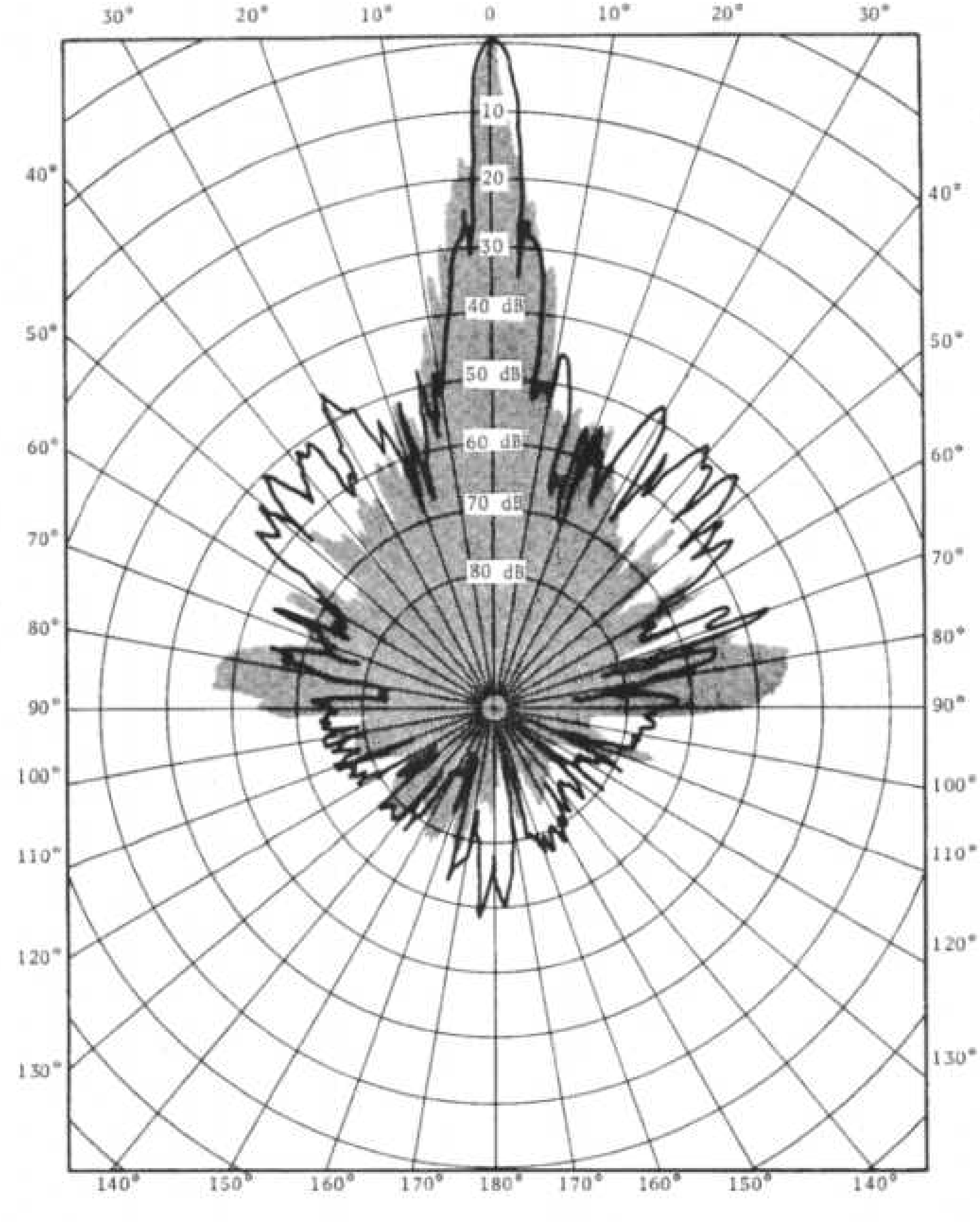


FIGURE B-2
AZIMUTHAL DIRECTIVITY GAIN PATTERN FOR AT&T HORN-REFLECTOR KS-15676 AT 4 GHz FOR VERTICAL (OPEN) AND HORIZONTAL (SHADED) POLARIZATION

CNR_{min}, the controlling criterion may be determined from the following inequalities:

$$SNR|_{min} - CNR|_{min} < \eta_{mod} \rightarrow \text{Criterion (1) controlling} \quad (B-32)$$

$$SNR|_{min} - CNR|_{min} > \eta_{mod} \rightarrow \text{Criterion (2) controlling} \quad (B-33)$$

Thus, the controlling criterion depends only upon the performance objective of the interceptor (refer to Section B-2) and the modulation characteristics of the targeted traffic.

The maximum range or distance separating the targeted terrestrial microwave system transmitters from the interceptor's receiver depends only upon the maximum acceptable propagation loss, $L_p(\max)$. Depending upon which performance limiting criterion is controlling,

$$L_p \leq \eta_t + \eta_r - CNR|_{min} \quad \text{(Criterion 1)} \quad (B-34)$$

$$L_p \leq \eta_t + \eta_r + \eta_{mod} - SNR|_{min} \quad \text{(Criterion 2)} \quad (B-35)$$

Consideration of Inequalities (B-34) and (B-35) reveals, in the light of the defining relations for η_t, η_r, and η_{mod} [Equations (B-22), (B-28), and (B-26)] that for specific target systems, where $CNR/_{min}$, $SNR/_{min}$ and η_{mod} are constant, η_t and η_r are azimuthally dependent variables as a consequence of their dependence upon the antenna gains G_t and G_r. Thus, either inequality can be written in the form

$$L_p \leq f_t(\theta) + f_r(\theta) + \text{constant} = L_p(\max) \quad (B-36)$$

where the functions $f_t(\theta)$ and $f_r(\theta)$ reflect, respectively, the azimuthal dependence of the antenna gain relative to bore-sight for the target microwave system's transmitting antenna and the interceptor's receiving antenna. Since the interceptor has the freedom to orient the receiving antenna to achieve bore-sight gain, it may be assumed that

$$L_p \leq f_t\ (\theta) + \text{constant} = L_p\ (\max) \qquad \text{(B-37)}$$

The maximum range corresponding to the maximum acceptable transmission loss depends upon a multiplicity of factors which affect propagation: carrier frequency, obstacle clearance, defraction, refraction, terrain roughness, etc. A model which accounts for these and other factors, however, has been developed by the ESSA Research Laboratories of the U.S. Department of Commerce*. This model, in consonance with the preceeding analysis, provides the basis of a methodology for assessing the vulnerability of terrestrial microwave systems to interference.

B.4.2 Example: Vulnerability of the TD-2 Microwave System

The methodology described above in Section B.4.1 may be exemplified by evaluating the vulnerability of the Western Electric TD-2 microwave system. Three different equipment configurations (I, II, and III) will be postulated for the interceptor: Equipment Configuration I will be based upon a TD-2 radio receiver and a large, ten-foot diameter parabolic receiving antenna; Equipment Configuration II will also employ a TD-2 radio receiver but a small, standard-gain horn antenna, and Equipment Configuration III will employ a compact, surveillance receiver and a small, standard-gain horn. Equipment Configuration I, which is essentially equivalent to the receiving system employed by the TD-2 system itself, should provide a reasonable upper-bound on TD-2 system vulnerability. Further details on the characteristics of these interceptor equipment configurations can be found in Table B-5.

* A. G. Longley and P. L. Rice, "Prediction of Tropospheric Radio Transmission Loss over Irregular Terrain," ESSA Technical Report ERL-79 - ITS 67 (July, 1968).

On the basis of Section B.4.1 and the assumption of a 10 dB CNR discriminator threshold, the interceptor performance objectives will be

$$CNR \geq CNR|_{min} = 10 dB, \quad SNR \geq SNR|_{min} = 23 \text{ dB}$$

Inequalities (B-32) and (B-33) of the Methodology will be employed to determine which of these two objectives is controlling; first, however, it is necessary to compute the modulation figure-of-merit, η_{mod} (η_{FDM}). For the Western Electric TD-2 microwave system

f_r = 100 kHz	b = 3.1 kHz
f_m = 5684 kHz	PE = 9.0 dB
B = 35 MHz	W = 1.5 dB

Thus, according to Equation (B-26)

$$\eta_{FDM} = 20 \log_{10}(100/5684) + 10 \log_{10}(35{,}000/3.1) + 9 + 1.5$$

$$\eta_{FDM} = 15.9 \text{ dB}$$

Since

$$SNR|_{min} - CNR|_{min} = 13 \text{ dB},$$

$$SNR|_{min} - CNR|_{min} \leq \eta_{FDM}$$

and, according to Inequality (B-32), criterion (1) will be controlling (i.e., if the CNR is in excess of 10 dB, the SNR will be in excess of 23 dB.

Under the constraint that criterion (1) is controlling, inequality (B-34) can be employed to assess, quantitatively, the vulnerability of the TD-2 system to interception. Consider, first, the vulnerability of the TD-2 system to receiving Equipment Configuration I. Noting that the electrical characteristics of Configuration I receiving system are essentially the same as the TD-2 radio receiving system, the sum of the transmission figure-of-merit and the interceptor's receiver figure-of merit can be derived directly from the data provided in Table B-1. Using the relation

$$\eta_t + \eta_r = P_t - (\text{Section Loss} - \text{Free Space Loss}) - 10 \log_{10} nkTB \quad \text{(B-38)}$$

Thus,

$$\eta_t + \eta_r = 33.0 - 65.3 + 136.6 - 7.5 + 173 - 10 \log_{10} (35 \times 10^6) + F_t(\theta) \quad \text{(B-39)}$$

$$\eta_t + \eta_t = F_t(\theta) + 194.4 \text{ dB} \quad \text{(B-40)}$$

In the equations above, the azimuthal gain dependence of the target TD-2's transmitting antenna system relative to bore-sight, $F_t(\theta)$, has been introduced to account for the possibility that the interceptor may be located off bore-sight. A reasonable estimate of $F_t(\theta)$ for the TD-2 antenna system, derived by smoothing the antenna gain patterns of Figure B-2, is presented in Figure B-3.

Thus, according to Inequality (B-34), the allowable transmission loss between the targeted TD-2 system's transmitting antenna and the interceptor's receiving antenna satisfies the Inequalities,

$$L_p \leq \eta_t + \eta_r - CNR|_{min} \quad \text{(B-41)}$$

$$L_p \leq 194.3 + F_t(\theta) \quad \text{(B-42)}$$

Consider, now the interception of a TD-2 system having a repeater site spacing (d_s) of 50 km (refer to Figure B-4). To intercept westbound traffic the interceptor's receiving antenna at site I will be oriented either (1) toward site A to intercept westward-propagated, front-lobe radiation [transmission path A], or (2) toward site B to intercept eastward-propagated, back-lobe radiation [transmission path B]. Successful interception of the westbound traffic thus requires either

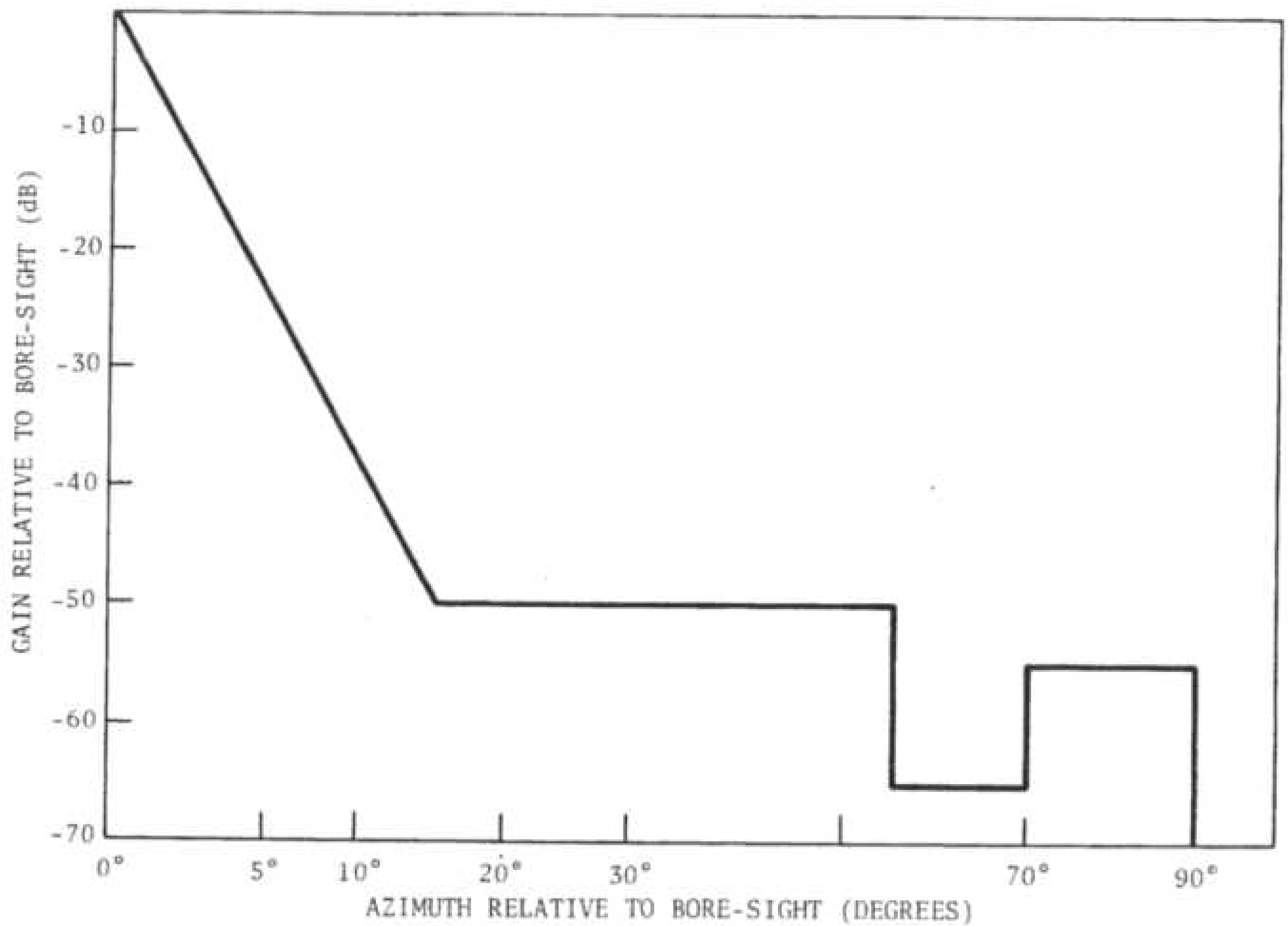


FIGURE B-3
SMOOTHED RADIATION PATTERN
(AT&T Horn Reflector Antenna KS-15676 @ 4 GH_z)

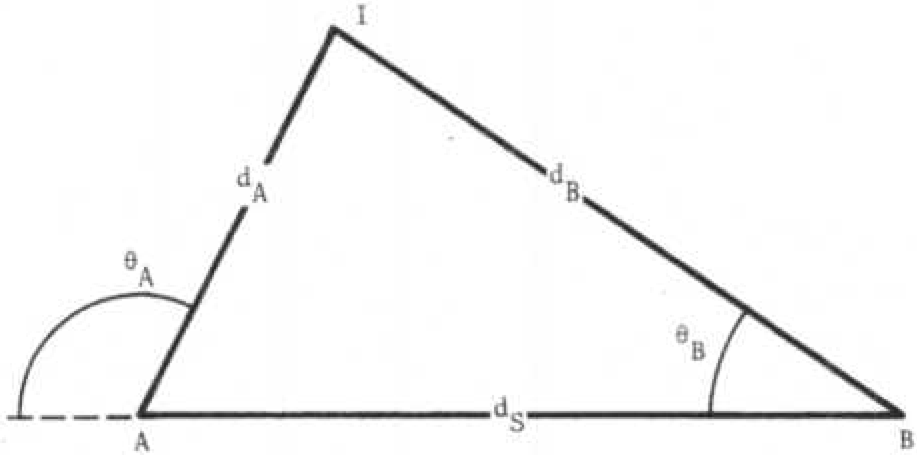


FIGURE B-4
INTERCEPTOR PROPAGATION PATH GEOMETRY

$$L_p(A) \leq f_t(\theta_A) + 194.4 \qquad (0 \leq \theta_A \leq 90^\circ) \qquad \text{(B-43)}$$

$$L_p(B) \leq f_t(\theta_B) + 194.4 \qquad (90^\circ \leq \theta_B \leq 180^\circ) \qquad \text{(B-44)}$$

depending upon the orientation of the interceptor's receiving antenna.

The maximum acceptable propagation loss for the transmission path A and B is given, respectively, by the right-hand sides of Inequalities (B-43) and (B-44). The maximum ranges between the targeted TD-2 system's transmitting antenna and the interceptor's receiving antenna consistent with these losses is summarized in Table B-5 as a function of the angular variables θ_A and θ_B. The function relation between the transmission loss and distance has been derived from the ESSA propagation model for a choice of parameters consistent with the TD-2 microwave relay system and rights-of-way in the continental U.S.: antenna heights of the targeted TD-2 system repeaters at sites A and B (h_A and h_B, respectively) equal to 50 meters; antenna height of the interceptor also equal to 50 meters; interdecile (10-90 percent) probability for the hilltop-to-valley height of 90 meters; and r-f carrier frequency of 4 GHz. The dependence of the transmission loss with distance, derived on the basis of these postulates, is shown in Figure B-5.

The data of Table B-5 are sufficient to determine the loci of interception sites within which the TD-2 terrestrial microwave system can be successfully intercepted bi-directionally. In Figures B-6 through B-8 loci are plotted as contours for each of the three interceptor configurations (I, II, and III). Each figure corresponds to a different repeater site spacing (d_s) of the targeted TD-2 system: 30, 40, or 50 kilometers. The details of selected loci in the vicinity of the target TD-2 system repeaters are shown in Figures B-9 through B-11. For these loci the propagation loss is due only to free-space geometric spreading and the loci exhibit much of the azimuthal dependence of the TD-2 antenna gain.

TABLE B-5

TD-2 INTERCEPTION: SUMMARY OF MAXIMUM RANGES

		Interceptor's Equipment Configuration*					
		I		II		III	
$\|\theta_{A,B}\|$	$F_t(\theta)$	L_p(dB)	d(km)	L_p(dB)	d(km)	L_p(dB)	d(km)
0°	0dB	184.4	74.0	161.4	52.0	148.9	41.0
5°	-24.0	160.4	51.0	137.4	31.0	124.9	10.1
10°	-38.5	145.9	38.0	122.9	8.5	110.4	2.0
15°	-50.0	134.4	36.0	111.4	2.2	98.9	0.5
20°	-50.0	134.4	36.0	111.4	2.2	98.9	0.5
30°	-50.0	134.4	36.0	111.4	2.2	98.9	0.5
40°	-50.0	134.4	36.0	111.4	2.2	98.9	0.5
50°	-50.0	134.4	36.0	111.4	2.2	98.9	0.5
60°	-65.0	119.4	5.5	96.4	0.4	83.9	0.1
80°	-55.0	129.4	17.5	106.4	1.2	93.9	0.3
100°	-75.0	109.4	1.8	86.4	0.1	73.9	-
120°	-75.0	109.4	1.8	86.4	0.1	73.9	-
140°	-75.0	109.4	1.8	86.4	0.1	73.9	-
160°	-75.0	109.4	1.8	86.4	0.1	73.9	-
180°	-70.0	114.4	3.1	91.4	0.2	78.9	0.1

---

*Equipment Configuration I: TD-2 RCVR (NF = 7.5 dB)
10' diameter parabolic reflector (Gain = 39.5 dB)

Equipment Configuration II: TD-2 RCVR (NF = 7.5 dB)
Small Horn (Gain = 16.5 dB)

Equipment Configuration III: Surveillance RCVR (NF = 20 dB)
Small Horn (Gain = 16.5 dB)

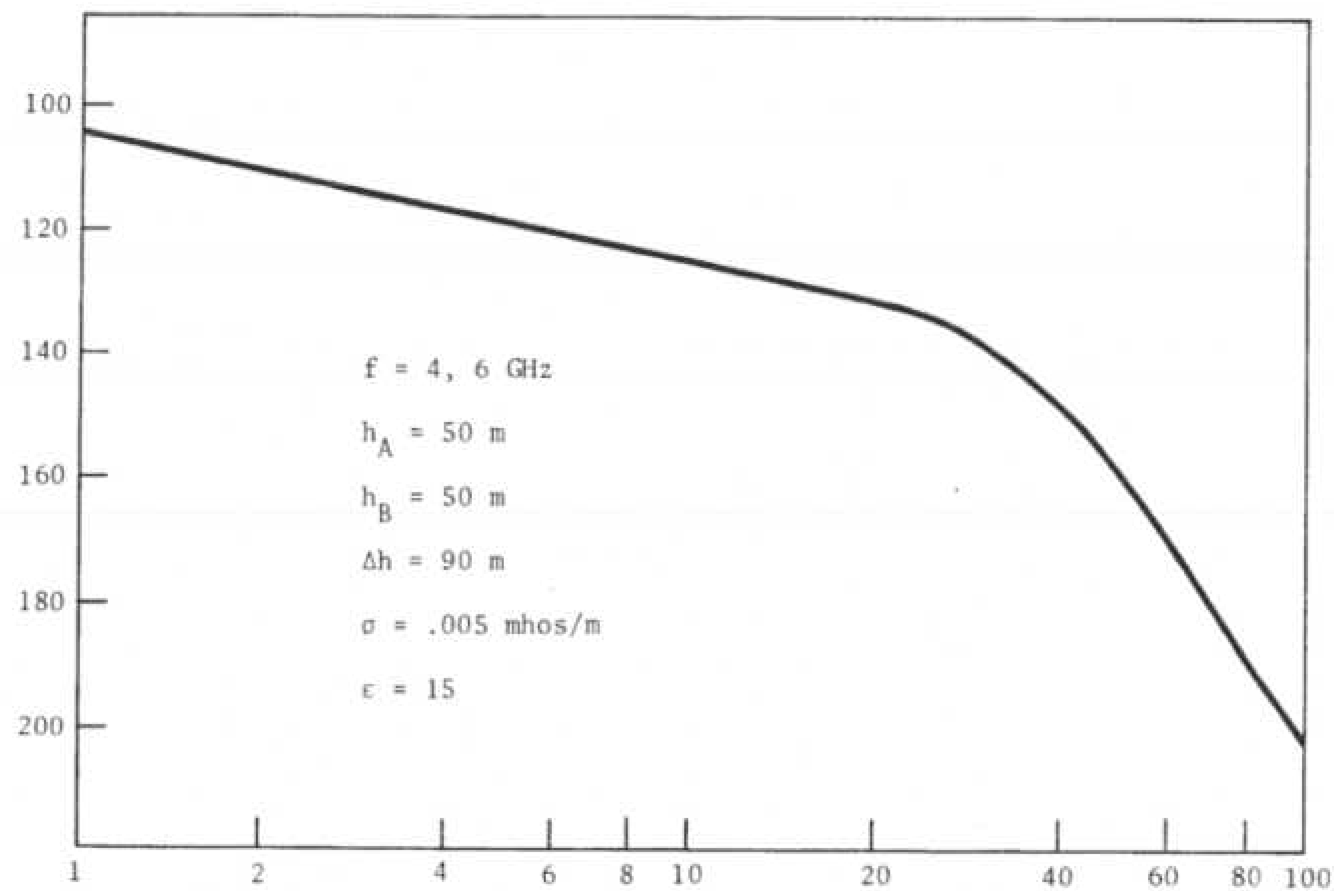


FIGURE B-5
TRANSMISSION LOSS
(Longly-Rice Propagation Model)

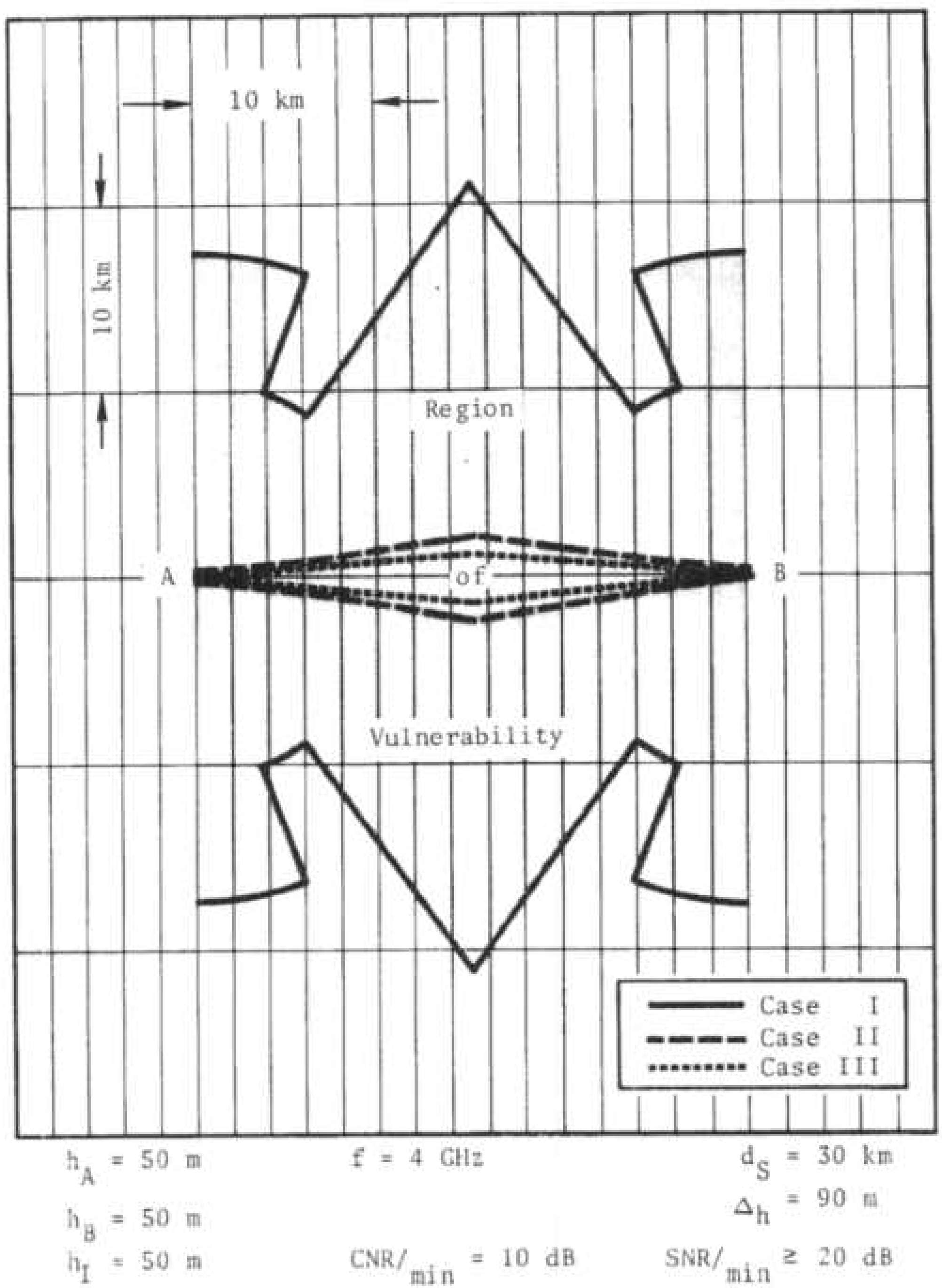
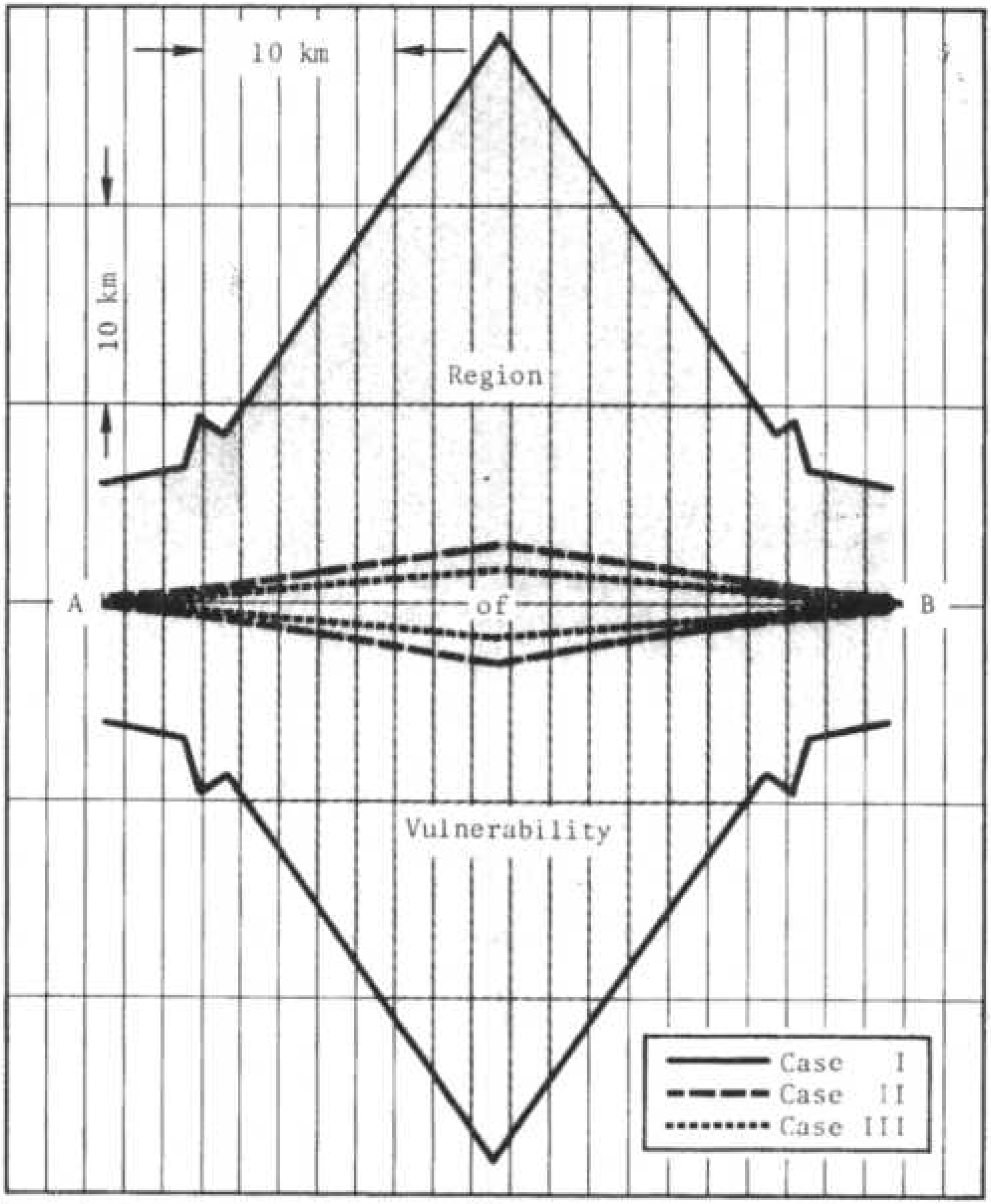


FIGURE B-6
TERRESTRIAL MICROWAVE: BI-DIRECTIONAL RECEPTION OF TELEPHONY-LOCI OF POTENTIAL RECEPTION SITES

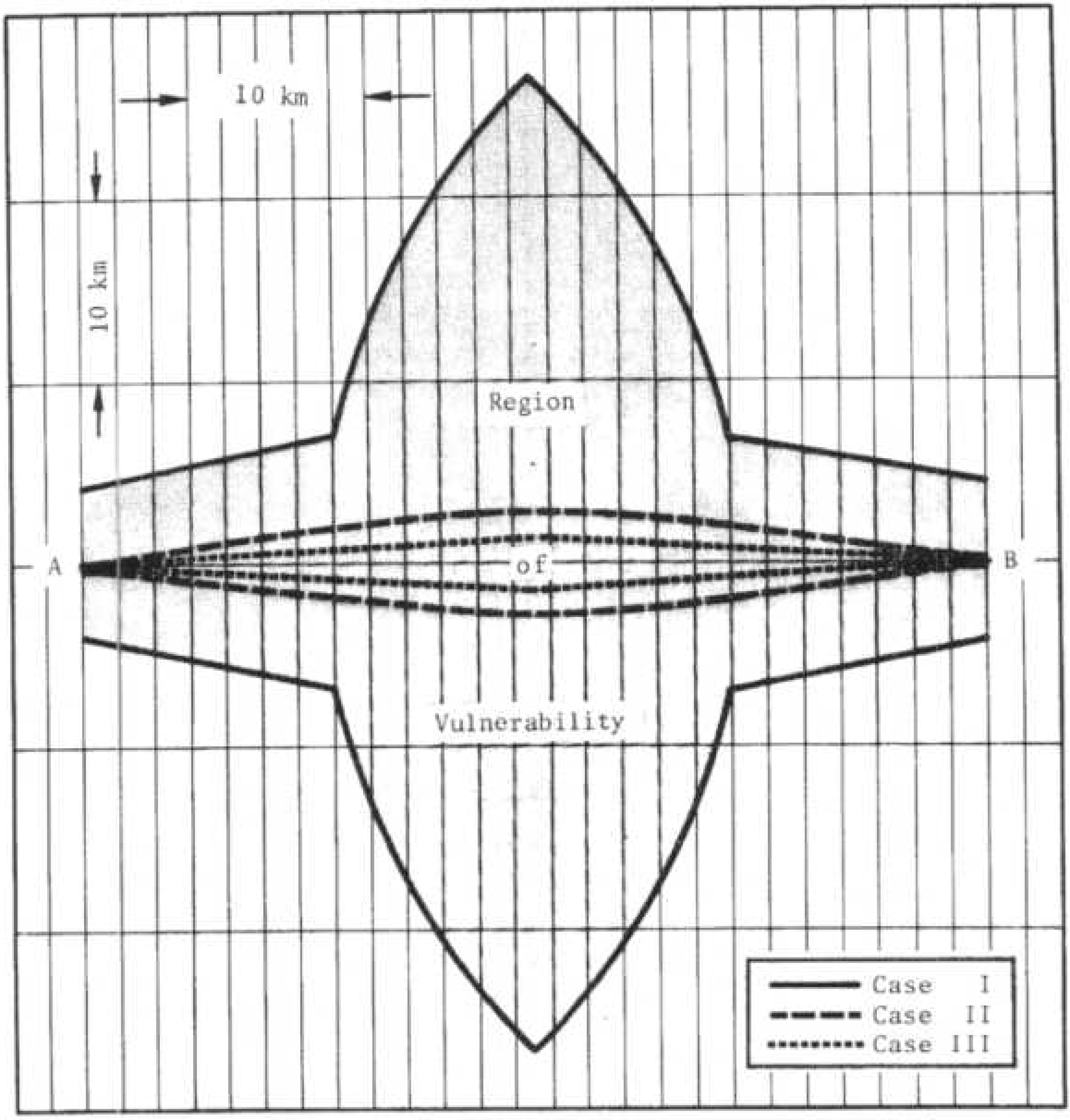


h_A = 50 m   f = 4 GHz d_S = 40 km

h_B = 50 m Δ_h = 90 m

h_I = 50 m   CNR/$_{min}$ = 10 dB   SNR/$_{min}$ ≥ 20 dB

FIGURE B-7
TERRESTRIAL MICROWAVE: BI-DIRECTIONAL RECEPTION OF TELEPHONY-LOCI OF POTENTIAL RECEPTION SITES



h_A = 50 m　　f = 4 GHz　　d_S = 50 km

h_B = 50 m　　Δ_h = 90 m

h_I = 50 m　　CNR/$_{min}$ = 10 d_B　　SNR/$_{min}$ ≥ 20 dB

FIGURE B-8
TERRESTRIAL MICROWAVE: BI-DIRECTIONAL RECEPTION OF TELEPHONY-LOCI OF POTENTIAL RECEPTION SITES

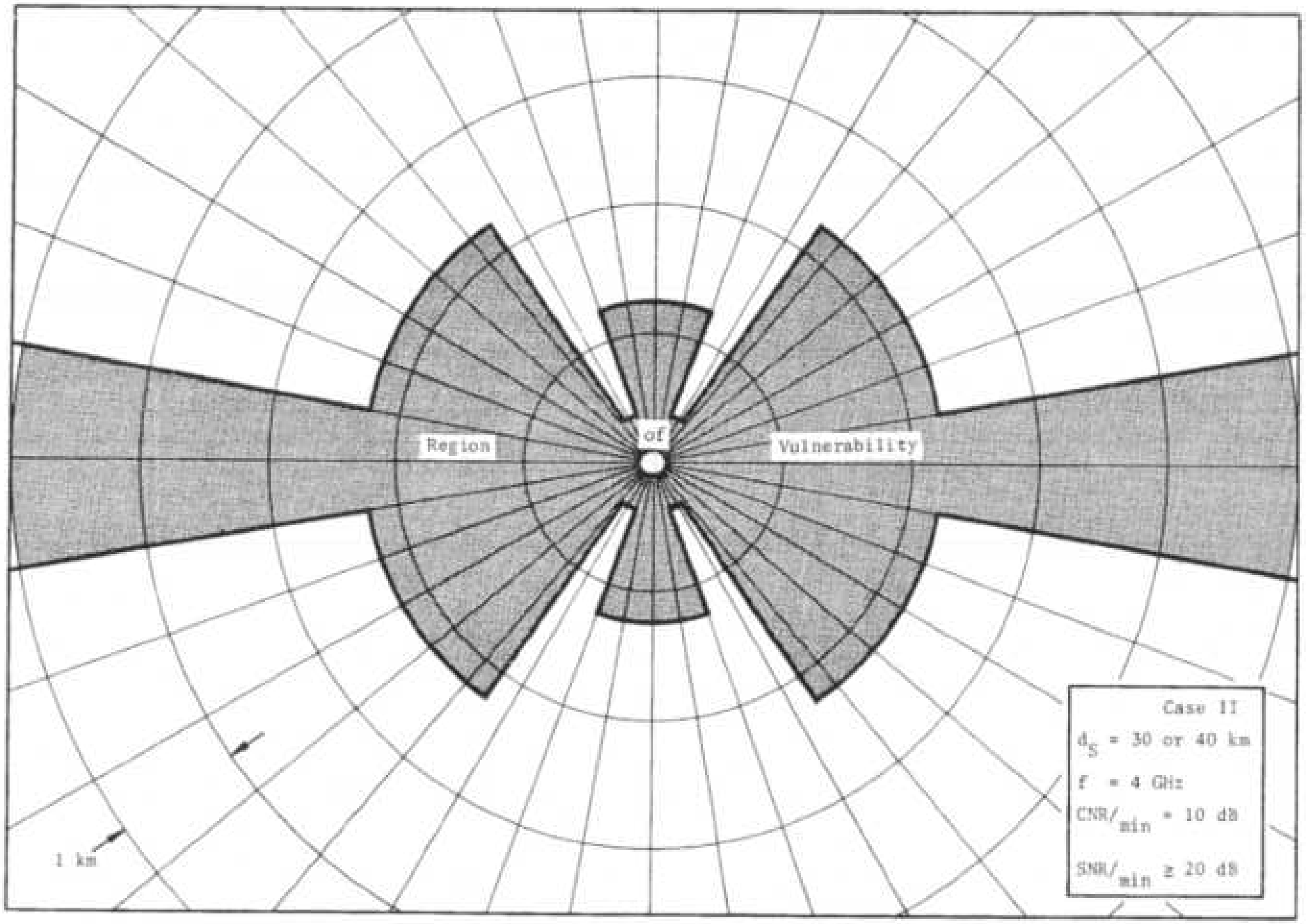


FIGURE B-9
TERRESTRIAL MICROWAVE: BI-DIRECTIONAL RECEPTION OF TELEPHONY-
LOCI OF POTENTIAL RECEPTION SITES

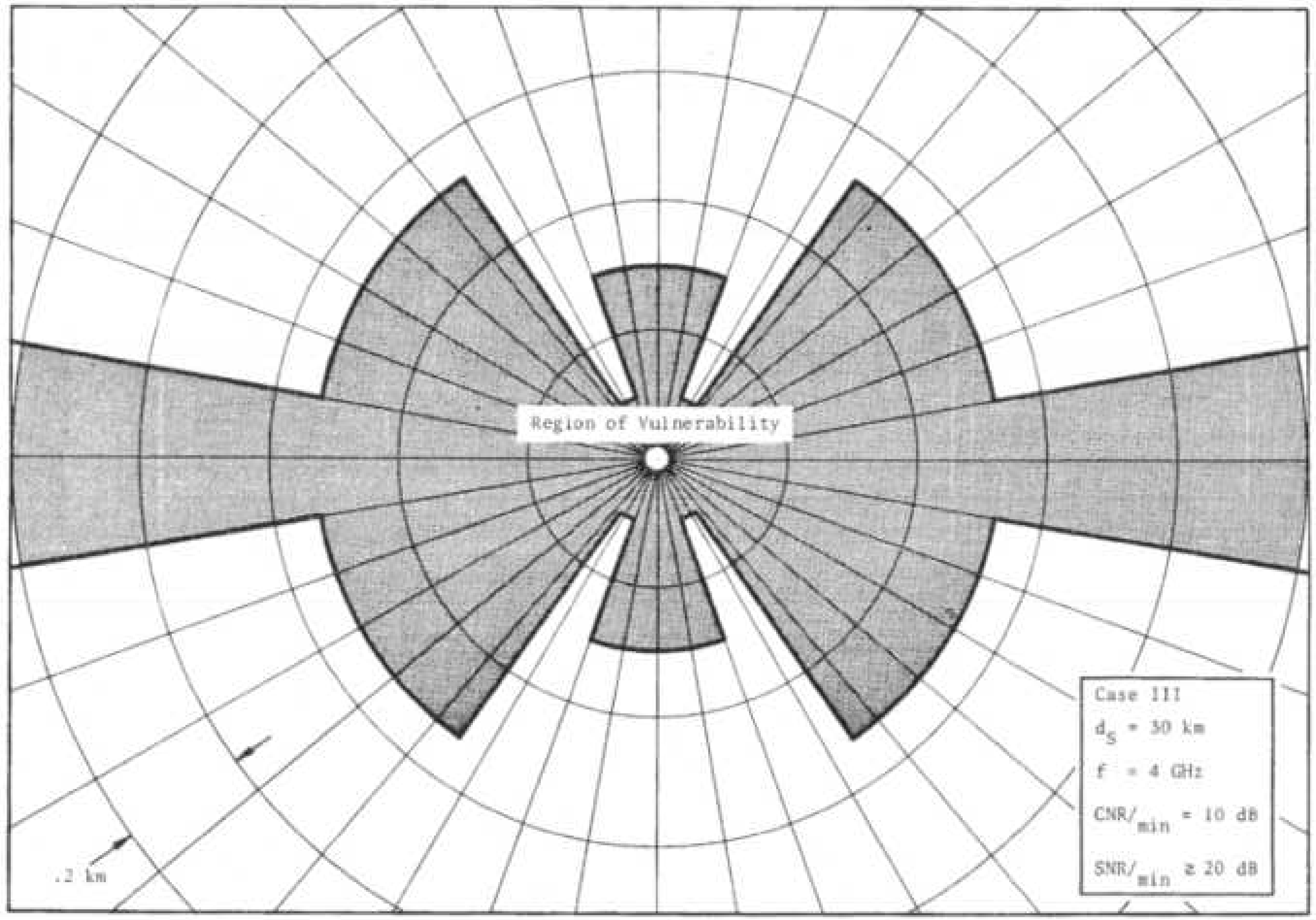


FIGURE B-10
TERRESTRIAL MICROWAVE: BI-DIRECTIONAL RECEPTION OF TELEPHONY
LOCI OF POTENTIAL RECEPTION SITES

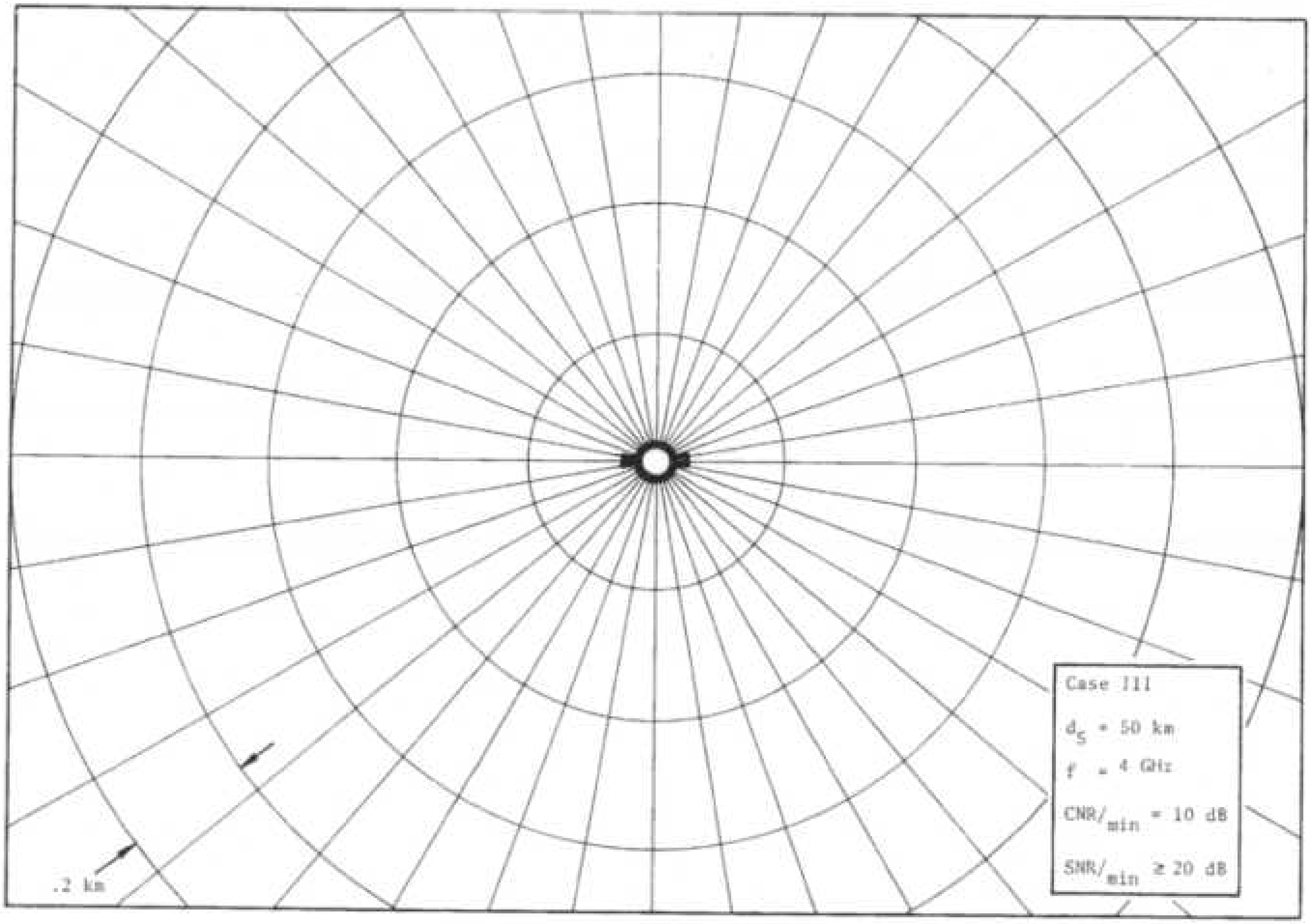


FIGURE B-11
TERRESTRIAL MICROWAVE: BI-DIRECTIONAL RECEPTION OF TELEPHONY·
LOCI OF POTENTIAL RECEPTION SITES

It is apparent from Figures B-6 through B-8 that with high quality intercept equipment (i.e., equipment quality comparable to that of the target system), the target TD-2 microwave system appears vulnerable to interception even if the interceptor's antenna is as much as 20 km from the line-of-sight right-of-way. For poorer quality intercept equipment, the target TD-2 system is vulnerable to interception only along the line-of-sight right-of-way and within a small region about the repeater. Configuration I, because it employs essentially the same equipment as the targeted TD-2 system, represents something of an upper bound on interceptor performance; Configurations II and III, because they employ receivers with poorer noise figures and/or antennas with lower gain, exhibit poorer figures-of-merit, η_r. The figures-of-merit for Configuration II and III are degraded relative to that of Configuration I by 23 dB and 35.5 dB, respectively. Thus, the example also reveals that the vulnerability of a targeted terrestrial microwave system is strongly dependent upon the figure-of-merit, η_r, of the interceptor's receiver. The two parameters impacting most strongly upon η_r are the interceptor's receiving system noise figure and antenna gain.

B.5 SATELLITE SYSTEMS

The interception of a satellite communication system may be exemplified by considering INTELSAT IV (refer to Table B-2). This satellite, which employs frequency-division-multiple-access (FDMA) to achieve multi-carrier FDM-FM transponder operation, typifies the configuration of all satellite systems employing U.S. earth stations with the exception of that proposed by Satellite Business Systems (SBS). However, this system, which as noted previously, will employ digital modulation and time-division multiple-access (TDMA), is not expected to be operational until 1981.

Nearly all of these systems, which typically require earth stations with G/T ratios in excess of 30 dB/°K, employ large steerable antennas with diameters in excess of 10 meters. The cost and size associated with building and controlling such a structure probably precludes its utilization by any unauthorized interceptors. A smaller antenna system with diameter less than 5 meters used in conjunction with sophisticated low-noise receiving equipments would seem much more acceptable in spite of a probable decrease in reliability.

B.5.1 Methodology for Signal Acquisition

As for any terrestrial microwave system, the successful interception of a satellite communications system employing FDM-FM requires satisfaction of the following two criteria: (1) the CNR of the intercepted carrier should exceed any discriminator threshold (e.g., nominally about 10 dB for typical FM discriminators); and (2) the SNR of the intercepted traffic should exceed the minimum required for the extraction of intelligibility (refer to Section B.2). For any specific performance objectives of the interceptor, say, $SNR|_{min}$ and $CNR|_{min}$, the controlling criterion may be determined from the following inequalities:

$$SNR|_{min} - CNR|_{min} < \eta_{mod} \rightarrow \text{Criterion (1) controlling} \qquad (B\text{-}45)$$

$$SNR|_{min} - CNR|_{min} > \eta_{mod} \rightarrow \text{Criterion (2) controlling} \qquad (B\text{-}46)$$

In contradistinction to terrestrial microwave systems where it is not unusual for either criterion (1) or criterion (2) to be controlling (refer to Section B.4), for satellite systems criterion (1) is nearly always controlling due to down-link power limitations. This may be shown by considering INTELSAT IV. The transmission parameters necessary to achieve the INTELSAT performance objective of 8000 pwp are summarized in Tables B-6 & B-7. A critical review of these parameters reveals that, apparently, for the case of standard carriers with m = 24,60,96 and 132 voice channels/carrier the rms test-tone deviation, f_r, was selected so as to exactly meet the thermal noise objective of 8000 pwp at 2.7 dB above the FM discriminator threshold of 10 dB. From Equations (B-27) and (B-28) it follows that

$$SNR = CNR + \eta_{mod} \qquad (B\text{-}47)$$

Since a single voice-channel noise level of 8000 pwp is equivalent to a test-tone signal-to-noise ratio of 48.5 dB, Equation (B-47) yields the result that

$$\begin{aligned} \eta_{mod} &= SNR - CNR \\ &= 48.5 - 12.7 \\ &= 35.8 \text{ dB} \end{aligned} \qquad (B\text{-}48)$$

For successful interception

$$SNR|_{min} = 23 \text{ dB} \qquad CNR/_{min} = 10 \text{ dB} \qquad (B\text{-}49)$$

so that for these performance objectives

$$\mathrm{SNR}\big|_{min} - \mathrm{CNR}\big|_{min} = 13\ \mathrm{dB} \qquad \text{(B-50)}$$

and

$$\mathrm{SNR}\big|_{min} - \mathrm{CNR}\big|_{min} \leq \eta_{mod} \qquad \text{(B-51)}$$

Thus, according to Equation (B-45), criterion (1) is controlling.

B.5.2 Example: INTELSAT IV

The INTELSAT IV e.i.r.p.s. shown in Tables B-6 and B-7 are predicated on an earth station G/T of 40.7 dB/°K and a margin above the discriminator threshold of 2.7 dB. They have been derived with the help of Equation (B-17) or, more exactly, from the equivalent relation

$$\frac{C}{T} = \left[\frac{e.i.r.p}{L_p}\right]\left[\frac{G}{T}\right]_r \qquad \text{(B-52)}$$

For these values of e.i.r.p., any interceptor of standard carrier transmissions would require an earth station G/T of at least 38.0 dB/°K; for any smaller G/T the interceptor's C/N at the discriminator input would be less than threshold.

The INTELSAT IV satellite communication system achieves a G/T of 40.7 dB/°K with a standard earth station configuration consisting of a 30 meter diameter steerable parabolic reflector antenna and a system noise temperature of about 78°K. The cost of such an antenna structure, reportedly about $1,500,000, appears prohibitive for any but the most determined interceptor. However, several alternative earth station configurations are available which could result in significantly reduced costs in implementation and construction although not without decreased reliability and increased maintenance. For example, instead of employing a nitrogen-cooled (77°K) parametric amplifier, a helium-cooled (4°K) parametric amplifier could be employed to reduce the receiving system noise temperature from 78°K to about

TABLE B-6

GLOBAL-BEAM INTELSAT IV TRANSMISSION PARAMETERS (8,000 pWp) FOR STANDARD AND EXPANDED CARRIERS

Channels/Carrier, n	Top Baseband Frequency, f_m (kHz)	Allocated Satellite BW Unit (MHz)	Occupied BW (b_{IF} at Earth Station) (MHz)	rms Multicarrier Deviation, f_{rms} (kHz)	Carrier-To-Total Noise Temp. Ratio $(C/T)_T$ (dBW/°K)	Carrier-To-Noise Ratio in Occupied BW, C/N (dB)	Satellite e.i.r.p. at Beam Edge (dBW)	Earth Station e.i.r.p. at 10° Elevation (dBW)
24	108.0	2.5	2.00	275.0	-153.0	12.7	5.8	74.7
36	156.0	2.5	2.25	307.0	-150.0	15.1	8.8	77.7
60	252.0	2.5	2.25	276.0	-144.0	21.1	14.8	83.7
60	252.0	5.0	4.00	546.0	-149.9	12.7	8.9	77.8
72	300.0	5.0	4.50	616.0	-149.1	13.0	9.7	78.6
96	408.0	5.0	4.50	584.0	-145.5	16.6	13.3	82.2
132	552.0	5.0	4.40	529.0	-141.4	20.7	17.4	86.3
96	408.0	7.5	5.90	799.0	-148.2	12.7	10.6	79.5
132	552.0	7.5	6.75	891.0	-145.9	14.4	12.9	81.8
192	804.0	7.5	6.40	758.0	-140.6	19.9	18.2	87.1
132	552.0	10.0	7.50	1020.0	-147.1	12.7	11.7	80.6
102	804.0	10.0	9.00	1167.0	-144.4	14.7	14.4	83.3
252	1052.0	10.0	8.50	1009.0	-139.9	19.4	18.9	87.8
252	1052.0	15.0	12.40	1627.0	-144.1	13.6	13.9	82.8
312	1300.0	15.0	13.50	1716.0	-141.7	15.6	16.3	85.2
432	1796.0	17.5	15.75	1919.0	-138.5	18.2	18.0	88.0
432	1796.0	20.0	18.00	2276.0	-139.9	16.1	17.7	86.6
432	1796.0	25.0	20.70	2688.0	-141.4	14.1	16.2	85.1
972	4028.0	36.0	36.00	4417.0	-135.2	17.8	22.4	90.1
1092	4892.0	36.0	36.00	4118.0	-132.4	20.7	23.7	93.6

TABLE B-7

SPOT-BEAM INTELSAT IV TRANSMISSION PARAMETERS (8,000 pWp)
FOR STANDARD AND EXPANDED CARRIERS

Channels/Carrier, n	Top Baseband Frequency, f_m (kHz)	Allocated Satellite BW Unit (MHz)	Occupied BW (b_{IF} at Earth Station) (MHz)	rms Multicarrier Deviation, f_{mc} (kHz)	Carrier-To-Total Noise Temp. Ratio, $(C/T)_T$ (dBW/°K)	Carrier-To-Noise Ratio in Occupied BW, C/N (dB)	Satellite e.i.r.p. Beam Edge (dB)	Earth Station e.i.r.p. at 10° Elevation (dBW)
60	252.0	2.5	2.25	276.0	-144.0	21.1	15.2	81.4
72	300.0	2.5	2.25	261.0	-141.7	23.4	17.5	83.7
132	552.0	5.0	4.40	529.0	-141.4	20.7	17.7	83.9
192	804.0	5.0	4.50	459.0	-136.3	25.8	22.8	89.0
192	804.0	7.5	6.40	758.0	-140.6	19.9	18.5	84.7
252	1052.0	7.5	6.75	733.0	-137.1	23.2	22.0	88.2
252	1052.0	10.0	8.50	1009.0	-139.9	19.4	19.2	85.4
312	1300.0	10.0	9.00	1005.0	-137.1	22.0	22.0	88.2
432	1796.0	15.0	13.00	1479.0	-136.2	21.2	22.2	88.4
612	2540.0	20.0	17.80	1996.0	-134.2	21.9	23.9	90.1
792	3284.0	20.0	18.00	1784.0	-129.9	26.2	28.2	94.4
792	3284.0	25.0	22.40	2494.0	-132.8	22.3	25.3	91.5
972	4028.0	25.0	22.50	2274.0	-129.4	25.7	28.7	94.9
1872	8120.0	36.0	36.00	3181.0	-123.5	29.5	34.2	98.6

50°K. Further, an interceptor could eliminate the margin requirement for equipment degradation and rain and accept the increased outage time and reduction in time availability. Finally, an interceptor could employ a threshold extension applique-unit to reduce the FM discriminator threshold and so increase the sensitivity of the receiving system. The sum improvement due to the introduction of the helium-cooled parametric amplifier, the elimination of the system margin, and the use of threshold extension is about 7.7 dB. If this improvement factor is used only to reduce the antenna size, the antenna diameter can be reduced from 30m to about 12m.

The discussion above is applicable to all down-link traffic relayed by the satellite transponder including the low traffic density (up to 132 voice channels), global-beam, standard r-f carriers which are, potentially, the most difficult to intercept. Considerably more vulnerable to interception, however, are the so-called expanded global-beam carriers which provide greater-than-standard traffic densitites within standard bandwidths and the standard spot-beam carriers. For both of these carrier types the INTELSAT IV satellite transponder employs effective radiated powers which are at least 7.3 dB above the effective radiated powers employed for standard global-beam carriers. At the expense of poorer received quality, the interceptor can employ this 7.3 dB in conjunction with the previously realized 7.7 dB advantage to further reduce the earth station antenna diameter to about 5-meters.

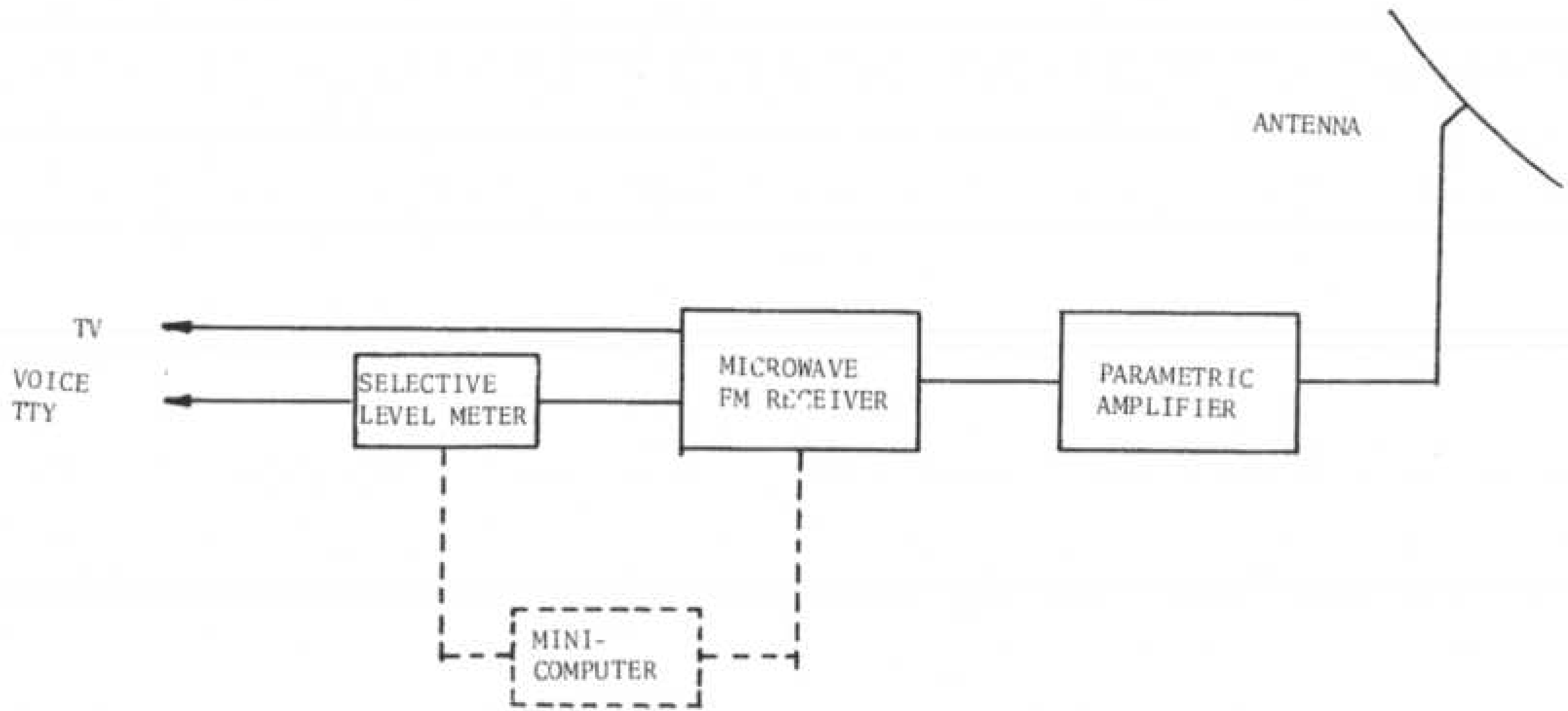
The equipment configurations required for the successful reception of r-f transmissions employing either global- or spot-beam satellite transmitting antennas with either standard or expanded traffic are summarized in Table B-8. In that table Cases I and II refer, respectively, to: (1) He-cooled parametric pre-amplifier,

TABLE B-8

SATELLITE MICROWAVE: EQUIPMENT CONFIGURATIONS FOR BI-DIRECTIONAL RECEPTION OF FDM-FM TELEPHONY

RECEIVER SYSTEM			ANTENNA	
CASE	TYPE	OPERATING NOISE FIGURE	DIAM-ETER	GAIN
I	He-Paramp	0.7 dB	12 m	51.5 dB
II	He-Paramp	0.7 dB	5 m	43.5 dB

microwave receiver, and steerable 12-meter antenna; and (II) He-cooled parametric amplifier, microwave receiver, and steerable 5-meter antenna. A generic block diagram, valid for both configurations, is shown in Figure B-12.



NOTE: Dashed lines denote optional automatic control functions

FIGURE B-12
EQUIPMENT CONFIGURATION FOR ACQUISITION OF SATELLITE SYSTEMS SIGNALS

APPENDIX C

MULTIPLEXING, MODULATION AND CARRIER SYSTEMS

C.1 INTRODUCTION

Cable-carrier, coaxial-carrier and radio-carrier transmission systems utilize a process called "multiplexing" to combine two or more voice, teletype, data or video circuits for transmission over a common medium. The multiplexing process employs any of several standard signal modulation techniques to translate a signal to an appropriate frequency slot or time slot for combining it with other modulated signals. Alternatively, modulation serves to convert a signal to a form more suitable for transmission through a specific medium. The reverse of the modulation and multiplexing processes are called "demodulation" and "demultiplexing", respectively.

The combination of multiplexing and transmission medium used over a particular route is generally a function of the amount of traffic between two points. Where the required capacity is 60 channels or less, the channels will probably be multiplexed on wire or cable. On routes where the capacity is to be 60 channels or more (up to hundred or thousands) coaxial cable or microwave radio will probably be installed. However, microwave radio systems may be found carrying anywhere from a few voice channels to more than thirty thousand. Rough or impassable terrain may preclude the laying of any type of cable leaving microwave radio as the only practical way of providing even a very few channels.

Carrier transmission systems make use of frequency division multiplexing (FDM) and time division multiplexing (TDM). FDM can be further subdivided into amplitude modulation (AM) and frequency modulation (FM) type systems. Most carrier transmission systems are of the AM variety. Each of these techniques is discussed in the following sections.

C.1.1 Frequency Division Multiplex (FDM) Systems

Virtually all FDM carrier systems in use today have their designs based on the requirement to multiplex the so-called "standard" voice channel, which is defined as the frequency band lying between roughly 300 Hz and 3400 Hz. When a number of voice channels are to be combined for transmission over a single medium, the FDM system shifts each basic 300 - 3400 Hz channel to a different frequency band by means of modulation and "stacks" the "modulated" signals.

In amplitude modulation, the amplitude of a high frequency sine-wave carrier is controlled by the amplitude of a baseband signal which is said to "modulate" the carrier. The resultant "modulated" wave consists of the carrier itself and signal components with frequencies above and below the carrier frequency. In this form, the modulated wave is referred to as a Double Sideband - Transmitted Carrier (DSB-TC) Signal. The component frequencies above and below the carrier frequency differ from the carrier frequency by an amount equal to the modulating frequency. A modulating wave such as speech consists of a complex band of frequencies, and hence the modulated speech wave consists of the carrier and bands of frequencies above and below the carrier. These bands are called the "upper" and "lower" sidebands, respectively.

Various combinations of these two classifications can be found in existing carrier systems. They include:

(1) Double-sideband transmitted-carrier (DSBTC)

(2) Double-sideband suppressed-carrier (DSBSC)

(3) Single-sideband transmitted-carrier (SSBTC)

(4) Single-sideband suppressed-carrier (SSBSC)

Each modulation technique has its own peculiar advantage.

Modern multiplex systems frequently have more than one stage of modulation. For example, three stages of modulation are employed to obtain the L1 line signal, five for L5, and as many as seven to achieve the signal broadcast from the microwave transmitters of certain types of radio systems.

To allow for adequate spacing between voice bandwidths, 4 kHz is allotted to each channel in most modern multiplex systems. For example, in one open wire carrier system, 12 voice channels are simultaneously carried on a single pair using a 108 kHz bandwidth with two mutually exclusive frequency ranges to effect two-way tranmsission. In one direction 12 voice conversations are inserted between 40 kHz and 88 kHz, and the band between 100 kHz and 148 kHz carries 12 voice bandwidths in the opposite direction.

Cable carrier systems are similar but usually operate in different frequency ranges. For example, Bell's N-carrier system transmits two 4 kHz sidebands for each voice channel and places 12 double-sidebands between 36 kHz and 140 kHz in one cable section and 12 between 164 kHz and 268 kHz in the next. A separate cable pair is used for each direction of transmission.

A standard modulation plan for high capacity multiplex systems, which ride either radio or coaxial media, assembles 12 voice channels into a basic "group" having a frequency range of 60 kHz to 108 kHz. Five groups are then combined to form a basic 60-channel "supergroup" in the range 312 kHz to 552 kHz. Ten supergroups are combined to form a basic 600-channel "mastergroup" lying between 564 kHz and

3084 kHz. Six mastergroups are combined to form a basic 3600-channel "jumbogroup" lying between 564 kHz and 17.548 MHz.

A class of low-capacity multiplex systems permits the superposition of more than one channel on one or two pairs between a group of telephone instruments and an exchange office. Such multiplex systems are referred to as "station-carrier" or "subscriber-carrier" systems. Station-carrier systems have a number of different channel capacities and modulation plans. A typical 6-channel system uses an 8 - 56 kHz band for transmission in one direction and 72 - 140 kHz for the other direction over a single pair.

In todays telecommunications systems, the 300 - 3400 Hz voice channels carry not only voice conversations but also digital data signals. Voice channels can also be subdivided into low-speed data or teletype channels by means of filtering techniques. For example, a bandwidth of 120 Hz can carry a 75 bit per second teletype channel so that up to 25 such channels (each modulating its own subcarrier) can be made to share a single voice channel.

In most high-capacity frequency division multiplexed carrier systems, pilot signals are transmitted along with the modulated voice channels to effect total flat and frequency selective level regulation, frequency synchronization and alarm capabilities in the event of medium degradation or system failure. Pilots are often surveyed during routine maintenance and trouble-shooting as an indication of trouble location and general system performance. In some cases meters are provided as part of the system so that pilot levels may be observed at a glance. In other cases, pilots are "read" with a frequency selective voltmeter which can be tuned to observe a very narrow "slot" at any frequency across the carrier band.

C.1.2 Time Division Multiplex (TDM) Systems

A TDM system permits the simultaneous transmission of a number of individual digital signals over a single path by synchronously sequencing pulses taken alternately from each separate signal into a single bit stream. TDM equipment exists that can handle low-speed data (teletype), voice-band data (1200 - 9600 bits per second), or wideband data (above 9600 bits per second).

TDM systems have found their greatest usage in Bell's T1 cable-carrier and other similar systems which utilize a number of processes, in addition to TDM, to achieve the line signal format. For example, the T1 system utilizes Pulse Amplitude Modulation (PAM), followed by TDM, followed by Pulse Code Modulation (PCM) to obtain the final sequence of pulses transmitted onto the line. The T1-Carrier system multiplexes 24 channels onto a cable pair. A separate cable pair is required for each direction of transmission. On typical 22 gauge non-loaded cable, regenerative repeaters are nominally spaced at 6000 foot intervals.

Table C-1 lists the significant characteristics of operational Bell System Carrier Systems. The relevant characteristics of the systems will be discussed in the following sections.

TABLE C-1

MAJOR BELL SYSTEM CARRIER SYSTEMS
SHORT HAUL

	N1	N2	O	ON1	ON2	T1	N3	T2
Line Facility	Cable	Cable	Open Wire	Cable	Cable	Cable	Cable	Cable
Channels on Cable Pair or Coaxial Tube	12	12	16	20	24	24	24	26
Multiplex Type	FDM	FDM	FDM	FDM	FDM	TDM	FDM	TDM
Frequency Allocations								
Lowest Trans.Freq.(KHz)	36	36	2	40	36	(1)	36	(2)
Highest Trans.Freq.(KHz)	268	268	156	264	268	(1)	268	(2)
System Length (Miles)								
Minimum	15	15	15	15	15	10	35	--
Maximum	200	200	150	200	200	50	200	500
Approx. Repeater Spacing (Miles)	5	5	50	5	5	6000 Ft.	5	205

NOTES:

(1) Line signal consists of bipolar ulses at rate of 1.544×10^6 bits/sec which occupies band between DC and 1.544 MHz.

(2) Line signal consists of bipolar pulses at rate of 6.32×10^6 bits/sec which occupies band between DC and 6.312 MHz.

TABLE C-1 (Continued)

MAJOR BELL SYSTEM CARRIER SYSTEMS
LONG HAUL

	C5	J2	K2	L1	L3	L4	L5
Line Facility	Open Wire	Open Wire	Cable	Coax	Coax	Coax	Coax
Channels on Cable Pair or Coaxial Tube	3	12	12	600(1)	1860(2)	3600	10,800
Multiplex Type	FDM	FDM	FDM	FDM	FDM	FDM	FDM
Frequency Allocations							
Lowest Trans. Freq.(kHz)	6	36	12	60	308	280	1,590
Highest Trans. Freq.(kHz)	30	143	60	3096	8320	20,448	68,780
System Length (Miles)							
Maximum	60	125	75	75	75	75	75
Minimum	1000	4000	4000	4000	4000	4000	4000
Approx. Repeater Spacing	150	30	17	8	4	2	1

NOTES:

(1) Or two one-way TV Channels
(2) Or 660 Telephone Channels and two one-way TV Channels

C.2 FREQUENCY DIVISION MULTIPLEX SYSTEMS

Early multiplex systems evolved from attempts to get more than one telegraph circuit at a time onto a single metallic path. Like the carrier telegraph systems, the early voice multiplex systems were also designed for use on metallic pairs -- first open wire and later multi-pair cable.

In the Bell System, early carrier systems were all designed to operate over a single open-wire pair. Later systems were "equivalent four-wire" systems - that is, even though they used a single pair for both directions of transmission, the voice-frequency inputs and outputs were separated from each other, so that only four-wire circuits or circuits that were converted to four-wire could be connected to the system. In a few cases these early systems were adopted for use on multi-pair cable and used as four-wire systems, but the first system designed for end-to-end four-wire operation on multi-pair cable was the K-Carrier system.

Later systems such as the N1-, N2-, N3-, ON1- and ON2- Carriers were all designed to function as fully four-wire multi-pair cable systems for short-haul applications (less than 200 miles). The K2-Carrier was a long-haul system with a maximum permissible circuit length of 4000 miles.

C.2.1 Amplitude Modulation (AM) Multiplex Systems

In amplitude modulation, the amplitude of a high frequency sine-wave carrier is controlled by the amplitude of a baseband signal which is said to "modulate" the carrier. The resultant "modulated" wave consists of the carrier itself, and signal components with frequencies above and below the carrier frequency. In this form, the modulated wave is referred to as a "Double Sideband -

Transmitted Carrier" (DSB-TC) Signal. The component frequencies above and below the carrier frequency differ from the carrier frequency by an amount equal to the modulating frequency. A modulating wave such as speech consists of a complex band of frequencies, and hence the modulated speech wave consists of the carrier and bands of frequencies above and below the carrier which are called the "upper" and "lower" sidebands, respectively.

Specific examples of AM FDM systems are described below:

(1) <u>Double Sideband - Transmitted Carrier (DSB-TC) AM Multiplexing</u>

The DSB-TC multiplexing method is the simplest and earliest form of multiplexing used in communications. AM radio broadcasting employs this method of modulation. Cable-carrier transmission systems such as the N1 and N2 systems also employ this technique although the carrier is transmitted at a much lower power level than the sidebands.

(2) <u>Double Sideband-Suppressed Carrier (DSB-SC) AM Multiplexing</u>

The DSB-SC multiplexing method resembles the DSB-TC system except that the carrier has to be provided somehow at the receiving end to permit demodulation. This is accomplished by recovering carrier from a pilot tone transmitted along with the modulated sidebands, or locally generating a carrier at the receiving end of the circuit.

Although DSB AM utilizes about twice as much bandwidth on the line as the Single Sideband (SSB) systems described below, there are certain advantages to DSB multiplexing, such as the simplicity and economy of the modulation/demodulation process, a somewhat higher signal to noise ratio obtained from the energy contained by both sidebands and the simplicity and economy of the system filters. The large bandwidth required by the DSB line signal roughly halves the number of channels per cable pair as compared with a SSB system. The tendency is to trade cost for bandwidth by building DSB systems "cheap and dirty" and limiting their ultimate range to 200 miles.

(3) Single Sideband (SSB) Multiplexing

SSB multiplexing permits twice the number of channels to be transmitted on a cable pair or coaxial tube than does DSB. The SSB signal is obtained by filtering out either the upper or lower sideband obtained from the DSB AM process and transmitting the remaining sideband over the medium. The carrier may either be transmitted over the line (SSB-TC) or suppressed (SSB-SC). In the latter case either a pilot must be transmitted over the line and used to re-derive the carrier at the receive terminal or the carrier must be locally generated at the receive terminal.

C.2.2 Frequency Modulation (FM) Multiplex Systems

In Frequency Modulation, the varying amplitude of a modulating baseband signal is used to control the frequency of a sinusoidal carrier. Accordingly, for each value that the modulating signal assumes, the carrier signal frequency is shifted to a corresponding value. Positive peaks of the modulating signal will cause the carrier to shift to frequencies greater than its unmodulated value and negative peaks will shift it to frequencies less than its unmodulated value. The frequency of the modulating signal determines how quickly the carrier-frequency will swing back and forth around its unmodulated value.

When examined in the time domain, the frequency of the modulated wave will change constantly between limits which depend on the maximum amplitude of the complex modulating signal. The rate at which the modulated signal varies in frequency will depend on the frequency content of the modulating signal. The amplitude of the modulated signal is always held constant (limited). When viewed in the frequency domain, the spectrum of the modulated signal will consist of a large number of constantly shifting "sidebands", rather than the two produced by AM. The FM sidebands will always appear symmetrically about the carrier frequency, but separated from the carrier by integral multiples of the modulating signal's frequency components, with sum and difference frequencies interspersed in between. Bessel Functions must be used to determine the component amplitudes of an FM modulated wave.

Although the number of FM multiplex systems is small when compared to SSB-SC, there are some in use - e.g., Bell's U1-Carrier, Lynch's B630-Carrier, and Panhandle's X-Carrier. However, most microwave radio systems employ wide-band FM as their intermediate frequency stage of modulation which furnishes the baseband input to the microwave transmitters.

C.3 TIME-DIVISION MULTIPLEXING (TDM)

TDM is the sharing of a common transmission medium among a number of users by permitting each user to transmit a piece of information in turn at a preassigned time. Each user is connected through a "commutator" or "scanning" device to the transmission medium for a short interval. This process is usually "synchronous" in the sense that a train of synchronizing pulses is fed to each user to enable him to have his piece of information present on the input terminals of the scanning device at exactly the right time. Usually the user's information is presented to the TDM input as a series of binary pulses whether they are digital representations of analog speech or simply binary coded alphanumerics.

Bell's Time Assignment Speech Interpolation (TASI) system is a special form of TDM system in that speech syllables rather than binary data streams are interleaved to multiplex a large number of speakers on a smaller number of voice channels. TASI takes advantage of natural pauses between verbal quanta, such as words and statements, so that the verbal quanta of each speaker are inserted in the pauses of other speakers.

Because of its recent development and limited usage the term, "TDM", has often been used to include elements of communications systems and methods of modulation which are comptabile with TDM, but are not of themselves TDM processes. For example, the Bell T1-carrier System is often classified as TDM or a pulse code modulation (PCM) system, but T1-carrier actually uses three separate pulse modulation processes in tandem -- these are, pulse-amplitude modulation (PAM), TDM and PCM, In the T1 cable-carrier system, 24 separate voice signals are sampled at 8000 bits per second producing a train of pulses with amplitudes proportional to that of the voice signal at each sampling instant. The PAM samples from each channel are then interposited among the samples from the other channels resulting in a TDM stream of amplitude modulated pulses. The PAM/TDM stream is then presented to an analog-to-digital (A/D) converter which encodes the magnitude of each pulse into an eight bit binary number. This A/D conversion process is referred to as "Pulse Code Modulation (PCM)". The PAM/TDM/PCM pulses are then converted to a "bipolar" format (alternate positive and negative voltages with return to zero voltage between each pulse) for transmission over the T1-Carrier line.

The T1-Carrier system has a capacity of 24 voice channels, each of which are sampled at 8000 bits per second, and an 8 bit word is generated for each sample. This produces an 8 x 24 = 192 bit frame, and one synchronization bit is added at the end of each frame, making a 193 bit total frame length. Since 8000 samples are made on each channel in each second, and all 24 channels are sampled, there are 8000 frames transmitted each second. Consequently, a pulse rate of 8000 x 193 = 1,544,000 bits per second is sent into the line. Each T1 channel is said to absorb 8 bits x 8000 samples per second = 64,000 bits per second of the 1.544 Mbps T1-Carrier line signal. The T1WB4 modem permits the combination of 64,000 bps data streams from sources other than the T1 channel bank with the 1.544 Mbps line signal. Such data signals can only be combined if the corresponding T-1 Carrier channels are not operative. The T1WB4 modem is used to add Digital Data Service (DDS) channels to an existing T1CXR line.

The Bell SLM (subscriber line multiplex)-carrier system is also commonly known as a TDM system. The SLM system not only utilizes the TDM process to interleave the outputs from individual channel terminals, but the channel terminal outputs are the result of an adaptive delta-modulation (ADM) process. The ADM process uses a feedback method which compares a reconstructed signal against the voice input signal to detect changes in the input which are encoded into strings of "1's" and "0's" suitable for TDM. The ADM coded outputs of the channel units are then interleaved to form a 1,544,000 bps pulse stream which is compatible with the T1-carrier line. TDM systems combine a number of lower data rate bit streams to form a high bit rate stream. For example teletype bit rates (50 to 600 bps), voice-band data bit rates (1200 to 9600 bps), wide-band data bit rates (19,200 bps and up), or combinations of these can be sent over a single TDM channel.

Bell's Digital Data Service (DDS) is a "pure" TDM system which does nothing but interleave streams of Digital Data originating at customer premises for transmission over the Bell System communications network. The quondam Datran Network also used purely digital TDM techniques as will the proposed Satellite Business System (SBS) network.

C.4 HYBRID SYSTEMS

Up to this point straightforward modulation techniques where a number of voice channels have been somehow multiplexed for transmission over a common medium have been discussed. Yet, the real situation in the common carrier communications networks is somewhat more complex than this, especially when data transmission is considered.

The term "hybrid" transmission refers to the superposition of one type of multiplex system as a baseband on the channels of a different type, or the transmission of two completely different types of multiplex systems on a common medium. It is not at all unusual to find two different but similar multiplex systems operating on a common cable pair, but it is somewhat more unusual to find two dissimilar kinds of multiplex on a common medium.

Most people are familiar with the more prosaic hybrid systems which are prevalent throughout the entire common carrier communications network. These are the voice-band data circuits or telegraph carrier systems superimposed on voice carrier channels. For example, both telegraph carrier systems and certain of the voice-band data sets prepare digital data signals originating in subscriber equipment for carrier transmission by Amplitude-Shift Keying (ASK) or Frequency-Shift Keying (FSK) a voice frequency carrier signal. These ASK or FSK signals are then presented as a baseband signal to the voice channel input of a DSB-TC, SSB-SC or TDM system. Other types of data-sets use Phase-Shift Keying (PSK) or Multilevel Amplitude Modulated Vestigal Sideband (MAMVSB) modulation techniques to prepare digital data for the channels of analog transmission systems.

The most common example of a hybrid situation is the FM intermediate frequency state which produces the microwave baseband for most microwave systems by frequency modulating the SSB-SC output of high capacity multiplex terminals.

Hybrid transmission systems are particularly numerous in the field of wideband data transmission, especially if Bell's Digital Data Service (DDS) is considered. However, aside from the DDS, which will be treated later, hybrid systems are created when wideband data signals, which usually occupy a bandwidth equivalent to between 6 and 12 SSB voice channels, are transmitted over long-haul carrier systems. Most wideband data signals originate from 303 type data sets located at the customer premises. The 303 data set usually handles digital data signals at speeds between 19,200 bps and 50,000 bps, either synchronously or nonsynchronously. The 303 accepts a digital data signal from the customer, scrambles it, and converts it to a restored-polar format for transmission over a "wide-band loop".

Modems designated T1WB-1 through T1WB-3, and T1WM-1 are used to combine the various wideband signals originating in the 303 Data Set to form the 1.544 Mbps T1 digital line format. The T1WB-3 can also accept between 12 and 21 voice channels to add to the bit stream depending on the wideband data rate presented at its input.

Up to two 6.312 Mbps digital T2 lines can be transmitted over the L4 voice channel "mastergroup". The digital signal is modulated into the mastergroup spectrum by means of 15-level partial response VSB homodyne modem. The terminal is referred to as an L4 Digital Master Group (DMG).

Up to three 6.312 Mbps digital T2 lines can be transmitted over the TD2B radio system in place of a 1200 voice circuit TD2B radio channel. The digital signal is modulated into the radio baseband by means of a suitable modem. The terminal is referred to as an M2R digital radio terminal.

C.5 MULTIPLEX FOR WIRE-/CABLE-CARRIER TRANSMISSION SYSTEMS

This section describes a few selected multiplex systems commonly used on open wire and multi-pair cable. Table C-1 at the end of Section C.1.2 summarizes the essential characteristics of these multiplex systems.

C.5.1 Open Wire-Carrier Transmission Systems

(1) The O-Carrier System (Bell)

The O-Carrier System is a short-haul carrier system designed to operate over an open-wire pair up to a maximum distance of 150 miles. This system is an "equivalent four-wire" system inasmuch as voice frequency circuits must inter-connect with its inputs and outputs on a four-wire basis, but the multiplexed signals are transmitted in both directions over a single open-wire pair. In this system the voice channels are modulated using an SSB-TC technique.

O-Carrier transmits up to 16 voice channels over an open-wire pair. The 16 voice channels are divided into 4 subsystems having 4 channels each. Each subsystem has two line transmission frequency ranges called "Low Group" and "High Group" which are separated in frequency sufficiently for them to both simultaneously occupy a single line. One group is used for one direction of transmission and the other for the opposite.

The voice channels of the O-Carrier system employ companders and out-of-band 3700 Hz signaling.

(2) The J-Carrier System (Bell)

The J-Carrier System is a long haul carrier system designed to operate over an open-wire pair up to a maximum distance of 4000 miles. The J-Carrier System transmits up to 12 voice channels over an open-wire pair. The voice channels are modulated using a SSB-SC technique. A C-Carrier System and a metallic voice-frequency circuit can be operated on the pair along with the J-Carrier System for a total capacity of sixteen two-way telephone channels.

In this system the 12 west-to-east channels are transmitted in the 36 to 84 kHz band, and the east-to-west in the 92 to 143 kHz band. These two bands are put on the same pair to effect two directions of transmission. The two groups of frequencies traveling in opposite directions on the same pair are separated from each other for amplification at each repeater by means of directional filters. The J-Carrier repeaters are spaced between 30 and 50 miles apart and have one amplifier for each direction of transmission.

In the J-Carrier System, 12 voice channels are SSB modulated to form a basic "group" whose bandwidth extends from 60 to 108 kHz. This group consists entirely of lower sidebands. Likewise the 12 channel group has become the standard throughout the world for the first stage of any FDM system.

The J-Carrier System either uses Single Frequency in-band signaling units or some other form of external signaling system must be employed.

(3) <u>GTE Lenkurt's 82A Station Carrier System</u>

The 82A-Carrier System is a Subscriber Loop Carrier System designed to multiplex up to six channels on a single open-wire or cable pair. The system employs DSB-TC modulation in two frequency sets to convey two directions of transmission over the cable. The frequency allocation used to transmit from the subscriber to the central office extends from 8 kHz to 56 kHz and is divided into six contiguous DSB blocks each of which are 8 kHz wide. The frequency allocation transmitting from the central office to the subscriber extends from 72 kHz to 140 kHz. This allocation also consists of six 8 kHz DSB blocks, but they are all separated from each other by 4 kHz guard bands.

For long distances, repeaters must be used. The cable repeater is hermetically sealed in a metal housing for pedestal, pole, cross-arm or strand mounting. The station terminal is enclosed in the same type of housing as the repeater.

Signaling is accomplished in both directions by switching the carrier on and off. In the idle state, the carrier is transmitted from the central office to the subscriber on all six channels. No carriers are transmitted from the subscribers to the central office. When a subscriber takes his telephone off-hook, he turns on his individual carrier toward the central office which, in turn, presents an off-hook to the dial machine. The subscriber then sends dial pulses by turning the carrier off for the duration of each pulse, and these pulses are repeated by the carrier terminal to the dial machine.

On an incoming call, the carrier terminal will detect the 20 Hz ringing signal coming from the dial machine and turn the carrier off for the particular subscriber being signaled.

C.5.2 Multiplexing for Cable-Carrier Transmission Systems

(1) The K-Carrier System (Bell)

The K-Carrier System is a long-haul carrier system designed to operate over two 19 gauge non-loaded cable pairs up to a maximum distance of 4000 miles. This system is a four-wire system inasmuch as the multiplexed system uses a separate pair for each direction of transmission (each on a separate cable) and voice frequency circuits must interconnect with its inputs and outputs on a four-wire basis. A SSB-SC modulation technique is employed to multiplex twelve voice channels onto a single pair in a 12 - 60 kHz band. All carriers are suppressed.

K-Carrier repeaters are spaced approximately 17 miles apart. If a cable contains both voice pairs and K-Carrier pairs, two unattended K-Carrier "auxiliary" repeaters have to be installed between main stations where both voice and K-Carrier repeaters are located. On new routes, not previously equipped with voice frequence repeaters, unattended repeater stations are space about 17 miles apart, and attended main stations are spaced between 100 and 200 miles apart. The unattended auxiliary stations are equipped with appropriate transmission, fuse and burglar alarms which are telemetered to a selected main station.

In the K2-Carrier System, pilot tones at 12, 28, 56 and 50 kHz are transmitted along with the SSB-SC signal to permit automatic regulation of the flat-gain and frequency response of the system.

SF units or other adjunct signaling systems must be used to signal through the K-Carrier System.

(2) <u>The N1 Carrier System (Bell)</u>

The N1-Carrier System is a twelve channel, short-haul carrier system designed to operate on non-loaded cable over distances up to 200 miles. The N1-Carrier System is a fully four-wire system needing two non-loaded pairs, one for each direction of transmission, and voice frequency circuits must interconnect with its inputs and outputs on a four-wire basis. A DSB-TC modulation technique is used to eliminate the requirement for a synchronous carrier supply at the receiving end of the circuit.

Each modulated channel is transmitted on the line as an 8 kHz DSB with the carrier transmitted in the middle of the 8 kHz block. A different frequency band is used for each direction of transmission. All twelve channels occupy a 96 kHz bandwidth on the line. The "High" group extends from 164 to 260 kHz and the "Low" group extends from 44 to 140 kHz.

N1-Carrier repeaters are spaced at 5 mile intervals along the cable and are powered by central office battery simplexed over the cable pair used for transmission.

(3) The N3-Carrier System (Bell)

The N3-Carrier System is a 24-channel short-haul carrier system designed to operate on non-loaded cable over distances up to 200 miles. The N3-Carrier System is a four-wire system needing two non-loaded pairs, one for each direction of transmission. Voice-frequency circuits must interconnect with the systems inputs and outputs on a four-wire basis. A SSB-TC modulation technique is used to partially eliminate the need for a synchronous carrier at the receiving end of the circuit.

The N3-Carrier uses the same high group and low group frequency sets as the N1-Carrier System. Each N3 group contains 24 4-kHz channels rather than 12 8-kHz channels.

One difference between the N3 and N1 systems is that no out-of-band 3700 Hz signaling is used in N3-Carrier, and SF units or other signaling adjuncts must be employed for supervision and dial pulsing.

C.5.3 Time Division Multiplexing Systems

(1) The T1-Carrier System (Bell)

The most common TDM-PCM system being installed throughout the country today is Bell's T1-Carrier System. The T1 line conveys 24 two-way voice channels over two non-loaded cable pairs. T1 carrier voice channels are used for all types of traffic including voice conversations, teletype carrier systems, and high speed data. T1 carrier repeaters, such as Bell's 208A through 209D, can be installed in the 475 type apparatus case for mounting on poles and in manholes. Older types were only mounted in manholes and were much larger than the pole mounted variety. T1-Carrier repeaters are spaced at 6000 foot intervals on 22 gauge non-loaded cable pairs and are powered by central office battery simplexed onto the pairs used for transmission.

(2) The T2-Carrier System (Bell)

The T2-Carrier System is a cable-carrier transmission system capable of handling up to 96 two-directional, voice-frequency channels at 6.312 Mbps line rate over two 22 gauge, low capacity, non-loaded cable pairs. The maximum circuit length for a T2 system is 500 miles. Regenerative repeaters are spaced at 14,800 foot intervals. The T2 system was designed to carry a 6.312 MBPS bipolar pulse stream. The T2 System can also accept the 6.312 MBPS output of a picturephone CODEC.

The T2 lines are accompanied in the same cable by order-wires and fault-locating systems which use loaded voice frequency pairs. Gas-pressure monitoring is accomplished by the use of an auxiliary alarm circuit. Order wires interconnect power points and are essentially multipoint conference circuits. A separate fault-locating line is furnished for every 48 two-way T2 lines. A maintenance span can contain up to 43 regenerative repeater sections.

Central office battery power is sent over the transmission pairs to power the regenerative repeaters. A power span extends up to 18.6 miles. Where the central office power feed terminals are significantly more than 18.6 miles apart, an intermediate power feed section is inserted. The inserted section is fed from an intermediate powering station which is capable of powering the line in both directions.

C.6 TELEGRAPHY

The term "telegraph" refers collectively to all forms of low-speed binary data transmission. The terms "low-speed data", "teletype" and "manual telegraphy" all denote specific methods of telegraphic communications. Many communicators now use the term "low-speed data" to cover the entire field of telegraphic communications.

Today telegraph circuits are employed mostly for teletype and computer to computer and computer to terminal communications, although there is also considerable application involving telemetry and control. Since the entire modern evolution of telegraphy has been centered around the teletypewriter, a description of teletype telegraphy will answer virtually all questions that can arise on telegraph technology.

In 1874, J. M. E. Baudot of France invented a workable 4-channel telegraph multiplex system which employed a 5 element code. The 5 element binary code permitted 32 unique characters. Baudot's code employed shift characters to shift from letters transmission to numbers and back. This shift arrangement is still employed. A five element "Baudot" code is still used in start-stop teletype transmission today but it is not the original code devised by Baudot.

Around the year 1901, D. Murray improved Baudot's invention with the addition of a tape printer and keyboard. He devised a new 5 unit code with two shifts entirely different from Baudot's code. Murray's code is the basis for the present CCITT International Telegraph Alphabet no. 2.

In 1907, C. L. Krumm and H. Krumm devised the first start-stop system which retained the essential elements of the Murray Code. A start-stop system uses the five element binary code for each alphanumeric, but inserts an element at the end of each character to let all the equipment catch up, or resynchronize, and a start element at the beginning of a character to start each individual receiving unit in synchronism. The start-stop system is also called "asynchronous" transmission and is in general use today. The various five-element codes used in the United States -- i.e., the Military Standard, Weather, TWX or Telex -- are each slightly different from the others but they all resemble Murray's original five-element code, especially in the letters. Any five-element code, however, is often referred to as the "Baudot" code. Eight element codes most frequently used for data and high speed teletype are the Bell System Information Interchange Code, the IBM Data-Transceiver Code, the U.S. Department of Defense 8 - Unit Code, and the USA Standard Code for Information Interchange (USASCII).

Teletype Communications Systems make extensive use of DC open and closed loop signals on metallic facilities over relatively short distances, and Voice Frequency Carrier Telegraph (VFCT) and Radio Systems over long distances. VFCT Systems can multiplex up to 24 low speed teletype channels over a single voice channel. Examples of teletype systems are given below.

(1) <u>DC Telegraph Systems</u>

Transmission over metallic loops extending from the telegraph central office to the customer's premises is usually accomplished by means of DC. This is also occasionally done on relatively short lines between central offices. There are three types of DC telegraph systems.

(a) The Neutral System

In neutral telegraph systems, transmission is accomplished by making and breaking the current in a metallic loop by means of a relay contact or switch. When the circuit is made, and the current flows, a "marking" condition or signal is said to have been transmitted by the contact; when the circuit is broken, a "spacing" signal is said to have been transmitted by the contact.

The neutral telegraph system permits transmission from the central office to the teletypewriter, or vice-versa, but only in one direction at a time. This is called "Half-duplex" operation. If Full Duplex operation is required, then either two half-duplex circuits must be provided, or the proper terminal equipment must be used at both ends of the loop.

(b) The Polar System

In the Polar System, direct current is present on the line during both the Spacing and Marking conditions. A teletypewriter transmits neutral opens and closures to a relay winding whose contacts repeat the neutral signals as different polarities of a DC battery. As mark signal is transmitted as positive battery and a space signal as negative battery. The receiving circuitry distinguishes the different polarities and convert the polar marks and spaces to neutral marks and spaces at the input to the receiving teletypewriter.

In its simplest form, polar transmission permits only one way transmission, so that to achieve full duplex, or even half duplex, operation, two separate signal paths must be provided. This system can operate on open wire over distances up to 200 or 300 miles, and on cable up to about 100 miles.

(c) The Differential Duplex Polar (DDP) System

The DDP System transmits the same polar mark and space signals as the common polar system. However, in the DDP system, a rather intricate and sensitive differential winding relay system is used to determine the differences in loop current which occur at each terminal. Thus the DDP System permits full duplex transmission over a single metallic circuit.

(2) Carrier Telegraph Systems

The development of carrier telegraph was the first attempt at any type of multiplexing, and its concepts are generally thought to have led to voice multiplexing. The simplest approach to carrier telegraphy is to transmit bursts of alternating current of a particular frequency to represent "marking" signals with the absence of the frequency representing "spacing" signals. This form of modulation is known as Amplitude Shift Keying (ASK) and, by employing more than one frequency, a number of telegraph channels can be multiplexed on a single voice facility. The individual channels are picked off at the receiving end of the circuit by means of simple band-pass filters. One of the earliest ASK telegraph carrier systems permitted the multiplexing of up to ten two-way low speed telegraph channels on a single open wire pair. This system used twenty carrier frequencies in a frequency range extending from 3330 to 10,000 hertz. The ten lower frequencies were used for transmission in one direction and the ten upper frequencies transmitted in the other direction. The open wire pair to which this system was applied could also be used for a voice circuit and a DC telegraph circuit at the same time. This type of system has for the most part been superseded by the voice frequency carrier telegraph (VFCT) systems which can be made to operate either on a metallic voice circuit or a voice frequency channel of a telephone multiplex system. Modern VFCT systems, instead of turning a single frequency off and on to denote "space" and "mark", alternate between two different frequencies. A different pair of frequencies is used for each telegraph channel in a system. This type of telegraph transmission is called Frequency Shift Keying (FSK). (In the following discussions the term "telegraph circuit" and "teletype circuit" are synonymous.)

(a) The Type 40-Voice Frequency Carrier Telegraph System (VFCT) (Bell)

The type of 40 VFCT System is a four-wire ASK system capable of multiplexing up to 18 two-way (or full-duplex (FDX)) telegraph channels on a four-wire voice facility. The same set of frequencies is used in each direction of transmission. These carrier frequencies range from 255 Hz to 3145 Hz. The carriers are placed at odd multiples of 85 Hz with channel 1 at 425 Hz, channel 2 at 595 hz, and the others spaced at 170 Hz intervals up to channel 17 at 3145 Hz. When the low frequency transmission characteristics of a voice facility permit, a channel 18 is operated at 255

(b) The 43A1 VFCT System (Bell)

The 43A1 VFCT System is a two-wire/four-wire FSK system capable of multiplexing up to 18 two-way teletype channels on a four-wire voice facility, or up to 9 two-way teletype channels on a two-wire voice facility. For open-wire applications the two-wire capacity can be expanded to 13 teletype channels. But, if a voice circuit is used on the open-wire pair, only 4 teletype channels can be applied. In four-wire applications, the same set of 17 carriers is used in both directions. The carriers are placed at odd multiples of 85 Hz. Occasionally, transmission quality permitting a channel 18 is added at 3315 Hz. In two-wire cable applications, the same frequencies are used and the same spacing applies, but the frequencies 425 through 1785, are used for one direction of transmission for channels 1 through 9, and 1955 through 3315 are used for channels 9 through 1 in the other direction of transmission. Usually channel 1 is omitted in cable applications because of bandwidth limitations. In two-wire open-wire applications, channels 1 through 9 are applied as just described for normal two-wire usage, but an additional four channels can be inserted at frequencies 3550 Hz through 5050 Hz. These four channels can be applied to an open-wire pair by themselves if a voice frequency circuit is already riding the pair.

In the 43A1 system the carrier is shifted ±35 Hz in the voice band (up to 3315 Hz) and ±40 Hz in the high frequency band (between 3550 and 5050 Hz) to achieve transmission speeds up to 110 baud. To achieve 150 baud operation, only 6 channel carriers are allotted in the voice band.

(c) The 6580 VFCT System (RFL)

The 6580 series VFCT System is a two-wire/four-wire FSK system capable of multiplexing up to 24 (50 or 75 baud) two-way telegraph channels on voice frequency circuit if the transmission distortion is negligible over the occupied band.

C.7 MULTIPLEX FOR COAXIAL-CARRIER AND RADIO TRANSMISSION SYSTEMS

The high capacity multiplex systems which are used to drive coaxial-carrier and radio transmission systems, such as Bell's U-600, can be used to drive any one of a number of coaxial-carrier or radio systems. Basic to the concept of modern high capacity FDM systems is the Analog Hierarchy. Starting with the J- and K-Carrier Systems, the "A" type channel bank, which acted as the first stage (lowest level) of modulation in those systems, became a 12 channel standard that was later built upon to form the present standardized, multi-stage FDM hierarchy that is utilized all over the world. To start with, 12 voice channels are multiplexed together to form a "Group"; five groups are multiplexed to form a "Supergroup" (60 voice channels); ten super-groups are multiplexed to form a "Mastergroup" (600 voice channels); and six mastergroups are multiplexed to form a "Jumbogroup" (3600 voice channels). Table C-2 outlines the salient features of the members of the analog hierarchy.

In addition to the stages of Multiplex shown in Table C-2, there are the half-mastergroups consisting of 300 channels, the sub-master group 1 (L3) consisting of 420 or 360 channels, the submaster group 2 (L3) consisting of 240 channels, the L3 line (Subjumbogroup) consisting of 1800 or 1860 channels, and the L1 line which can carry up to 600 channels by inserting a Supergroup 1 between 60 and 300 kHz.

(1) The Lenkurt 46A3 Multiplex System

The 46A3 Multiplex System is a single-sideband suppressed carrier system designed to combine up to 2400 voice channels for transmission on microwave radio and coaxial-carrier transmission systems. The system is modular with terminal equipment comprising channel, group, supergroup, mastergroup modems and frequency generation equipment.

TABLE C-2

FDM HIERARCHY

Stage of Multiplex in Hierarchy	Low Frequency Baseband	Baseband Bandwidth	Number of Channels in Baseband	Frequency Multiplexed Signal	High Frequency Multiplexed Signal Bandwidth	Number of Channels in Multiplexed Signal
Channel Bank	Voice Channel	3.2 kHz (250-3450 Hz)	1	Group	48 kHz	12
Group Bank	Group	48 kHz (60-108 kHz)	12	Supergroup (5 Groups)	240 kHz	60
Supergroup Bank	Supergroup	240 kHz (312-552 kHz)	60	Mastergroup (10 Supergroups)	2.52 MHz	600
Mastergroup Bank	Mastergroup	2.52 MHz (.564-3.084 MHz)	600	Jumbogroup (6 Mastergroups)	16.984 MHz	3,600
Jumbogroup Bank	Jumbogroup	16.984 MHz (.564-17.548 MHz)	3600	Super-Jumbogroup (3 Jumbogroups)	57.432 MHz (3.124-60.556 MHz)	10,800

Mastergroup equipment can be omitted from 46A3 terminals to furnish a reduced capability handling anything between 12 to 960 channels. Supergroup options are available to interface with the 46A/CCITT, Bell L600, or Bell U600 line frequency spectrum. Mastergroup equipment may be augmented to provide from 600 to 2400 channels (4 mastergroups).

Equipment is available to furnish basic 12-channel groups in the 60 - 180 kHz band, or to directly modulate five groups into the 312 to 552 kHz basic supergroup band. Eleven groups with a maximum of 132 channels may be directly modulated for line applications without the necessity for intervening supergroup equipment.

(2) The L-Multiplex System (Bell)

The L-Multiplex System is a single-sideband suppressed carrier system designed to combine between 60 and 10,800 voice channels for transmission on microwave radio and coaxial-carrier transmission systems. The system is modular with terminal equipment comprising channel, group, supergroup, mastergroup, jumbogroup modems and frequency generation equipment. The L1-Carrier System uses the L600A and the L3-Carrier System uses the L1860A. The capacities of the L600A and L1860 are 600 and 660 voice channels, respectively. The L600A has been superseded by the U600 (Universal) Multiplex System and the L1860A by the U660 Multiplex System. The L1860A and the U660 add 60 extra channels in Mastergroup 1 only. The U600 and U660 are used in L1, L3, L4, L5, TD2A, TD2B, TD3 (MG1&2), TH-1 and TH-3 (MG1, 2 & 3). The capacities of the U600 and U660 are 600 and 660 voice channels, respectively.

The following L-Multiplex Systems are also in general use:

L60A - 60 voice channels on TD2, Tj, TL/TM Systems

L120A - 120 voice channels on TD2, TJ, TL/TM Systems

There are half-mastergroup systems called the U300A and U300B which multiplex 300 voice circuits (5 Supergroups) onto TD2, TJ, TL and TM radio systems.

(3) The MMX Mastergroup Multiplex System

The MMX-Multiplex System is a single-sideband suppressed carrier system designed to combine between 600 (10 Supergroups) and 660 (11 Supergroups) for transmission on microwave radio and coaxial carrier transmission systems.

The MMX-2R Mastergroup Bank is available in several different terminal arrangements with applications shown in Table C-3.

(4) The JMX Jumbogroup Multiplex System

The JMX Jumbogroup Multiplex System translates three jumbogroups baseband signals to and from the L5 line spectrum. In the L5 spectrum, each of three JMX-1C Jumbogroups carries 6 mastergroups or 3600 voice channels. The total L5 Coaxial-Carrier Transmission system carries three jumbogroups (18 mastergroups) for a total of 10,800 voice channels.

TABLE C-3

MMX TERMINAL ARRANGEMENTS

Mastergroup Terminal	Voice Channels per MG Bank	Radio Channels per Terminal	Mastergroup Banks per Terminal	LMX Source	
				MG1	MG2 and 3
MMX-2R63	1860	6	6	L1860A or U660	L600A or U600
MMX-2R33	1200 or 1860	3	3	L600A or U600 or 4860A or U660	L600A or U600
MMX-2RA12	1200	2	1	L600A or U600	L600A or U600

C.8 THE BELL SYSTEM DIGITAL DATA SYSTEM (DDS)

The DDS is used to provide 4-wire, full duplex, synchronous private line digital data circuits at speeds of 2.4, 4.8, 9.6, and 56 Kbps between any two customer locations in areas having access to the DDS. It is expected that by 1976 as many as 96 metropolitan areas will have access to the DDS.

In the DDS, synchronous data signals are transmitted from the Channel Service Unit (CSU) or the Data Service Unit (DSU) in the subscriber's terminal to the serving central office via a 4-wire loop consisting of two non-loaded cable pairs. The transmission between the customer and the central office has a digital bipolar format similar to the T1-Carrier line signal, but at the lower data speeds furnished by the DDS. After reaching the central office, each low speed data stream is multiplexed onto a DSO 64 Kbps bit stream. Twenty three DSO bit streams can be further multiplexed via a T1DM modem into a DS1 level 1.544 Mbps T1-Carrier line. The DS1 line of the T1DM is then carried by digital facilities to an appropriate DUV office where the 1A Radio Digital System (1ARDS) modulates the 1.544 Mbps digital signal into a 7-level partial response analog data signal

The 1ARDS analog data signal has an energy spectrum extending from nearly DC to 500 Khz with nulls at DC and 386 KHz. A data pilot is inserted at 386 KHz to permit synchronous demodulation at the receiver. The 1ARDS analog signal is inserted into the radio baseband just below Mastergroup - 1 (MG1). If MG1 is derived from a U600 multiplex system, the lower frequency space is adequate for the 1ARDS analog signal. If MG1 is derived from a U660, L1860 or an L1860A multiplex system, then the bottom supergroup must be deactivated to provide enough spectrum for the 1ARDS signal. If the L600 or L600A multiplex is used to derive MG1, then the bottom two supergroups

(SG1 and SG2) must be deactivated. Intercity transmission is achieved by means of the TD-2, TD-3, TH-1, or TH-3 radio baseband. In most microwave systems, a 308 khz pilot is used to determine radio continuity. Since the 308 khz pilot would interfere with the 1ARDS analog signal, a 312 khz pilot derived from an existing primary frequency supply is used instead.

(1) The 1A Radio Data Terminal (1ARDT)

The 1ARDT transforms the DS1 signal into an analog signal having a 500 khz bandwidth for Data Under Voice (DUV) transmission below Mastergroup 1 on microwave radio systems.

A scrambler randomizes the incoming data stream by superimposing it on a "maximum length" pseudorandom word. Treatment with an identical synchronized pseudorandom word in the receiver will permit recovery of the original data. Scrambling acts to remove single frequency and DC components from the line signal.

The 1.544 Mbps output of the scrambler is passed on to the serial to seven level data converter which transforms the signal into a 7 level partial response analog signal which occupies only about 500 kHz on the line.